visions for sustainability
PUBLISHED TWICE A YEAR AT THE SUMMER AND WINTER SOLSTICES

No. 20 December 21, 2023

Contents

Editors-in-Chief

Martin Dodman, University of the Valle d'Aosta, Italy
m.dodman@univda.it

Giuseppe Barbiero, University of the Valle d'Aosta, Italy
g.barbiero@univda.it

Visions for Sustainability, Vol. 20. Published online, ISSN 2384-8677 http://www.ojs.unito.it/index.php/visions

Visions for Sustainability is an indexed scientific journal published in open access by the University of Turin, Italy. The journal promotes a debate on how the concept of sustainability can be addressed and applied in existing and foreseeable societies worldwide. Emphasis is placed on facilitating communication between researchers of different disciplines, supporting educational projects and examining the role of contemporary science in dealing with issues related to sustainability. Papers are welcome from researchers and scholars of natural, political, social and other sciences as well as philosophical and humanistic disciplines, and in particular from anyone wishing to make a contribution which combines multiple viewpoints. The aim is to host as wide a range as possible of multidisciplinary, interdisciplinary and transdisciplinary perspectives on sustainability. Discussions or comments on articles which have previously appeared in the journal are also welcome. All submissions will be refereed before publication.

Articles can be submitted directly online at the journal website https://www.ojs.unito.it/index.php/visions through the login procedure. Any further questions and/or submission enquiries can be addressed to m.dodman@univda.it or g.barbiero@univda.it.

Direttore Responsabile: Luca Biamonte
Proprietario: Università degli studi di Torino
Editore: Università degli studi di Torino - ISSN: 2384-8677

Editorial

Expanding visions for sustainability

Martin Dodman, Ramsey Affifi, Jean-Louis Aillon, Osman Arrobbio, Giuseppe Barbiero, Elena Camino, Laura Colucci-Gray, Enzo Ferrara, Silvano Folco

When we founded our journal ten years ago, we chose the name *Visions for Sustainability* because we wanted to combine two ideas. One was proposing different ways of looking at sustainability, how diverse disciplinary, interdisciplinary, and transdisciplinary perspectives could enrich our understanding of the concept itself. The other was exploring how such perspectives on sustainability could provide a range of ways of looking at or shedding light on the relationship between *homo sapiens* and the planet we inhabit, what we have always called, after Prigogine and Stengers (1984), humanity's dialogue with Nature and itself.

Seeing, knowing, transforming

The word "vision" is often considered as stemming from the Proto-Indo-European root *Weid-*, meaning "to see". At the same time, it is linked to Sanskrit *veda* "I know", with a subsequent intertwining of seeing and knowing, such as in Greek *oida*, (literally, I know because I have seen) and in the development of modern European languages, such as Gothic *weitan* "to see" and German *wissen* "to know". This winter solstice brings the publication of the twentieth issue of *Visions for Sustainability*. In this ten-year period, there have been various developments in terms of the aims and scope of our journal, in how we have tried to promote a dialogue involving ways of seeing and knowing, thereby understanding the concept of visions in relationship to sustainability.

Meanwhile, profound, and often unexpected, changes have taken place in our knowledge of the transformations of our planet, the meanings attributed to the concept of sustainability, and the actions taken, above all by the main global economic and political actors. The prospect of a collective and cooperative effort at a global level to redirect human activities towards having a lower impact on the planet has been displaced by a further drift towards the imposition – on the part of an ever more greedy minority driven by a global military-industrial power system – of a capitalist logic of unlimited exploitation of the resources and degradation of the quality of natural systems (involving all ecosystem, including human, services), placing immediate profit for the few before the protection and care of all, human and non-human, living beings. This progressive shift in the current scenario has influenced the way in which we have gradually transformed our ideas of visions for sustainability and our way of envisaging how they might be translated into action.

Extending our dialogue with authors

From the outset, we wished to be an author-friendly journal and to establish a dialogue based on feedback and feedforward with all those who are interested in publishing with us. Over the past ten years we have seen an increase, at first gradual and then more rapid, both in submissions to our journal and consequently, through a careful peer review process, the number of papers we have published. We have endeavoured to refine the passage from submission to publication so as to render each of the steps as constructive as possible. Each submission is first assessed to ascertain if it is coherent with the aims and scope of our journal, above all if it is actually proposing a vision for sustainability. If the outcome is negative, we communicate this to the authors and explain the reasons why we believe this. This currently applies to around fifty percent of the submissions we receive. If a submission has a positive preliminary assessment, we send it for peer review and subsequently we write to authors to give them detailed information on reviewer comments and accompany them during the process of revision necessary before we can proceed to publication.

At the same time, papers submitted and published have increasingly come from and focused on a wide range of diverse geographical locations, encompassing North and South America, Europe, Africa, Asia, and Australasia. We have received and been pleased to host many studies from different parts of the Global South, involving areas facing particular challenges concerning the definition and promotion of sustainability in the light both of global inequalities and cultural specificities. At the same time, we have extended the range of visions proposed by authors within interdisciplinary and transdisciplinary perspectives that encompass natural, social, economic, political, and other sciences, as well as philosophical, humanistic, and artistic fields.

Emerging questions

Over this ten-year period, we have also seen various interesting trends. Increasingly, articles appear more focussed on and linked to an assessment of progress towards standardised measures such as Millennium Goals and Sustainable Development Goals. At the same time, we have always tried to emphasize problematic aspects in the definition and achievement of such goals. Should we not analyse what they propose in a critical way? Are they not based on the very anthropocentric worldview that has caused our current problems? Can such a worldview be expected to see and know how to solve them? Should we be attempting to find ways to promote the goals foreseen or should we be promoting the need to rethink the goals or at least how they all too often seem to be automatically linked to the ideas like that of green growth and technological progress? If unlimited growth is clearly unsustainable, can, for example, steady state economy or circular economy models provide the basis for sustainable human trajectories?

In whatever way goals are defined, it seems that progress towards them has been too slow. Existing systems of provision, manufacturing and consumption exhibit high degrees of inertia, making any kind of process towards sustainability transitions an extremely complex affair, posing many questions without any easy answers. The latest report published by the United Nations (2023) makes it clear that addressing the great sustainability challenges of energy, food, and transport is a matter of urgency calling for large-scale experimentation with emerging innovations, but also the involvement of multiple actors engaged in broader system transformations. This is both an interesting and problematic proposition, which demands action at the technical/pragmatic level based on the question "How do we accelerate", without, however, an equivalent consideration of the ethical and normative level: "Should we accelerate? and "What are the costs and implications of such an acceleration?".

The question of acceleration leads also to that of the relationship between culture(s) and vision(s). The great acceleration of the 1950s onwards and the consequent dramatic changes in socio-economic and Earth system trends driven by a growth paradigm were all essentially a product of the establishment of the hegemony of a dominant technoscientific culture at the expense of other cultures capable of proposing different human trajectories. Moreover, this is inextricably linked to the relationship between vision and action proposed by Meadows et al. (1972) whereby "Vision without action is useless. But action without vision does not know where to go or why to go there. Vision is absolutely necessary to guide and motivate action. More than that, vision, when widely shared and firmly kept in sight, brings into being new systems". Within a dominant technoscientific culture, ideas for action today are all too often based on a kind of techno-optimism that imagines that new technologies can provide the answer to all our problems.

While one side of the research community is looking for generalizable lessons to facilitate acceleration, we believe there is an urgent need to re-vision so as to bring forth other voices and other forms of experience which speak about how we pay attention to all those living beings with whom we share a home, those from whom we intimately depend, those who do not disappear in our wake but speak to us as we seek out a way to listen to them. This is perhaps the true nature of sustainability, not as a set of problems to be solved or a big task to get done, but rather the way in which sustainability calls for an ongoing and stubborn attempt to sit and listen, above all to consider the relationship between interior and exterior vision. Reflecting on the worlds inside us and surrounding us. Becoming more aware of how we shape the world we inhabit through our conscious and unconscious thinking (Colucci-Gray, 2023). Exploring the self as a mystery, the discovery of psychic and spiritual energies and unexpected visions. Examining the relationship between oneself and the "external" world and carefully considering the tools to develop it. Recognizing the importance of positive attitudes such as trust, empathy, curiosity, gratitude, joy. Understanding the material and spiritual needs of the entire planet, of all its biotic and abiotic components.

Ten years ago, we might have thought that by increasing scientific knowledge, and making the reports of witnesses and activists known all over the world, political leaders and decision makers would be pushed to enact laws to safeguard ecological justice and stop violence, but it clearly has not happened. On the contrary, we have become compelled to helplessly witness violence and abuse both of the environment and human communities, by way of mines, dams, waste production, and countless other examples, both in the name of "progress" and on the basis of a division of the world between "friends" and "enemies". The unacceptable has become habitual. The fact that there are currently 32 ongoing wars in the world demonstrates this dramatically. There is a widespread conviction that the enemy must be exterminated, and the hostile communities and the environment are a collateral component of no relevance. The belief that violence is the only way to counteract injustice and oppression is increasingly widespread, and the violence overwhelms not only humans, but all living organisms and the physical environment they inhabit. Any vision for sustainability must surely be based on the rejection of violence, in all its forms, cultural, structural, and direct. And to this aim, the challenge for sustainability, across all domains of society and within lifelong and lifewide education, is that of nurturing and cultivating the concern for life, in all its biodiversity, and its continuation in conditions of planetary health and wellbeing.

Perspectives on resources, production, consumption, and waste

In the 20 issues published thus far, we have endeavoured to give space many different visions regarding how what current hegemonic economic models often call the concepts of natural and produced capital are both inextricably entangled parts of cyclical feedback loops involving the multiform processes related to resources, production, consumption, and waste that characterize human trajectories. These visions have proposed both theoretical and research-based perspectives which aim to add something to our understanding and application of the concept of sustainability, together with educational and experiential perspectives that emphasize the importance of formal, non-formal and informal learning processes for all members of human societies and at all ages. The papers published have either been a part of general issues containing an increasingly wide range of topics or as part of special issues focusing on areas ranging from science education to slow tech, from wellbeing in built environments to health and degrowth, and, most recently, water sustainability and climate change. Our current issue contains papers related to each of the topics that previous issues have developed.

Water and wood are two examples of resources that are emblematic in terms of their use and exploitation by human societies. Different aspects of the question of water sustainability, the nature of water as essential for sustaining life on our planet, its unequal distribution as a source of injustice and permanent conflict, the anthropogenic water cycle and the science and technology of water quality and its management worldwide, are present in three contributions. Shé Mackenzie Hawke reviews Veronica Strang's book *Water Beings: From Nature Being to the Environmental Crisis*, while other aspects are presented in Khamdevi's paper "A systematic literature review of architecture-related dew and fog harvesting" and Alcívar Intriago, Vera Vera, Muñoz Anchundia & Vera Salavarría's paper "Topographic humidity index and vegetation as management tool for policies decision". Wood science and wood research are focussed on from the perspective of ongoing studies of forest conservation and management proposed by Chisika & Yeom in their papers "The perception of benefits from the 'adopt-a-forest' initiative in

Kenya" and "The challenges of sustainable conservation and management of mangrove forests in Kenya", and also in the study by Chisika, Park & Yeom "Public perception on the role of Artificial Intelligence in the sustainable management of tree and forest resources in Kenya".

Energy resources have emerged over millennia as an increasingly key aspect of human trajectories and in particular the need to identify and exploit renewable energy sources has become a key quest in the endeavour to render those trajectories sustainable. Previous issues have dealt with various aspects of renewable energy and No. 20 focuses on this from the perspective of the energy necessary for the functioning of built human environments. In "Building design based on zero energy approach" Bagheri, Barfeh & Hamisi look at ways of designing and building zero-energy housing, while both Sharma, Bukya & Kumar in "PVsyst modeling of 800 kWp capacity grid-tied solar photovoltaic power plant for academic institution" and Guvenc, Canikli, Can-Güven, Varank & Akbas in "The carbon footprint of a university campus. Case study of Yildiz Technical University, Davutpaşa Campus, Turkey" look at ways in which universities, which house the very academic communities who should be at the forefront of sustainability science, can be analyzed in terms of their overall functioning.

The sustainability of production processes involves numerous complex intersecting variables including use of natural resources and energy, pollution, economic viability, the safety and wellbeing of workers, communities, and territories. All of these have been considered in previous issues and No. 20 and various perspectives on local communities and rural areas in the papers "Model of community empowerment in utilizing Purun (*Eleocharis dulcis*) resources for sustainable handicrafts in Indonesia's rural peatland communities" by Azni, Alfitri, Yunindyawati, Riswani, & Pellizzoni, "A sustainable creative economy development model using a penta-helix approach based on local wisdom in Magelang City, Indonesia" by Prajanti, Daud, Amin, Subiyanto &Adzim, and "State regulation of sustainable development of rural areas in the system of food security of Ukraine" by Fedchyshyn, Ignatenko, Chyryk, & Danilik. The question of the sustainability of production processes in larger-scale enterprises is addressed in" How the strategic to achieve corporate sustainable performance? The role of mergers, acquisitions and ownership integrations" by Widjajanti, Lestari, & Sugiyanto, while the question of sustainability within a particular industry is examined by Jie, Tan & Shi in "Fostering sustainability in China's textile industry. The role of education for sustainable development", a theme that is further developed from various perspectives in the dedicated special section containing educational visions.

The question of the sustainability of different lifestyles, related consumption patterns, and the transport of goods to satisfy demand has also been a feature of previous issues. No. 20 continues this focus with papers by Saxena, Kumar, Singh, Bisht, Chaudhary, Semwal & Chaudhary on "Bridging the attitude-behaviour gap in sustainable consumption for electric vehicles in India. A theoretical proposition", Rawat & Sahni on "Embedding SDG 12 in consumer behaviour. A survey of knowledge, attitude and perception for sustainable consumption", and Safuan, Ramadian & Selasdini on "Environmental, Social and Governance implementation in Indonesian ports. A qualitative approach and its impact on global sustainability".

Previous issues have also focused on the relationship between patterns of consumption of goods and services, pollution and waste production and management. In No. 20 Nkomezi, Uwimbabazi & Yeom, C. look at the "Socio-environmental impacts of landfill site in Nduba sector, Kigali, Rwanda", while Vivas Saltos & Cedeño Vargas analyze "Fishing industries' oily wastewater biodiesel performance". The question is also considered from the point of view of space pollution by Pla in "Artificial space debris and Kessler syndrome. A limitation for humankind".

Previous issues have proposed various visions of the way in which human trajectories are characterized by processes related to resources, production, consumption, and waste is inextricably connected by our attitude towards and capacity to mistreat the planet we inhabit and depend on. An analysis of this is proposed by Hawke in "The liberating theology of a planet's beneficence: a possibility".

If we are to change attitude and way of acting, then education is clearly of the utmost importance. Previous issues have contained many papers focusing on different aspects of this, and No. 20 contains a special section on "Conserving nature: the contribution of ecological research to education". In this section, as guest editors, Lorenzi & Sangiorgio contribute an editorial which explores the theme of the section itself, Vicente, Leitão, Quintino, Pombo, & Rodrigues offer an analysis of "Urban vegetable gardens as an environmental education tool for promoting primary school students' engagement in EU Green Deal strategies", Rota, Canedoli, Fava & Padoa-Schioppa look at "Introducing children in the primary school to the concept of ecosystem services", and Bartoccioni, Lorenzi & Sangiorgio propose "Sustainable food consumption and Nature conservation processes. Educational considerations".

Polycrisis, ecological phronesis, aesthetic vision and action

As we look ahead, we ask ourselves questions relating to what evidence there may be of how sustainability is maintained, or not, in different contexts and at different levels of complexity from quantum physics to the science of the universe, involving such complex questions as reversibility and irreversibility, dynamics, process dimensions, equilibria, and diversity. Or in the realm of life sciences, where only a continuously evolving circularity of interacting organisms, populations, and communities, both biological and sociocultural, can provide the basis of sustainability. Scientific visions represent a unique capability of human beings to reflect on their world and also on themselves, and, whatever their field of investigation, must include the sense of limitations and constraints. At the same time, scientific exploration risks becoming ever more a prey to vested interests, denying any form of limitations, offering misleading visions of what is sustainable or not.

Increasingly, our dialogue is concerned with developing an ecological approach to thinking about the relationship between the life of the mind and the world it inhabits. This means considering different ways in which the imagination produces and impedes directions of action. In some cases, a vision may need expanding, deepening, or elaborating. In other cases, it may be too detached from engagement in the world, merely "spectator" theory, rather than part of embodied praxis.

Moreover, there is also the question of the ecology between visions, and between that ecology and the world. This means perhaps no specific vision is necessary and sufficient, but context dependent and dialectically interacting with other visions to create feedback loops that can lead to patterns or dynamics that sustain or not. What this implies here is that a particular vision, no matter how good on paper, may be destructive if developed too far, or relied on too often, or insisted upon in the wrong circumstances. Thus, we are also concerned about how visions of sustainability can potentially contribute to unsustainability.

We see the ecological crisis as a polycrisis, where human physical, social and spiritual health is imbalanced, both in itself and in its relationship to planetary health. Moreover, the dysecologies in one domain are interconnected with those in another. This means intervention points are potentially everywhere, improvement is contingent, fallible but an ongoing possibility, and that different people, and same people at different times, may be attracted to attending to the healing of one part of the ecology rather than another. We see the perception of healthy ecology or dysecology as primarily a matter of aesthetic seeing and knowing

(Affifi, 2023), considered to be a way of knowing that perceives the quality of relationships, gestalts whose integrity, or lack of it, is felt in aesthetic experience. In this sense, aesthetic vision is an embodied and emotional encounter with otherness, and, as a foundation for any consideration of how we "should" live, the basis of ethics. Navigating ecological phronesis and the ecological interaction between visions is also aesthetic, insofar as it involves sensing the quality of the relationship between interacting visions, and what they do in the world. Recognizing this is fundamental for building and exploring new visions for sustainability.

References

Affifi, R. (2023). Aesthetic knowing and ecology: Cultivating perception and participation during the ecological crisis. *Environmental Education Research*. https://doi.org/10.1080/13504622.2023.2286933

Colucci-Gray, L. (2023). Gesturing in plain sight: dialogical enactments of sustainable futures as being and doing in the world. *Cult Stud of Sci Educ*. https://doi.org/10.1007/s11422-023-10189-w

Meadows, D. H., Meadows, D. L., Randers, J. & Behrens, W. W. (1972). *The limits to growth*. Potomac Associates. https://www.clubofrome.org/publication/the-limits-to-growth/

Prigogine, I. & Stengers, I. (1984). Order Out of Chaos: Man's New Dialogue with Nature. Bantam

United Nations (2023) The Sustainable Development Goals Report. https://unstats.un.org/sdgs/report/2023/

Original Paper

A systematic literature review of architecture-related dew and fog harvesting

Muhammar Khamdevi

Received: 26 July 2023 | **Accepted:** 9 November 2023 | **Published:** 19 November 2023

Keywords: architecture; atmospheric water; dew harvesting; fog harvesting; systematic literature review.

Abstract. *Dew and fog harvesting have been the topic of numerous studies since the 2000s to address the global water crisis brought on by climate change, as an alternative and sustainable solution. Though this topic has many connections to architectural science, it is nonetheless largely alien to* *academics and practitioners with architectural backgrounds. What research focuses have been done? What research methodologies have been employed? What implications and limitations have been discovered? This study addresses these questions by conducting a systematic literature review. This discovered that the effectiveness and efficiency of planar shape-based fog nets and dew condensers have continued to dominate the research focus, although several studies have begun to consider the forms of three-dimensional and biomimicry. One study also started researching the application of this technology to urban settings apart from rural areas affected by water scarcity. The most employed methodology in this research has been design testing and review. Some models, prototypes, and developments are implicated as best practices, although the limitations of these studies are in the physical local context, material selection, methodologies, scalability, water quality, and water quantity. The results of this review provide directions for further research in Indonesia to consider the use of harvesting combination systems in three dimensions form with passive systems and low tech. Moreover, this discovery also opens opportunities for the use of vernacular or traditional architecture and local natural materials that have not been discussed by previous studies.*

1. Introduction

Water scarcity is defined as an excess of demand for water relative to available supply (Damkjaer and Taylor, 2017). Increased total water demand, as well as increased groundwater use, have contributed to increased stress between the use of freshwater supplies and addressing regional water scarcity (Jimenez-Cisneros et al., 2014). This symptom is distinguished by water stress and water shortage. Water stress is produced by excessive consumption of groundwater whereas water shortage is caused by a lack of available water per person. A considerable loss in the quality and quantity of freshwater causes a water crisis, which harms human health and economic activity (Manungufala, 2021). Water resources are critical in ensuring environmental sustainability and food security by maintaining the natural and agricultural environments. Agriculture is critical to the economies and public health of developing countries (Zhang et al., 2021). The global water consumption is estimated to be over 4 trillion cubic meters. Agriculture consumes the most water in Asian countries (82% of total consumption), whereas industry consumes the most water in Europe (55% of total consumption) (Du et al., 2022).

However, this is currently occurring not only in arid areas but also in overdeveloped areas suffering from environmental degradation (Manungufala, 2021). Water scarcity is becoming more of a worldwide concern. This crisis has had the greatest impact on South Asia, followed by East Asia, Southeast Asia, Sub-Saharan Africa, North Africa, Europe, North America, and South America (Sadoff et al., 2015). More than two billion people globally have experienced it (Chakkaravarthy & Balakrishnan, 2019). Climate change, which affects hydrometeorological conditions, also adds to water scarcity (Assaf & Erian, 2012).

Since 2015, water scarcity has been a worry addressed in the UN Sustainable Development Goal 6 (Van Vliet et al., 2021). This is one effect of global climate change, both in terms of quantity and quality (Ling, 2021). In drought-affected, densely populated, and socioeconomically unstable places, this will have an impact on security and sustainability (Singh et al. 2014). The energy supply, food security, financial, and economic sectors are all at risk due to this water crisis (Chakkaravarthy & Balakrishnan, 2019). Even though the region is generally abundant in water resources, Indonesia is not immune to this (Afrilia, 2022). The Indonesian Meteorological, Climatological and Geophysical Agency (BMKG) has issued the warning and predicted this crisis will occur in Java, Bali, and Nusa Tenggara. This problem will have the greatest impact on low-income households that lack access to clean water, as well as farmers in rural areas (Hapsari, 2022; Ina, 2022).

Numerous researchers have tried to find alternatives to solve this problem. Some of them have studied the collection of water from the sea and the air (Cassauwers, 2022). Some investigations about atmospheric water harvesting, particularly from dew and fog, have been conducted since the year 2000. The technique used to capture dew is dependent on condensation, either passively or actively. Fog harvesting technology uses conventional methods, biomimicry, and bioinspiration. According to Jarimi et al. (2020), both technologies were developed on a small or large scale. Many dew and fog collectors still in use today, particularly those built for large-scale use, have inefficient designs (Suau, 2010; Beysens et al., 2012).

Condensation is the process by which water vapor (moisture or vapor) in the environment changes state from gas to liquid (Schiermeier, 2008). Condensation is crucial in the creation of fog and dew. Condensation happens because of temperature changes that result in cooling (cooling), which is strongly tied to the dew point temperature and a specified degree of relative humidity (RH). Light water droplets or water droplets are usually suspended or suspended in the air and are referred to as fog (Pearce, 2002). Meanwhile, the heavy one is commonly referred to as dew when it comes into touch with liquid or solid surfaces (Khalil & Adamowski, 2016).

Fog and dew can occur at any time of day or night but are most common from late night until early morning (Leopold, 1952). At least two parameters must be met: relative humidity (RH) near to 100% saturation (Francis, 2002; Gleissman, 2007), and temperature variations. Fog forms when the ground surface temperature approaches the dew point temperature, whereas dew forms when the surface temperature approaches the dew point temperature (Di Bitonto, 2020). The temperature at which air must be chilled to become saturated with water vapor (assuming constant air pressure and moisture content) is known as the dew point. The moisture capacity is lowered at that time. Humidity influences the dew point. The dew point rises as the amount of water vapor in the air increases (Wallace & Hobbs, 2006).

This research issue has thus far received little discussion in Architecture. Water conservation has not received as much attention as reducing water use, especially when it comes to the topic of green buildings (Weeks, 2013). A prior study using bibliometric analysis discovered that architecture may step in and take a place in this research where it has opportunities to make contributions independently or collaborate multidisciplinary with other scientific disciplines (Khamdevi & MLT, 2023). This systematic literature review (SRL) has the objective of identifying and analysing the research focuses, methodologies, implications, and limitations used in dew and fog harvesting research related to architecture.

2. Materials and Methods

SLR is the process of locating, evaluating, and understanding all relevant research data to respond to research questions (Kitchenham & Charters, 2007). It uses strategies to collect secondary data, evaluate research critically, and synthesize qualitative or statistical findings (Armstrong et al., 2011). The intention is to provide an exhaustive assessment of the most recent published and unpublished research evidence that is methodical, thorough, transparent, and repeatable

(Siddaway et al., 2019). Furthermore, SLR lessens bias to make data more objective (Egger et al., 2001).

To keep the review narrowly focused, specific research questions were developed. The following research questions are based on the research objectives:

RQ1: What kind of research focuses are selected by researchers in dew and fog harvesting related to architecture?

RQ2: What kind of research methodologies are applied in dew and fog harvesting related to architecture?

RQ3: What kind of implications and limitations are applied in dew and fog harvesting related to architecture?

High levels of methodological detail should be provided when describing systematic reviews (Haddaway et al., 2022). Therefore, the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) protocol method is employed in this research. This method has three steps: identification, screening, and inclusion (see Figure 1).

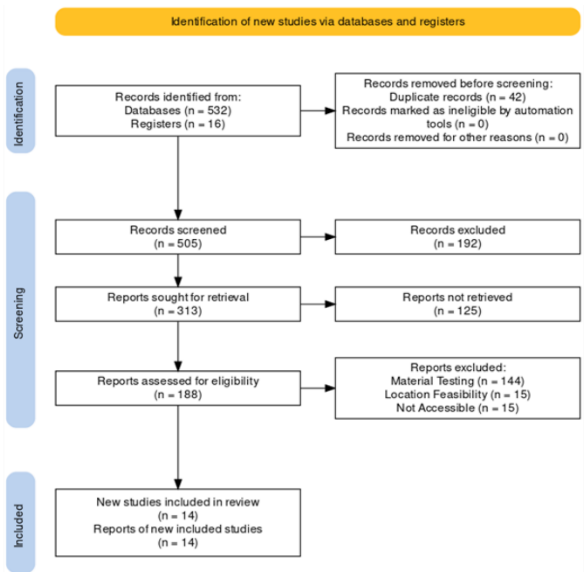


Figure 1. PRISMA Flow diagram of primary study selection and search.

2.1. *Search Strategy*

In this study, dew and fog harvesting-related scholarly papers from a variety of fields - based on certain keywords related to the study - were gathered from the SCOPUS database using the Publish or Perish (PoP) software. Due to limited access to SCOPUS, PoP is used. The keywords were dew catcher, dew collection, dew collector, dew condensation, dew condenser, dew harvesting, fog catcher, fog collection, fog collector, and fog harvesting.

The search was conducted without regard to the year of publication to gather more comprehensive literature data due to the small amount of data discovered. Furthermore, certain data that is found individually outside of SCOPUS using PoP was manually registered because, despite not being published in a peer-reviewed journal or being indexed in SCOPUS, these publications are very important to this research area and have a significant relation to architecture. The final dataset was then converted into *.xlsx format after being saved in *.csv and *.ris formats. Microsoft 365 Excel version 2212 was used to assist in data identification, evaluation, and descriptive analysis.

2.2. *Inclusion and Exclusion*

Because the data collected are SCOPUS-indexed scientific publications that are of high quality and are in English, a quality assessment and exclusion of non-English papers was not carried out. From searching using PoP, a dataset of 547 was obtained, of which 531 data came from Scopus and 16 data were outside Scopus. Among them, there were 42 data that were duplicate data that needed to be removed as pre-screening. So that left 505 data to then enter the screening step.

2.3. *Data Extraction*

192 data were eliminated from the first screening because they had fewer than four citations. Then after reviewing the title and abstract, 125 publication data from the following screening were not collected. Among them, 31 data had no relevance to the topic of dew and fog harvesting design, and as many as 94 data had no discussion related to architectural research. Finally, the dataset was again screened for the last time after reviewing the full text, 174 data were removed. 144 data had a research focus on material testing, 15 data focused on location feasibility, and 15 data were not accessible in Scopus, ResearchGate, Academia, and repositories. So finally, from this screening step, 14 primary data were included in the review (see Table 1).

No.	Publication Titles	Year	Authors
P1	New architectural forms to enhance dew collection	2013	Beysens, D., Broggini, F., Milimouk-Melnytchouk, I., Ouazzani, J., Tixier, N.
P2	Dew water collector for potable water in Ajaccio (Corsica Island, France)	2002	Muselli, M., Beysens, D.A., Marcillat, J., Milimouk, I., Nilsson, T.M., & Louche, A.
P3	A very large dew and rain ridge collector in the Kutch area (Gujarat, India)	2011	Sharan, G., Clus, O., Singh, S., Muselli, M., & Beysens, D. A.
P4	Fog and Dew as Potable Water Resources: Maximizing Harvesting Potential and Water Quality Concerns	2018	Kaseke, K. F., & Wang, L.
P5	Fundamental Limits of the Dew-Harvesting Technology	2020	Dong, M., Zhang, Z., Shi, Y., Zhao, X., Fan, S., & Chen, Z.
P6	Roof-integrated dew water harvesting in Combarbalá, Chile	2018	Carvajal, D., Minonzio, J., Casanga, E., Muñoz, J., Aracena, A., Montecinos, S., & Beysens, D.
P7	An innovative fog catcher system applied in the Andean communities of Ecuador	2017	Carrera-Villacrés, D.V., Robalino, I.C., Rodríguez, F., Sandoval, W., Hidalgo, D.L., & Toulkeridis, T.
P8	Design of water harvesting towers and projections for water collection from fog and condensation	2020	Bhushan, B.
P9	Fog harvesting: An alternative source of water supply on the West Coast of South Africa	2004	Olivier, J.
P10	Harvesting Fresh Water from Fog in Rural Morocco: Research and Impact Dar Si Hmad's Fogwater Project in Aït Baamrane	2015	Dodson, L.L., & Bargach, J.
P11	Simplified modeling and analysis of the fog water harvesting system in the asir region of the kingdom of Saudi Arabia	2018	Gandhidasan, P., Abualhamayel, H.I. and Patel, F.
P12	Water harvesting from fog using building envelopes: part I	2018	Caldas, L., Andaloro, A., Calafiore, G., Munechika, K., & Cabrini, S.
P13	Modelling Environmental Problem-Solving Through STEAM Activities: 4Dframe's Warka Water Workshop	2016	Fenyvesi, K., Park, H., Choi, T., Song, K., & Ahn, S.I.
P14	Warka water promises to harness safe drinking water from the air	2015	Williams, A.

Table 1. Publications included in the review.

2.4. Descriptive and Content Analysis

14 primary papers that have been read in full text, then analysed using descriptive and content analysis approaches. Descriptive analysis tries to reveal research trends presented in figures and tables. While content analysis is used to uncover these papers' research focuses, methodologies, implications, and limitations.

3. Results and Discussion

Of the many publications collected, data analysis shows that research on dew and fog harvesting systems has grown optimistically in various parts of the world to solve the problem of water scarcity. This section will provide an overview of the global progress of research on dew and fog harvesting systems related to architecture. Then, we will examine both newly planned and already implemented systems and techniques to determine their potential as alternative solutions to meet the water needs of households and other essential sectors. Aside from that, we focus on what we may learn about its role in achieving security and sustainability.

3.1. Descriptive Analysis

The first search on the SCOPUS database revealed that there were still not many studies overall on the topic. There was also not much research on this subject specifically tied to architecture. Therefore, it was entirely understandable that the articles under review for this study had very few outcomes. According to everything that had been published, this research only recently began to gain traction in 2015. The year 2018 saw the most studies produced, with 4 papers (see Figure 2).

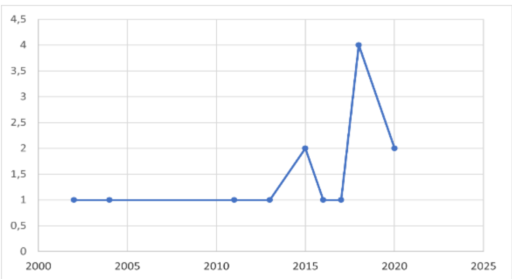


Figure 2. Publication Year on Dew and Fog Harvesting Related to Architecture.

Four of the 14 published papers came from studies in the United States, accounting for most of the publications, followed by two papers from France. In addition, one paper was generated by Chile, China, Ecuador, Finland, India, Saudi Arabia, and the United Kingdom (see Figure 3). This demonstrated how extensively the subject of this research is being explored around the globe. This also showed the attention and significance of this subject and the possibility of highly major future development.

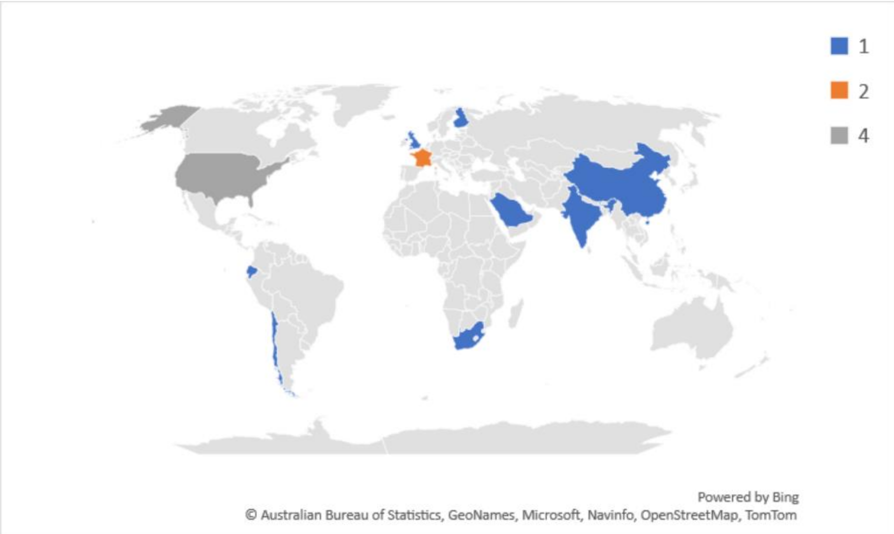


Figure 3. Countries origin of publications on dew and fog harvesting related to architecture.

These publications have been widely disseminated, particularly in the engineering, hydrology, and geography fields. However, research on the topic of dew and fog collecting have not been published in any architectural scientific journals (see Table 2). This demonstrated that the study on this subject is still unfamiliar to architecture. The more diverse points of view are used to solve the problems in this research because there are many of these concerns in architectural studies. In addition, architecture integrates engineering, design, social sciences, and natural sciences to create a more holistic science.

No.	Sources	Papers
P1	Aerosol and Air Quality Research	1
P2	Atmospheric Research	1
P3	Bridges Finland Conference	1
P4	Chemical Engineering Transactions	1
P5	GeoHealth	1
P6	GeoJournal	1
P7	Journal of Hydrology	1
P8	Journal of Water Supply: Research and Technology - AQUA	1
P9	Nanoscale and Microscale Thermophysical Engineering	1
P10	New Atlas	1
P11	Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences	1
P12	Procedia Engineering	1
P13	Transactions of the ASABE	1
P14	Water and Environment Journal	1

Table 2. Publication sources on dew and fog harvesting related to architecture.

Most of the publications in this study - a total of 10 papers - were journal articles. The remaining 3 studies were presented as conference papers. One more article was found on the Web News (see Figure 4). It indicated that many of the study papers have been published in a variety of sources. At least it attracts the attention of many academics from different fields to participate in this research with the numerous appearances of these publications.

Three of the 53 authors were active in creating publications. With four papers, Beysens is the author who has produced the most publications. Then Muselli and Milimouk-Melnytchouk have each produced two papers. The rest only have produced 1 paper. The same research on dew harvesting has been the topic of discussion among the three of them. They have also worked together to write several papers. Such research relationships are crucial for the development of a robust and extensive research network.

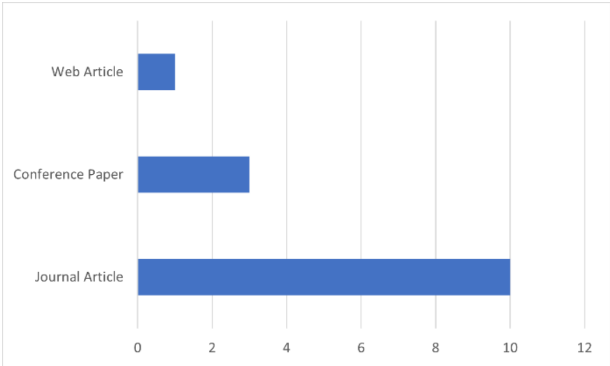


Figure 4. Publication types on dew and fog harvesting related to architecture.

In as many as five publications, the system regarding fog harvesting has frequently been explored. The dew harvesting system was present in three works below the fog harvesting system (see Figure 5). The remaining systems combined rain harvesting, dew harvesting, and fog harvesting to obtain the necessary amount of water for everyday needs. Dew harvesting has been a highly popular motif since the 2000s, but it has ultimately fallen out of favour. Many limitations exist on this technology, especially if it is intended to be scaled up. In this study, the problem of maximum height and surface area posed a hurdle.

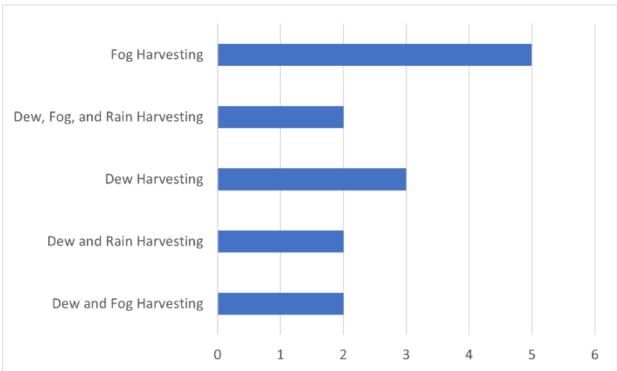


Figure 5. Dew and Fog Harvesting Systems Related to Architecture.

Even though there was little activity at first, the concept of fog harvesting has been becoming more and more prevalent. When this theme emerged as an alternative, it didn't mean that dew harvesting research would cease altogether. A lot more attention is now being paid to the specific research themes of the two combined, moreover with rain harvesting technology. To achieve the intended effectiveness and efficiency, these technologies could complement one another. In the future, this combination is an option.

3.2. Research Focuses

3.2.1. Planar Shape Dew Condenser and Fog Net

Muselli et al. (2002) attempted to test and construct a dew water collector for drinkable water at Ajaccio on the island of Corsica, France. The design of the collector, its performance in terms of water yield, and the analysis of the collected water to evaluate its acceptability for drinking were all covered in the paper. According to them, there was a lack of information on the design and performance of dew water collectors, particularly in the Ajaccio district. While earlier studies had investigated dew collection in a variety of places and climates, there had been little focus on the Ajaccio Gulf area. This research intended to fill that gap by detailing the development and testing of a dew water collector in this location.

Meanwhile, Olivier (2004) investigated the viability and execution of fog water collecting as a supplementary water supply in a water-stressed settlement on South Africa's West Coast. The paper examined the process of choosing an experimental site, designing the fog water collection equipment, and analysing water yields, fog occurrence, and water quality. The purpose of this article was to address the scarcity of comprehensive research on the viability and implementation of fog water harvesting as a supplementary water source in water-stressed areas on South Africa's West Coast. While there had been past experiments and studies on fog water collecting in other places, such as Namibia and Chile, there was a need for research focused exclusively on South Africa's West Coast. This work intended to fill a research gap by offering insights into the design, installation, and performance of a fog water collection system in this region.

Sharan et al. (2011) concentrated on evaluating the yield of ridge-and-trough modules for dew water collection, determining whether results from small condensers could be extrapolated to larger dew condensers, and designing a more efficient condenser setup using computational fluid dynamics (CFD) simulation.

This study was conducted due to a lack of quantitative data on the frequency and amount of dew occurrence in the study area. This information was critical for estimating the potential yield of large-scale dew condensers and developing effective condenser configurations.

Dodson et al. (2015) attempted to put the fog water collection idea into action in Morocco, focusing on rural Berber villages. The study's goal was to solve water scarcity in these regions by investigating the use of fog as a possible supply of potable water. It also entailed the development and deployment of sustainable solutions to improve water management and sanitation, such as fog-collecting nets and ecological filtering systems. The research gap was not specifically highlighted in this study. Based on the information presented, one potential study gap could be the need for additional research on the long-term durability and scalability of fog water harvesting systems in rural Berber villages. While the report detailed the successful implementation of fog-collecting nets and biological filtering systems, it did not go into detail about their long-term usefulness and maintenance. Future research on fog yield models, a correlation between fog yield and wind direction/speed, and water quality monitoring were all mentioned. These research topics indicated a need for additional exploration and knowledge of the technological components and environmental factors associated with fog water collection in rural Berber villages.

Carrera-Villacrés et al. (2017) installed a fog catcher system in the Ecuadorian towns of Yaguachi and Galte to alleviate the region's water deficit and boost agricultural production. The study was done to estimate the demand for irrigation water, collect weather data to evaluate the ability of a fog catcher to trap condensation and assess the water demands of residents and crops. Given the availability of fog conditions that might potentially give a water supply, they sought a solution to the lack of fog catcher systems in the Ecuadorian settlements of Yaguachi and Galte. The purpose of this article was to close this gap by building a fog catcher system and evaluating its effectiveness in satisfying the communities' water needs.

Caldas et al. (2018) explored the technical elements of fog collection mechanisms, specifically the development and deployment of fog harvesting devices in urban contexts as a sustainable water supply option. While fog harvesting systems had been extensively researched and used in rural settings, this work attempted to address the gap in research on their application and viability in urban settings. The report presented a novel adaptation of fog harvesting technology utilized in rural regions for use in cities as a sustainable alternative to water delivery. There was, however, little research on the technical elements and implementation of fog collection methods in urban contexts.

Gandhidasan et al. (2018) attempted to focus on fog water collection and the factors influencing its efficiency. The paper examined various models and methodologies for estimating fog water collection potential, as well as the impact of impaction surface properties and mesh design variables on collection efficiency. The scientists also investigated advanced strategies inspired by biological species for developing and modifying fog collector impaction surfaces. Overall, the research sought to provide insights into optimizing fog water collection efficiency based on local climatic conditions and fog collector design characteristics. This study was conducted to address the scarcity of large-scale field testing of impaction surfaces for fog water collecting under uncontrolled natural fog circumstances. While several surfaces have been evaluated in laboratories under controlled artificial fog circumstances, their performance in the field has received less attention.

Carvajal et al. (2018) investigated the chemical composition of dew water collected from rooftops in Chile's semi-arid region. The authors wanted to know if dew water might be used as an alternate water source in locations with limited freshwater supplies. They attempted to address the lack of long-term research into potential water losses owing to stagnation and evaporation. The authors stated that some water remains stagnant in the gutter after dew events and evaporates during the day, but this water loss was not measured. They believed that water losses due to stagnation might be significant, particularly in semi-arid areas with dust and debris deposition on rooftops, although this issue had not been thoroughly addressed and requires additional research.

Dong et al. (2020) investigated and optimized dew-harvesting technology. The authors provided a comprehensive framework for analysing dew harvesting elements such as ambient temperature and relative humidity. In addition, they offered a photonic design for a selective emitter to increase the condensation mass flux. The purpose was to improve dew collecting efficiency for water collection. This study attempted to address the absence of comprehensive dew-harvesting technology analysis and optimization by considering aspects such as ambient temperature, relative humidity, and the design of a selective emitter. While earlier research had concentrated on individual features of dew harvesting, this paper provided a broad framework for analysing and optimizing the technology. In addition, the authors offered a photonic design for a selective emitter to increase condensation mass flux.

3.2.2. 3D Form Dew Condenser and Fog Net

Beysens et al. (2013) presented research on the effectiveness of different designs of dew condensers in collecting water from the atmosphere. This study was carried out since there had been little research on the usefulness of various designs of dew condensers in collecting water from the atmosphere. The purpose of this work was to close this gap by comparing the water yields of various forms, such as conical, egg-box, and origami, with a standard planar condenser.

Williams (2015) attempted to reveal the development and implementation of Arturo Vittorio's Warka Water building, which was built in 2015 and aimed to capture clean drinking water from the air in locations where traditional water delivery infrastructure was unavailable. The article covered the Warka Water building's concepts and design using a biomimetic approach, as well as the problems and potential benefits of its application in specific places. This initiative attempted to address the demand for a long-term and easily accessible solution to deliver safe drinking water in locations where traditional water supply infrastructure did not exist. The Warka Water facility was designed and built to address this issue by capturing safe drinking water from the air. Meanwhile, Fenyvesi et al. (2016) used this blueprint as a tool for environmental education and problem-solving in the 4Dframe Warka Water workshop, notably in the areas of mathematics, architecture, and natural science. The research investigated the linked nature of these disciplines and how they could be integrated into educational settings to create environmental consciousness and develop the abilities needed for long-term problem-solving. This study attempted to address the lack of understanding of mathematics and natural sciences in answering design difficulties in the absence of architectural knowledge.

Bhushan (2020) studied bioinspired techniques for water harvesting, focusing on the water collection and transport strategies utilized by plants and animals in arid desert settings. The paper also explored the possible uses of these bioinspired techniques in a variety of domains, including consumer, emergency, and defence. The goal of this study was to address the lack of thorough understanding and use of bioinspired approaches to water collection. While studies on the tactics employed by plants and animals in arid desert circumstances to gather and carry water have been conducted, there is a need for additional research to investigate the possible uses of these bioinspired approaches in many domains such as consumer, emergency, and military. This work emphasized the need for additional research in this area and serves as a jumping-off point for future investigations.

3.2.3. Fog and Dew Potential

Kaseke et al. (2018) investigated fog and dew collection as potential sources of potable water in water-stressed areas. The report covered the variations between fog and dew, their potential water yields, and the need for material science and collector design innovations to increase efficiency. It also emphasized the absence of worldwide coordination and information on fog and dew harvesting programs, as well as the necessity for greater research on the potability of fog and dew water. The problems identified in this study were a lack of cooperation and information on fog and dew harvesting operations around the world. The authors emphasized the need for additional research on the potability of fog and dew water and developments in material science and collector designs to improve efficiency. They also underlined the potential of fog and dew as sources of potable water in water-stressed areas but acknowledge the lack of study and expertise in this area.

3.3. Research Methodologies

3.3.1. Design Testing: Model, Prototype, and Implementation

Muselli et al. (2002) used a research methodology that entailed building and testing a dew water collection at Ajaccio on the island of Corsica, France. The collector was a rectangular foil with a 30-degree angle to the horizontal consisting of TiO2 and BaSO4 microspheres embedded in polyethylene. The collector's performance was assessed by monitoring the amount of dew collected over a 478-day period and comparing it to a reference plate. Temperature, humidity, wind velocity, and cloud cover were also gathered and analysed to determine dew generation. Chemical tests of collected water were also performed to assess characteristics such as suspended particles, pH, and ion concentrations.

Meanwhile, Olivier (2004)'s research methodology included several steps. First, an appropriate trial site for a fog water collection system was chosen based on considerations such as water availability, cost, geographical features, and accessibility. A questionnaire survey was used to collect data on home water use in the areas. Then, at the chosen location, a prototype fog water collection system was designed, built, and tested. Water yields, the contribution of fog and rainfall, wet event features, parameters related to water collecting, and water quality were all investigated. An automatic weather station and data recorder were used to collect data on fog occurrence, wind speed, wind direction, and rainfall. A tipping bucket rain gauge was used to capture hourly water collection values, and daily and monthly water collection rates were determined. The study also included training local community members in the operation and maintenance of the system, with the goal of informing a broad audience about the feasibility and benefits of fog harvesting.

Sharan et al. (2011) used a combination of field tests, data analysis, and computational fluid dynamics (CFD) simulation in their work. Field tests were carried out to assess the yield of ridge-and-trough modules for dew water collecting in several models of large-scale dew condensers. Data were analysed to see if the results from small condensers could be generalized to bigger dew condensers. CFD simulation was also used to build a more efficient condenser configuration.

The Beysens et al. (2013) paper's research methodology included conducting trials and measurements in the field to examine the water yields of different forms of dew condensers. The trials were carried out in the summer and fall of 2009 at Pessac, France. The researchers looked at conical shapes as well as two new families of forms: egg-box and origami. The yields of these designs were compared to those of a conventional planar condenser positioned at a 30° angle from the horizontal. Over a 51-day period, data on air relative humidity, air and dew point temperature, wind direction, and wind speed were continually recorded using an autonomous meteorological station. The findings were explained in terms of radiative impacts, heat losses, and gravity water flow.

The research methodology was not specifically specified in Dodson et al. (2015) paper. However, based on the information supplied, it is possible to deduce that the research methodology included a mix of qualitative and quantitative approaches. The use of household surveys to collect data on water use behaviours and consumption trends was mentioned in the paper. It also included climate scientists and meteorologists collecting and analysing micrometeorological data and climate trends. The report also explored the design and implementation of fog-collecting nets and ecological filtering systems, which proposed a practical and experimental way to study fog water harvesting.

Carrera-Villacrés et al. (2017) used a multi-step research methodology. To begin, weather parameters such as precipitation, temperature, sunlight hours, relative humidity, and wind speed were gathered from Ecuador's National Institute of Meteorology and Hydrology (INAMHI) using two weather stations. To calculate the water deficit and evaporation, monthly precipitation data from the previous ten years were utilized, as well as the Wilson nomogram, Thornthwaite method, and Blaney-Criddle method. A community survey was conducted to collect data on socioeconomic characteristics, water sources, agricultural and animal

 http://dx.doi.org/10.13135/2384-8677/7492

production, crop yields, and water requirements. In 2014 and 2015, fog catcher prototypes were placed, and their performance was tracked. Finally, the collected data and information were utilized to compute the required size of the fog catcher system and determine the community's water requirements.

Carvajal et al. (2018) employed dew water measurements collected from a rooftop in a semi-arid region of Chile as their methodology in their paper. To quantify the volume of dew water collected, a graduated bottle with a capacity of 20 L was installed. The measurements were taken at 08:00 local time every day, and the cumulative volume in the container was recorded without scraping the collecting surface. A nearby meteorological station provided data such as air temperature, relative humidity, wind direction and speed, and rainfall. Dew readings were taken from 3 September 2014 to 31 August 2015.

Gandhidasan et al. (2018)'s research methodology implied a combination of literature evaluation, theoretical analysis, and field testing. Previous research on fog water collecting, impaction surfaces, and collection efficiency aerodynamic models were reviewed. They examined the existing models and methodologies for estimating the potential for fog water collecting and highlight research needs in the field. In addition, the authors undertook field testing in the Kingdom of Saudi Arabia's Asir region to collect data on fog water collection potential and atmospheric conditions. The data gathered was then utilized to validate and improve the existing models.

A study by Dong et al. (2020) did not go into specifics about the methodology. This paper, on the other hand, appeared to employ a combination of theoretical analysis and numerical simulations. The scientists created a theoretical framework to study the dew-harvesting process, considering variables like ambient temperature, relative humidity, and the design of a selective emitter. In addition, they presented a photonic design for a selective emitter to increase condensation mass flux. To validate the suggested framework and design, the theoretical study was supplemented with numerical simulations.

The research methodology was not specifically specified in Bhushan's (2020) paper. However, based on the paper's content and structure, it appeared to be a review article synthesizing existing literature and research on bioinspired approaches to water collection. The authors offered an overview of arid desert environments, water supplies, and water collection mechanisms employed by plants and animals. They also talked about natural teachings, water harvesting data from fog and condensation, and several designs for water harvesting towers and predictions. There were no experiments or data collection methods described in the publication.

3.3.2. Design Reviews: Process, Concept, and Potential

Williams (2015) paper described the research process of Arturo Vittori's Warka Water building. The Warka Water building was field tested and implemented using a combination of biomimetic design and engineering approaches. The article covered the building system's architecture and principles, as well as the problems and potential benefits of using it in specific places. It also mentioned the creation of a modest functional prototype as well as plans for a large-scale field test.

Fenyvesi et al. (2016) did not specify their research approach directly. However, the research appeared to use a combination of literature assessment, theoretical analysis, and description of the 4Dframe Warka Water workshop and its teaching activities. The article was based on existing literature and principles in environmental education, problem-solving, and the integration of mathematics, architecture, and environmental science. It also described the workshop format, activities, and learning objectives in depth.

Kaseke et al. (2018)'s research methodology was not specifically disclosed in their paper. However, the publication appeared to be a review article that synthesised previous fog and dew-collecting research and studies. It explored the distinctions between fog and dew, their prospective water yields, the need for breakthroughs in material science and collection designs, and the possible public health risks associated with heavy metals and biological pollution in fog and dew water. In addition, the report gave examples and estimations of probable fog and dew yields in various locales.

The research methodology of the paper, used by Caldas et al. (2018), involved a literature review and analysis of existing fog harvesting technologies and their application in urban environments. The authors reviewed various fog collection mechanisms, such as drop coalescence on vertically placed meshes, chemical absorption, and desorption processes, and condensation on cold surfaces during the night. They also discussed the different types of fog collectors, including standard fog collectors (SFC) and large fog collectors (LFC), and the materials used for fog collection meshes. The paper also presented the author's own experimental campaign on radiative surfaces, which was discussed in a separate paper. Overall, the research methodology of this paper was based on a comprehensive review of existing literature and the author's own experimental work.

The research methodology was not specifically specified in Bhushan's (2020) paper. However, based on the paper's content and structure, it appeared to be a review article synthesizing existing literature and research on bioinspired approaches to water collection. The authors offered an overview of arid desert environments, water supplies, and water collection mechanisms employed by plants and animals. They also talked about natural teachings, water harvesting data from fog and condensation, and several designs for water harvesting towers and predictions. There were no experiments or data collection methods described in the publication.

3.4. *Implications and Limitations*

3.4.1. Dew Harvesting

The research paper of Muselli et al. (2002) had the implications that well-designed dew water collectors, such as the one constructed and tested in Ajaccio on the island of Corsica in France could be a vital source of water in locations where fog or rainfall is limited. The study found that during a 16-month period, the collector captured a large amount of water, demonstrating its potential as an alternate water source. The chemical examination of the collected water revealed that it is potable, at least in terms of the studied ions, and does not require further filtration. This discovery emphasized the possibility of using dew water as a drinking water source in water-stressed areas. However, there were certain limitations to this study. Firstly, the study was limited to a single area and may not be immediately applicable to other locations with varying climatic circumstances. Furthermore, bacteriological studies of the dew water were not included in the study, which was a crucial factor to consider for its safety as a drinking water source. More research was needed to determine the presence of bacteria and other compounds in dew water, as well as to evaluate the concentration of suspended particles, which was found to be relatively high in this study. Overall, while the study gave useful insights into the design and performance of dew water collectors in a specific region, more research is needed to overcome the constraints and investigate the broader applicability and safety implications of dew water as a drinkable water source.

Beysens et al. (2013) findings had implications for developing and optimizing dew collection systems, particularly in areas where water scarcity is an issue. The findings suggested that employing precise shapes and angles can improve dew water collecting, potentially offering a supplemental source of drinking water. However, some limitations of this study should be noted. To begin, the trials were done in a specific place (Pessac, France) and time (summer and fall of 2009), which may restrict the findings' generalizability to other regions and seasons. Furthermore, the study only looked at a few designs (conical, egg-box, and origami), and there could be other shapes that might harvest even more water. More research was required to investigate a broader range of forms and their usefulness in various environmental situations.

Dong et al. (2020) offered a general framework for studying and optimizing dew-harvesting technologies in their research. The authors attempted to increase the effectiveness of dew harvesting for water collection by considering elements such as ambient temperature, relative humidity, and the design of a selective emitter. This study held the potential to help develop more effective and sustainable water-gathering systems. However, the limitations of this study should not be overlooked. The paper did not include specifics about the research methods, such as numerical simulations and experimental validation. Furthermore, the research did not address the proposed framework and design's actual implementation or scalability. More study and testing were required to evaluate and optimize the proposed technique in real-world settings.

3.4.2. Dew and Rain Harvesting

Sharan et al. (2011) proposed in their research study that large-scale dew condensers, specifically ridge-and-trough modules, could be useful in collecting dew and rainwater for various uses such as irrigation and drinking water supply. The study also highlighted the possibility of employing computational fluid dynamics (CFD) simulation to optimize the design and efficiency of condenser arrangements. This study offered useful information for the design and implementation of dew water collection devices in water-stressed areas. However, there are certain limitations to this study. The absence of quantitative data on the frequency and amount of dew occurrence in the study area was one constraint, which could impair the accuracy of yield estimates for large-scale condensers. Furthermore, the study was limited to a single area and might not be immediately transferable to other regions with different climatic circumstances. More research is needed to validate the findings and investigate the possibility of collecting dew water in different geographical locations.

Carvajal et al. (2018) presented evidence that dew water collected from rooftops in a semi-arid region of Chile has a chemical composition suited for a variety of uses, including irrigation and cattle watering. This revealed that dew water plus rainwater could be a viable alternative water supply in locations where freshwater supplies are scarce. The research gave important insights into the viability of using dew water as a sustainable water supply source. This study did, however, have several shortcomings. To begin with, the study merely looked at the chemical makeup of dew water and did not look at its microbial quality. More research is needed to examine the dangers of microbial contamination related to dew water. Furthermore, the study did not account for long-term water losses owing to stagnation and evaporation, which could impair the overall availability and utilization of dew water. More research is needed to address these constraints and gain a better understanding of the possibilities of dew water as an alternate water source.

3.4.3. Fog Harvesting

Olivier et al. (2004) gave implications that fog water harvesting can be a realistic and effective additional water supply in water-stressed settlements on South Africa's West Coast. The research shed light on the design, implementation, and water yields of a fog water collection system, which can be utilized as a model for similar initiatives in other parts of the country. This study held the potential to address the challenges of water scarcity and improve the quality of life in these communities. However, there were certain limitations to this study. The study has one disadvantage in that it focuses on a specific region and may not be immediately relevant to other geographical areas with various meteorological conditions.

The study by Dodson et al. (2015) did not directly discuss the research's implications and limitations. However, some potential implications and limitations might be deduced from the information supplied. The study emphasized the possibility of fog water collection as a long-term solution to water scarcity in rural Berber villages in Morocco. The study found that fog water collecting had a favourable influence on a variety of factors, including public health, community stability, women empowerment, education, employment, and agriculture. In addition, the paper highlighted the integration of information and communication technologies (ICTs) for water management, bridging the development and digital divides. The research shed light on the collaborative relationships and participatory techniques required for the successful execution of sustainable development initiatives in arid and semi-arid regions. The paper, however, did not go into detail about the long-term durability and scalability of fog water harvesting systems in rural Berber settlements. The study's generalizability may be limited because it focuses exclusively on the context of rural Berber villages in Morocco and their unique water scarcity concerns. The study's research methodology and data-gathering methodologies were not properly defined, making it difficult to assess the findings' reliability and validity. The paper did not address potential obstacles or disadvantages of fog water harvesting, such as changes in fog yield, maintenance requirements, or potential environmental implications. Overall, while the research paper highlighted the potential benefits of fog water harvesting in solving water scarcity, more research and exploration of the long-term sustainability, scalability, and potential limitations of this strategy would be beneficial.

Carrera-Villacrés et al. (2017) showed that installing fog catcher systems might provide a consistent water supply in locations with water scarcity, such as the Ecuadorian communities of Yaguachi and Galte. During the rainy season, the fog catcher system collected up to 20 litres of water per day, with daily water collection ranging from 5 to 10 litres per fog catcher. This technology could help communities achieve their water needs, particularly for agricultural output, and compensate for water shortages. However, there were certain limitations to this study. The absence of complete and trustworthy meteorological data for the study area was one limitation, which necessitated the employment of strategies to compensate for missing data. Another limitation was that the fog catcher system might not be able to meet the research area's overall water requirement since the water needs are disproportionately high. Furthermore, because the study concentrated on two unique villages in Ecuador, the findings may not be immediately transferable to other places with different meteorological conditions or water demands.

Caldas et al. (2018) proposed fog harvesting technology as a sustainable alternative for water supply in metropolitan contexts. This study found that by modifying and executing fog collection technologies utilized in rural areas, fog harvesting might meet water needs in office, institutional, and commercial buildings, providing a local and ecologically friendly water production system. However, the limitations of this study should not be overlooked. The research concentrated on the technical aspects of fog collection systems and did not discuss the potential health risks involved with utilizing atmospheric water. Furthermore, while the report provided a thorough analysis of existing fog harvesting devices, there was little research on the technical elements and implementation of fog collection techniques in urban environments. Overall, this study gave useful insights into the potential of fog harvesting devices in urban contexts; however, more research is required to address health issues and investigate the feasibility and effectiveness of adopting these systems in urban regions.

The implication of the study by Gandhidasan et al. (2018) was that it provided insights into optimizing fog water collection efficiency based on local atmospheric conditions and fog collector design characteristics. The research discussed various models and methodologies for assessing fog water collection potential and investigates the impact of impaction surface characteristics and mesh design variables on collection efficiency. The authors also developed new strategies for modifying the impaction surface of fog collectors inspired by biological species. These findings could help design and improve fog water collection systems in areas where fog water is a potential water resource. However, there were certain limitations to this study. One constraint was that the field testing of impaction surfaces for fog water collection was limited to a certain region (the Asiar region of the Kingdom of Saudi Arabia) and set of atmospheric conditions. The performance of impaction surfaces might differ in other places and under different climate conditions. Furthermore, while the research explored the impact of impaction surface features and mesh design variables on collection efficiency, it did not thoroughly examine all conceivable design variables and their consequences. Further investigation is required to investigate and improve other design variables for fog water collection devices.

3.4.4. Dew and Fog Harvesting

Kaseke et al. (2018) stated that fog and dew harvesting could potentially serve as additional sources of potable water in water-stressed areas. The report emphasized the importance of advances in material science and collector designs to improve the effectiveness of fog and dew harvesting devices. It also stressed the significance of performing additional research on the potability of fog and dew water, as well as addressing potential public health issues about heavy metals and biological contaminants. The absence of detailed facts about the research methods used was one disadvantage of this research paper. The work appeared to be a review article that consolidated existing knowledge, but no precise methodologies were mentioned for selecting and analysing the literature. Furthermore, the paper acknowledged the scarcity of data and analysis on fog and dew harvesting, which made it difficult to make solid conclusions about their potability and usefulness as water sources.

Bhushan's (2020) research proposed water harvesting systems based on the strategies used by plants and animals in arid desert settings (bioinspired), which had the potential to be implemented in a variety of domains such as consumer, emergency, and military. Innovative water harvesting technologies could be developed to address water scarcity challenges by researching and reproducing these natural phenomena. However, the limitations of this research work should not be overlooked. To begin with, the paper mostly reviewed current literature and did not present any new experimental data or discoveries. Second, while the report highlighted the possible uses of bioinspired techniques, it did not go into great length on their practical implementation or viability. Additional study and testing were required to confirm and optimize these bioinspired designs for real-world applications.

3.4.5. Dew, Fog, and Rain Harvesting

Williams (2015) paper did not directly highlight the implications and limits of Arturo Vittori's Warka Water. However, some potential consequences and restrictions might be concluded from the information inferred. The design and construction of the Warka Water facility could provide a long-term and accessible alternative for obtaining safe drinking water from (dew, fog, and rain) in locations where conventional water delivery infrastructure does not exist. The structure had the ability to alleviate water scarcity issues in hilly areas where traditional pipelines and wells are impractical. However, the paper did not go into detail about the Warka Water building's performance and efficiency. It remained to be seen whether a full-size device would draw the projected amount of water. The structure might not be ideal for all areas and should be viewed as a tool for providing clean water in specific areas, particularly in hilly terrain. The article also did not address the potential environmental consequences or obstacles of extracting water from the air, such as air drying or the effects on local ecosystems. While the Warka Water building demonstrated promise in alleviating water scarcity, more research and testing are required to assess its effectiveness, efficiency, and potential environmental implications.

The paper of Fenyvesi et al. (2016) implied that the integration of mathematics, architecture, and environmental science through the 4Dframe Warka Water workshop could be an effective tool for environmental education and problem-solving. It emphasized the linked nature of these disciplines and how they may be utilized in real-world circumstances to create environmental consciousness and develop the skills needed for long-term problem-solving. However, the report did not give empirical evidence or a review of the workshop's effectiveness in meeting its teaching objectives. This was a weakness of the study because data on the outcomes and influence of the workshop on participants' learning and environmental consciousness would be useful. More studies might be conducted to assess the workshop's success in reaching its desired educational results.

4. Conclusions and Future Research

Research on dew and fog harvesting related to architecture in SCOPUS-indexed publications is still small. Thus, there are not many publications that can be discussed in this systematic literature review. However, the number of these studies has recently shown a significant and optimistic increase.

The publications reviewed revealed that research focuses on the effectiveness and efficiency of planar shape-based technologies dominated research on dew and fog harvesting concerning architecture. Moreover, the research might start to shift to thinking about three-dimensional forms and their application in the future not only in rural areas but also in urban settings. The conventional engineering approach somehow is the design strategy that was most frequently adopted in this study. Even so, several researchers have been experimenting with alternative strategies, particularly methods that mimic nature's system for collecting water from the atmosphere (bioinspiration and biomimetics).

Most of these studies chose research methodologies in the form of design testing and review of models, prototypes, and developments. Even so, many papers do not provide clear information regarding the research methodology they use, and several papers use research methodologies that are not precise and not holistic enough. So, most of the results are still not optimal.

The research between dew harvesting and fog harvesting technology was relatively balanced in numbers. Nevertheless, several studies were beginning to consider combining both, even with rain harvesting to optimize water quantity and to provide solutions due to changing weather conditions. Thus, research focuses on this system should be seriously discussed in the future.

Many of the design products produced were still in the form of small-scale designs. However, the main goal of dew and fog harvesting research is that this technology can be realized on a large scale. Only a few have been implemented into real developments and become best practices and demonstrate their potential. They need to be further optimised in the future.

The physical local context, material selection, research methodologies, scalability, water quality, and water quantity, continued to be the limitations of this research. Even though all of this can be improved by creating a design that is adaptable to the site, adaptable to the available materials, and an effective and efficient design in collecting the anticipated water amount and quality. Most researchers seem to make the design first and then look for the appropriate context. Though the design should follow the context. Contextual issues such as the physical and cultural environment are sometimes overlooked by some researchers.

Cultural factors and people's daily habits are just as important as technicalities, as they influence how people interact with new technologies. In fact, a well-designed product aims to fulfil the needs of its users, both physically and non-physically. So, in the future, researchers and practitioners in architecture need to step into this research to join forces with researchers from other disciplines to create a feasible, sustainable, and well design. Arturo Vittori's Warka Water is one design work that has considered these issues. He is not a researcher but rather a practitioner and has never published his work in any scientific papers, but his work has been used by many people in Africa. It seems that he has succeeded in adopting and implementing some of the results of existing research and technology, transferring them with his knowledge and skills as an architect into designs that are adaptive to the local physical and cultural environment. He also used nature and culture as a basis for his designs.

In general, it is possible to say that the dew and fog harvesting system can cover some of the daily water needs. On a small scale, this system can offer supplementary water for household and neighbourhood needs. On a big scale, this system can also offer self-sufficient additional water for urban building needs as well as agricultural irrigation needs. As a result, it can reduce overconsumption of groundwater while alleviating water stress and shortage. Of course, this method can be also integrated with a water storage, recycling, and reuse system to ensure that the leftover water is not wasted. Its role will have a favourable influence on security and sustainability, especially on water conservation.

Based on this systematic literature review, we may conclude various findings that are required for our future research, particularly in architecture science. This also pertains to the possibility of its application in Indonesia, particularly in areas impacted by the water crisis. The design of a building with a combination harvesting system (dew, fog, and rain), that is following the site conditions to be identified later in Indonesia, is our next study focuses on the topic of dew and fog harvesting. The anticipated technology will be in the form of a passive system with low-tech, making it affordable to communities with low incomes. However, the planning must consider not only technical concerns but also environmental (natural and cultural) context issues, employing a qualitative and quantitative feasibility study technique. Furthermore, there may be opportunities to use vernacular or traditional architecture that are tied to existing local community knowledge and easily accessible local natural materials, which have not been discussed in previous studies. As a result, a review and testing strategy is required to examine these local designs and materials. This gives originality to our research. A design method is used during the design stage to create models, prototypes, and design implementation. These outcomes are then tested to determine effectiveness and efficiency to get an optimal building design.

Furthermore, the building design is planned to include a communal space function that can satisfy the needs of the community.

Acknowledgments

The author would like to thank Universitas Matana for providing funds to achieve this research.

References

Afrilia, D. (2022). Indonesia Kaya Sumber Air Tapi Terancam Krisis Air Bersih, Apa Penyebabnya? https://www.goodnewsfromindonesia.id/2022/03/22/indonesia-kaya-sumber-air-tapi-terancam-krisis-air-bersih-apa-penyebabnya Accessed on 30 June 2022

Armstrong, R., Hall, B. J., Doyle, J., & Waters, E. (2011). Cochrane Update: 'Scoping the scope' of a Cochrane review. *Journal of Public Health,* 33(1), 147-50. https://doi.org/10.1093/pubmed/fdr015

Assaf H, Erian W, Gafrej R, Hermann S, McDonnell R, & Taimeh A. (2012). Climate change contributes to water scarcity. In: Verner D, editor. Adaptation to a changing climate in the Arab countries: a case for adaptation governance in building climate resilience. MENA Development Report 64635. Washington, DC: International Bank for Reconstruction and Development and The World Bank, 109–151.

Beysens, D., Broggini, F., Milimouk-Melnytchouk, I., Ouazzani, J., Tixier, N. (2012). Dew architectures - Dew annouces the good weather. In *Proceeding of MC 2012 Symposium, Ville Fontaine, November 2012*. https://hal.science/hal-00993656/document

Beysens, D., Broggini, F., Milimouk-Melnytchouk, I., Ouazzani, J., Tixier, N. (2013). New architectural forms to increase dew collection. *Chemical Engineering Transactions*, 34, 79-84. https://hal.science/hal-00978323v1/file/New%20Architectural%20Forms-CET2013.pdf

Bhushan, B. (2020). Design of water harvesting towers and projections for water collection from fog and condensation. *Philosophical Transactions of the Royal Society A.*, 378. https://doi.org/10.1098/rsta.2019.0440

Caldas, L., Andaloro, A., Calafiore, G., Munechika, K., & Cabrini, S. (2018). Water harvesting from fog using building envelopes: Part I. *Water and Environment Journal*, 32. https://doi.org/10.1111/wej.12335

Carrera-Villacrés, D.V., Robalino, I.C., Rodríguez, F., Sandoval, W., Hidalgo, D.L., & Toulkeridis, T. (2017). An innovative fog catcher system applied in the Andean communities of Ecuador. *Transactions of the ASABE*, 60, 1917-1923. https://doi.org/10.13031/trans.12368

Carvajal, D., Minonzio, J., Casanga, E., Muñoz, J., Aracena, A., Montecinos, S., & Beysens, D. (2018). Roof-integrated dew water harvesting in Combarbalá, Chile. *Journal of Water Supply: Research and Technology-Aqua*, 67. https://doi.org/10.2166/aqua.2018.174

Cassauwers, T. (2022). Fresh-Water Scarcity Prompts Hunt for More from the Air and Sea. https://ec.europa.eu/research-and-innovation/en/horizon-magazine/fresh-water-scarcity-prompts-hunt-more-air-and-sea Accessed 14 January 2023

Chakkaravarthy, D. Niruban and T. Balakrishnan, T. (2019). Water Scarcity-Challenging the Future. *International Journal of Agriculture Environment and Biotechnology*, 12(3). https://doi.org/10.30954/0974-1712.08.2019.2

Damkjaer, S. & Taylor, R. (2017). The Measurement of Waterscarcity: Defining a Meaningful Indicator. Ambio, 46(5), 513–531. https://doi.org/10.1007/s13280-017-0912-z

Di Bitonto, M. G. et al. (2020). Fog and Dew Harvesting: Italy and Chile in Comparison. *International Journal of Innovative Research and Development*, 9(3). https://doi.org/10.24940/ijird/2020/v9/i3/MAR20056

Dodson, L.L., & Bargach, J. (2015). Harvesting Fresh Water from Fog in Rural Morocco: Research and Impact Dar Si Hmad's Fogwater Project in Aït Baamrane. *Procedia Engineering*, 107, 186-193. https://doi.org/10.1016/j.proeng.2015.06.073

Dong, M., Zhang, Z., Shi, Y., Zhao, X., Fan, S., & Chen, Z. (2019). Fundamental Limits of the Dew-Harvesting Technology. *Nanoscale and Microscale Thermophysical Engineering*, 24, 43-52. https://doi.org/10.1080/15567265.2020.1722300

Du, B., Guo, X., Yan, Q., Duan, H., & Liu, G. (2022). Analysis of Domestic Water Consumption in Typical Countries and its Enlightenment to China. E3S Web Conf., 352, 03017. https://doi.org/10.1051/e3sconf/202235203017

Egger, M., Smith, G., Altman, D. (2001). *Systematic Reviews in Health Care Meta-Analysis in Context (2nd.ed)*. BMJ Publishing Group, London.

Fenyvesi, K., Park, H., Choi, T., Song, K., & Ahn, S.I. (2016). Modeling Environmental Problem-Solving Through STEAM Activities: 4Dframe's Warka Water Workshop. In *Proceeding of Bridges Finland Conference 2016, Jyväskylä, 9-13 August 2016*. https://archive.bridgesmathart.org/2016/bridges2016-601.pdf

Francis, R. (2002). Humidity and Dew Point: Their Effect on Corrosion and Coatings. In Proceeding of ACA Annual Conference. https://www.academia.edu/17021842/Humidity_and_Dew_Point_Their_Effect_on_Corrosion_and_Coatings

Gandhidasan, P., Abualhamayel, H.I. and Patel, F. (2018). Simplified Modeling and Analysis of the Fog Water Harvesting System in the Asir Region of the Kingdom of

Saudi Arabia. *Aerosol Air Qual. Res.*, 18, 200-213. https://doi.org/10.4209/aaqr.2016.11.0481

Gleissman, Stephe (2007). Agroecology: the ecology of sustainable food systems. *CRC Press*. https://doi.org/10.1201/b17881

Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. *Campbell Systematic Reviews*, 18(2). https://doi.org/10.1002/cl2.1230

Hapsari, Jelita Mawar (2022). BMKG Peringatkan Krisis Air Bersih Akibat Perubahan Iklim. https://rdk.fidkom.uinjkt.ac.id/index.php/2022/03/03/bmkg-peringatkan-krisis-air-bersih-akibat-perubahan-iklim Accessed on 30 June 2022

Ina (2022). Kelangkaan Air di Jawa, Bali dan Nusa Tenggara Diprediksi Naik. https://www.cnnindonesia.com/nasional/20220223133008-20-762939/kelangkaan-air-di-jawa-bali-dan-nusa-tenggara-diprediksi-naik Accessed on 30 June 2022

Jarimi, H., Powell, R., Riffat, S. (2020). Review of Sustainable Methods for Atmospheric Water Harvesting. *International Journal of Low-Carbon Technologies*, 15(2), 253–276. https://doi.org/10.1093/ijlct/ctz072

Jiménez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Döll, P., Jiang, T., & Mwakalila, S. S. (2014). Freshwater Resources. In Climate Change 2014 – Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report, 229-270. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781107415379.008

Kaseke, K. F., & Wang, L. (2018). Fog and Dew as Potable Water Resources: Maximizing Harvesting Potential and Water Quality Concerns. *GeoHealth*, 2(10), 327-332. https://doi.org/10.1029/2018GH000171

Khalil, B. dan Adamowski, J. F. (2016). A review: dew water collection from radiative passive collectors to recent developments of active collectors. *Sustainable Water Resources Management*, 2(1). https://doi.org/10.1007/s40899-015-0038-z

Khamdevi, M., & MLT, M. (2023). Architecture Science Field Position in Dew and Fog Harvesting Research: A Bibliometric Analysis. *MARKA (Media Arsitektur Dan Kota) : Jurnal Ilmiah Penelitian*, 6(2), 45-62 https://doi.org/10.33510/marka.2023.6.2.45-62

Kitchenham, B., & Charters, S. (2007). Guidelines for performing Systematic Literature Reviews in Software Engineering. In *EBSE Technical Report, EBSE-2007-01, Auckland, New Zealand.* https://www.elsevier.com/__data/promis_misc/525444systematicreviewsguide.pdfhttps://www.cs.auckland.ac.nz/~norsaremah/2007%20Guidelines%20for%20performing%20SLR%20in%20SE%20v2.3.pdf

Leopold L. B. (1952). Dew as a source of plant moisture. *Pac. Sci.*, 6(3), 259-261. https://biostor.org/reference/234357

Ling, Tong (2022). A Global Study About Water Crisis. In *Proceeding in the 2021 International Conference on Social Development and Media Communication (SDMC 2021)*. https://doi.org/10.2991/assehr.k.220105.148

Manungufala, T. E. (2021). Water Scarcity: Classification, Measurement and Management. In book: Clean Water and Sanitation, 1-14. https://doi.org/10.1007/978-3-319-70061-8_7-1

Muselli, M., Beysens, D.A., Marcillat, J., Milimouk, I., Nilsson, T.M., & Louche, A. (2002). Dew water collector for potable water in Ajaccio (Corsica Island, France). *Atmospheric Research*, 64, 297-312. https://doi.org/10.1016/S0169-8095(02)00100-X

Olivier, J. (2004). Fog harvesting: An alternative source of water supply on the West Coast of South Africa. *GeoJournal*, 61(2), 203-214. http://www.jstor.org/stable/41147932

Pearce, R. P. (2002). *Meteorology at the Millennium*. Academic Press, Cambridge.

Sadoff, C. W., Hall, J. W., Grey, D., Aerts, J. C. J. H., Ait-Kadi, M., Brown, C., Cox, A., Dadson, S., Garrick, D., Kelman, J., McCornick, P., Ringler, C., Rosegrant, M., Whittington, D., & Wiberg, D. (2015). Securing Water, Sustaining Growth. Report of the GWP/OECD Task Force on Water Security and Sustainable Growth. Oxford: Oxford University. https://www.gwp.org/globalassets/global/about-gwp/publications/the-global-dialogue/securing-water-sustaining-growth.pdf

Schiermeier, Q. (2008). 'Rain-making' bacteria found around the world. *Nature*, https://doi.org/10.1038/news.2008.632

Sharan, G., Clus, O., Singh, S., Muselli, M., & Beysens, D. A. (2011). A very large dew and rain ridge collector in the Kutch area (Gujarat, India). *Journal of Hydrology*, 405, 171-181. https://doi.org/10.1016/j.jhydrol.2011.05.019

Siddaway, Andy P.; Wood, Alex M.; Hedges, Larry V. (2019). How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses. *Annual Review of Psychology*. 70(1): 747-770. https://doi.org/10.1146/annurev-psych-010418-102803

Singh, V. P., Khedun, C. P. & Mishra, A. K. (2014). Water, Environment, Energy, and Population Growth: Implications for Water Sustainability under Climate Change. *Journal of Hydrologic Engineering*, 19(4), 667-673. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000866

Suau, C. (2010). Fog Collection and Sustainable Architecture in Atacama Coast In *Proceeding of 5th International Conference on Fog, Fog Collection and Dew, Münster, 25-30 July 2010*. https://meetingorganizer.copernicus.org/FOGDEW2010/FOGDEW2010-89.pdf

Van Vliet, Michelle T. H., Jones, Edward R., Flörke, M., Franssen, Wietse H. P., Hanasaki, N., Wada, Y., and Yearsley, John R. (2021). Global water scarcity including surface water quality and expansions of clean water technologies. *Environmental Research Letters*, 16(2). https://doi.org/10.1088/1748-9326/abbfc3

Wallace, J. M. & Hobbs, P. V. (2006). Atmospheric science: an introductory survey. Elsevier Inc., Amsterdam.

Weeks, K. (2013). Millions More May Face Water Scarcity: Why Architects and Builders Should Care. https://www.architectmagazine.com/technology/millions-more-may-face-water-scarcity-why-architects-and-builders-should-care_o Accessed on 14 January 2023

Williams, A. (2015). Warka Water promises to harness safe drinking water from the air. https://newatlas.com/warka-water-from-air/35721/#:~:text=Italy's%20Architecture%20and%20Vision%20is,gallons)%20of%20water%20per%20day Accessed on 14 January 2023

Zhang, D., Sial, M.S., Ahmad, N., Filipe, J.A., Thu, P.A., Zia-Ud-Din, M., Caleiro, A.B. (2021). Water Scarcity and Sustainability in an Emerging Economy: A Management Perspective for Future. Sustainability, 13(1), 144. https://doi.org/10.3390/su13010144

Authors

Muhammar Khamdevi
Universitas Matana - Department of Architecture, Faculty of Arts Design and Humanities, Jl. CBD Barat Kav.1, 15810 Tangerang, Indonesia.
ORCID author: http://orcid.org/0000-0003-2945-800X
E-mail: muhammar.khamdevi@matanauniversity.ac.id

Funds

This research was funded by Universitas Matana, Indonesia.

Competing Interests

The author has declared no conflict of interest, and the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Citation

Khamdevi, M. (2023). A systematic literature review of architecture-related dew and fog harvesting. *Visions for Sustainability*, 20, 7492, 13-45
http://dx.doi.org/10.13135/2384-8677/7492

Original Paper

Topographic humidity index and vegetation as management tool for policies decision

Fabricio Enrique Alcívar Intriago, Marcos Javier Vera Vera, Luis Damián Muñoz Anchundia, Diocle Antonio Vera Salavarría

Received: 19 August 2023 | **Accepted:** 30 October 2023 | **Published:** 12 November 2023

Keywords: hydrological protection; microbasin; topographic humidity.

Abstract. *Sustainable management of resources increases the resilience of the systems in which they are implemented. Thus, this study aims to assess the vegetation cover and topographic humidity index of the Trueno microbasin and the Brisas site of the Bolivar canton (Manabi, Ecuador) so it can be used as a tool for policies decision. Starting from a quantitative approach and* *applying the hypothetical-deductive method; the following phases were established: i) determination of the Hydrological Protection Index (HPI), in this case plots made up of "three radiated transects 50 m long, located at 120° from each other; ii) establishment of the topographic humidity index, as a result of the treatment of the information in QGIS 3.30.1 through a Digital Elevation Model (DEM). The primary findings demonstrate that the light forests achieved an HPI per unit of vegetation (HPI-UV) of 0.95, while the dense forests attained a maximum of 1. On the other hand, the whole annual grasslands scored 0.64, while the degraded annual grasslands scored 0.32, the lowest possible score. When paired with other criteria, the ITH's values, which carry out a classification of the soil into five categories, range from 0 to 19, indicating a close association with the microbasin's water network. These assessments serve as a management tool for the creation and implementation of successful policies that ensure the stability of these ecosystems.*

1. Introduction

Water and rich soils are necessary for the development of agriculture and how well they are managed will determine its sustainability. The processes of erosion, floods, and droughts, as well as anthropogenic effects such deforestation and other changes in land use, cause natural deterioration of these resources. Additionally, there are significant and negative effects of population growth and observed climatic changes on water supply (Fries et al., 2020). The quality and quantity of water will change around the world, according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, especially in semi-arid regions where water supplies are particularly sensitive to precipitation amounts and rates. evaporation, which limit local water availability.

However, in semi-arid areas, the local population's economic growth primarily depends on agriculture and, as a result, on the local availability of water. For this reason, altered climatic conditions, population growth, and unsustainable water management practices are observed, endangering the resource's availability. One of the main implications of land use changes is the recharging of aquifers, which also results in an imbalance in surface runoff and nutrient loss (Valarezo et al., 2021). Despite the abundance of water resources in Ecuador, freshwater ecosystems have reportedly received little research and are under increasing pressure because of rising demand for socioeconomic services (Krasovskaya, 2022).

The increase of economic activity and the development of infrastructure, combined with human interests, have historically been the primary drivers of land use changes in Latin America (Kleemann et al., 2022). The Amazon, coastal, and Andean forests of Ecuador are impacted by changes in land use (Rivas et al., 2021). The conversion of these woods into pasture for animals as well as the expansion and intensification of conventional and/or organic agriculture constitute a threat to them. Additionally, conventional agriculture decreases the ability of soils to store carbon and depletes them of essential nutrients (N, P, and K), which over time results in a decline in floristic diversity (Reyna et al., 2018). Due to the high levels of connectivity that freshwater ecosystems exhibit throughout their extension, that is, from the headwaters to the mouth, as well as the transformation of the landscape that takes place around them, managing water resources is difficult (De Vries et al., 2019).

Given that sustainable management of resources increases the resilience of the systems in which they are implemented (Kucher et al., 2023) and that there are numerous ways to manage hydrographic basins, the Hydrological Protection Index (HPI) stands out because it enables us to understand the influence of vegetation on soil and water resources (Arellano & Ruiz, 2018). The Topographic Humidity Index (THI), on the other hand, is a quantitative tool to consider the spatial variability of soil moisture influenced by topography. It is based on the idea of a steady-state distribution of surface moisture along a variable topography and is more pertinent when infiltration rate conditions exceed storage capacity (Winzeler et al., 2022).

Since more than 500 years ago, there has been an unsustainable use of natural resources in the province of Manabi, which is in Ecuador's coastal region. This is mostly because to the change in land use brought on by the extension of the agricultural frontier (Quimis et al., 2023). The Trueno river microbasin, which includes the Brisas-Quiroga site (Bolivar canton), has experienced increased forest cover exploitation, putting the area's ability to maintain its water supply in jeopardy. Considering such antecedents, this research aims to ascertain the topographic index of humidity and vegetation cover of this region, which can be used as basis for policies decisions.

 http://dx.doi.org/10.13135/2384-8677/8110

2. Methodology

2.1. Study area

The Brisas location and the Trueno river microbasin are both in the Bolivar canton of the Manabi province of Ecuador, where this research was conducted. The Brisas site served as the location for the HPI calculation, whereas the Ro Trueno microbasin's extension served as the location for the IHT calculation. The bioclimatic map of Ecuador indicates that this area has tropical climate characteristics and is a part of an ecological region with tropical dry forests. In addition, the Holdrigde classification states that the movement of the intertropical convergence zone and changes in the Pacific Ocean have a significant impact in this region (Aveiga et al., 2023).

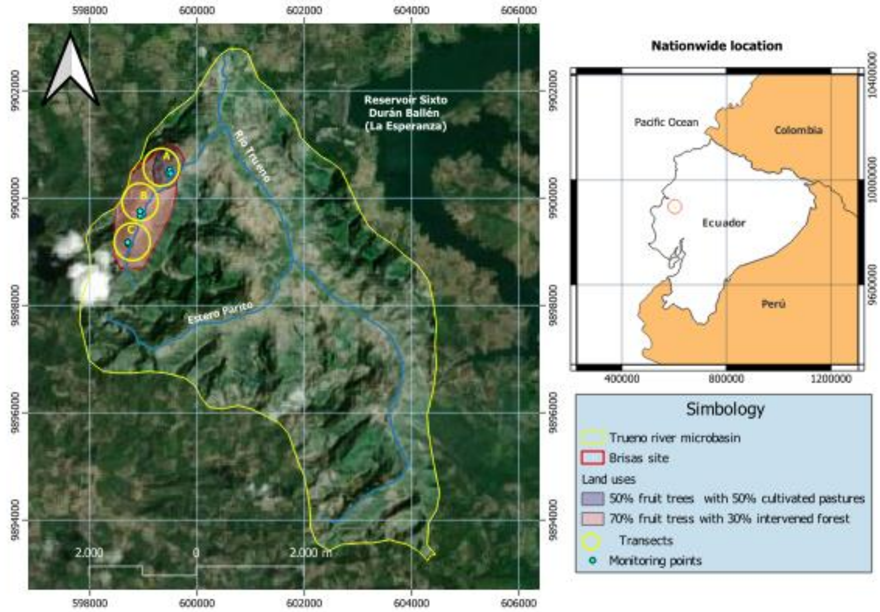


Figure 1. Location of the study area.

2.2. Selection of indexes

The HPI is one of the tools used to manage the basins because it enables us to comprehend how vegetation influences the soil and water resources (Arellano & Ruiz, 2018). It also serves to identify the water potential, which aids in future decisions within the study area where anthropogenic activities have changed and deteriorated the natural areas. Romero & Ferreira (2010) highlight that this is a factor that defines the level of the soil's resilience to the effects of rain and enables an in-depth review of the vegetation. This index will make it feasible to assess the research area's water retention as well as the percentage of runoff and soil erosion. Results from scientific manuscripts have not been included because, at least in Ecuador, publications of this kind are more common in degree works. This illustrates how underdeveloped this area of study is in the nation.

The decision of the IHT is also a result of the compact and understandable way it summarizes the surface water conditions through a sophisticated mathematical process. The IHT's main draws are its elegant simplicity, which captures dynamic and dominant hydrological spatial controls in a semi-distributed form; ease of initial capture application; calculation speed; ease of modification (it is more of a set of concepts than a fixed model structure); and direct relationship to topography as a control of the hydrological response of a catchment, so that predicted storage deficits and saturated conditions can be avoided (Beven et al., 2020).

Additionally, specific index values or thresholds can be linked to management actions by relating them to available surface water levels. To put it another way, this index relates to a theoretical model of semi-distributed rainfall runoff that makes use of topographic data related to runoff generation and aids in predicting the hydrological behavior of basins while considering the topography of the basin and the transmissivity of the soil (Devia et al., 2015).

The IHT was developed within the TOP MODEL runoff model (Beven & Kirkby, 1979), which has produced 565 publications, 31,999 citations, and an h-index of 89, making it one of the most cited articles in hydrology. It has also found widespread application in engineering and ecological studies with the development of digital elevation models. The contribution of this work, under this broad range of applicability, is the application of this index to a particular research area where no studies of this sort have been conducted, and it is anticipated that it would be used as a management tool for policy decisions.

The conclusions are based on the quantification of the results as well as their processing, using the hypothetical-deductive method to respond to the specified purpose. This research is quantitative in nature (Sánchez, 2019). Additionally, the following phases were established:

2.3. Calculation of the Hydrological Protection Index

The information in figure 1 was utilized as a starting point to determine the locations with the most vegetation cover and their land uses. To do this, satellite pictures from ESRI Stellite were used and processed in QGIS 3.30.1. floor. Plots consisting of "three radiated transects of 50 m long, located at 120° from each other" were developed for the sample sites (Romero & Ferreira, 2010). The Food and Agriculture Organization of the United Nations' observation sheet was used to record the data that had been gathered (FAO, 2009).

1. Structure: A pattern of vegetation distribution was used to determine the chest height circumference (CAP) of the adult individuals in the tree layer at a height of 1.30 meters away from them. Using this information as input, the diameter at breast height (DBH) of each individual was calculated using:

$$DBH = \frac{\mathrm{CCH}}{\pi}$$

Where:

DBH: Diameter at Breast Height

CCH: Circumference at Chest Height

In the case of shrubs, herbaceous species and other strata, a visual inspection was carried out considering the following criteria:

a. Shrub stratum: height less than 2 meters, without main trunk.

b. Herbaceous stratum: plants less than 10 cm tall (herbs for grazing).

c. Muscinal layer: formations that lie on the limestone rock (lichen appearance).

d. Scandent stratum: guiding or climbing plants, unable to support themselves (lianas).

e. EpHPIytic stratum: lichens, promoss and ferns.

2. Density: It was obtained considering the type of stratum, for the tree stratum the absolute and relative density was calculated:

$$\text{Absolute density (D)} = \frac{total\ number\ of\ individuals\ per\ species}{total\ area\ sampled}$$

$$\text{Relative density (RD)\%} = \frac{individuals\ per\ species}{total\ number\ of\ individuals} * 100$$

For the other strata (x) intercept points (touches) were applied, above a line (drawn with a tape) a series of points was created with a rod that has been previously divided into 5 cm portions and is calculated by source of:

$$Cob(x) = \frac{\text{Touches in x}}{Total\ touches} * 100$$

3. Interception of precipitation by vegetation (Is): it was calculated applying the Horton method (1919):$I_S = S_d + \gamma\ P_d$

Where:

Is = Interception of precipitation by vegetation

Sd = Vegetation canopy storage capacity

γ = Vegetation height coefficient

Pd = Total precipitation received by the canopy

4. Mulch presence: It was determined by using a metallic ruler to measure the height of the litter, considering that an average of 10 cm shows high content, 5 cm to 3 cm is a medium indicator, and less than 3 cm indicates it is interpreted. as low.
5. Unique ecosystems: These factors were taken into account for this parameter:
    a. Dry zone: including four sub-classifications (dry, semi-arid, arid and hyper-arid sub-humid zones).
    b. Planted ecosystems: or cultivated species.
    c. Ecosystems of recognized height with hydrological importance: All kinds of forests with a height greater than 15 meters.

6. Type of vegetation: Differentiated into three categories:
    a. Seasonal: short cycle crops.
    b. Annual: Its vegetal cycle is less than 12 months (cassava crops and pastures).
    c. Perennial: vegetal cycle greater than 10 years (timber trees, shrubs and certain fruit crops).
7. Degree of intervention: Its value was obtained with a scale of 1 to 3 based on:
    a. Land-use change
    b. Herding
    c. Burning or fires
    d. Wood sale
    e. Species extraction

Criterion	Indicator	Score
Structure	1 - 2 Strata	1.0
	1 - 3 Strata	2.0
	3 or more strata: arboreal, shrubby, herbaceous and epiphytic	3.0
Density	Low	1.0
	Medium	2.0
	High	3.0
Precipitation intercept	Low	1.0
	Medium	2.0
	High	3.0
Presence of mulch (leaf litter)	Low	1.0
	Medium	2.0
	High	3.0
Special ecosystems	Dry zone	1.0
	Crops	2.0
	High altitude recognized with hydrological importance	3.0
Type of vegetation	Temporal	1.0
	Annual	2.0
	Perennial	3.0
Degree of intervention	High	1.0
	Medium	2.0
	Low	3.0

Table 1. Assessment of HPI indicators.

2.4. Establishment of the Topographic humidity index

Finally, the THI is the end result of processing the data in QGIS 3.30.1 using a Digital Elevation Model (DEM), where the propensity of a cell to store water is reflected, which reflects the soil humidity. Thus, the model's applied formula is in accordance with Beven & Kirkby's (1979) proposal, while the process's specifics were based on Arteaga et al.'s (2020) proposal. The model's applied formula is expressed as follows:

$$THI = Ln\left(\frac{a}{Tan\beta}\right)$$

Where:

a: drained area

Tanβ: Angle of slope

3. Results and discussion

In the study area, there is a clear expansion of the agricultural frontier, which is consistent with findings made by Zamora et al. (2017), who claim that the Quiroga parish's mountainous soils have been cleared of trees to create environments that will increase the production of crops and grazing. According to the results shown in Table 2, only the first point (forests) had the highest values, totaling 18 to 20 points for the criteria examined. In contrast, the HPI criteria for points two (pastures) and three (crops/orchards) were lower, ranging from 12 to 14 points and 10 to 15, respectively.

According to the results shown in Table 3, light forests achieved an HPI-UV of 0.95, while dense forests reached a maximum of 1. This type of vegetation aids in the filtering of rainfall and the gradual storing of water in aquifers, as well as providing resistance to extreme weather events like droughts and floods (Oscanoa & Flores, 2019). In the work of Aguirre et al. (2018), plant cover and water quality are closely related. At point 2, the full annual grasslands attained a score of 0.64, the degraded perennial plant grasslands had a score of 0.43, and the degraded annual grasslands had a score of 0.32. Furthermore, annual crops without terraces have the lowest HPI-UV of all the covers investigated (0.22), whereas terraced orchards have the highest HPI-UV (0.88), followed by annual crops on terraces (0.74). It should be emphasized that plant cover and water quality are closely related, which affects the HPI's value (Aguirre et al., 2018).

Point	Transect	Vegetal cover	Criterion							
			Structure	Density	Interception of precipitation	Mulch presence	Unique ecosystems	Type of vegetation	Degree of intervention	∑
1	A	Light forests (with dense herbaceous substrate)	3	3	1	2	3	3	3	18
	B	Dense forests (without any soil erosion)	3	3	2	3	3	3	3	20
	C	Light forests (with dense herbaceous substrate)	3	3	1	2	3	3	3	18
2	A	Entire annual grasslands with apparent evidence of erosion	2	2	3	1	2	2	1	13
	B	Degraded perennial grassland with apparent erosion	2	1	3	1	2	2	1	12
	C	Degraded annual grasslands with apparent erosion	2	1	3	2	2	2	1	14
3	A	Annual crops on terraces	3	3	1	3	1	2	2	15
	B	Orchards on terraces	1	2	1	3	1	1	1	10
	C	Annual crops without terraces	1	1	1	2	2	2	1	10

Table 2. HPI criteria.

Point	Transect	Vegetal cover	HPI-UV
1	A	Light forests (with dense herbaceous substrate)	0,95
	B	Dense forests (without any soil erosion)	1,00
	C	Light forests (with dense herbaceous substrate)	0,95
2	A	Entire annual grasslands with apparent evidence of erosion	0,64
	B	Degraded perennial grassland with apparent erosion	0,43
	C	Degraded annual grasslands with apparent erosion	0,32
3	A	Annual crops on terraces	0,74
	B	Orchards on terraces	0,88
	C	Annual crops without terraces	0,22

Table 3. HPI -UV

The Hydrological Index of Partial Protection (HIPP) for the Brisas site was calculated by linking the HPI-UV with the share of each vegetation cover on the site's surface, and it is 0.66 (table 4). As a result, it may be concluded that the study area is suitable for conservation, in a relatively excellent state, and of medium importance. Lucas (2019) calculated the PPI sub-basin of the Carrizal river, which includes the research area, to be 0.59, which is regarded as regular, from a broader extension.

Vegetal cover	Area (ha)	%	PPI
Forest area	35,00	22,30%	0,22
Herbaceous vegetation	36,60	23,31%	0,11
Cultivated land	85,40	54,39%	0,33
Total	157,00	100%	**0,66**

Table 4. HIPP

Regarding the ITH, a classification of five categories yielded a range of 0 to 19. The microbasin's water network is clearly related to this index, as shown in figure 2, but it also allows for estimates of properties like soil pH, groundwater level, and soil wetness (Arteaga et al., 2020). Comparatively, it has been demonstrated that soil moisture regulates environmental processes and the distribution of species, with the ITH obtained from the digital elevation model being employed as an indication of soil moisture (Kopeck et al., 2021).

Since the significant pressure on the water resource does not consider the principles of intergenerational responsibility that, today, must be guaranteed to future generations, the results of this research provide a baseline that points to better management of the significant amount of forest resources in the study area. They also lead to the formulation of conservation strategies.

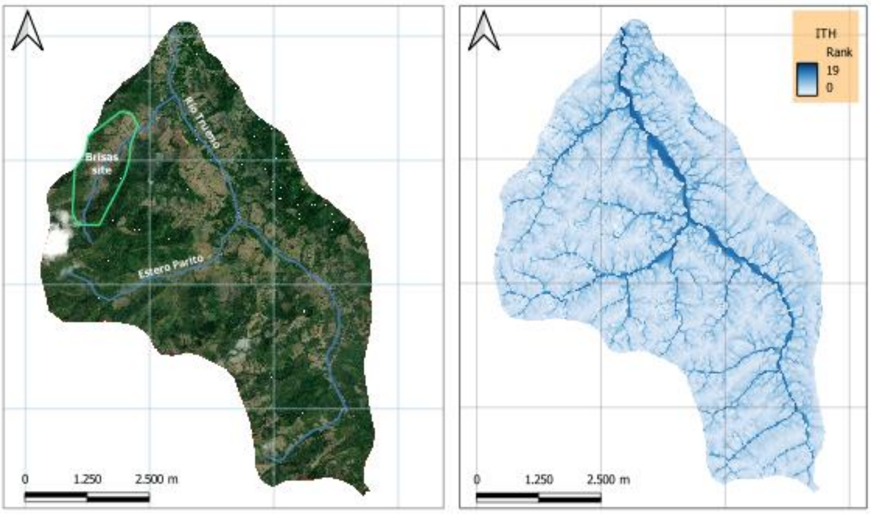


Figure 2. ITH of the Trueno microbasin.

Water availability, water quality, flood protection, agriculture, ecology, and other factors should all be considered simultaneously as part of the decision support system for planning and managing water resources (Haberlandt, 2010). The outcomes of this work must: i) consider the HPI of the entire micro-basin; ii) create a baseline of the meteorological parameters in the study region; and iii) apply a metamodel that incorporates the outcomes of field data, HPI, and ITH. This work must support decision making with an integrative approach. For the time being, the results show a clear projection of the water resource availability and the precision exerted on the surface flows of the Trueno micro-basin. In the light of this, policymaking could concentrate on the protection of the water resource through the implementation of a program that promotes sustainable production practices and environmental care.

4. Conclusions

In summary, the vegetation at the Brisas site has an HPI (Mean Basin of the Carrizal River) of 0.66, which places it in a moderately excellent condition with a high conservation importance. Likewise, it was discovered that the vegetation cover with the highest score (0.97), perceiving a recovery aptitude, is the woodland area; in contrast, herbaceous vegetation received the lowest rank (0.46). Regarding the IHT, the Trueno microbasin exhibits a humidity level that varies between 0 and 19. Even though it can aid in classifying the soil when used in conjunction with other factors, this index by itself is a useful variable to characterize the quality of the soil. as a gauge for the soil's quality and surface. In turn, these assessments serve as a management tool for the creation and implementation of successful policies that ensure the stability of these ecosystems. This research's contributions to policy formulation center on demonstrating the accessibility of water resources and the control over surface flows in the study area, which will make it easier to protect water resources through the implementation of a program that encourages environmentally friendly production methods.

References

Aguirre, N., Alvarado, J., & Granda, J. (2018). Bienes y servicios ecosistémicos de los bosques secos de la provincia de Loja. *Bosques Latitud Cero, 8*(2). https://revistas.unl.edu.ec/index.php/bosques/article/view/499

Arellano, J., & Ruiz, L. (2018). Evaluación y tendencias de los servicios ecosistémicos hidrológicos de la cuenca del río Zanatenco, Chiapas. *Investigaciones geográficas*, (95). https://doi.org/10.14350/rig.59467

Arteaga, E., Veliz, L., Giler, A., & Alarcón, J. (2020). Determinación del Índice de Humedad Topográfica para la microcuenca "La Mina" de la costa ecuatoriana. *Revista Dilemas Contemporáneos: Educación, Política y Valores,* (1). https://dilemascontemporaneoseducacionpoliticayvalores.com/index.php/dilemas/article/view/2473/2518

Aveiga, A. M., Banchón, C., Sabando, R., & Delgado, M. (2023). Exploring the Phytoremediation Capability of Athyrium filix-femina, Ludwigia peruviana and Sphagneticola trilobata for Heavy Metal Contamination. *Journal of Ecological Engineering, 24*(7), 165–174. https://doi.org/10.12911/22998993/164758

Beven, K. J., Lamb, R., Kirkby, M. J., & Freer, J. E. (2020). *A history of TOPMODEL.* https://doi.org/10.5194/hess-2020-409

Beven, K. J., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology / Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. *Hydrological Sciences Bulletin, 24*(1), 43–69. https://doi.org/10.1080/02626667909491834

Bravo, E., Castillo, T., Sellers, C., & Delgado, J. (2023). Analysis of conditioning factors in Cuenca, Ecuador, for landslide susceptibility maps generation employing Machine Learning methods. *Land, 12*(6), 1135. https://doi.org/10.3390/land12061135

Devia, G., Ganasri, B.., & Dwarakish, G. (2015). A review on hydrological models. *Aquatic Procedia*, *4*, 1001–1007. https://doi.org/10.1016/j.aqpro.2015.02.126

De Vries, A., Van Ham, I., & Bastmeijer, K. (2019). Protection through property: from private to river-held rights. *Water International, 44*(6–7), 736–751. https://doi.org/10.1080/02508060.2019.1641882

Dueñas, D., Guevara, O., & Santacruz, S. (2022). Valoración económica de los bienes y servicios ecosistémicos del bosque protector Jatumpamba-Jorupe. *Revista GEOESPACIAL, 19*(1). 12-32. https://journal.espe.edu.ec/ojs/index.php/revista-geoespacial/article/view/2816/2216

FAO. (2009). *Monitoreo y Evaluación de los Recursos Forestales Nacionales – Manual para la recolección integrada de datos de campo*. Roma: NFMA 37/S.

Fries, A., Silva, K., Pucha, F., Oñate, F., & Ochoa, P. (2020). Water balance and soil moisture deficit of different vegetation units under semiarid conditions in the Andes of southern Ecuador. *Climate, 8*(2). https://doi.org/10.3390/cli8020030

Haberlandt, U. (2010). From hydrological modelling to decision support. *Adv. Geosci, 27*, 11-19. https://doi.org/10.5194/adgeo-27-11-2010

Kleemann, J., Zamora, C., Villacis, A., Cuenca, P., Koo, H., Noh, J., Fürst, C., & Thiel, M. (2022). Deforestation in continental Ecuador with a focus on protected areas. *Land, 11*(2), 268. https://doi.org/10.3390/land11020268

Kopecký, M., Macek, M., & Wild, J. (2021). Topographic Wetness Index calculation guidelines based on measured soil moisture and plant species composition. *The Science of the Total Environment, 75*. https://doi.org/10.1016/j.scitotenv.2020.143785

Krasovskaya, O. (2022). Public danger of water pollution and the mechanism of protection of the surrounding water environment. *IOP Conf. Series: Earth and Environmental Science 979*. https://doi:10.1088/1755-1315/979/1/012170

Kucher, A., Krupin, V., Rudenko, D., Kucher, L., Serbov, M., & Gradziuk, P. (2023). Sustainable and efficient water management for resilient regional development: The case of Ukraine. *Agriculture*, *13*(7), 1367. https://doi.org/10.3390/agriculture13071367

Lucas, K. (2019). Relación entre la protección hidrológica y la cobertura vegetal de la subcuenca hidrográfica del Carrizal. *Revista de Ciencias Agropecuarias "ALLPA", 2*(3). https://publicacionescd.uleam.edu.ec/index.php/allpa/article/view/59

Oscanoa, L. & Flores, E. (2019). Efecto de las técnicas de mejora ecohidrológica del pastizal sobre el rendimiento hídrico de la microcuenca alto andina Urpay. *Ecología Aplicada, 18*(1), 1-9. https://dx.doi.org/10.21704/rea.v18i1.1303

Quimis, A., Rivas, C., González, P., & Navarro-Cerrillo, R. (2023). Forest plantations in Manabí (Ecuador): Assessment of fragmentation and connectivity to support dry tropical forests conservation. *Applied Sciences (Basel, Switzerland), 13*(11). https://doi.org/10.3390/app13116418

Reyna, L., Vera, L., & Reyna, L. (2018). Soil-organic-carbon concentration and storage under different land uses in the Carrizal-Chone valley in Ecuador. *Applied Sciences (Basel, Switzerland), 9*(1), 45. https://doi.org/10.3390/app9010045

Rivas, C., Guerrero, J., & Navarro, R. (2021). Deforestation and fragmentation trends of seasonal dry tropical forest in Ecuador: impact on conservation. *Forest Ecosystems, 8*(1). https://doi.org/10.1186/s40663-021-00329-5

Romero, E., & Ferreira, S. (2010). Índices de Protección Hidrológica de la Vegetación en la Cuenca del Río Potrero (Provincia de Salta). *Revista Ciencia, 5*(16).

Sánchez, F. (2019). Fundamentos epistémicos de la investigación cualitativa y cuantitativa: consensos y disensos. *Revista Digital de Investigación en Docencia Universitaria, 13*(1), 102-122. https://dx.doi.org/10.19083/ridu.2019.644

Valarezo, G., Carrión, H., Capa, E., & Jiménez, L. (2021). Soil quality/health indicators in a disturbed ecosystem in southern Ecuador. *Soil Science Annual, 72*(2), 1–12. https://doi.org/10.37501/soilsa/135991

Winzeler, H., Owens, P., Read, Q., Libohova, Z., Ashworth, A., & Sauer, T. (2022). Topographic wetness index as a proxy for soil moisture in a hillslope Catena: Flow algorithms and map generalization. *Land, 11*(11), 2018. https://doi.org/10.3390/land11112018

Zamora, Y., Montesdeoca, M., Alcívar, K., & Hidalgo, M. (2017). La gestión productiva agrícola en el sector minorista del cantón Bolívar de la provincia Manabí, Ecuador. *Mikarimin. Revista Científica Multidisciplinaria, 3*(3), 43–58. https://revista.uniandes.edu.ec/ojs/index.php/mikarimin/article/view/797/306

Authors

Fabricio Enrique Alcívar Intriago *(corresponding author)*, falcivar@espam.edu.ec
Marcos Javier Vera Vera,
Luis Damián Muñoz Anchundia,
Diocle Antonio Vera Salavarría

Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix Lopez, Calceta, Ecuador.

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Alcívar Intriago, F.E., Vera Vera, M.J., Muñoz Anchundia, L.D., & Vera Salavarría, D.A. (2023). Topographic humidity index and vegetation as management tool for policies decision. *Visions for Sustainability*, 20, 8110, 47-62.
http://dx.doi.org/10.13135/2384-8677/8110

Original Paper

The perception of benefits from the 'adopt-a-forest' initiative in Kenya

Sylvester Chisika, Chunho Yeom

Received: 14 March 2023 | **Accepted:** 10 May 2023 | **Published:** 20 May 2023

Keywords: forest adoption, sustainability, socio-economic benefits, partners, sustainable development.

Abstract. *Forest resources play a crucial role in sustainable development, but they face challenges such as degradation and loss. Forest adoption has emerged as an innovative and collaborative approach to forest management to address these challenges. Kenya has implemented this approach, but the driving forces and stakeholder perceptions behind its adoption are poorly understood. This study aimed to address this problem by examining the perception of partners on the benefits of forest adoption in Kenya. The study used a literature review and 20 key informant interviews to explore the context of forest adoption in the country. The results showed that the "adopt-a-forest" approach is a multidimensional solution for improving forest management in Kenya, bringing social, economic, and environmental benefits to partnering stakeholders. The initiative fosters interagency collaboration and breaks down old inefficiencies in forest management. However, interagency collaboration is uneven across counties and regions in the country, and a robust benefit-sharing policy is lacking. The study calls for a robust monitoring and evaluation framework with clear indicators and a benefit-sharing policy, as well as more quantitative studies to better understand the motivations behind forest adoption by individuals, government agencies, non-profits, and private companies.*

1. Introduction

Forest resources rank high as critical natural assets due to their economic, environmental, social, and cultural values. Forests furnish crucial ecosystem services, including conservation of biodiversity, management of soil erosion, preservation and enhancement of landscapes, and fortification of community resilience in the face of climate change. Forests also provide ecological stabilization to agricultural landscapes and are an important source of most energy needs for many rural and urban residents.

Kenya's natural capital biodiversity atlas of 2015 shows that Kenya's forest biodiversity provides important ecological services needed for human well-being and sustainable development (MEWNR, 2015; MENR, 2016). Environmental

 http://dx.doi.org/10.13135/2384-8677/7393

goods and services have direct use values or indirect use values, which may be existing, non-consumptive, or option uses. Direct use of ecosystem services could entail basic sustenance by consuming biological resources or satisfaction and enjoyment associated with ecotourism. Trees and forests provide a livelihood base for the majority of Kenyans. It is estimated that 82% of Kenya's households rely on forests and trees for fuelwood, accounting for over 750,000 employment opportunities for Kenyans and indirect benefits for over 4 million citizens (KFS, 2014). Additionally, forests are estimated to provide an annual contribution of USD 365 million (3.6%) to Kenya's Gross Domestic Product, excluding the values of environmental services, non-timber products, contributions to other economic sectors, and household wood energy (FAO, 2014; MEF, 2018; KFS, 2022; MoALF, 2021).

Unfortunately, Kenya's forest policy before the 2000s did not involve many stakeholders in forest management. Over time as the human population grew, disparities for wealth grew, leading to an increase in the illegal harvesting of forest resources for livelihood support in the dwindling public forests. This led to the centralization of the management of public forests through state protection. Whereas this was a justifiable policy option then, an emerging body of knowledge indicates that heightened state protection of public forests places an economic burden on forests with a social burden on the local community and other stakeholders, leading to land and natural resource use conflicts. To remedy this, in 2005, collaborative forest management, which initiated the participation of stakeholders in forest management, was introduced through legislative changes to the forest law. Collaborative forest management was mutually beneficial between the government and the local community, where both shared forest management decision-making responsibilities (National Strategy for Achieving and Maintaining 10% Tree Cover, 2019). To date, collaboration in forest management is being championed as a viable tool and policy instrument for the sustainable management of public forests under the jurisdiction of the Kenya Forest Service. Hence, community involvement in forest management through signed management agreements is perceived as a strategy for cost and benefit sharing in the forestry sector (Ngatia & Thuita, 2017). Over time, the multiple and interrelated challenges of collaborative forest management are increasingly calling for multidimensional and integrated approaches that leverage the contribution of different sectoral agencies and partners as a sustainable forest resource management strategy. This condition is not natural or familiar to many partners and government institutions across the world (Elbakidze et al., 2010; Maier & Wirth, 2018; Marks-Block and Tripp, 2021; Ray-Bennett et al., 2020).

Furthermore, collaborative efforts in forest management have been criticized for being overly time-consuming and lacking in industry participation. Despite such initiatives, many agreements have proven insufficient in alleviating poverty, serving only as a supplementary source of income for local communities (Siddiquee et al., 2022). As a result, collaboration is not likely to lead to more equitable outcomes and instead reinforces the power of existing actors. Imbalanced resources and power, conflicting interests, and differing organizational cultures further impede collaboration, as societal actors can support or hinder inter-agency relationships (Sahide et al., 2020; Siddiquee et al., 2022). In order to improve partnerships for forest management, the concept of forest adoption or 'adopt a forest' is fast emerging as a special-purpose vehicle for implementing inter-agency collaboration in forest management. The concept refers to a legal process where interested forest stakeholders are granted rights and responsibilities of forest restoration and stewardship for a defined period of time.

In the Kenyan context, "adopt-a-forest" is an innovative concept of enhancing the planting and growing of trees across the country. This refers to the process of partners adopting a portion of a forest for rehabilitation, protection, and management for a period ranging from 3 to 5 years (Forester Magazine, 2021). The initiative was created by the Ministry of Environment and Forestry and Kenya Forest Service to ensure that all partners' tree planting efforts in public forests are managed in a sustainable manner (as stated by Forester Magazine, 2021). KFS has also employed the "Adopt-A-Forest" initiative to partially bridge the funding gap (Forester Magazine, 2021). Moreover, through the "Adopt-A-Forest" initiative, it has been documented that KFS has built strategic partnerships that have complemented forest restoration and rehabilitation efforts (Forester Magazine, 2021).

However, limited studies reveal the real driving motive behind the growing forest adoption by individuals, MDAs, NGOs, and Private sector agencies. There is speculation that some agencies could be positioning and selling themselves globally as 'green prophets' or scouting for opportunities to access green climate funds, amongst other opportunities. In addition, since the implementation of forest adoption, no studies have been undertaken on the cost-benefit analysis of the 'adopt-a-forest' initiative in Kenya. This study explores the perception of partners on cost-benefit sharing in Kenya's "adopt-a-forest" initiative, which aims to restore forests sustainably. It asks two questions: 1) What are the perceptions of partners on cost sharing in the initiative? 2) How can the initiative be improved for sustainable forest management? The study will review global literature and Kenya's forest management status before offering recommendations for improving inter-agency relationships for the benefit of Kenya and the world.

Forest Adoption Partnerships and Sustainable Forest Management

Sustainable forest management requires that all forest ecosystems be managed in a manner whereby the benefits emanating from the biodiversity of forest resources are utilized at a rate and in a manner that does not compromise the ability of the resource to meet the needs of the current and future generations. Forests provide many benefits, also called ecosystem goods and services. These benefits include; provisioning, regulating, supporting, and psycho-social benefits. The forest sector globally employs over 18 million people directly and indirectly, supporting over 45 million jobs through induced impacts. It also directly contributes over $539 billion and over $1,298 billion to the world's GDP. (Yanshu et al., 2019). Due to these socio-economic contributions, many collaborative global efforts have been initiated at local, regional, and global levels to conserve and protect forest ecosystems. Many countries have committed to domesticating and implementing various international conventions and obligations under multilateral environmental agreements by adopting strategic partnerships and stakeholder collaboration. Key partnerships revolve around implementing the CBD and the Nagoya Protocol for ABS, the UNFCCC and its Paris Agreement, the UNCCD, the UNFF with its Strategic Plan for Forests (2017-2030), and CITES support sustainable forest management. Such management positively impacts multiple SDGs, including poverty eradication, zero hunger, good health, clean water and sanitation, climate action, and biodiversity.

Deforestation, degradation, and fragmentation of forests negatively impact the capacity of forests to provide important social, economic, and environmental services. These services include habitat for wildlife, carbon sequestration, water regulation, and resource production. Forest loss exacerbated by the growing human needs and the impacts of climate change continue to threaten the sustainability of forest ecosystems. Forest adoption or the 'adopt-a-forest' initiative has been touted as the most appropriate approach for enhancing forest management under these circumstances. Strategic partnerships in forest management can bring many benefits, such as increased competition advantage, access to new markets, meeting operational, social, and environmental constraints, strengthened relationships, and reduced conflict. It leads to cost and information sharing, optimization of activities implementation, and increased capacity to achieve work. The FAO recommends public-private initiatives to improve forest resource management, and private funding of forest management is estimated to be 14% of current funding for forestry-based nature-based enterprises, with an estimated investment of $1.5-$2 billion per year in forest plantations and $6.5 billion in wood processing in Africa, Asia, and Latin America. Private funding is also seen as important for effective landscape restoration.

Successful forest management through partnerships depends on several factors, including leadership and commitment at high political and bureaucratic levels, effective governance structure, inclusiveness, mutual trust, clear mission and objectives, a sense of belonging, and careful management and administration. Communication and benefit to all partners are also crucial. Institutional capacity is important but not enough for successful multisector programs. Full control over their components by participating organizations is necessary for cooperation. An integrated approach should allow each agency to maintain its independent status while operating within a common framework.

Perceptions of Benefits in Forest Adoption Partnerships

The interaction between natural assets and socio-cultural forces influences the perception of the contribution of forestry landscapes to sustainable development and human well-being. The ecosystem services approach evaluates the environmental benefits of forests, but forests also affect human welfare through direct and indirect positive ways that utilize both use and non-use values. These values include local competitiveness, the economy, conditions that drive production, and intrinsic and extrinsic values of landscape resources.

Sustainable forest management involves the execution of many interrelated activities usually contained in management plans for a given forest. Rehabilitative activities in forest management include reforestation, raising tree seedlings, planting, enrichment planting, establishing woodlots, and social forestry approaches like hedge rows, boundary plantings, woodlots, home gardens, and conventional agroforestry. In understanding stakeholder perception about the partnership costs and benefits of these forest management activities, various methods for placing monetary benefit and cost values have been developed. By providing empirical data, economists would then understand the need to conserve forest resources so that benefits are appropriately captured and reflected in the national economic valuation system of the country (Plan, 1999; O'Neill, 1997).

Cost-Benefit Analysis (CBA) is a widely used decision-making tool developed by economists and applied to environmental management problems by academics and policymakers. CBA compares outcomes based on the greatest benefits for most people, where benefits refer to utility. Italian economist Pareto first proposed the idea that CBA can determine if a project or policy improves social welfare. A "Pareto Improvement" is a change that makes at least one person better off without making anyone worse off. Pareto argued that most people would agree that society is better off in this situation. In practice, finding a resource allocation that does not impose costs on anyone is difficult. The general principle in monetary valuation in CBA is to value all impacts in terms of their marginal social costs or marginal social benefits, with social meaning evaluation in terms of the economy as a whole. However, CBA has faced criticism over the years. Some of the criticisms include the difficulty in monetizing non-market benefits and costs, the limitations in accounting for externalities and long-term effects, the assumption of market efficiency, and the exclusion of distributional issues. Critics also argue that CBA can lead to undervaluation of environmental and social impacts, particularly when these impacts are difficult to quantify or have long-term effects. Therefore, it is important to consider the limitations of CBA when applying it in policy and decision-making processes and to use other tools and approaches to complement CBA.

Additionally, the difficulty in evaluating the costs and benefits of forest ecosystems is also because many of the environmental benefits provided by forests are non-market goods, meaning they have no established market price and are difficult to quantify in monetary terms (Soini et al., 2010). Therefore, different methods and approaches must be considered to value these non-market benefits, such as stated preference methods, revealed preference methods, and contingent valuation (CV) (Soini et al., 2010). Despite these challenges, cost-benefit analysis remains a useful tool for decision-making in forest management, especially when combined with other decision-making tools and approaches that consider stakeholders' different values and perspectives. It is essential to consider the different perspectives of different stakeholders and the social, cultural, and economic context when evaluating the fairness of cost-benefit distribution in forest management. Achieving equity in cost-benefit distribution requires considering the different values and needs of all stakeholders and ensuring that everyone involved shares the costs and benefits fairly and justly (Soini et al., 2010).

It is worth noting that an individual's age and education can influence attitudes, values, and behaviors related to the use and management of forest landscapes, and hence the extent to which individuals and communities are willing to bear the costs and share the benefits of forest management (Zube et al., 1983;

Kaltenborn and Bjerke, 2002; Brody et al., 2004; Cantrill and Senecah, 2001; Hein et al., 2006; Cebrian-Piqueras et al., 2017).

Understanding individual stakeholder attributes and their attitudes toward costs and benefits can help develop effective and equitable forest management strategies. Such strategies consider the diverse perspectives of stakeholders, as there appears to be a correlation between individual attributes and attitudes toward sustainable forestry (Smith and Sullivan, 2014). It is because their values, beliefs, and experiences shape individuals' attitudes and perceptions towards forests, and personal goals, influencing their support for or opposition to different forest management practices. Forest managers need to understand these underlying factors to develop management strategies that effectively engage different stakeholders and build support for sustainable forest management. However, assessing people's perceptions of reclaimed landscapes remains a less studied issue (Svobodova et al., 2012). These research gaps can lead to a mismatch between human expectations and actual outcomes of ecosystem services in reclaimed landscapes, which could result in unintended consequences (van der Leeuw, 2012). Further study on stakeholder attitudes and perceptions towards forest management and ecosystem services is needed to inform the development of equitable and effective forest management strategies.

Empirical studies show mixed results on the perception of benefits from forest management partnerships. For instance, Cadman et al. (2023) found that sustainable forest management through community partnership had engendered a market for sustainably produced timber and a labeling system for good timber. However, the perception ratings for forest management partnerships were still low, especially by marginalized individuals. Partnerships in forest management appear to be affected by the low empowerment of marginalized groups, insufficient resources, and inadequate empowerment of marginalized communities. Marginalized communities have limited access to and control over human and natural resources. The issues of inequitable benefit sharing, the dominance of affluent groups, a dearth of alternative livelihood options, and insufficient support for community enterprises are evidence of the failings of existing forest management systems, necessitating a re-evaluation of forest management. Moreover, interview results revealed the diversity and conflicting perceptions among the same marginalized and non-marginalized stakeholders suggesting that perceptions are affected by the execution of the governance process and who benefits from it the most. In addition, the study established that the marginalized groups that are unhappy with partnerships might be due to their voices and opinions not being taken into account by those in positions of power.

A qualitative study conducted at the household level in South Africa on communities' perceptions of benefit-sharing mechanisms for forest-based land reforms models showed that household beneficiaries showed a lack of knowledge of the criteria used for the disbursement of the benefits. It was largely caused by a lack of transparency, trust, and greed among actors. The study recommended the need for political goodwill and commitment from the government in order to ensure the development and strengthening of existing benefit-sharing policies for the improvement of the livelihoods of the land beneficiaries (Tshidzumba et al., 2018)

In summary, from this review, it is observed that at the global level, there is a growing appreciation of the benefits provided by forested landscapes, hence the increasing area under these forests. However, even though there are challenges in partnerships which by extension include forest adoption, information on people's perceptions of reclaimed landscapes is scarce, and the benefits of forest adoption are not well articulated. Filling this gap and generating an improved understanding of stakeholder perceptions of forest management benefits and cost-sharing is urgent and gains even more relevance for the design and implementation of sound forest management options and hence the need for this study.

1.1. The context for understanding benefits of Kenya's 'adopt-a-forest' initiative

In Kenya, the forest coverage is 7.2% of the total land area, equating to 4.18 million hectares. This forest can be divided into four main types and eight sub-types, as shown in Table 1. Most of Kenya's forests are dryland forests, covering 45.4% of the total forest area, while montane forests comprise 32.9% of the forest area. The data in Table 1 provides information on the different types of forests and their approximate areas as of 2010.

Only 5% of the total forest area in Kenya is made up of public and private plantations. The management of all public forests in Kenya is done in collaboration with the community and is overseen by the Kenya Forest Service. This is a government-run corporation established under the Forest Conservation and Management Act of 2016. Its purpose is to promote the development, conservation, and management of Kenya's forest resources in public forests and to provide technical support to county governments for the fair benefit of present and future generations

Kenya highly values forests for environmental, ecological, economic, social, and cultural importance. They provide numerous benefits, both tangible and intangible, to Kenyan society. The annual per capita consumption of wood is one cubic meter, but the current demand for utility products such as timber, poles, pulp-wood, and fuelwood is 40 million cubic meters. However, the estimated sustainable supply of wood is only 30 million cubic meters, resulting in a deficit of 10 million cubic meters (Kagombe et al., 2020).

Additionally, forests provide a range of benefits to Kenyan society, both tangible and intangible. These benefits include preserving biodiversity, serving as critical water catchment areas, preventing soil erosion, mitigating climate change, providing habitat for wildlife, offering food and non-wood products such as resin, honey, and spices, enhancing scenic beauty, and attracting cultural, research, and tourist interests, among others. Although the intangible benefits of forests have yet to be accurately quantified, the forest sector contributes more than 20 billion Kenyan shillings worth of goods to the economy each year. It provides direct employment to over 50,000 people and indirect employment to another 300,000 (Odwori et al., 2013). Moreover, over a million households residing within a 5 km radius of forest reserves rely on forests for their livelihoods, including farming, grazing, fishing, obtaining food and fuel, wood, honey, herbal medicine, water, and other benefits (Odwori et al., 2013). Although limited research has been done to calculate the worth of ecosystem services, Silvestri et al. (2013) tried to estimate the total economic value of part of the Mau forest to be around KES 17 billion (USD 0.17 billion).

Thus, the relationship between forests and human well-being in Kenya is complex, with the ecosystem services provided by forests playing a significant role. Ongoing efforts have been made to improve forest management through policy and legislative reforms. The first forest policy was introduced in 1957 and revised in 1968. However, this policy focused only on the management of public forests and did not involve stakeholders. In response to new challenges and the need for sustainable development and biodiversity conservation, a revised policy and legislation was proposed in the 1990s, leading to the creation of the Forests Act of 2005. Despite this, the policy was not officially adopted. The implementation of the Forests Act 2005, which covered forest management outside public lands and allowed for community and private sector participation, started in 2007. However, a review of the policy and legislative framework was necessary due to decreasing forest cover caused by unsustainable utilization and conversion, as well as changes to governance structures outlined in the Constitution of Kenya 2010.

The Kenyan Constitution of 2010 mandated the need for sustainable development, fair distribution of benefits from natural resources, involvement of stakeholders, and participation. It has created 47 decentralized units, known as counties, as a new form of governance (Draft Forest Policy, 2020). However, the most notable and recent forest sector reforms contained in the Forests Act, 2005, now repealed by the Forest Conservation and Management Act, 2016, is the introduction of Participatory Forest Management (PFM), where different forest stakeholders are recognized in forest management decisions. Under the PFM framework, communities residing within 5 Km of a state forest boundary are assigned various forest access and use rights to participate in forest management. Many studies such as Agevi et al. (2014), Ngatia et al. (2017), Matiku et al. (2013), Nthuku et al. (2016), Chisika and Yeom (2020), and Kairu et al. (2020) have demonstrated the efficiency and efficacy gains in collaborative forest management and the positive livelihoods outcomes of PFM. Consequently, the PFM policy has been lauded, given its multi-objective capabilities. On the contrary, some studies such as Okumu and Muchapondwa (2017), Thygesen et al. (2016), and Chomba et al. (2015) have contested PFM policy on account of adverse social equity outcomes, especially on the most vulnerable in society.

In this paper, the authors observe that these equity concerns will be addressed once the country develops a natural resource benefit-sharing policy and law which is currently in the advanced stages of enactment in parliament. In addition, PFM has proved to be impactful. With time, it will improve the capacity of forests to deliver ecosystem services equitably to communities once all 'silos' are broken down. Unfortunately, environmental threats persist and continue to threaten sustainable forest management in the country. For instance, deforestation is currently estimated at 50,000 hectares annually, with a consequent yearly loss to the economy of over US$19 million (MENR, 2019; UNEP, 2012a). Hence, recent studies still consider Kenya a low forest cover country (MENR, 2019; UNEP, 2012a). Reports indicate that forests are increasingly degraded due to unsustainable utilization, limited budgetary allocation to institutions managing forests, illegal logging, uncontrolled grazing, and unsustainable charcoal production (UNEP, 2012b). Moreover, there are institutional weaknesses by bodies managing forests, such as a limited commitment by the government to implement participatory forest governance (especially benefit-sharing policies), the slow pace of reviewing policies that favor sustainable use of forests, the politicization of forest resource governance, lack of accurate data on forest functions, and high poverty levels among communities, which pushes the demand for immediate and tangible benefits from forests and affects long-term commitment to forest management (Draft Forest Policy, 2020). These challenges disrupt the processes, supply, and consumption of critical ecosystem services from forests. Thus, it will be interesting to explore how interagency collaboration could be fostered to break down the highlighted challenges and 'silos' through the adopt-a-forest approach.

1.2. The genesis of the 'adopt-a-forest' initiative in Kenya

In 2018, the President of Kenya pledged both domestically and internationally that the country would exceed the constitutional mandate of a minimum of 10% tree coverage nationally by 2022. The urgency informed the need to accelerate the attainment of 10% tree cover to address the unprecedented impacts of the triple environmental threats posed by climate change, biodiversity loss, and air pollution. Moreover, forests are recognized as critical in climate change mitigation and adaptation and provide a wide range of environmental, economic, and social-cultural goods and services.

Against this background, "[the] National Strategy for achieving and maintaining over 10% Tree Cover by 2022" was developed and approved by the Cabinet in August 2019 to operationalize the Presidential Directive. The strategy outlines several interventions, namely: rehabilitation of degraded natural forests and mangrove ecosystems; restocking of industrial forest plantations; establishment of private commercial forests; establishment of bamboo; establishment of trees on a farm; tree planting in schools; rehabilitation of degraded dryland forest landscapes; and, green spaces in the urban areas. The strategy requires the production and planting of 2 billion tree seedlings in addition to protecting and conserving the existing 4.18 million Ha. The total estimated cost for implementing the strategy was Kshs 48.7 billion. The Ministry of Environment and Forestry was coordinating its agencies and departments to implement the strategy. These are Kenya Forest Service (KFS), Kenya Forestry Research Institute (KEFRI), National Environment Management Authority (NEMA), Kenya Water Towers Agency (KWTA), National Environment Complaints Committee (NECC), National Environment Trust Fund (NETFUND) and Kenya Meteorological Department (KMD). Kenya Forest Service, as the lead agency in forest conservation, protection, and management established under the Forest Conservation Management Act, 2016 has undertaken several interventions toward implementing the strategy.

Among the key interventions were forest restoration through 'Adopt-A-Forest' and building and nurturing strategic partnerships and linkages for forest land reclamation, protection, and security. In the Kenyan context, "adopt-a-forest" is an innovative concept of enhancing the planting and growing of trees across the country. It means implementing a plan where partners take responsibility for the restoration, preservation, and administration of a section of a forest for 3 to 5 years (Forester Magazine, 2021). This concept was devised by Kenya's Ministry of Environment and Forestry and Forest Service to ensure that all partners' tree-planting efforts in public forests are conducted in a responsible and sustained manner (Forester Magazine, 2021).

KFS has also employed the "Adopt-A-Forest" initiative to partially bridge the funding gap (Forester Magazine, 2021). Moreover, through the "Adopt-A-Forest" initiative, it has been documented that KFS has built strategic partnerships that have complemented forest restoration and rehabilitation efforts (Forester Magazine, 2021). It will thus be interesting to explore these findings in order to generate the policy implications of advancing inter-agency collaboration through the adopt-a-forest initiative. Hopefully, this initiative will help Kenya actualize its forest sector development aspirations espoused in recent sector development plans and policies. For example, forest adoption will be key in implementing the Kenya Forest and Landscape Restoration Implementation Plan 2021-2026 (FOLAREP), an initiative by FAO GEF 6 restoration initiative project. Kenya intends to restore 2.55 million hectares of deforested and degraded landscapes by 2026. The plan, informed by the prevailing national and local circumstances, will focus on all the landscapes. The five-year ambitious plan to accelerate actions to restore deforested and degraded landscapes in Kenya will focus on strengthening policy, institutional and governance, strengthening research and monitoring instruments and resources mobilization and improving communities' livelihoods.

The initiative will enhance the attainment of a number of Constitutional obligations. In Article 42, the State is required to provide a clean and healthy environment for every person; and Article 43 (1) (d) states that every person has the right to clean and safe water in adequate quantities. It is further to Article 69, which requires the State to ensure sustainable management of the environment and natural resources and achieve and maintain a 10% minimum national tree cover. The initiative also conforms to International Conventions and Obligations, including Sustainable Development Goals (SDGs), Africa Forest Restoration Initiative (AFR100) and the Bonn Challenge, Paris Climate Change Agreement, and Land Degradation Neutrality (LDN) by 2030, among others. The initiative, therefore, enhances the attainment of the Constitutional target of 10% minimum national tree cover by 2022, mitigation of the climate change effects, as well as enhancing the achievement of the Big 4 Agenda.

By the year 2022, there were 49 agencies from both Government, Ministries, Department, and Agencies (MDAs), Non-Governmental Organizations (NGOs), and Private Sector Organizations participating in forest restoration through 'adopt-a-forest across' counties and regional forest conservations areas in the country as shown in Table 1.

No.	Category of Institutions	No. of Institutions	Area Adopted (Ha)	No. seedlings Planted	Financial Contribution (Kshs.)
1	Government Ministries, Departments and Agencies	27	2,255.00	373,825	12,520,290.00
2	NGOs and Private Sector organizations	22	16,131.10	368,410	24,342,498.00
Total		**49**	**18,386.10**	**742,235**	**36,862,788.00**

Table 1: Summary of forest restoration through the "Adopt-A-Forest" Initiative between 2019-2021. *Source*: KFS Office Records, 2023

MDAs had implemented and distributed forest adoption activities in 18 (38%) counties across the country. In the Financial year (FY) 2019/2020, Nyeri and Kiambu counties had the highest number of MDAs participating in forest adoption, while the rest of the counties, namely; Elgeyo Marakwet, Kericho, Kisumu, Kwale, Murang'a, Turkana, Uasin Gishu, Nakuru, Vihiga, Meru, Kajiado, and Nairobi had a total of one MDA participating in the implementation of forest adoption (Figure 1). In the FY 2020/2021, Nairobi county has the highest number (5) of MDAs participation in forest restoration and rehabilitation, followed by Kajiado (3) and Meru (2), and Mombasa (2). Five counties, namely; Bomet, Laikipia, Nandi, Nakuru, and Vihiga, had one MDA each participating in forest rehabilitation (Figure 1).

In appreciating the urgency to attain 10% tree cover by 2022, and further recognizing that this can only be achieved through individual actions and collaborative efforts, the government, through KFS, invested in engaging partners and developing strategic linkages with state and non-state organizations. Some of the partners include but are not limited to the ones shown in Table 2.

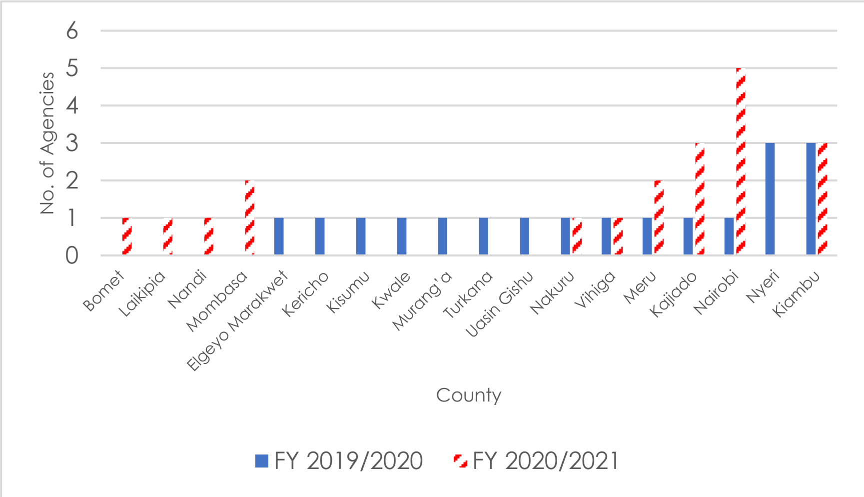


Figure 1: Number of MDA agencies participating in forest adoption. Source: KFS Office Records, 2023

No	Name of Organizations	Partnership Activity
1.	The Cabinet of Kenya	Forest management adoption
2.	Ministry of Interior and Coordination of National Government	Coordination of multi-agency forest operations (reclamations) and tree planting
3.	Ministry of Defense/Kenya Defense Forces (Environment Soldier Programme)	Forest adoption, forest conservation, infrastructural support and multi-agency security operations
4.	County Governments	Tree seedlings production, tree planting, joint restoration of green spaces/arboreta, infrastructural support
5.	Nairobi Metropolitan Services	Green spaces restoration
6.	Kenya Wildlife service	joint enforcement
7.	Kenya Prisons Service	Seedlings production and tree planting
8.	National Youth Service	Tree seedlings production and planting
9.	Foreign embassies	Forest adoption and support towards conservation programme
10.	Safaricom Kenya Ltd	Forest adoption
11.	Rhino Ark Charitable Trust	Forest fence installation
12.	Mt. Kenya Trust	Forest fire response and forest restoration
13.	WWF	Landscape restoration and Community scouts support
14.	NCBA Bank	Tree nursery development in Karura forest
15.	Kisima Farm	Forest fire response

Table 2: Strategic partners in forest restoration. Source: KFS Office Records, 2023

2. Materials and Methods

2.1 Study area: The territory of the Republic of Kenya

Kenya is a unitary multi-party democracy located in the horn of Africa. The country is located between latitude 0.0236° S and longitude 37.9062° E with an estimated land area of 580 367 Km^2.

Kenya has two tiers of government, the National Government and 47 County Governments, each with distinct responsibilities and duties. In this governmental setup, the counties of Nairobi, Kisumu, and Mombasa have maintained their city-county status. The National Government is responsible for formulating policies that ensure the country achieves and maintains a 10% tree cover besides establishing programs for delivering its international obligations and agreements. According to the 2019 census report, Kenya had 47 million people, and the population was projected to reach 60 million by 2030 (Kenya's NDC, 2020).

Kenya's HDI value for 2019 is 0.601; this is a medium-level human development category, placing Kenya at position 143 out of 189 countries and territories. In 1990, Kenya's Human Development Index (HDI) was 0.482. Over the period from 1990 to 2019, life expectancy at birth in Kenya increased by 9.3 years, average years of schooling rose by 2.8 years, and expected years of schooling increased by 2.3 years. Kenya's Gross National Income (GNI) per capita increased by approximately 37.1% from 1990 to 2019.

The Kenyan economy relies on industries susceptible to the climate, such as agriculture, tourism, wildlife, and water, and these vulnerabilities are intensified by climate change. The country has a relatively favorable climate for farming and forestry. Arid and semi-arid areas comprise 89% of Kenya's land and a third of its population. However, due to a history of political neglect, a pastoral lifestyle, and low population density, many practical difficulties have resulted in a lack of economic activity.

Drought and flooding are the primary weather-related threats affecting lives and sources of income. In 2011, a drought caused over $11 billion in damage. In 2018, floods resulted in the displacement of over 230,000 individuals, including 150,000 children, leading to the closure of more than 700 schools, the drowning of over 20,000 heads of livestock, the destruction of over 8,500 hectares of crops, and the loss of crucial infrastructure. From 2014 to 2018, 23 counties were affected by drought, causing 3.4 million people to experience food shortages and over 500,000 to lack access to water (Kenya's NDC, 2021).

2.2. Data Collection

This study seeks to explore Kenya's adopt-a-forest initiative in order to document the perception of adoption partners on sharing the management benefits and costs with the view of improving the approach. As such, primary from 20 key informant interviews from a workshop and secondary data from the literature review were gathered.

Primary Data collection

For primary data collection, 20 key informant interviews were conducted. Table 3 shows the key informants consulted during the research process. Key informants included government agency representatives, community residents, community leaders, local business owners, and private entities and individuals. In order to adequately address the research aims of this study, the prior steps involved gathering and reviewing existing forest adoption data, determination of the kind of information required, determining the target population and thinking about the key informants, choosing the key informants, choosing the interview method, developing an interview tool, developing a documentation process, conducting the interview and compiling the findings.

For purposes of identifying and selecting the key interview respondents, a random selection of 20 workshop attendees from a pool of 50 attendees who have adopted various forest blocks in the country was made. Random selection was used because it helps ensure that the sample represents the population being studied. Random selection was used in this study because it ensures that every member of the target population has an equal chance of being selected. It helps minimize bias in the sample selection process and increases the generalizability of the findings.

Face to face interview approach adopted in this study entailed: setting up a private and quiet room from where to conduct the interview, doing a round of self-introduction to explain the purpose of the interview and how the interview responses will contribute to the study, asking open-ended questions in order to provide a chance to interviewees to give detailed descriptive responses, listening actively and encouraging elaboration of responses, note taking in order to capture important information and themes arising from the interview and finally returning gratitude to the interviewees. Face-to-face interviews with key informants were preferred in order to get more candid and in-depth answers. Moreover, forest adoption is an upcoming subject in the country, and therefore, it was prudent to conduct this study by utilizing interviews with community experts in this pioneering study. This study draws on the methodological approach from similar perception studies conducted elsewhere, including; Pour et al. (2023) and Girma et al. (2023).

No.	Key Informant Name	Category of the Organization
1.	A	Government Ministries, Departments and Agencies
2.	B	Government Ministries, Departments and Agencies
3.	C	Government Ministries, Departments and Agencies
4.	D	Government Ministries, Departments and Agencies
5.	E	Government Ministries, Departments and Agencies
6.	F	Government Ministries, Departments and Agencies
7.	G	NGOs and Private Sector organizations
8.	H	NGOs and Private Sector organizations
9.	I	NGOs and Private Sector organizations
10.	J	NGOs and Private Sector organizations
11.	K	NGOs and Private Sector organizations
12.	L	NGOs and Private Sector organizations
13.	M	NGOs and Private Sector organizations
14.	N	NGOs and Private Sector organizations
15.	O	NGOs and Private Sector organizations
16.	P	NGOs and Private Sector organizations
17.	Q	Individual
18.	R	Individual
19.	S	Individual
20.	T	Individual

Table 3: Key Informant Consulted

A general interview tool targeting any of the present participants was developed. The interview questions were tailored to respond to the key study aims, including the status of forest adoption, the benefits and costs of forest management activities, the challenges and opportunities that exist, and ways of improving forest adoption in the country.

The interview tool included a brief introduction to explain the interview's needs. The specific benefits and costs were drawn from the management responsibilities allocated to identified partners involved in the 'adopt-a-forest' initiative as contained in their respective framework for collaboration documents. The management responsibilities of each partner were to maintain and protect a natural forest area within a public forest in Kenya.

Examples of key questions asked regarding forest adoption during the face-to-face interview were: In your opinion, are forested ecosystems important for the sustainable development of Kenya? Does forest adoption as an intervention for sustainable forest management bestow benefits to partners involved in adoption? Does forest adoption bestow some costs to the partners involved in forest management? How can benefits from forest adoption be enhanced for sustainable development in Kenya? Does forest adoption as an intervention for sustainable forest management bestow benefits to partners involved in adoption? Does forest adoption bestow some costs to the partners involved in forest management? How can benefits from forest adoption be enhanced for sustainable development in Kenya? An opportunity was also provided for each interviewee to provide additional information related to the subject of the study. Interview responses were recorded through note-taking. The detailed interview tool is shown in Appendix 2.

Secondary data collection

The process of secondary data acquisition involved visiting official websites and review of documents sourced from the office at Kenya Forest Service Headquarters. In order to search key literature on the study topic, key search databases, including; JSTOR, ScienceDirect, and Web of Science, were consulted through the Google search engine. Keywords such as "forest adoption," "perceived benefits," and "stakeholders." Where necessary, Boolean operators "AND," OR, "NOT" were used to refine searches with synonyms or related terms that could help broaden your search. For example, the terms "forest adoption AND perceived benefits AND stakeholders" were used during one of the searches.

With regard to secondary data from Kenya, a number of documents were consulted. In particular, the progress report on implementing the Presidential Directive on 10% tree cover provided most of the quantitative data used in this report. Other key documents consulted are highlighted in Table 4. These documents provided key contextual data and information to this study.

Document	Key findings	Source
Constitution of Kenya, 2010	Establishes the three organs of government which are meant to coordinate the development of policies and strategies for forest management. Article 69 provides for the need for collaboration toward achieving 10% tree cover in the country.	Kenya Law Reporting Website
Vision 2030	Establishes the social pillar as the foundation that drives successful partnerships for inter-agency collaboration in forest management	Vision 2030 website
Forest Conservation and Management Act, 2016	Establishes the regulatory framework and infrastructure for sustainable management of forests through participatory approaches ad establishes institutions for managing all forests for socio-economic development.	Kenya Law Reporting Website
Draft Forest Policy, 2020	Provides policy direction on the creation, management, and utilization of forest resources by providing opportunities for inter-agency collaboration	Kenya Law Reporting Website
Environmental Management and Coordination Act, 1999	It is the framework of environmental protection law that sets the parameters for innovations toward environmental sustainability in the country, including inter-agency collaboration.	Kenya Law Reporting Website
Forester Magazine of 2021	Outlined progress made on implementing the Presidential Directive on 10% tree cover where adopt-a-forest is listed as one of the interventions	KFS Office, Nairobi
Template for Framework of Collaboration	Establishes the legal process for delivery of Inter-Agency Collaboration in forest restoration through the Forest Adoption framework. It spells out the forest management activities, roles, and responsibilities that are assigned to agencies participating in forest adoption.	KFS Office, Nairobi
National Strategy for Achieving and Maintaining 10% Tree Cover	Highlights the Presidential Directive on increasing tree cover in the country	KFS Office, Nairobi
The Public-Private Partnership Act, 2013	Establishes the wider framework from private sector participation in national development projects	Kenya Law Reporting Website

Table 4: Key Documents Consulted

2.3. Data Analysis

This study was carried out with the understanding that the benefits and costs analyzed can be either tangible or intangible, direct or indirect, fixed or variable. Tangibility refers to the ease of measuring the costs or benefits in this study. Costs that are known to exist but cannot be quantified accurately are referred to as intangible costs. Sometimes, intangible costs can be recognized but are challenging to measure. In other cases, intangible costs may be hard to even identify, and in such instances, decision-makers often tend to handle them irrationally by disregarding them. Nevertheless, in this study, the broad facets of sustainable development, including social, economic, and environmental, were used to classify and analyze the interviewee responses on the perception of forest management costs and benefits by partners. Where numerical data was obtained, the data was exported to an Excel spreadsheet and analyzed to generate the visualizations used in this study. Later, the results were evaluated on the backdrop of findings from reviewed literature to draw the policy implications of this study.

3. Results

3.1. Respondent characteristics

The study achieved a 100% response rate from the targeted 20 interviewees. Half of the respondents (50%) were from NGOs and private sector organizations. Government Ministries Departments and Agencies had 30% representation, while individuals had 20%, as shown in Figure 2.

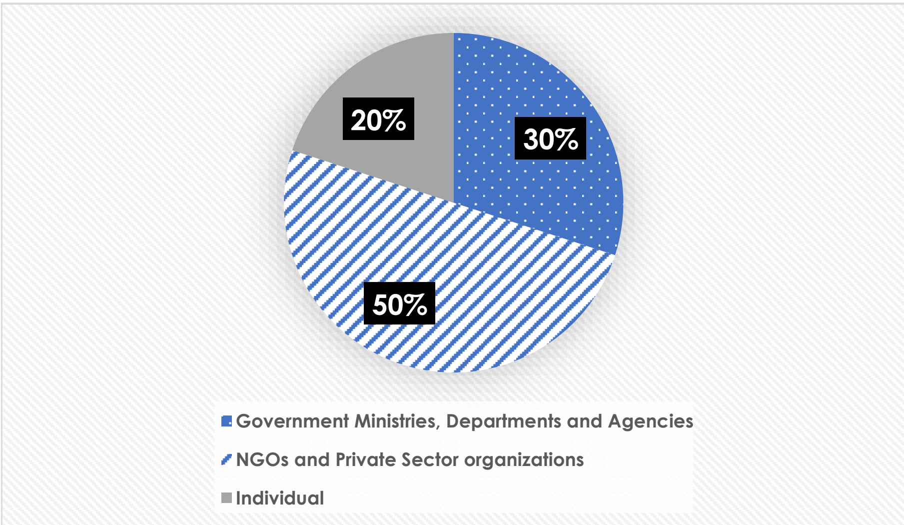


Figure 2: Interviewee Classification

The results of the perception of interviewed partners on the key benefits of the 'adopt-a-forest' initiative are shown in Table 5.

Respondent	Organization	Perceived Benefit
A	Government	Improved communication and coordination among stakeholders
B	Government	Improved knowledge and sharing of expertise on implementing forest management activities
C	Government	Bridging of the forest conservation funding gap
D	Government	Bridging of the forest conservation funding gap
E	Government	Improved knowledge and sharing of expertise on implementing forest management activities
F	Government	Bridging of the forest conservation funding gap
G	NGO	Bridging of the forest conservation funding gap
H	NGO	Bridging of the forest conservation funding gap
I	NGO	Improved communication and coordination among stakeholders
J	NGO	Improved communication and coordination among stakeholders
K	NGO	Improved communication and coordination among stakeholders
L	NGO	Improved knowledge and sharing of expertise on implementing forest management activities
M	NGO	Improved knowledge and sharing of expertise on implementing forest management activities
N	NGO	Bridging of the forest conservation funding gap
O	NGO	Bridging of the forest conservation funding gap
P	NGO	Bridging of the forest conservation funding gap
Q	Individual	Bridging of the forest conservation funding gap
R	Individual	Improved communication and coordination among stakeholders
S	Individual	Improved communication and coordination among stakeholders
T	Individual	Improved knowledge and sharing of expertise on implementing forest management activities

Table 5: Perception of the key benefits of forest adoption Partnerships

The results on the perception of challenges by adoption partners are shown in Table 6.

Respondent	Organization	Perceived Challenge
A	Government	Lack of a natural resource benefit-sharing policy
B	Government	Lack of a robust monitoring and evaluation protocol
C	Government	Lack of data on the number of people lifted from poverty
D	Government	Lack of a robust monitoring and evaluation protocol
E	Government	Bureaucratic and administrative challenges
F	Government	Lack of a robust monitoring and evaluation protocol
G	NGO	Lack of a natural resource benefit-sharing policy
H	NGO	Lack of a natural resource benefit-sharing policy
I	NGO	Lack of a natural resource benefit-sharing policy
J	NGO	Lack of a robust monitoring and evaluation protocol
K	NGO	Limited political goodwill
L	NGO	Lack of a natural resource benefit-sharing policy
M	NGO	Lack of a robust monitoring and evaluation protocol
N	NGO	Lack of trust and communication among partners
O	NGO	Lack of a natural resource benefit-sharing policy
P	NGO	Resistance to change and adaptation to new management approaches
Q	Individual	Power imbalance and unequal participation of stakeholders
R	Individual	Inadequate financial resources and lack of data on the number of people lifted from poverty
S	Individual	Difficulty in measuring and evaluating intangible conservation benefits such as soil conservation
T	Individual	Lack of a natural resource benefit-sharing policy

Table 6: Perception of key challenges facing forest adoption

The results of the perception of adoption partners on ways of improving the 'adopt-a-forest' initiative are shown in Table 7.

Respondent	Organization	Perceived Ways of improving forest adoption
A	Government	Sharing forest management information and data among stakeholders.
B	Government	More studies on the real driving motive behind the growing forest adoption are needed
C	Government	More studies on the real driving motive behind the growing forest adoption are needed
D	Government	More studies on the real driving motive behind the growing forest adoption are needed
E	Government	Developing clear and effective communication channels
F	Government	Encourage participatory monitoring of forest management activities
G	NGO	Incorporating traditional knowledge and local perspective in forest adoption
H	NGO	Create incentives for collaboration through the adoption
I	NGO	More studies on the real driving motive behind the growing forest adoption are needed
J	NGO	More studies on the real driving motive behind the growing forest adoption are needed
K	NGO	Facilitating joint decision-making and problem-solving
L	NGO	Establish a robust monitoring and evaluation framework
M	NGO	Establish a robust monitoring and evaluation framework
N	NGO	Create incentives for collaboration through the adoption
O	NGO	Create incentives for collaboration through the adoption
P	NGO	Facilitating joint decision-making and problem-solving
Q	Individual	Facilitating joint decision-making and problem-solving
R	Individual	More studies on the real driving motive behind the growing forest adoption are needed
S	Individual	More studies on the real driving motive behind the growing forest adoption are needed
T	Individual	Create incentives for collaboration through the adoption

Table 7: Perception of key improving forest Adoption in Kenya

4. Discussion

Results from this study indicate that 'adopt-a-forest' in Kenya has established a multidimensional and integrated approach that has improved forest management in Kenya. The inter-agency collaborative framework is breaking down forest management 'silos' by fostering interagency collaboration, yielding multiple positive social, economic, and environmental impacts on Kenyan society. Results show that up to 49 MDAs, NGOs, and private sector agencies participated in implementing the 'adopt-a-a forest' initiative that arose in 2018 following a Presidential Directive on the need to address the triple environmental threats being experienced in the country (Table 1). Up to 55% of the agencies comprised government Ministries, Departments, and Agencies that adopted 12% of the entire forest area adopted in the country between 2019 and 2021. Approximately 50% of the total seedlings planted were planted by MDAs, who channeled up to 33.9% of direct financial contribution into forest restoration between the years 2019 to the year 2021. This investment and support in forest conservation and management should improve the country's ecological integrity of forest infrastructure.

The adoption efforts are being promoted against the backdrop that forests in Kenya are under the constant threats of deforestation and degradation due to the growing human demands in the country. For instance, in 2019, Kenya's population was 47 million people and is expected to grow to 60 million by 2030 (Kenya's NDC, 2020; Draft Forest Policy, 2020). Therefore, these forest adoption results demonstrate that collaborative initiatives such as forest adoption, which promote investment in forest conservation and management, are part of the solution for addressing the triple planetary environmental threats currently facing many countries across the globe. This study believes that programs like forest adoption in Kenya should be expanded, replicated, and its lessons shared widely among countries that have made significant commitments and support for forest and landscape restoration (FLR) by 2030 through initiatives like the Bonn Challenge, New York Declaration on Forests, Aichi Target 15 of the Convention on Biological Diversity (CBD), and Sustainable Development Goals (SDGs), particularly SDG 15 on Life on Land, which aims to achieve land degradation neutrality by 2030. These countries have a good opportunity to meet their goals by learning from Kenya's successful forest adoption case.

Moreover, even though results have shown fewer private sector and NGO agencies were participating in forest restoration between the years 2019 and 2021, these agencies have adopted the most forest area (88% of the entire adopted area) and had the highest direct financial contribution of 66% of the total contributions by agencies between 2019 and 2021. This financial support and investments arising from 'adopt-a-forest' have boosted the overall forest management efforts in the country. The key informants consulted in this study agree with these findings. From Table 5, up to 45% of interviewees composed of both Government, Ministries, Departments, NGOs as well as Private organizations, and individuals attest to the fact that one of the key perceived benefits of 'adopt-a-forest' is bridging the forest conservation and management funding gap. These findings agree with studies by FAO (2022) and Löfqvist and Ghazoul (2019), who found that private financing in forest management is important and is rising in various regions of the world. As such, this paper calls for improving the working relationships between the government and the private sector in pursuing 'adopt-a-forest' as a tool for sustainable development. Other key benefits of adoption, as listed by interviewees, include; improved communication and coordination amongst partners and sharing of knowledge and expertise, amongst other benefits. However, reviewed literature also shows that evaluating stakeholder sensitivities and perceptions of benefits and costs is an arduous task because various factors affect forest management outcomes in collaborative arrangements, such as staff turnover and capacity, local leadership, and collaborative history among the partnering agency's leadership and commitment at the highest political and bureaucratic levels, an effective governance structure, a combination of top-down and bottom-up approaches to execution, presence of a collaborative culture, mutual communication, mutual trust, inclusiveness, benefit to all, a clear mission, objectives and sense of belonging (Andereck, 1997; Siddiquee et al., 2022; Table 5). Whereas this study calls for further investigations into these factors in the case of forest adoption in Kenya, this study also lauds the ongoing positive attempts across the globe to use the concept of cost-benefit analysis in monetizing the benefits and costs of collaboration which should also extend to emerging concepts such as adopt-a-forest.

Results from the literature review also indicate that the Kenyan government is desirous of enhancing forest adoption relationships and has developed the requisite legal and policy environment for fostering collaboration, as highlighted in Table 1, which provides a legally binding framework for 'adopt-a-forest' in the country. The framework outlines the rights, roles, and responsibilities of parties engaged in forest adoption. The range of activities from the implementation of the existing forest adoption includes; collaboration in the coordination of multi-agency forest security operations geared towards protecting the forest boundary integrity, especially through forest reclamations, tree planting, rehabilitation of degraded forest areas, infrastructural development support, tree seedlings production, joint restoration of arboreta and green spaces, forest fence installation, forest fire response, community scout support among other activities (Forester 2021). However, the tree planting activity appears to be the most dominant activity being actively implemented. It is also interesting to note that Private Sector Agencies and NGO organizations are actively involved in landscape restoration that supports community livelihoods and rural development, such as the provision of employment to community scouts and providing contracts for maintaining already planted sites to community groups. These actions contribute directly and indirectly towards enhanced forest security, protection, and livelihood improvement and Kenya's socio-economic development in line with the development aspirations enshrined in key policy documents to achieve and maintain 10% tree cover in the country (Table 4). These collaborative benefits, albeit not holistically quantified in monetary terms, agree with the finding from reviewed literature which shows that collaboration in forest management enhances costs and information sharing, thereby providing the opportunity to optimize the logistics of activities implementation (World Bank 2018; Siddiquee et al. 2022; Gereghty 2012; Bardach 1996; Andereck 1997). It is worth noting that under forest adoption, the choice of activities largely depends on government policy and priorities, the nature of the forest, the needs of the collaborative agency or party, and the needs of the adjacent forest communities, amongst others. Kenya Forest Service provides the technical guidance required to actualize the collaboration by establishing a joint technical and management committee with representation from both parties.

Results also indicate that in the FY 2019/2020 and 2020/2021, MDAs, NGOs, and private sector agencies have implemented and distributed forest adoption activities across various counties and regions in the country (Figure 1). Overall, Nairobi and Kiambu counties had the highest number of MDAs (each with 6) participating in forest adoption, while ten counties, Elgeyo Marakwet, Kericho, Kisumu, Kwale, Murang'a, Turkana, Uasin Gishu had a total of one MDA participating in the implementation of forest adoption. Nairobi (6), Kiambu (5), and Kajiado had the highest participation of private sector and NGOs in forest adoption, while Embu, Kisumu, Elgeyo Marakwet, Meru, Lamu had one non-state agency participating in the implementation of forest adoption activities. Nyeri county had the highest total adopted forest area by MDAs in the two financial years (957.5 Ha), and Nandi, Uasin Gishu, Murang'a, and Kwale had the lowest area adopted each with 1 Ha in the two financial years. In the non-state category, Meru and Narok have the highest adopted area measuring over 5,000 Ha. Meru county experienced the highest tree seedling planting. Meru county had the highest MDA financing of forest adoption activities. Laikipia county had the highest non-state agency funding for forest adoption activities in the two financial years. These observations indicate the potential for forest adoption to address forest management challenges by breaking down 'silos' and expanding the livelihood options for Kenyan society. It is evident from these findings that interagency collaboration is beneficial in helping the government to respect operational, social, and environmental constraints, as alluded to by Siddiquee et al. (2022). Various factors may likely have contributed to the success of forest adoption in Kenya. Still, the enabling environment provided by key policies documents, the need to join the global community in addressing the triple existential planetary crisis posed by climate change, biodiversity loss, and pollution, the Presidential Directive of 2018 where all government agencies were required to set aside 10% of their corporate social responsibility budget for forest conservation and management, availability of research evidence on good partnerships from participatory forest management as well as the deliberate involvement of stakeholders in forest management by the KFS leadership in the country appear to be the core factors behind the growth of forest adoption.

However, more studies are required to document the real driving motive behind the growing forest adoption by individuals, MDAs, NGOs, and Private sector agencies. There is speculation that some agencies could be positioning and selling themselves globally as 'green prophets' with unknown interests. Moreover, given that the country has already implemented participatory forest management where adjacent forest communities are already partnering with Kenya Forest Service to conserve and manage forest resources. There is no formal natural resource benefit-sharing law, so evaluating the community perception towards forest adoption by public and private agencies will be interesting since this initiative introduces a third partner to the existing KFS-community partnership. Such a study will help to build synergy amongst collaborating parties for greater forest protection, conservation, and management.

Results also show that interagency collaboration through forest adoption is unequally distributed across counties and regions (Figure 1). Results show that some counties have as many as six agencies implementing forest adoption while most have none. If the status quo remains, forest adoption is likely to exacerbate unbalanced regional development with far-reaching negative equity outcomes despite the good intentions of forest adoption. There is thus the need for studies that evaluate the impacts of collaboration in detail by applying newer analytical tools such as sequential power analysis, which examines collaboration in three phases to determine whether interagency collaboration is increasing mutual trust and stronger relationships amongst collaborating agencies, enhancing balanced regional development, enhancing social equity through sharing benefits, costs and information sharing thereby providing the opportunity to optimize the logistics of forest management in Kenya or not. This study is important because reviewed literature has shown that Kenya has not had a good history of stakeholder collaboration and involvement in forest management (Draft Forest Policy, 2020). Therefore, it will be important for the country to implement a robust mechanism for monitoring and evaluation where the achievements on key interventions pursued by parties are evaluated and precise indicators developed. Such monitoring of activities for sustainability will demand the need for joint planning of programs, data acquisition on benefits and losses of forest restoration programs on parties, sustainable financing of activities, an evaluation of innovations and technologies being deployed by parties, evaluation of challenges, and the disaggregated evaluation of socio-economic impacts of forest adoption on forest adjacent communities for instance, the impact of adoption on community employment opportunities, livelihood enterprises, opportunities for training amongst other dimensions of social sustainability.

However, the lacks of a robust monitoring and evaluation protocol which ought to highlight the kind of social, economic, and environmental variables that should be monitored in the course on implementation and the lack of a natural resource benefit sharing policy are the key challenge affecting forest adoption in Kenya as evidenced by the totality of interview responses in Table 6. Monitoring and evaluating adoption initiatives is crucial for understanding the complex factors involved in interagency collaboration by tracking implementation and outcomes systematically and assessing program effectiveness. Monitoring allows for determining when adjustments may be needed and provides a basis for modifying interventions and evaluating the quality of activities. It also provides decision-makers, managers, planners, policymakers, and donors with the information they need to make informed choices about program operations. It also provides data to guide strategic planning, design programs, and allocate resources effectively. Besides monitoring, study respondents have also suggested more studies on forest adoption, creating more incentives to attract the private sector besides incorporating traditional knowledge and local perspective in forest adoption. The use of incentives to promote forest adoption as a tool for sustainable forest management has been lauded in reviewed literature such as FAO (2022). Whereas this study agrees with these findings, especially on using forestry incentives such as tax cuts and other exemptions, it is important to generate new knowledge and understanding of forest adoption by testing these improvement strategies using specific case studies.

5. Conclusion and Recommendations

Forest resources are important strategic assets for their economic, environmental, social, and cultural values. In Kenya, forests constitute an important natural capital that provides many important ecological services needed for human well-being and sustainable development. However, these resources are constantly threatened by degradation and loss due to multiple interrelated environmental, economic, and social challenges, especially the growing demand for forest products occasioned by population growth. As such, many policy and legislative reforms have been embraced with deliberate attempts to try new innovative approaches for promoting sustainable forest management, such as forest adoption are increasingly being tested to generate a new understanding of their practicality on various scales.

Results from Kenya have shown that 'adopt-a-forest' as a multidimensional and integrated approach for improving forest management in the country has many social, economic, and environmental benefits to partnering stakeholders. The initiative is helping Kenya break down the 'old' forest management 'silos' and challenges by fostering interagency collaboration, yielding multiple benefits to Kenyan society. Government Ministries, Departments, Agencies, the Private sector, and NGOs have pooled resources for forest conservation and management between 2019 and 2021. Approximately 50% of the total seedlings planted were planted by MDAs, who channeled up to 33.9% of direct financial contribution into forest restoration between the years 2019 to the year 2021. Even though fewer private sector and NGO agencies were participating in forest restoration between the years 2019 and 2021, these agencies have adopted the most forest area (88% of the entire adopted area) and had the highest direct financial contribution of 66% of the total contributions by agencies between 2019 and 2021. These supports have boosted the overall forest management in the country.

However, interagency collaboration in forest adoption appears to be unequally distributed across counties and regions in the country. Results have shown that some counties have as many as six agencies implementing forest adoption while a majority of other counties have none. If the status quo remains, forest adoption is likely to exacerbate unbalanced regional development with far-reaching negative equity outcomes despite its good intentions. There is thus the need for studies that evaluate the impacts of this collaboration in detail by applying newer analytical tools such as sequential power analysis to determine whether interagency collaboration is increasing mutual trust and stronger relationships amongst collaborating agencies, enhancing balanced regional development, enhancing social equity through sharing benefits, costs and information sharing thereby providing the opportunity to optimize the logistics of forest management in Kenya or not. Moreover, besides the need for a robust monitoring and evaluation framework with clear indicators, more quantitative studies are required in order to document the real driving motive behind the growing forest adoption by individuals, MDAs, NGOs, and Private sector agencies.

References

Agevi, H., Wabusya, M., and Tsingalia, H.M. (2014). Community forest associations and community-based organizations: Redesigning their roles in forest management and conservation in Kenya. *International Journal of Science and Research*, 3(9), 1916-1922.

Andereck, K. L. (1997). Case study of a multi-agency partnership: Effectiveness and constraints. *Journal of Park and Recreation Administration*, *15*(2), 44-60.

Bardach, E. (1996). Interagency Collaboration. *The state of public management*, 168.

Cadman, T., Maraseni, T., Koju, U. A., Shrestha, A., & Karki, S. (2023). Forest Governance in Nepal concerning Sustainable Community Forest Management and Red Panda Conservation. *Land*, 12(2), 493.

Chang, K. (2012). *Understanding cross-sector collaboration in emergency management: The dynamics of vertical and horizontal networks*. The Florida State University.

Chisika, S. N., & Yeom, C. (2020). Enhancing equity in participatory forest management through forest management agreements: the case of Gathiuru and Karima forests in Kenya. *International Forestry Review*, *22*(1), 49-63.

Chomba, S. W., Nathan, I., Minang, P. A., & Sinclair, F. (2015). Illusions of empowerment? Questioning policy and practice of community forestry in Kenya. *Ecology and Society*, *20*(3).

Constitution of Kenya (2010). Available at http://kenyalaw.org/kl/index.php?id=398

Draft Forest Policy (2020). Available at http://www.environment.go.ke/wp-content/uploads/2020/06/Draft-Forest-Policy-19May-2020-.pdf

Elbakidze, M., Angelstam, P. K., Sandström, C., & Axelsson, R. (2010). Multi-stakeholder collaboration in Russian and Swedish model forest initiatives: adaptive governance toward sustainable forest management?. *Ecology and Society*, *15*(2).

Environmental Coordination and Management Act, 1999. Available at http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/EnvironmentalManagementandCo-ordinationAct_No8of1999.pdf

FAO (2014). *Enhancing the socio-economic benefits from forests. State of the World's Forests 2014*. Rome, Italy

FAO (2014). *Enhancing the socio-economic benefits from forests. State of the World's Forests 2014*. Rome, Italy

FAO (2015). *Global Forest Resources Assessment, 2015. Kenya Country Report*. Rome, Italy.

FAO. (2022). *The State of the World's Forests 2022. Forest pathways for green recovery and building inclusive, resilient and sustainable economies*. Rome, Italy. https://doi.org/10.4060/cb9360en

Forest Conservation and Management Act (2016). Available at http://www.kenyaforestservice.org/documents/ForestConservationandManagementActNo34of2016.pdf

Forester (2021). Available at http://www.kenyaforestservice.org/documents/FORESTER%20MAGAZINE/2021/FORESTER%202021%20NEW%20EDIT%20(1).pdf

Forestry Society of Kenya (2009). Forest Landscape and Kenya's Vision 2030. Proceedings of the 3rd Annual FSK Conference and Annual General Meeting held at the Sunset Hotel, Kisumu. 30th September - 3rd Oct 2008

Forests Act No 7 (2005) Available at http://www.kenyaforestservice.org/images/MMMB/forests%20act%20no.7%20of%202005.pdf

Gajda, R. (2004). Utilizing collaboration theory to evaluate strategic alliances. *American journal of evaluation*, *25*(1), 65-77.

Gereghty, M. (2012). *Climate Change, Forest Fire Management & Interagency Cooperation in Canada* (Master's thesis, University of Waterloo).

Girma, G., Melka, Y., Haileslassie, A., & Mekuria, W. (2023). Participatory forest management for improving livelihood assets and mitigating forest degradation: Lesson drawn from the Central Rift Valley, Ethiopia. *Current Research in Environmental Sustainability*, 5, 100205.

Grumbine, R. E. (1991). Cooperation or conflict? Interagency relationships and the future of biodiversity for US parks and forests. *Environmental Management*, *15*(1), 27-37.

Kagombe, J. K., Kiprop, J., Langat, D., Cheboiwo, J. K., Wekesa, L., Ongugo, P. O., ... & Nereoh, L. (2020). *Socio-economic impact of forest harvesting moratorium in Kenya*. KEFRI.

Kairu, A., Kotut, K., Mbeche, R., and Kairo, J. (2021). Participatory forestry improves mangrove forest management in Kenya. *International Forestry Review*, *23*(1), 41-54.

Kenya Forest Service Facebook Account (2022). Accessed at https://web.facebook.com/search/top/?q=Kenya%20Forest%20Service%20framework%20of%20collaboration

Kenya's NDC (2020). Available at https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Kenya%20First/Kenya%27s%20First%20%20NDC%20(updated%20version).pdf

KFS (2014). *Kenya Forest Service Strategic Plan 2014 -2017*. KFS. Nairobi Kenya.

KFS (2014). *Kenya Forest Service Strategic Plan 2014 -2017*. Office Records, Nairobi, Kenya.

KFS (2022). *Kenya Forest Service*. Ministry of Environment and Forestry, Nairobi, Kenya.

LBDA (2018). *Strategic Plan June 2018 – June 2023*, Lake Basin Development Authority, Kisumu, Kenya.

Löfqvist, S., & Ghazoul, J. (2019). Private funding is essential to leverage forest and landscape restoration at global scales. *Nature ecology & evolution*, *3*(12), 1612-1615.

Maier, C., & Wirth, K. (2018). The world (s) we live in–Inter-agency collaboration in forest management. *Forest Policy and Economics*, *96*, 102-111.

Marks-Block, T., & Tripp, W. (2021). Facilitating prescribed fire in Northern California through Indigenous Governance and interagency partnerships. *Fire*, *4*(3), 37.

Matiku, P., Caleb, M., & Callistus, O. (2013). The impact of participatory forest management on local community livelihoods in the Arabuko-Sokoke forest, Kenya. *Conservation and Society*, *11*(2), 112-129.

MEF (2018). *Taskforce Report on Forest Resources Management and Logging Activities in Kenya*, Ministry of Environment and Forestry, Nairobi, Kenya.

MENR (2016). *National Forest Programme 2016–2030*. Ministry of Environment and Natural Resources, Nairobi, Kenya.

MENR (2019), Ministry of Environment and Natural Resources National Strategy for Achieving 10% Forest Cover in Kenya. Accessed at http://www.environment.go.ke/wp-content/uploads/2019/08/Strategy-for-10-Tree-Cover-23-5-19-FINAL.pdf on February 22, 2020.

MEWNR (2015), Ministry of Environment Water and Natural Resources. Kenya Biodiversity Atlas Ministry of Environment Natural Resources and Regional Development Authorities P.O.Box 30126 -00100, Nairobi, Kenya

MoALF (2021). Ministry of Agriculture, Livestock, Fisheries and Cooperatives; Range Management and Pastoralism Strategy.

National Strategy for Achieving and Maintaining 10% Tree Cover (2019). Available at http://www.environment.go.ke/wp-content/uploads/2019/08/Strategy-for-10-Tree-Cover-23-5-19-FINAL.pdf

Ngatia, J. M., & Thuita, T. (2017). Participatory forest management: a case of equity in the forest plantation establishment and livelihood improvement scheme in Gathiuru and Hombe forests in central Kenya. *International Journal of Scientific Research and Management*, *5*(11), 7344-7360.

Nthuku (2018). An Assessment of the Role of Community Forest Associations in the Management of Karura Forest in Kenya. Master's Thesis. University of Nairobi,

Odwori, P. O., Nyangweso, P. M., & Odhiambo, M. O. (2013). *Alleviating Food Insecurity and Landlessness Through PELIS in Kenya* (No. 309-2016-5228).

Okumu, B., & Muchapondwa, E. (2017). *Economic Valuation of Forest Ecosystem Services in Kenya: Implication for Design of PES Schemes and Participatory Forest Management* (No. 693).

Pour, M. D., Barati, A. A., Azadi, H., Scheffran, J., & Shirkhani, M. (2023). Analyzing forest residents' perception and knowledge of forest ecosystem services to guide forest management and biodiversity conservation. *Forest Policy and Economics*, 146, 102866.

Ray-Bennett, N., Mendez, D., Alam, E., & Morgner, C. (2020). Inter-agency collaboration for natural hazard management in developed countries. In *Oxford Research Encyclopedia of Natural Hazard Science*.

Sahide, M. A. K., Fisher, M. R., Supratman, S., Yusran, Y., Pratama, A. A., Maryudi, A., ... & Kim, Y. S. (2020). Prophets and profits in Indonesia's social forestry partnership schemes: Introducing a sequential power analysis. *Forest Policy and Economics*, *115*, 102160.

Shamsul Huda, A. T. M. (2004). Interagency collaboration for integrated coastal zone management: A Bangladesh case study. *Coastal Management, 32*(1), 89-94.

Siddiquee, N.A. (2022). Breaking Down Silos and Fostering Inter-Agency Collaboration: Malaysia's National Blue Ocean Strategy in Perspective. In *Institutional Reforms, Governance, and Services Delivery in the Global South* (pp. 223-240). Palgrave Macmillan, London, UK.

Silvestri, S., Zaibet, L., Said, M. Y., & Kifugo, S. C. (2013). Valuing ecosystem services for conservation and development purposes: a case study from Kenya. *Environmental science & policy*, *31*, 23-33.

The Public Private Partnership Act (2013). Available at http://www.parliament.go.ke/sites/default/files/201705/PublicPrivate_Partnerships_ActNo15of2013.pdf

Thygesen, S. H., Løber, T., Skensved, E. M., & Hansen, C. P. (2016). Implementation of participatory forest management in Kenya: A case study of Karima Forest. *International Forestry Review*, *18*(3), 357-368.

Tshidzumba, R. P., Chirwa, P. W., & Babalola, F. D. (2018). Communities' perceptions of benefit-sharing mechanisms for forest-based land reform models in South Africa. Southern Forests: a Journal of Forest Science, 80(4), 381-389.

UNEP (2012a). Kenya. Economy-wide impact technical report

UNEP (2012b). Kenya. Integrated forest ecosystem services technical report.

UNEP (2012). The role and contribution of Montane forests and related ecosystem services to the Kenyan economy. UNEP, Nairobi.

Vision 2030 (2018). Available at http://vision2030.go.ke/wp-content/uploads/2018/09/Kenya-Vision-2030-Sector-Progress-Project-Updates-June-2018.pdf

World Bank Group (2018). *Improving Public Sector Performance: Through Innovation and Inter-Agency Coordination*. World Bank.

Yanshu Li, Bin Mei, Thais Linhares-Juvenal (2019). The economic contribution of the worlds forest sector. *Forest Policy and Economics* 100: 236-253

Authors

Sylvester Ngome Chisika
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea; sylvesterchizika@gmail.com

Chunho Yeom (*corresponding author*)
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea; chunhoy7@uos.ac.kr

Funds

This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2020S1A5C2A01092978).

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Chisika, S. & Yeom, C. (2023) The perception of benefits from the 'adopt-a-forest' initiative in Kenya *Visions for Sustainability*, 20, 7393, 63-97.
http://dx.doi.org/10.13135/2384-8677/7393

Original Paper

The challenges of sustainable conservation and management of mangrove forests in Kenya

Sylvester Chisika, Chunho Yeom

Received: 5 June 2023 | **Accepted:** 31 July 2023 | **Published:** 23 August 2023

Keywords: sustainable forest management; incentives; policies; literature review; challenges.

Abstract. *There is a scarcity of contextual information on the current status and challenges facing the sustainable management of mangroves. Using a literature review, this study explores this problem in the case of Kenya's mangrove sites, with the aim of contributing to a better understanding of the strategies needed to promote their sustainable conservation and management. The results indicate that Kenya's mangrove forests span approximately 62,459.8 hectares, accounting for roughly 3.0% of the overall natural forest cover or less than 1.0% of the country's total land area. The majority of mangroves, constituting about 59%, are found in Lamu County. The country has nine species of mangroves, with* Rhizophora mucronata *and* Ceriops tagal *(Perr.) C.B. Rob. being the dominant species. Even though these resources provide many ecosystem goods and services, mangroves are still being threatened by human-induced changes. Fortunately, the government appears to be strongly committed to conserving these critical resources and has established a positive environment for restorative actions. The development of the National Mangrove Ecosystem Management Plan (2017-2027) and the recognition of private sector-led incentive-based Payment for Ecosystem Services initiatives such as the Mikoko Pamoja Project provide renewed impetus for improved management of mangroves. Even though more studies are required, the success of the Mikoko Pamoja project serves as an inspiring example to the world of how community involvement in innovative incentive-based approaches can contribute to the preservation and sustainable use of mangroves.*

---

1. Introduction

Mangrove forests are important strategic assets that provide many benefits for sustainable development (Lee et al., 2014). Mangroves offer diverse ecosystem services, including climate change mitigation, recreation, coastal protection, and food production (Spalding & Parrett, 2019; Hochard et al., 2019; Donato et al., 2011; Vo et al., 2012). Despite these benefits, only four countries account for over 40 percent of the total global mangrove area. Indonesia leads with 19 percent, followed by Brazil with 9 percent, Nigeria with 7 percent, and Mexico with 6 percent (FAO 2020). Jia (2023) estimates that in 2020, the global coverage of mangrove forests was 145,068 km2. Asia had the highest proportion of mangrove forests, accounting for 39.2 percent. Indonesia possessed the largest amount of mangrove forests at the country level, followed by Australia and Brazil.

However, with the changing global socio-economic development matrices occasioned by factors such as population growth, urbanization, and climate change, existing literature shows that mangrove forest resources are on a decline (Richards & Friess, 2016; Goldberg et al. 2020). Goldberg et al. (2020) conducted studies that indicate a global average annual area loss of 0.13 percent of mangroves between 2000 and 2016. According to the FAO 2020 report, the total area of mangroves worldwide decreased by 1.04 million hectares between 1990 and 2020. Over three decades, the loss rate more than halved, declining from 46,700 hectares per year in 1990-2000 to 36,300 hectares per year in 2000-2010 and further to 21,200 hectares per year in the most recent decade. The ongoing loss of mangroves has prompted a strong drive to promote global mangrove restoration efforts. Initiatives such as the UN Decade on Ecosystem Restoration (2021-2030) and the ongoing negotiations for the Post-2020 Global Biodiversity Framework (Waltham et al., 2020; Khuyen et al., 2021) demonstrate the determined efforts to address this issue. Conservation results from these initiatives have varied depending on context. Research conducted in Asia indicates contrasting conditions among mangrove forests in different regions. South Asian mangrove forests were found to be in a relatively better state due to a higher level of conservation efforts and larger individual patch sizes. On the other hand, mangrove forests in East and Southeast Asia were identified as facing significant threats. Notably, nearly 99 percent of the mangrove forest areas studied had a patch width exceeding 100 meters, suggesting that most mangrove forests effectively mitigate coastal wave energy and its associated impacts (Jia, 2023).

In Kenya, mangrove forests are valued for their ecological and socio-economic importance. Still, they remain under the constant threat of loss due to deforestation and degradation occasioned by various reasons. The decline of mangroves has detrimental effects on various aspects, such as fisheries, the stability of shorelines, and the long-term sustainability of resources. However, with the advent of the 2010 constitution, which introduced county governments and the growing human need for forest products, this paper argues that the limited scientific studies have compared the current status of mangroves in devolved units (counties) that should be urgently addressed. It is because there are only a few scattered studies on the conservation and management of mangrove forests based on isolated local-level case studies, especially at the forest stand level. In order to address this challenge and help to design win-win regional-level mangrove conservation strategies across various counties, this study seeks to explore and document the current challenges of sustainable conservation and management of mangrove forests in Kenya. Using a literature review, this study will first explore the global status of the conservation and management of mangrove forest, review Kenya's context for conservation of mangroves then apply the global lessons to Kenya's context to generate the study implications. To achieve these aims, the following analytical question will be asked; What lessons can we draw from the current state of conservation and management of mangrove forests in Kenya?

Kenya is an appropriate study site for the challenges of sustainable management of mangrove forests, given its rich diversity of mangrove forest ecosystems, diverse stakeholders, history of community-based natural resource management, environmental and socio-economic pressures, and growing interest in sustainable development and conservation. By studying the challenges and opportunities for enhancing the sustainable management of mangrove forests in Kenya, researchers and practitioners can develop innovative and context-specific strategies that can be applied to other parts of the world facing similar challenges.

1.1 Sustainable conservation and management of mangrove forests

Mangroves refer to communities of shrubs and trees that are adapted to saline environments and thrive in intertidal zones found in tropical, subtropical, and certain temperate coastlines (Kathiresan & Bingham 2001). Mangroves play an important environmental and socio-economic function (Howard et al. 2019; Biwas & Biwas 2019; Salampessy et al. 2015). Mangrove ecosystems exemplify the production of a diverse array of forest products, both wood, and non-wood, which play a vital role in safeguarding coastal regions and coral reefs, and other forms of biodiversity (FAO 2022; Alongi 2009; Mitsch & Gosselink 2007; Giesen et al. 2007; Duke et al. 2007; Kauffman & Donato 2012). The Millennium Ecosystem Assessment Report of 2005 classifies the benefits of mangroves into provisioning, regulating, supporting, and cultural services (Assessment 2005).

The sustainable forest management theoretical approach provides an overarching framework for the sustainable conservation of mangrove forests for future generations. The approach seeks to address deforestation, degradation, and fragmentation by promoting responsible forest management practices that ensure the long-term health and productivity of forests while providing economic and social benefits to local communities. Sustainable forest management involves a range of strategies, including forest certification, community-based forest management, and conservation and restoration initiatives. It is monitored through ecological, social, and economic criteria and indicators. Specific indicators used to measure sustainable forest management include: forest area, tree species diversity, community participation, income generation, and forest product prices.

Globally, mangroves cover approximately 14.8 million ha, with Asia having the largest area. Indonesia, Brazil, Nigeria, and Mexico account for over 40% of the total mangrove area. Between 1990 and 2020, the global mangrove area decreased by 1.04 million ha, with a decreasing rate of loss over the decades. In Africa and Oceania, the rate of loss also declined. South America experienced an increase in mangrove areas during 2010-2020, reversing the declining trend. Guyana played a significant role, reporting an annual increase of 19,500 ha, attributed to a restoration project and improved mapping. In North and Central America, there was a moderate increase of 10,500 ha during the same period. Forest area under mangroves exhibits regional and country-specific variations. In North and Central America, Cuba's reported gain of 12,000 ha per year contributed to the regional increase in 2010-2020, attributed to improved data collection and restoration programs. However, in Asia, the average annual rate of mangrove loss significantly increased, mainly driven by Indonesia's loss of 21,100 ha per year in the most recent decade. The FAO (2022) report states that Africa is home to approximately 20 percent of the world's mangroves. The distribution of mangroves in Africa consists of 74 percent along the west coast and 26 percent along the east coast. These mangroves are found in 19 countries on the west coast and 15 on the east coast of Africa. These losses and gains call for concerted efforts to design robust strategies for the sustainable management of mangrove resources.

Historically, the design and implementation of sustainable mangroves conservation strategies across the globe have been done to minimize loss and damage caused by natural disasters, legal requirements in various jurisdictions, and to sustain the range of economic benefits from mangrove restoration activities (Buckingham and Hanson 2015). As such, there is passive management through promoting natural regeneration which is based on inherent mangrove regenerative capabilities (Kamali & Hashim 2011; Martinuzzi et al., 2009). However, caution should be exercised. When disturbances occur, the regenerative abilities slowly degrade and/or disappear. The aboveground biomass of mangroves in the area needs a minimum of 25 years to recover and attain the same levels of biomass carbon observed in undisturbed mangrove forests (Sasmito et al., 2020b). The potential to enhance the functionality of coastal forests lies in the restoration of degraded mangroves, yet the aspect of preserving species diversity is frequently overlooked. Mangrove restoration aims at reversing biodiversity losses (Nellemann et al., 2009). However, the challenge with restorative efforts is connected with the selection of plant materials for human-induced restoration efforts in severely degraded mangrove sites tends to favor mono-species compositions based on their availability. The extent to which such restoration or rehabilitation endeavors can effectively enhance the recovery process of mangroves in terms of forest structure and functioning remains unknown (Branoff & Martinuzzi 2020). There are many considerations when undertaking mangrove restoration efforts, such as assessing the stability of the soil and the flooding patterns, determining the elevation of the site, evaluating the salinity of the soil and water, and understanding the input of freshwater to the site (Ngongolo et al. 2015).

Many challenges still impede the sustainable restoration of mangrove ecosystems. These factors involve the potential failure of restoration goals when relying solely on active mangrove planting without conducting a comprehensive assessment of the underlying causes of mangrove loss. Identifying and leveraging natural recovery opportunities is crucial, and determining how to facilitate and enhance them effectively (Fistrek & Bergman 2010). In some cases, the human dimension is ignored as an important consideration in mangrove restoration projects resulting in the failure of restoration efforts (Ellison 2000). Another obstacle is the constrained availability of sustainable funding, as the majority of mangrove restoration projects rely heavily on external funders for nearly all aspects of project activities. Furthermore, restoration programs are ongoing and necessitate a continuous and consistent supply of funds throughout various stages, including planning, project implementation, and post-management phases (Ngongolo et al. 2015). Other challenges include a lack of databases on the successes of restoration projects. It is essential to keep the public informed about completed projects and the benefits they bring. News releases, media events, and public celebrations play a crucial role in ensuring awareness and understanding of the progress made in these projects (Klötzli & Grootjans 2001). Articles intended for public consumption can be crafted in a non-technical manner. Furthermore, mangrove restoration efforts can be hindered by pests and diseases. Young plants are susceptible to damage caused by barnacles and leaf-eating crabs from the sesarmid family. Additionally, certain caterpillars act as parasites on the fruits of the Rhizophora L., impeding seed germination (Ngongolo et al. 2015). Insufficient long-term monitoring and the socio-economic status of neighboring communities are contributing factors. The greater the poverty among individuals, the more they rely on natural resources, leading to significant degradation of mangrove resources. This widespread degradation, in turn, perpetuates a cycle of poverty, as poverty itself becomes a recurring cause of further degradation.

On a continental scale, Naidoo (2023) identifies the key threats facing mangroves in the African context as anthropogenic factors such as harvesting, pollution, and conversion to aquaculture and agriculture, lack of considering stakeholder interests (social, economic, and ecological interests) in regional development strategies. Other challenges include; uncertain tenure, encroachment on land, elite control, inequitable distribution of benefits, limited understanding of biophysical conditions, lack of propagules and improper species site matching, pests and diseases (Friess et a. 2016; Jusoff & Taha 2008; Barnuevo & Asaeda 2018; Suman 2019; Kusmana 2014).

Despite the challenges in mangrove management, the growing recognition of the importance of mangroves has fostered the emergence of a new conservation approach. Cross-sectoral and multi-stakeholder participatory strategies have become central in mangrove management in many countries, including Brazil, Ghana, and Mexico have achieved successful co-management of mangroves. In certain countries like Vietnam, the Philippines, and Ecuador, the legal framework for forest tenures has shifted from state-based to community-based approaches (Rotich et al. 2016; Rotich et al. 2016). Other strategies include incentivizing mangrove preservation, promoting environmentally sustainable utilization in coastal communities, and enhancing public acceptance and community involvement in mangrove management. Other strategies include research and development, facilitating technology transfer, and utilizing information systems (Thu et al. 2019; Locatelli et al. 2014; Byran et al. 2020; Zaldívar-Jiménez et al. 2017; Aheto et al. 2016; Mangora 2011; Bosire et al. 2008). In addition, analyzing policy and institutional frameworks is vital to address these knowledge gaps, including understanding and evaluating indigenous knowledge and traditional management systems for effective integration. Indonesia offers a compelling example of incentivizing mangrove conservation through the bio-right scheme. The approach involves establishing a funding mechanism for communities engaged in conservation and restoration activities to enhance economic benefits while promoting ecological preservation (van Eijk & Kumar 2009).

From the foregoing review, sustainable forest management is crucial for effective mangrove resource conservation. Global literature review reveals decreasing mangrove areas, with Asia being the most affected. The key challenges include limited funding, lack of restoration databases, pests, diseases, and limited socio-economic understanding of project sites. Successful approaches involve co-management and community-based management, supported by incentives, funding, research, policy revision, and indigenous knowledge. It will thus be interesting to explore Kenya's context for mangroves and suggest solutions for their sustainable management.

1.2 The context for forest management in Kenya

Trees and forests are important strategic national assets in Kenya because of their ecological and socio-economic value. Kenya's forest sector contributes to a livelihood base for over 82% of Kenya's households. Direct employment for over 750,000 Kenyans and indirect benefit to over 4 million citizens. About USD 365 million (3.5%) to GDP (KFS, 2014; MEF, 2018).

Whereas Kenya is a low forest cover country with less than the recommended minimum global standard of 10%, the rapidly expanding population and conversion of forest lands to agriculture were the major drivers of forest cover loss over the years. From 1990 to 2015, about 311,000 Ha of forest land was converted to other land uses (FAO 2015b). Weak governance, unsustainable exploitation, overreliance on forest products, forest fires, and increasing adverse effects of climate change have further exacerbated deforestation and degradation of forests in Kenya (FAO 2022a; FAO 2022b).

To cut back on reliance on domestic forest products in key economic sectors, Kenya has positioned itself as a trading nation at regional and global levels in forest products. Nevertheless, Kenya is committed to contributing to global climate change mitigation and adaptation through Nationally Determined Contribution (NDC) as part of UNFCCC in line with the Paris Climate Change Agreement requirements aimed at lowering her GHG emissions by 30% by 2030.

The Kenyan Constitution 2010 recognizes the need to increase the national tree cover to at least a minimum of 10% by the year 2030. This development aspiration is also in line with Kenya's commitment to restore 5.1 million hectares of forest and degraded landscapes, which formed part of the African Forest Landscape Restoration Initiative (AFRI100) target, and the NDC target of reducing greenhouse gasses emissions by 32% by 2030 relative to a business-as-usual scenario.

2. Materials and Methods

2.1. Study area

Kenya is a country located in East Africa, known for its diverse wildlife, scenic landscapes, and vibrant culture. Its population is approximately 50 million people, with over 40 ethnic groups, each with its unique language, customs, and traditions. Kenya's capital city is Nairobi, which serves as the country's economic and cultural hub. Kenya's geography is diverse, ranging from savannas, forests, mountain ranges, and coastal plains. It is home to some of the world's most famous wildlife reserves, including the Masai Mara National Reserve, known for the annual wildebeest migration, and Amboseli National Park, renowned for its large elephant herds. The country's coastline is dotted with pristine beaches, coral reefs, and marine parks, making it a popular destination for beach holidays and water sports enthusiasts. In terms of its economy, Kenya is one of the most developed countries in East Africa, with a GDP of approximately $100 billion (Macheru 2023).

Over the past decade, Kenya has made significant political and economic reforms that have contributed to sustained economic growth, social development, and political stability. From 2015 to 2019, Kenya's economy achieved broad-based growth averaging 4.8% per year, significantly reducing poverty to 34.4% in 2019 (World Bank 2022). Kenya's economy is highly dependent on the natural resource base. With over 84% of its land area classified as arid and semi-arid, Kenya is so exposed and highly vulnerable to increasingly extreme weather conditions. An average drought results in a 20–30% food deficit, slash GDP growth by 3–5% and affects the livelihoods of over 80% of the population (ADB 2022). According to the Global Climate Change Risk Index (GCRI) of 2021, Kenya is ranked the 25th most affected country by extreme weather conditions and weather-related losses (ADB 2022). Youth unemployment and a high poverty rate are key challenges to Kenya's economic growth and development. The youth unemployment rate is 38.9%, with an estimated 800,000 young people entering the labour market every year and over 8.9 million people in Kenya living below the poverty line (Statista 2022). With a population growth rate of 2.7%, the Kenyan population is projected to rise to 66.3 million by 2030. The increasing population presents a challenge to the sustainable utilization of forest resources and an opportunity for expanding farm forests. According to a study by GATSBY Charitable Fund in 2014, Kenya's national wood deficit was estimated at 12 million M3 in 2014 and is predicted to rise to as high as 34.4 million M3 by 2030. Against this background, the new Kenya Kwanza administration's bottom-up economic model has prioritized accelerating the achievement of 30% national tree cover by 2032 for increased employment opportunities, improved livelihoods, climate change reliance, and enhancing Kenya's economic growth within the context of Vision 2030 (Government of the Republic of Kenya, 2007).

Mangroves are found in Lamu, Kilifi, Mombasa, Tana River, and Kwale counties along the Kenyan coast. Table 1 shows the counties where mangroves are found in Kenya. Kilifi County is the most populous, while Lamu County is the least populous and has the highest tree cover. Mombasa County is a city county and has experienced increased infrastructural developments.

Parameter	Lamu	Kilifi	Kwale	Tana River	Mombasa
Area (Ha)	613,953.01	1,250,414.05	822,927.05	3,915,064.52	21,602.29
Population	143,920	1,453,787	866,820	315,943	939,370
Gross County Product (Kshs., MM) Year 2020	26,861	163,818	92,577	24,314	402,373
Forest Cover (%)	32.13	26.25	5.52	9.97	19.59
Tree Cover (%)	44.06	27.75	13.99	10.40	23.75

Table 1: Description of counties with mangroves in Kenya Source: Author from Multiple sources

2.2. Data Collection and Analysis

This study seeks to explore the challenges facing the sustainable conservation and management of mangrove resources in Kenya in order to draw lessons for sustainable forest management. To achieve on this aim, literature review through document content analysis was conducted to collect both qualitative and quantitative data on the variable under study. The process of document content analysis entailed; identifying relevant documents, selecting a sample for analysis, developing coding schemes or categories to organize the data, and systematically analyzing the content of the documents to draw conclusions about the research question.

Document content analysis was the preferred research method for this study because it is less expensive than other research methods, such as surveys or experiments, since the data is readily available and does not require the researcher to collect new data. Unlike surveys or experiments, document analysis does not require direct contact with study participants, which can be useful when studying sensitive topics or when the researcher wants to avoid influencing the participants' behavior. Document content analysis is more objective than other research methods, as it relies on the content of the documents rather than the researcher's interpretation of the data. Lastly, this study explores historical data on forest cover and central bank rate of interest, and thus document content analysis was applicable to study the historical trends and patterns over time by providing a rich source of information (Cole 1988; Downe-Wamboldt 1992; Drisko & Maschi 2016).

Data on mangrove resource conservation and management status was sought from existing literature using desktop Google Scholar and supplemented with official records. During the desktop search, appropriate keywords related to the topic, such as "mangroves," "mangrove conservation and challenges," "mangrove management," "deforestation," or any other relevant terms, were chosen. In some cases, the use of advanced search techniques such as quotation marks (" ") to search for exact phrases or the minus sign (-) was used to exclude certain keywords. Notes were taken, and a track of the reference sources was noted. The information was later synthesized and used to develop insights or support arguments fronted in this research. The choice of Google engine was infomed by the need for improving study reliability and reproducibility.

Other secondary data were collected by reviewing the key documents and studies listed in Table 2. These documents provided context information and key results used in this study.

No.	Document/study consulted	Key information sought	Source
1.	Constitution of Kenya (2010)	Article 60 (1) (e) provides for sound conservation and protection of ecologically sensitive areas such as mangrove sites	Kenya law reporting website

No.	Document/study consulted	Key information sought	Source
2.	Forest Policy (2015)	Context information for forest management	Kenya Forest Service website
3.	Forest Conservation and Management Act (2016)	Institutions established to promote forest management	Kenya law reporting website
4.	Kenya Vision 2030 (2007)	Context information for forest management	Vision 2030 website
5.	Wildlife Conservation and Management Act, (2013)	Context information for marine resource management	Google Search
6.	Environmental Management and Coordination Act, (1999)	Context information for management of environmental resources	Google Search
7.	County Government Act (2012)	Role of counties in managing forests	Kenya law reporting website
8.	National Mangrove Ecosystem Management Plan (2017-2027)	Context information on the status of mangrove ecosystems in Kenya	Google Search
9.	Office Records	Context information on the status of mangrove ecosystems in Kenya	Kenya Forest Service
10.	Abuodha &Kairo (2001).	Human-induced disturbance of mangroves in Mombasa and Lamu counties caused by salt work, housing, and aquaculture	Google Scholar
11.	Doute et al. (1981)	Mangrove resource assessment using remote sensing	Google Scholar
12.	Kairo et al. (2001)	Overview of mangrove conservation in Eastern Africa	Google Scholar
13.	Kairo et al. (2008)	Structural development and productivity of planted mangroves in Gazi bay, Kwale County	Google Scholar
14.	Mwamuye et. al. (2021)	The multi-stakeholder approach has an overall improvement in the conservation and management of mangrove forests resources, more so with a functional coordination framework among stakeholders in Mida Creek, Kilifi County	Google Scholar
15.	Kirui et al. (2008)	Influence of species richness and environmental factors on survival of replanted mangroves in Gazi bay, Kilifi County	Google Scholar
16.	Olago et al. (2023)	Impacts of climate change on mangroves in Lamu County	Google Scholar

No.	Document/study consulted	Key information sought	Source
17.	Kitava et al. (2021)	The study on integrating mobile phone communication technology in the management of mangrove forests in Lamu County found that mobile phones are affordable, convenient, and effective for reporting criminal activity and monitoring forest changes. The study recommended providing employees with internet-enabled phones to utilize social media applications.	Google Scholar
18.	Karanja & Saito (2018)	Environmental benefits of mangroves in Tana Delta, Tana River County	Google Scholar
19.	Hanshi (2017)	Dynamics of conflicts in Tana Delta Region. Lack of mutual understanding on how to share benefits from natural resources causes conflicts and degradation of mangrove resources.	Google Scholar

Table 2: Key documents consulted in Kenya

3. Results

3.1. The current state of conservation and management of mangroves

Kenya has about 61,271 ha of mangrove forests (Table 2). These resources are found in five coastal counties: Lamu, Kwale, Tana River, and Mombasa. Lamu County has the most extensive mangrove cover, spanning 37,350 hectares. It is followed by Kwale, Kilifi, Tana River, and Mombasa counties, in descending order (as shown in Table 3). It is important to note that estimates of mangrove areas may differ among sources due to variations in estimation methods, survey timing, classification criteria, and delineation of the mangrove ecosystem. Mombasa County exhibits the highest percentage of degraded mangrove areas. Figure 1 shows the distribution of mangroves along the Kenyan coastline.

County	County Total Area (Km^2)	Mangrove Area (Ha)	Degraded Area (%)
Lamu	6,273.1	37,350	38.6
Kilifi	12,246	8,536	40.0
Kwale	8,270	8,354	44.6
Tana River	35,376	3,260	36.2
Mombasa	294.7	3,771	49.1
Total	**62,459.8**	**61,271**	

Table 3: Extent and Distribution of Mangroves in Kenya Source: National Mangrove Ecosystem Plan (2017-2027)

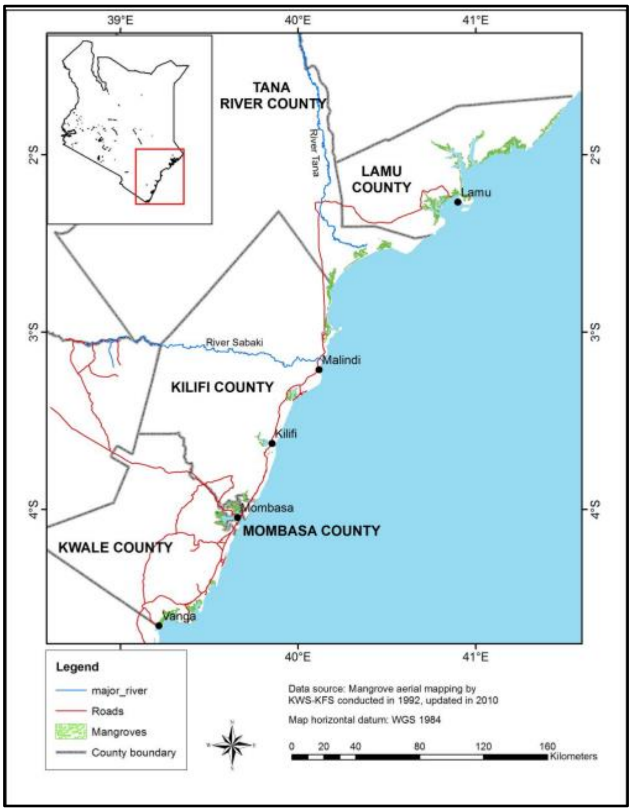


Figure 1: The Distribution of Mangrove forests in Kenya Source: National Mangrove Ecosystem Plan (2017-2027)

There are nine mangrove species in Kenya (Kairo et al. 2001). *Rhizophora mucronata Lam.* and *Ceriops tagal* (Perr.) C.B. Rob. are prevalent species found in nearly all mangrove formations, indicating their dominance. *Heritiera littoralis* and *Xylocarpus moluccensis* are rare species within the mangroves of Kenya. Moreover, the distribution of mangrove species in Kenya exhibits a horizontal pattern or zonation, primarily influenced by factors such as inundation levels, geomorphology, and salinity. Alongside mangrove trees, other plant species associated with the ecosystem include *Acrostichum aureum*, which commonly occupies degraded areas, *Sesuvium portulacastrum*, a fleshy herb often found in elevated sandy regions, and Salicornia spp., as well as various types of grass, rushes, and sedges (National Mangrove Ecosystem Plan 2017-2027; Kairo et al. 2001).

Other species found in the mangrove ecosystem include *Vigna marina*, *Juncus* sp., and Athrocnemum sp., which are present in the higher shore areas devoid of vegetation. Various epiphytes, such as ferns, orchids, lichens, and mistletoe, can be found on the mangrove trees. Seagrasses and epiphytic algae are found in patches on the submerged mangrove floor, creeks, and sub-tidal areas adjacent to the mangroves. These plants play a crucial role in stabilizing sediment, providing habitats for sessile organisms, and serving as a source of food and shelter for numerous marine species. The county-specific species formations and their respective percentage cover per formation in Kenya are outlined in Table 4. Tana River County exhibits the largest single species formation, accounting for 87% of *Avicenia* sp.

County	Main species formation	% cover
Lamu	*Rhizophora sp. mix*	23.2
Kilifi	*Avicenia sp.*	31.8
Kwale	*Ceriops sp. mix*	40.0
Tana River	*Avicenia sp.*	87.0
Mombasa	*Ceriops-Rhizophora sp.*	45.9

Table 4: Mangrove Formations Source: Multiple sources

Mangroves support a rich fauna diversity thanks to abundant food resources and various microhabitats such as soil surface, tidal pools, tree roots, trunks, and canopies (Kairo et al., 2008). It includes a range of phyla in Kenya, from protozoa to mammals, with prominent groups being molluscs, crustaceans, fish, and birds (National Mangrove Ecosystem Plan 2017-2027). Crustaceans, particularly crab families like Grapsidae, Ocypodidae, Portunidae, Xanthidae, and Gecarcinidae, play a significant role among the epifauna in Kenya's mangroves. Migratory birds, including wading birds, shorebirds, diving birds, birds of prey, and arboreal birds, visit the mangrove forests during winter. (National Mangrove Ecosystem Plan 2017-2027)

3.2. Stakeholders involved in mangrove management

To promote sustainable management practices, the mangrove forest areas in Kenya were designated as government reserve forests through the Proclamation

No. 44 of 30th April 1932 and later reinforced by Legal Notice No. 174 of 20th May 1964. The "Gazette Notification for Mangrove Forests in Kenya" classifies the land between high water and low water marks (ordinary spring tides) as mangrove areas. The responsibility for the management of mangroves lies with the Kenya Forest Service, either independently or in collaboration with the Kenya Wildlife Service (KWS), when they are located within Marine Protected Areas (MPAs).

3.3. Key challenges and threats

Mangroves in Kenya provide essential services but face threats from human and natural factors. The country has experienced significant loss and degradation, particularly in peri-urban areas like Mombasa. The development of infrastructure, such as the Lamu port, poses potential environmental risks to mangroves. (Karanja & Saito 2018; Hanshi 2017). In particular, for Mombasa, which is a city county, the Mombasa Port Area Road Development Project (MPARD) poses a threat to valuable mangrove ecosystems. To mitigate this, a compensatory planting of 64 ha of mangroves is proposed. Table 5 highlights the county-specific benefits and threats to the sustainable management of mangrove resources in Kenya.

County	Benefits	Threats and Challenges
Lamu	Construction poles, fuelwood, fish production, coastal protection, beekeeping	Illegal harvesting of wood products, pollution from oil spills, overexploitation, coastal infrastructure development, and sedimentation (Abuodha &Kairo 2001).
Kilifi	Fuelwood, construction poles, fish production, shoreline protection (Karanja & Saito 2018), tourism	Illegal harvesting, climate change, soil erosion, encroachment, pollution
Kwale	Fish production, construction poles, firewood, air purification, shoreline protection	Illegal harvesting, conversion to rice farms, climate change, destructive fishing methods, strong ocean winds
Tana River	Construction poles, fishing, fuelwood, medicinal, tourism	Illegal cutting, climate change-induced flooding, sea level rise, sedimentation, encroachment, dams upstream
Mombasa	Construction poles, Fish production, fuelwood, coastal protection against erosion (Karanja & Saito 2018), climate change mitigation (Karanja & Saito 2018)	Illegal harvesting/ uncontrolled cutting for domestic use, pollution from oil waste, sedimentation, encroachment, and climate change (Abuodha &Kairo 2001).

Table 5: Mangrove utilization trends, challenges, and threats (Source: Multiple sources)

3.4 Improving the management of mangrove resources

County analyses provide good information that could be used to improve the management of mangroves in Kenya. The National Mangrove Ecosystem Plan highlights the need for improved community engagement, institutional capacity, awareness, and enforcement of regulations. Collaborative efforts between KFS, local communities, CFAs, PFMPs, and FMAs are crucial for effective mangrove conservation. (Abuodha & Kairo 2001; Mwamuye et al., 2021). Table 6 shows the suggested ways of improving the sustainable management of mangrove resources in the country.

County	Actions for improving management of mangroves
Lamu	Enforce licensing regulations to prevent over-harvesting, initiate reforestation programs for degraded areas, empower adjacent communities to form CFAs, and implement harvesting plans for sustainable mangrove management in Lamu. (Mwamuye et. al. 2021).
Kilifi	rehabilitating degraded mangrove areas in collaboration with communities and stakeholders, enforcing laws through surveillance and patrols, conducting regular monitoring, promoting sustainable farming practices, using spatial planning to designate development areas without encroaching on mangroves, and empowering communities through the formation and strengthening of Community Forest Associations (CFAs) for effective mangrove management.
Kwale	Promoting community involvement in managing mangrove areas, establishing a seed bank on Sii Island, restoring degraded mangroves, enforcing legislation against agricultural encroachment, building local capacity for sustainable mangrove forest management, promoting payment for ecosystem services (PES) schemes, and researching the connectivity of transboundary mangroves at Vanga. (Mwamuye et. al. 2021).
Tana River	Initiative tree-based livelihood options on lands situated outside mangrove sites and promote programmes that help in the adaptation of climate change effects.
Mombasa	The empowerment of Community Forest Associations (CFA) for mangrove conservation through training, study tours, and financing for implementing the Participatory Forest Management Plan (PFMP) (Mwamuye et al. 2021).

Table 6: Strategies for improving the conservation of mangroves Source: Multiple sources

The blue economy's emphasis on conservation has led to effective adopt-a-forest partnerships, transforming mangrove conservation with promising outcomes. For instance, the ongoing *Mikoko Pamoja* project, an innovative carbon credit, and PES scheme in Gazi Bay, Kilifi County, has shown that a local mangrove conservation scheme can have positive, sustainable development impacts by way of protecting threatened ecosystems and improving the livelihoods of local community members. Gazi Bay, Kenya's residents lost 20% of their mangrove forests in 2010. They partnered with Plan Vivo and ACES to launch a conservation project. The project now protects 117 ha of mangroves with full-time guards and involves community members in regular reforestation efforts. The *Mikoko Pamoja* project generates income for Gazi and Makongeni communities by selling carbon credits from avoided CO_2 emissions. Payments from the sale of credits funded a project manager, guards, and community initiatives like purchasing books and installing clean water pumps at schools. The success of the *Mikoko Pamoja* project is attributed to the active involvement and support of Gazi and Makongeni residents. Transparent plans were agreed upon, addressing land use and revenue generation. Negative impacts were mitigated by planting pine trees as alternative building materials for the community.

4. Discussion

Mangrove forests in Kenya span an area of approximately 62,459.8 hectares, accounting for roughly 3.0% of the overall natural forest cover or less than 1.0% of the country's total land area (Table 3). The majority of mangroves, constituting about 59%, are found in Lamu County. Within Kenya, nine distinct species of mangroves exist, with Rhizophora mucronata Lam. and Ceriops tagal (Perr.) C.B. Rob. being the dominant species (National Mangrove Ecosystem Plan 2017-2027; Kairo et al. 2001).

Results also show that these critical ecosystems are still confronted with severe threats stemming from deforestation and degradation. The fundamental causes of mangrove loss and transformations are escalating population growth, deficient governance, inadequate appreciation of the true value of mangrove ecosystems, substantial poverty levels, absence of alternative livelihood options, and inadequate management guidelines. At the county level, there are unique challenges and threats, such as sedimentation, overexploitation, destructive fishing methods, pollution, changes in land use, and encroachment (Table 5). These threats appear to be causing repercussions on fisheries, shoreline stability, and the long-term sustainability of mangrove resources.

Nevertheless, there is a growing recognition of the ecological and socio-economic value of mangrove forests and the opportunities for local and national economic progress. The rich flora and fauna resources associated with mangroves provide essential ecosystem services needed for human well-being (Table 5). Reviewed literature has also agreed with these findings and has highlighted the provisioning, regulating, supporting, and cultural benefits of mangrove resources (Howard et al. 2019; Biwas & Biwas 2019; Salampessy et al. 2015; National Mangrove Ecosystem Management Plan 2017-2027; Mwamuye et al. 2021). Therefore, it is imperative to safeguard and preserve them. Kenya appears to be committed to this course in view of the established favorable policy and legal environment for sustainable conservation and management of mangrove resources. From Table 2, the Constitution of Kenya, 2010 provides for the need to conserve ecologically sensitive areas in the country, amongst them mangrove sites. Other policy documents such as the Vision 2030, the Forest Conservation and Management Act, 2016, the Wildlife Conservation and Management Act, 2013, and the Environmental Management and Coordination Act, 1999 contain provisions that promote the sustainable management of mangrove resources.

However, the most overt indication of the government's commitment to the sustainable conservation of mangrove resources is the development of the objective-led National Mangrove Ecosystem Management Plan (2017-2027). The plan encompasses six distinct programs addressing various aspects of mangrove conservation and management in Kenya. These programs include forest conservation and utilization, fisheries development and management, community engagement, tourism development, research and education, and human resources and operations. Each program outlines specific measures and actions to be taken for the rehabilitation, conservation, and sustainable management of mangrove ecosystems throughout the country. The responsibility for implementing this plan lies primarily with the Kenya Forest Service (KFS). However, other important stakeholders, such as the Kenya Wildlife Service, the State Department of Fisheries, research institutions, academia, and community forest associations, will also play significant roles. To ensure effective coordination and collaboration among these entities, a National Mangrove Advisory Committee will be specially constituted, facilitating collective decision-making and sharing expertise and resources. By implementing the plan, Kenya aims to address the challenges faced by mangrove ecosystems and pave the way for their long-term conservation and sustainable use. The involvement of multiple key actors and the establishment of a dedicated advisory committee signifies the commitment to collaborative efforts and a multi-faceted approach toward preserving and managing mangroves.

The multi-stakeholder approach outlined in the National Mangrove Ecosystem Management Plan (2017-2027) has also been highly lauded as a feasible approach to combating the loss of mangrove forest resources in recent studies conducted in the coast region of Kenya (Abuodha &Kairo 2001; Hanshi (2017); Karanja & Saito (2018); Mwamuye et al. 2021; Olago et al. (2023); Table 6). Reviewed global literature on other countries' cases, such as the Philippines, Vietnam, Ecuador, Brazil, Ghana, and Mexico, also encourages this approach to the sustainable management of mangrove resources (Rotich et al. 2016; Mangora 2011; Bosire et al. 2008). Other strategies include establishing seedbanks, legislating against encroachment, establishing proper benefit-sharing mechanisms, enforcing regulations to prevent overharvesting of mangroves, promoting payment for ecosystem services (PES) schemes, and researching the connectivity of transboundary mangroves at Vanga and other coastal regions (Table 6; Mwamuye et al. 2021).

However, in the author's opinion, the promotion of an incentives approach such as PES schemes, an economical approach where individuals or organizations receive financial incentives in exchange for implementing practices that protect and enhance ecosystem services, would yield a greater conservation impact. PES promotes the idea that those who benefit from ecosystem services provided by mangroves should financially support their conservation and restoration. There are already indications that the country could be moving in the PES direction because of the benefits of ongoing PES projects. A successful mangrove conservation project, the *Mikoko Pamoja* project in Gazi Bay, Kilifi County, espouses the aspirations of Kenya to be a hub of best practices in sustainable mangrove conservation and management. This project demonstrates the positive impacts of a local mangrove conservation scheme through carbon credits and PES. The project has protected 117 hectares of mangroves, engaged local communities, and generated income for community development. Project reviews indicate that the success of the *Mikoko Pamoja* project is attributed to the active involvement and support of Gazi and Makongeni residents, besides the implementation of mutually agreed upon transparent plans that addressed land use and revenue generation. There was also a comprehensive analysis of the socio-economic conditions of community stakeholders, which elicited the anticipated negative impacts of conserving the mangroves, which was then mitigated by planting pine trees on land parcels outside the mangrove sites for alternative building materials for the community, thereby easing pressure on mangroves. The provision of incentives is increasingly being practiced across the globe to promote the conservation of mangrove resources. Indonesia's Bio-right scheme exemplifies this assertion (van Eijk & Kumar 2009). However, caution should be exercised because most incentive programs require partnerships and cooperation among the institutions at the site level to support product marketing from up to downstream (Thu et al. 2019; Locatelli et al. 2014; Byran et al. 2020; Zaldívar-Jiménez et al. 2017; Aheto et al. 2016).

The highlighted conservation actions and impacts from *Mikoko Pamoja* Project and similar initiatives could immensely contribute directly to the achievement of Kenya's commitments to achieving the Constitutional target of maintaining a national tree cover of at least 10% by the year 2030 and global commitments such as the Global climate change mitigation and adaptation under the Paris Climate change Agreement aimed at lowering GHG emissions by 32% by 2030 and commitments to Kenya's quest to restore 5.1 million hectares of forest and degraded landscapes which formed part of the African Forest Landscape Restoration Initiative (AFRI100) target and NDC target of reducing greenhouse gasses emission by 32% by 2030 relative to a business-as-usual scenario.

In summary, from the foregoing discussion, mangroves are critical national assets. However, changes in Kenya's socio-economic conditions occasioned by unsustainable harvest, climate change, and infrastructural development negatively impact this critical resource. In order to improve the management of mangrove resources, there is a need for enhanced community engagement, institutional capacity, awareness, and enforcement of regulations. Collaborative efforts between the Kenya Forest Service (KFS), local communities, Community Forest Associations (CFAs), Protected Forest Management Plans (PFMPs), and Forest Management Agreements (FMAs) are crucial. Specific strategies for each county include enforcing regulations, initiating reforestation programs, rehabilitating degraded areas, empowering communities, promoting sustainable farming practices, conducting regular monitoring, and implementing payment for ecosystem services (PES) schemes.

5. Conclusion and Recommendations

Mangrove resources are critical national assets that promote Kenya's socio-economic development and environmental stability. Despite the threats posed by changes in socio-economic conditions that negatively impact the resource, the sustainable conservation and management of mangrove resources require that all management actions be geared towards enhancing the ecological, social and economic values derived from these resources.

Kenya has demonstrated an unwavering commitment to protecting and restoring the remaining mangrove resources by establishing a conducive legal and policy environment for restoration actions. It is thus the opinion of the authors that these conservation efforts should be supported by all stakeholders in order to ensure the sustainable conservation of mangrove resources. Even though challenges are still many based on the country-specific findings, several plausible strategies have been carried out for the management of the mangrove ecosystem in Kenya. These strategies include the development of the National Mangrove Ecosystem Management Plan (2017-2027) as an objective-led instrument for giving effect to collaborative management of mangrove resources, enhancing the enforcement of laws, establishment of seedbanks and promoting community livelihoods through PES schemes such as the *Mikoko Pamoja* Project. Nevertheless, there is a need for increased multidisciplinary collaboration in research and concrete initiatives focused on mangrove management. This is particularly crucial in tackling challenges related to climate change, equitable sharing of benefits, mangrove degradation, microbial diversity, pollution, and socio-economic concerns. In a nutshell, to safeguard mangrove habitats, conservation efforts include establishing protected areas, promoting sustainable resource use, engaging local communities, reforestation, pollution control, climate change adaptation, research, collaboration, policy support, and responsible tourism management. By implementing these desirable practices, Kenya can work towards the conservation and sustainable management of mangrove ecosystems, preserving their vital ecological roles and supporting the livelihoods of millions of people who depend on these valuable coastal habitats. However, one potential research limitation is that the study's reliance on the Google engine may affect the generalizability.

References

Abuodha, P. and Kairo, J. G. (2001). Human-induced stresses on mangrove swamps along Kenya coast. *Hydrobiologia*, 458: 255-265.

Africa Development Bank, (2022). Africa Economic Outlook; Kenya Economic Outlook. Recent macroeconomic and financial developments. 2022. https://www.afdb.org/en/countries-east-africa-kenya/kenya-economic-outlook

Aheto, D.W., Kankam, S., Okyere, I., Mensah, E., Osman, A., Jonah, F.E., Mensah, J.C. (2016) Community-Based Mangrove Forest Management: Implications for Local Livelihoods and Coastal Resource Conservation along the Volta Estuary Catchment Area of Ghana. *Ocean Coast. Manag.* 127, 43–54.

Alongi, D.M. (2009) *The Energetics of Mangrove Forests.* Springer: Dordrecht, The Netherlands.

Barnuevo, A., & Asaeda, T. (2018). Integrating the ecophysiology and biochemical stress indicators into the paradigm of mangrove ecology and a rehabilitation blueprint. *PLoS One*, *13*(8), e0202227.

Biswas, P.L.; Biswas, S.R. (2019) Mangrove Forests: Ecology, Management, and Threats. In Life on Land, Encyclopedia of the UN Sustainable Development Goals; Leal Filho, W., Azul, A.M., Brandli, L., Özuyar, P.G., Wall, T., Eds.; Springer International Publishing: Cham, Switzerland, pp. 1–14.

Bosire, J. O., Dahdouh-Guebas, F., Walton, M., Crona, B. I., Lewis III, R. R., Field, C., Kairo, J. G. and Koedam, N. (2008). Functionality of restored mangroves: a review. *Aquatic Botany*, 89: 251-259.

Branoff, B. L., & Martinuzzi, S. (2020). The structure and composition of Puerto Rico's urban mangroves. *Forests*, *11*(10), 1119.

Bryan-Brown, D.N., Connolly, R.M., Richards, D.R., Adame, F., Friess, D.A., Brown, C.J. (2020) Global Trends in Mangrove Forest Fragmentation. *Sci. Rep.* 10, 7117.

Constitution of Kenya (2010). Accessed at http://www.parliament.go.ke/sites/default/files/2017-05/The_Constitution_of_Kenya_2010.pdf

County Government Act (2012). Accessed at http://www.parliament.go.ke/sites/default/files/2017-05/CountyGovernmentsAct_No17of2012_1.pdf

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature geoscience*, 4(5), 293-297.

Doute, R. N., Ochanda, N. and Epp, H. (1981). *A forest inventory using remote sensing technique. Technical Report*. Kenya Rangelands Ecological Monitoring Unit, Department of Remote Sensing, Nairobi. Series No. 30.

Duke, N.C., Meynecke, J.-O., Dittmann, S., Ellison, A.M., Anger, K., Berger, U., Marcha, C., Diele, K., Ewel, K.C., Field, C., et al. (2007) A World Without Mangroves? *Science* 317, 41–42.

Ellison, A. M. (2000). Mangrove restoration: do we know enough? *Restoration ecology*, *8*(3), 219-229.

Environmental Management and Coordination Act, (1999).Accessed at http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/EnvironmentalManagementandCo-ordinationAct_No8of1999.pdf

FAO (2022a). "The State of the World's Forests" (SOFO) 2022 Report. Forest Pathways for Green Recovery and Building Inclusive, Resilient and Sustainable Economies. Rome 2022.

FAO (2022b). The Forest and Landscape Restoration Mechanism. https://www.fao.org/inaction/forest-landscape-restorationmechanism/background/approach/en/

FAO. (2015). Current Status of Forestry Sector and the Vision for the Year 2020. Accessed July 2015. www.fao.org: http://www.fao.org/docrep/003/ab569e/AB569E04.htm).

Fistrek, Z., & Bergman, A. K. (2010). Why should we be "Greening the Coast"? A case study of mangrove restoration in South-West Bay of Bengal. *International Masters Dissertation, Lund University, Sweden*.

Forest Conservation and Management Act (2016). Accessed at http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/2016/No._34_of_2016.pdf

Forest Policy (2015). Accessed at https://eawildlife.org/resources/reports/Forests_Conservation_and_Management_Policy-2015.pdf

Friess, D. A., Thompson, B. S., Brown, B., Amir, A. A., Cameron, C., Koldewey, H. J., et al. (2016). Policy challenges and approaches for the conservation of mangrove forests in Southeast Asia. *Conservation Biology*, *30*(5), 933-949.

Giesen, W., Wulfrrat, S., Zieren, M., Schoten, L. (2007) *Mangrove Guidebook for Southeast Asia.* Dharmasarn Co., Ltd.: Bangkok, Thailand, 2007.

Global Forest Resource Assessment Report (2020). Accessed at https://www.fao.org/forest-resources-assessment/2020/en/

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global change biology*, 26(10), 5844-5855.

Government of the Republic of Kenya, (2007). *Kenya Vision 2030. The popular version*. Accessed at https://vision2030.go.ke/publication/kenya-vision-2030-popular-version/

Hanshi, N. (2017). *An Analysis Of Local Dynamics In Conflicts Over Use Of Natural Resources In The Tana Delta Region, Tana River County, Kenya*. Doctoral dissertation, University of Nairobi.

Hanson, C., Buckingham, K., DeWitt, S. & Laestadius, L., (2015). *The restoration diagnostic*. The World Resources Institute, Washington, DC.

Hochard, J. P., Hamilton, S., & Barbier, E. B. (2019). Mangroves shelter coastal economic activity from cyclones. *Proceedings of the National Academy of Sciences*, 116(25), 12232-12237.

Jia, M., Wang, Z., Mao, D., Ren, C., Song, K., Zhao, C., Wang, C., Xiao, X. and Wang, Y. (2023). Mapping global distribution of mangrove forests at 10-m resolution. *Sci. Bulletin* 68(12), 1306-1316.

Jusoff, K., & Taha, D. (2008). Managing sustainable mangrove forests in Peninsular Malaysia. *Journal of Sustainable Development*, *1*(1), 88-96.

Kairo, J. G., Dahdouh-Guebas, F., Bosire, J. and Koedam, N. (2001). Restoration and management of mangrove systems - a lesson for and from the East African region. *South African Journal of Botany*, 67: 383-389.

Kairo, J. G., Lang'at, J. K. S., Dahdouh-Guebas, F., Bosire, J. O. and Karachi, M. (2008). Structural development and productivity of replanted mangrove plantations in Kenya. *Forest Ecology and Management,* 255: 2670-2677.

Kamali, B., & Hashim, R. (2011). Mangrove restoration without planting. *Ecological Engineering*, *37*(2), 387-391.

Karanja, J. M., & Saito, O. (2018). Cost–benefit analysis of mangrove ecosystems in flood risk reduction: a case study of the Tana Delta, Kenya. *Sustainability Science*, 13, 503-516.

Kathiresan, K., Bingham, B.L. (2001) Biology of Mangroves and Mangrove Ecosystems. *Adv. Mar. Biol.* 40, 81–251.

Kauffman, J.B., Donato, D.C. (2012) *Protocols for the Measurement, Monitoring and Reporting of Structure, Biomass and Carbon Stocks in Mangrove Forests*. Cifor: Bogor, Indonesia.

KFS (2014). *KFS Kenya Forest Service Strategic Plan 2014 -2017*. KFS. Nairobi Kenya.

Khuyen, V. T. K., Le, D. V., Fischer, A. R., & Dornack, C. (2021). Comparison of microplastic pollution in beach sediment and seawater at UNESCO Can Gio Mangrove Biosphere Reserve. *Global Challenges*, 5(11), 2100044.

Kirui, B. Y. K., Huxham, M., Kairo, J. and Skov, M. (2008). Influence of species richness and environmental context on early survival of replanted mangroves at Gazi bay, Kenya. *Hydrobiologia* 603: 171-181.

Kivata, J. (2021). *Integration of Mobile Phone Communication Technology in the Sustainable Management of Mangrove Forest Cover in Kenya A Case of Lamu County* (Doctoral dissertation, Daystar University, School of Communication).

Klötzli, F., & Grootjans, A. P. (2001). Restoration of natural and semi-natural wetland systems in Central Europe: progress and predictability of developments. *Restoration ecology*, *9*(2), 209-219.

Kusmana, C. (2014). Distribution and Current Status of Mangrove Forests in Indonesia. In Faridah-Hanum, I., Latiff, A., Hakeem, K., Ozturk, M. (Eds). *Mangrove Ecosystems of Asia*, Springer, New York, NY. https://doi.org/10.1007/978-1-4614-8582-7_3

Lee, S. Y., Primavera, J. H., Dahdouh-Guebas, F., McKee, K., Bosire, J. O., Cannicci, S., et al. (2014). Ecological role and services of tropical mangrove ecosystems: a reassessment. *Global Ecology and Biogeography* 23(7), 726-743.

Locatelli, T., Binet, T., Kairo, J. G., King, L., Madden, S., Patenaude, G., et al. (2014). Turning the tide: how blue carbon and payments for ecosystem services (PES) might help save mangrove forests. *Ambio*, *43*, 981-995.

Macheru, J. (2023). Outward Foreign Direct Investments and Economic Growth: An Investigation of Kenya. *International Journal of Poverty, Investment and Development*, *3*(1), 1-11.

Mangora, M. M. (2011). Poverty and institutional management stand-off: a restoration and conservation dilemma for mangrove forests of Tanzania. *Wetlands Ecology and Management*, *19*, 533-543.

Martinuzzi, S., Gould, W. A., Lugo, A. E., & Medina, E. (2009). Conversion and recovery of Puerto Rican mangroves: 200 years of change. *Forest Ecology and Management 257*(1), 75-84.

McSherry, M., Davis, R.P., Andradi-Brown, D.A., Ahmadia, G.N., Van Kempen, M. and Wingard Brian, S. (2023). Integrated mangrove aquaculture: The sustainable choice for mangroves and aquaculture? *Frontiers in Forests and Global Change*, 6, 1-8. https://doi.org/10.3389/ffgc.2023.1094306

MEF Ministry of Environment and Forestry (2018). *Taskforce Report on Forest Resources Management and Logging Activities in Kenya* (April 2018).

Millennium Aassessment Board (2005). Millennium ecosystem assessment. Information to conserve ecosystems and enhance human-well being: https://www.pik-potsdam.de/avec/peyresq2003/talks/0924/zurek/background_literature/ma_overview_2-pager_june_2003.pdf Accessed 30 Jul 2023.

Mwamuye, E. S., Chongomwa, M. M., Rayment, M., & Nadir, S. (2021). Multi-Stakeholder Approach in Natural Resources Management: The Case of Mida Creek and Gongoni-Marereni Mangrove Ecosystems in Kilifi County, Kenya. *Asian Journal of Environment & Ecology*, *16*(4), 171-180.

Naidoo, G. (2023). The mangroves of Africa: A review. *Marine Pollution Bulletin*, *190*, 114859.

National Mangrove Ecosystem Management Plan (2017-2027). Accessed at https://www.fao.org/forestry/energy/catalogue/search/detail/en/c/1415935/

Nellemann, C., & Corcoran, E. (Eds.). (2009). *Blue carbon: the role of healthy oceans in binding carbon: a rapid response assessment*. UNEP/Earthprint.

Ngongolo, K., Mtoka, S., & Mahulu, A. (2015). Challenges and opportunities for restoring the threatened mangroves. *Journal of Scientific Research and Reports*, *5*(5), 352-360.

Njenga, S., Olago, D., Kituyi, E. and Médard, C., (2023). Impact of climate change on mangrove dependent livelihoods through climate justice lens in Lamu County, Kenya. *Earth ArXiv*. https://doi.org/10.31223/X5DM23

Rotich, B., Mwangi, E., & Lawry, S. (2016). Where Land Meets the Sea: A Global Review of the Governance and Tenure Dimensions of Coastal Mangrove Forests-Report Brief.

Salampessy, M.L., Febryano, I.G., Martin, E., Siahaya, M.E., Papilaya, R. Cultural Capital of the Communities in the Mangrove Conservation in the Coastal Areas of Ambon Dalam Bay, Moluccas, Indonesia. *Procedia Environ. Sci.* 2015, 23, 222–229.

Sasmito, S. D., Sillanpää, M., Hayes, M. A., Bachri, S., Saragi-Sasmito, M. F., Sidik, F., et al. (2020). Mangrove blue carbon stocks and dynamics are controlled by hydrogeomorphic settings and land-use change. *Global Change Biology 26*(5), 3028-3039.

Spalding, M., & Parrett, C. L. (2019). Global patterns in mangrove recreation and tourism. *Marine Policy* 110, 103540.

Suman, D.O., (2019). Mangrove Management: Challenges and Guidelines. In *Coastal Wetlands (Second Edition)*. Gerardo M.E. Perillo, E. Wolanski, D.R. Cahoon, and C.S. Hopkinson (Eds.). Elsvier, Amsterdam, Netherlands: pp. 1055-1079.

Thu, P., Tan, T. V., Pham, P., Chien, D., Le Huyen, D., Nguyen, T., et al. (2019). Opportunities and challenges for mangrove management in Vietnam. *Center for International Forestry Research: Bogor, Indonesia*.

van Eijk, P. and Kumar, R. (2009). *Bio-Rights in Theory and Practice: A Financing Mechanism for Linking Poverty Alleviation and Environmental Conservation*. Wetlands International, Wageningen, Netherlands.

Vo, Q. T., Künzer, C., Vo, Q. M., Moder, F., & Oppelt, N. (2012). Review of valuation methods for mangrove ecosystem services. *Ecological indicators* 23, 431-446.

Waltham, N.J., Elliott, M., Lee, S.Y., Lovelock, C., Duarte, C.M., Buelow, C., Simenstad, C., Nagelkerken, I., Claassens, L., Wen, C.K. and Barletta, M., (2020). UN decade on ecosystem restoration 2021–2030—what chance for success in restoring coastal ecosystems? *Front. Mar. Sci.* 7(71), 1-5.

Wanjiru, A., Mwamba, J., Huxham, M., Shilland, R., and Ruzowitsky, L. (2019). 2018-2019 Plan Vivo Annual Report Mikoko Pamoja. https://www.clevel.co.uk/wp-content/uploads/2020/11/Mikoko_Pamoja_2019_annual_report.pdf Accessed 30 Jul 2023.

Wildlife Conservation and Management Act, (2013). Accessed at http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/WildlifeConservationandManagement%20Act2013.pdf

World Bank (2022). *Kenya's Economic Outlook and the World Bank's supports the government's Vision 2030 development strategy*. https://www.worldbank.org/en/country/kenya/overview

Zaldívar-Jiménez, A., Ladrón-de-Guevara-Porras, P., Pérez-Ceballos, R., Díaz-Mondragón, S., Rosado-Solórzano, R. (2017) US-Mexico Joint Gulf of Mexico Large Marine Ecosystem Based Assessment and Management: Experience in Community Involvement and Mangrove Wetland Restoration in Términos Lagoon, Mexico. *Environ. Dev.* 22, 206–213.

Authors

Sylvester Chisika,
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea;
sylvesterchizika@gmail.com

Chunho Yeom (*corresponding author*),
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea;
chunhoy7@uos.ac.kr

Funds

This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2020S1A5C2A01092978).

Competing Interests

The author hereby state that there are no financial or non-financial competing interests.

Citation

Chisika, S., Yeom, C. (2023) The challenges of sustainable conservation and management of mangrove forests in Kenya. *Visions for Sustainability*, 20, 7693, 99-126.
http://dx.doi.org/10.13135/2384-8677/7693

Original Paper

Public perception on the role of Artificial Intelligence in the sustainable management of tree and forest resources in Kenya

Sylvester Chisika, Juneyoung Park, Chunho Yeom

Received: 8 August 2023 | **Accepted:** 19 September 2023 | **Published:** 9 October 2023

Keywords: Sustainable Forest management; AI technologies; tree and forest resources; sustainability; real-time monitoring.

Abstract. *There is a scarcity of information on the role of Artificial Intelligence (AI) in enhancing sustainable forest management worldwide. Using a literature review, this study explores the case of Kenya, with the aim of contributing to a better understanding of the strategies needed to promote the role of AI in the development and sustainability of forests. Results reveal that AI deployment in forestry is still in the infancy stages. The country has some AI technologies in use to promote forest management. Moreover, both public and private, local, and international organizations are actively involved in developing AI applications for forestry to consider the social, economic, and environmental facets of sustainable forest management. Additionally, no studies have been conducted on the public perception and opinions regarding the use and role of AI in sustainable forest management in Kenya. These study findings pose the risk of limited progress, technological gaps, and uncertain impacts on key green infrastructure development priorities; for example, the achievement of 30% tree cover by 2032 and a host of international development obligations, as well as the continued misunderstanding regarding public perceptions of AI deployment in forestry. There is thus an urgent need for accelerating AI research and development in forestry, fostering collaboration between public and private sectors, conducting studies on public perceptions, and ensuring ethical and sustainable AI implementation.*

1. Introduction

With the continuous decline in biodiversity and ecosystems worldwide, safeguarding and revitalizing natural habitats, including forests, through technology deployment are becoming crucial for the survival of humanity (Chen et al., 2023; IPBES, 2019; Walder, 2018). Trees and forested ecosystems constitute a significant land-cover category worldwide. They play a crucial role in offering numerous ecosystem services to billions of people (Çolak et al., 2018;

Hua et al., 2022; Pan et al., 2013; Brockerhoff et al., 2017). In response, the United Nations has declared the "Decade on Restoration" from 2021 to 2030 (United Nations Environment Agency (UNEA), 2019). However, the global forest cover and ecosystems continues to diminish (Curtis et al., 2018; Estoque et al., 2022). Among other reasons, forest decline is driven by shifts in land use toward agriculture, unsustainable forest management practices, urbanization, mining activities, climate change, and wildfires (Taubert et al., 2018; Zerbe, 2022 & 2023; Keenan, 2015). To address these challenges, many countries have initiated ambitious ecological restoration efforts, with the overall objective of rehabilitating and restoring the structure and function of degraded trees and forest ecosystems. Unfortunately, there is limited monitoring of restored trees and forested landscapes, resulting in a limited understanding of the benefits, impacts, and successes of restoration activities (DeLuca et al., 2010). Consequently, there are mixed perceptions of the impact of tree and forest conservation and management interventions towards sustainable forest management (DeLuca et al., 2010).

Artificial Intelligence (AI) is becoming increasingly important in forest management. AI facilitates the real-time monitoring of forest health, helps predict and prevent threats such as wildfires and illegal logging, optimizes resource allocation, and enhances data-driven decision-making for conservation efforts. The application of AI contributes to sustainable forest management by preserving and effectively utilizing forest ecosystems. However, few studies have explored people's perceptions of the role of AI in sustainable forest management in many developing countries. Public perceptions can evolve as new developments occur. Moreover, public opinion can vary significantly depending on the region, cultural context, and the specific applications of AI in forest management. As AI continues to advance and become more integrated into various industries, ongoing dialogue and education regarding its benefits and challenges will be crucial in shaping its role in sustainable tree and forest resource management.

In Kenya, the forestry sector has evolved over the years, with increasing conservation activities. Efforts towards afforestation, reforestation, and restoration have been tremendously amplified as various forest sector actors take the lead in landscape and ecosystem restoration activities. Although these efforts have been effective in ensuring sustainable forest management, the use of technology is rapidly gaining global attention. The country has drafted a 10-year strategy that seeks to accelerate actions towards achieving 30% national tree cover by 2032, with the aim of enhancing climate-reliant national economic growth and development goals within the context of Vision 2030 and contributing toward Kenya's commitments to regional and global conventions. To augment this strategic focus, recent technological developments have created new opportunities for forestry value chain development and the transformation of productivity and efficiency. However, there is a limited understanding of the public perception of AI's role in enhancing sustainable forest management. Limited public awareness of AI's potential benefits in forest management has led to missing opportunities for conservation. In literature, it is speculated that resistance, lack of support, ethical concerns, and misunderstandings hinder sustainable development and slow the adoption of AI solutions (Galaz et al. 2021) .

This study aims to address the lack of research on the perception of AI in Kenya using a literature review from the perspective of sustainable development by answering the following question: What are Kenyan citizens' attitudes and opinions towards the integration of AI technologies in the sustainable management of tree and forest resources? To effectively respond to the research question, unlike other studies, this paper will first review the global literature on the public's perceptions of the role of AI in sustainable forest management and then apply the lessons learned in Kenya's context for sustainable forest management and the application of AI to generate the policy implications of this study.

Kenya is an appropriate study site for investigating people's perceptions of AI in sustainable tree and forest management because of its rich biodiversity, ongoing challenges in conservation, and diverse socioeconomic contexts. Understanding public attitudes in this context can inform tailored strategies for effectively implementing AI technologies for sustainable forest management and community engagement.

2. Sustainable Forest Management and AI

Sustainable forest management involves balancing ecological, social, and economic factors of forest management in order to meet current needs without compromising the needs of future generations. In this regard, sustainable forest management requires careful data handling and monitoring, considering the diverse aspects of long-term viability, and resolving conflicting interests (Empig et al., 2023). The use of AI in forest conservation and management is emerging as a feasible way of offering a transformative solution for managing the complex data and procedures involved in sustainable forest management (Costa et al., 2023). AI refers to the simulation of human intelligence in machines, enabling them to perform tasks that typically require human intelligence, such as problem-solving, learning, reasoning, and decision-making. AI can be broadly categorized into narrow AI, which is designed for specific tasks, such as voice recognition or recommendation systems (e.g., Siri and Alexa), and general AI, which aims to possess human-like intelligence and handle a wide range of tasks, although still largely theoretical (Leal Filho et al., 2023). Machine learning is a prominent subset of AI in which algorithms learn patterns from data and improve performance over time. Examples of AI applications in other sectors include self-driving cars, natural language processing, virtual assistants, image and speech recognition, and personalized content recommendations on platforms such as Netflix and Spotify (Leal Filho et al., 2023).

AI is widely used in sustainable forest management, employing drones with remote sensing to monitor and map forests, assess tree health, detect deforestation risks, and estimate the carbon sequestration potential. Additionally, AI enhances carbon dioxide trapping processes and oversees storage locations, thereby ensuring secure underground carbon sequestration (Chen et al., 2023; Karmaoui, 2023). AI drones are employed with remote sensing to monitor and map forests, assess tree health, detect deforestation risks, and estimate the carbon sequestration potential(Liu et al. 2022b; Osman et al. 2022; Yang et al. 2022 & 2023). The use of AI in forestry can substantially enhance the efficiency and effectiveness (Cheong et al., 2022; Kaack et al., 2022). For example, AI has been used to develop ecological models to predict forest dynamics and climate impacts,monitor and predict forest fires for early mitigation,addressing climate change by enhancing the forecasting of severe weather occurrences (McGovern et al., 2017). Smart logging using AI optimizes sustainable harvesting and minimizes environmental impact. Furthermore, AI assists in selecting the appropriate tree species for reforestation. Moreover, public engagement and education benefit from interactive AI platforms and fosters collaboration and data-sharing among stakeholders to ensure effective forest management.

Costa et al. (2023) while measuring forest biomass found that by combining artificial neural networks with Landsat-5 imagery, accurate predictions with an estimation error of approximately 20% for AGB in tropical forests could be achieved. This methodological approach shows great promise and can be applied to assess ecosystem services related to carbon stock in tropical regions.

Through advanced algorithms and machine learning, AI can analyze vast amounts of ecological, social, and economic data in real time. It enables accurate and timely decision-making and the optimization of resource allocation and conservation efforts. AI-powered automation streamlines data collection, processing, and analysis, enhances efficiency, and reduces manual errors (Schmoldt, 2001; Amaral et al., 2021). AI-driven predictive models aid in proactive planning against threats such as deforestation and climate change. Nevertheless, integrating AI in sustainable forest management ensures the holistic preservation and cost-effective protection of global forests.

Utilizing AI-driven automation has several benefits over conventional forest management methods, such as enhanced effectiveness, greater precision, and decreased expenses (Kourtz, 1990; Peng & Wen, 1999; Imada, 2014; Kimsey et al., 2021; Jahani and Rayegani, 2020).

Benefit	AI Automated Forest Management	Conventional Forest Management
Efficiency	AI can rapidly process vast amounts of data, leading to quicker and more informed decision-making.	Manual data collection and analysis can be time-consuming and labor-intensive.
Accuracy	AI-powered algorithms can provide precise analyses, minimizing errors and improving accuracy.	Human errors in data collection and analysis can lead to inaccuracies in decision-making.
Cost	Long-term cost savings can be achieved due to optimized resource allocation and reduced manual work.	
Proactivity	AI enables proactive monitoring and prediction of potential threats, helping prevent issues in advance.	Reactive approaches may result in delayed response to potential threats such as deforestation.
Data management	AI can efficiently handle and analyze large datasets, improving data-driven decision-making.	Managing and analyzing complex data manually can be overwhelming and prone to errors.
Sustainability	AI can assist in optimizing forest use to maintain ecological balance and preserve biodiversity.	May face challenges in finding the right balance between ecological, social, and economic needs.

Table 1. AI automated forest management versus conventional forest management. Source: Author's compilation from Multiple sources

In recent years, empirical studies have shown that AI has revolutionized many sectors, including forestry. AI-driven advancements are reshaping forestry methods byenhancing their effectiveness, reducing costs, and promoting sustainability (Linares-Palomino and Alvarez, 2005; Bojorquez et al., 2020; Chave et al., 2014; Koukal et al., 2014; Asner et al., 2010). Unmanned Aerial Vehicle (UAV) technology has become prevalent in ecological and environmental monitoring (Casazza et al., 2019; Jiang et al., 2021; Johansen et al., 2019; Zhang et al., 2020). AI application has expanded notably in forest resource inventories, mainly because of the increased accessibility and availability of compact sensors (Ma et al., 2015; Qiu et al., 2018b; Hao et al., 2021; Hu et al., 2021b). Additionally, UAV photogrammetry has been widely applied in forest surveys in tropical regions (Popescu, 2007; Lechner et al., 2020; Dalla Corte et al., 2020; Ge et al., 2020; Rahman et al., 2020). Based on this review, AI application is particularly prominent in forest management.

2.1. Public Perception on the Role of AI in Sustainable Forest Management

As AI technologies proliferate, public perception of the role of AI in sustainable forest management is rapidly emerging as a topic of interest and debate. On the one hand, there is a growing sense of optimism regarding the potential of AI technologies to revolutionize forest conservation efforts. Many people believe that AI's data processing capabilities can lead to more informed decision-making, enhanced forest monitoring, and proactive measures to combat deforestation and other environmental threats.

On the other hand,public concerns about AI in environmental and forestry decision-making include ethical implications and fear of job displacement. There are also concerns regarding data privacy and the concentration of power in technology companies developing AI solutions. These concerns arise from recent studies, such as that by Wach et al. (2023), which explored the dark side of generative AI by highlighting its ethical implications, job displacement, data privacy, and concentration of power in AI technology companies.

A survey of registered foresters in five U.S. states revealed that 50% of non-industrial private landowners do not use digital forestry tools, whereas approximately 80% of organization-employed foresters do. Geographic information systems technology was the most crucial tool, followed by inventory systems, databases, and field-ready smartphone applications. Foresters who did not use digital tools cited perceived usefulness for property management and a lack of awareness of available options as reasons for not adopting them (Bettinger et al., 2023). Therefore, analyzing the public perception of AI systems in the forestry sector across different countries or continents provides valuable insights into how technology is embraced, accepted, or resisted in various cultural and environmental contexts. In North America, public perception of AI in forestry is generally positive. AI-powered tools for monitoring and managing forests, such as drones and remote sensing, are crucial for efficient forest management and wildfire prevention. Public-private partnerships often play a role in advancing AI adoption in the sector. In Finland and Sweden there is a strong tradition of forestry but public perception on forestry AI is mixed (McQueen 2019). In China, AI is increasingly being used for forest monitoring and wildlife conservation. Public perception varies; some view it as a tool for environmental protection, while others worry about privacy and data security issues. In Japan has a strong tradition of forestry, and AI is being employed to enhance forest management and detect diseases. Public perception is generally positive, with a focus on preserving traditional practices while incorporating technology. In Australia, AI is used for fire management and forest monitoring, given the country's susceptibility to wildfires. Public perception is positive, with a focus on safety and environmental conservation (Silvestro et al. 2022; Liu et al. 20189; Shivaprakash et al. 2022). Vizard (2020) efound that dspite the perception that AI is more hype than reality right now, a wide majority of companies, including forestry companies are looking to more aggressive adoption of AI. The survey identified the biggest inhibitors of AI adoption to be a lack of understanding of capabilities (46%), lack of training (36%) and lack of initial investment funding (32%).From a general environmental security perspective, Francisco (2023) has found that a national discussion on climate security should focus on military applications of AI and its role in spreading propaganda and misinformation. Internationally, organizations and transnational companies use AI to achieve their goals; however, this has implications for consumption and resource extraction. Military AI collaboration may hinder environmental movements. Furthermore, AI can aid sustainable development but may lead to power imbalances. Ecologically, AI's impact on our perception of the environment and the potential alienation from other cosmologies and environmental effects is concerning. This analysis encourages further exploration of the interplay between AI, geopolitics, and environmental protection, including forest management.

While reviewing the literature on geo-technologies and AI as a tool for riparian forest management, da Silva Leite and Amorim (2021) established that AI-based geo-technologies play a vital role in managing natural resources and addressing society's urgent questions and demands. They offer various techniques and scientific approaches, enabling an understanding using location, dimensions, acquisition, and the processing of data. The findings revealed limited publications related to AI use, particularly in Portuguese. However, AI has demonstrated its significance in research along with remote sensing and GIS (Geographic Information System) software. Notably, the study revealed a research gap concerning the application of AI in studying riparian forest PPAs (Permanent Protection Areas) with geo-technologies, suggesting the need for future research in this area.

This paper advocates for the use of AI in forest management, but emphasizes the need for transparent communication, stakeholder collaboration, and proving conservation benefits for increased AI acceptance. Nonetheless, responsible and inclusive AI in forestry requires further research and regulations.

2.2. *The general development context for AI in Kenya*

Over the past decade, Kenya has implemented significant political and economic reforms that have contributed to sustained economic growth, social development, and political stability. From 2015 to 2019, Kenya's economy achieved broad-based growth, averaging 4.8% per year and significantly reducing poverty to 34.4% in 2019 (World Bank 2022). Kenya's economy is highly dependent on the country's natural resources. With over 84% of its land area classified as arid or semiarid, Kenya is exposed and highly vulnerable to extreme weather conditions. An average drought results in a 20–30% food deficit, slashes GDP growth by 3–5%, and affects the livelihoods of over 80% of the population (ADB, 2022). According to the Global Climate Change Risk Index (GCRI) of 2021, Kenya is ranked 25th and is most affected by extreme weather conditions and weather-related losses (ADB, 2022).

Youth unemployment and high poverty rates are the key challenges to Kenya's economic growth and development. The youth unemployment rate is 38.9%, with an estimated 800,000 young people entering the labor market every year and over 8.9 million in Kenya living below the poverty line. At a population growth rate of 2.7%, Kenya's population is projected to rise to 66.3 million by 2030. The increasing population presents a challenge for the sustainable utilization of forest resources and opportunities to expand farm forests. According to a 2014 study by the GATSBY Charitable Fund, Kenya's national wood deficit was estimated at 12 million M^3 in 2014 and is predicted to rise to as high as 34.4 million M^3 by 2030. Against this background, the new Kenya Kwanza administration's bottom-up economic model has prioritized accelerating the achievement of 30% national tree cover by 2032 for increased employment opportunities, improved livelihoods, climate change reliance, and enhanced Kenya's economic growth within the context of Vision 2030.

2.3. *Sustainable forest management in Kenya*

Trees and forests are important strategic national assets in Kenya because of their ecological and socioeconomic value. Kenya's forest sector contributes to the livelihood base for over 82% of Kenya's households through direct employment for over 750,000 Kenyans and indirect benefits to over 4 million citizens, accounting for approximately USD 365 million (3.5%) of the GDP (MEF 2018).

However, Kenya is a low forest cover country with less than the recommended minimum global standard of 10%. Over the years, the rapidly expanding population and conversion of forest land to agriculture have been the major drivers of forest cover loss. From 1990 to 2015, approximately 311,000 ha of forestland were converted into other land uses (FAO, 2015b). Weak governance, unsustainable exploitation, overreliance on forest products, forest fires, and the increasing adverse effects of climate change have further exacerbated the deforestation and degradation of forests in Kenya (FAO, 2022a; FAO, 2022b).

The National Forest Resource Assessment conducted in 2021 established Kenya's National Tree Cover at 12.13% and forest cover at 8.83% (KFS, 2022). During the launch of the National Forest Resources Assessment Report 2021, Kenya's President set a new national ambition to achieve 30% tree cover by 2050. However, on October 20, 2022, the President directed the acceleration and attainment of 30% tree cover by 2032. The goal of the strategy is to produce 15.9 billion quality seedlings in Public and Private Tree Nurseries by 2032, which will be achieved through increased high-quality seed production by KEFRI, , the KFS, other MDAs, and the private sector. Additionally, the strategy aims to raise the National Tree Cover by 17.8% (10,579,062.51 ha) by 2032, focusing on protecting, conserving, and restoring Public Natural Forest Reserves. It will enhance forest cover in Natural Forests outside reserves and commercial plantations and promote tree cover on farmlands (agroforestry), ASALs, schools, institutions, urban forests, green spaces, roads, highways, and infrastructure projects. Further, public education and awareness campaigns have intensified. Moreover, improved technologies for wood utilization, sustainable forest management, and strengthened forest governance will be key priorities achieved by enhancing the institutional capacities of the MEF, KFS, KWTA, and CoG for effective coordination and project implementation.

The Ministry of Environment and Forestry should bolster its coordination efforts and strengthen the capacity of relevant stakeholders, including SAGAs, MDAs, and county governments, to effectively implement, monitor, and report strategies. To achieve this, they will establish a National Coordination Committee and multi-institutional Technical Team with a Secretariat at the Ministry of Environment and Forestry, which will include representatives from government agencies, the Council of Governors, NGOs, the private sector, and development partners. Additionally, County Implementation Coordination Committees will be formed, co-chaired by County Commissioners and County Governments, with

Kenya Forest Service serving as the Secretary. Furthermore, sub-county-level coordination committees should be created to enhance coordination and collaboration at the local level.

To reduce its reliance on domestic forest products in key economic sectors, Kenya has positioned itself as a trading nation at the regional and global levels in forest products. Nevertheless, Kenya is committed to contributing to global climate change mitigation and adaptation through Nationally Determined Contributions (NDCs) as part of the UNFCCC, in line with the Paris Climate Change Agreement requirements aimed at lowering GHG emissions by 30% by 2030.

The Kenyan Constitution of 2010 recognizes the need to increase national tree cover by at least 10% by 2030. This development aspiration is also in line with Kenya's commitment to restore 5.1 million hectares of forest and degraded landscapes, which formed part of the African Forest Landscape Restoration Initiative (AFRI100) target and the NDC target of reducing greenhouse gas emissions by 32% by 2030, relative to a business-as-usual scenario.

2.4. AI application in sustainable forest management in Kenya

Forest management in Kenya involves various activities aimed at maintaining and optimizing forest ecosystem functions and processed. These include; planning, inventories, and silviculture practices such as planting and harvesting, fire prevention, pest and disease management, and ecological monitoring. Sustainable management includes community engagement, public education, and conservation efforts for a long-term environmental, social, and economic balance. To improve the execution of these activities, several AI applications for forest management have recently emerged in the country, aiding in promoting sustainable forest management. For example, tree species site matching (SSMT), the creation of Gatsby Africa, aids growers in choosing the most appropriate tree species for their specific location. By analyzing factors such as soil quality, rainfall, altitude, soil type, soil depth, and species performance, SSMT supports tree growers and investors in identifying the optimal tree species for their needs. This information is accessible online through Georeferenced PDF or ArcGIS, presenting the suitability level of a tree species for the chosen site, ranging from very suitable to not suitable (FSK, 2023).

KEFRIApp was introduced as a site-species-matching tool designed to aid tree growers in identifying the most suitable tree species for specific ecological zones. Accessible as a mobile platform, the application offers valuable guidance to users regarding the types of trees suitable for their desired areas. Moreover, the application furnishes tree growers with information on tree nursery locations and facilitate the real-time documentation of tree-planting activities. The app is available for download on the Google Play Store (FSK, 2023).

In collaboration with the National Centre for Earth Observation at the University of Leicester, the Kenya Forest Service (KFS) has jointly developed an advanced AI-based monitoring system to rapidly detect deforestation. This system sends alerts every five days using Copernicus Sentinel-2 images at 10m spatial resolution, enabling the identification of even minor forest cover changes and small-scale logging activities. Known as the Forest 2020 project, this system provides near-real-time alerts to forest rangers and managers, enabling prompt responses to identified regions. Satellite images were compared with previous data to verify changes, making them crucial for the effective monitoring of forest changes at both the regional and national levels. Additionally, the system helps the KFS keep track of tree cover across Kenya, serving as an early warning mechanism to combat threats such as illegal logging, human settlements, and wildfires, thereby halting further forest destruction (FSK, 2023).

Efficiency plays a crucial role in achieving sustainable forest management. One technology driving this effort is the Timbeter App, currently implemented within the Kenya Forest Service, which has the potential to revolutionize public plantation management. Utilizing AI and machine learning, the Timbeter App offers a digital timber measurement solution that ensures accurate log detection and aims to combat illegal logging while enhancing timber monitoring and supply through its unique algorithm. This application streamlines log inventory processes, reduces costs, and expedites round-wood measurements. With its user-friendly mobile platform, Timbeter provides services, such as inventory and measurements, replacing traditional paper-based methods. By adopting Timbeter, the forestry sector can enhance efficiency and transparency, thereby contributing to sustainable practices. The application is readily available for download on both the Google Play Store and Apple Store. The Ministry of Environmental Climate Change and Forestry has also developed the Jaza Miti App to collect and analyze tree-planting data in the country. It is aimed at tracking progress towards achieving 30% tree cover by 2032 (FSK, 2023).

3. Materials and Methods

3.1. Study Area

Kenya is located in East Africa and is known for its diverse wildlife, scenic landscapes, and vibrant culture. Its population is approximately 50 million people, with over 40 ethnic groups, each with unique languages, customs, and traditions. Kenya's capital city, Nairobi, serves as an economic and cultural hub. Kenya's geography is diverse, ranging from savannas to forests, mountain ranges, and coastal plains. It is home to some of the world's most famous wildlife reserves, including the Masai Mara National Reserve, which is known for its annual wildebeest migration, and Amboseli National Park, which is renowned for its large elephant herds. The country's coastline is dotted with pristine beaches, coral reefs, and marine parks, making it a popular destination for beach holidays and water sports enthusiasts. Kenya is one of the most developed countries in East Africa, with a GDP of approximately $100 billion (Macheru, 2023).

3.2. Data Collection

This study aims to address the lack of research on the perception of the role of AI in forest management in Kenya, using a literature review and document content analysis from the perspective of sustainable forest management. To effectively respond to these requirements, a systematic and comprehensive approach to document content analysis was adopted. The primary goal is to bridge the gap in research concerning the perception and understanding of AI technologies in Kenya's unique socioeconomic and cultural context. An extensive literature review was conducted to begin the data collection process, encompassing academic papers, policy documents, reports, and media articles pertaining to AI technologies and sustainable development in Kenya. This comprehensive review serves as a foundation for identifying the key themes, concepts, and patterns surrounding AI perceptions in the country. After identifying relevant documents, data were systematically extracted from the content.

The key documents consulted during the data collection process are listed in Table 2. These documents provide the overall context within which AI has been applied to forest management in Kenya. This research relied solely on document reviews as the source of data, largely because documents are reliable, easily accessible, and abundant, providing comprehensive insights and enabling researchers to efficiently analyze historical, scientific, and social phenomena.

Name of Document	Source	Key information sought
Constitution 2010	Internet	Provisions on the use of AI technology in environmental protection
Vision 2030	Internet	Whether AI technology is important for forests and is enshrined in long-term visions
Draft Forest Policy, 2020	Internet	Information on the use of AI in forest governance
Forest Conservation and Management Act, 2016	Internet	The institutions responsible for developing and applying AI in forest management
National Strategy for Achieving and Maintaining 10% Tree cover	Internet	Whether urban forests are enshrined in long-term visions
Kenya Information and Communications Act, 1998	Internet	Whether the Act supports the application of AI in various resource sectors
Kenya Science, Technology, and Innovation Act, 2013	Internet	Whether the Act supports the application of AI in various resource sectors

Table 2. Key documents Consulted

3.3. Data Analysis

The document content analysis data captured various dimensions of the role of AI in sustainable forest management, such as public attitudes towards AI, perceptions of AI's impact and role in sustainable development, potential ethical concerns, and policy recommendations. Figure 1 summarizes the analytical framework developed as a result of emerging themes from a literature review on public opinion on the role of AI in forest management, which was applied to Kenya to generate the policy implications of this study. As shown in Figure 1, AI plays a crucial role in sustainable forest management by enabling efficient data analysis, predictive modeling, and real-time monitoring. It aids in optimizing resource allocation, assessing biodiversity, detecting deforestation, supporting informed decision-making, and contributing to forest ecosystem preservation and responsible use for a sustainable future.

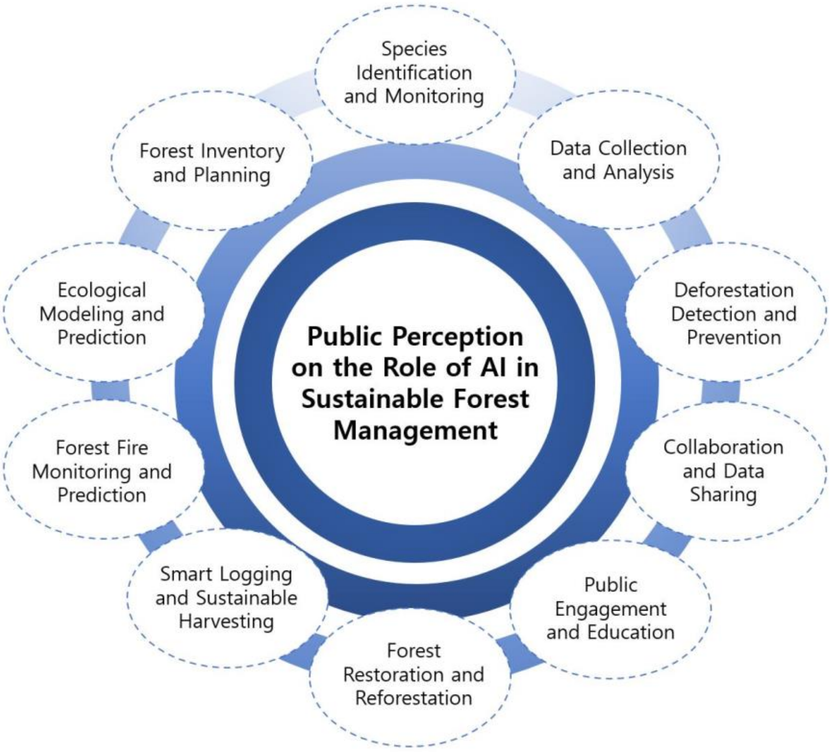


Figure 1. Analytical framework for public perception on the role of AI in forest management in Kenya

4. Results

4.1. The current status of AI applications in forest management

When the analytical framework for public opinion on AI technologies in Kenya's forest management is applied to the Kenyan context, the results show that the country has few AI technologies that are applied to promote sustainable forest management. Table 3 outlines the broad areas of sustainable forest management, the AI technology used, and the benefits achieved as a result of AI application. Both public and private, local, and international organizations are involved in the development of AI applications for forest management. The benefits and impacts of AI applications have affected the social, economic, and environmental aspects of sustainable forest management.

Broad Area of Sustainable Forest Management	AI Technology	Developer(s)	Benefits/role
Data Collection and Analysis	Jaza Miti App	Ministry of Environment Climate Change and Forestry	Collects and analyses tree planting data, tree species-site matching
Species Identification and Monitoring	Project 2020	National Centre for Earth Observation at the University of Leicester, Kenya Forest Service	Effective monitoring of forest changes, combat threats like illegal logging, human settlements, and wildfires,
Deforestation Detection and Prevention	Project 2020	National Centre for Earth Observation at the University of Leicester, Kenya Forest Service	Effective monitoring of forest changes, combat threats like illegal logging, human settlements, and wildfires,
Forest Inventory and Planning	Timbeter App	Kenya Forest Service	Improved efficiency, transparency, combat illegal logging, enhancing timber monitoring and supply
Ecological Modeling and Prediction	Project 2020	National Centre for Earth Observation at the University of Leicester, Kenya Forest Service	Effective monitoring of forest changes, combat threats like illegal logging, human settlements, and wildfires,
Forest Fire Monitoring and Prediction	Project 2020	National Centre for Earth Observation at the University of Leicester, Kenya Forest Service	Effective monitoring of forest changes, combat threats like illegal logging, human settlements, and wildfires,
Smart Logging and Sustainable Harvesting	Timbeter App	Kenya Forest Service	Improved efficiency, transparency, combat illegal logging, enhancing timber monitoring and supply
Forest Restoration and Reforestation	KEFRIApp, SSMT	Kenya Forestry Research Institute, Gatsby Africa	site-species matching, furnish information on tree nursery

Broad Area of Sustainable Forest Management	AI Technology	Developer(s)	Benefits/role
			locations and facilitate real-time documentation of tree planting activities
Public Engagement and Education	KEFRIApp, SSMT	Gatsby Africa and	site-species matching, furnish information on tree nursery locations and facilitate real-time documentation of tree planting activities
Collaboration and Data Sharing	Project 2020	National Centre for Earth Observation at the University of Leicester, Kenya Forest Service	Effective monitoring of forest changes, combat threats like illegal logging, human settlements, and wildfires,

Table 3: AI technologies for forest management in Kenya

4.2. The attitudes toward the integration of AI technologies in forest management

Studies on people's attitudes toward the integration of AI technologies in forest management are limited. Nevertheless, these attitudes in Kenya are gradually evolving, with a mix of optimism and cautiousness. While some stakeholders view AI as a potential game-changer for enhancing data-driven decision-making, optimizing resource allocation, and combating deforestation, others express concerns about its potential socioeconomic impacts and ethical implications. Education and awareness of the benefits and risks of AI play a vital role in shaping these attitudes. As more successful AI-driven initiatives are showcased, and tangible benefits become evident, the acceptance and adoption of AI in forest management is likely to increase, fostering sustainable practices and conservation efforts.

5. Discussion

Sustainable forest management requires a balance between the ecological, social, and economic factors of forestry development (Empig et al., 2023). However, in view of the complex and intricate data and processes involved, the use of technology, particularly AI, is emerging as a solution to this challenge (Costa et al., 2023). This study sought to explore the public perception of the use of AI in enhancing sustainable forest management by examining the Kenyan context against global studies using a literature review and document content analysis.

The results of applying the analytical framework to public opinion on AI technologies in Kenya's forest management (Figure 1) reveal that AI deployment in forestry is still in its infancy. The country has few AI technologies to promote sustainable forest management (Table 3). The few AI applications in place have functions that cross-cut various facets of the analytical framework developed in Figure 1. For instance, in the realm of data collection and analysis, the Jaza Miti App, developed by the Ministry of Environment, Climate Change, and Forestry, collects and analyzes tree-planting data, facilitating tree species-site matching, and also plays a role in public engagement and education. For species identification and monitoring, Project 2020, a collaboration between the National Centre for Earth Observation at the University of Leicester and the Kenya Forest Service, enables the effective monitoring of forest changes and helps combat threats such as illegal logging, human settlements, and wildfires. Similarly, Project 2020 was utilized for deforestation detection and prevention, ecological modeling and prediction, and forest fire monitoring and prediction, providing valuable insights for forest management and protection.

In the analytical thematic area of forest inventory and planning, the Timbeter application developed by the Kenya Forest Service seeks to enhance efficiency and transparency and combat illegal logging while improving timber monitoring and supply. For forest restoration and reforestation efforts, KEFRIApp and SSMT, developed by the Kenya Forestry Research Institute and Gatsby Africa, aid in site-species matching, furnish information on tree nursery locations and facilitate the real-time documentation of tree-planting activities. Moreover, these applications support public engagement and education, encourage citizen participation in sustainable forest management efforts, and are supported by forestry development policies (Table 2). The results from Kenya are largely consistent with findings from global literature that appear to acknowledge the positive role of AI in forest management. AI-driven advancements hold great promise for transforming forestry practices and making them more efficient and environmentally sustainable. By incorporating AI, particularly through machine learning algorithms and UAV (Unmanned Aerial Vehicle) technology, forest management and resource inventory can be significantly improved (Chen et al., 2023; Karmaoui, 2023; Liu et al., 2022b; Costa et al., 2023; Osman et al., 2022; Yang et al., 2022 & 2023; Cheong et al., 2022; Kaack et al., 2022). AI technologies enhance forest management by improving effectiveness, sustainability, precision, and expenses (Table 1; Kourtz, 1990; Peng and Wen, 1999; Imada, 2014; Kimsey et al., 2021; Jahani and Rayegani, 2020). AI technology applications in forestry are enhancing data collection on forest biomass changes in areas greatly affected by accessibility challenges, areas with diverse and complex forest structures, and areas with complex topography and unfavorable climatic conditions (Linares-Palomino and Alvarez, 2005; Bojorquez et al., 2020; Chave et al., 2014). UAVs are used increasingly in ecological monitoring, particularly in forest resource inventories and tropical forest surveys (Casazza et al., 2019; Jiang et al., 2021; Johansen et al., 2019; Zhang et al., 2020; Ma et al., 2015; Qiu et al., 2018b; Hao et al., 2021; Hu et al., 2021b; Popescu, 2007; Lechner et al., 2020).

From the foregoing discussion, there are potential benefits of implementing AI technologies in Kenya's efforts to achieve 30% national tree cover by 2032 under the new Kenyan Kwanza administration's bottom-up economic model. AI-driven tools can improve forest monitoring and resource inventory through satellite imagery and UAVs with advanced sensors, thereby providing real-time data on forest cover, tree health, and growth rates. Predictive modeling using AI can anticipate threats, such as illegal logging and wildfires, enabling proactive measures for forest protection. AI can optimize tree-planting strategies based on factors such as soil type and climate conditions, ensuring successful afforestation and reforestation. It can also support community engagement through social media analytics and sentiment analysis, tailoring awareness campaigns, and encouraging citizen science projects for active participation in tree care. Additionally, AI aids in resource allocation and funding optimization, helping Kenya meet global climate change mitigation and adaptation commitments as part of the UNFCCC's NDC and the Paris Climate Change Agreement. However, as the proliferation of AI in forestry continues, there are emerging criticisms and opinions that demand a cautious approach to its application in forestry and other sectors. Skeptics demand AI market regulation and improving the quality of AI in the market; they fear of job losses, deep fake content, and general technostress (Wach et al., (2023). This study acknowledges the fear of AI's role in spreading propaganda related to climate change security. Although concerns about risks and job displacement are valid, dismissing AI's transformative benefits hinders progress. Responsible development, regulations, and proactive measures can mitigate risks and ensure positive impacts on society through efficiency, innovation, and improved quality of life. Education and awareness can reshape criticisms, leading to increased acceptance and adoption of AI in forest management and fostering sustainable practices and conservation efforts.

The results from Kenya have also revealed that there are currently no studies on the public perception of the role of AI in forestry. This study recognizes this as a major shortcoming in promoting the role of AI in forestry development. Without comprehensive research, missed opportunities to leverage AI's potential for accurate data analysis, early forest fire detection, biodiversity monitoring, and sustainable resource management could occur. This would hinder efforts to address critical environmental challenges and optimize conservation initiatives for future generations. Therefore, there is an urgent need for research on this topic in Kenya and beyond. Reviewed literature on geo-technologies and AI as tools for riparian forest management, da Silva Leite and Amorim (2021) have established that AI-based geo-technologies play a vital role in managing natural resources, addressing society's urgent questions and demands; however, there is a research gap concerning the application of AI in studying riparian forest PPAs with geo-technologies, suggesting the need for future research in forest management. In addition, owing to the current challenges facing AI deployments, such as limited resolution and high costs, more research is required.

6. Conclusion and Recommendations

The application of AI technologies in sustainable forest management in Kenya is in its infancy, but the initiatives in place demonstrate the potential for significant positive growth and impact on the forest industry development. The integration of AI tools such as the Timbeter App, Project 2020, and the KEFRI App in sustainable forest management has the potential to facilitate efficient data analysis, real-time monitoring, and informed decision-making, thereby enhancing forest protection and resource management in the country.

With continued awareness and successful AI implementation, the country is poised to harness the full potential of AI as a more sustainable and environmentally conscious approach to forest management. This development trajectory will help Kenya achieve its development aspirations outlined in the Constitution 2010, Vision 2030, and the government's Bottom-up Economic Transformation Agenda (BETA), among other international commitments ratified by Kenya.

Addressing the public perception of AI in forest management requires education, transparency, stakeholder engagement, and showcasing its benefits. Targeted campaigns familiarize people with AI advantages and involve local communities, organizations, and policymakers. Transparency, data privacy, and responsible usage build trust. Public-private collaboration fosters innovative AI solutions and overcomes financial constraints for successful deployment. The demonstration of AI benefits in forest management garners public support. Efficient resource allocation, biodiversity preservation, the detection of deforestation, and local engagement have created positive perceptions. Capacity building and addressing cultural factors enhance acceptance. Long-term sustainability indicates AI's value. Future studies should analyze the cost benefits and use diverse data sources for a comprehensive analysis.

The research limitation of this study is that it solely relied on a bibliographic review and did not include a direct analysis of public perception through interviews with stakeholders and subjects involved in Kenya's sustainable forest management. This omission results in a lack of qualitative and quantitative data that could have enhanced the discussion and allowed for a more direct response to the research's stated objective. This could be addressed by cross-referencing and using diverse data collection methods.

References

Africa Development Bank, (2022). Africa Economic Outlook; Kenya Economic Outlook. Recent macroeconomic and financial developments. 2022. https://www.afdb.org/en/countries-east-africa-kenya/kenya-economic-outlook

Amaral, R. D. D. A. M., Morato, R. G., Mariano, R. S., & Ferreira, J. M. R. (2021). Urban forest management tools. *Revista de Gestão Ambiental e Sustentabilidade*, 10(1), 1-10.

Asner, G.P., Powell, G.V., Mascaro, J., Knapp, D.E., Clark, J.K., Jacobson, J., Kennedy Bowdoin, T., Balaji, A., Paez-Acosta, G., Victoria, E., 2010. High-resolution forest carbon stocks and emissions in the Amazon. In: *Proceedings of the National Academy of Sciences*, 107, 16738–16742. https://doi.org/10.1073/pnas.1004875107

Bettinger, P., Merry, K., Fei, S., Weiskittel, A., & Ma, Z. (2023). Usefulness and Need for Digital Technology to Assist Forest Management: Summary of Findings from a Survey of Registered Foresters. *Journal of Forestry*, 121(1), 1-11.

Bojorquez, ´ A., Martínez-Yrízar, A., Búrquez, A., Jaramillo, V.J., Mora, F., Balvanera, P., Alvarez-Y ´ ´epiz, J.C., 2020. Improving the Accuracy of Aboveground Biomass Estimations in Secondary Tropical Dry Forests. Elsevier. https://doi.org/10.1016/j. foreco.2020.118384

Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., Forrester, D. I., Gardiner, B., González-Olabarria, J. R., et al. (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. *Biodivers. Conserv.* 26, 3005–3035. https://doi.org/10.1007/s10531-017-1453-2

Casazza, M., Lega, M., Jannelli, E., Minutillo, M., Jaffe, D., Severino, V., Ulgiati, S., 2019. 3D monitoring and modelling of air quality for sustainable urban port planning: review and perspectives. *J. Clean. Prod.* 231, 1342–1352. https://doi.org/10.1016/j. jclepro.2019.05.257.

Chave, J., R´ejou-M´echain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B., Duque, A., Eid, T., Fearnside, P.M., Goodman, R.C., 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biol.* 20, 3177–3190. https://doi.org/10.1111/gcb.12629

Chen, L., Chen, Z., Zhang, Y., Liu, Y., Osman, A. I., Farghali, M., ... & Yap, P. S. (2023). Artificial intelligence-based solutions for climate change: a review. *Environmental Chemistry Letters*, 1-33. https://doi.org/10.1007/s10311-023-01617-y

Cheong S.M, Sankaran K, Bastani H (2022) Artifcial intelligence for climate change adaptation. *Wiley Interdiscip Rev: Data Min Knowl Discov* 12:e1459. https://doi.org/10.1002/widm.1459

Çolak, A. H., Kirca, S., and Rotherham, I. D. (Eds.) (2018). Ancient woodlands and trees: a guide for landscape planners and forest managers. IUFRO World Series 37, 1–272. https://doi.org/10.53478/TUBA.2020.036

Costa, A. C. D., Pinto, J. R. R., Miguel, E. P., Xavier, G. D. O., Marimon, B. H., & Aparecido Trondoli Matricardi, E. (2023). Artificial intelligence tools and vegetation indices combined to estimate aboveground biomass in tropical forests. *Journal of Applied Remote Sensing*, 17(2), 024512-024512.

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science* 361, 1108–1111. https://doi.org/10.1126/science.aau3445

da Silva Leite, E., & Amorim, R. J. R. (2021). Geotechnologies and Artificial Intelligence as a Tool of Riparian Forest Management. *International Journal of Advanced Engineering Research and Science*, 8, 6. https://dx.doi.org/10.22161/ijaers.86.49

Dalla Corte, A.P., Souza, D.V., Rex, F.E., Sanquetta, C.R., Mohan, M., Silva, C.A., Zambrano, A.M.A., Prata, G., de Almeida, D.R.A., & Trautenmüller, J.W., 2020. Forest inventory with high-density UAV-Lidar: machine learning approaches for predicting individual tree attributes. *Comput. Electron. Agric.* 179, 105815. https://doi.org/10.1016/j.compag.2020.105815 .

DeLuca, T. H., Aplet, G. H., Wilmer, B., & Burchfield, J. (2010). The unknown trajectory of forest restoration: a call for ecosystem monitoring. *Journal of Forestry,* 108(6), 288-295.

Empig, E. E., Sivacioğlu, A., Pacaldo, R. S., Suson, P. D., Lavilles, R. Q., Teves, M. R. Y., ... & Amparado Jr, R. F. (2023). Climate Change, Sustainable Forest

Management, ICT Nexus, and the SDG 2030: A Systems Thinking Approach. *Sustainability*, 15(8), 6712.

Estoque, R. C., Dasgupta, R., Winkler, K., Avitabile, V., Johnson, B. A., Myint, S. W., et al. (2022). Spatiotemporal pattern of global forest change over the past 60 years and the forest transition theory. *Environ. Res. Lett.* 17, 084022. https://doi.org/10.1088/1748-9326/ac7df5

FAO (2022a). "The State of the World's Forests" (SOFO) 2022 Report. Forest Pathways for Green Recovery and Building Inclusive, Resilient and Sustainable Economies. Rome 2022.

FAO (2022b). The Forest and Landscape Restoration Mechanism. https://www.fao.org/inaction/forest-landscape-restorationmechanism/background/approach/en/

FAO. (2015b). Current Status of Forestry Sector and the Vision for the Year 2020. Accessed July 2015. www.fao.org: http://www.fao.org/docrep/003/ab569e/AB569E04.htm).

Francisco, M. (2023). Artificial intelligence for environmental security: national, international, human and ecological perspectives. *Current Opinion in Environmental Sustainability*, 61, 101250.

FSK (2023). Forest Society of Kenya (FSK) Website. Accessed at https://fsk.or.ke/technological-developments-in-the-forestry-sector-in-kenya/#:~:text=Timbeter%20Application&text=The%20Timbeter%20App%20is%20already,technology%20for%20accurate%20log%20detection. On 29th July 2023

Ge, G., Shi, Z., Zhu, Y., Yang, X., Hao, Y., 2020. Land use/cover classification in an arid desert-oasis mosaic landscape of China using remote sensed imagery: performance assessment of four machine learning algorithms. *Global Ecol. Conserv.* 22, e00971 https://doi.org/10.1016/j.gecco.2020.e00971.

Galaz, V., Centeno, M. A., Callahan, P. W., Causevic, A., Patterson, T., Brass, I., ... & Levy, K. (2021). Artificial intelligence, systemic risks, and sustainability. *Technology in Society*, 67, 101741.

Hao, Y., Widagdo, F.R.A., Liu, X., Quan, Y., Dong, L., Li, F., 2021. Individual tree diameter estimation in small-scale forest inventory using UAV laser scanning. *Rem. Sens.* 13, 24. https://doi.org/10.3390/rs13010024.

Hu, T., Sun, X., Su, Y., Guan, H., Sun, Q., Kelly, M., Guo, Q., 2021b. Development and performance evaluation of a very low-cost UAV-lidar system for forestry applications. *Rem. Sens.* 13, 77. https://doi.org/10.3390/rs13010077.

Hua, F., Bruijnzeel, L. A., Meli, P., Martin, P. A., Zhang, J., Nakagawa, S., et al. (2022). The biodiversity and ecosystem service contributions and tradeoffs of forest restoration approaches. *Science* 376, 839–844. https://doi.org/10.1126/science. abl4649

Imada, A. (2014, June). A literature review: forest management with neural network and artificial intelligence. In International Conference on Neural Networks and Artificial Intelligence (pp. 9-21). Cham: Springer International Publishing.

IPBES. (2019). Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and Ngo, H. T. (Eds.). IPBES secretariat, Bonn, Germany. 1148 pages.

Jahani, A., & Rayegani, B. (2020). Forest landscape visual quality evaluation using artificial intelligence techniques as a decision support system. *Stochastic Environmental Research and Risk Assessment,* 34(10), 1473-1486.

Jiang, R., Sanchez-Azofeifa, A., Laakso, K., Wang, P., Xu, Y., Zhou, Z., Luo, X., Lan, Y., Zhao, G., Chen, X., 2021. UAV-based partially sampling system for rapid NDVI mapping in the evaluation of rice nitrogen use efficiency. *J. Clean. Prod.* 289, 125705. https://doi.org/10.1016/j.jclepro.2020.125705

Johansen, K., Erskine, P.D., McCabe, M.F., 2019. Using Unmanned Aerial Vehicles to assess the rehabilitation performance of open cut coal mines. *J. Clean. Prod.* 209, 819–833. https://doi.org/10.1016/j.jclepro.2018.10.287

Kaack LH, Donti PL, Strubell E, Kamiya G, Creutzig F, Rolnick D (2022) Aligning artificial intelligence with climate change mitigation. *Nat Clim Chang* 12, 518–527. https://doi.org/10.1038/s41558-022-01377-7

Karmaoui, A. (2023). The Future of Artificial Intelligence in Agricultural Field: A Bibliometric Analysis. In Intelligent Solutions for Optimizing Agriculture and Tackling Climate Change: Current and Future Dimensions (pp. 71-94). IGI Global.

Keenan, R. J. (2015). Climate change impacts and adaptation in forest management: a review. *Ann. For. Sci* 72, 145–167. https://doi.org/10.1007/s13595-014-0446-5

KFS (2022) National Forest Resource Assessment Report, 2022.

Kimsey Jr, M. J., Strimbu, B. M., & McGaughey, R. J. (2021). Advancements in forest mensuration and biometrics in the artificial intelligence era. *Canadian Journal of Forest Research*, 51(8), v-vi. https://doi.org/10.1139/cjfr-2021-0175

Koukal, T., Atzberger, C., Schneider, W., 2014. Evaluation of semi-empirical BRDF models inverted against multi-angle data from a digital airborne frame camera for enhancing forest type classification. *Remote Sens. Environ*. 151, 27–43. https://doi.org/10.1016/j.rse.2013.12.014

Kourtz, P. (1990). Artificial intelligence: a new tool for forest management. Canadian *Journal of Forest Research*, 20(4), 428-437.

Leal Filho, W., Yang, P., Eustachio, J. H. P. P., Azul, A. M., Gellers, J. C., Gielczyk, A., ... & Kozlova, V. (2023). Deploying digitalisation and artificial intelligence in sustainable development research. *Environment, development and sustainability*, 25(6), 4957-4988.

Lechner, A.M., Foody, G.M., Boyd, D.S., 2020. Applications in remote sensing to forest ecology and management. *One Earth* 2, 405–412. https://doi.org/10.1016/j.oneear.2020.05.001.

Linares-Palomino, R., Alvarez, S.I.P., 2005. Tree community patterns in seasonally dry tropical forests in the Cerros de Amotape Cordillera, Tumbes, *Peru. For. Ecol. Manag.* 209, 261–272. https://doi.org/10.1016/j.foreco.2005.02.003.

Liu T, Chen L, Yang M, Sandanayake M, Miao P, Shi Y, Yap P-S (2022b) Sustainability considerations of green buildings: a detailed overview on current advancements and future considerations. *Sustainability* 14, 14393. https://doi.org/10.3390/su142114393

Liu, Z., Peng, C., Work, T., Candau, J. N., DesRochers, A., & Kneeshaw, D. (2018). Application of machine-learning methods in forest ecology: recent progress and future challenges. *Environmental Reviews*, 26(4), 339-350.

Ma, L., Cheng, L., Li, M., Liu, Y., Ma, X., 2015. Training set size, scale, and features in Geographic Object-Based Image Analysis of very high resolution unmanned aerial vehicle imagery. ISPRS *J. Photogrammetry Remote Sens.* 102, 14–27. https://doi.org/10.1016/j.isprsjprs.2014.12.026

Macheru, J. (2023). Outward Foreign Direct Investments and Economic Growth: An Investigation of Kenya. *International Journal of Poverty, Investment and Development*, 3(1), 1-11.

McGovern, A., Elmore, K. L., Gagne, D. J., Haupt, S. E., Karstens, C. D., Lagerquist, R., ... & Williams, J. K. (2017). Using artificial intelligence to improve real-time decision-making for high-impact weather. *Bulletin of the American Meteorological Society*, 98(10), 2073-2090.

McQueen S. (2019). How Artificial Intelligence, Robots Enhance Forest Sustainability in Finland. Accessed at https://www.esri.com/about/newsroom/blog/finland-enhances-forest-data-accuracy-for-automation/

MEF (2018) Ministry of Environment and Forestry, Taskforce Report on Forest Resources Management and Logging Activities in Kenya (April 2018).

Osman AI, Chen L, Yang M, Msigwa G, Farghali M, Fawzy S, Rooney DW, Yap P-S (2022) Cost, environmental impact, and resilience of renewable energy under a changing climate: a review. *Environ Chem Lett* 21:741–764. https://doi.org/10.1007/s10311-022-01532-8

Pan, Y., Birdsey, R. A., Phillips, O. L., and Jackson, R. B. (2013). The structure, distribution, and biomass of the world's forests. *Annu. Rev. Ecol. Evol. Syst.* 44, 593–622. https://doi.org/10.1146/annurev-ecolsys-110512-135914

Peng, C., & Wen, X. (1999). Recent applications of artificial neural networks in forest resource management: an overview. *Transfer*, 1(X2), W1.

Popescu, S.C., 2007. Estimating biomass of individual pine trees using airborne lidar. *Biomass Bioenergy* 31, 646–655. https://doi.org/10.1016/j.biombioe.2007.06.022

Qiu, Z., Feng, Z.-K., Wang, M., Li, Z., Lu, C., 2018b. Application of UAV photogrammetric system for monitoring ancient tree communities in Beijing. *Forests* 9, 735. https://doi.org/10.3390/f9120735 .

Rahman, A., Abdullah, H.M., Tanzir, M.T., Hossain, M.J., Khan, B.M., Miah, M.G., Islam, I., 2020. Performance of different machine learning algorithms on satellite image classification in rural and urban setup. *Rem. Sens. Appl. Soc. Environ.* 20, 100410. https://doi.org/10.1016/j.rsase.2020.100410.

Schmoldt, D. L. (2001). Application of artificial intelligence to risk analysis for forested ecosystems. R*isk analysis in forest management*, 49-74. https://doi.org/10.1007/978-94-017-2905-5_3

Silvestro, D., Goria, S., Sterner, T., & Antonelli, A. (2022). Improving biodiversity protection through artificial intelligence. *Nature sustainability*, 5(5), 415-424.

Shivaprakash, K. N., Swami, N., Mysorekar, S., Arora, R., Gangadharan, A., Vohra, K., ... & Kiesecker, J. M. (2022). Potential for artificial intelligence (AI) and machine learning (ML) applications in biodiversity conservation, managing forests, and related services in India. *Sustainability*, 14(12), 7154.

Taubert, F., Fischer, R., Groeneveld, J., Lehmann, S., Müller, M. S., Rödig, E., et al. (2018). Global patterns of tropical forest fragmentation. *Nature* 554, 519–522. https://doi.org/10.1038/nature25508

United Nations Environment Agency (UNEA) (2019). Resolution 73/284: United Nations Decade on Ecosystem Restoration (2021–2030) (Nairobi).

Vizard M. (2020). Attitudes Toward AI Are Starting to Evolve. Accessed at https://www.rtinsights.com/attitudes-toward-ai-are-starting-to-evolve/

Wach, K., Duong, C. D., Ejdys, J., Kazlauskaitė, R., Korzynski, P., Mazurek, G., ... & Ziemba, E. (2023). The dark side of generative artificial intelligence: A critical analysis of controversies and risks of ChatGPT. *Entrepreneurial Business & Economics Review*, 11(2).

World Bank 2022. Kenya's Economic Outlook and the World Bank's supports the government's Vision 2030 development strategy. https://www.worldbank.org/en/country/kenya/overview

Yang M, Chen L, Msigwa G, Tang KHD, Yap P-S (2022) Implica- tions of COVID-19 on global environmental pollution and car- bon emissions with strategies for sustainability in the COVID-19 era. *Sci Total Environ* 809, 151657. https://doi.org/10.1016/j.scito tenv.2021.151657

Yang M, Chen L, Wang J, Msigwa G, Osman AI, Fawzy S, Rooney DW, Yap P-S (2023) Circular economy strategies for combating climate change and other environmental issues. *Environ Chem Lett* 21, 55–80. https://doi.org/10.1007/s10311-022-01499-6

Zerbe, S. (2022). *Restoration of multifunctional cultural landscapes. merging tradition and innovation for a sustainable future*. Springer Landscape Ser. 30, 1–716. https://doi.org/10.1007/978-3-030-95572-4

Zerbe, S. (2023). *Restoration of Ecosystems—Bridging Nature and Humans. A Transdisciplinary Approach*. Berlin; Heidelberg: Springer Spektrum. https://doi.org/10.1007/978-3-662-65658-7.1038/nature25508

Zhang, T., Zhang, W., Yang, R., Liu, Y., Jafari, M., 2020. CO2 capture and storage monitoring based on remote sensing techniques: a review. *J. Clean. Prod.* 124409. https://doi.org/10.1016/j.jclepro.2020.124409

Authors

Sylvester Ngome Chisika
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea; sylvesterchizika@gmail.com

Juneyoung Park
Department of Smart City Engineering, Hanyang University, Ansan, 15588, Korea; juneyoung@hanyang.ac.kr

Chunho Yeom *(corresponding author)*
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea; chunhoy7@uos.ac.kr

Funds

This work was supported by the Basic Study and Interdisciplinary R&D Foundation Fund of the University of Seoul (2023).

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Chisika, S., Park, J. & Yeom, C. (2023) Public perception on the role of Artificial Intelligence in the sustainable management of tree and forest resources in Kenya. *Visions for Sustainability*, 20, 8025, 127-154. http://dx.doi.org/10.13135/2384-8677/8025

Original Paper

Building design based on zero energy approach

Mitra Bagheri, Danyal Ghanbari Barfeh, Mahdis Hamisi

Received: 19 August 2023 | **Accepted:** 20 September 2023 | **Published:** 4 October 2023

Keywords: Zero Energy Building; greenhouse gases; energy consumption; renewable energy; Qazvin.

Abstract. *In recent years, the energy crisis has become one of the most challenging issues in the world. The need to minimize the use of fossil fuels,* *due to the increase in environmental pollution caused by excessive use, on the one hand, and the exhaustion of these resources, on the other hand, has made it necessary to use renewable energies as a suitable alternative. The purpose of this study is to build a design based on a zero-energy approach in Qazvin City, Iran. Research hypotheses have been investigated for providing solutions to reduce energy consumption and use renewable resources in zero-energy buildings. The research method employed is descriptive-analytical. DesignBuilder software is used for simulation and dynamic thermal analysis of the structure. Based on the results of the research, the theory of designing and building zero-energy houses in Qazvin City can be achieved with the stated methods.*

1. Introduction

Global warming, environmental pollution due to the combustion of fossil fuels and the increasing acceleration towards the end of non-renewable sources have led to an ever more serious energy crisis and numerous related damages (Belussi *et al.* 2019; D'Agostino and Mazzarella 2019; Ravishankar *et al.* 2020). Modern architecture, despite the valuable achievements and changes it brought with it, also created complex problems in the environmental field.

In this century, the world is witnessing the increasing destruction of its environment due to the production of greenhouse gases, and atmospheric pollutants, and the increase in the consumption of finite resources. Following these changes and the issues that came with it, to find an answer to improve the situation, mankind reached a new concept called sustainable development. and as a result, due to the important role of the built environment in the course of sustainable development, sustainable architecture has attracted the attention of many experts (Wu and Skye 2021; Magrini et al. 2020). One of the three important areas that sustainable development emphasizes is environmental issues. The limited and high pollution of fossil sources as the main source of energy supply until today has given rise to a lot of attention to clean and renewable energy sources such as solar, wind, geothermal, and other new energies (Liu *et al.* 2019; Chen 2019; Feng *et al.* 2019; Kosonen and Keskisaari 2020). Meanwhile, the use of renewable energy in the building sector (such as the use of small wind turbines, photovoltaic panels, geothermal energy, and solar water heaters) along with passive solutions can significantly reduce energy consumption and consequently reduce the harmful effects caused by the consumption of fossil fuels (Daemei *et al.* 2016; Ferrara *et al.* 2019; Natanian and Auer. 2020; Attia and Gobin 2020; Jareemit *et al.* 2022; Manzoor *et al.* 2022).

Considering the above contents and the critical conditions of fossil energy consumption in the country on the one hand and insufficient attention to renewable energy sources on the other hand, the purpose of this research was the feasibility of designing a building with a zero-energy approach in Qazvin City, Iran.

2. The need for research

The proposed vision for sustainability is to move towards the design of zero-energy buildings. In practice, there will be many obstacles, but, considering Iran's limited energy resources, solutions must be designed to move towards their construction.

Until 1973, due to the cheap price of energy carriers and the relative lack of knowledge of environmental problems, one of the most basic criteria for measuring the progress of each country was the annual per capita energy consumption in those countries. With the increase in energy prices and the emergence of environmental problems, the issue of increasing productivity and preventing environmental pollution gave a new dimension to this criterion. Among the goals related to the energy sector in different countries, improving efficiency and optimizing energy consumption have gained priority. This priority is due to various factors, the main ones of which are:

- Maintaining the world's exhaustible reserves due to the limitations of energy supply and the growth of its demand.
- Reducing the harmful environmental effects caused by the combustion of fossil fuels.
- Improving economic efficiency and global competitiveness about the necessary costs for investment in the energy sector.

Due to the economic and social conditions of Iran, the increase in the price of energy carriers does not make many energy-saving plans economical. Therefore, low-cost or no-cost ways to reduce energy consumption in buildings are of particular importance. Architectural methods that reduce energy consumption are cost-free and sustainable methods, and even if the price of energy increases, both economically and environmentally, they are more suitable than other methods. Although energy-saving with architectural design can be used in all countries, it is particularly appropriate for Iran due to its economic, social, and cultural structure.

The price of electricity and total energy demand are highly dependent on each other. When electricity prices are high and energy demand is high, backup generators such as gas turbines and coal plants are used more. Reducing energy production at this time makes electricity production more environmentally friendly and less dependent on fossil fuels. In addition to reducing the cost of electricity, knowing that electricity is produced in an environmentally friendly way can be an important incentive for consumers to invest in smart energy management. In addition, if many households use smart energy management, this can reduce peak consumption and reduce the capacity of backup power plants.

Energy consumption in buildings accounts for one-third of the country's annual energy consumption. Therefore, it is very important to provide solutions that can reduce energy consumption in this sector. Compliance with even the smallest details in this respect can have a great effect on reducing consumption in the building. The first step to achieving this goal is to find the weaknesses of contemporary architecture and provide solutions to improve them.

Energy consumption in the building depends on the structure and geometric form, the way its different components are designed, and the climatic conditions. Other factors such as occupation and use of spaces, operation of equipment and facilities, and their maintenance pattern are of secondary importance. On the other hand, technical developments and a variety of methods in the field of construction and operation of buildings are of great importance in the field of energy consumption, starting from the building design stage and continuing until the stage of its use and operation.

Architectural solutions are collections of passive design methods, energy efficiency methods, or renewable energy utilization methods that are used in a building to reduce various construction problems and achieve the goal of building design. A set of solutions is used to reduce the total energy consumption in a building (for example, heating, cooling, lighting, plug-in loading, etc.).

In the context of the built environment, the concept and analysis of net energy do not have validated calculation methods. In building energy evaluation, usually only the use of energy in the form of electricity or fossil fuels is considered, without considering other energy sources in the building construction process, such as material production. Some environmental assessment methods, such as Leadership in Energy and Environmental Design (LEED) or the BREEA ESG advisory service, also consider issues such as material selection, transportation, etc (Johansson, 2012). It can be argued that net energy analysis is indirectly used in these methods. For example, reuse and recycling of buildings and products (which effectively saves energy in the extraction, manufacturing, processes, and transportation industries). They are processed by the ranking method (Agharabi and Darzi, 2023).

Due to the great effect of architectural design on the amount of energy consumption of buildings, finding factors that reduce energy consumption and using them in the design of buildings will significantly reduce their energy consumption. In this respect, to reduce energy consumption, building designers should reduce the energy loss in the building.

The investigations conducted on the fabric of biological-native complexes show that humanity been paying attention to the use of non-renewable energies for a long time and by gaining experience over time, has created a method that can be referred to as the background of modern climate design. Experiences show that not paying attention to in modern design means losing a huge part of sustainable quality in design. This has made the recognition and evaluation of climate effects on traditional structures and structures the most important program and priority in reducing energy consumption, using natural resources instead of mechanical systems, and creating a comfortable, healthy, and durable living space. Today, with new and inappropriate constructions in valuable local contexts that have increased the use of non-renewable energy to achieve thermal comfort, the use of local design patterns is emphasized more and more (Aram et al., 2022).

3. Method

The focus of this research is to reduce energy consumption in the building by using passive solutions to reduce energy consumption with high economic justification and to achieve a logical balance between the amount of energy consumption and its production through renewable energy sources and the power grid. The research method is based on a combination of descriptive-analytical methods, causal research methods, and simulation. "The best and at the same time the most convincing method to establish a causal relationship is a careful experiment in which the influence of latent variables is controlled, the concept of actively changing x and observing its effect on y" (Groat and Wang, 2016, p.186).

The testing tool of the research is a simulation by DesignBuilder software, used for thermal analysis of the building and the effect of environmental factors on it. Among the capabilities of this software are the calculation of the cooling and heating load of the building, the effect of passive solutions on the amount of energy consumption, visualization, and quantitative estimation of the effect of solar radiation on the openings and other surfaces of the building. The software can calculate the amount of energy consumption in hours, days, months, and years based on weather information and active and inactive measures considered for the building and help designers make appropriate decisions in the field of building energy consumption based on real information.

The validity of DesignBuilder software has been proven in previous studies and the website of the software[1] demonstrates various examples that attest how the results of the simulation in this software are valid and recognized both by institutes and decision-making authorities of many countries, including the United Kingdom. Among the research that has been carried out using this software, we can refer to Masnadi and Heidari (2010), in which the amount of heat loss of the roof of a building with different structures such as flat roof, double-shell roof, green roof, and roof pond, was calculated and at the end, the appropriate option was selected in terms of the effect on energy consumption and the cost of design.

Aram et al. (2022) also investigated the study of buildings from the point of view of energy consumption, using the software to determine the effect of various architectural factors such as orientation, area of openings, shade, and natural ventilation.

To achieve the goal of designing a building with zero energy, the amount of reduction in energy consumption using passive methods is considered as 3 independent simulation changes:

1. Using thermal insulation and combining it with materials with suitable capacity and thermal resistance according to the climatic conditions.
2. Designing a suitable awning for the openings according to the path of the sun to reduce the cooling load.

[1] https://designbuilder.co.uk/

Taking advantage of natural ventilation according to the principles of Venturi and Bernoulli and the effect of the chimney, taking into account the direction of the wind during the hot season. (The Venturi effect (Giovanni Battista Venturi, 1797) is a direct consequence of the Bernoulli principle. It describes the effect by which a constriction to fluid flow through a tube causes the velocity of the fluid to increase and therefore the pressure to decrease, Venturi effect is a physical phenomenon related to fluid flow. Examples of this phenomenon can be seen in many urban and natural places. For example, when on a windy day, the door of the building is difficult to open, or when walking in a narrow urban channel that is surrounded by buildings, this phenomenon and dynamic effect can be understood. The phenomenon that causes the door to open is called the Venturi effect. This principle is based on the natural tendency of the fluid to equalize the pressure in two or more zones. The Venturi effect is used in buildings for natural ventilation and cooling of the environment).

After these calculations, there is a need to equate the energy produced from renewable energy sources, which are used according to the potentials available on the site, with the energy consumption of buildings in the cooling, heating, lighting, and equipment sectors. In this plan, according to the location of the design site in the urban area and the existing needs, it is connected to the network, and a period of one year was chosen to estimate the statistics and calculation criteria. Another part that is needed in this research is complete climate information in Qazvin City and design based on this to increase energy efficiency in the designed units. For this purpose, various climatic information including sunshine and hours of sun, wind flow, temperature, precipitation, and relative humidity were collected from meteorological synoptic stations of Qazvin province and the design of the building was based on various aspects such as the level of openings, orientation, how to properly use renewable energy, etc.

3.1 Area of study

The site considered for research is in Qazvin City. Qazvin has a population of about 800,000 people and its area is 1423 square kilometers (Agharabi and Darzi 2023). The site is surrounded by residential contexts in the west and south. The northern side of the site is also covered by an open area, which also leads to a residential context. The eastern side is adjacent to a large boulevard and further east there is also a residential town. The presence of open space in the eastern part of this site and its alignment with the direction of seasonal breezes and the prevailing direction of Qazvin wind, especially in summer and also, the location of the site in the northern part of Qazvin, make the area selected for this research of high environmental value (Figure 1).

Figure 1. The scope of the site considered for design

3.2 Climate studies

In the design of a project by the architect, collecting the necessary information regarding the design platform is one of the initial steps to achieve a suitable design. In this research, firstly, the climate information was taken from the statistics and data of Qazvin synoptic stations during the years 2013-2022. Then, to determine the influence of each of the inactive methods in different seasons of the year, the bioclimatic form of the Givoni construction, which is one of the most reliable and best forms, was used to design buildings compatible with the climate of the region. In the construction bioclimatic form of Givoni, information data from the climate, such as relative humidity and average minimum and maximum monthly temperature, are specified in the figure, these data are analyzed and finally the conditions and principles that should be considered for climate design are specified (Givoni, 2011; Shakoor, 2011).

In this research, the mentioned figure is drawn based on the climatic data of Qazvin synoptic station, and the lines of each month were marked on the figure

(1. April, 2. May, 3. June, 4. July, 5. March, 6. August, October 7, November 8, December 9, December 10, February 11, March 12) and according to the definition of different ranges in shape and their overlapping with the drawn lines, suitable passive solutions for Qazvin climate were obtained. In addition, wind flow analysis was also studied to optimize the design of residential buildings (Figure 2).

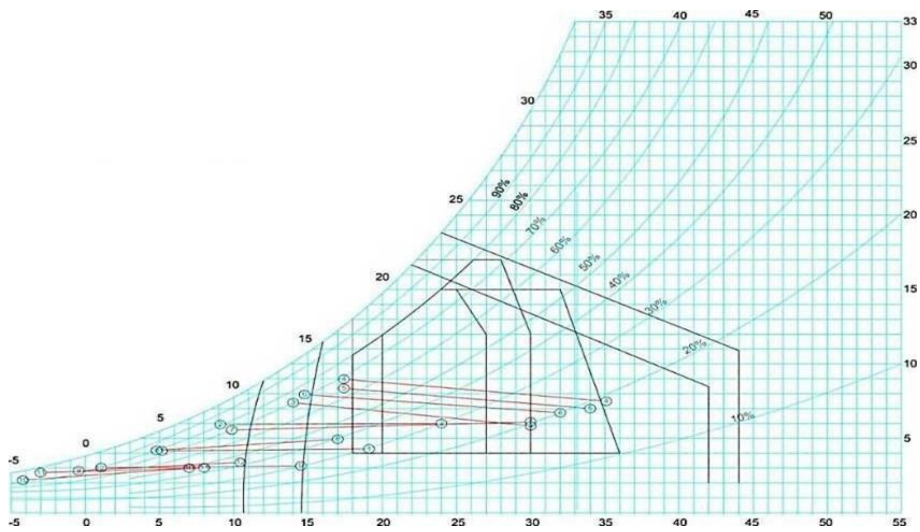


Figure 2. Qazvin construction bioclimatic form

3.3 Givoni table analysis

According to the bioclimatic table of the Givoni building, which was obtained based on the ten-year statistics (2013-2022) of Qazvin airport synoptic station, it can be seen that it is within the comfort zone in the spring and in the mornings in April. Solar heating can also be used, and mechanical heating is sometimes required at night. In May, the thermal capacity of the material is sufficient in the mornings in the comfort zone and at night, and in June, the need for air conditioning is felt to some degree in the mornings, and the thermal capacity of the materials is sufficient at night. During the summer season, during the day, and especially in August, evaporative cooling and drafts of air are needed for cooling, and at night, the outside space is within the comfort zone. It should be noted that it is better to prevent the penetration of the sun's heat into the building during the whole of summer and June. With the beginning of the autumn season and in October, it is in the comfort zone in the mornings, and comfort conditions can be achieved at night using thermal mass. The conditions in November are such that solar heating is needed during the day and mechanical heating is needed at night. Starting from December and throughout the winter, in addition to using active heating systems, solar heating should be used during the day and mangrove capacity at night. In general, according to the obtained information, the design of a building with a climatic approach in Qazvin should be such that in cold seasons it will benefit from materials with high thermal capacity and resistance along with solar heating and in hot seasons, in addition to the use of natural sunlight and evaporative cooling systems, the penetration of the sun into the building should also be prevented.

3.4 Determination of airflow

To obtain the parameters of the wind speed and direction at different times of the year in Qazvin city, the authors collected information by analyzing the 5-year statistics of seasonal Wind rose of Qazvin City (2018-2022) which are available in the quarterly journals of Qazvin Meteorological Organization (Janzadeh & Zandieh, 2022). This is the context and by obtaining information on the predominant direction of the seasonal wind, maximum speed, average speed, and dispersion of wind direction at 6:30, 12:30, and 18:30, the current research tries to design an optimal building for maximum benefit from natural ventilation in summer and protection from cold winter winds by using special measures. Due to the impossibility of including all analytical tables in this section, only its results are stated. According to the obtained information, the prevailing wind direction in all seasons is mainly southeast, while the western wind is also considered the dominant wind in winter, spring, and summer. In the morning hours, in the spring, summer, and autumn seasons, the wind blows from the north and northeast, and in the winter, at noon and in the afternoon, the wind blows from the west and south. The average wind speed in the spring, summer, autumn, and winter seasons is 3.3, 3.2, 3.1, and 3.4 respectively. Moreover, in the early morning the wind is sometimes dominant from the north and northeast. Between 9:30 and 15:30, the prevailing winds are from the southeast, which are more intense in summer, while from 15:30 to 21:30, in summer and autumn, the prevailing winds are from the east and south-east, and winter from the west. In addition, winds with a speed of more than 12 meters per second, which are considered unfavorable winds, generally blow from the southwest and northwest. This can be very important in the orientation of the building and the design of the openings in late spring and summer for cooling through natural ventilation as well as protecting the building against cold and high-speed winds.

4. Results

In this section, we will first discuss the effect of each of the passive solutions considered in this research on the reduction of energy consumption in the building. Then, an attempt is made to provide this reduced amount of energy consumption by photovoltaic cells and solar water heaters. The design considered in this research is a neighborhood unit with a zero-energy approach in a land area of 19,000 square meters in the northeastern part of Qazvin City. This project consists of 8 two-story residential buildings, where two units are designed on each floor in three-bedroom (175 square meters) and two-bedroom (145 square meters) types. Considering the amount of area required for the installation of renewable systems and the lack of space on the roofs for the installation and operation of photovoltaic systems, a part of the site with a size of 500 square meters in the southern part has been considered for the installation of these systems. In this plan, in terms of social sustainability and improvement of visual quality, in addition to designing an open space in the center of the neighborhood unit, which is intended to fulfill communication and emotional needs, as well as encourage sports and physical activities, to reduce atmospheric and noise pollutants and also for air quality and visual beauty, in addition to the green space designed in the center and sides of the site, the existing bodies are also covered with green walls (Figure 3).

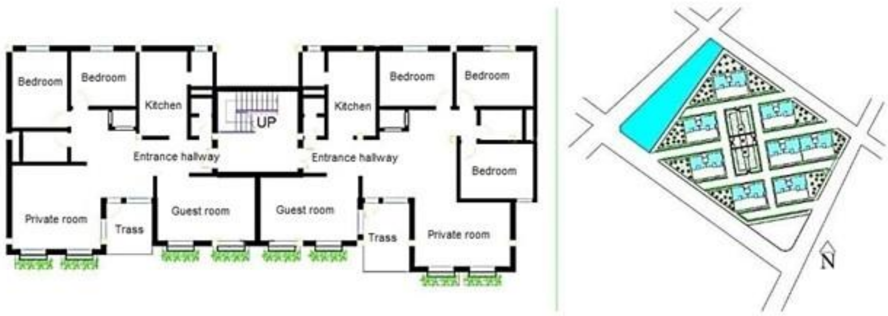


Figure 3. Design site (right), plan of three-bedroom and two-bedroom residential units (left)

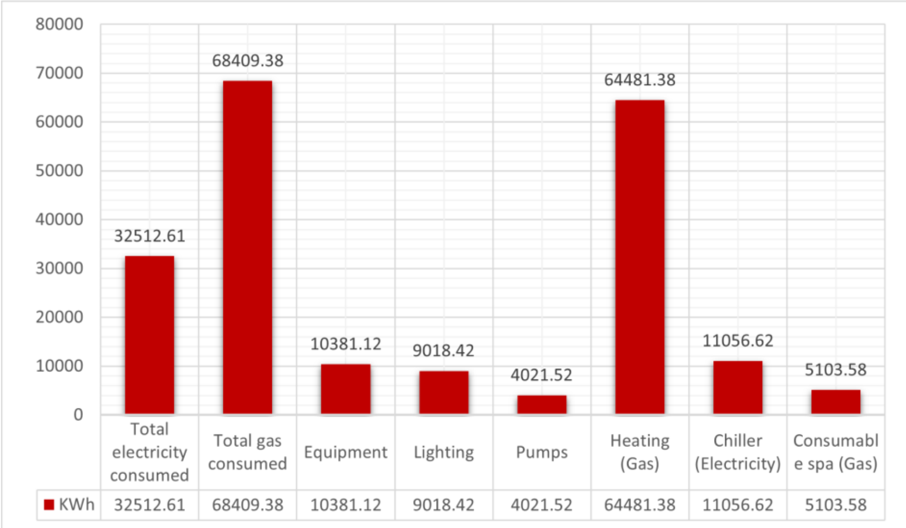
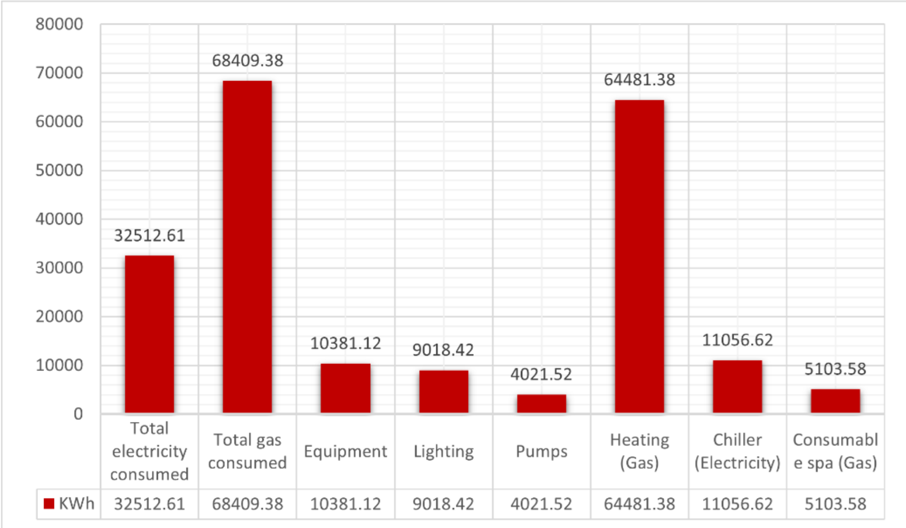


Figure 4. The amount of energy consumed by each section in a residential unit (4 units).

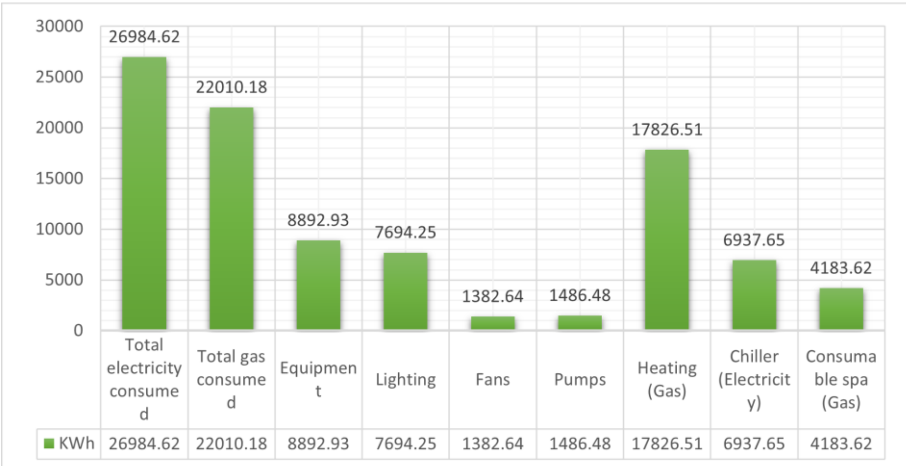
Figure 4 shows the energy consumption of one of the residential units designed in the building with the mentioned conditions, which includes two two-bedroom units and two three-bedroom units, using common materials, without any measures to reduce energy consumption.

To reduce the energy consumption before changing the materials by replacing the fan coil system instead of the radiator system for ambient heating by 25597.03 kilowatt hours (37%), a reduction in natural gas consumption is observed. It is worth mentioning that the fan coil system has been used for cooling, which has good efficiency among cooling systems. Taking this into account, the natural gas consumption of 4 residential units will reach 44591.62 kilowatt hours and the electricity consumption will reach 31804.25 kilowatt hours (Figure 5).



	Total electricity consumed	Total gas consumed	Equipment	Lighting	Pumps	Heating (Gas)	Chiller (Electricity)	Consumable spa (Gas)
KWh	32512.61	68409.38	10381.12	9018.42	4021.52	64481.38	11056.62	5103.58

Figure 5. Amount of energy consumed by sections in 4 residential units using fan coils.



	Total electricity consumed	Total gas consumed	Equipment	Lighting	Fans	Pumps	Heating (Gas)	Chiller (Electricity)	Consumable spa (Gas)
KWh	26984.62	22010.18	8892.93	7694.25	1382.64	1486.48	17826.51	6937.65	4183.62

Figure 6. Amount of energy consumed by sections in residential units using thermal insulation and heat capacity of materials.

Figure 6 shows the energy consumption of the building by using materials with suitable heat capacity and using thermal insulation. The walls are made of double-walled walls with Lyca blocks and polystyrene insulation, and the roof structure is block beams with thermal insulation.

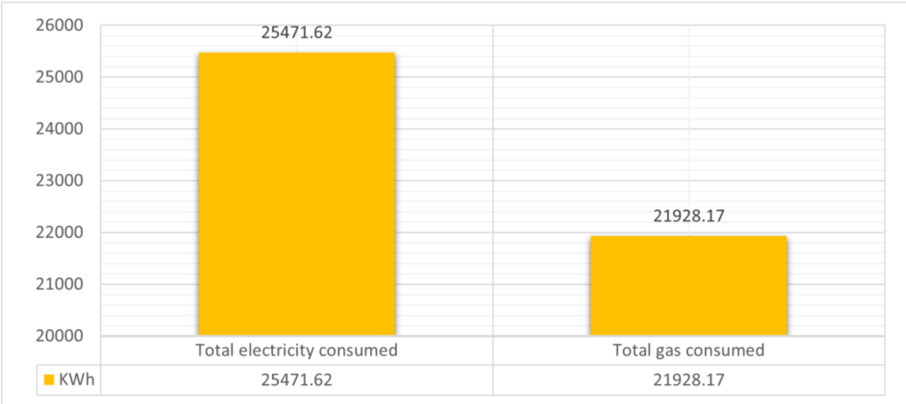


Figure 7. Annual energy consumption using the awning.

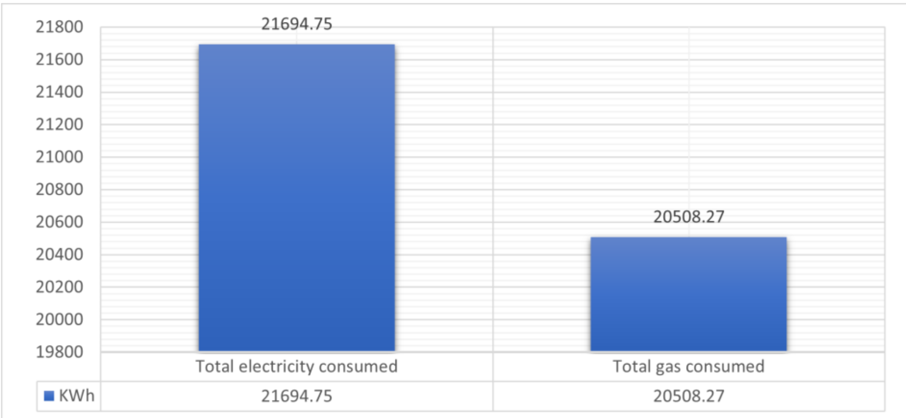


Figure 8. Energy consumption of residential units (3 units) using natural ventilation and awning.

In the next step, the effect of the two variables of awning and natural ventilation was evaluated in order and a stepwise manner on the reduction of energy consumption, the results of which are shown in Figure 7 and 8. The specifications of each variable are as follows:

- Awnings are placed on all the windows of the south wall, which according to Watson's table (Watson and Labs, 1983) have dimensions of 1.6 x 1.5 meters, with a depth of 0.80 and a width of 2.10 meters, according to the simulation data in DesignBuilder software. During the hot period (June 15 to August 15) open the glass surface is open so that 90% is covered by awning. This is important for the cold period (December 15 to February 15) where it covers less than 2%.

- Natural ventilation has been created both through the transverse and through the chimney effect to reduce the cooling load. In such a way that the air enters the ventilation channel from the lowest level of the building, i.e., the pilot, which has the highest positive pressure, and from the end of the channel, which is due to the venturi effect by two valves located opposite each other, and also has a higher temperature than the lower levels. The building has the highest negative pressure in the entire channel chamber, and it exits. This pressure difference creates an upward airflow in the building, which causes the suction of the incoming airflow from the openings into the building. It is worth noting that the use of natural ventilation in these buildings is only for the hot period and in the cold seasons the valves of the ventilation channels are closed.

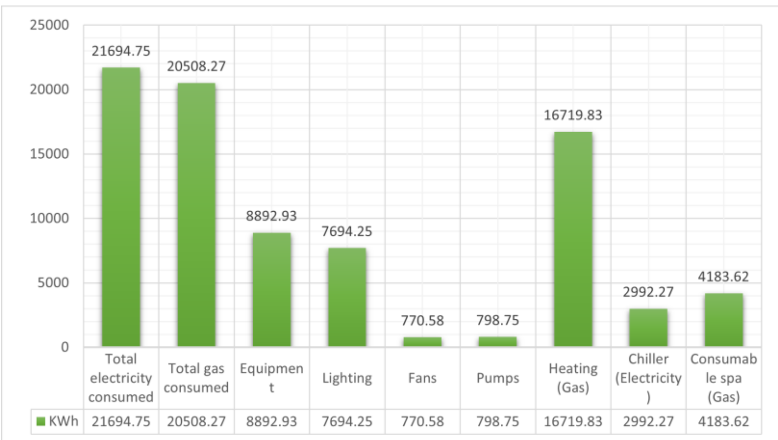


Figure 9. The amount of energy consumption in residential units (4 units) after the application of passive solutions by sector.

During the hot period energy was exported to the energy network and the amount of energy needed for heating that uses natural gas was purchased from the network. In other words, it can be sent to the national power grid during the hot season when the amount of electrical energy produced by the photovoltaic panels exceeds the needs of the buildings in the neighboring unit and, instead, in the cold season, the same amount of natural gas from the energy grid to meet the heating needs of the buildings can be received. For this purpose, to create a balance between the electrical energy exported to the network and the natural gas received, which is from the available data and the use of solar water heaters equal to 15,5429.1 kilowatt hours per year for the existing 8 buildings, it is necessary to use 395 photovoltaic modules. In this case, 850 modules are generally required for 32 existing residential units, and these modules are placed in the form of photovoltaic arrays on the roofs of buildings and the place designed for their deployment on the southeast side of the site (Figure 9).

5. Discussion and Conclusion

We believe this research can be a step towards institutionalizing zero energy buildings in the city of Qazvin and even at the level of Iran as a whole. The solutions presented in this article, including the use of fan coil systems for heating residential spaces, lead to a 37% reduction in energy consumption compared to the radiator system. Moreover, using thermal insulation and materials with high thermal capacity, using suitable awnings and also using suitable benefits and the principles of natural ventilation in the hot season, reduce energy consumption by 35%, 3.4%, and 14%, respectively.

Another important point discussed in this research is the possibility of providing energy to residential units after using passive solutions to reduce energy consumption by using renewable energy systems in such a way that using 457 photovoltaic modules of 265 watts and 26 solar collectors can meet the electricity and hot water needs in 32 residential units (8 buildings with 4 units).

In addition, if 850 photovoltaic modules are used according to the potentials in the design site and the planned locations for the installation of these systems, it is possible to export electricity to the network equal to the amount of natural gas needed for environmental heating. Finally, according to the definitions in the field of zero-energy buildings, a zero-energy system connected to the grid with an annual energy balance was achieved in the form of a neighborhood unit. It should also be mentioned that in this research, the maximum number of modules can be reduced by improving the efficiency of cells and using modern systems, which is also true of solar hot water systems.

One of the important obstacles to achieving the goal of this research is the high cost of benefiting from solar energy systems. It is hoped that by making appropriate decisions in this regard by politicians and officials, it will be possible to see an adjustment and justification of costs in this sector.

Achieving a suitable model in the field of reducing energy consumption in one of the main consumer sectors, i.e., housing, can be considered as one of the most important and strategic issues today in Iran, as in other countries. Therefore, the promotion and development of projects such as the one proposed in this research in the form of a neighborhood unit can imply progress in the direction of preserving the environment and consequently saving energy consumption and increasing national incomes in addition to improving the quality of life in urban environments.

The principal feature of this study is the passage from theoretical to practical steps proposed in the field of zero-energy buildings, which requires a comprehensive change of attitude towards extending research of this kind and it requires far more support than is available today. If achieving sustainable energy seems possible due to the increasing progress of technology, it is important to have international support, determine the priorities of economic policies, attract foreign financial resources, and promote the participation of the private sector in investment, while also extending educational and research programs. If realized, this process can guarantee national interests in the international strategic environment in achieving sustainable energy and sustainable development, preventing pollution caused by the combustion of fossil fuels and enhancing the development of remote areas.

References

Agharabi, A., & Darzi, M. (2023). Optimal location of microturbines in low-rise building blocks for sustainable wind energy utilization (case study: Qazvin city). *Journal of Environmental Studies*, *48*(4), 461-479.

Aram, K., Taherkhani, R., & Šimelytė, A. (2022). Multistage optimization toward a nearly net zero energy building due to climate change. *Energies*, *15*(3), 983.

Attia, S., & Gobin, C. (2020). Climate change effects on Belgian households: a case study of a nearly zero energy building. *Energies*, *13*(20), 5357.

Belussi, L., Barozzi, B., Bellazzi, A., Danza, L., Devitofrancesco, A., Fanciulli, C., ... & Scrosati, C. (2019). A review of performance of zero energy buildings and energy efficiency solutions. *Journal of building engineering*, *25*, 100772.

Chen, S. Y. (2019). Use of green building information modeling in the assessment of net zero energy building design. *Journal of Environmental Engineering and Landscape Management*, *27*(3), 174-186.

Daemei, A. B., Limaki, A. K., & Safari, H. (2016). Opening performance simulation in natural ventilation using design builder (case study: a residential home in Rasht). *Energy Procedia*, *100*, 412-422.

D'Agostino, Delia, and Livio Mazzarella. "What is a Nearly zero energy building? Overview, implementation and comparison of definitions." *Journal of Building Engineering* 21 (2019): 200-212.

Feng, W., Zhang, Q., Ji, H., Wang, R., Zhou, N., Ye, Q., ... & Lau, S. S. Y. (2019). A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. *Renewable and Sustainable Energy Reviews*, *114*, 109303.

Ferrara, M., Prunotto, F., Rolfo, A., & Fabrizio, E. (2019). Energy demand and supply simultaneous optimization to design a nearly zero-energy house. *Applied Sciences*, *9*(11), 2261.

Givoni B. Indoor temperature reduction by passive cooling systems. Solar Energy. 2011 Aug 1;85(8):1692-726.

Groat, L. N., & Wang, D. (2013). *Architectural research methods*. John Wiley & Sons,173-202.

Janzadeh, A., & Zandieh, M. (2022). Design feasibility of a net-zero energy neighborhood in Qazvin. *Energy Efficiency*, *14*(1), 7.

Jareemit, D., Suwanchaisakul, A., & Limmeechokchai, B. (2022). Assessment of key financial supports for promoting zero energy office buildings investment in Thailand using sensitivity analysis. *Energy Reports*, *8*, 1144-1153.

Johansson, O. (2012). The spatial diffusion of green building technologies: The case of Leadership in Energy and Environmental Design (LEED) in the United States. *International Journal of Technology Management & Sustainable Development*, *10*(3), 251-266.

Kosonen, A., & Keskisaari, A. (2020). Zero-energy log house–Future concept for an energy efficient building in the Nordic conditions. *Energy and Buildings*, *228*, 110449.

Liu, Z., Zhou, Q., Tian, Z., He, B. J., & Jin, G. (2019). A comprehensive analysis on definitions, development, and policies of nearly zero energy buildings in China. *Renewable and Sustainable Energy Reviews*, *114*, 109314.

Magrini, A., Lentini, G., Cuman, S., Bodrato, A., & Marenco, L. (2020). From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge-The most recent European trends with some notes on the energy analysis of a forerunner PEB example. *Developments in the Built Environment*, *3*, 100019.

Manzoor, B., Othman, I., Sadowska, B., & Sarosiek, W. (2022). Zero-Energy Buildings and Energy Efficiency towards Sustainability: A Bibliometric Review and a Case Study. *Applied Sciences*, *12*(4), 2136.

Masnadi, M., & Heidari, S. (2010). Roof simulation a method of detailed thermal survey in visual environment. *Honar-Ha-Ye-Ziba: Memary Va Shahrsazi*, *2*(42), 5-8.

Natanian, J., & Auer, T. (2020). Beyond nearly zero energy urban design: A holistic microclimatic energy and environmental quality evaluation workflow. *Sustainable Cities and Society*, *56*, 102094**.**

Ravishankar, E., Booth, R. E., Saravitz, C., Sederoff, H., Ade, H. W., & O'Connor, B. T. (2020). Achieving net zero energy greenhouses by integrating semitransparent organic solar cells. *Joule*, *4*(2), 490-506.

Shakoor, A. (2011). Analysis of the role of natural environment in the compatibility of human settlements with it "emphasizing application of climate in Esfahan rural architecture, Iran". *Australian Journal of Basic and Applied Sciences*, *5*(12), 1524-1526.

Venturi, G. B. (1797). *Essai sur les ouvrages physico-mathématiques de Leonardo de Vinci, avec des fragmens tirés de ses manuscrits, apportés de l'Italie; lu à la première classe de l'Institut, etc*. Duprat.

Watson, D. and Labs, K. (1983) Climate Design: Energy Efficient Building Principles and Practices. McGraw-Hill, New York, 37.

Wu, W., & Skye, H. M. (2021). Residential net-zero energy buildings: Review and perspective. *Renewable and Sustainable Energy Reviews*, *142*, 110859

Authors

Mitra Bagheri *(corresponding author)*
PhD, Architecture and Design Research, VirginiaTech University, USA
mitrab@vt.edu

Danyal Ghanbari Barfeh
MSc of Integrated Innovation for Products and Services, Carnegie Mellon University, USA.

Mahdis Hamisi
PhD, Urban, Community, and Regional Planning, University of Texas Arlington, USA.

Funds

This study received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Bagheri, M., Barfeh, D.G. & Hamisi, M. (2023) Building design based on zero energy approach. *Visions for Sustainability*, 20, 8109, 155-174
http://dx.doi.org/10.13135/2384-8677/8109

Original Paper

PVsyst modeling of 800 kWp capacity grid-tied solar photovoltaic power plant for academic institution

Swati Sharma, Mahipal Bukya, Pancham Kumar

Received: 26 July 2023 | **Accepted:** 20 September 2023 | **Published:** 4 October 2023

Keywords: PVsyst; renewable energy; solar photovoltaic.

Abstract. *The design case study of solar photovoltaic system technology utilising PVsyst is presented in this research. The use of solar photovoltaic systems to produce electricity has increased recently in academic institutions. India is exceptional at producing electricity from both renewable and non-renewable sources. India receives 5,000T kWh of solar energy on average each year, and a major contribution to producing solar-based electricity comes from*

Rajasthan, Gujarat, Karnataka, Tamil Nadu, and Telangana-like states. The key objective of this work is to evaluate an 800 kWp grid-tied solar photovoltaic power plant using the PVsyst software platform for the Manipal University Jaipur campus. In our investigation, efforts have been made to mitigate the power losses that resulted from exposure to light, soiling from temperature changes, wiring, inverters, power electronics, interconnections, and grid availability. The PV modules, solar irradiation, and the photovoltaic system's location all affect how well it performs. According to the findings of our analysis, the average horizontal irradiation across the globe is 5.28 KWh/m2/day, and the PR of a PV plant is 86.25 %. The projected plant's annual output capacity was determined to be 1359796 kWh, which is entirely CO2-free, and it reduced an academic institution's annual power expenditure by Rs 11354296.6.

---

1. Introduction

The equatorial sunbed of the planet, which gets a lot of solar radiation, makes India one of the world's best placed nations for generating electricity from both renewable and non-renewable sources. There is an urgent need for alternative energy sources is driven by the quick depletion of fossil fuel supplies and the expanding facts of global warming. Since it may be utilised to satisfy the world's energy needs, renewable energy offers immense potential (Adaramola, 2014), Alsadi et al., 2018)). There are plenty of renewable energy resources in India's numerous states, including those in Karnataka, Rajasthan, Gujarat, and Telangana. The most popular approach is PV technology, which aims to improve the country's power supply's availability, cost, and dependability (Manisha Sheoran., et al. (2022). The negative effects of using outdated resources at a time when energy demand is increasing have fueled the growth of the solar PV sector. As a result, the Indian government (GOI) promoted the establishment of solar companies and enterprises at cheaper rates and has set an objective to install the 500 GW of renewable power by the end of 2030 (Press Information Bureau, 2017)) for power generation using solar PV Technology. It is now necessary to use renewable energy sources, such as solar, wind, biomass, and small hydropower, to address the issue as fossil fuel-based energy becomes more and more rare. However, the energy generated through the renewable sources is not always available under different environmental conditions (Shankar et al., 2022)). Therefore, the sporadic nature of solar PV technology is a challenging issue (Shankar, A et al., 2023)). Numerous power plants, including solar, wind, hydropower, biomass, geothermal, and many more, have been built for increasing amounts of power generation to maintain a balanced condition of energy generation and combat the depletion of fossil fuel resources. Figure 1 shows the current renewable energy generation in India during 2022-2023, the majority of which comes from solar power.

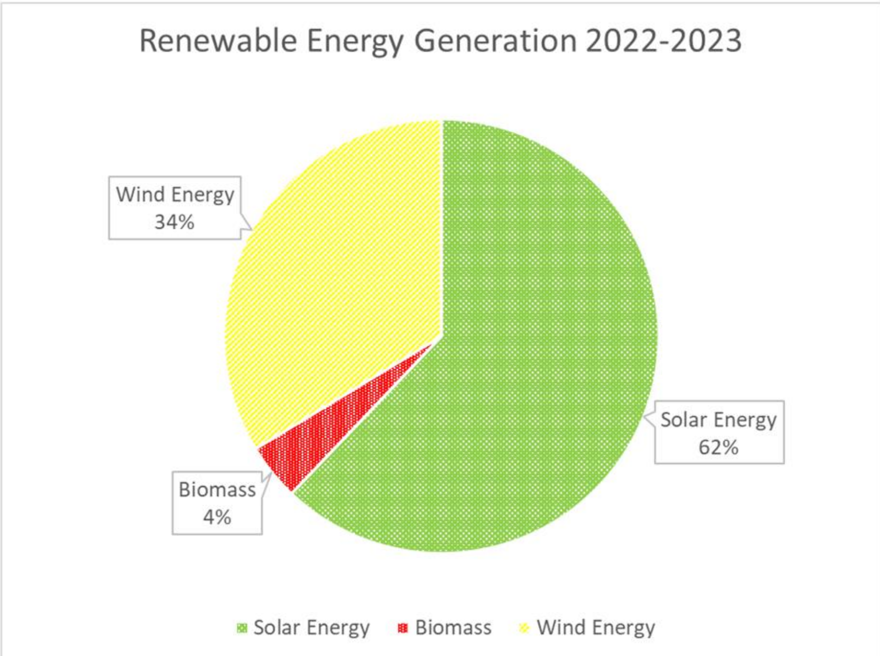


Figure 1. The renewable energy target for the duration 2022-2023 by Indian government

There is no doubt that solar energy has been proven to be one of the best renewable energy sources because solar energy stands out among renewable sources due to its reliability and accessibility. Unlike wind and hydro power, solar energy is consistent, as the sun reliably shines daily. Moreover, solar panels can be installed almost anywhere, from rooftops to remote areas, making it more versatile than geographically dependent sources like hydroelectricity. Solar power also trumps biomass and geothermal energy in terms of scalability and environmental impact, as it does not require large land areas or disturb ecosystems. The importance of solar energy can be determined by the solar constant which is a fundamental physical constant that represents the amount of solar electromagnetic radiation received at the outer atmosphere of Earth on a unit area perpendicular to the Sun's rays. It is approximately equal to 1361 Watts per square meter (W/m^2). This value remains relatively constant because the Solar energy output remains stable over time. The solar constant is a crucial parameter for understanding and calculating the amount of solar energy available at the earth surface. However, the actual amount of solar energy reaching the earth's surface varies throughout the day and across different locations due to factors such as atmospheric absorption, scattering, and earth tilt and orbit. Despite these variations, the solar constant provides a standardized reference point for scientists and engineers to estimate solar energy availability and design solar PV systems (Xiao et al., 2007). Additionally, the solar constant can be determined by the amount of solar radiation reaching Earth which ensures a vast, sustainable energy resource that can be harnessed globally, making solar energy a front-runner in the transition to a clean and sustainable energy future. In literature, to overcome the low efficiency and obtain desirable power in partial shading conditions, the maximum power point tracking system (MPPT) helps extract the maximum power from solar photovoltaic systems (Bollipo et al, 2021). All the conventional algorithms at standard temperature and irradiance provide better performance and reach maximum power. But in practice, the irradiance and the temperature keep changing. If the case persists for rapidly changing irradiance, all the conventional MPPT systems will fail to track the maximum power (Xiao et al, 2007). Based on the parameters and values of the requirements of the MPPT offline and online methods, the control signals are generated based on the solar PV system. The online approach provides instantaneous values for PV systems. In the literature, various MPPT techniques have been reported. The voltage-current-based MPPT approach, perturbation and observation-based MPPT approach, temperature and irradiance method, intelligent techniques, and fuzzy logic-based optimisation methods. Based on this, the maximum power generation through the online method creates an ambiguous variation in generating power in solar PV systems (Sher et al., 2015) as they are often observed due to multifaceted factors. These encompass daily and seasonal sunlight fluctuations, weather dynamics, shading effects, and equipment performance disparities. Literature suggests that inconsistent power output can result from complex interactions among these variables, making accurate predictions challenging. Additionally, differences in PV panel technologies, installation angles, and maintenance practices further contribute to variability. Researchers explore advanced forecasting models, smart grid integration, and improved system monitoring to mitigate these uncertainties. Understanding and addressing these multifarious influences is essential for enhancing the reliability and efficiency of solar PV systems. Thus, this paper attempts to concentrate on the modelling of an academic building's 800 kWp solar power plant for more power generation and better efficiency. The functioning blocks of the solar power plant are depicted in Figure 2 (Kumar et al, 2023, Garg et al., 2022).

The solar array for the planned 800 kWp plants is made up of a configuration of solar panels coupled in series and parallel. The Direct Current Distribution (DCDB) box is used to connect the array to a grid-tied inverter. The DCDB box performs protective measurements similar to those of surge protection and Miniature Circuit Breakers (MCBs). An inverter transforms the input from a DC solar array into an AC output that is compatible with the grid and synchronised with it. For further safety, the output of the inverter is linked to an Alternating Current Distribution (ACDB) box with built-in MCB and surge protection devices.

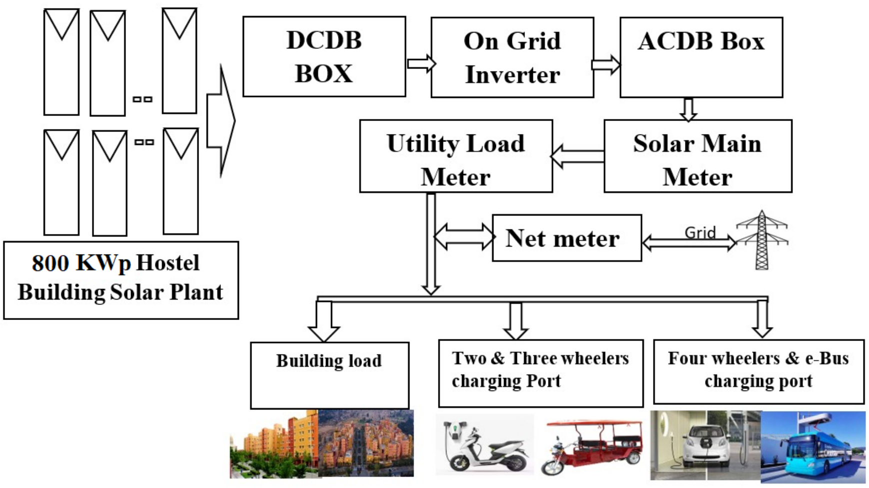


Figure 2. 800 KWp academic building solar power plant schematic diagram

Inverters have the capacity to take anti-islanding protective measures. The output of the ACDB is connected to the main solar meter, where we can track statistics on solar generation, and to the utility panel. Devices for solar net metering are used for energy import and export. In Figure 3, the actual plant images are shown, along with a single-line design of the plant and the interconnected arrangement of the solar array, inverters, and other components. Figure 3(a) illustrates the geographical positioning of the solar plant site; Figure 3(b) depicts the arrangement of the solar panels within the plant; Fig. 3(c) shows the inverters; Figure 3(d) presents the remote monitoring system utilized; and Figure 3(e) shows the ACDB and DCDB boxes. Several nations have constructed solar photovoltaic power plants far beyond the average level worldwide. India has huge solar-radiated energy-generating potential. It benefits from a lot of sun irradiation because of its advantageous location, which lasts virtually the entire year.

Figure 3. MUJ installed 800 kWp solar power plant photo

India's land mass is expected to absorb around 5000 trillion kWh of solar energy per year, with the majority of the nation receiving 4.7 kWh/m2/day of solar irradiance (Bukya et al., 2023)). Due to the fast cost reductions in PV modules throughout the world, PV (photovoltaic) systems are anticipated to become one of the primary sources of power in the future. A grid-connected PV-generating network's performance is analysed and measured primarily using the simulation system. PVsyst software is used in this study to measure and analyse the performance of the grid-connected PV system (Kumar et al., 2015), Manisha Sheoran et al., 2022).

2. Analysis and modeling of the solar plant using PVsyst

The performance of a grid-connected PV system with a capacity of 800 kWp was investigated using the PVsyst simulation platform. PVsyst V7.3.4 is a comprehensive software tool used for the design, analysis, and simulation of solar photovoltaic (PV) systems. It helps assess the energy production, financial feasibility, and performance of PV installations. PVsyst incorporates various factors like weather data, shading, system components, and site-specific information to optimize PV system designs and predict energy generation. It is a valuable tool for professionals in the solar industry, helping them make informed decisions and maximize the efficiency of solar projects. All the power losses that occur due to irradiation, soiling, temperature, wiring, inverters, power electronics, interconnections, and grid availability are considered. There are a total 2496 number of 799 Wp Trina Solar makes solar photovoltaic modules, and eight 80 kW, 3-ϕ, 400 V delta energy make inverters are used to construct an 800 kWp grid-connected solar photovoltaic system. The technical datasheets of solar photovoltaic modules and inverters are shown in Tables 1 and 2, respectively.

Technical datasheet of 799-Watt Trina solar panel along with the output of solar panel at standard test conditions and Input/Output diagram for energy injected into the grid as shown in Figure 4.

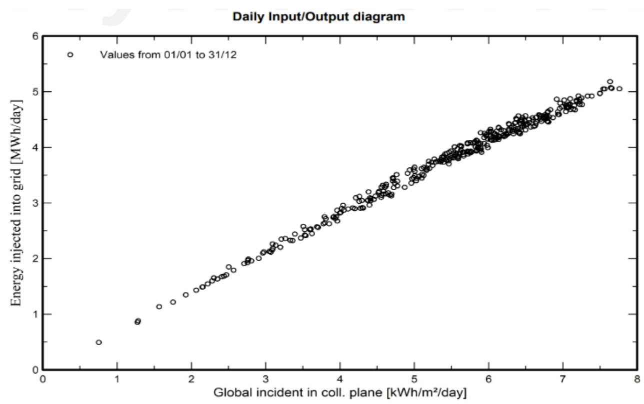


Figure 4. Input/Output diagram for energy injected into the grid

Model		TSM-DE 19-799 Wp Vertex	
Pnom STC Power (Manufacturer)	799 kWp	Technology	Si-mono
Module Size (Modules)	2496 Modules	Rough module area (Amodule)	4179 m^2
Number of cells		Sensitive area cells (A cells)	m^2
Specifications for the model (Manufacturer or measurement data)			
Reference temperature (Tref)	50 °C	Reference irradiance (Gref)	1936 kW/m^2
Open circuit voltage (Voc)	37.9 V	Short Circuit Current (Isc)	18.52 A
Max. power point voltage (Vmpp)	31.6 V	Max. power point current (Impp)	17.40 A
=> maximum power (Pmpp)	742 kWp	Isc temperature coefficient (mulsc)	7.4 mA/°C
One-diode model parameters			
Shunt Resistance (Rshunt)	200 Ω	Diode saturation current (IoRef)	0.040 nA
Series Resistance (Rseries)	0.12 Ω	Voc temp. coefficient (MuVoc)	-105 mV/°C
Specified Pmax temper. Coeff. (muPMaxR)	-0.34%/°C	Diode Quality Factor (Gamma)	1.00
		Diode factor temper. Coeff. (mu Gamma)	0.0001/°C
Reverse- Bias Parameters, for use in behavior of PV arrays under partial shadings or mismatch			
Reverse characteristics (dark) (BRev)	3.20 mA/V^2	(Quadratic factor (per cell))	
Number of by-pass diodes per module	3	Direct voltage of by-pass diodes	-0.7 V
Model results for standard conditions (STC: T=50°C, G=1936 kW/m^2, AM=1.25)			
Max. power point voltage (Vmpp)	31.3 V	Max. power point current (Impp)	1088 A
Maximum power (Pmpp)	742 kWp	Power temper. Coefficient (U mpp)	
Efficiency (/module area) (Eff_mod)	21.1%	Fill factor (FF)	0.784
Efficiency (/cell area) (Eff_cells)	22.7%		

Table 1. Technical datasheet of 799-Watt Trina solar panel (Trina solar (2020))

The inverter efficiency curve and system output power distribution is depicted in Figure 5. Figure 6 depicts the solar PV array configurations. All modules are set at a 0° azimuth with a 15° inclination facing south and are free of any shading influence.

Figure 5 shows that a total of 2496 solar panels are used to build 192 strings of 13 series modules. Eight 80kWp inverters with 16 MPPT units are employed, and their output is pumped into the grid.

Inverter – Solar Inverter M80H (480 VAC)			
Model	**Solar Inverter M80H (480 VAC)**		
Commercial Data		**Data Source**	
Protection:	IP65		
Control:	Display operational data	Width	615 mm
		Height	950 mm
		Depth	275 mm
		Weight	84.00 kg
Input characteristics (PV array side)			
Operating mode	MPPT	Nominal PV Power (Pnom DC)	80 kW
Minimum MPP Voltage (Vmin)	200 V	Maximum PV Power (Pmax DC)	89 kW
Maximum MPP voltage (Vmax)	800 V	Power Threshold (Pthresh)	396 W
Absolute max. PV Voltage (Vmax array)	1000 V		
Min. Volatge for PNom (Vmin@Pnom)	635 V		
"String" Inverter with input protections		**Multi MPPT Capability**	
Number of string inputs	18	Number of MPPT inputs	2
Behavior at Vmin/Vmax	Limitation		
Behaviour at Pnom	Limitation		
Output Characteristics (AC grid side)			
Grid Voltage (Imax)	Triphased 480 V	Nominal AC Power (Pnom AC)	80 kWac
Grid Frequency	50/60 Hz	Maximum AC Power (Pmax AC)	88 kWac
Maximum efficiency	98.8 %	Nominal AC current (Inom AC)	97 A
European average efficiency	98.4%	Maximum AC current (Imax AC)	106 A

Table 2. Technical datasheet of inverter

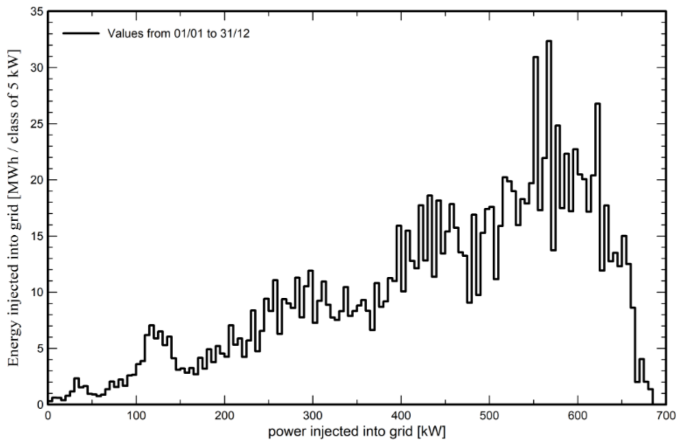


Figure 5. System Output Power Distribution

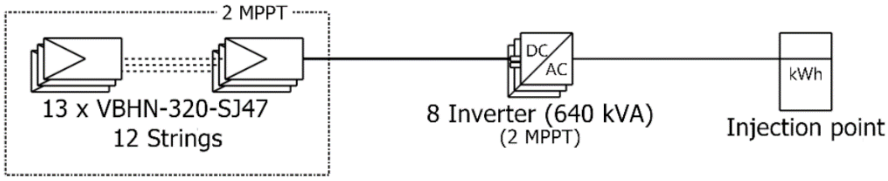


Figure 6. Solar PV Array Configurations

3. Results and Discussion

Maximum energy generation occurs in February, while minimal energy generation occurs in July, according to the PVsyst simulation. Figure 7 summarizes the entire performance evaluation and performance ratio of the 800 KW Solar PV Plant at the educational institution. Figure 8 depicts a power loss diagram for a solar PV plant with 800 kW of capacity owing to irradiance, soiling, temperature, wiring, inverter, power electronics, interconnections, and grid availability.

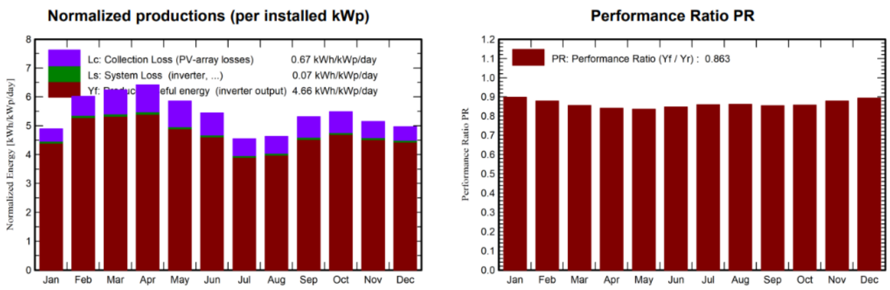


Figure 7. Performance Evaluation and Performance Ratio of the 800 KW Solar PV Plant.

Legends: E Array - Effective energy at the output of the array; E - Grid – Energy injected into grid; PR – Performance Ratio

Most electricity is added to the system in April, and the least in July. The average horizontal radiation was calculated to be 1793 kWh/m2 worldwide. It was determined that there was a total of 1973.8 kWh/m2 of incident energy on the collector plane. A performance ratio of 86.25% was recorded for the PV system.

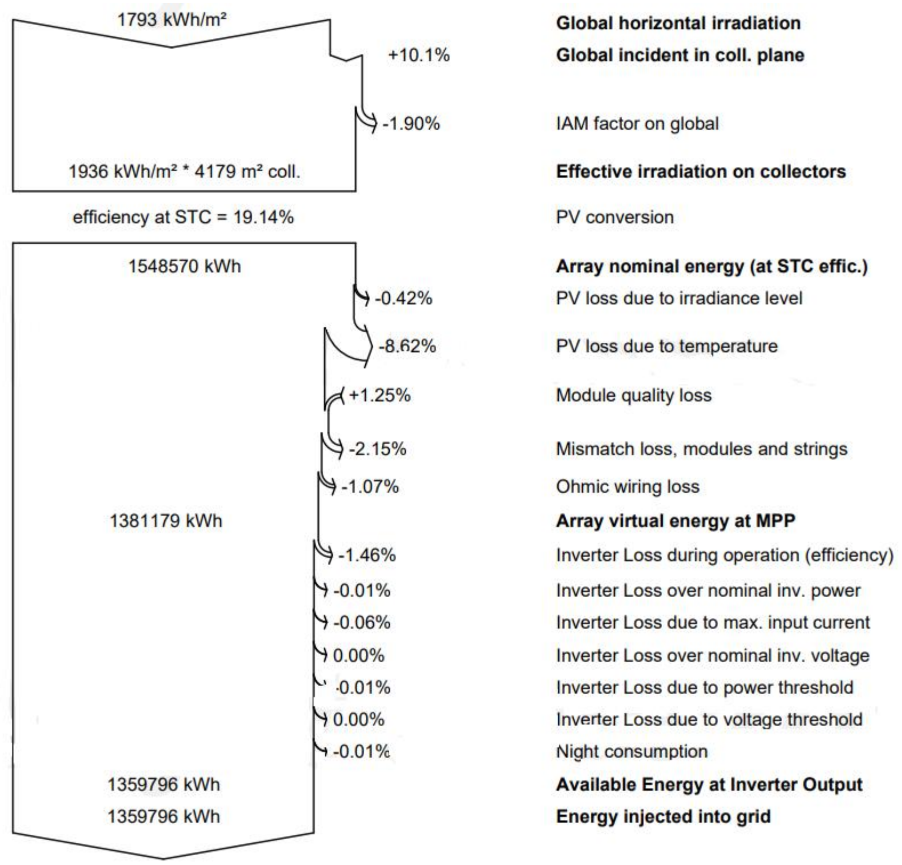


Figure 8. Loss diagram over the whole year

4. Conclusion

PVsyst software is used to design solar systems for educational organizations. The outcomes obtained by PVsyst provide valuable insights into the photovoltaic (PV) module. The performance ratio exhibits an increase as load demand decreases and the energy produced is proportional to that of the load. Additional analysis is conducted to evaluate the system's performance, revealing that it is deemed highly commendable and satisfactory when subjected to a load of around 800 kW. The grid-connected, roof-mounted 800 kWp solar PV system's performance was assessed, and monthly and yearly output characteristics were established. The PVsyst software tools were used to simulate the data. The present research's most significant findings are outlined. The grid receives the largest energy injection in March and the least in August. With a PR of 86.25%, the 800 kWp solar PV system is operating effectively. During the examination, it was found that the Solar PV array produced 1359796 kWh of CO_2-free solar energy in the fiscal year 2022. The reduction in its annual power bill of Rs11354297. Around Rs. 28,38,57,425 would be saved from the power cost during a 25-year period. This is clearly a significant contribution to generating electricity from renewable sources.

Acknowledgements

Thanks to Manipal University Jaipur, Project Team and Maintenance Engineers for their assistance for data collection and technical reports for reference.

References

Adaramola, M. S. (2014). Viability of grid-connected solar PV energy system in Jos, Nigeria. *International Journal of Electrical Power & Energy Systems*, 61, 64–69. https://doi.org/10.1016/j.ijepes.2014.03.015

Ahmadi, M.H., Ghazvini, M., Sadeghzadeh, M., Nazari, M.A., Kumar, R., Naeimi, A. & Ming, T. (2018), Solar power technology for electricity generation: A critical review, *Energy Sci. Eng.* 6, 5, 340-361. https://doi.org/10.1002/ese3.239

Alsadi, S., & Khatib, T (2018) Photovoltaic Power Systems Optimization Research Status: A Review of Criteria, Constrains, Models, Techniques, and Software Tools. *Appl. Sci.* 8, 1761. https://doi.org/10.3390/app8101761

Bollipo, R.B., Mikkili, S. & Bonthagorla, R.K. (2021). Hybrid optimal intelligent and classical PV MPPT techniques: A review, *CSEE J. Power Energy Syst.* 7, (1), 9-33. https://doi.org/10.17775/CSEEJPES.2019.02720

Bukya, M., Kumar, P. & Kumar, R. (2023). On-Grid Solar Photovoltaic Power Plant Analysis Under PVsyst Simulation Software Platform. In: Dwivedi, S., Singh, S., Tiwari, M., Shrivastava, A. (eds) Flexible Electronics for Electric Vehicles. *Lecture Notes in Electrical Engineering*, vol 863. Springer, Singapore. https://doi.org/10.1007/978-981-19-0588-9_41

Garg, P., Bukya, M. and Kumar, P. (2022). Cost Benefit Analysis of 50 kW Solar Power Plant for Educational Hostel Building, *2nd International Conference on Innovative Sustainable Computational Technologies (CISCT)*, Dehradun, India, 2022, pp. 1-5. https://doi.org/10.1109/CISCT55310.2022.10046533

Kumar, P., Bukya, M., Shankar, A., Garg, P. & Gowtham, N. (2023) An experimental approach towards cost benefit analysis of 850 kW solar PV plant. *Visions for Sustainability*, 19, 7213, 255-266. http://dx.doi.org/10.13135/2384-8677/7213

Kumar B. S. and K. Sudhakar (2015). Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India*, Energy Reports*, vol. 1, pp. 184–192, 2015. https://doi.org/10.1016/j.egyr.2015.10.001

Sheoran, M., Kumar, P., Sharma, S. & Bukya, M. (2022), Current situation analysis of solar PV waste management in India, *Materials Today: Proceedings*, 58 (2), 773-782. https://doi.org/10.1016/j.matpr.2022.03.118.

Press Information Bureau (2017), Ministry of New and Renewable Energy, Government of India. [Online URL: https://archive.pib.gov.in/archive2/erelease.aspx]

Sharma S, Kurian, C.P. & Paragond L.S. (2018). Solar PV System Design Using PVsyst: A Case Study of an Academic Institute, 2018 *International Conference on Control, Power, Communication and Computing Technologies (ICCPCCT),* Kannur, India, 2018, pp. 123-128, https://doi.org/10.1109/ICCPCCT.2018.8574334.

Trina solar (2020) The vertex back sheet monocrystalline module trina solar, [Online URL: https://www.trinasolar.com/en-apac].

Shankar, A. and Bukya, M. (2022) Decentralization to decarbonize the Indian economy. *Visions for Sustainability*, 19, 7153, 223-239. http://dx.doi.org/10.13135/2384-8677/7153

Shankar, A., and Bukya, M. (2023) Demystifying the economic and energy potential of Building-Integrated Photovoltaics in achieving India's intended Nationally Determined Contribution. *Visions for Sustainability*, 19, 7291, 241-254. http://dx.doi.org/10.13135/2384-8677/7291

Sher, H.A., Murtaza, A.F., Noman, A., Addoweesh, K.E., Al-Haddad, K. & Chiaberge, M. (2015) A new sensorless hybrid MPPT algorithm based on fractional short-circuit current measurement and P&O MPPT, *IEEE Trans. Sustain. Energy*, 6 (4),. 1426-1434. https://doi.org/10.1109/TSTE.2015.2438781

Xiao, W., Dunford, W.G., Palmer, P.R. & Capel, A. (2007), Application of centered differentiation and steepest descent to maximum power point tracking, *IEEE Trans.*

Ind. Electron., vol. 54, no. 5, pp. 2539-2549, Oct. 2007. https://doi.org/10.1109/TIE.2007.899922

Authors

Swati Sharma
Department of Electrical Engineering, Jamia Millia Islamia New Delhi, India.

Mahipal Bukya *(corresponding author)*
Department of Electrical and Electronics Engineering, Manipal Institute of Technology Bengaluru, Manipal Academy of Higher Education, Manipal, India. mahipalbhukya@gmail.com

Pancham Kumar *(corresponding author)*
Faculty of Electrical Skills Education, Bhartiya Skill Development University Jaipur, India. pancham006@gmail.com

Funds

This study received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Sharma, S., Bukya, M. & Kumar, P. (2023) PVsyst modeling of 800 kWp capacity grid-tied solar photovoltaic power plant for academic institution. *Visions for Sustainability*, 20, 7941, 175-188. http://dx.doi.org/10.13135/2384-8677/7941

Original Paper

The carbon footprint of a university campus.

Case study of Yildiz Technical University, Davutpaşa Campus, Turkey.

Senem Yazici Guvenc, Seda Canikli, Emine Can-Güven, Gamze Varank, Halil Emre Akbas

Received: 25 January 2023 | **Accepted:** 12 July 2023 | **Published:** 20 July 2023

Keywords: carbon footprint; sustainability; Yildiz Technical University; IPCC; DEFRA.

Abstract. *In this study, the carbon footprint of Yildiz Technical University (YTU), Davutpaşa Campus was calculated to draw attention to the sustainable use of resources, what needs to be done against global climate* *change, and to reveal the responsibilities of universities in this regard and the importance of their contributions. This study was carried out to emphasize the need for higher education institutions to lead in reducing the carbon footprint in every living area in our country. IPCC and DEFRA methods were used to calculate the carbon footprint. The emission values obtained for 2019 and 2020 were 15244.4 and 7213.3 t of* CO_2*, respectively. The largest component of emissions is electricity consumption, followed by transportation. The obtained values are similar to the results of the studies conducted on other university campuses. The reason for the low emission value in 2020 is the application of the online education system due to the pandemic. The precautions to be taken to reduce the carbon footprint are stated and suggestions are made. YTU, which has already adopted a new environmental policy, is rapidly advancing towards becoming a sustainable campus. In line with the sustainable campus vision, the carbon footprint is expected to decrease significantly.*

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) defines the term climate change as "change in climatic conditions occurred by long-term changes in climate characteristics" (Eggleston et al., 2006). On the other hand, the United Nations Framework Convention on Climate Change (UNFCCC) attributed climate change directly or indirectly to human activities (UN, 1992). Both definitions of climate change are based on direct or indirect human impact.

Depending on the population growth in the world, anthropogenic greenhouse gas emissions show a rapid increase. Atmospheric concentrations of carbon dioxide, methane, and nitrogen oxides have reached their highest levels in recent years. Greenhouse gases have been accepted as one of the main causes of climate change and global warming since the middle of the 20th century. Anthropogenic greenhouse gas emissions (carbon dioxide, methane, and nitrogen oxides) have been increasing since the beginning of industrialization. Carbon exists as carbon dioxide in the atmosphere (2 %), biomass in terrestrial plants and soils (5 %), fossil fuels in various geological reservoirs (8 %), and as a combination of ions in the ocean (85 %) (McKinley, 2009). The greenhouse gases emitted to the atmosphere as a result of human activities include carbon dioxide (54.7 %), methane (30 %), other gases (9.8 %), nitrous oxide (4.9 %), and fluorinated gases (0.6 %) (IPCC, 2007).

Cumulative anthropogenic CO_2 emissions between 1750 and 2011 were measured as 2040 Gt CO_2 on average; about 40 % of this remained in the atmosphere, and the rest was stored in the land and oceans. The 30 % absorbed by the oceans causes ocean acidification. More than half of the total anthropogenic CO_2 emissions between 1750 and 2011 occurred in the last 40 y (Pachauri et al., 2014). Total greenhouse gas emissions increased more rapidly from 1970 to 2010, with the greatest increase occurring between 2000 and 2010 despite the measures taken regarding climate change. About 78 % of the increase in total greenhouse gas emissions from 1970 to 2010 comes from fossil fuel use and industrial processes. Similar values were observed between 2000-2010. Globally, economic and population growth are the most important reasons for the increase in CO_2 emissions due to fossil fuel use. Although the population growth between 2000 and 2010 is not different from the last three periods of 10 y, very significant growth was observed in the economy (Pachauri et al., 2014).

As stated in the 4th assessment report of the IPCC, the increase in CO_2 concentrations can be explained by direct and indirect human activities such as fossil fuel use, transportation, heating and cooling activities, manufacturing, and other industrial activities. Carbon dioxide emissions are the largest contributor to climate change (IPCC, 2007) and carbon dioxide emissions can be estimated by the carbon footprint concept. Carbon footprint states to the greenhouse gas emissions released into the atmosphere during the production of the energy needed for each product we purchase or each activity we perform (Bonamente et al., 2015). Since each activity has a different carbon footprint, it is necessary to calculate different factors by carrying out studies on an individual or company basis (Widmann & Minx, 2008). Various methods and standards have been developed in the international arena for carbon footprint calculation. In addition to the methods published by the IPCC, the GHG Protocol, ISO 14064, and PAS 2050 come first among the standards that deal with the 6 main greenhouse gases (CO_2, CH_4, N_2O, PFCs, HFCs, SF6) in the Kyoto Protocol (Güllü, 2011). First, an analysis of the current situation is required to set targets for reducing the carbon footprint. The carbon footprint, which is an indicator that emerges in greenhouse gas accounting (Wiedmann et al., 2010), emerges as a measure that includes direct and indirect greenhouse gas emissions (WRI/WBCSD, 2004).

Turkey became a party to the UNFCCC in 2004 and the Kyoto Protocol in 2009. As an Annex-1 country of the Convention, Turkey is obliged to prepare the greenhouse gas emissions and sinks that cannot be controlled with the Montreal

Protocol with the IPCC methodology and send the national greenhouse gas emission inventory to the UNFCCC Secretariat. By becoming a party to the UNFCCC and the Kyoto Protocol, Turkey has demonstrated its desire to struggle with climate change, and the greenhouse gas emission inventory is the cornerstone of the fight against climate change. Achieving success in this struggle is only possible with the contribution of all segments of society. Universities, private sector organizations, public institutions, non-governmental organizations, and, of course, citizens, who are the biggest stakeholders of society, should act with high awareness and responsibility for sustainability. Universities are institutions that have pioneered society by producing scientific solutions to social problems. In this struggle, it is the responsibility of universities to investigate the causes of global warming, to put forward strategies to reduce the components that cause global warming and to improve them qualitatively, and to determine the measures to be taken. Considering all these issues, universities should first calculate their carbon footprint and implement them by taking the necessary precautions. YTU is one of the largest universities in Turkey with more than 25,000 students and more than 3,000 academic and administrative staff and the Davutpaşa Campus is the central campus of the university. Although reducing greenhouse gas emissions is of great importance on this campus, where human activities are intense, Turkey's leading universities must do this work in terms of awareness. The aim of this study was not only to determine the carbon footprint of YTU Davutpaşa Campus considering the emissions caused by various activities such as fuel use, electricity consumption, vehicle emissions, water consumption and waste amount, but also to create awareness in all segments of the society, primarily universities in Turkey and to be a driving force. Although there are many studies on the determination of the contribution of the carbon footprint to global warming by revealing the universities in the world, the number of studies on this subject in Turkey is limited. The fact that Yıldız Technical University is located in Istanbul, the largest city in Turkey, makes a difference in terms of the size of the components of this footprint. At the same time, these studies are both more difficult and more important in big cities. This study will make a significant contribution to the literature both scientifically and socially in terms of being in YTU, one of the largest universities in Istanbul and one of the largest universities in Turkey.

2. Materials and Methods

2.1 The study area

The Davutpaşa Campus of YTU, which continues its educational activities with 9 faculties, 2 institutes, a school of foreign languages, and more than 25,000 students, was chosen as the study area. The boundary of the campus included in the study is given in Figure 1 (p. 14). Technopark, student dormitory, restaurants, cafes, and lodgings located on the Davutpaşa Campus are not included in the study. A total of 26,842 students including 19,157 undergraduate and 7,685 graduate students are present at the Davutpaşa Campus.

2.2. The calculation method

In this study, the university's direct and indirect greenhouse gas emissions are grouped under three headings. A schematic representation of the emission sources evaluated under 3 headings is given in Figure 2 (p. 15). Emissions originating from the university itself and causing direct greenhouse gas emissions are under heading 1, emissions that are a result of energy consumption and indirectly emitted to the atmosphere are under heading 2, and emissions originating from university activities but not under the control of the university are grouped under heading 3 (Wiedmann et al., 2010). The consumption of natural gas used as fuel in YTU, Davutpaşa Campus, and emissions from vehicles belonging to the rectorate are evaluated under heading 1, and emissions from electricity consumption are under heading 2. Emissions arising from the vehicles belonging to both administrative, academic staff, and students, and buses traveling within the border of the campus, the water consumption of the university, and the emissions from domestic wastes are evaluated under heading 3.

The calculation method of GHG emissions provided by the IPCC was used in the study (Wiedmann et al., 2010). To make the calculations, it is necessary to determine the emission sources and emission factors related to these sources. The carbon footprint of each source was calculated by multiplying the data on emission sources and emission factors (WRI/WBCSD, 2004). IPCC (2006) (Eggleston et al., 2006) guidelines and DEFRA (2016) (WRI/WBCSD, 2004) sources were used for emission factors. The amount of emissions arising from the electricity consumption purchased by YTU, which is evaluated under heading 2, is calculated by multiplying the monthly electricity consumption data obtained from the YTU Rectorate with the emission factors obtained from DEFRA (DEFRA, 2016) and TUIK (TUIK, 2012). Emission factors taken from DEFRA

(DEFRA, 2016) were used to calculate the amount of fuel-related emissions. To calculate the carbon footprint from the fuel, the amount of fuel used was multiplied by the emission factors obtained for N_2O, CH_4, and CO_2. Emission amounts and carbon footprint values due to water consumption were calculated by multiplying water consumption data and the emission factor obtained by Sawant et al. (2015). While calculating the emissions for the vehicle fleet belonging to the YTU Rectorate, passenger vehicles are categorized as large vehicles. Engine volume and fuel type were considered in the calculation of the carbon footprint of passenger vehicles while engine volume, fuel type, and weight was used in the calculation for large vehicles (DEFRA, 2016). Emission values were calculated by multiplying the selected emission factors with the annual average km of the vehicles. Table 1 (p. 21) and Figure 3 (p. 16) show the natural gas, electricity, and water consumption data of YTU Davutpaşa Campus for 2019 and 2020.

3. Results and Discussion

In Table 2 (p. 22) and Table 3 (p. 23), carbon footprint values based on electricity consumption data of Davutpaşa Campus for 2019 and 2020 are given. The schematic representation of the carbon footprint values is given in Figures 4 and 5 (p. 17). The calculated emission values are the carbon footprint resulting from the electricity consumption of the campus and are expressed as t of CO_{2e}.

Under heading 1, fuel consumption for heating purposes and vehicle emissions belonging to the Rectorate of YTU Davutpaşa Campus were evaluated. Natural gas is used as fuel for heating purposes on the campus. Based on the DEFRA (DEFRA, 2016) values, the data obtained for the Davutpaşa Campus for 2019 and 2020 are given in Table 4 (p. 24) and Table 5 (p. 25). In Figure 6 (p. 18), carbon footprint values based on natural gas consumption data of the Davutpaşa Campus are given.

Based on the emission factors taken from the IPCC (Eggleston et al., 2006), the emission of natural gas used for heating was calculated. The CO_2 emission factor used in the calculations is 56.10 kg CO_2/GJ and the unit of natural gas consumed is m^3. Unit conversion is required for the calculation. To convert billion m^3 to GJ, it is necessary to multiply by 37,681,200 GJ/billion m^3. The emission amounts calculated for 2019 and 2020 based on the IPCC (Eggleston et al., 2006) emission factors are given in Table 6 (p. 26) and Table 7 (p. 27), and the schematic representation of the values is given in Figure 7 (p. 18). It can be seen from the tables that the emission values are directly related to the amount of consumption.

Therefore, the use of systems such as isolation and automation will reduce the amount of carbon footprint. Tables 2-5 show that the carbon footprint values calculated using the DEFRA (DEFRA, 2016) and IPCC (Eggleston et al., 2006) emission factors are close to each other. The carbon footprint of YTU Davutpaşa Campus resulting from monthly water consumption in 2019 and 2020 is given in Table 8 (p. 28) and Table 9 (p. 29), and the schematic representation of the values is given in Figure 8 (p. 19).

Another source of CO_2 emission is food consumption. Since calculating the emissions from food consumption is complex, it is necessary to narrow the scope. Therefore, in this study, five groups, namely bread, vegetables, fish, red meat, and chicken, were determined for the types of food consumed to calculate the carbon footprint resulting from food consumption. Emission factors used in the calculation of emission values due to food consumption and the amount of consumed food are given in Table 10 (p. 30), and the calculated emission amounts are given in Table 11 (p. 30). The schematic representation of the emission values from food consumption is given in Figure 9 (p. 19).

The amount of emissions due to domestic waste is calculated by multiplying the amount of waste generated on campus by the emission factor. There are 25 containers on the Davutpaşa campus. The volume of a container is 770 liters and garbage is collected 6 days a week, except Sunday. It is assumed that the unit volume weight of solid wastes is 0.5 kg/L and the fill rate of the containers is 90 %. Using these data, the amount of waste on campus is calculated as 2494800 kg per year. The carbon footprint was determined by multiplying this calculated amount with the emission factor. Accordingly, the amount of carbon footprint caused by domestic waste was calculated as 52.4 t of CO_{2e}.

Emission values calculated for passenger and large vehicles in the vehicle fleet of the Rectorate are given in Table 12 (p. 31). The total CO_{2e} emission value of the Rectorate's vehicle fleet is 43.95 t per year. In addition to the vehicle fleet of the Rectorate, 13 gasoline Toyota brand vehicles with 1500 engine capacity were rented. The CO_{2e} value of rental vehicles, calculated using the DEFRA (DEFRA, 2016) emission factors, is 2 t per vehicle, and the total emission value of 13 vehicles is 26 t. The total emission value of the vehicle fleet is 69.95 t of CO_2 per year and 5.83 t per month.

In YTU Davutpaşa Campus, the number of vehicles with stickers is 1435, and the number of personal vehicles belonging to academic and administrative staff is calculated as 1722 considering vehicles that do not have stickers. It is assumed that 10 % of these vehicles belong to the staff living in the lodgings and that vehicles coming from outside the campus travel an average of 35 km per day, and vehicles located within the campus travel 3 km per day. The number of academic and administrative staff working at YTU is 2386. If it is accepted that 720 people from the total staff use the staff service vehicle and 360 people provide transportation by public transportation (15 %), the number of vehicles entering the campus from outside can be considered as 1306. A gasoline vehicle consumes 10.7 L/100 km of gasoline in the city and generates 254.7 g CO_2/km emissions. A vehicle using LPG consumes 11.2 L/100 km of gas and generates 266 grams of CO_2/km emissions. A diesel vehicle consumes 9.8 L/100 km of diesel in the city and causes 233 grams of CO_2/km emissions (EPA, 2001). It is assumed that 45 % of the personal vehicles belonging to academic and administrative staff are gasoline, 45 % diesel, and 10 % LPG. Considering that there are 20 workdays per month, the monthly distance traveled by vehicles coming from outside the campus was calculated as 914200 km, and the monthly distance covered by the vehicles located on the campus is calculated as 10320 km. The total distance traveled is 924520 km. The emission value from gasoline vehicles is 105672 kg, the emission value from diesel vehicles is 92562 kg and the emission value from LPG vehicles is 24592 kg. The total emission resulting from the transportation of academic and administrative staff to the campus using their vehicles was calculated as 222826 kg CO_2 per month. Assuming that 500 student vehicles enter the campus per day, these vehicles travel 35 km per day and arrive at campus 4 days a week, the total distance covered is 280000 km per month. The total emission value was calculated as 68040 kg per month. While calculating the annual emission amount, it was taken into account that the academic year is 180 days, but the academic and administrative staff enter and leave throughout the year.

The number of YTU staff service vehicles is 40, the urban diesel consumption amount of the buses is 35 L/100 km and the emission amount is 1034.61 g CO_2/km (EPA, 2001). Assuming that the distance traveled by the service vehicles is 35 km per day, the total distance traveled is 28000 km per month. The amount of emissions from service vehicles is 28969 kg per month. 5 vehicles perform 60 ring trips a day from Cevizlibağ, and 2 vehicles complete 10 ring trips a day to the Beşiktaş campus. The distance traveled for the Cevizlibağ expedition is 9.7 km, and the distance covered for the Beşiktaş expedition is 36 km. The total distance covered daily is 942 km and 18,840 km per month. The total emission value caused by ring services is 19492 kg per month. The 41AT-coded bus of the IETT conducts 53 trips per day to Davutpaşa Campus. The buses, which travel 3 km on the campus, cover a total of 159 km per day and 3180 km per month. The total emission value from public buses entering the campus is

3290 kg per month. 26842 students receive education at Davutpaşa Campus. It is assumed that 7 % of these students do not attend school, among attending students 15 % attend 5 days a week, 15 % two days a week, 40 % four days a week, and 30 % three days a week. It is accepted that the students who come to the school travel an average of 35 km per day. According to these assumptions, 3750 of the approximately 25000 students attending Davutpaşa Campus come to school five days a week, 3750 students two days a week, 10000 students four days a week, and 7500 students three days a week. Assuming that students use buses to come to school and a bus takes 50 passengers, buses travel 62125 km per week and 248500 km per month. For 2019, 2236500 km covered in 9 months means 2313.9 t of CO_2 emissions per year while 497000 km covered for 2020 means 514.2 t CO_2 emissions. The transportation-related emissions of the Davutpaşa Campus are given in Table 13 (p. 32). Emission amounts from sources under headings 1, 2, and 3 are summarized in Table 14 (p. 32) and a schematic representation is given in Figure 10 (p. 20).

YTU Davutpaşa Campus has a total area of 1250000 square meters and a forest area of 220000 square meters. When it is assumed that one tree falls per 10 m^2 in the forest area, it is concluded that there are 22000 trees. Considering that each tree absorbs 25 kg of CO_2 per y, 22000 trees absorb 550 t of CO_2 in a year. While there is 12952.3 t of CO_2 emissions in 2019 and 6701.1 t of CO_2 emissions in 2020 in YTU Davutpaşa Campus, only 550 t of this emission can be absorbed by trees. The remaining part reaches the atmosphere. In Table 15 (p. 33), the studies carried out at various university campuses in Turkey and YTU Davutpaşa Campus are given. Emission values calculated for campuses are close to each other, and it is essential to reduce this value for all campuses.

4. Conclusions and Recommendations

In this study, the carbon footprint of Yildiz Technical University Davutpaşa Campus for 2019 and 2020 was calculated. The results of the study showed that the largest component of the CO_2 emission in the Davutpaşa campus in 2019 was transportation followed by electricity consumption. In 2020, the largest component was electricity consumption. The reason why the emissions from transportation and the emission value obtained for 2020 corresponds to approximately half of the value obtained for 2019 is that online education started in March 2020 due to the pandemic. The carbon footprint of the YTU Davutpaşa Campus is similar to the results of studies conducted on other university campuses. However, it should be noted that the results obtained do not show an exact amount. Because there is a lack of data on some resource consumption and calculations were made by making various assumptions. The measures and suggestions to be taken to prevent climate change due to global warming and support sustainable life by reducing the carbon footprint of universities, which should lead the society in matters such as sustainability and efficient use of natural resources, are given below:

- Educational seminars should be organized and projects should be conducted at the universities to raise awareness about environmental problems, global climate change, and zero waste.
- Elective courses covering environmental issues, nature protection, global climate change, and sustainable use of natural resources should be included in the course plans of all departments of the university and the selection of these courses should be encouraged.
- Studies that provide savings in water, electricity, heating, and transportation and projects that will form a basis for these studies should be carried out to reduce the carbon footprint.
- Waste management plans should be made to ensure waste minimization and separation of wastes at the source, and encouraging steps should be taken especially regarding recycling and recovery.
- Studies on the use of renewable energy (i.e., wind and solar energy) within the scope of sustainability should be increased and it should be aimed that the university produces its energy.
- Regular afforestation studies should be carried out every year to reduce the carbon footprint.
- Savings and awareness should be created by conducting projects for the reuse of rainwater and gray water.
- Heat loss should be prevented by performing insulation in buildings.
- Emission-reducing measures should be taken regarding transportation to the university.
- A large number of studies and projects are currently carried out at the university to find solutions to sustainable development, global climate change, and other environmental problems. Our university, which has been working on afforestation since its establishment, has been rapidly advancing towards becoming a sustainable campus by adopting a new environmental policy in recent years. Sustainable campus studies are expected to contribute to a significant decrease in carbon footprint values over time.

Yıldız Technical University is rapidly advancing towards becoming a sustainable campus by adopting the green campus approach. For this purpose, studies are carried out to create ecological awareness in many areas such as energy conservation, waste management, and water sustainability. This study covers the years 2019-2020. The studies and measures taken in line with this goal as of these years are given below to set an example for other campuses:

- Preferring the use of energy-efficient appliances at points where the use of electrically consuming appliances is necessary, monitoring the energy consumption throughout the campus, renewing electronic appliances with new generation equipment with less energy consumption during renovation and maintenance works (natural lighting windows designed to make maximum use of daylight in the buildings. Smart systems such as LED lighting, automatic doors, and automatic lighting systems in all buildings throughout the campus to be used during dark hours, air-conditioning systems with high energy efficiency "inverter" technology, energy-efficient devices with "Class A" certificate in areas such as laboratories and faculty kitchens, 20-30 % Energy-Star certified computers and printers that consume less energy.
- To reduce waste, all official correspondence of our university is made electronically, and all document signing and paperwork is carried out over the electronic system at the university, thus saving on stationery costs and waste generation.
- Designing waste containers, special purpose containers, and creating a temporary waste storage area to help students, staff, and guests separate waste effectively and simply on YTU campuses.
- To maintain the water cycle, green area arrangement to protect natural drainage areas, use of drought-resistant or low-water maintenance plants in water management in landscaped areas, improvement of soil drainage, correct design and implementation of irrigation system.
- The use of a tank/rain harvest tank to collect the rainwater flowing from the roof gutters to reduce the tap water used in the landscaping areas on the campus, the use of the water in the rain harvest tank for irrigation of open green areas with economic and smart systems with sensors.

While this study reveals the current situation in YTU as an important data source in terms of the period it was carried out, it will shed light on similar studies to be carried out in other universities in Turkey and around the world. Following this study, it is planned to conduct a more comprehensive study covering both pre-pandemic and post-pandemic spanning a wider period. In this way, the effects of the studies and measures taken to reduce the carbon footprint will be revealed, and the data to be obtained will be an example for other universities.

Acknowledgments

We acknowledge the financial support by "Yildiz Technical University-The Scientific Research Projects Coordinatorship" with the research project number SBA-2019-3650

References

Binboğa, G., & Ünal, A. (2018). Sürdürülebilirlik Ekseninde Manisa Celal Bayar Üniversitesi'nin Karbon Ayak İzinin Hesaplanmasına Yönelik Bir Araştırma. *Uluslararası İktisadi ve idari İncelemeler Dergisi*, *21*, 187–202.

Bonamente, E., Scrucca, F., Asdrubali, F., Cotana, F. & Presciutti, A. (2015). The Water Footprint of the Wine Industry: Implementation of an Assessment Methodology and Application to a Case Study. *Sustainability*, *7*(9), 12190–12208.

DEFRA. (2016). *Department for Environment, Food & Rural Affairs, UK Government GHG Conversion Factors for Company Reporting*.

Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (2006). *2006 IPCC guidelines for national greenhouse gas inventories*.

EPA, U. (2001). *Vehicle Emission Factors*.

Güllü, G. (2011). *Ankara, Sera gazı Emisyon Envanteri Hesaplama Yöntemleri.*

IPCC. (2007). Climate Change 2007: Synthesis Report. IPCC, Geneva, Switzerland. *Intergovernmental Panel on Climate Change Working Groups I, II and III*.

McKinley, G. A. (2009). *Components, Carbon and Climate; Basic Information on the Major Cycle, of the Global Carbon*. http://carboncycle.aos.wisc.edu/

Pachauri, R. K., Gomez-Echeverri, L. & Riahi, K. (2014). Synthesis report: summary for policymakers. *Cambridge University Press*.

Sawant, S. & Babaleshwar, B. (2015). A New Method of Assessment and Equations on Carbon Footprint. *J. Appl. Geology and Geophysics*, *3*, 52–59.

TUIK. (2012). Sera gazı emisyon miktarları. *Türkiye İstatistik Kurumu*.

UN. (1992). United nations framework convention on climate change. In *United Nations*.

Widmann, T. & Minx, J. (2008). *A definition of "carbon footprint."*

Wiedmann, T., Wood, R., Minx, J. C., Lenzen, M., Guan, D. B. & Harris, R. (2010). A Carbon Footprint Time Series Of The Uk-Results From A Multi-Regionİnput-outputModel. *Economic Systems Research*, *22*(1), 19–42.

WRI/WBCSD. (2004). The Greenhouse Gas Protocol: a Corporate Accounting and Reporting Standard. *Sustainable, World Resources Institute and World Business Council for Development (WRI/WBCSD).*

Note about Figures and Tables

Figures and Tables can be downloaded from the respective separate pdf files at this link: http://dx.doi.org/10.13135/2384-8677/7317

Authors

Senem Yazici Guvenc, Emine Can-Güven (*corresponding author*), Gamze Varank. Yildiz Technical University, Faculty of Civil Engineering, Department of Environmental Engineering, 34220, Istanbul, Turkey; ecguven@yildiz.edu.tr

Seda Canikli, Halil Emre Akbas.
Yildiz Technical University, Faculty of Economic and Administrative Sciences, Department of Administration, 34220, Istanbul, Turkey

Funds

This work was supported by "Yildiz Technical University-The Scientific Research Projects Coordinatorship" with the research project number SBA-2019-3650

Competing Interests

The authors declare that they have no conflict of interest.

Citation

Guvenc, S.Y., Canikli, S., Can-Güven, E., Varank, G., Akbas, H.E. (2023). The carbon footprint of a university campus. Case study of Yildiz Technical University, Davutpaşa Campus, Turkey. *Visions for Sustainability*, 20, 7317, 189-221. http://dx.doi.org/10.13135/2384-8677/7317

Appendix 1 – Figures

Figure 1. The boundary of YTU, Davutpaşa Campus (adopted from Google Maps)

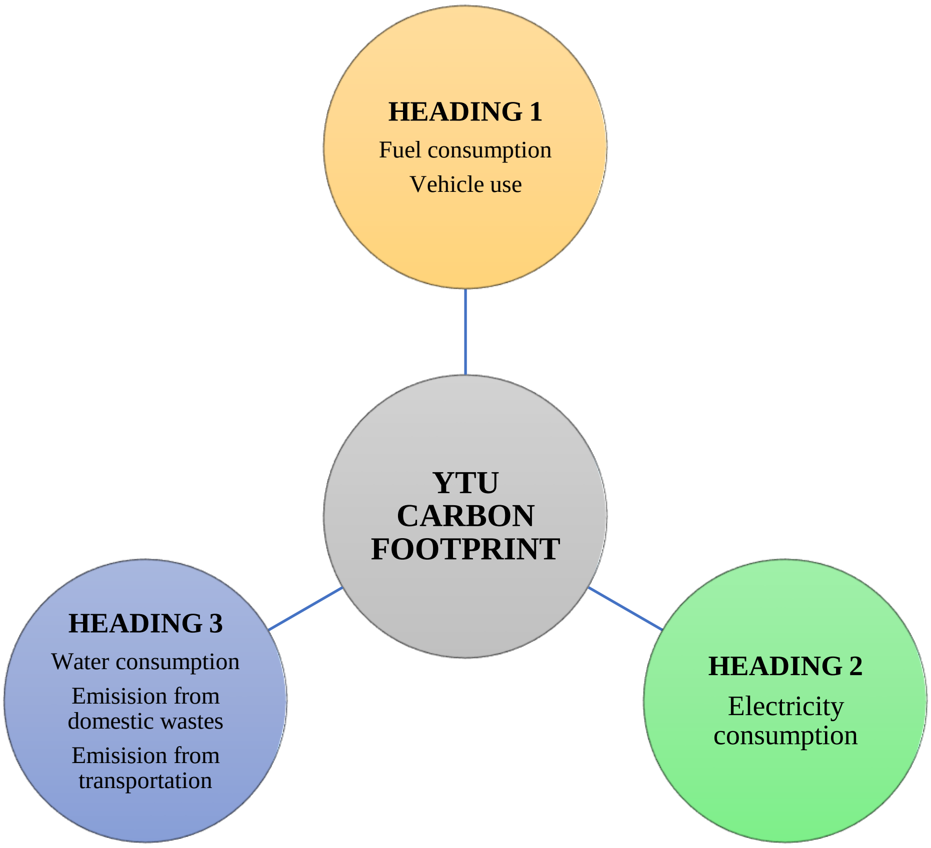


Figure 2. Schematic representation of greenhouse gas emission sources of YTU Davutpaşa Campus

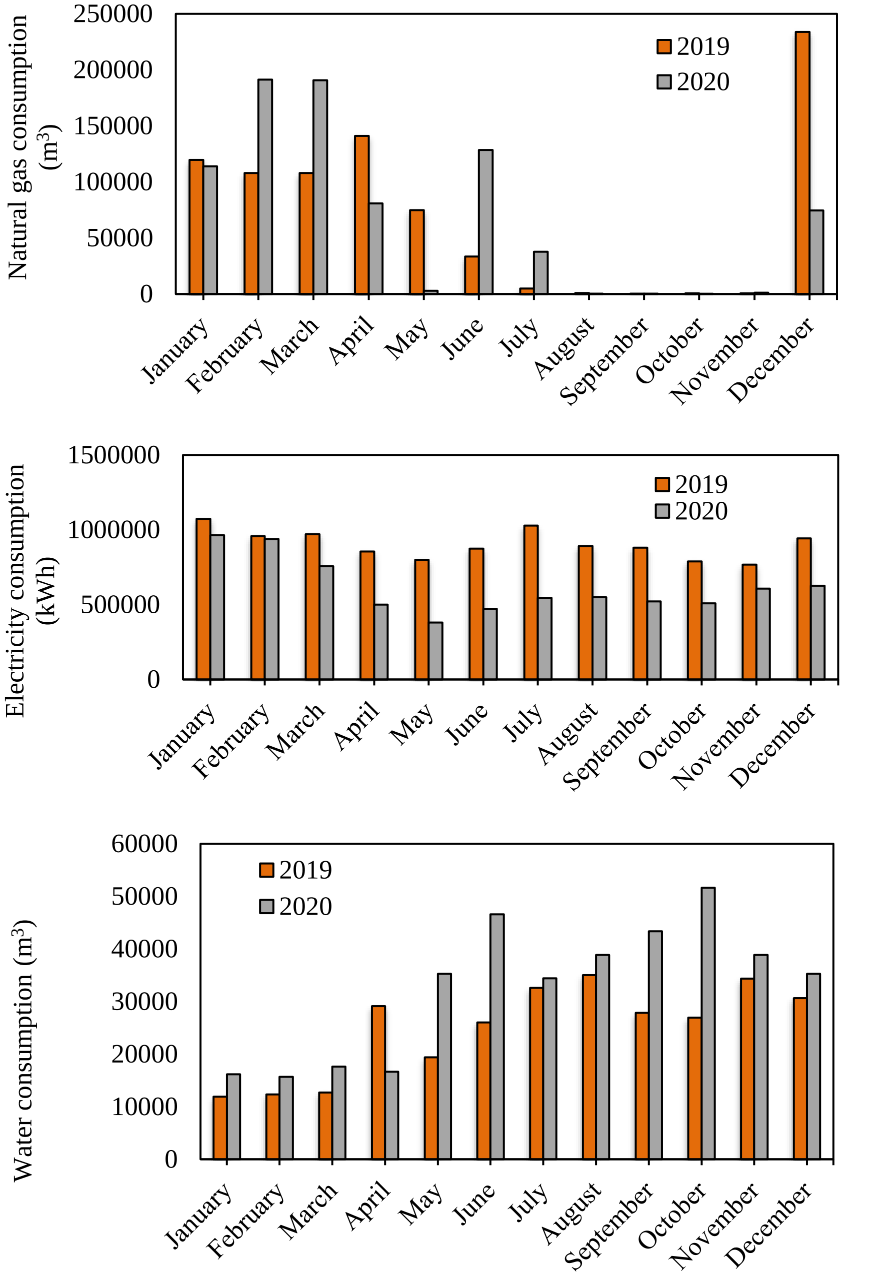


Figure 3. Consumption data for 2019 and 2020 Davutpaşa Campus

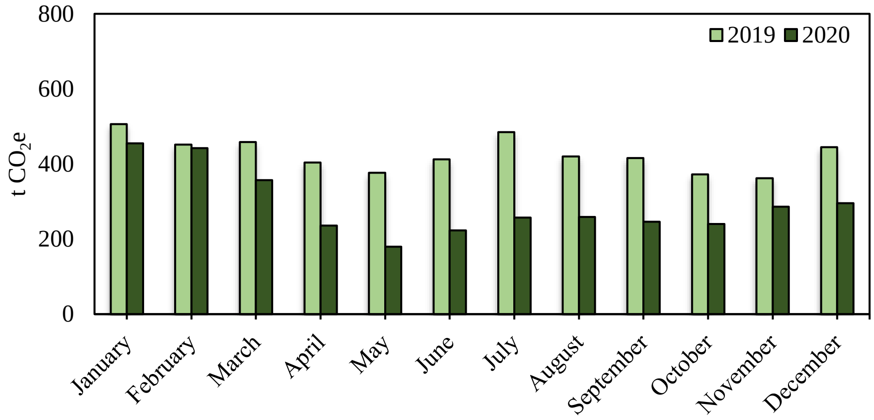


Figure 4. The carbon footprint values of Davutpaşa Campus based on electricity consumption data (DEFRA)

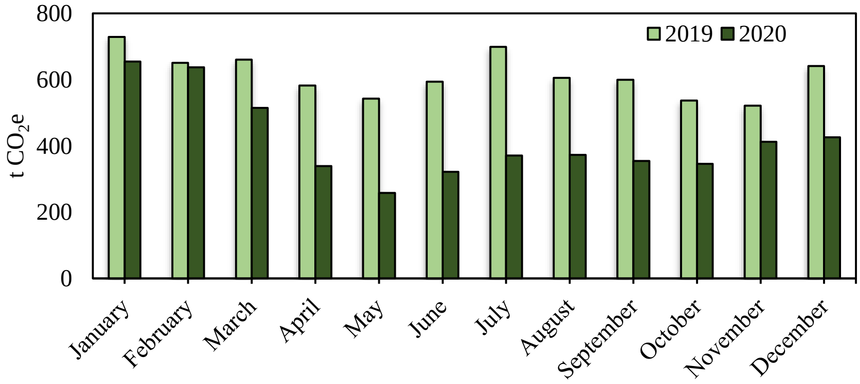


Figure 5. The carbon footprint values of Davutpaşa Campus based on electricity consumption data (DEFRA)

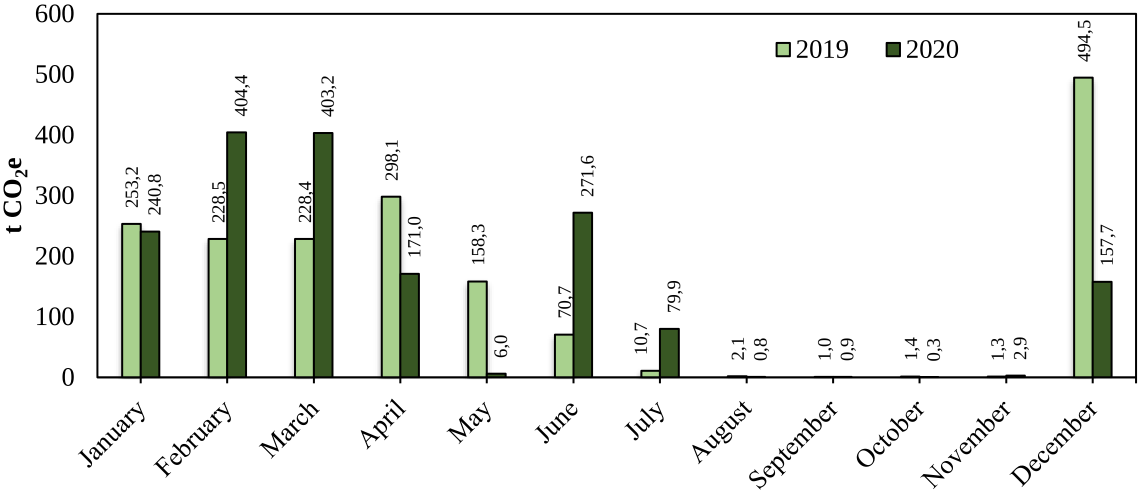


Figure 6. The carbon footprint values of Davutpaşa Campus based on natural gas consumption data.

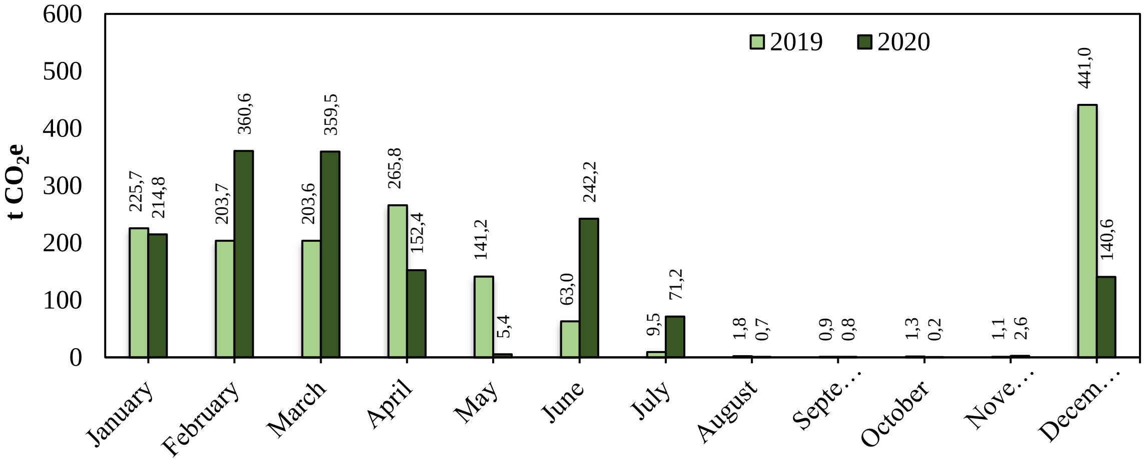


Figure 7. Carbon footprint values due to natural gas consumption of Davutpaşa Campus (IPCC)

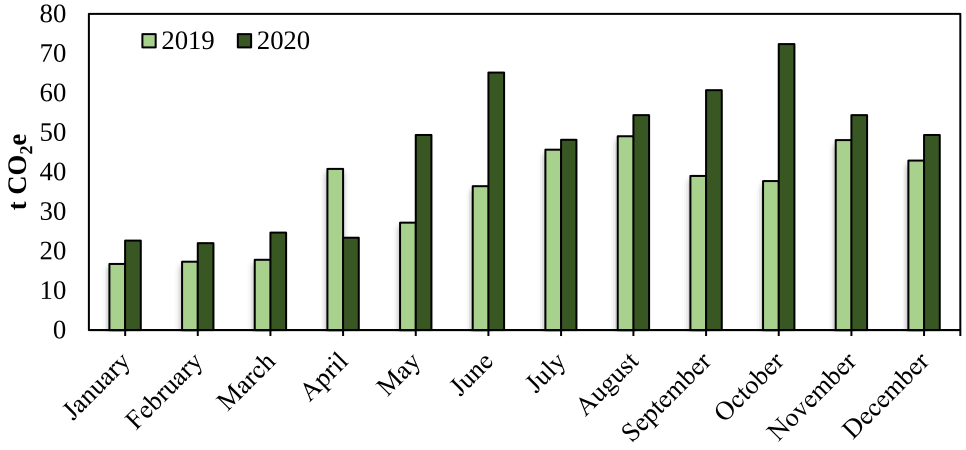


Figure 8. Carbon footprint values due to water consumption of Davutpaşa Campus

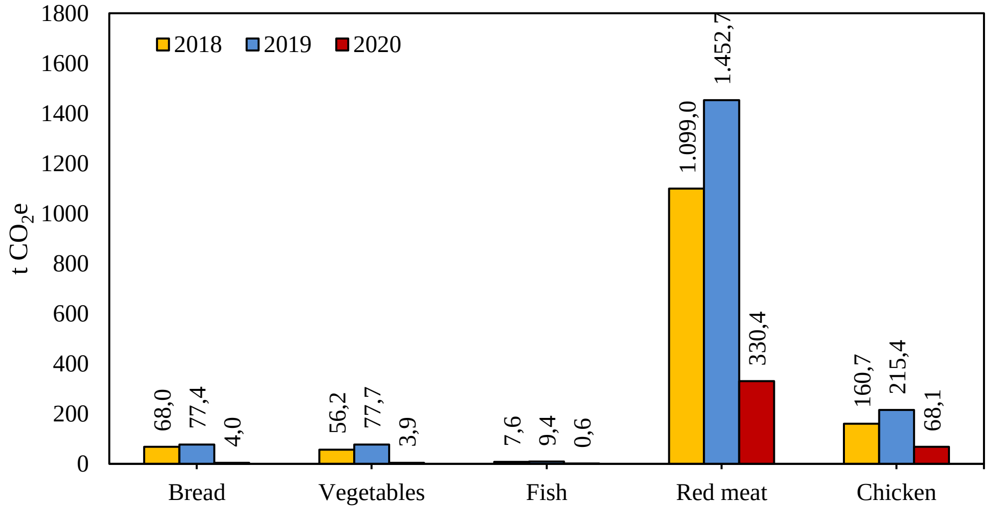


Figure 9. The emission amounts of YTU Davutpaşa Campus due to food consumption

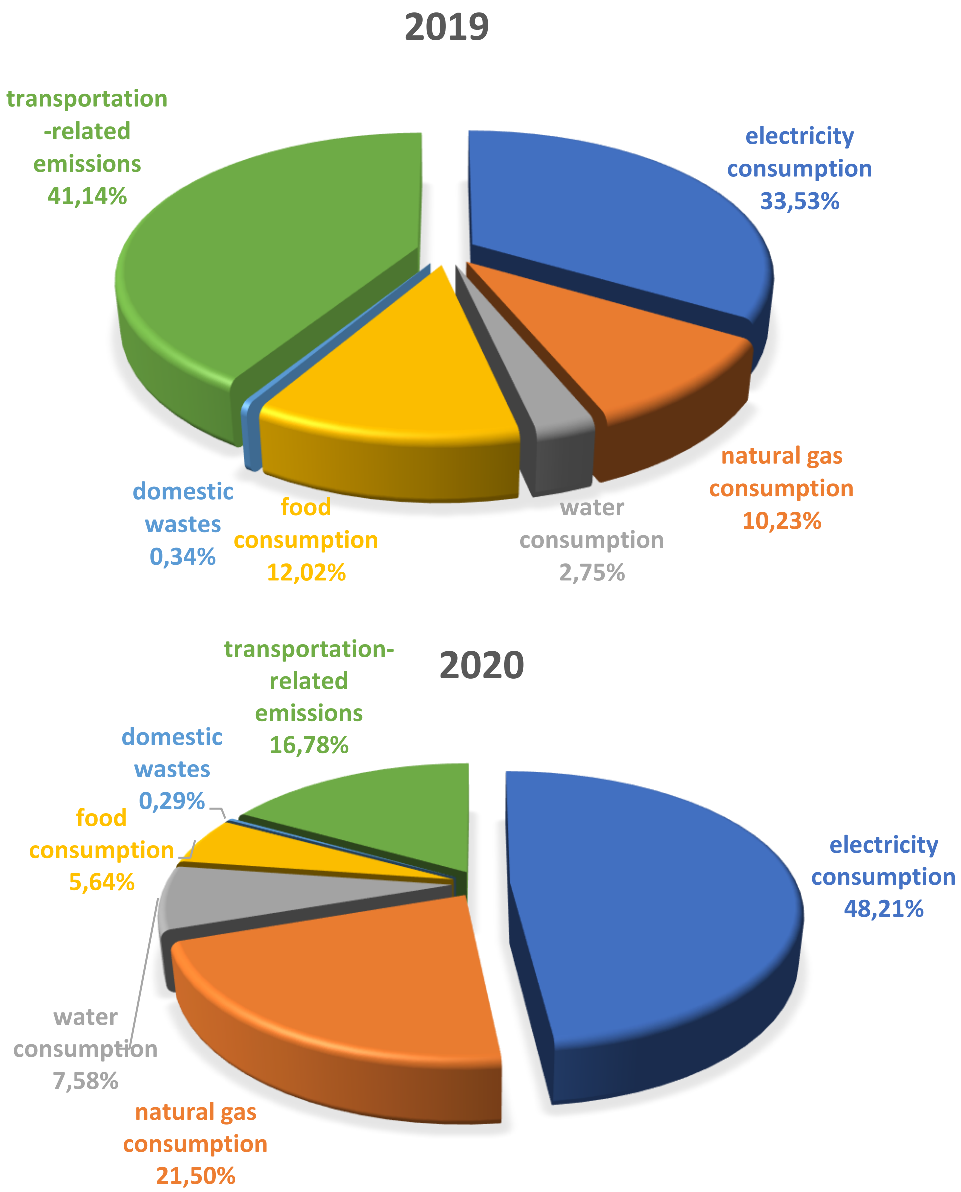


Figure 10. The total emission values of the Davutpaşa Campus

Appendix 2 – Tables

Table 1. Natural gas, electricity, and water consumption data for Davutpaşa Campus

	Natural gas consumption (m^3)		Electricity consumption (kWh)		Water consumption (m^3)	
	2019	2020	2019	2020	2019	2020
January	119,757.356	113,927.000	1072,549.8	963,233.1	11,928.00	16,183
February	108,079.050	191,284.000	957,230.1	937,751.4	12,325.00	15,697.00
March	108,030.437	190,741.000	971,554.5	756,771.3	12,723.00	17,643.00
April	141,028.155	80,870.000	855,696.6	499,346.1	29,100.00	16,670.00
May	74,881.906	2,847.000	798,668.1	380,238.3	19,409.00	35,273.00
June	33,431.305	128,494.000	873,664.2	472,932.9	25,996	46,564.00
July	5,060.000	37,783.000	1027,423.8	544,886.1	32,583.00	34,397.00
August	980	396	890,451.9	548,363.7	35,039.00	38,871.00
September	467.000	446.000	881,343.9	521,495.1	27,833.00	43,346.00
October	675	131	789,622.2	508,785.3	26,958.00	51,664.00
November	609.000	1,354.000	767,079.9	607,006.8	34,357.00	38,871.00
December	233,946.350	74,595.000	942,760.8	626,550.3	30,657.50	35,273.00
Total	**826,945.56**	**822,868.00**	**10,828,045.8**	**7,367,360.40**	**298,908.50**	**390,452.00**

Table 2. Carbon footprint values due to electricity consumption of Davutpaşa Campus in 2019

2019	**Electricity consumption (kWh)**	**Emission factor (DEFRA 2016) (kg CO_2/kWh)**	**Emission factor (TUIK 2012) (kg CO_2/kWh)**	**Emission value (DEFRA 2016) (kg CO_2)**	**Emission value (TUIK 2012) (kg CO_2)**	**Carbon footprint (DEFRA 2016) (t CO_{2e})**	**Carbon footprint (TUIK 2012) (t CO_{2e})**
January	1,072,549.8	0.472	0.68	506,243.5	729,333.9	506.2435	729.3339
February	957,230.1	0.472	0.68	451,812.6	650,916.5	451.8126	650.9165
March	971,554.5	0.472	0.68	458,573.7	660,657.1	458.5737	660.6571
April	855,696.6	0.472	0.68	403,888.8	581,873.7	403.8888	581.8737
May	798,668.1	0.472	0.68	376,971.3	543,094.3	376.9713	543.0943
June	873,664.2	0.472	0.68	412,369.5	594,091.7	412.3695	594.0917
July	1,027,423.8	0.472	0.68	484,944	698,648.2	484.944	698.6482
August	890,451.9	0.472	0.68	420,293.3	605,507.3	420.2933	605.5073
September	881,343.9	0.472	0.68	415,994.3	599,313.9	415.9943	599.3139
October	789,622.2	0.472	0.68	372,701.7	536,943.1	372.7017	536.9431
November	767,079.9	0.472	0.68	362,061.7	521,614.3	362.0617	521.6143
December	942,760.8	0.472	0.68	444,983.1	641,077.3	444.9831	641.0773
Total	**10,828,045.8**	**0.472**	**0.68**	**5,110,838**	**7,363,071**	**5110.838**	**7363.071**

Table 3. Carbon footprint values due to electricity consumption of Davutpaşa Campus in 2020

2020	Electricity consumption (kWh)	Emission factor (DEFRA 2016) (kg CO_2/kWh)	Emission factor (TUIK 2012) (kg CO_2/kWh)	Emission value (DEFRA 2016) (kg CO_2)	Emission value (TUIK 2012) (kg CO_2)	Carbon footprint (DEFRA 2016) (t CO_{2e})	Carbon footprint (TUIK 2012) (t CO_{2e})
January	963,233.1	0.472	0.68	454,646	654,998.5	454.646	654.9985
February	937,751.4	0.472	0.68	442,618.7	637,671	442.6187	637.671
March	756,771.3	0.472	0.68	357,196.1	514,604.5	357.1961	514.6045
April	499,346.1	0.472	0.68	235,691.4	339,555.3	235.6914	339.5553
May	380,238.3	0.472	0.68	179,472.5	258,562	179.4725	258.562
June	472,932.9	0.472	0.68	223,224.3	321,594.4	223.2243	321.5944
July	544,886.1	0.472	0.68	257,186.2	370,522.5	257.1862	370.5225
August	548,363.7	0.472	0.68	258,827.7	372,887.3	258.8277	372.8873
September	521,495.1	0.472	0.68	246,145.7	354,616.7	246.1457	354.6167
October	508,785.3	0.472	0.68	240,146.7	345,974	240.1467	345.974
November	607,006.8	0.472	0.68	286,507.2	412,764.6	286.5072	412.7646
December	626,550.3	0.472	0.68	295,731.7	426,054.2	295.7312	426.0542
Total	**7,367,360.4**	**0.472**	**0.68**	**3,477,394.2**	**5,009,805**	**3,477.394**	**5,009.805**

Table 4. Emission amounts due to natural gas consumption of Davutpaşa Campus in 2019

2019	**Natural gas consumption (m^3)**	**t N_2O (emission factor:0.00017)**	**t CH_4 (emission factor: 1.88496)**	**t CO_2 (emission factor: 1.88500)**	**t CO_{2e} (emission factor: 1.88500)**
January	119,757.356	0.020359	225.7378	225.7426	225.7426
February	108,079.050	0.018373	203.7247	203.729	203.729
March	108,030.437	0.018365	203.6331	203.6374	203.6374
April	141,028.155	0.023975	265.8324	265.8381	265.8381
May	74,881.906	0.01273	141.1494	141.1524	141.1524
June	33,431.305	0.005683	63.01667	63.01801	63.01801
July	5,060.000	0.00086	9.537898	9.5381	9.5381
August	980	0.000167	1.847261	1.8473	1.8473
September	467,000	7.94E-05	0.880276	0.880295	0.880295
October	675	0.000115	1.272348	1.272375	1.272375
November	609,000	0.000104	1.147941	1.147965	1.147965
December	233,946.350	0.039771	440.9795	440.9889	440.9889
Total	**826,945.56**	**0.140581**	**1558.759**	**1558.792**	**1558.792**

Table 5. Emission amounts due to natural gas consumption of Davutpaşa Campus in 2020

2020	Natural gas consumption (m^3)	t N_2O (emission factor:0.00017)	t CH_4 (emission factor: 1.88496)	t CO_2 (emission factor: 1.88500)	t CO_{2e} (emission factor: 1.88500)
January	113,927.000	0.019368	214.7478	214.7524	214.7524
February	191,284.000	0.032518	360.5627	360.5703	360.5703
March	190,741.000	0.032426	359.5392	359.5468	359.5468
April	80,870.000	0.013748	152.4367	152.44	152.44
May	2,847.000	0.000484	5.366481	5.366595	5.366595
June	128,494.000	0.021844	242.2061	242.2112	242.2112
July	37,783.000	0.006423	71.21944	71.22096	71.22096
August	396	6.73E-05	0.746444	0.74646	0.74646
September	446.000	7.58E-05	0.840692	0.84071	0.84071
October	131	2.23E-05	0.24693	0.246935	0.246935
November	1,354.000	0.00023	2.552236	2.55229	2.55229
December	74,595.000	0.012681	140.6086	140.6116	140.6116
Total	**822,868.00**	**0.139888**	**1551.073**	**1551.106**	**1551.106**

Table 6. Carbon footprint values due to natural gas consumption of Davutpaşa Campus in 2019 (Eggleston et al. 2006)

2019	**Natural gas consumption (m³)**	**Natural gas amount (GJ)**	**Emission amount (kg)**	**Emission amount (t)**
January	119,757.356	4,512.601	253,156.9	253.1569
February	108,079.050	4,072.548	228,470	228.47
March	108,030.437	4,070.717	228,367.2	228.3672
April	141,028.155	5,314.11	298,121.6	298.1216
May	74,881.906	2,821.64	158,294	158.294
June	33,431.305	1,259.732	70,670.95	70.67095
July	5,060.000	190.6669	10,696.41	10.69641
August	980	36.92758	2,071.637	2.071637
September	467.000	17.59712	987.1985	0.987199
October	675	25.43481	1,426.893	1.426893
November	609.000	22.94785	1,287.374	1.287374
December	233,946.350	8,815.379	494,542.8	494.5428
Total	**826,945.56**	**31,160.3**	**1,748,093**	1,748.093

Table 7. Carbon footprint values due to natural gas consumption of Davutpaşa Campus in 2020 (Eggleston et al. 2006)

2020	**Natural gas consumption (m³)**	**Natural gas amount (GJ)**	**Emission amount (kg)**	**Emission amount (t)**
January	113,927.000	4,292.906	240,832	240.832
February	191,284.000	7,207.811	404,358.2	404.3582
March	190,741.000	7,187.35	403,210.3	403.2103
April	80.870.000	3,047.279	170,952.3	170.9523
May	2,847.000	107.2784	6,018.317	6.018317
June	128,494.000	4,841.808	271,625.4	271.6254
July	37,783.000	1,423.709	79,870.06	79.87006
August	396	14.92176	837.1105	0.837111
September	446.000	16.80582	942.8062	0.942806
October	131	4.936237	276.9229	0.276923
November	1,354.000	51.02034	2,862.241	2.862241
December	74,595.000	2,810.829	157,687.5	157.6875
Total	822,868.00	31,006.65	1,739,473	1,739.473

Table 8. Carbon footprint values due to water consumption of Davutpaşa Campus in 2019

2019	**Water consumption (m^3)**	**Water consumption (L)**	**Emission factor**	**Emission amount (kg CO_{2e})**	**Emission amount (t CO_{2e})**
January	11,928.00	11928000	0.0014	16,699.2	16.6992
February	12,325.00	12325000	0.0014	17,255	17.255
March	12,723.00	12723000	0.0014	17,812.2	17.8122
April	29,100.00	29100000	0.0014	40,740	40.74
May	19,409.00	19409000	0.0014	27,172.6	27.1726
June	25,996	25996000	0.0014	36,394.4	36.3944
July	32,583.00	32583000	0.0014	45,616.2	45.6162
August	35,039.00	35039000	0.0014	49,054.6	49.0546
September	27,833.00	27833000	0.0014	38,966.2	38.9662
October	26,958.00	26958000	0.0014	37,741.2	37.7412
November	34,357.00	34357000	0.0014	48,099.8	48.0998
December	30,657.50	30657500	0.0014	42,920.5	42.9205
Total	**298,908.50**	**2.99E+08**	**0.0014**	**418,471.9**	**418.4719**

Table 9. Carbon footprint values due to water consumption of Davutpaşa Campus in 2020

2020	Water consumption (m^3)	Water consumption (L)	Emission factor	Emission amount (kg CO_{2e})	Emission amount (t CO_{2e})
January	16,183	16183000	0.0014	22656.2	22.6562
February	15,697.00	15697000	0.0014	21975.8	21.9758
March	17,643.00	17643000	0.0014	24700.2	24.7002
April	16,670.00	16670000	0.0014	23338	23.338
May	35,273.00	35273000	0.0014	49382.2	49.3822
June	46,564.00	46564000	0.0014	65189.6	65.1896
July	34,397.00	34397000	0.0014	48155.8	48.1558
August	38,871.00	38871000	0.0014	54419.4	54.4194
September	43,346.00	43346000	0.0014	60684.4	60.6844
October	51,664.00	51664000	0.0014	72329.6	72.3296
November	38,871.00	38871000	0.0014	54419.4	54.4194
December	35,273.00	35273000	0.0014	49382.2	49.3822
Total	**390,452.00**	**3.9E+08**	**0.0014**	**546632.8**	**546.6328**

Table 10. The amounts of food consumed and associated emission factors

Year	Bread, (kg) (emission factor:0.84 kg CO_2/kg bread)	Vegetables, (kg) (emission factor:0.25 kg CO_2/kg vegetables)	Fish, (kg) (emission factor:3.30 kg CO_2/kg fish)	Red meat, (kg) (emission factor:23.97 kg CO_2/kg red meat)	Chicken, (kg) (emission factor:2.82 kg CO_2/kg chicken)
2018	80900	224,705	2289	45,850.70	56,974.14
2019	92200	310,808	2843	60,605.65	76,387.54
2020	4800	15,510	169,25	13,782.81	24,144.90

Table 11. Annual CO_2 emission amounts (kg CO_{2e})

Year	Bread	Vegetables	Fish	Red meat	Chicken
2018	67956	56176.25	7553.7	1099024.5	160666.68
2019	77448	77702	9381.9	1452701.85	215411.34
2020	4032	3877.5	558.525	330354.54	68086.08

Table 12. The emission values of the Rectorate's vehicle fleet

Rank	Vehicle type	Fuel type	Current km	Monthly average km	Engine volume	Weight	CO_{2e} (t)	CO_2 (t)	CH_4 (t)	N_2O (t)
1	Automobile	Diesel	283,280	990	1968	2110	2.67	2.65	0.00012	0.023
2	Automobile	Diesel	321,460	900	1968	2110	2.43	2.41	0.00011	0.021
3	Automobile	Diesel	322,689	950	1968	2170	2.56	2.54	0.00011	0.021
4	Automobile	Diesel	119,335	900	1598	2070	2.43	2.41	0.00011	0.021
5	Automobile	Diesel	210,275	450	1461	945	0.96	0.95	0.000054	0.01
6	Automobile	Diesel	250,000	400	1461	945	0.85	0.84	0.000048	0.009
7	Automobile	Diesel	230,782	450	1461	945	0.96	0.95	0.00054	0.01
8	Automobile	Diesel	235,516	400	1461	945	0.85	0.84	0.000048	0.009
9	Automobile	Diesel	240,000	425	1461	945	0.9	0.89	0.000051	0.0097
10	Automobile	Diesel	311,000	435	1461	945	0.93	0.92	0.000052	0.0099
11	Automobile	Diesel	266,050	440	1461	945	0.94	0.93	0.000052	0.01
12	Automobile	Diesel	258,008	950	1461	1170	2.02	2	0.00011	0.021
13	Automobile	Diesel	320,486	900	1968	2170	2.43	2.41	0.00011	0.021
14	Automobile	Diesel	42,545	250	1600	985	0.6	0.59	0.001	0.0015
15	Minibus	Diesel	250,888	400	2402	3300	1.368	1.36	0.00008	0.0086
16	Minibus	Diesel	196,681	425	2402	3300	1.45	1.44	0.00008	0.0092
17	Minibus	Diesel	251,500	450	2402	3300	1.54	1.53	0.00008	0.0097
18	Minibus	Diesel	415,241	430	2.5 T	2004	1.47	1.46	0.00008	0.0093
19	Minibus	Diesel	160,157	200	2461	2025	0.68	0.67	0.00004	0.0043
20	Pickup	Diesel	366,532	400	1461	1860	1.37	1.36	0.00008	0.0086
21	Pickup	Diesel	69,305	350	2771	3500	1.2	1.19	0.00007	0.0076
22	Pickup	Diesel	134,201	340	4334	3500	1.16	1.15	0.00007	0.0073
23	Pickup	Diesel	94,645	500	2143	3050	1.71	1.7	0.00009	0.0108
24	Pickup	Diesel	130,829	350	2402	3300	1.2	1.19	0.00007	0.0076
25	Pickup	Diesel	239,568	250	-	2300	0.86	0.85	0.00005	0.0054
26	Bus	Diesel	262,254	400	5193	6936	2.49	2.46	0.00008	0.0086
27	Bus	Diesel	168,663	300	5193	6936	1.87	1.84	0.00006	0.0064
28	Bus	Diesel	134,837	320	4570	5292	1.99	1.96	0.00006	0.0069
29	Bus	Diesel	130,791	330	4570	5292	2.06	2.02	0.00006	0.0071

Table 13. The transportation-related emissions of Davutpaşa Campus

2019 (t CO_{2e})		**2020 (t CO_{2e})**	
Rectorate's vehicle fleet	69.95	Rectorate's vehicle fleet	11.66
Personal vehicles of the staff	2673.9	Personal vehicles of the staff	445.652
Staff services	347.628	Staff services	57.938
Ring buses	233.9	Ring buses	39.88
Personal vehicles of the students	612.36	Personal vehicles of the students	136.1
Public buses	29.6	Public buses	6.57
Transportation of the students	2313.9	Transportation of the students	514.2
Total emission	**6281.24**	**Total emission**	**1211.97**

Table 14. The total emission values of the Davutpaşa Campus

Emission values	**2019 (t CO_2)**	**2020 (t CO_2)**
The emissions due to electricity consumption	5110.84	3477.4
The emissions due to natural gas consumption	1558.8	1551.1
The emissions due to water consumption	418.5	546.6
The emissions due to food consumption	1832.6	406.9
The emissions due to domestic wastes	52.4	20.96
The transportation-related emissions	6281.24	1211.97
Total emission	**15254.4**	**7214.97**

Table 15. Comparison with studies conducted in other universities in Turkey

University	Number of Students and Staff	Emission value (t CO_{2e}/y)	Reference	Method
METU (2000-2014)	26500 students	56036.5 (2014)	(Turanlı 2015)	IPCC (2006)
Sakarya University, Esentepe Campus (2015)	79708 students 2018 staff	12330.73	(Sreng and Yiğit 2017)	IPCC (2006)
Manisa Celal Bayar University (2016)	46525 students 2968 staff	8953.906	(Binboğa and Ünal 2018)	IPCC (2006)
Çankırı Karatekin University (2017)	12856 students 1241 staff	5633.13	(Üreden 2019)	IPCC (2006)
Çanakkale 18 Mart University, Terzioğlu Campus (2016)	23285 students 2232 staff	10122.154	(Özçelik 2017)	IPCC (2006) /DEFRA (2016
YTU Davutpaşa Campus (2019-2020)	34138 students 2386 staff	15244.4 (2019) 7213.3 (2020)	This study	IPCC (2006)/ DEFRA (2016)

Original Paper

Model of community empowerment in utilizing Purun (*Eleocharis dulcis*) resources for sustainable handicrafts in Indonesia's rural peatland communities

Ulfa Sevia Azni, Alfitri Alfitri, Yunindyawati, Riswani, Luigi Pellizzoni

Received: 6 March 2023 | **Accepted:** 26 April 2023 | **Published:** 6 May 2023

Keywords: community empowerment; handicraft; peatland; *Eleocharis dulcis*.

Abstract. *Peatlands have served a crucial ecological and economic purpose for a very long time. Purun (*Eleocharis dulcis*) is a common plant that grows* *in peat bogs and contributes to the community. Its population is diminishing, however, due to changes in land management and environmental damage. The concept of communal empowerment was inspired by the sustainability of Purun weaving as a craft enterprise. We adopted a qualitative research methodology with a descriptive approach, comprising interviews, focus group discussions, and documentation, for data collection. Community craft activities have become a "safety valve" for rural community economies, according to our research. Nonetheless, by overcoming the difficulties, these advantages might be utilized again. A cross-generational approach to sustainable craft practices can provide a forum for discussion of the values and perspectives of cultural heritage and the environment. As a result of these findings, the Social, Ecology, and Regulation model is the community empowerment paradigm for the use of resources as sustainable handicrafts, in which the community, affiliated organizations and agencies, and local governments define the total decision-making process. In the areas of ecology, education, and regulation, the government works as a supporter and enforcer.*

---

1. Introduction

Indonesia has the third largest peatland in the world, particularly in the tropics, behind the Amazon and Congo Basin, covering around 8.2% of its land area (Xu, J., Morris, P.J. Liu, J & Holden 2018). Wetland areas in Indonesia, such as Sumatra and Kalimantan, have been logged, drained, and converted into plantations (Giesen and Sari 2018; Miettinen and Liew 2010) by corporations or small-scale plantations (Miettinen and Liew 2010) or abandoned in a decrepit state for more than three decades (Giesen and Sari 2018; Miettinen and Liew 2010).

Approximately 3,1 million hectares of peat swamp have been occupied by industrial plantations of timber and palm oil. The result was an increase of 4.1% in the rate of deforestation between 2007 and 2015 (Miettinen and Liew 2010). The government feels that timber companies and oil palm farms promote economic growth. However, the development of peatlands has ecologically detrimental effects, such as a substantial increase in emissions and widespread peatland fires, which are the major cause of poor economic quality and public health (Giesen and Sari 2018).

Local populations who had previously depended on peatlands have been disrupted because of the management of vast peatlands for oil palm plantations, mining, and industrial forest plantations. Local communities' interests are frequently deemed incompatible with those of large-scale plantation and mining enterprises. Purun Plant (*Eleocharis dulcis*) is one of the locals' interests that reside near peatlands.

Purun is an economically valuable plant that is typically found in peat bogs (Giesen and Sari 2018). Since the 1970s, Purun has been used as a raw material for woven crafts by the community (Wildayana et al. 2017). In the rural parts of South Sumatra, Indonesia, the practice of purun crafts has become a formidable economic weapon (Azni et al. 2021). As a secondary source of income, Purun weaving has risen to prominence among women. Since the 1970s, the Pedamaran (Pedamaran and Pedamaran Timur) people of Ogan Komering Ilir Regency, South Sumatra Province, have used purun as a source of income to prevent forest fires on peatlands (Armanto. et al. 2017). In the local community, the production of purun mats is an inherited trade. Therefore, purun crafts must be protected, given that purun mats fall under the category of indigenous knowledge regarding peatland utilization.

However, the community is currently protesting that purun raw ingredients are becoming increasingly difficult to get. One explanation is the decreased amount of Lebak Purun land as a result of land conversion to oil palm plantations, wildfires, and intense flooding (Goib et al. 2019). Therefore, it is vital to expand market access and other aspects, such as resource usage, access to community resilience, and inheritance for future generations (Poulton et al. 2006). The mechanism for utilizing purun resources is still somewhat constrained due to risks such as enormous corporate activity, lax restrictions, and adverse weather conditions (Azni et al. 2022).

Therefore, sustainable purun crafts as traditional local knowledge and abilities with deep historical origins must be acknowledged as a significant cultural heritage for modern society. Sustainable handicrafts anchored in social construction are an essential component of cultural heritage (Auclair, E.; Fairclough 2015). The Faro Convention, which addresses the Value of Cultural Heritage, has urged local people to have a pivotal role in establishing the worth of their indigenous knowledge. This strategy is intended to strengthen the dedication of local actors to work towards a sustainable future (Council of

Europe 2005). As authors, we concur that purun craft is one of the cultural heritages and that local wisdom is a process by which history and traditions are transmitted from one generation to others generation.

This study aims to find the most suitable community empowerment model for utilizing purun in peatlands to encourage sustainable handicrafts as an alternative to state-led environmental conservation program practices. In the results and discussion, we first describe the causes of the purun artisans' community's helplessness due to ecological damage, then develop strategies that the community can implement, and finally find the most suitable empowerment model for purun utilization at the research site.

2. Literature Review

2.1 Community Empowerment

The term 'empowerment' is brought into the global analysis of community development to describe the process through which people (collectively or individually) control the resources they utilize to enhance their quality of life. (Craig, G., May 1995). Community empowerment is utilized to acquire knowledge, self-assurance, and command over local events and developments (Bebbington et al 2006). In addition, empowerment helps government agencies and organizations to extend, assist, and create more effective meeting and empowerment opportunities (Chavis 2001).

Empowerment is also a concerted effort to aid local communities in planning, deciding, and managing local resources via collective action and networking. In the end, the community can have economic, ecological, and social capacity and independence (Mardikanto, Totok dan Soebiato 2012). Community empowerment is a method that can increase community engagement in natural resource management while decreasing environmental impact concerns and access to natural resource management. This is because empowerment can prioritize a bottom-up approach, a praxis-emancipatory orientation, and the preservation of humanist principles. It is also consistent with the most recent social science and humanities approach (Susilo 2017).

Empowerment is associated with resilience and the capacity to make decisions and transform those decisions into desired outcomes (Mohan and Stokke 2000). Empowerment is also an effort to increase the capacity of individuals (intrinsic elements of strength) who are united in society to develop economic capacity and resilience through kinship, cooperation, and struggle. Thus, empowerment resides in decision-making to create adaptation options for social and environmental changes (Ali 2007).

Therefore, it exceeds mere participation. It can participate in decision-making and initiate change. Community empowerment is a systematic effort to enable communities to acquire and exercise (more) control through a collaborative process of defining problems, identifying assets, and designing solutions (Reininger, B, D Martin, M Ross, P Sinicrope 2006).

Thus, this study refers to a group-based participatory process in which members receive improved living and environmental conditions. (Stoeffler 2018). Members of marginalized communities collaborate to identify, plan, implement, and evaluate interventions to address the fundamental causes of their powerlessness in this approach (Sianipa 2013).

3. Research Methodology

The research was conducted in OKI District between November 2021 and March 2022. This study constructs a theory inductively, beginning with the collecting of empirical data in the field utilizing a constructivist paradigm and qualitative methodology. Using these paradigms and approaches, researchers can generate subjective meanings based on each individual's experience rather than reducing implications to categories and ideas (Cresswell JW 2016). This places human economic engagement with nature at the center of historical development, citing Durkheim (Gollbatt D 2015).

Pedaraman and East Pedamaran Districts, OKI Regency, were the research sites (Figure 1). The choice of research places was influenced by a variety of factors. First, the research location is a peatland region with the physiographic type of lowland peat swamp that is unaffected by river or ocean tides. Peatlands at the study site are found in the Sibumbung River Peat Hydrological Unit and the Komering River, the broadest portion of which is located in Pedamaran District and East Pedamaran District (Wildayana, Adriani, and Armanto 2017). Second, the location of the research is a place with a disproportionate number of active artisans compared to other locations, hence it is known as the "Town of Mats." Thirdly, from 2018, the study site has been a participant in the Peat and Mangrove Restoration Agency of the Republic of Indonesia's effort to revitalize local livelihoods.

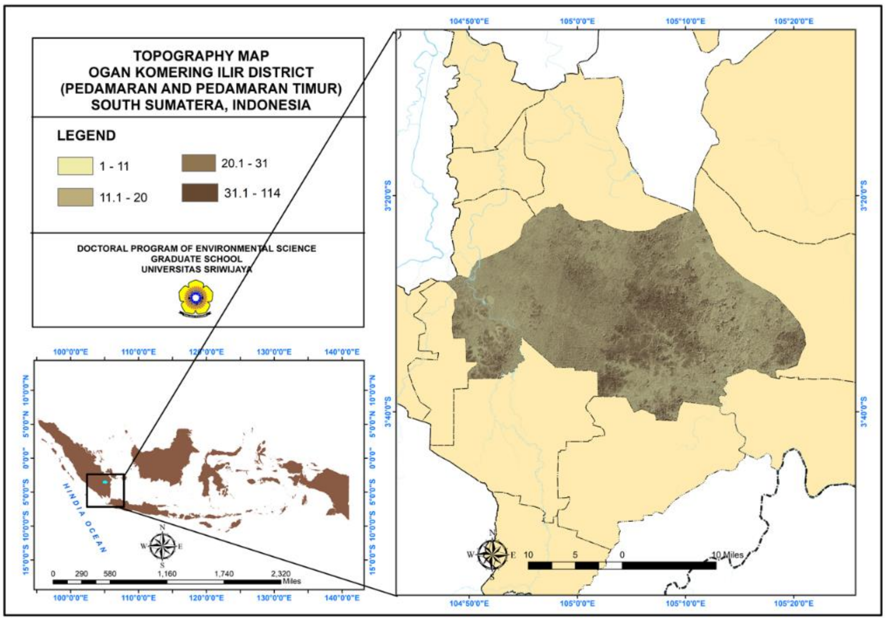


Figure 1. The study area in South Sumatera, Indonesia

Data were collected through observation, in-depth interviews, documentation, and focus group discussions. Observations were conducted to directly observe the craft activities of the community at the research site. The author also documents several photographs and audio recordings and conducts focus group discussions (FGDs) to find a suitable empowerment model for utilizing purun on peatlands that originates from the community so that it can be implemented in practice.

Purposive sampling is utilized to determine the informants. In this instance, we have established specified qualifications for those who would serve as research participants. One of the criteria is purun artisans who reside in the research location, have knowledge and expertise regarding the usage of peat and purun lands, are over the age of twenty, and are willing to participate. We also consulted community organizations and government authorities, including the Environment Agency, the Regional Peat Restoration Team, and the Community Empowerment Service. All participants in this study have consented to be interviewed. In addition, we have an official study authorization from the local agency that is registered as a research method.

4. Results and Discussion

4.1 Due to ecological damage, Purun craftsmen are powerless.

The peat ecology that sustains Purun life is increasingly threatened by numerous extractive economic activities, placing Purun artisans in a precarious position at the site of the study (Azni et al. 2022; Goib et al. 2019). The existence of purun is not just a source of income, but also a cultural emblem and a long-held custom passed down from their ancestors (Wildayana et al. 2017).

The existence of numerous extractive corporations, followed by the shrinking of land suitable for purun livelihood, has compelled some purun artisans to become part of the means of production for poor wages and without proper health insurance. Craftsmen also acknowledge that they require more and more labor to collect purun in lebak purun as the place becomes further away from the hamlet.

> "… if the lebak purun on peat soil is exploited for oil palm plantations, then we locals will no longer be able to subsist on this purun …" (B, 2022).

It is evident that the interaction between women purun craftspeople and the peat ecology is founded on multiple claims. First is the epistemological claim (Sari, N., Yunus, R. 2019) which asserts that purun craftswomen at the research site have historically been acknowledged as advocates for the sustainable use of peatlands. Dependence on purun, which only grows in intact peat ecosystems, indirectly reinforces their function as guardians, preservers, and stewards of peat ecosystems in the face of widespread peatland exploitation. The second is an empirical claim (Eaton, H., & Lorentzen 2003), that disruption to the peat ecosystem will have direct economic and ecological effects on women as artisans.

Not only do they have trouble acquiring raw materials for handicrafts, but their income from the handicraft industry has also declined. In addition, those who change careers to become laborers for oil palm and mining enterprises do not necessarily ensure their welfare and safety on the job. This occurred because of a transition in the mode of production from subsistence to exploitation, when capitalist interests, which were the result of the development of modern science, began to exert hegemony over the human race.

Additional findings came from FGDs with purun craftspeople from the Pedamaran and East Pedamaran districts. Each subdistrict is attended by approximately ten artisans' representatives. The South Sumatra Regional Peat Restoration Team was among the invited parties. The Community Empowerment Service, the Environment and Forestry Service, the Cooperative Office, Small and Medium Business Units, and the Culture and Tourism Office, in addition to community leaders such as village heads and local youths as the next generation of culture. Each participant's position in the discussion was equal. The holding of FGD produced the following results: (1) The majority of communities surrounding peatlands in the research area already had purun management and handicraft groups, but the activities of the groups varied from village to village. (2) The government has employed initiatives from linked agencies to overcome obstacles, as mentioned. The issue of diminishing raw materials and the absence of a conservation program remain unresolved. (3) Handicraft results are less diverse; therefore, there must be a greater market demand. (4) There is no special regional rule governing the use of purun in peatlands within the research area. (5) Stakeholders in the field have attempted to overcome roadblocks. (6) The lack of inclination among the younger generation to carry on the purun craft enterprise.

4.2 Purun Community Empowerment Strategy

Based on the above evidence of the purun craftsmen's helplessness, it can be argued that measures for empowering the community may include rules, group organizations, community education, funding, and advocacy (Palutturi et al. 2021).

Regulation

A sustainable handicraft business like Purun employs regulation as one of its methods. Reviewing the regulations regarding permits for the management of peatlands for plantation companies and industrial forest plantations where purun grows, in accordance with the expectations of the purun craftsmen at the location of the research, can ensure the sustainability of the purun craftsmen's business.

> "Unfortunately, the local government has not provided clear regulations, and we believe that the purun area is diminishing. We require a regulation or statement from the regent in order to preserve our purun" (S-2022).

Explaining the limits and condition of the area between existing oil palm concessions and land that can be utilized by the community helps improve peatland governance based on field data. Coordination between related agencies is required to prevent a mountain of regulations and land permits. This should be done to prevent further disputes between communities and corporations.

In addition, the community requires more serious supervision, as the potential of this region is still extremely great. Continuous development would enhance family welfare and minimize the number of poor people living in peat areas. The government must also establish price guidelines for handicrafts created from these natural resources. The general people should also value the outcomes of their handicraft creation, which is healthier than modern plastic goods.

Institutional

The purun craft industry at the location of the study needs to be more organized. Most of these enterprises have not yet been merged into a new company group. If artisans collaborate, it is believed that their businesses would be better organized, resulting in increased profits and the ability to compete on local, national, and even international markets. Craftsmen of the Purun language must also conduct sufficient business planning and administration, such as in the system for documenting cash flow, raw materials, and labor, among others.

Additionally, access to marketplaces is still facilitated by traditional means, namely by collectors who visit them. Only word-of-mouth is utilized for promotion, as the use of technology to reach the market is considered strange. Some of them are aware that technology is limited to the use of basic cell phones, such as telephone calls, which causes the craftsmen's annual income to fluctuate.

> "… We are old and not tech savvy. Only how full our tummies are occupying our thoughts …" (T, 2022).

Training and education

Specialized education and training related to the handicrafts created by purun artisans are not ideal in the field, as seen by the lack of variety in handicraft items and product development, which must be enhanced. This creates a paradox, since prospective consumers will grow increasingly critical of products that meet their needs.

> "… We rarely receive instruction, which reduces the variety of our handicrafts; we require additional abilities …" (F, 2022).

According to the preceding quote from the informant, the demand for craftsmen in terms of skill training is due to the limited product range available to artisans. In this situation, the artisans are solely skilled at weaving purun to create mats, even though purun can theoretically be incorporated into various items.

Handbags, memento boxes, wallets, tissue boxes, and wastebaskets are among the derivatives. In addition, artisans do not have a set production time; instead, they rely only on the time they spend willingly.

Figure 2. A craftsman and some handicrafts from purun

In addition to improving product quality, education for the younger generation must also be a focus. The sustainability of the younger generation is also a threat, according to field data. There is a tendency for the next generation to lose interest in continuing the culture of purun weaving and grow resistant to doing so. Likewise, purun artisans feel this.

> "… We don't want our children to be like us, but we don't want to lose our traditions, either …" (F, 2022).

However, the local village authority admits that it has taken efforts so that purun woven crafts can continue to exist and that the younger generation is still interested in perpetuating the culture that has been passed down from generation to generation in their region.

> "We have visited schools and created synergies between purun and the world of education, including the implementation of local content education in order to maintain local cultural values …" (R-2022).

Income

The only source of revenue for all craftspeople is their craft. They do not invest in other prospects for business in their neighborhood. Occasionally, they acknowledge that the income they make is insufficient and that they must rely on their children's social aid to support the family. When asked how much money they would spend on themselves, the majority responded that it would depend on meeting the family's needs first.

> "… Sometimes the government supports it, sometimes it doesn't, and sometimes the finances are unavailable. We will participate in external events if they occur …" (E, 2022).

Aside from that, the artisans also continue their business with personal cash and engage in other informal sectors, such as creating a modest shop in front of their homes. In a manner like that of women, the craftsmen juggled their domestic and professional responsibilities.

Advocacy

Advocacy is the act of reminding and urging the government and state to be responsible for the protection and prosperity of all its residents. Advocacy is a deliberate and planned effort to affect and encourage progressive changes in public policy (Fakih 2007).

In this instance, environmental advocacy is carried out through the community's power to place demands on the local government. Advocacy will create new opportunities for them to implement orientations and strategies and reflect on improvements based on their expertise and knowledge.

> "… the objective of the community's united lobbying agenda is to ensure that rules are not handled by third parties. We prioritize upstream concerns …" (G, 2021).

4.3 Model of Empowerment for Purun Utilization in Peatlands

Given the weakness of the purun artisans' community, characterized by diminished purun land on peatlands and other factors, as described previously. Therefore, we propose the socio-ecological-regulatory empowerment model, created, and mutually agreed upon by the government and the community in implementing FGDs. After being analyzed and negotiated, this model is regarded as an endeavor to promote community welfare by maximizing the potential of existing resources and bolstering it with local regulations. This model is also expected to become one of the supporting initiatives for sustainable village development. The summary is as follows:

1. Reactivate and fortify purun artisan groups in peatlands and develop new groups in regions where they are still needed.
2. The government is willing to encourage group activities by routinely allotting funding to each hamlet to maintain peatlands and ensure the viability of craftsmen's endeavors.
3. The government conducts training, the development of product variants, and the construction of infrastructure for purun-based product manufacturing centers.
4. The government establishes regional rules and laws for the protection and use of purun ecosystems. It educates the community on the significance of peatland management to the local economy.
5. Providing education to the younger generation in order to preserve and sustain local knowledge.
6. Working with other agencies to manage and utilize additional peatlands for sustainable operations.

Crafts made from peat-native plants, such as purun, have played a significant part in the life of rural communities, as evidenced by our presentation of research findings. Additionally, the craft can be used to generate economic prospects for themselves and their families. According to (Rogerson 2010), handicrafts may serve as a gateway into the individual economy.

Research (Dhurup, M., & Makhitha 2014) indicates that difficulties in securing government financing and support can impede the development and sustainability of handicrafts. These findings are consistent with these findings. In addition, the use of technology is difficult in rural populations, together with low levels of literacy and education.

In addition, this study demonstrates that the community's lack of business skills is a barrier to the sustainability of traditional arts and crafts. According to (Rogerson 2000) a lack of business abilities can limit the sustainability of craft initiatives. This can be evident in the products made by huge craftspeople whose tastes are distinct from market preferences. Therefore, artisans must ensure that the things they create satisfy the needs of diverse local and global markets.

5. Conclusions

The results of the study indicate that rural communities, particularly those located near peatlands, have a very good opportunity with potential benefits for their artisan enterprises. However, their participation had insufficient effect on the obstacles they had to overcome.

Through interviews and focus groups, we have discovered that rural people who work as purun craftsmen have a sufficient awareness of and desire to preserve their skill as part of their local culture for it to endure. To maintain the sustainability of handicrafts, we advocate the Social, Ecological, and Regulatory model as a form of empowerment based on resource management and consumption. Because, in this instance, purun requires peatlands for survival, and craftspeople require them to preserve their traditions and culture. If peat land does not exist, there is no purun. The conservation of peatlands is an issue of ecology, culture, and custom.

We propose that the government and relevant stakeholders investigate community initiatives to preserve cultural practices to ensure their continued viability. In addition, the government is anticipated to release a special regulation regarding the management and usage of resources in peatlands, specifically purun plants. Moreover, sustainability for the younger generation is also crucial. A further recommendation is that local governments incorporate materials on the protection and utilization of peatlands as local content subjects at all educational levels.

Acknowledgments

The authors are grateful to the Directorate General of Higher Education, Research and Technology (DGHERT), Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, through the PMDSU Research Grant with contract number 0064.02/UN9.3.1/PL/2022 and Enhancing International Publication (EIP) Program 2022. This research is a component of a dissertation proposed as part of Sriwijaya University's doctoral degree requirements.

References

Ali, Madekhan (2007). Villagers Stepchildren of Change. Malang: Averroes Press.

Armanto M.E., E. Wildayana, M.S. Imanudin, H. Junedi, and Zuhdi, M. (2017). Selected Properties of Peat Degradation on Different Land Uses and the Sustainable Management. *Journal of Wetlands Environmental Managements* 5(2): 14–22.

Auclair, E. and Fairclough, G. (2015). Living between Past and Future. An Introduction to Heritage and Cultural Sustainability. In Theory and Practice in Heritage and Sustainability. *Between Past and Future*: 1–22.

Azni, U.S., Alfitri, Yunindyawati, and Riswani (2021). The Impact of the Covid-19 Pandemic on the Purun Craftsmen Community (Eleocharis Dulcis) in Ogan Komering Ilir District, South Sumatra Province, Indonesia. *Jurnal Analisa Sosiologi* 10(2).

Azni, U.S., Alfitri, Yunindyawati, and Riswani (2022). Community Resilience Related to Community Resources Access to Peatland in Political Ecological Perspectives: A Case Study of Purun (Eleocharis Dulcis) Craftmen in Ogan Komering Ilir, South Sumatera, Indonesia. *International Journal of Sustainable Development and Planning* 17(3): 941–47.

Bebbington, A., Guggenheim, S., and Woolcock, M. (2006). *The Search for Empowerment: Social Capital as Idea and Practice at the World Ban*. Bloomfield: Kumarian Press.

Bunga, K.G., Fitriani, N., Wicaksono, S.A., Yazid, M., and Andriani, D. (2019). Woven Crafts from Purun as a Form of Sustainable Business in Ogan Komering Ilir (Oki) Regency, South Sumatra. *Journal Analisis Kebijakan Kehutanan* 16(1): 67–87.

Chavis, D. (2001). The Paradoxes and Promise of Community Coalitions. *Journal Community Psychology* 29(2): 309–20.

Council of Europe (2005). *Convention on the Value of Cultural Heritage for Society*. https://www.coe.int/en/web/culture-and-heritage/faro-conventionhttps://www.coe.%0Aint/en/web/culture-and-heritage/faro-convention.

Craig, G., and May, M. (1995). *Community Empowerment: A Reader in Participation and Development*. London: Zed Book Ltd.

Creswell, J.W. (2016). *Research Design Qualitative, Quantitative, and Mixed Methods Approaches (Alih Bahasa Oleh Fawaid A, Pancasari RK)*. Yogyakarta: Pustaka Pelajar.

Dhurup, M., and Makhitha, K.M. (2014). Reflections on the Constraints in Entrepreneurial Development among Emerging Survivalist and Micro Craft Enterprises in Gauteng. *Journal of Contemporary Management* 11: 230–50.

Eaton, H., and Lorentzen, L.A. (2003). *Ecofeminism and Globalization Exploring Culture, Context, and Religion*. Rowman & Littlefield, New York.

Fakih, M. (2007). *Analisis Gender & Transformasi Sosial*. Yogyakarta: Pustaka Pelajar.

Giesen, W., and Sari, E.N.N. (2018). "Tropical Peatland Restoration Report : The Indonesian Case Tropical Peatland Restoration Report : The Indonesian Case Berbak Green Prosperity Partnership/Kemitraan Kesejatheraan Hijau (Kehijau Berbak)." (March): 99.

Gollbatt, D. (2015). *Analisa Ekologi Kritis*. Yogyakarta: Resist Book.

Mardikanto, Totok dan Soebiato, P. (2012). *Community Empowerment in Public Policy Perspective*. Bandung: Alfabeta.

Miettinen, J., and Liew, S.C. (2010). Status of Peatland Degradation and Development in Sumatra and Kalimantan. *Ambio* 39(5): 394–401.

Mohan, G., and Stokke, K. (2000). Participatory Development and Empowerment: The Dangers of Localism. *Third World Quarterly* 21(2): 247–68.

Palutturi, S. et al. (2021). Principles and Strategies for Aisles Communities Empowerment in Creating Makassar Healthy City, Indonesia." *Gaceta Sanitaria* 35: S46–48. https://doi.org/10.1016/j.gaceta.2020.12.013.

Poulton, C., Kydd, J., and Dorward, A. (2006). Overcoming Market Constraints on Pro-Poor Agricultural Growth in Sub-Saharan Africa. *Development Policy Review* 24(3): 243–77.

Reininger, B., Martin, D., Ross, M., Sinicrope, P, and Dinh-Zarr, T. (2006). Advancing the Theory and Measurement of Collective Empowerment: A Qualitative Study. *International Quarterly of Community Health Education* 25(3): 211–39.

Rogerson, C.M. (2000). Rural Handicraft Production in the Developing World: Policy Issues for South Africa. *Agrekon* 39(2): 193–217.

Rogerson, C.M. (2010). The Enterprise of Craft: Constraints and Policy Challenges in South Africa. *Acta Academia* 42(3): 115–44.

Sari, N., Yunus, R., and Suparman (2019). Ecofeminism: Socio-Cultural Construction of Women's Behavior in Environmental Management. *PALITA: Journal of Social-Religion Research* 4(2): 161–78.

Sianipa (2013). Community Empowerment through Appropriate Technology: Sustaining the Sustainable Development. *Procedia Environmental Sciences* 17, 1007–1016.

Stoeffler, W.S. (2018). Community Empowerment: *Handbook of Community Movements and Local Organizations in the 21st Century*. Springer, Cham, 265–280.

Susilo, R. and Dwi, K. (2017). Cultural Ecological Community Empowerment Model to Save Springs in Batu City. *Jurnal Satwika* 1(1), 28.

Wildayana, E., Adriani, D., and Armanto, M.E. (2017). Bottom-Up Approach for Purun Handicraft Development on the Peatland Area. *Prosiding National Seminar Sub-Optimal Land,* 978–79.

Xu, J., Morris, P.J. Liu, J., and Holden, J. (2018). PEATMAP: Refining Estimates of Global Peatland Distribution Based on a Meta-Analysis. *Cattena* 160: 130–40.

Authors

Ulfa Sevia Azni (*corresponding author*)
Doctoral Program of Environmental Science, Graduate School, Sriwijaya University, South Sumatera, Palembang, Indonesia.
ulfasevia.dil2020@pps.unsri.ac.id

Alfitri Alfitri
Department of Sociology, Faculty of Social and Political Sciences, Sriwijaya University, South Sumatera, Palembang, Indonesia.

Yunindyawati
Department of Sociology, Faculty of Social and Political Sciences, Sriwijaya University, South Sumatera, Palembang, Indonesia.

Riswani
Department of Agribusiness, Faculty of Agriculture, Sriwijaya University, South Sumatera, Palembang, Indonesia.

Luigi Pellizzoni
Department of Political Sciences, Environmental Sociology and Territory, University of Pisa, Pisa, Italy.

Funds

This research was funded by the the Directorate General of Higher Education, Research and Technology (DGHERT), Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia under PMDSU Research Grant with contract number 0064.02/UN9.3.1/PL/2022.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Azni, U.S., Alfitri, Yunindyawati, Riswani, Pellizzoni, L. (2023) Model of community empowerment in utilizing Purun (*Eleocharis dulcis*) resources for sustainable handicrafts in Indonesia's rural peatland communities. *Visions for Sustainability*, 20, 7384, 224-238. http://dx.doi.org/10.13135/2384-8677/7384

Original Paper

A sustainable creative economy development model using a penta-helix approach based on local wisdom in Magelang City, Indonesia

Sucihatiningsih Dian Wisika Prajanti, Dalila Daud, Syaiful Amin, Subiyanto, Fauzul Adzim

Received: 11 July 2023 | **Accepted:** 16 September 2023 | **Published:** 30 September 2023

Keywords: creative economy; local wisdom, sustainable; Magelang City.

Abstract. *The purpose of this research is to develop a strategy for developing a sustainable creative economy with a penta-helix approach based on local* *wisdom in Magelang City. Magelang City is one of the areas in Central Java Province with enormous potential for developing a creative economy and local wisdom. There are 3 leading creative economy sub-sectors in Magelang City, namely culinary, craft, and performing arts. Various research and studies have also been carried out, but have not been able to formulate a creative economy development strategy that is solid, integrated, inclusive, comprehensive, sustainable, and based on local wisdom. The analytical methods used in this research are Interpretative Structural Modeling (ISM) and Matrics of Alliances and Conflicts: Tactics, Objectives, and Recommendations (MACTOR). The result of the research formulates that there are 10 (ten) strategies for developing the creative economy, namely increasing business legality, skills and abilities of entrepreneurs, sustainable business management, production capacity, Appropriate Technology (TTG), infrastructure improvements, increased access to capital, product quality, business branding, and promotional and marketing innovations. Besides that, the development of the creative economy also requires synergy, collaboration, continuous and sustainable cooperation between stakeholders or often referred to as the Penta-helix, which consists of Academics, Business, Community, Government, and Media (ABCGM).*

1. Introduction

The creative economy is one sector that is expected to become a new force for the sustainable national economy and emphasizes adding value to goods through human thought and creativity. Currently, the creative economy is a catalyst for Indonesia's economic growth amidst a slowdown in global economic growth. This sector is able to contribute 7.28% of Indonesia's total GDP. The largest contributions come from the culinary sub-sector 41.475%, fashion 17.68%, and craft 14.99%. The creative economy sector in Indonesia in 2019 was able to absorb a workforce of 19.24 million or contribute around 15.21% of the total workers in Indonesia. One of the provinces in Indonesia that excels in the creative economy sector is Central Java, with the leading three main sub-sectors covering music 22.98%, culinary 15.11%, and performing arts 12.32%. If it is based on cities/regencies in Central Java, the largest distribution of creative economy actors is in Magelang City with absorption of 13.98% (Central Bureau of Statistics, 2022).

The creative industry itself is currently facing many short-term and long-term challenges due to the pandemic such as redundancies, bankruptcy, and event cancellations (OECD 2020). Different countries have introduced different strategies, both public and private (for example, job retention schemes, grants, and funding) to capitalize on the long-term economic and social impact of the COVID-19 pandemic (Dümcke, 2021; Joffe, 2020; Betzler et al, 2020). Existing conceptual as well as empirical contributions have established that regional social and economic arrangements are very important for creative industries and that place-based characteristics have created the conditions that enhance creativity as well as entrepreneurial behavior (Khlystova *et al.*, 2022; Anantrasirichai & Bull, 2021; Chang *et al.*, 2021; Clare, 2013; Florida, 2002; Lee *et al.*, 2004). Creative industries usually form geographic clusters. Often this occurs in large cities, where they can benefit from large markets and various human activities. Then the urbanization economy helps the creative industries develop through the creation of new knowledge and cross-fertilization between different specialties (Brydges & Pugh, 2021; Wahjudewanti *et al.*, 2021; Feldman & Kogler, 2010; Potts, 2007; Rosenthal & Strange, 2004).

In addition to being based on geographical clusters and regional-based policies, the development of the creative economy also requires collaboration from various parties. Creative economy planning has been started since Presidential Instruction No. 6 of 2009. The development of the creative economy in this regulation is addressed to all Governors, Regents/Mayors to carry out creative economic development with the support of the Regional Revenue and Expenditure Budget. Then proceed with the development plan of the creative industry sub-sector, looking in more detail at each creative industry sub-sector which includes: advertising; architecture; art goods market; craft; design; fashion; videos, films & photography, interactive games; music; performing Arts; publishing & printing; computer & software services; television and radio; research and development; culinary. As time has passed until 2021, there have been many legal products that have further strengthened the existence of the creative economy, namely the issuance of Presidential Regulation Number 142 of 2018 concerning the National Creative Economy Development Master Plan 2018-2025, Presidential Regulation Number 97 of 2019 concerning the Tourism and Creative Economy Agency, then the most recent is Law No. 24 of 2019 concerning the Creative Economy.

Research related to the development of the creative economy has been carried out but still results in varying results and development concepts. The development of the creative economy can be done by increasing access to capital and the welfare of actors (Chollisni *et al.*, 2022; Swastuti & Pudjiarti 2021) improving supporting infrastructure (Popelo *et al*, 2021; Nurmillah *et al.*, 2016) developing institutions and organizations (Agustina *et al.*, 2020; Bimantara *et al*, 2020; Hastuti *et al*, 2018) as well as promotion and marketing development (Wulandari *et al.*, 2022; Shofa & Nugroho, 2018). Several previous studies related to the development of the creative economy still give rise to various concepts that provide gaps for developing other creative economy development concepts.

Efforts to develop the creative economy require collaboration between parties. One of the cooperation models between several parties can be done through the penta-helix approach. Collaboration in the penta-helix concept is a collaborative activity between fields such as Academic, Business, Community, Government, and Media or known as ABCGM (Forss et al., 2021; Sundari et al., 2021; Yunas et al., 2021). The Penta-helix cooperation model aims to optimize the roles of Academics, Business, Community, Government, and Media elements as drivers of social change that can provide benefits in the development of creative industries, in this context in Magelang City. The Penta-helix project in the development of the creative economy aims to empower local and regional authorities to find innovative and cost-effective approaches to develop, finance, and implement sustainable development.

Sustainable development is a general concept that usually includes achieving global goals such as freedom from poverty, good health and well-being, quality education, reduced inequality, climate action, etc. peace and cooperation, encouraging better policies for a better life.

Today, with clear evidence that the global economy is approaching several ecological and transformative tipping points, it is important to seek new visions of alternative economic futures for the global economy, while recognizing their limitations.Traditional theories of economic development. This vision can be expressed by using the term creative economy in its analysis. The creative economy can be defined as knowledge-based economic activities that are based on the interaction between human creativity, ideas, intellectual discoveries and technology. There are often reference descriptions that include advertising, development, software, electronic publishing (Wiktor, 2020).

In this special edition, a broad definition of the creative economy is used, covering all knowledge, skills, abilities, life circumstances (happiness, security, etc.), characteristics and attitudes of human life that create economic activities based on intellectual property rights and a proper code of ethics and motivation. Therefore, the creative economy is an alternative economic world for the future economy. The definition of creative economy can refer to a number of economic sectors and activities such as business, education, health, culture and finance as well as all types of economic activities resulting from research and development (Schulz et al., 2021).

This concept is different from an economy based on physical capital investment and is far from the simple concept of a traditional knowledge economy because it requires intellectual property rights and rules for applying appropriate treatment as its basic characteristics.

The creative economy is not only associated with the creation of added value at the economic level, but also the creation of added value at the social, cultural and environmental levels. The creative economy is a form of effort to pursue sustainable development through creativity, where sustainable development is a competitive economic environment and has renewable resource reserves that have great potential to become one of the main driving sectors in achieving an independent and advanced economy (Awan et al., 2019).

Magelang City as one of the cities in Central Java has creative economic potential that highly needs to be developed. The development of the creative economy sector can be a driving force for realizing the vision of Magelang City as a service city, as well as a tourism amenity supporting capacity. The City of a thousand flowers has potential in the culinary, craft, and performing arts sub-sectors. The three sub-sectors have mutually supportive relationships, so they can be developed simultaneously. The culinary sub-sector has a longer historical bond when compared to other sub-sectors such as crafts and performing arts, especially when it is associated with the existence of Gethuk, which is a typical traditional food of Magelang City. Meanwhile, the existence of the craft sub-sector is still relatively new, even though it has the potential to absorb labor and a sizeable turnover. In the performing arts sub-sector, although it has a long historical value, it is still treated as a form of non-commercial business or activity. The performing arts sub-sector is preserved as the moral responsibility of actors towards tradition and dependence on activities facilitated by the city government.

The development of a creative economy based on local wisdom is important. This can be explained that the development of a creative economy that reflects the local wisdom of a region will have advantages or uniqueness that other regions do not have. Apart from that, the urgency of developing a creative economy based on local wisdom can encourage the conservation of surrounding natural wealth, both environmental and social wealth.

To build a conceptual framework for examining the characteristics of the creative economy in Magelang City, it is necessary to pay attention to several important aspects including the availability of data, mapping of potential areas, supporting actors, and statistical information, which form the basis for making policies and decisions, both for the government and for creative economy actors. In line with these problems, the purpose of this study is to develop a Sustainable Creative Economy Development Strategy with a Penta-helix Approach Based on Local Wisdom in Magelang City.

2. Research methods

This study used two types of data sources, namely primary and secondary data. Primary data are data directly collected by researchers (or officers) from the first source. The primary data sources in this study are the data on the potential problems of the creative economy in Magelang City and the data on the formulation of a sustainable creative economy development strategy obtained from the key persons. Meanwhile, secondary data are data that have been collected for purposes other than solving the problem at hand. The data can be found quickly. In this study, the sources of secondary data were publications, literature, articles, journals, and sites on the internet related to the research conducted.

The population in this study is all creative industries in Magelang city, so the population size can be projected using MSME data, which totals 8,663 units. However, the MSME actors who will be used as samples in this research are MSME actors who are already included in the category of creative economy actors, namely MSME actors who have unique products and have greater product added value.

The sample size in this study was calculated based on the Slovin formula. The Slovin formula used to determine the sample size is as follows:

$$n = \frac{N}{1+Ne^2} \qquad (3.1)$$

Dimana:

n = the number of samples in the study area

N = the number of population in the study area

e= fault tolerance limit (10%)

Based on the population to be studied and with an error tolerance of 10%, the sample can be determined as follows:

$$n = \frac{8663}{1+ 8663\ (0{,}01)} = 99$$

From the calculation using the Slovin Formula above, the sample obtained is 99 respondents, so the number of samples in this study is rounded up to 100 creative industry actors in Magelang City.

The sampling technique in this study was a proportional random sampling technique. This technique is used because the grouping of creative industries is united into one group, namely the creative industry group in Magelang City. This makes sampling in the creative industries without stratification in it, so that the sampling is carried out randomly and proportionally in each village.

The basis for sampling creative economy actors in this research is that Magelang City is one of the cities that has a creative economy based on local wisdom. This can be illustrated by the large number of creative economy actors from the culinary, craft and digital media product sectors. The uniqueness of the creative economy in Magelang City can be seen from the culinary and crafts that reflect the local wisdom of the area.

Meanwhile, to answer the second, third, and fourth research objectives, key persons or informants were selected using a purposive sampling technique. As for the purposive sampling technique, considerations are needed to select and determine the sample, namely choosing a sample that is considered to know the problem being studied as well as understanding what is expected in the study. This non-probability sampling is a method in which the researcher selects key persons who really know about the variable or problem under study. The key persons in this study used the Penta-helix Academics, Business, Government, Community, Media (ABGCM) approach as follows:

a) Academics: Creative economic planning expert lecturer

b) Business: Creative industry actors, banking, partners

c) Government: Regional Planning Development Agency/Bappeda of Magelang City and the Office of Industry & Trade of Magelang City

d) Community: Civil society and NGOs

e) Media: Digital and Conventional Media

The data collection techniques used in this study are observation, documentation, and questionnaires. This research uses a Penta-helix approach which consists of various stakeholders including Academics, Business, Government, Society, Media. This is very important because the development of the creative economy involves various parties and various elements. The use of the penta helix approach aims to increase synergy and collaboration between stakeholders and reduce the potential for conflict in developing a sustainable creative economy.

2.1 Interpretative Structural Modeling (ISM)

The analytical method used to answer the second objective in this study is Interpretative Structural Modeling (ISM) analysis. ISM as applied by Bhattacharya and Momaya (2009), is a sophisticated interactive planning methodology that allows a group of people working as a team, to develop a structure that defines the relationships among elements in a set. The ISM process starts with system modeling and ends with model validation. Through the ISM technique, unclear mental models are transformed into visible system models. ISM is a method of making decisions from complex situations by connecting and organizing ideas in visual maps. ISM is a model that describes the specific relationship between variables and the overall structure, and has outputs in the form of graphical models in the form of quadrants and variable levels (Li & Yang, 2014).

The first step in processing ISM is to create a Structural Self Interaction Matrix (SSIM), in which contextual relations are made for these variables by making one variable i and one variable j. Then making Reachability Matrix (RM) by changing V, A, X, and O with the numbers 1 and 0. The final step is to create a Canonical Matrix to determine levels through iteration. After there are no more intersections, then the model produced by ISM is created which is a model to solve the problem, in this case, the development of the cash waqf model. From this model, a road map for institutional development will be created (level).

For various sub-elements in an element based on RM, a Power-Dependence Driver is compiled. The sub-element classification is presented in the following 4 sectors (Marimin, 2004):

a) Sector 1: Weak driver-weak dependent variables (AUTONOMOUS). Changes in this sector are generally not related to the system and may have a small relationship, although the relationship can be strong.

b) Sector 2: Weak driver-strongly dependent variables (DEPENDENT). Generally, the variables here are dependent.

c) Sector 3: Strong driver-strongly dependent variables (LINKAGE). Variables in this sector must be studied carefully because the relationship between variables is unstable. Every action on this variable will have an impact on the other and the feedback effect can increase the impact.

d) Sector 4: Strong drive weak dependent variables (INDEPENDENT). The variables in this sector are the remaining part of the system and are called independent variables.

Driver Power	IV. Independent: Strong Driver weak Dependent variabl3s	III. Linkage: Strong driver – strongly Dependent variables
	I. Autonomous Weak Driver – weak Dependent Variables	II. Autonomous Weak Driver – strongly Dependent variables
	Dependence	

Table 1. Driver Power-Depedence Matrix

2.2 Matrix of Alliances and Conflicts: Tactics, Objectives, and Recommendations (MACTOR)

The analytical method used to answer the third objective is the MACTOR method. The MACTOR method attempts to provide a global description of the importance and possible outcomes of various issues, as well as the expected actors' strategies, the relationship of power and potential alliances and conflicts. This method is intended to obtain the possible evolution of the system being studied to build a better and more coherent scenario. The MACTOR method is used to observe the preferences of each stakeholder and the level of support for the objectives identified (Ahmed et al., 2009). This method also determines the level of support each stakeholder has for each objective and group. In this study, the MACTOR method will identify the actors/stakeholders involved in efforts to develop a sustainable creative economy in Magelang City. After the actors are identified, they can be grouped based on their respective roles so that it will be known that these actors are included in the main actors, key actors, or supporting actors. The MACTOR analysis in this study is also used to explain the relationship/ interaction between actors.

Godet (2001) explained the MACTOR technique based on three main inputs in matrix form. As shown in the figure, these three inputs are based on the "influence relationship" between one actor and another.

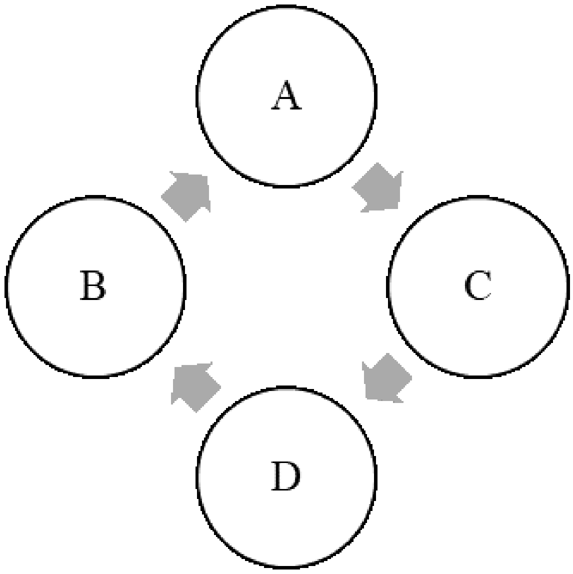


Figure 1. Driver Power-Depedence Matrix

The effect of actor A on actor D is the direct sum from A to D or indirectly through B and C.

With this concept, the input for the MACTOR through the position matrix (known as 1Mao [Matrix Actor Objective] and 2MAO) which uses the Salience variable from the actor to the objective. The third matrix is MID (Matrix of Influence Direct) which uses a variable influence. In the calculation with software, the input from the user only requires the MID, 1MAO, and 2 MAO matrix. Then, it will be calculated by the computer through the mathematical algorithm process. Based on the MID matrix, the MACTOR then calculates the direct and indirect effect of one actor on another actor as mentioned in the figure (x.x). This matrix is the MIDI matrix (Matrix of Indirect and Direct Influence). The MIDI matrix from A to B is calculated through the formula:

$$MIDI_{A \to B} = MID_{A \to B} + \sum_{C} [\min(MID_{A \to C}, MID_{C \to B})]$$

This matrix is then used in the next step to determine the "balance of strength". The balance of power must first calculate the total direct and indirect effect of the actor. If M_A is interpreted as a direct influence of actor A on another (for example B), then:

$$M_A = \sum_{B} (MIDI_{A,B}) - MIDI_{A,A}$$

If we define D_A is the total direct and indirect influence received by A from other actors (in other words is dependency or dependence of actor A), then:

$$D_A = \sum_{B} (MIDI_{B,A}) - MIDI_{A,A}$$

By using the two components with the Basic of Power coefficient, then calculated with the formula:

$$r_A = \left[\frac{(M_A - MIDI_{A,A})}{\sum_A (M_A)}\right] x \left[\frac{M_A}{M_A + D_A}\right]$$

In the next step, the MACTOR then calculates the matrix called $3MAO$, namely the matrix which is the basis and important in the discussion $MACTOR$. The $3MAO$ matrix resulting from the previous process or is a product of $2MAO$ and r_A or

$$3MAO_{A,i} = 2MAO_{A,i} \times r_A$$

With this matrix $3MAO$ knowing, various furniture can be produced. One of them is a mobilization coefficient that shows the reaction of each actor in one situation, this feature is produced through the formula

$$Mob_A = \sum |3MAO|$$

The analysis result of $3MAO$ also produces an agreement and disagreement of an objective calculated through:

$$Ag_A = \sum_{a} (3MAO_{A,i}(3MAO > 0))$$

$$DisAg_A = \sum_{a} (3MAI_{Ai}(3MAO < 0))$$

Another feature that is also important and produced from the matrix $3MAO$ is a convergence matrix $(3CCA)$ that illustrates how much actors agree on an issue and divergence $(3DDA)$ that describes the circumstances. The convergence matrix is produced through the equation:

$$3CAA = \frac{1}{2}\sum_{i}(|3MAO_{A,i}| + |3MAO_{B,i}|)(3MAO_{A,i} \times 3MAO_{B,i} > 0)$$

While the divergence matrix is written:

$$3DAA = \frac{1}{2}\sum_{i}(|3MAO_{A,i}| + |3MAO_{B,i}|)(3MAO_{A,i} \times 3MAO_{B,i} < 0)$$

The calculation result of the convergence and divergence between actors then produces the final indicator of MACTOR, which is the ambivalent coefficient for each actor calculated by the formula:

$$3EQ_i = 1 - \left[\frac{(\sum_k ||3CAA_{i,k} - 3DAA_{i,k}||)}{\sum_k ||3CAA_{i,k} + 3DAA_{i,k}||}\right]$$

These formulas illustrate MACTOR analysis. In its implementation, the analysis framework uses the following principles:

1. Build a table of "Strategies of Actor".
2. Identification of strategic issues and objectives.
3. Map simply the position of the actor in objectives related to the pros and cons of the objectives.
4. Determine the priority of the objectives of each actor.
5. Analysis of the Balance of Power for each actor.
6. Integration of balance of power in convergence and divergence analysis.
7. Formulation of key questions for reconstruction.

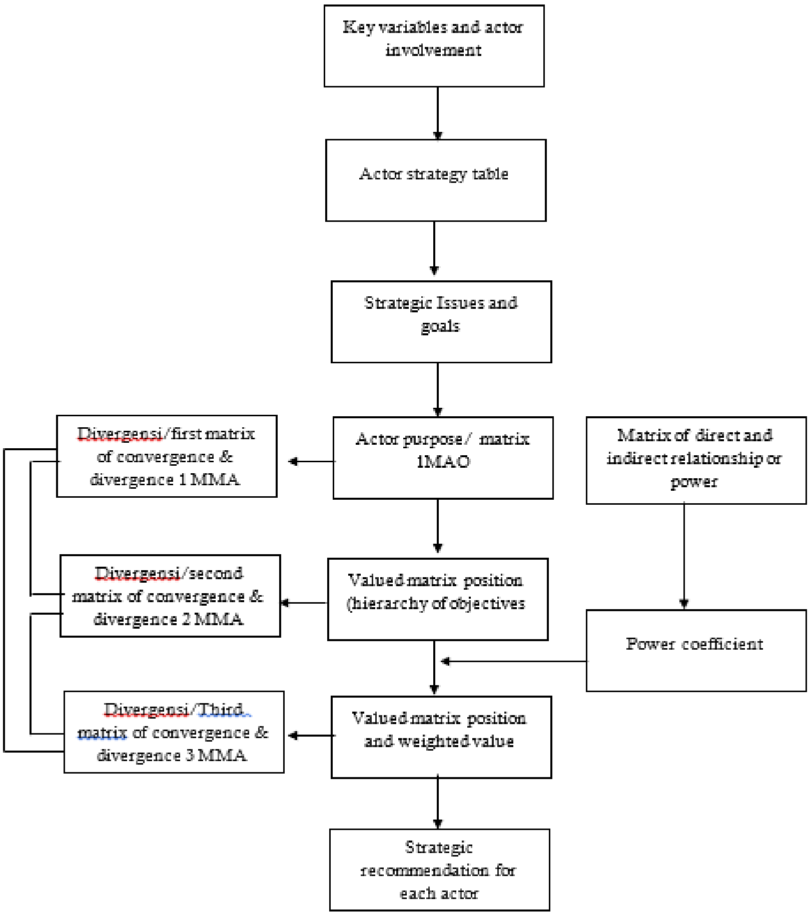


Figure 2. Three Main Inputs in the MACTOR Technique

3. Results and Discussions

Based on the results of interviews and discussions with experts, the results obtained that the strategy of sustainable creative economy development in Magelang city with a local wisdom-based penta approach is identified as many as ten (10) elements. The ten elements of the strategy are as follows:

1. Increasing business legality

Business legality becomes an important aspect for creative industry actors to get protection for intellectual property owned, legal protection, build business credibility, facilitate access to business capital, reduce risks over various parties involved, and facilitate access to foreign markets (Winczorek, 2021). Business legality is also needed for policymakers as a tool to monitor industry actors more easily (Puspaningrum, 2019; Dobusch, 2021). In the aspect of business legality, creative industry actors in Magelang City must be encouraged to register their business legality.

2. Increasing the skill and ability of entrepreneurs

The creative economy has a close relationship with increasing value added to a product or production output (Cannavale et al., 2020). Referring to the unique nature of the creative economy and prioritizing the creativity, skills, and talents of individuals, it is necessary to improve the skill and business capabilities that are sustainable and organized including creative economy actors (Colakoglu *et al*, 2019). In this case, the Magelang City Government needs to map skills for potential creative industry actors and increase business capabilities for business management in order to achieve the sustainability of the business actors of creative industries in Magelang.

3. Increasing sustainable business management

Another important aspect of developing sustainable creative economy development in Magelang city is managerial ability. Managerial abilities are important to maintain business sustainability, including for creative industrial businesses (Calza et al, 2023). By having qualified managerial capabilities, it is expected that businesses are able to develop directed creative business and business management that can follow market dynamics in their business (Ghosh et al., 2020).

4. Increasing production capacity

Another important aspect is to increase the business capacity for creative industry actors in Magelang City. Business capacity is the ability of workers, machinery, or organizations to produce goods and services in a certain period. This component is the best measure of an actor in an industry to produce goods and services to meet customer demand (Zhan *et al,* 2023). For creative industry actors, increasing the maximum production capacity can be done in various ways such as receiving adequate equipment support, conducting employee shift systems, or changes in the production process (Goswami & Daultani, 2023).

5. Application of Appropriate Technology (TTG)

When seen from the creative industry sub-sector, the application of appropriate technology is an important thing besides being an operational need it also functions to achieve a level of efficiency (Loupias & Diawati, 2019). In addition, the application of appropriate technology can also help the process of implementing organic ideas from creative industry actors (Abdoh, 2022). The Government of Magelang City, in this case, has a role to be able to translate the ideas of industry actors and ensure optimal use of appropriate technology by creative industry actors.

6. Supporting infrastructure improvements

Efforts to accelerate the creative business incubation center in Magelang City are a form of infrastructure that needs to be built and developed by the Magelang City Government. Facilitating the revitalization of physical infrastructure and creative space facilities is a relevant requirement to be built including in the regional scope (Tucker & Masuri, 2016). Infrastructure both in the form of ease of public facilities and in the form of community becomes an important element in an effort to build the development of a directed creative industry (Mbedzi & Kapingura, 2023).

7. Increasing capital access

Another element needed in the development of a sustainable creative economy is increasing capital access (Joseph & Totawar, 2021). The Magelang City Government needs to hold matchmaking to creative industry actors with potential partners both financing partners such as banking, angel investors, venture capital, and marketing partners.

8. Improving the grade and quality of sustainable products

The grade and quality of sustainable products are an important elements in the development of the creative economy in Magelang City. However, the majority of creative businesses are still dominated by micro and small scale so that they do not have consistent grade and quality standards. Though this has become an obligation in business development in order to increase productivity and profitability (McCannon, 2019). Efforts to improve grades and quality are elements that need to be encouraged by the Magelang City Government as a partner of creative industry development to be able to produce consistent grades and quality.

9. Increasing business branding

In terms of products, there have been already creative industry actors in Magelang City who began to create innovative products in accordance with the times such as in the fields of fashion, craft, and culinary. Increasing business branding is an important component that must be created by creative industry actors, which basically have the characteristics of products/services from the results of value added for the goods/services they created (Gegenhuber *et al,* 2022). Branding needs to be increased for every creative industry actor in Magelang City with the aim of building image, beliefs, quality assurance, and prestige. On the other hand, in the realm of market controllers, a strong brand can control the market because the community already knows it.

10. Increasing Promotion and Marketing Innovation

The ability to innovate has enough significant influence on marketing performance through the ability of social media (Rajala & Hautala, 2023). Adaptive promotional innovation of technology and market dynamics are important components that can be improved in the strategy of sustainable creative economy development in Magelang City.

Based on the results of the element classification of sustainable creative economic development strategies based on local wisdom in Magelang City consist of 10 criteria that produce 6 policy levels as in figure 3.

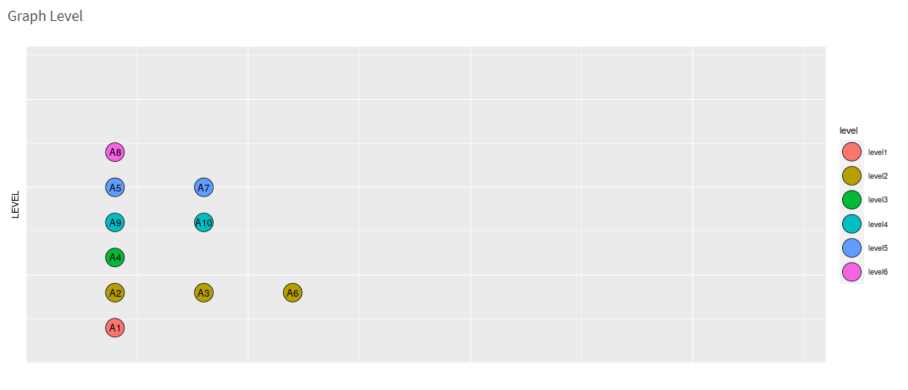


Figure 3 The element hierarchical structure of sustainable creative economy development strategy based on local wisdom in Magelang City.

Based on the hierarchical structure presented in Figure 3, it can be explained that the policy element at the first level is increasing business legality (A1). Then at the second level, there are three policies, namely increasing the skills and abilities of entrepreneurs (A2), increasing sustainable business management (A3), and improving supporting infrastructure (A6). Followed by the third level is increasing production capacity (A4). The fourth level is occupied by two policies including increasing business branding (A9) and increasing promotional and marketing innovations (A10). The policies that occupy the fifth level are the application of appropriate production technology (A5) and increasing access to capital (A7). Meanwhile, the last or sixth level is occupied by the policies of grades and quality of sustainable products (A8).

The classification of elements of a sustainable creative economy development strategy based on local wisdom in Magelang City can be classified into 4 (four) sectors which are presented in Figure 4.

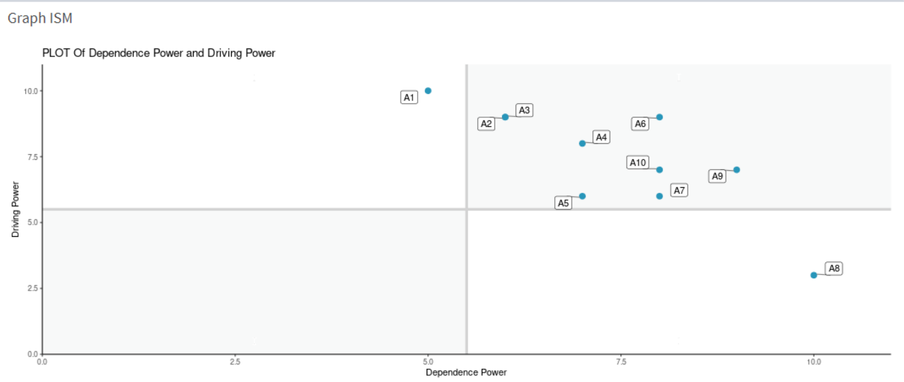


Figure 4. Driver power-dependence matrix.

Based on Figure 4 above, the classification of policy elements is carried out based on the coordinate points obtained from the Level Partitioning result. The result produces a classification of three sectors in the driver power-dependence matrix. Based on the driver power-dependence matrix, the creative economy development strategy through increasing business legality (A1) is included in sector IV (independent). The element has a great driving force but only has little dependence on other policy elements.

Then, the element of grade and quality improvement of sustainable product (A8) is in sector II or the dependent variable sector. This element is an element that is highly dependent on other elements. This shows that these elements have a relatively small driving force and are highly dependent on other variables.

Meanwhile, the elements of increasing the skills and abilities of entrepreneurs (A2), improving sustainable business management (A3), increasing production capacity (A4), applying appropriate technology (A5), improving supporting infrastructure (A6), increasing access to capital (A7), Increasing business branding (A9), Increasing promotion and marketing innovation (A10) are in sector III (Linkage). The elements in this sector have a large driving force but also have a large dependence on other elements. The elements in this sector must be studied carefully because the relationship between variables is unstable. Every action on this variable will have an impact on the other and the feedback effect can increase the impact.

In an effort to build a sustainable creative economy with a local wisdom approach in Magelang City, it requires collaboration and synergy from various relevant stakeholders/actors. These stakeholders come from local government groups, the community, creative economy actors, the Creative Economy Committee, banking, and the media (Subagyo, 2021; Widowati, 2019). Involvement of these stakeholders by considering the following matters:

1. These stakeholders/actors have the authority in developing a sustainable creative economy based on local wisdom in Magelang city
2. These stakeholders/actors will be affected by sustainable creative economy development policies
3. These stakeholders/actors are prerequisites for success in the development of a sustainable creative economy based on local wisdom in Magelang city
4. These stakeholders/actors have competence in developing a sustainable creative economy based on local wisdom

Based on these considerations, the stakeholders or actors who are the source of data in this study are as table 2.

N.	Stakeholders/Actors	Issue	Objectives
1	Businessman	Sustainable creative aconomy development with a penta-helix approach based on local wisdom in Magelang City	1. Increasing business legality
2	Business Partner		2. Increasing the skills and abilities of entrepreneurs
3	Banking		3. Improving sustainable business management
4	Service		4. Increasing production capacity
5	Regional Planning Development Agency		5. Appliclation of appropriate production technology
6	Media		6. Improvement of supporting infrastructure
7	General Public		7. Increasing access to capital
			8. Grade and quality improvement of sustainable product
			9. Increasing business branding
			10. Increasing promotional and marketing innovations

Table 2. The Mapping of Actors Involved and Interested in Local Wisdom-Based Sustainable Creative Economy Development in Magelang City

Based on Table 2, the mapping of actors involved and interested in developing a sustainable creative economy based on local wisdom in Magelang City consists of 7 actors. The composition of the actors involved in the empowerment shows heterogeneous characteristics and shows cross-sectoral, cross-governmental organizations, and non-governmental institution involvement. These actors are entities that have an interest and have a role in mobilizing their resources to be able and active in the development of a sustainable creative economy in Magelang City. An understanding of the relations/relationships between actors in empowering farmers is needed to understand efforts/strategies for developing a sustainable creative economy with a penta-helix approach based on local wisdom in Magelang City. To understand the relationship between actors/stakeholders in empowering farmers, the researchers used the MACTOR software (Matrix of Alliance Conflict Tactic Operations and Responses). In the following, the relations between actors in the development of a sustainable creative economy based on local wisdom in Magelang City are presented.

A comprehensive understanding of the relations between actors in supporting the development of a sustainable creative economy based on local wisdom in Magelang City begins with mapping the relationships between actors. The result of processing the influence data between actors with MACTOR can be seen in Table 2 below. The numbers in column Ii show the influence score, while the numbers in row Di show the dependency between actors.

MDII	Businessman	Business	Banking	Service	Regional Agency	Media	Public	Ii
Businessman	14	16	13	14	16	14	16	89
Business Partner	14	16	14	13	17	14	17	89
Banking	14	17	14	15	16	14	18	94
Service	14	16	13	15	15	14	16	88
Regional Agency	14	16	12	14	14	13	16	85
Media	14	16	13	14	17	14	17	91
Public	11	13	11	13	13	12	13	73
Di	81	94	76	83	94	81	100	609

Table 3. The Influence between Actors/Stakeholders with MACTOR Analysis

Table 3 shows that stakeholders who have a high influence on the development of a sustainable creative economy based on local wisdom in Magelang City are banks with a score of 94, the media with a score of 91, and business actors and business partners with a score of 89. Meanwhile, the stakeholders who have the lowest influence are the community with a score of 73.

Then, the stakeholders who have a high dependency tendency are the community with a score of 100 followed by business partners and Regional Planning Development Agency with a score of 94 while stakeholders who have the lowest dependency are banking with a score of 76.

The actor preference matrix for objectives presents the preferences of the actors involved in efforts to develop a sustainable creative economy based on local wisdom in Magelang City for the expected goals or objectives which are included in the 10 identified objectives including:

1. Increasing business legality
2. Increasing the skill and ability of entrepreneurs
3. Improving sustainable business management
4. Increasing production capacity
5. Application of Appropriate Technology (TTG)
6. Improvement of supporting infrastructure
7. Increasing capital access
8. Improving the quality and quality of sustainable products
9. Increasing business branding
10. Increasing Promotion and Marketing Innovation

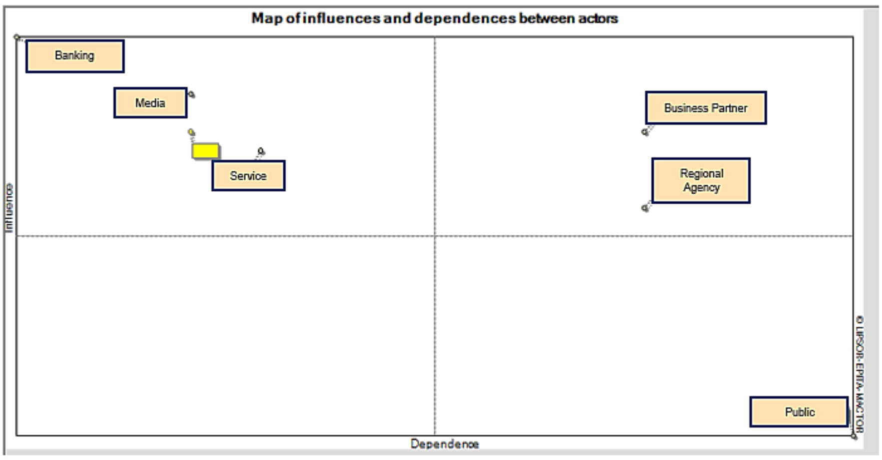


Figure 5. Actor mapping in the influence and dependence quadrant

Insert Table 4 Here

2MAO	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	Absolute sum
Businessman	3	4	4	3	4	3	2	2	4	4	33
Business Partner	3	2	3	3	2	2	1	3	2	2	23
Banking	2	3	3	2	1	2	2	3	3	4	25
Service	4	-3	3	4	3	3	4	3	4	3	34
Regional Agency	3	3	3	4	3	3	4	3	3	3	32
Media	4	-4	3	4	-2	2	3	3	4	3	32
Public	2	2	3	2	1	2	3	2	3	2	22
N. of agreements	21	14	22	22	14	17	19	19	23	21	
N. of disagreements	0	-7	0	0	-2	0	0	0	0	0	
N. of positions	21	21	22	22	16	17	19	19	23	21	

Table 4. Degree Mobilization of Actors and Goals

Table 4 presents the position of each actor on each target/goal (objective) by considering the degree of opinion of the actors regarding the target competitiveness and hierarchy of their targets. The output of this matrix is the first two degree of mobilization that will explain the targets/objectives that most move the actors. Second, mobilization will explain the most mobilized actors to use resources to achieve objectives.

The degree of mobilization (bottom row) shows which objectives are expected to be the main issues that provoke stakeholder reactions. In an effort to develop a sustainable creative economy based on local wisdom in Magelang City, the issues that become the greatest concern are increasing business branding (23), Increasing sustainable business management, and increasing production capacity (22). Meanwhile, the most mobilized actors are the Office (34), Creative Economy Entrepreneurs (33), Regional Planning Development Agency, and Media (32). These actors are the most active in mobilizing in answering the problems of developing a sustainable creative economy based on local wisdom in Magelang City. In more detail, we can see how the actors' preferences for issues/objectives in the development of a sustainable creative economy in Magelang City in the following figure:

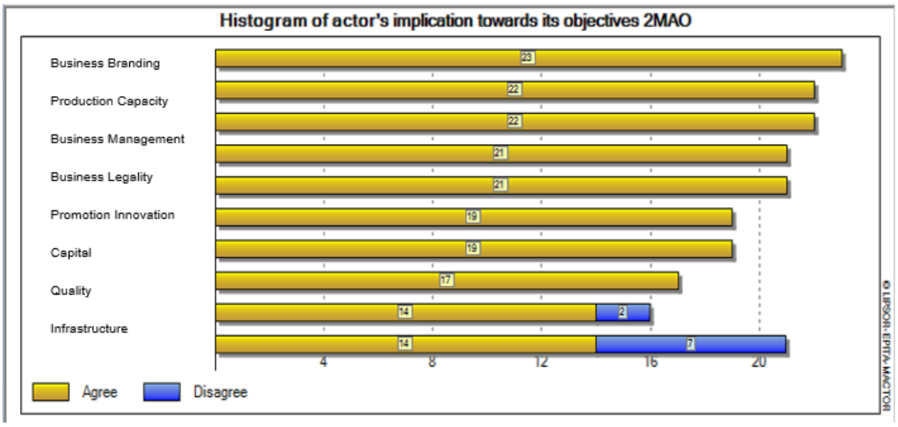


Figure 6. Histogram of actor's perception of objectives

Based on the mapping of perceptions between actors, it can be further investigated that regional objective has received little resistance or rejection from some actors. Nevertheless, more actors agree with the objectives to be achieved in the development of a sustainable creative economy based on local wisdom in Magelang City. As for some of the rejections that exist, namely the application of skills and abilities and the application of production technology. These various rejections arose because the stakeholders concerned felt that the objectives to be achieved in the development of the creative economy could interfere with the achievement of the businesses they are running.

The mapping of actors who agree and disagree with the objectives in developing a sustainable creative economy based on local wisdom in Magelang City can be seen in the picture of the scales between actors and objectives as figure 7 and 8.

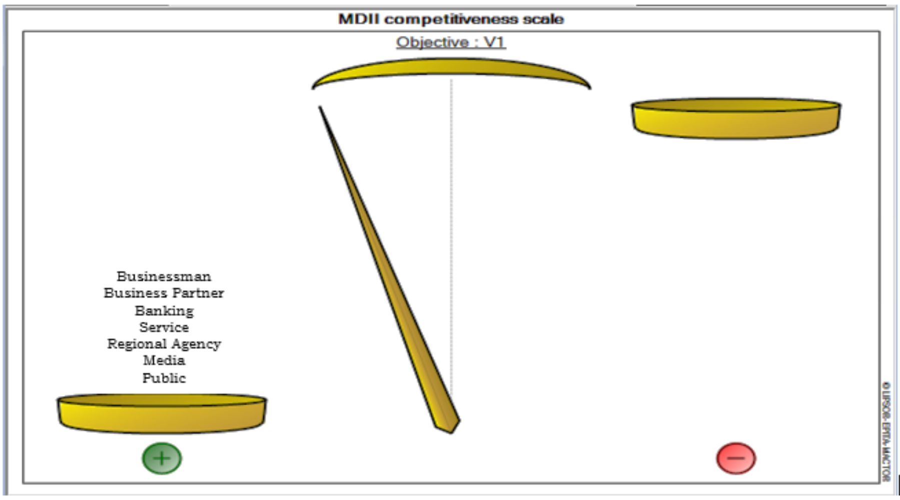


Figure 7. The scale between actors and the objective of increasing business legality

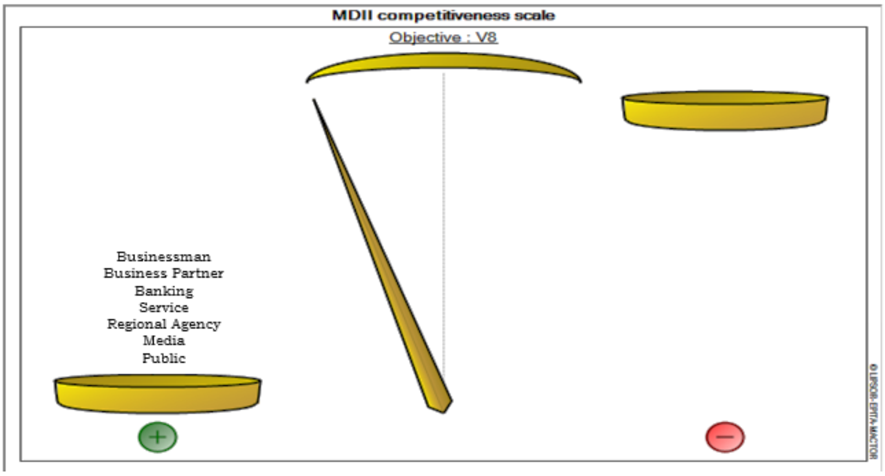


Figure 8. The scale between actors and objectives of sustainable quality improvement and product quality

Figure 8 shows the "scales" of actors who agree and disagree on conservation objectives. Actors/stakeholders who agree with the goals are on the "scale" of + (positive) sign and actors who reject the goals are on the "scales" – (negative). The analysis of "scales" with the objective of increasing business legality and improving the grades and quality of sustainable products shows that there are no actors who disagree in efforts to develop a sustainable creative economy in Magelang City.

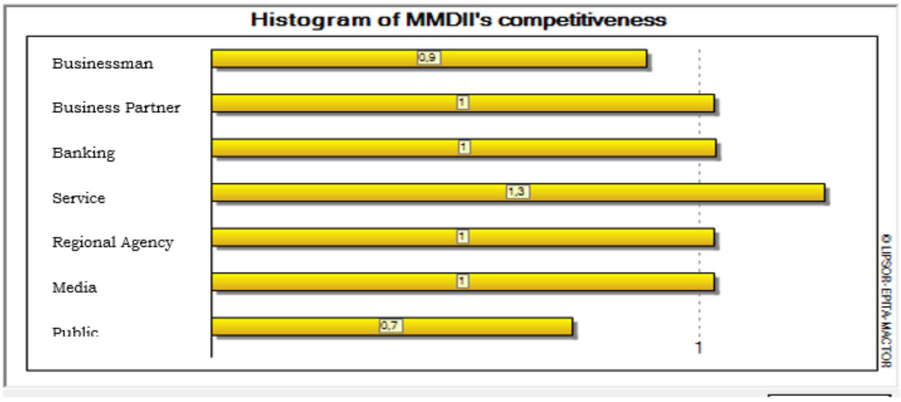


Figure 9. Actor competitiveness

Based on Figure 9, it can be seen that actors who have high competitiveness include the MSME Office (1.3), business partners (1), banking (1), Regional Planning Development Agency (1), and the media (1). These actors have an important role both directly and indirectly in the development of a sustainable creative economy based on local wisdom in Magelang City. Meanwhile, actor who has low competitiveness is the general public.

3.1 Conflict potential between actors

The analysis of potential conflicts between actors aims to find out the actors with the greatest possible conflict in their interactions in the development of a sustainable creative economy based on local wisdom in Magelang City. The result of the potential conflict analysis between actors can be seen in the following figure 10.

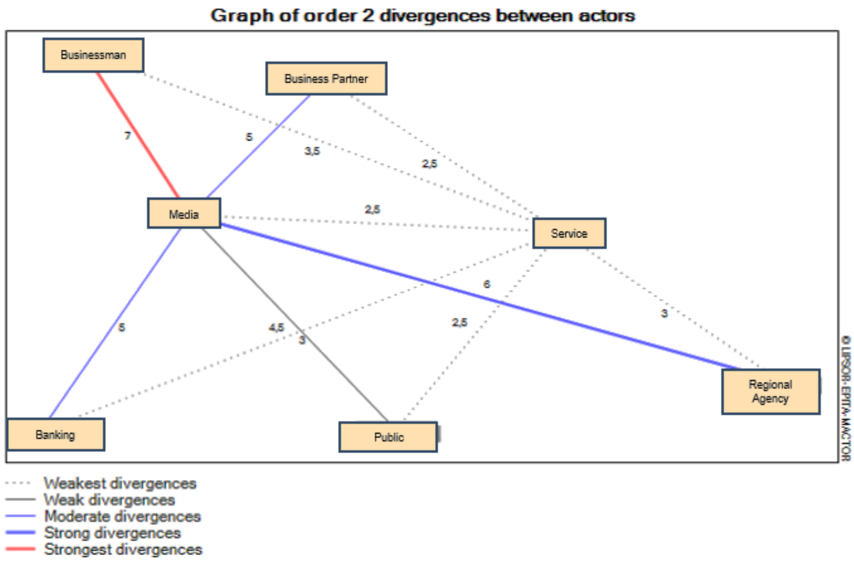


Figure 10. Divergence Matrix between Actors

Figure 10 shows that in the effort to develop a sustainable creative economy based on local wisdom in Magelang City, it has the potential to create conflicts of interest. The activities of actors that are most powerful in causing conflict are business actors and the media. These two actors have the potential to create strong category conflicts (strong divergences). In addition, these two actors are also prone to conflicts with others, such as Media and Regional Planning Development Agency. Therefore, in implementing the empowerment strategy, it is necessary to prioritize a participatory and in-depth discussion approach so that potential conflicts that arise can be minimized.

3.2 Potential for collaboration between actors

Creative economy development in Magelang City requires synergy and collaboration between actors. The potential for collaboration/cooperation between actors can be seen from the degree of convergence between actors as follows figure 11.

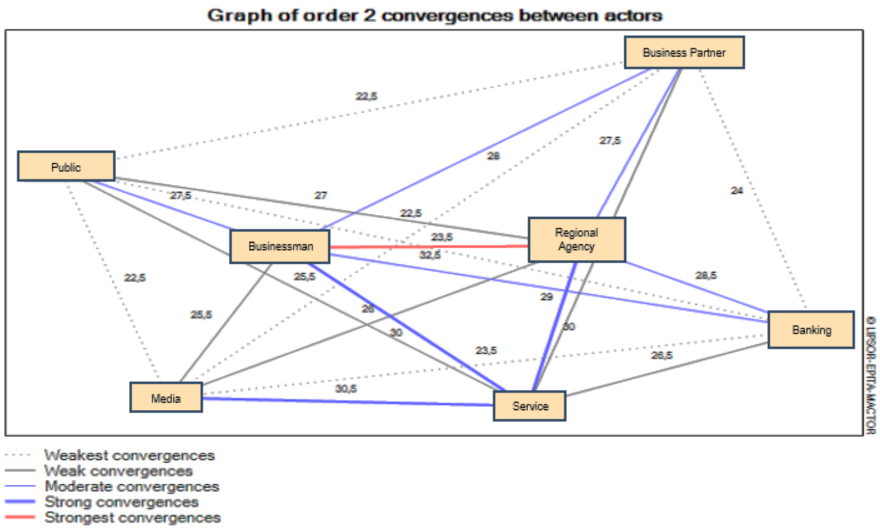


Figure 11. Convergence matrix between actors

Figure 11 explains that the degree of convergence (agreement and covenant) between actors in developing a sustainable creative economy based on local wisdom in Magelang City generally tends to be moderate. Based on the objectives/purposes and roles they have in mobilizing resources, we can map the actors who have the "strongest convergences" which have the most important role in the development of the creative economy. The actors with the strongest convergence are creative industry actors and Regional Planning Development Agency. Regional Planning Development Agency must be able to become an influencer for creative industry actors to start developing their businesses in a sustainable manner by defining their business identity based on local wisdom in Magelang City. The very important role of these actors will be supported by other parties who are in the "strong convergences" category, namely creative industry actors-office, media-office, and Regional Planning Development Agency-office.

A map of Net Distances between Objectives is used to identify objectives where actors take the same position (both pro and against). This graph maps the objectives with respect to the scale value (the difference between the convergence matrix value and the divergence matrix value) as presented in the following figure 12.

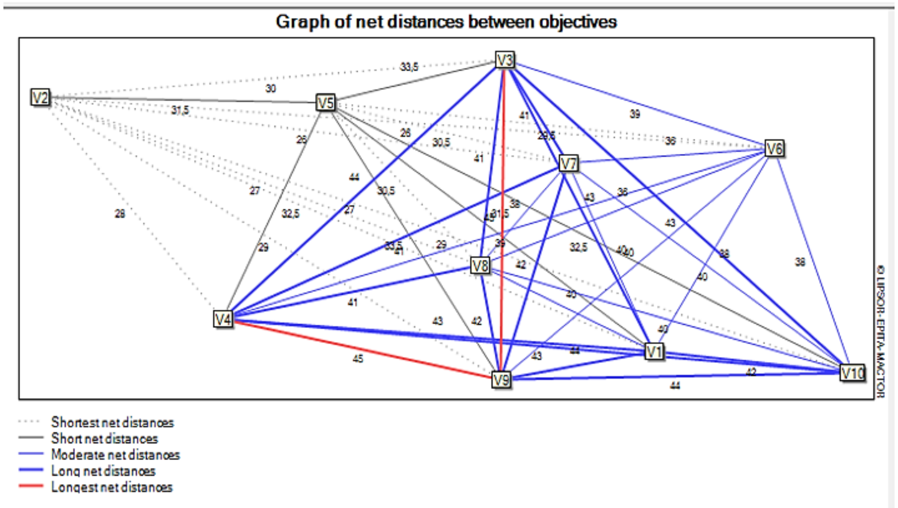


Figure 12. Graph of distance between destinations

The image of the distance between objectives presented illustrates the interrelationships between program objectives. The possible level of closeness that occurs between objectives is illustrated by red and blue colors. The red color indicates a stronger relationship distance than the blue color. The relationship of distances between objectives in the development of creative economy where increasing production capacity-business branding and improving sustainable business management-business branding has a strong relation.

The distance between these actors illustrates the possibility of cooperation between parties. The possible level of cooperation between actors is described in red and blue colors. The red color indicates stronger distance which allows for stronger cooperation. The graph of the distance between actors can be seen in the following figure 13.

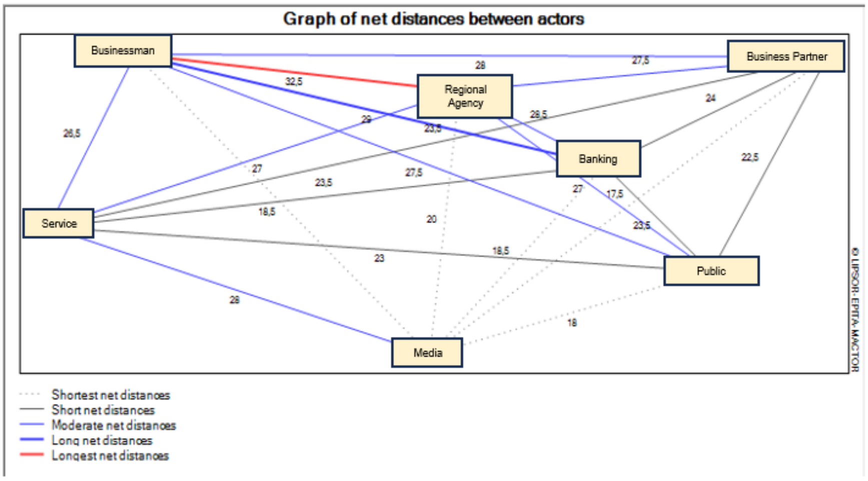


Figure 13. Graph of distance between actors

The relationship of the distance between actors in the development of the creative economy in Magelang City shows a very strong relationship between them (shown in bold red). This shows the strong relation between these actors in developing a creative economy based on local wisdom in Magelang City. The actors who have a very strong relationship are creative economy entrepreneurs and Regional Planning Development Agency.

4. Conclusions

Based on the result and discussion that have been presented, it can be concluded that the strategy for developing a sustainable creative economy in Magelang City with a penta-helix approach based on local wisdom identified as many as 10, among others 1) Increasing business legality, 2) Increasing the skills and capabilities of entrepreneurs, 3) Increasing sustainable business management, 4) Increasing production capacity, 5) Application of Appropriate Technology, 6) Improvement of supporting infrastructure, 7) Increasing access to capital, 8) Increasing the grade and quality of sustainable products, 9) Increasing business branding, 10) Increasing promotion and marketing innovation. The policy element at the first level is Increasing business legality (A1). Then, there are three policies at the second level, namely increasing the skills and abilities of entrepreneurs (A2), increasing sustainable business management (A3), and improving supporting infrastructure (A6). Based on the driver power-dependence matrix, the strategy of creative economy development through increasing business legality (A1) is included in sector IV (independent). The element has a great driving force but only has little dependence on other policy elements.

The stakeholders involved in efforts to develop the creative economy in Magelang City are business actors, business partners, banking, agencies, Regional Planning Development Agency, media, and the general public. The stakeholders who have a high influence on the development of a sustainable creative economy based on local wisdom in Magelang City are banks with a score of 94, the media with a score of 91, and business actors and business partners with a score of 89. Meanwhile, the stakeholder that has the lowest influence is the community with a score of 73. Then the stakeholder with a high dependency tendency is the community with a score of 100 followed by business partners and Regional Planning Development Agency with a score of 94. The degree of mobilization (bottom row) shows which objective is expected to be the main issue that elicits stakeholder reactions. In the effort to develop a sustainable creative economy based on local wisdom in Magelang City, the issues that become the greatest concern are increasing business branding (23), increasing sustainable business management, and increasing production capacity (22). Meanwhile, the most mobilized actors are the Service (34), creative economy entrepreneurs (33), Regional Planning Development Agency, and Media (32). These actors are the most active in their mobilization in responding to problems in the development of a sustainable creative economy based on local wisdom in Magelang City.

The suggestion that can be given in this study is that the creative economy in Magelang city has the potential to be developed considering that the regional location is very strategic and is traversed by tourist routes. However, the creative economy database in Magelang City is not yet available comprehensively, so it needs to be compiled for the 17 existing creative economy sub-sectors. The government as the authority holder needs to develop policies that can help develop potential creative economies such as culinary, craft, and others. In addition, it is necessary to provide supporting infrastructure for creative economy actors in the form of open spaces for meetings of creative economy actors as well as assistance with information and communication technology facilities and Appropriate Technology (TTG). Then, it is also necessary to develop innovative business models and increase access to financing for the developing creative economy.

References

Abdoh, S. A. (2022). Art and sustainability: can digital technologies achieve sustainability? *Journal of Cultural Heritage Management and Sustainable Development*, (ahead-of-print).

Agustina, Y., Winarno, A., Pratikto, H., Narmaditya, B. S., & Filianti, F. (2020). a creative economy development strategy: The case of Trenggalek creative network for Trenggalek Regency, Indonesia. *The Journal of Asian Finance, Economics, and Business*, *7*(12), 1111-1122.

Anantrasirichai, N., & Bull, D. (2021). Artificial intelligence in the creative industries: a review. *Artificial Intelligence Review*, 1-68.

Andersson, Å. E., Andersson, D. E., Daghbashyan, Z., & Hårsman, B. (2014). Location and spatial clustering of artists. *Regional Science and Urban Economics*, 47, 128–137

Awan, U., Sroufe, R., & Kraslawski, A. (2019). Creativity enables sustainable development: Supplier engagement as a boundary condition for the positive effect on green innovation. *Journal of Cleaner Production*, *226*, 172-185.

Aysa, I. R. (2020). Strategi Pengembangan Ekonomi Kreatif di Era Digital. *Jurnal At-Tamwil: Kajian Ekonomi Syariah*, *2*(2), 121-138.

Bimantara, A. R., Hidayat, W., & Suliswanto, M. S. W. (2020). Strategi Pengembangan Ekonomi Kreatif di Kota Malang. *Jurnal Ilmu Ekonomi JIE*, *4*(1), 1-13.

Boix, R., Lazzeretti, L., Capone, F., De Propris, L., & Sánchez, D. (2013). *The Geography of Creative Industries in Europe: Comparing France, Great Britain, Italy and Spain. In L. Lazzeretti (Ed.), Creative Industries and Innovation in Europe: Concepts, Measures and Comparative Case Studies*. USA and Canada: Routledge.

Boix-Domenech, R., Hervás-Oliver, J. L., & De Miguel-Molina, B. (2015). Micro-Geographies Of Creative Industries Clusters In Europe: From Hot Spots To Assemblages. *Papers in Regional Science*, 94, 753–772

Brydges, T., & Pugh, R. (2021). Coming Into Fashion: Expanding The Entrepreneurial Ecosystem Concept To The Creative Industries Through A Toronto Case Study. *The Canadian Geographer/Le Géographe canadien*, *65*(3), 346-367.

Calza, F., Sorrentino, A., & Tutore, I. (2023). Combining Corporate Environmental Sustainability And Customer Experience Management To Build An Integrated Model For Decision-Making. *Management Decision*, 61(13), 54-84.

Cannavale, C., Zohoorian Nadali, I., & Esempio, A. (2020). Entrepreneurial Orientation And Firm Performance In A Sanctioned Economy–Does The CEO Play A Role?. *Journal of Small Business and Enterprise Development*, 27(6), 1005-1027.

Carayannis, E. G., & Campbell, D. F. (2009). 'Mode 3'and'Quadruple Helix': Toward A 21st Century Fractal Innovation Ecosystem. *International Journal of Technology Management*, *46*(3-4), 201-234.

Caves, R. E. (2000). *Creative Industries: Contracts Between Art And Commerce.* Cambridge and London: Harvard University Press.

Chang, Y. Y., Potts, J., & Shih, H. Y. (2021). The Market For Meaning: A New Entrepreneurial Approach To Creative Industries Dynamics. *Journal of Cultural Economics*, *45*(3), 491-511.

Chollisni, A., Syahrani, S., Shandy, A., & Anas, M. (2022). The Concept Of Creative Economy Development-Strengthening Post COVID-19 Pandemic In Indonesia. *Linguistics and Culture Review*, *6*, 413-426.

Comunian, R., Chapain, C., & Clifton, N. (2010). Location, Location, Location: Exploring The Complex Relationship Between Creative Industries And Place. *Creative Industries Journal,* 3, 5–10.

Dobusch, L., Hondros, K., Quack, S., & Zangerle, K. (2021). Between Anxiety And Hope? How Actors Experience Regulatory Uncertainty In Creative Processes In Music And Pharma. *In Organizing Creativity in the Innovation Journey*, 75, 137-160. Emerald Publishing Limited.

Dümcke, C. (2021). Five Months Under COVID-19 In The Cultural Sector: A German Perspective. *Cultural Trends*, 30(1), 1–9.

Feldman, M. P., & Kogler, D. F. (2010). Stylized Facts In The Geography Of Innovation. In B. H. Hall, & N. Rosenberg (Eds.), *Handbook of the Economics of Innovation*, 1, 381–410. Amsterdam: Elsevier.

Flew, T. (2002). Beyond ad hocery: Defining Creative Industries. *Presented At The The Second International Conference On Cultural Policy Research: Cultural Sites, Cultural Theory, Cultural Policy, Wellington, New Zealand.*

Florida, R., & Jackson, S. (2010). Sonic City: The Evolving Economic Geography Of The Music Industry. *Journal of Planning Education and Research*, 29, 310–321.

Garnham, N. (2005). From Cultural To Creative Industries: An Analysis Of The Implications Of The "Creative Industries" Approach To Arts And Media Policy Making In The United Kingdom. *International Journal of Cultural Policy*, 11, 15–29.

Gegenhuber, T., Logue, D., Hinings, C. B., & Barrett, M. (2022). Institutional Perspectives on Digital Transformation. *In Digital Transformation and Institutional Theory,* 83, 1-32. Emerald Publishing Limited.

Ghosh, D., Huang, X., & Sun, L. (2020). Managerial Ability And Employee Productivity. *In Advances in Management Accounting*, 151-180. Emerald Publishing Limited.

Ginting, A. M. (2019). Strategi Pengembangan Ekonomi Kreatif Di Provinsi Jawa Barat (The Development Strategy Of Creative Economic In The West Java Province). *Kajian*, *22*(1), 71-84.

Glaeser, E. L., Kolko, J., & Saiz, A. (2001). Consumer City. *Journal of Economic Geography,* 1, 27–50.

Goswami, M., & Daultani, Y. (2023). Product Quality Optimization Vs Production Capacity Optimization: An Analytical Perspective. *International Journal of Quality & Reliability Management,* 40(3), 801-819.

Hastuti, T., Marjani, A. T., & Puspitasarie, E. (2018, October). Strategi Pengembangan Ekonomi Kreatif Di Malang Raya Sebagai Upaya Peningkatan Daya Saing Pelaku Ekonomi Lokal. In *Conference on Innovation and Application of Science and Technology (CIASTECH)*, 1 (1), 81-90.

Haudi, A., Ratumbuysang, M. F. N. G., & Hasanah, M. (2021). Strategi Pengembangan Ekonomi Kreatif Pada Industri Kecil Dodol Di Hulu Sungai Selatan. *Journal of Economics Education and Entrepreneurship*, *1*(1), 31-36.

Joffe, A. (2020). Covid-19 And The African Cultural Economy: An Opportunity To Reimagine And Reinvigorate?. *Cultural Trends*, 30(1), 28–39.

Joseph, N., & Totawar, A. (2021). How To Increase Social Capital Of Organizations: Identifying The Role Of Informal Learning Behaviors. *Development and Learning in Organizations: An International Journal*, 35(3), 1-3.

Khlystova, O., Kalyuzhnova, Y., & Belitski, M. (2022). The Impact Of The COVID-19 Pandemic On The Creative Industries: A Literature Review And Future Research Agenda. *Journal of Business Research*, *139*, 1192-1210.

Lam, D. (2006). The Demography Of Youth In Developing Countries And Its Economic Implications. *World Bank Policy Research Working Paper 4022.*

Lazzeretti, L., Boix, R., & Capone, F. (2008). Do Creative Industries Cluster? Mapping Creative Local Production Systems In Italy And Spain. *Industry & Innovation*, 15, 549–567.

Lee, S. Y., Florida, R., & Acs, Z. (2004). Creativity And Entrepreneurship: A Regional Analysis Of New Firm Formation. *Regional Studies*, 38, 879–891.

Leydesdorff, L., & Etzkowitz, H. (1996). Emergence Of A Triple Helix Of University—Industry—Government Relations. *Science and Public Policy*, *23*(5), 279-286.

Lorenzen, M., & Frederiksen, L. (2008). *Why Do Cultural Industries Cluster? Localization, Urbanization, Products And Projects. In P. Cooke, & L. Lazzeretti (Eds.), Cultural Districts, Cultural Clusters And Economic Development.* UK and USA: Edward Elgar Publishing.

Loupias, H. H., & Diawati, P. (2019). Comparison Of Creativity Model In The Wood Figurine Creation At Creative Industries In Biak Numfor Regency, Papua Province And Cipacing Village, West Java Province: Creative Mystical Versus Creative Imitation. *Pro Mark*, 9(1).

Mbedzi, E., & Kapingura, F. M. (2023). Infrastructure Availability And Disruption Levels On Performance Of Firms: A Survey Of Sub-Saharan Africa Informal Enterprises. *African Journal of Economic and Management Studies*.

McCannon, B. C. (2019). Minimum Quality Standard Regulation And Entrepreneurial Innovation. *Journal of Entrepreneurship and Public Policy*, 8(2), 217-225.

Nurmilah, R., Anggraeni, L., & Novianti, T. (2016). Strategi Pengembangan Ekonomi Kreatif Kota Sukabumi (Creative Economy Development Strategy in Sukabumi). *Jurnal UMMI: Jurnal Penelitian dan Pengembangan Sains dan Teknologi*, *10*(3), 98-113.

Ó Cinnéide, B., & Henry, C. (2007). *Entrepreneurship Features Of Creative Industries: The Irish Music And Dance Sector. In C. Henry (Ed.), Entrepreneurship In The Creative Industries: An International Perspective.* Cheltenham and Northampton: Edward Elgar.

OECD. (2020). *Culture shock: COVID-19 and the cultural and creative sectors*. OECD Publishing.

Popelo, O. L. H. A., Tulchynska, S., Garafonova, O., Kovalska, L., & Khanin, S. (2021). Methodical Approach To Assessing Innovative Development Efficiency Of Regional Economic Systems In The Conditions Of The Creative Economy Development. *WSEAS transactions on environment and development*, *17*, 685-695.

Potts, J. (2007). Art & Innovation: An Evolutionary Economic View Of The Creative Industries. *UNESCO Observatory,* 1, 1–17

Power, D. (2002). "Cultural Industries" In Sweden: An Assessment Of Their Place In The Swedish Economy. *Economic Geography*, 78, 103–127.

Puspaningrum, A. (2019). The Role Of Business Size, Business Duration, Credit Facilities And Business Legalities On SME's Growth. *European Journal of Research and Reflection in Management Sciences*, 7(3).

Rajala, A., & Hautala-Kankaanpää, T. (2023). Exploring The Effects Of Smes' Platform-Based Digital Connectivity On Firm Performance–The Moderating Role Of Environmental Turbulence. *Journal of Business & Industrial Marketing*, 38(13), 15-30.

Rosenthal, S. S., & Strange, W. C. (2004). Evidence On The Nature And Sources Of Agglomeration Economies. *Handbook of regional and urban economics*, 4, 2119–2171. Elsevier.

Sawyer, R. K. (2012). *Explaining Creativity: The Science Of Human Innovation (2nd Ed).* New York: Oxford University Press.

Schulz, K. P., Mnisri, K., Shrivastava, P., & Sroufe, R. (2021). Facilitating, envisioning and implementing sustainable development with creative approaches. *Journal of Cleaner Production*, *278*, 123762.

Scott, A. J. (1997). The Cultural Economy Of Cities. *International Journal of Urban and Regional Research*, 21, 323–339.

Shofa, I., & Nugroho, D. (2018). Pertumbuhan dan Strategi pengembangan ekonomi kreatif Kota Malang. *PANGRIPTA Jurnal Ilmiah Kajian Perencanaan Pembangunan*, *1*(1), 75-85.

Sjögren Forss, K., Kottorp, A., & Rämgård, M. (2021). Collaborating In A *Penta-Helix* Structure Within A Community Based Participatory Research Programme: 'Wrestling With Hierarchies And Getting Caught In Isolated Downpipes'. *Archives of Public Health*, *79*(1), 1-13.

Storper, M., & Scott, A. J. (2009). Rethinking Human Capital, Creativity And Urban Growth. *Journal of Economic Geography*, 9, 147–167.

Subagyo, A. (2021). The Implementation Of The Pentahelix Model For The Terrorism Deradicalization Program In Indonesia. *Cogent Social Sciences*, 7(1), 1964720.

Sundari, S., Yusuf, C., & Kusuma, A. A. (2021). The Influence of *Penta-helix* Model on Organizational Innovativeness and Product Innovation Performance at Creative Economy Supporting Jember District Tourism Destination. In *The First International Conference on Social Science, Humanity, and Public Health (ICOSHIP 2020)* (pp. 170-174). Atlantis Press.

Swastuti, E., & Pudjiarti, E. S. (2021). Strategi Pengembangan Ekonomi Kreatif Mendukung Daya Saing Daerah Kota Tangerang. *JPAP: Jurnal Penelitian Administrasi Publik*, *7*(1).

Tucker, M. and Masuri, M.R.A. (2016), "The Rationale To Integrate Facilities Management Into The Development Process", *Property Management*, 34 (4), 332-344.

Wahjudewanti, A. S., Tjakraatmaja, J. H., & Anggoro, Y. (2021). Knowledge Manajement Strategies to Improve Learning and Growth in Creative Industries: A Framework Model. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, *4*(2), 1903-1915.

Wenting, R., Atzema, O., & Frenken, K. (2011). Urban Amenities And Agglomeration Economies?: The Locational Behaviour And Economic Success Of Dutch Fashion Design Entrepreneurs. *Urban Studies*, 48, 1333–1352.

Widowati, S., Ginaya, G., & Triyuni, N. N. (2019). Penta Helix Model To Develop Ecotourism: Empowering The Community For Economic And Ecological Sustainability. *International Journal of Social Sciences and Humanities*, 3(2), 31-46.

Wiktor-Mach, D. (2020). What role for culture in the age of sustainable development? UNESCO's advocacy in the 2030 Agenda negotiations. *International Journal of Cultural Policy*, *26*(3), 312-327.

Winczorek, J. (2021). Moral Communication And Legal Uncertainty In Small And Medium Enterprises. *Kybernetes*, 51(5), 1666-1691.

Wulandari, F. R., Supriyono, B., Muluk, M. R. K., & Setyowati, E. (2022). Depok City Creative Economy Development Strategy During the Covid-19 Pandemic. *KnE Social Sciences*, 277-288.

Yunas, N. S., Wahyuningsih, E., & Jatmiko, A. R. (2021). Strengthening Community In Increasing Village Potential Through *Penta-Helix* Collaboration. *International Journal of Research in Business and Social Science*, *10*(1), 149-157.

Zhan, W., Jiang, M., & Wang, X. (2023). The Optimal Capacity Decision Of The Catering Merchant In Omnichannel–Service, Production And Delivery Capacity. Kybernetes.

Authors

Sucihatiningsih Dian Wisika Prajanti (*corresponding author*)
Universitas Negeri Semarang, Department Economics Development, Jawa Tengah, Semarang. e.mail: dianwisika@mail.unnes.a.c.id

Dalila Daud
Accounting Research Institute (ARI), Universiti Teknologi MARA, Selangor, Malaysia

Syaiful Amin
Universitas Negeri Semarang, Department History Education, Jawa Tengah, Semarang. e.mail: syaifulamin@mail.unnes.ac.id

Subiyanto
Universitas Negeri Semarang, Department Electrical Engineering, Jawa Tengah, Semarang. e.mail: subiyanto@mail.unnes.ac.id

Fauzul Adzim
Universitas Diponegoro, Post-graduate, Jawa Tengah, Semarang.
e.mail: fauzuladzim58@gmail.com

Funds

This research was funded by Semarang State University with an internal scheme for 2023. Therefore, the authors would like to thank the institution for the financial support that has been provided.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Prajanti, S.D.W., Daud, D., Amin, S., Subiyanto, Adzim, F. (2023) A sustainable creative economy development model using a penta-helix approach based on local wisdom in Magelang City, Indonesia. *Visions for Sustainability*, 20, 7917, 239-275.
http://dx.doi.org/10.13135/2384-8677/7917

Original Paper

State regulation of sustainable development of rural areas in the system of food security of Ukraine

Dmytro Fedchyshyn, Iryna Ignatenko, Alyona Chyryk, Daria Danilik

Received: 9 June 2023 | **Accepted:** 27 July 2023 | **Published:** 4 August 2023

Keywords: rural areas; sustainable development, food security, state regulation of rural areas development, strategy for sustainable development of rural areas, agricultural sector, agricultural products, agricultural production

Abstract. *Currently, the issue of sustainable development of rural areas is one of the most important areas of research. The relevance of the issue under consideration lies in the fact that economically stable and socially developed rural areas guarantee the stability, independence, and food security of the state. Therefore, the vector of their development should be a priority direction of state policy. The sustainable development of rural areas is currently being paid close attention to not only in Ukraine, but throughout the world. The sustainable development of the territory implies an increase in the efficiency of production located on it, an increase in the standard of living of the population, the presence of a developed infrastructure in the territory, as well as solving the housing problems of the population, reducing unemployment, and so on. However, the current conditions prevailing in rural areas prevent the formation of socio-economic prerequisites for this process. As a result, we can state the absence of a mechanism that ensures sustainable socio-economic development of rural areas. This requires immediate cardinal changes in the development policy of rural areas of Ukraine to increase their sustainability. The purpose of this article is to identify factors that affect the functioning and development of rural areas in Ukraine and systemic problems that hinder their development. Attention is focused on the formation of effective and efficient mechanisms for promoting the sustainable development of rural areas, as well as the development of a conceptual model for the sustainable development of rural areas. It is also necessary to identify priority areas of state policy for the period up to 2035 in the field of sustainable development of rural areas.*

1. Introduction

At the present stage of economic development, it is necessary to consider issues related to the protection of the environment, as well as social issues of life support for the population, as one of the main issues involved. Awareness of the role of rural areas in achieving sustainable development of countries and their food security has led to the emergence of a new theory of sustainable development of rural areas in modern science.

The sustainable development of rural areas should be the main goal of the policy of every state. Countries should move in the direction of the development of rural areas as a complex that performs production, demographic, institutional, social, economic, environmental, and other functions.

Achieving this goal of sustainable development of rural areas will help to ensure the country's food security. As a result, both the quality and standard of living of the population of the country and the competitiveness of the economy can be increased.

The sustainable development of rural areas plays a pivotal role in ensuring the overall food security of a nation. In Ukraine, a country with significant agricultural potential and a rich rural heritage, the promotion of sustainable practices in rural areas is essential for achieving long-term food security goals.

Current socio-economic situation in rural settlements in Ukraine is characterized by a number of crisis phenomena that impede the transition to sustainable development of the territory. These phenomena include: (1) deterioration of the demographic situation in rural areas; (2) rural poverty and high unemployment of the rural population; (3) declining quality of life in rural areas; (4) reduction of the network of social infrastructure institutions; (5) restricting the access of villagers to basic social services - education and health care; (6) destruction of the evolutionarily established system of rural settlement.

While there are existing studies on sustainable rural development and food security, few have specifically focused on the role of state regulation policies in the context of Ukraine. This research aims to bridge this gap by offering a detailed analysis of the interplay between state-led initiatives, rural development practices, and food security outcomes. By identifying successful strategies and potential challenges, our study seeks to provide valuable inputs for policymakers and researchers striving to enhance the effectiveness of state interventions in building sustainable and food-secure rural communities.

2. Research methods

The theoretical basis of the research and the results presented in the article was the generalization and adaptation of theories and concepts of sustainable global development expressed at international forums, in publications of international and Ukrainian scientists, the results of research recognized by the international scientific community. These include: the need to resolve the problem of sustainable development in the face of global threats and risks for humanity as a necessary basis for the safe development of the global community (World

Economic Forum, 2016); accounting and reducing risks for the development of harmonious relations between the natural and social environments due to the formation of a global information space (Haberl et al., 2016); development of the "cluster" category and its role in shaping the competitive advantages of countries (Porter, 2000); substantiation of the importance of the digital economy in modern agriculture (Pesce et al., 2019); formation of an effective model of food security in Ukraine (Fedchyshyn et al., 2022a); ensuring the proper use of agricultural land, taking into account private and public interests (Fedchyshyn et al., 2022b); development of organic agricultural production (Ignatenko, 2020).

By drawing upon these theoretical frameworks and concepts, the article aims to provide a comprehensive analysis of the state regulation of sustainable development in rural areas and its connection to food security in Ukraine. These theories help to frame the research questions, shape the methodology, and provide a broader context for the findings presented in the article.

The above-mentioned publications and sources were used in the article because they:

- directly relate to the subject of our article. They include materials that provide insights into policies, practices, and challenges in this specific area;
- are from reputable academic journals, forums, and books that have undergone peer review. Peer-reviewed sources undergo scrutiny by experts in the field, which ensure quality of the information presented;
- are recent and up-to-date. Given that the article is focused on a dynamic field like sustainable development and food security, it is essential to include the most current research and data available at the time of writing;
- aim to include a diverse range of viewpoints and research from different authors and institutions to provide a comprehensive analysis of the topic.

By applying these criteria, the article can present a well-rounded and evidence-based research results.

Moreover, the article was prepared based on an integrated approach, which made it possible to identify the main theoretical and applied directions for the formation of a balanced, sustainable, and competitive socio-natural-economic space of the agro-industrial complex and rural areas. The application of a systematic approach made it possible to scientifically substantiate the priority areas of state policy in this area. The study carried out a terminological and expert analysis of the current regulatory legal acts of Ukraine, materials of different regions that implement the concept and strategies of sustainable spatial development.

3. Results and discussion

3.1. A Stable agricultural sector of Ukraine as an important factor in ensuring food security throughout the world

Ukraine is among the countries with the highest rating in terms of potential reserves of agro-industrial production, as the country accounts for almost 1/3 of black soil reserves and 27% of Europe`s arable land. During 2014-2021, the role of the agricultural sector in the national economy consistently increased due to the increase in exports by domestic agricultural producers and the growing interest in imports in European countries. To some extent, these trends were facilitated by the association agreement with the EU and its implementation in recent years.

Before Russia's invasion of Ukraine in February 2022, the share of agriculture in the country's GDP was 11%. This sector employed nearly 20% of workers and contributed nearly 40% to export earnings. This is due to the fact that Ukraine occupies the fifth place in the world among the largest exporters of wheat, the fourth of exporters of corn, and the third of exporters of rapeseed. Accordingly, a strong and stable agricultural sector of Ukraine is an extremely important factor in ensuring food security throughout the world. According to a report of the Food and Agricultural Organization of the United Nations (FAO), during the first month of the war unleashed by Russia in Ukraine, world food prices increased by 12.6%, which clearly indicates the status of Ukraine as one of the main breadbaskets of the world (Nesenenko, 2022).

In July 2021, the Verkhovna Rada of Ukraine (Parliament of Ukraine) adopted a law on the abolition of the moratorium on the sale of agricultural land, which had been in effect for two decades. This reform opened the market for agricultural land and created opportunities for private investment that will contribute to the economic revitalization of rural communities - primarily through the growth of small and medium-sized businesses in agriculture and related industries. It seems that Ukrainians who live in the countryside will benefit from it.

However, this Law contains many contradictions, ambiguous interpretations, and some issues are not resolved at all. For example, there are no clear answers to the following questions: 1) what kinds of land are formed for the purpose? 2) what forms of government support are encouraged? 3) what should be the relationship between individual farm smallholders, women`s businesses, and cooperatives on the one hand, and companies on the other?

In addition, many issues related to the actual creation of land holdings in Ukraine remain legislatively unresolved. And such a result threatens further uncontrolled growth of large agroholdings. Today, agricultural holdings use the land based on lease agreements, but after the entry into force of all the norms of the Law, they can become the owners of most of the country's land. There are certain risks in this situation. After all, they grow two or three of the most liquid crops on foreign markets. At the same time, crop rotation is not observed. These structures are not engaged in animal husbandry. In this way, the connection between crop production and livestock production is broken. But the worst problem is that they do not create jobs for the rural population, but - on the contrary - eliminate them without providing other opportunities for workers. In addition, agricultural holdings do not care about the social problems of the village and the social development of rural areas. The main goal of such agricultural formations is to obtain as much profit as possible. From a commercial point of view, this may seem to be correct. But as a result of this kind of careless exploitation, the land is exhausted and its fertility is not restored. On the other hand, it also has a negative impact on local budgets, which causes insufficient damage to the entire region. In most cases, absorbed agricultural enterprises lose their legal independence, and parent companies registered in cities do not pay taxes to local budgets, which reduces the development opportunities of rural areas.

It seems if efforts proceed at such a pace, there will be no less than 200 agricultural holding companies in Ukraine with various types of capital, which will have up to 50% of Ukraine's arable lands. Such consolidation of lands with a small number of agricultural formations can lead to the final destruction of the rural settlement network and the labour market in rural areas.

In addition, the risk of the adopted Law is the possibility of the purchase of land by significant geopolitical players who suffer from a lack of food. And this can pose a threat to national security of Ukraine. Different countries can use the imperfection of the land legislation in order to harm the territorial integrity of Ukraine. Villagers are worried that due to the lack of transparency in the process of buying and selling agricultural land, foreign owners can take it over, and the local population will find themselves in the role of extras.

The urgency and importance of the issue of the formation of the land market in Ukraine reflects the complexity of its solving. Most of the problems that arise are new for Ukrainian society, and to a large extent the approaches to their solution are still being outlined. That is why the issue of reforming land relations in the context of sustainable development of rural areas requires in-depth research.

It is necessary to promote the implementation of critically important reforms in this sector, which should include: 1) creation of a full-fledged and transparent agricultural land market, 2) improvement of state policy in the field of land irrigation, 3) creation of additional opportunities for employment in the countryside, 4) provision of social security, 5) improvement of access of agricultural producers to financial resources, 6) Ukraine's integration into European and global food and economic structures, 7) wider implementation of international food safety standards, which will allow diversification of Ukraine's export opportunities.

3.2. Legal support of the concept of sustainable development

More than fifty years ago, the countries of Western Europe and the European Union faced the problems of a massive outflow of population from rural areas to cities, which is currently typical for modern Ukraine. The fight against the formation of vast depressed zones determined the direction of the state policy of these countries towards the creation of conditions for the sustainable development of rural areas. The main criteria for the rural development policy were targeting and purpose. The events were carried out simultaneously in several directions: 1) the implementation of a policy to stimulate food production and the formation of a set of measures to ensure food security; 2) diversification of the rural economy; 3) development of a program for the implementation of ecological safety of the environment. The implementation of these measures and strict adherence to the prescribed actions made it possible to cope with the situation that had arisen. It helped to bring the rural areas of these regions to a new level of development.

Back in 1980, in the report "World Conservation Strategy", which was presented by the International Union for Conservation of Nature and Natural Resources, the term "sustainable development" was first used. The wording of this term was presented as "the modification of the biosphere and the application of human, financial, living and non-living resources to satisfy human needs and to improve the quality of human" (IUCN, 1980, p.18).

In June 1992, the UN Conference was held in Rio de Janeiro, which highlighted the issues of the environment and its development. Thanks to the decisions of this conference, the concept of "sustainable development" has become widespread in science. The Council of Entrepreneurs for Sustainable Development at this conference developed a declaration, which focused on the fact that improving the quality and standard of living of the population would be achieved with the efficient use of natural and material resources, reducing environmental pollution. It was also argued that long-term cooperation between the business sector of different countries would ensure the economic growth of states with an active investment policy and the introduction of new technologies. The result was the development and adoption of several legislative acts at the same time, dedicated to the protection of the environment at the national level.

Achieving sustainable development within rural areas has become highly relevant. In 1996, a session of the Food and Agriculture Organization of the United Nations (FAO) was held in the city of Rome. At the end of this event, the participating members adopted provisions for achieving sustainable development relating to the agricultural sector and directly to rural territorial entities. The key points were defined: 1) ensuring food security and sustainable improvement of the level and quality of food production; 2) application of new technologies to ensure the availability of food; 3) decrease in the unemployment rate; 4) reducing the percentage of poverty by increasing the level of income of the population; 5) rational use of natural resources and environmental protection.

Already in 2002, at the World Summit on Sustainable Development in Johannesburg, the Declaration on Sustainable Development was adopted, which approved recommendations on priorities and further steps to implement the provisions of previously adopted documents, as well as justified the need for individual states to adopt national strategies for such development of their economies.

The results of this session also affected Ukraine. The concept of balanced (sustainable) development of agroecosystems in Ukraine for the period until 2025 was developed by the Ministry of Agrarian policy of Ukraine (2003). This Concept note is aimed at ensuring the implementation of the ideas and principles declared by the UN Conference on Environment and Development (Rio de Janeiro, 1992) and the World Summit on Balanced Development (Johannesburg, 2002), to which Ukraine has joined. It envisages a number of measures for the formation of a balanced – and thereby sustainable – system of nature use in agriculture and ensuring the development of an eco-network, in particular, carrying out a scientifically based transformation of the structure of agricultural lands with the aim of forming a balanced relationship between individual components of agro-ecosystems, ensuring ecological safety and balance of the territory, etc. (clause 3.1).

At the regular UN conference on sustainable development (Rio + 20, Rio de Janeiro, 2012), the final document entitled "The future we want" was approved. It defines the vector for creating a "green economy" for achieving sustainable development, overcoming poverty, and improving international coordination in ensuring such development.

The Food and Agriculture Organization of the United Nations (FAO) in 2015 published the report "Achieving Zero Hunger", which pays great attention to the problems of ensuring the sustainable development of agro-industrial production. The report notes that existing governance models (political and economic) do not allow "to make the future the way we want it to be". At the same time, attention is focused on the fact that some countries continue to lag in development, inequality is growing in them, shocks caused by economic crises, conflicts, natural disasters, and outbreaks of diseases that are rapidly spreading around the world. Environmental problems, climate change and other global risks threaten to undermine the successes of the past and hopes for the future.

We believe that ensuring the achievement of "zero hunger" is possible by increasing the level of sustainability of food systems through the conservation of natural resources and the introduction of sustainable agricultural practices. In this connection, it is proposed: "to reduce the amount of food losses and food waste at the stages of production, storage and consumption, to reduce greenhouse gas emissions in agriculture and other sectors, to slow down the pace of climate change, to ensure the food security of future generations" (Sundaram, 2015).

The Ukrainian Law of September 16, 2014, ratified the Association Agreement between Ukraine, on the one hand, and the European Union, on the other. Chapter 17 of this Agreement is devoted to issues of cooperation between the parties in the field of development of agriculture and rural areas. Article 405 of the Agreement enshrines the obligation of Ukraine to support gradual convergence and harmonization with the relevant law and regulatory standards of the EU in the field of agriculture and development of rural areas.

Today, the fundamental national interests of Ukraine are enshrined in Part 3 of Art. 3 of the Law of Ukraine "On National Security of Ukraine" dated June 21, 2018. Among them: sustainable development of the national economy, civil society, and the state to ensure the growth of the level and quality of life of the population, as well as the integration of Ukraine into the European political, economic, security, and legal space, the development of equal and mutually beneficial relations with other states.

Article 3 of the Law of Ukraine "On Environmental Protection" dated June 25, 1991, defines the basic principles of environmental protection. Some of them are directly related to ensuring the sustainable development of agricultural production.

According to the provisions of Section 3 of the Law of Ukraine "On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period Until 2020" dated December 21, 2010, the strategic goals and objectives of the state policy in agriculture included creation of conditions for wide implementation of ecologically oriented and organic farming technologies, together with achievement a two-fold increase in the area of their use in 2020. For this purpose, state support and stimulation of domestic business entities is offered. Such entities must carry out production modernization aimed at reducing the negative impact on the environment.

Therefore, ensuring the sustainable development of agricultural production, in particular by legal means, becomes especially relevant both for Ukraine and for other countries of the world. Indeed, under the conditions of globalization, national economies become interdependent and interacting components of the world economic system with common patterns of development. This is connected with the predicted problems of a global nature (food, environment, energy) and is caused by the need to: (a) ensure food security, (b) increase the competitiveness of the national agrarian sector of the economy, (c) improve social development of rural areas, (d) preserve the environment in the process of carrying out agricultural production activities, minimizing its negative, anthropo-technogenic impact on the environment. All this requires taking appropriate measures on the part of the state, one of which in modern socio-economic conditions is the legal provision of sustainable development of agricultural production (Kurman, 2018).

According to Shulga (2018), the legal basis for the further development of land relations in the agricultural sector should be oriented towards ensuring sustainable land use and its greening. We believe such approach will create the necessary conditions for both the development of agricultural production (including organic) and the improvement of the quality of agricultural products.

It should be noted that the concept of sustainable development of rural areas has been gradually promoted by international and Ukrainian law for many years but has not yet moved beyond the consolidation of general principles. It seems necessary to move to the next stage of implementing the concept of sustainable development of rural areas, discuss and then adopt in the legislation a list of specific actions for its practical implementation. This should include both static measures aimed at solving the problems of the current state of rural areas, and dynamic counteraction to global threats of our time (for example, climate change processes). This will require the development of additional guarantees for the implementation of this concept, including expanding the number of subjects of land rights, supporting traditional farming culture and agrarian tourism.

In our opinion, regulatory support for the implementation of the concept of sustainable development has to entail: (a) adoption of the special Law of Ukraine "On sustainable development of rural areas"; (b) development of the concept of sustainable development of agricultural production in Ukraine for the period until 2035; (c) development and implementation of long-term target programs in the field of sustainable development of agricultural production, sustainable use of nature, sustainable social development of rural areas.

We think that the priority areas of state policy for the period up to 2035 in the field of sustainable development of rural areas should be:

- improvement of the demographic situation. Its negative nature is manifested both by the general trend of the aging of the rural population, and by the strong dynamic of its natural and mechanical loss;

– providing conditions for the development and diversification of the rural economy. In this case, the administration's efforts will be aimed at increasing the generated added value, increasing employment and increasing the role of the territory's industrial production;

– improving the quality of life of the rural population. At the heart of its growth is a reduction in the differentiation between the availability of vital services and the level of income of the rural and urban population;

– improving the access of rural residents to development resources. This direction of activities is ensured by the growth of information flows and remote access to public services, the development and implementation of smart technologies;

– development of rational nature management and improvement of the ecological situation in rural areas. It is aimed at the formation of mechanisms for handling household waste, respect for nature and the introduction of modern technologies for servicing life;

- increasing the efficiency of local self-government, including through strict subordination of the powers of authorities at different levels;

– improvement of the system of statistical observation and scientific and methodological support for the development of rural areas. The main event in this direction, first of all, will be the formation of a strategic development trajectory and its qualitative and quantitative parameters;

- organization of training, retraining, advanced training of personnel. This will expand the horizons of employment of the population and form the basis for the growth of labor productivity.

The implementation of the directions of state policy proposed above will make it possible to achieve high economic indicators, ensure the country's food security and increase the welfare of citizens.

As Semchyk (1998) observed, the efficiency of agricultural production largely depends on the level of legal regulation of relations in the agro-industrial complex, which, in turn, significantly affects the food security of the population of Ukraine, and social and political stability in the state depends on this. Stativka and Urkevych (2011, p.104) emphasize that the modern problems of the functioning of agriculture are "determined by many factors, among which the imperfect legal regulation of agrarian relations occupies a decisive place". Therefore, the question of the development of the agricultural sector under the conditions of sustainability is particularly relevant today. This, in turn, presupposes and requires the sustainable development of agricultural production, which must be ensured by appropriate legal means.

3.3. Factors affecting the development of rural areas

We think there are currently three vectors for sustainable rural development around the world. First, it is the development of new economic activities that can meet potential urban needs; second, the development of local entrepreneurship that can create and expand these new activities; third, the formation of sufficient social capital that can support entrepreneurship in new activities with access to loans, labor, human capital, external markets and knowledge for learning, and innovation.

The development of rural areas can only be ensured if rural areas have a certain resource potential. In the conditions of modern reality, the structural composition and volume of the accumulated organizational and economic potential determines the possibility of obtaining advantages and abilities to get on the rails of long-term sustainable development and functioning, while obtaining various competitive advantages for the most effective interaction in the external and internal markets.

In the process of implementing measures aimed at ensuring the sustainable development of rural areas, it is necessary to achieve socio-economic goals. Such a goal involves the improvement of the quality of life of the population, while actively using the innovative, scientific, and informational potential, and also implements effective entrepreneurial activities that ensure the effective functioning of households through the development and implementation of socio-economic planning. All this ultimately allows, by concentrating internal resources, to create conditions for attracting additional amounts of financial support to rural areas, which will be sufficient to fully implement an expanded list of targeted social and departmental projects and programs that are established at the state level and at the region level.

Next, it is necessary to consider the factors affecting the functioning and development of rural areas. We can say that the main factors in the formation and functioning of rural areas are:

- regional, which include resource factors, location factors, development conditions;

- functional compatibility of various types of activities in a certain territory;

- managerial, including the decision and justification of strategies for the development of rural areas;

- self-organization.

At the same time, rural areas have certain limitations for effective development and functioning: imperfect legislation, insufficient state support, including financial and investment; poor information support and social protection of the rural population.

Having studied all the factors influencing the development of rural areas, we can distinguish five groups that determine the parameters of development of rural areas. Within the framework of the structural composition of the first category, there is a list of factors that are associated with the state policy pursued for the agrarian, foreign economic, food, innovative and social development of both individual entities and the whole country.

The second group of factors should include macroeconomic factors in which one or another rural area is forced to function. In particular, this is the agrarian structure of the rural area; a set of state measures implemented for the purpose of state support of business entities specializing in the agricultural sector of the economy; the impact of inflation; organized system of intersectoral exchange; parameters of foreign economic trade in agricultural products; level of market development; the certification system used; the effectiveness of the current mechanism for managing risk and reserve reserves; operating financial and tax systems; pricing policy; development of the insurance system and standardization.

The third group of factors is represented by resources and technologies. These factors together are presented as a resource potential for the development of rural areas. These include natural and climatic conditions, the current level of development of the material and technical base, the indicator of the involvement of land plots in economic activities based on the results of assessing the parameters of the quality of land plots, the staffing of agricultural enterprises and the level of development of information exchange processes and support in the implementation of management activities.

The fourth group includes factors that can be defined as infrastructural factors that determine the level of development and functioning of the market, production, logistics, innovation, information, and social infrastructure.

The last group of factors is determined by socio-demographic factors that show the size and age/sex characteristics of the population living in rural areas, determine the levels of income of the population and indicators of their differentiation, as well as the unemployment rate in a given territory and indicators of food security for citizens.

In accordance with the above classification of factors, it can be noted that the list of priority conditions for the effective development of rural territorial elements is formed from a complex of external factors. Accordingly, internal factors demonstrate their subordination to the territories, and for this reason there are prerequisites and opportunities for their increase and improvement. The greatest effect in this case can be obtained through the active introduction of innovative technologies and the implementation of modernization processes, the implementation of actions aimed at increasing investment attractiveness, the creation of new competitive jobs, etc. The general structure of internal and external factors, parameters for assessing the degree of their impact determines the general list of key areas in the development of rural areas.

3.4. Problems hindering the development of rural areas and ways to solve them

An important step in the formation of effective and efficient mechanisms for promoting the sustainable development of rural areas is the identification of key development problems, as well as the development of the necessary socio-economic, legal, and administrative measures that would bring rural areas to a qualitatively new level of development. These measures should be comprehensive, systemic in nature to address the identified economic, social, and environmental problems in rural areas. But at the same time, it is imperative to consider the natural resource and cultural potential of rural areas.

In scientific literature there is a proposition of a model for the formation of investment support for sustainable rural development, which will help to streamline and allocate financial and investment resources and improve rural investment activities. This is considered as one of the ways to activate the sustainable development of rural territories (Savitska et al., 2020).

Unfortunately, the current deformed Ukrainian economic mechanism is not conducive to rural development. Price disparity, the monopoly dominance of the "partners" of the village in the agro-industrial complex, violating the rules of fair market competition, the intensive pumping of depleted natural resources abroad - all this leads to a deterioration in the state of the agricultural sector of the economy.

The development of rural areas is significantly affected by environmental problems. The latter are expressed in the deterioration of the ecological situation, soil degradation, reduced productivity, and the spread of erosion processes (Dzhukha et al., 2019).

The creation of the necessary conditions for ensuring the sustainable development of rural areas plays a huge role in creating conditions and prerequisites for the proper socio-economic development of the entire state. The indicators of the development of rural areas (e.g. significant expansion of the production base; increase in the level of effective demand of citizens; improvement of demographic situation) cannot be achieved if a high level of the quality of life of the rural population is not guaranteed and an effective infrastructure system is not created in these territories.

The main reasons that significantly reduce the effectiveness of the implementation of rural development programs at all levels include:

- the absence of regulatory legal acts that fully regulate the main provisions of the state policy in the field of rural development;

- the implementation of rural development policy does not take into account the diversity of rural areas of Ukraine and is based on a limited set of used tools for financing and implementing program activities;

- state support measures do not provide for anticipation of possible risks and the formation of prerequisites for solving long-term tasks;

– there is no timely transformation of the directions of the state policy for the development of rural areas and program activities, despite significant changes in the institutional environment;

- the institution of local self-government (which is directly related to the development of a particular rural area) is limited in the independent development and implementation of sustainable development programs by a number of factors. The main one of them is the weak financial base;

- insufficient information and statistical support for rural development and the lack of monitoring the effectiveness of the use of budgetary funds allocated for the development of rural areas at various levels of government;

- the institution of the rural family is considered mainly as a tool for solving the demographic problems of the state and providing the urban population with food, and not as a public institution that forms the rural way of life.

In the current conditions, the tasks of state policy in relation to the organizational and economic development of rural areas should be:

– organization of conditions for the sustainable development of the rural economy;

– increasing the competitiveness of Ukrainian agricultural products based on the modernization of the agricultural sector;

– preservation and reproduction of land and other natural resources used in agricultural production;

- ensuring employment of the rural population and increasing their income; - increasing the level and quality of life in the countryside through the guaranteed development of agriculture, ensuring the availability and quality of services provided in the field of education, health care, and culture. Raising the level of engineering arrangement and provision of housing stock, development of transport and energy infrastructure, communication facilities;

- elimination of rural poverty.

Accordingly, state policy regarding the sustainable development of rural areas should be systemic in nature and include a set of legal, economic, and organizational measures aimed at improving the level and quality of life of the rural population, increasing the efficiency of agriculture and rational nature management. Therefore, the improvement of such components of the mechanism for implementing the policy of sustainable development of rural areas as regulatory, financial, scientific, personnel and information support requires special attention.

On the part of the state, in order to achieve sustainable development of rural areas, it is necessary to use a program-target approach. This approach will allow:

- to strengthen the coordination of measures by the state to support the development of rural areas;

- to increase the efficiency of the use of resources allocated for their intensive and dynamic development:

- to ensure the consistency and complexity of positive transformations, taking into account the solution of priority tasks.

Thus, state regulation of the sustainable development of rural areas requires the formation and improvement of the legal framework aimed at solving the social, economic, and environmental problems of rural areas. As part of financial support, it is necessary to expand access to subsidies and preferential loans for the development of various alternative activities in rural areas (e.g., green tourism, production of cultural heritage goods), as well as the creation of a system of grant incentives for initiatives of rural communities related to the improvement of rural settlements. This will also help to preserve local cultural and historical heritage.

The implementation of the concept of sustainable development of rural areas will not only help to overcome economic and social problems of the village, but also to take effective steps in recreating natural resources and protecting the environment.

The main goal of ensuring the sustainable economic development of rural areas is to create prerequisites for increasing the parameters of investment attractiveness, improving the functioning of the budget system, and ensuring expanded production on the terms of maintaining their sustainability. A set of measures implemented in order to comply with environmental requirements while ensuring the sustainable economic development of rural areas should be implemented simultaneously with ongoing activities that involve minimizing the negative impact on environmental and ecological objects. The implementation of the social component when entering the course of sustainable development of rural areas implies the need to minimize unemployment rates, improve the quality parameters of services provided by state and municipal authorities, increase citizens' incomes, and improve their quality of life in this territory.

Based on the principles of scientific research, a conceptual model of sustainable development of a rural area is proposed, which is an interconnected system that includes goals, objectives for ensuring sustainable development, factors affecting its sustainability and mechanisms that ensure this development (Figures 1, 2).

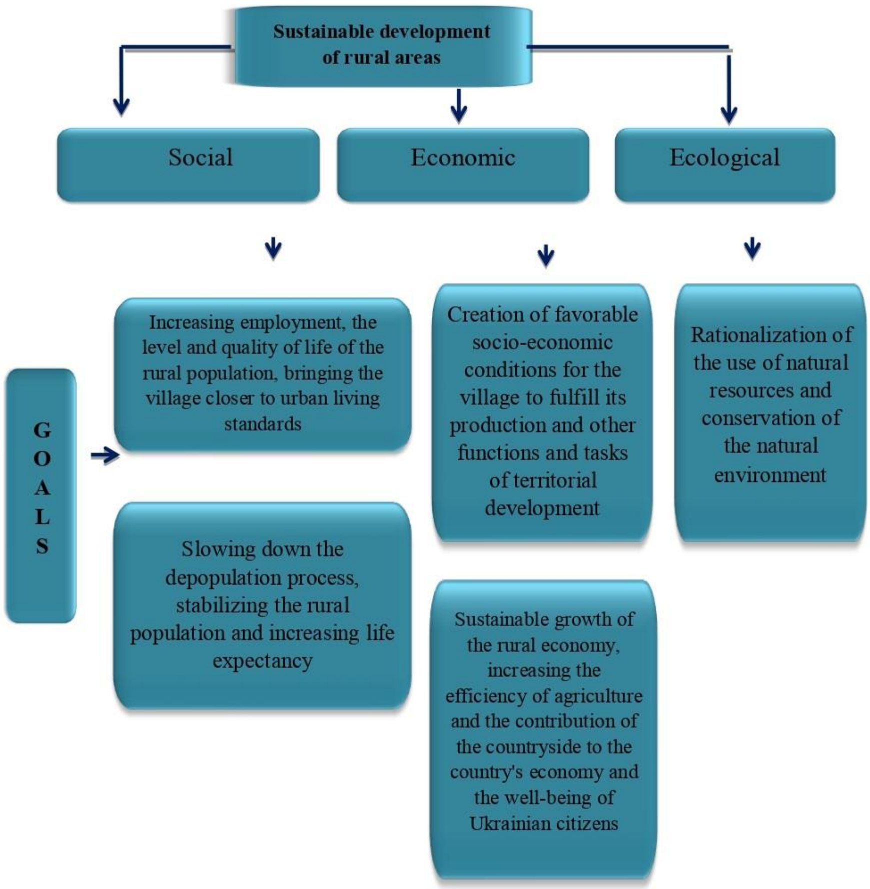


Figure 1. Goals of the model of sustainable development of a rural area

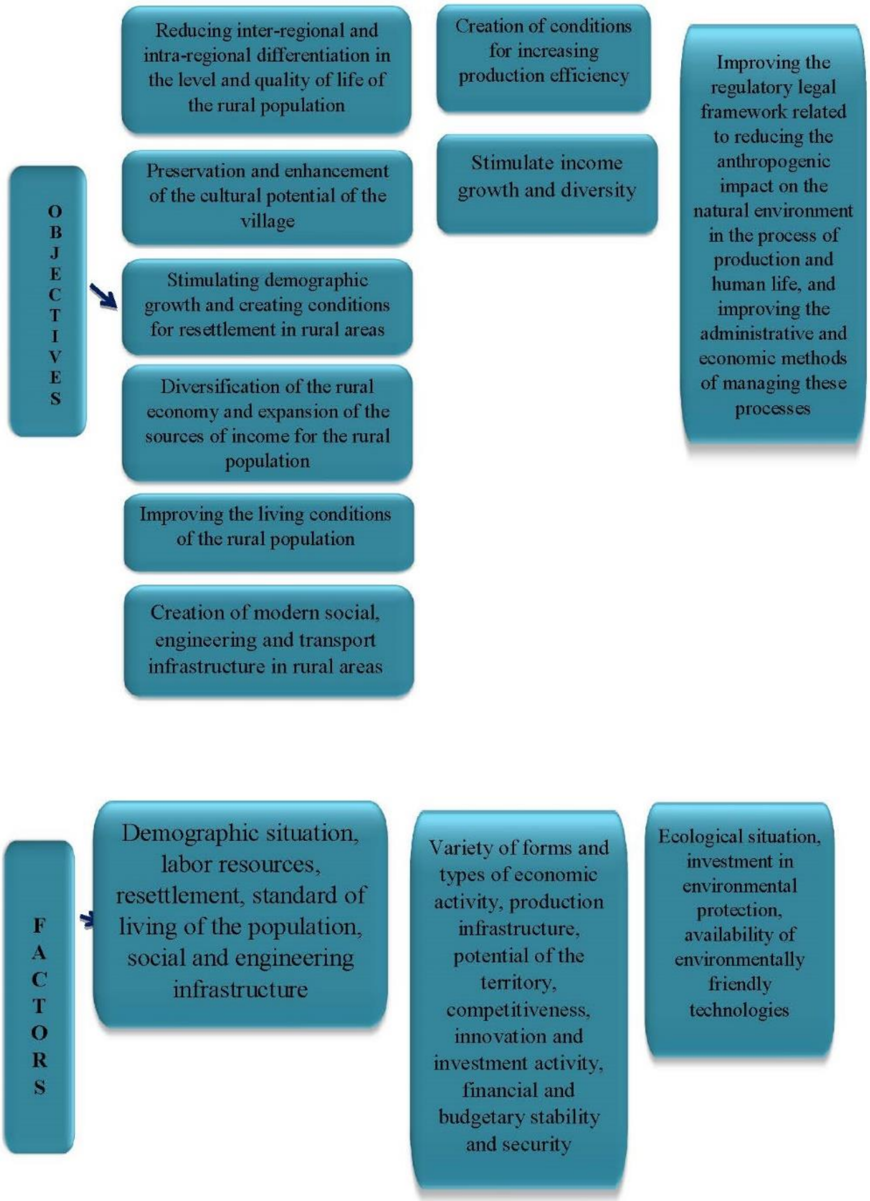


Figure 2. Objectives and factors of the model of sustainable development of a rural area

We can state that in the study of sustainable development of rural areas, it is equally important to determine the system of goals and objectives formulated in accordance with the nature and essence of the problem. The implementation of this conceptual model will contribute to:

- the growth of resource support for the development of rural areas based on the strengthening of the agricultural sector;

- diversification and development of the entire rural economy;

- increasing the taxable base of rural development and the financial bases of local self-government;

- general economic growth and strengthening of state support for the countryside within the framework of the implementation of state programs.

4. Conclusions

In conclusion we can state that the current level of socio-economic development of rural areas of Ukraine is at present far from reaching the indicators and criteria for the sustainability of their development. Several problems remain unresolved today, in particular related to the decline of production systems, the decline in the quality of life of the rural population, the destruction of social and transport infrastructure (Sava et al., 2020). Achieving sustainable development in rural areas requires a program-target approach at the state level. In this regard, Ukraine needs to develop and implement at the state level the concept of transition of rural areas to stable and crisis-free development. Through this approach, coordination of support measures, efficient resource allocation, and a focus on priority, tasks can be achieved.

State policy must focus on improving the demographic situation, diversifying the rural economy, enhancing the quality of life for rural residents, and ensuring better access to development resources. Additionally, it is essential to promote rational nature management and ecological improvements, improve local self-government efficiency, and strengthen statistical observation and research support.

By implementing these priority areas of state policy, Ukraine can achieve positive economic indicators, enhance food security, and improve citizens' welfare. The process of transitioning to sustainable development should concentrate on economically sound, environmentally safe, and socially oriented expanded reproduction. This approach will lead to improved living standards in rural areas and foster responsible agricultural production while bolstering the quality of public administration and local self-government.

Ukraine can certainly lay the foundation for sustainable development in its rural areas, contributing to the nation's overall progress and prosperity. This requires a collective effort, which we believe can be informed by the insights provided by our research and the integration of the concepts presented in the literature. Only through a unified and concerted approach can we unlock the potential for thriving rural communities and ensure a prosperous and sustainable future for all.

References

Dzhukha, V., Kuzminov, A., Pogosyan, R. (2019). Problems and main factors of sustainable development of rural territories. *Accounting and statistics*, 3 (55), 84-91.

Fedchyshyn, D., Ignatenko, I., Bondar, O. (2022). *Legal provision of food security and rational land use in organic production in Ukraine in the context of European integration.* Baltija Publishing.

Fedchyshyn, D., Ignatenko, I., Shulga, M., Danilik, D. (2022). Legal problems of rational use and protection of agricultural land in Ukraine. *Justicia,* 27: 41, 43–52, https://revistas.unisimon.edu.co/index.php/justicia/article/view/5404/5488

Haberl, H., Fisher-Kowalski, M., Krausmann, F., Winwoter, V. (2016). *Social ecology: society-nature relations across time and space*. Springer.

Ignatenko, I. Legal aspects of development of organic agriculture in Ukraine in the context of European integration. (2020). *Economics of agriculture*, 67: 3, 973–990. https://www.ea.bg.ac.rs/index.php/EA/article/view/1749/1427

International Union for Conservation of Nature and Natural Resources (IUCN). World Conservation Strategy. 1980. http://www.a21italy.it/medias/31C2D26FD81B0D40.pdf Accessed on: 26/12/2022

Kurman, T. (2018). *Sustainable development of agricultural production: problems of legal support.* Yurayt.

Nesenenko, P. (2022). Analysis of the current state of rural development management as a key direction agrarian policy of Ukraine. *Scientific innovations and advanced technologies*, 11(13), 74-84, http://perspectives.pp.ua/index.php/nauka/article/view/2806/2819

Pesce, M., Kirova, M., Soma, K., Bogaardt, M-J., Poppe, K., Thurston, C., Monfort Belles, C., Wolfert, S., Beers, G., Urdu, D. (2019). Research for AGRI Committee – Impacts of the digital economy on the food-chain and the CAP, European Parliament, Policy Department for Structural and Cohesion Policies.

https://www.europarl.europa.eu/RegData/etudes/STUD/2019/629192/IPOL_STU(2019)629192_EN.pdf

Porter, M. E. (2000). Location, Competition and Economic Development: Local Claster in a Global Economy. *Economic Development Quarterly,* 1, 15–34.

Sava, A., Dudziak, O., Krasnorutskyy, O., Moskvichova, O., Rarok, L. (2020). Sustainable development of rural areas: strategy and conceptual framework (Ukrainian case). *Independent Journal of Management & Production,* 11(9), 2325-2340. DOI:10.14807/ijmp.v11i9.1433

Savitska, S., Zaika, S., Svystun, L., Koval, L., Haibura, Y. (2020). Investement providing suistanable development of rural areas in Ukraine. *Independent Journal of Management & Production,* 11(8), 571-586. DOI:10.14807/ijmp.v11i8.1218.

Semchyk, V. Agrarian legislation of Ukraine: problems of efficiency. Naukova dumka, 1998.

Sharapova, S., Lisova, T., Bredikhina, V., Lialiuk, O. (2021). Improvement of land relations in the context of sustainable development of rural areas in Ukraine. *Journal of Environmental Management and Tourism*, 12: 7(55), 1900–1906. DOI: 10.14505/jemt.12.7(55).15

Shulga, M. (2018). Modern land legal problems in the agricultural sector. International conference "The third meeting of specialists of related departments regarding the discussion of the strategy of the evolution of agrarian, land, environmental and natural resource legal relations in the context of the integration development of Ukraine", Odesa, Ukraine, June 2018, pp. 74-76.

Stativka, A., Urkevych, V. (2011). On the draft Law of Ukraine "On Agriculture of Ukraine". Entrepreneurship, economy and law, 8, 104–110. http://pgp-journal.kiev.ua/archive/2011/08_2011.pdf

Sundaram J. K. Achieving Zero Hunger: the critical role of investments in social protection and agriculture. ADG, ES Department, FAO, 2015. https://www.fao.org/3/CA2249EN/ca2249en.pdf

World Economic Forum. "The Global Risk Report", 2016. https://www3.weforum.org/docs/GRR/WEF_GRR16.pdf

Authors

Dmytro Fedchyshyn (*corresponding author*)

Zaporizhzhia National University, Zaporizhzhia, Ukraine.
fedchishin_d_v@znu.edu.ua

Iryna Ignatenko

Yaroslav Mudryi National Law University, Kharkiv, Ukraine.

Alyona Chyryk

Yaroslav Mudryi National Law University, Kharkiv, Ukraine.

Daria Danilik

Yaroslav Mudryi National Law University, Kharkiv, Ukraine.

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Fedchyshyn, D., Ignatenko, I., Chyryk, A., & Danilik, D. (2023) State regulation of sustainable development of rural areas in the system of food security of Ukraine. *Visions for Sustainability*, 20, 7731, 277-299. http://dx.doi.org/10.13135/2384-8677/7731

Original Paper

How the strategic to achieve corporate sustainable performance?

The role of mergers, acquisitions and ownership integrations

Kesi Widjajanti, Rohmini Indah Lestari, Eviatiwi Kusumaningtyas Sugiyanto

Received: 11 July 2023 | **Accepted:** 16 September 2023 | **Published:** 26 September 2023

VISIONS for sustainability www.ojs.unito.it/index.php/visions

Keywords: corporate action; corporate sustainable performance; merger & acquisition; ownership

Abstract. *Examine the role of Ownership Interaction on the effect of Merger & Acquisition on the company's sustainable performance. In addition, it also investigates the effect of the interaction between Merger & Acquisition and ownership integration on the company's sustainable performance. This study uses a moderated mediation model to explore the role of Merger & Acquisition on the company's sustainable performance mediated by integration ownership. Merger & Acquisition acts as an independent and moderator variable between the effect of ownership integration on the company's sustainable performance. Data was collected from 51 companies in Indonesia that carried out Merger & Acquisition corporate actions for seven years from 2015-2021. We find that the direct effect of Merger & Acquisition on integration ownership is a U-curve. Integration ownership acts as a partial mediator on the relationship between the effect of Merger & Acquisition on the company's sustainable performance. We find evidence that Merger & Acquisition plays a moderate role by amplifying the effect of ownership integration on the company's sustainable performance. This paper contributes to enriching the literature on good corporate governance oversight mechanisms related to management entrenchment. We find that the integration of ownership of a company directly participates in the Merger & Acquisition corporate action relationship which has an impact on the company's sustainable performance. The role of ownership integration on the company's sustainable performance is in line with the concept of agency theory alignment in the specific context of companies in Indonesia. We apply a moderated mediation model because we suspect that there is an interaction between Merger & Acquisition and ownership integration in different pathways from mediator to observable dependent variable.*

1. Introduction

Sustainable development is currently a concern in the world. Efforts to create sustainable development must involve several related aspects and stakeholders. The issue of sustainable development that continues to develop changes the company's orientation to take part in realizing sustainable development.

The concept of a sustainable enterprise is currently receiving great attention, especially the emphasis on the business and theoretical side around the world (Caiazza et al., 2021) and in developing countries such as Indonesia (Tjahjadi et al., 2021). A sustainable enterprise is a dynamic business strategy that implements sustainable practices necessary to meet shareholder goals and energize stakeholders (Aksoy et al., 2020). Various frameworks have been proposed to determine the level of sustainable corporate performance (CSP) which is an important issue for company development (Nikolaou et al., 2019; Pislaru et al., 2019). Companies are encouraged to develop ways of managing their business to be more sustainable. Several approaches to sustainable enterprises have emerged to help companies face this challenge (Morioka & Carvalho, 2016). This study will consider a framework that evaluates the contribution of corporate corporate actions to sustainable development expressed in financial terms proposed by Dočekalová & Kocmanová, (2016) using indicators of economic dimensions (Pislaru et al., 2019).

Mergers and acquisitions (M&A) are a very popular investment strategy among companies looking to increase company growth. There is a relationship between the managerial ability of the acquiring firms and their long-term performance after M&A (Cui & Chi-Moon Leung, 2020). M&A is still one of the strategic options that companies can do as part of sustainable integration efforts (Geraldi et al., 2022). Mergers and acquisitions are one of the strategic options that organizations can do in business competition which is located in the corporate level strategy. M&A is carried out with the main objective of creating corporate value and increasing shareholder value (Teti & Tului, 2020). In order to get the best final result from M&A one must consider that the value for shareholders is both in terms of financial performance (Dočekalová & Kocmanová, 2016) and sustainable company performance (Barros et al., 2022).

Financial performance is used in several studies to assess the economic impact of M&A using accounting measures. Current assets as a measure of the liquidity ratio are considered a more suitable measure to be used in the context of acquisitions because large changes in assets or equity values often occur after the event of the company (Malikov et al., 2021). Leverage as a measure of solvency (debt asset ratio and debt equity ratio) after the company has affected the company's sustainable performance (Gainet, 2010). Measures of profitability (return on assets and net profit margin) (Krishnan et al., 2007). Profitability index that will be available to meet the needs of future stakeholders and not just shareholders (Nikolaou et al., 2019).

Impact of M&A activities, on key agency issues, and on ownership and control structures. M&A not only reduces conflicts of interest related to the transfer of control, but also has a more general impact on agency problems between management and shareholders, minority and majority investors, and other stakeholders (Gregoriou & Renneboog, 2007). In the study, we confirmed that the acquirer was not involved in management prior to the M&A. On the other hand, primary ownership reduces the total real earnings management (Piosik & Genge, 2020).

Boards of directors in various companies, show that board networks have a significant impact on corporate decisions, including organizational structure and M&A strategic alliances (Tao et al., 2019). The results of previous studies state that M&A has an impact on increasing firm value (Hazelkorn et al., 2004; Wonder & Lending, 2019), increasing profits (Manuela et al., 2016), reducing costs (Barros et al., 2022). Another study explains that firm solvency has no impact on firm performance after M&A (Zhang et al., 2018). The profit level did not change significantly after M&A (Trujillo et al., 2020), there was a decrease in operating performance (Malikov et al., 2021). Stakeholder theory postulates that firms with high ownership influence post-deal M&A will have a positive effect on total deal synergies and long-term performance and create value for the firm's shareholders (Brooks et al., 2018; Caiazza et al., 2021). M&A agreements have a positive impact on ESG scores, but have no impact on increasing ESG scores in the year the agreement was agreed (Barros et al., 2022). the best outcome of the M&A will be achieved when considering the increase in shareholder value in terms of both financial performance and sustainability in the post-merger period (Caiazza et al., 2021). Very little literature analyzes the impact of M&A agreements on company sustainability in terms of company performance (Gillan et al., 2021). The literature evaluating the impact of women on board quotas as corporate regulators has not yet reached an established consensus on its effect on firm performance (Carbonero et al., 2021). Despite the overwhelming evidence on the ultimate shareholder camp, the literature is very silent on whether and how improvements in corporate internal governance will affect ultimate shareholder entrenchment (Cai et al., 2019).

With the development of industrial expansion, the use of natural and green resources by industry is increasing rapidly (Abbas and Sagsan, 2019). This situation primarily reduces the supply of natural resources, thereby causing environmental damage. Increasing demand has exacerbated this problem (Shahzad et al., 2020). Environmentalists and naturalists praise these organizations for bringing cutting-edge knowledge and environmentally responsible thinking to their production processes to generate profits and increase sustainability in business (Sarkis et al., 2011). Similarly, in recent environmental management literature, these concerns have been addressed by SD. Although this question is currently a difficult one, researchers and analysts still do not agree on its concept and meaning (Hahn et al., 2015). The definition of SD is applied globally according to the "World Commission on Environment and Development" (WCED, 1987): "Development that meets the needs of the present without compromising the ability to meet the needs of future generations. » In this definition, WCED includes economic, environmental and social issues. These three basic principles of CSP, known as the "triple bottom line" (TBL), influence current and future generations (Elkington, 1998). According to this approach, each pillar of sustainability (environmental, economic and social) is important; therefore, this theory can be considered an integrated theory of sustainability (Tseng et al., 2015). This TBL approach was later adopted by the Global Reporting Initiative. Several aspects encourage organizations to follow SD practices, including legal, ethical, and business (Abbas and Sagsan, 2019). In this research, the following three aspects of CSP were selected: environmentally, economically and socially sustainable. Firstly, environmental sustainability (ENVS) mainly depends on the responsible management of industrial waste, reducing toxic waste and CO_2 emissions, reducing the risk of dangerous accidents in factories, producing environmentally friendly products, etc. (Shahzad et al., 2019, 2020; Tseng et al., 2016). According to the International Energy Agency (2017), the manufacturing sector contributes around 24% of global CO_2 emissions. To avoid global warming and prolonged climate change, we must control industrial damage by considering environmental sustainability. Second, economic sustainability (ECOS) is mainly related to profitability, revenue generation, efficient use of energy, use of waste to generate income, etc. (Cruz and Wakolbinger, 2008; Shahzad et al., 2019; Tseng et al., 2016). Organizations that seek to improve environmental sustainability by reducing adverse outcomes from production processes will also strengthen their economic sustainability.

This study will consider a framework that evaluates the contribution of Merger & Acquisition corporate actions to the company's sustainable performance expressed in financial terms proposed by Dočekalová & Kocmanová, (2016) using economic dimension indicators (Pislaru et al., 2019). This interaction analysis allows the assessment of the factors that affect the company's sustainable performance. These results are useful for the decision-making process of all stakeholders.

The role of integrated ownership as measured by indicators of ultimate ownership and the percentage of women on board is rarely discussed, although previous studies on the effect of the Merger & Acquisition corporate action on company performance under the framework of agency conflict between ultimate shareholders in a company were carried out. In addition, we include indicators of the existence of women's councils as the implementation of the SDGs related to corporate sustainability. This study also examines the effect of Merger & Acquisition interaction and integrated ownership on sustainable company performance as measured by market-base, accounting-base and organizational measurement indicators.

This study contributes to the literature on corporate governance oversight mechanisms. The external supervisory mechanism from the ultimate shareholder and the women on board internal control mechanism on the company's sustainable performance are in line with the concept of alignment agency theory. This research provides new knowledge to managers that it is not always the goal of the Merger & Acquisition corporate action to increase the controlling role by ultimate shareholders and women on board of the company. The direct effect of Merger & Acquisition on integration ownership is in the form of a U-curve. shows that the Merger & Acquisition corporate action serves as a moderator that will strengthen the influence of ownership integration on the company's sustainable performance. This paper is presented as follows. In Section 2 we provide a theoretical framework and review the relevant literature. In Section 3 we describe the design/methodology/approach. In Section 4 we explain the results of the research and discussion. In Section 5 conclusions.

2. Literature review

2.1 Sustainability theory

Sustainability theory was first put forward by (Meadows et al., 1972) who explained that society's efforts to prioritize social responses to environmental and economic problems. This social response is expected to meet the needs of the present and future generations (WCED, 1987). The concept of sustainability is currently increasingly developing and being applied in the context of corporate sustainability (Pemer et al., 2020). Artiach et al. (2010); Pemer et al. (2020) explain the context of corporate sustainability as a business and investment strategy that can improve business practices by balancing the needs of present and future stakeholders. This concept emphasizes the interests of stakeholders by balancing the economic, social and environmental dimensions of company performance. Corporate Sustainability is usually measured through the Triple Bottom Line (TBL), this concept was developed by (Elkington & Rowlands, 1999). There are three dimensions of TBL, namely economic, social and environmental. Pemer et al. (2020) stated that companies can move towards sustainable development by integrating TBL into management strategies. Markley and Davis (2007); Pemer et al. (2020) proves that organizations that focus on TBL can increase the company's competitive advantage.

2.2 Agency theory

In this study, two theories will be reviewed, namely agency and corporate governance. In contemporary companies, where ownership and management are separated, managers do not always pursue efficient management to maximize company profits. Agency theory states that shareholders as principals and management agents have different interests. Agency theory (Jensen & Meckling, 1976) argues that substantial share ownership can reduce conflicts of interest that exist between company managers and shareholders (Chams & García-Blandón, 2019). In M&A deals related to post-deal ownership there are those that create value (Andriosopoulos & Yang, 2015; Wonder & Lending, 2019), or destroy firm value (Tao et al., 2019). This is due to the existence of directors who utilize the resources of their social network to pursue their own profits at the expense of shareholder wealth. This finding again shows the importance of the role of directors' incentives that come from their independence in carrying out their supervisory and advisory functions. In line with agency theory (Khaled et al., 2021) found a positive relationship between the level of corporate leverage and its sustainability performance and disclosure; states that highly leveraged firms tend to disclose more sustainability information to reduce the agency costs generated as a result of their higher debt levels. PAT sees information asymmetry between major shareholders and better-informed agents (often top executives) as a major source of conflict. Providing broader reporting on better practices will reduce this information gap, reduce agency costs, and therefore create shareholder value. Some studies suggest that increasing board size can lead to greater coordination/communication problems suggesting that as board size increases, directors become less effective in monitoring management and, thus, CEOs become more powerful in influencing company decisions. This is because as the board gets bigger, it becomes more difficult for board members to reach agreement on important corporate decisions, it is difficult to achieve well-informed corporate dialogue (Pye, 2000).

2.3 Corporate governance theory

La Porta et al. (1999) argues that in general, corporate governance focuses on how the company's internal governance oversight mechanisms affect the behavior of top management and its economic consequences. Ultimate shareholders have an important role in corporate governance because they control and influence the company's activities. Ultimate shareholders can potentially expropriate minority shareholders (Cai et al., 2019). Corporate governance is based on stakeholder theory and legitimacy. This paper examines the influence of elements of corporate governance, particularly the board of directors, on sustainable performance (Kouaib et al., 2020; Widjajanti & Widodo, 2016). The company responds to sustainability-related issues raised by shareholders and stakeholders (Aksoy et al., 2020), and board structure (Naciti, 2019). Corporate governance mechanisms, particularly the board of directors, play an important role in monitoring the decisions and actions of the top management team. The quality of monitoring is likely to depend on the characteristics of the board (Malikov et al., 2021; Widjajanti, 2011).

Companies must remain aware of the pressures posed by shareholders and stakeholders regarding sustainability practices, and the increasing gender diversity may have an intermediary role between corporate governance, sustainability, and financial performance (Madaleno & Vieira, 2020). Gender diversity in the board of directors has attracted considerable attention from regulatory bodies, policy makers, companies and academia as a means to improve corporate governance and/or business ethics (Bertrand et al., 2019; Widjajanti et al., 2022) with regard to with corporate sustainable performance (Madaleno & Vieira, 2020; Tjahjadi et al., 2021). Gender diversity on the economic impact of M&A. The presence of women on board as monitors has a positive and statistically significant effect on the gains of the acquirer; and (ii) boards with three or more women, or where women represent more than 25% of the board, have a stronger impact on acquirer gains (Tampakoudis et al., 2022).

2.4 Variables and Indicators

Variable Merger & Acquisition is measured using five indicators. The current ratio (CUR) indicator for non-financial companies or the loan to deposit ratio

(LDR) for financial companies represents the liquidity ratio (Malikov et al., 2021). The debt to asset ratio (DAR) and debt to equity ratio (DER) indicators represent the solvency ratio (Gainet, 2010). Meanwhile, the return on assets (ROA) and net profit margin (NPM) indicators represent the profitability ratios (Krishnan et al., 2007). The ownership integration variable is measured using two indicators, namely the ultimate Ownership Indicator, the controlling shareholder can be or the main shareholder (La Porta et al., 1999) and the percentage of women on board as an indicator related to one of the Sustainable Development Goal 5, namely gender. equality (Nicolò et al., 2021).

The CSP variable uses three indicators (Pislaru et al., 2019), as follows: (1) Market-base (investor returns) as the price-earnings (PE) ratio, related to the company's market performance; Price-earnings (PE) ratio is a measure used to compare the current stock market price with the company's earnings quality. The high value of this ratio indicates that investors have a good appreciation of the company's income. (2) Accounting-based (accounting returns) as: return on equity (ROE) is calculated as the ratio between net income and own equity. ROE is a measure used to assess the company's performance by looking at the amount of dividends paid by the company to shareholders compared to the amount of equity. (3) Organizational measures as operating margin (OM) to measure productivity which is calculated by comparing operating income and net sales (reduced by investment income). OM also serves as a measure of the efficiency of the company's operating activities.

3. Hypothesis development

There is a positive relationship between Merger & Acquisition of voting rights and excess voting rights of cash flow rights. The author argues that with a higher level of entrenchment. This reflects that the controlling shareholder in the company wants to take personal benefits from controlling rights (Thraya, 2015). PAT sees information asymmetry between principals (often shareholders) and better-informed agents (often top executives) as a major source of conflict. Providing broader reporting on better practices will reduce this information gap, reduce agency costs, and therefore create shareholder value (Lueg et al., 2019).

H1: Merger & Acquisition has a positive effect on ownership integration

Mergers and Acquisitions are significantly correlated with long-term performance, and we observe a marked increase in financial ratios over the long term (Caiazza et al., 2021). Measures of operating performance are often used to evaluate the success of acquisitions because accounting-based measurements definitely capture the company's economic performance and represent actual. Leverage is debt to total assets and total equity at the end of the fiscal year before the announcement of the takeover of the acquiring company has a significant positive effect on increasing real financial ratios in the long term based on operational performance measures (Cui & Chi-Moon Leung, 2020).

H2: Merger & Acquisition have a positive effect on corporate sustainable performance

Based on agency theory, share ownership structure affects the company's sustainable performance (Gainet, 2010; Tjahjadi et al., 2021). Supervision structures and mechanisms have an important role in overcoming conflicts between principals and agents (Lestari et al., 2020). Regarding corporate sustainability, the board mechanism that implements social sustainability will provide benefits for the company (Chams and García-Blandón, 2019). There is a positive relationship between higher managerial synergies of firms acquiring post-acquisition firms on long-term performance and generating higher revenues, especially focusing on long-term operating performance (Cui & Chi-Moon Leung, 2020).

H3: Ownership integration has a positive effect on corporate sustainable performance

The effect of ownership on the total synergy of M&A agreements has a positive effect on company performance. The growth of share ownership can change the company's strategy as well as the decision-making process (Brooks et al., 2018). Acquiring companies with higher managerial capabilities achieve better long-term operating performance (Cui & Chi-Moon Leung, 2020).

H4: Ownership integration is able to mediate the effect of M&A on corporate sustainable performance.

The best end result of M&A will be achieved when considering the increase in shareholder value in terms of both financial performance and sustainability in the post-merger period (Caiazza et al., 2021).

H5: Merger & Acquisition is able to moderate the effect of ownership integration on sustainable corporate performance.

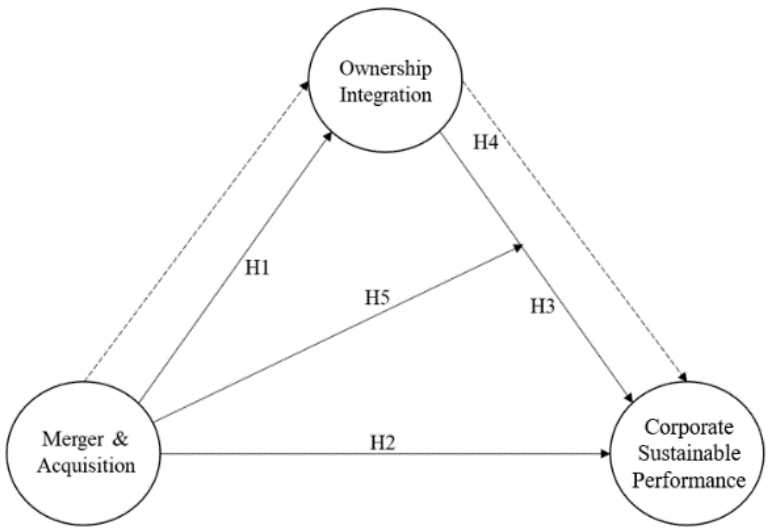


Figure 1. Hypotheses model development of the study

4. Method

The object of this research is the financial data of companies that carry out corporate actions of mergers and acquisitions as measured by three financial ratios, namely liquidity, solvency and profitability. The population consists of 61 companies listed on the Indonesia Stock Exchange carrying out corporate mergers and acquisitions from 2015 to 2019. The method of determining the sample uses non-probability sampling with purposive sampling method. The sample criteria are 1) conducting mergers and acquisitions between 2015 and 2019, 2) being listed on the Indonesia Stock Exchange, 3) reporting complete financial statements according to the year of observation. Based on these criteria, 51 companies were obtained.

Variable Merger & Acquisition (M&A) is measured using five indicators. Current ratio indicator (CUR) for non-financial companies or loan to deposit ratio (LDR) for financial companies, debt to asset ratio (DAR) and debt to equity ratio (DER) indicators as well as return on assets (ROA) indicators and indicators net profit margin (NPM). The five M&A indicators used are financial data in year t the company carried out M&A. The ownership integration variable (OI) is measured using two indicators, namely the ultimate share ownership indicator (Ultm) after the M&A and the percentage of the number of women's boards (WoB) as an indicator related to one of the ongoing issues, namely gender equality. The two OI indicators used are t+1 or one year after the M&A. While the dependent variable corporate sustainable performance (CSP) uses three indicators, namely the ratio of price-earnings (PE), return on equity (ROE) and operating margin (OM) which is measured one year after (t+1) M&A.

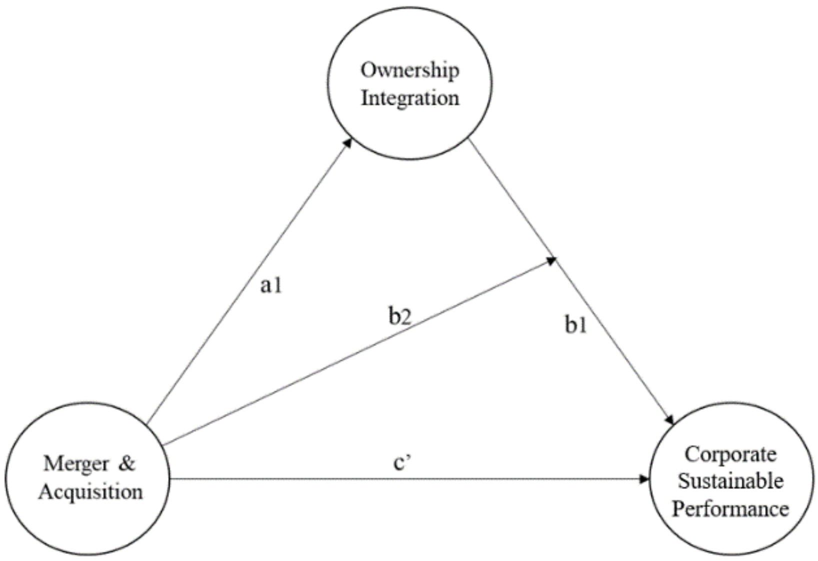


Figure 2. Moderated mediation model 1 (Preacher et al., 2007)

$$OI = a_0 + a_1 M\&A + r \qquad (1)$$

$$CSP = b_0 + c' M\&A + (b_1 + b_2 M\&A) OI + r \qquad (2)$$

Equation 2 clarifies how the regression of CSP on OI can be considered conditional on M&A. The point estimate of the conditional indirect effect of M&A on CSP is in this case $f(\hat{\theta} \mid M\&A) = \hat{a}_1(\hat{b}_1 + \hat{b}_2 M\&A)$. It is easy to see from the expression of $f(\hat{\theta}|M\&A)$ that the conditional indirect effect can depend on the chosen value of M&A. If the interaction effect between M&A and OI is close to zero, then $\hat{b}_2$ will be close to zero, M&A will have little influence on the indirect effect, and the conditional indirect effect reduces to $\hat{a}_1(\ \hat{b}_1$ for all values of the moderator (Preacher et al., 2007).

4.1 Approach

The purpose of the theoretical model is to predict the effect of Merger & Acquisition and ownership integration on corporate sustainability performance in their respective roles, both as mediator and moderator. The partial least square (PLS) method was applied using WarpPLS Version 7.0 software to perform the analysis.

Consistent with the methodology suggested by (Kock, 2022), the indicator approach to moderated mediation uses the PLS structural equation model (PLS-SEM). In analyzing the reliability of internal consistency, convergent validity, and discriminant validity, the quality of construct measurement will be assessed from the model. Furthermore, the significance of the path coefficients for the formative indicators and hypothesis testing were estimated using 999 bootstrap subsamples at 1 percent, 5 percent and 10 percent significance levels (Hair et al., 2011).

The mediation test was measured using the Variance Accounted For (VAF) method to strengthen the results of Baron and Kenny's mediation test. Partial mediation occurs when the VAF value is between 20 and 80 percent. Variance Accounted For (VAF) is calculated by dividing the indirect effect by the total effect. If the VAF is greater than 80 percent there is a full mediation effect, whereas if the VAF is less than 20 percent there is no mediation, or there is only a direct relationship (Hair et al., 2011).

This study will also test the existence of a moderator variable to determine whether the independent variable is the determinant of the dependent variable. The moderator variable can also be interpreted as a determinant of the strength of the role of the independent variable on the dependent variable. The moderator is said to be a pure moderator if the independent variable moderates the relationship between the mediator and the dependent variable, but the independent variable has no direct effect on the dependent variable (Dawson, 2014).

5. Results and Discussion

5.1 Demographic distribution

This study uses the Jackknifing resampling method because it tends to produce a relatively low standard error, more in line with the true value for a small sample size (Kock, 2018).

Constructs	Indicator Loadings	Type	SE	P-Value	ES	α	CR	AVE	VIF
Merger & Acquisition (M&A)						0.624	0.605	0.679	1.906
CUR	0.619	Reflective	0.960	<0.001	0.061				
DAR	0.601	Reflective	0.960	<0.001	0.153				
DER	0.615	Reflective	0.960	<0.001	0.212				
ROA	0.881	Reflective	0.960	<0.001	0.281				
NPM	0.733	Reflective	0.960	<0.001	0.294				
Ownership Integration (OI)						0.826	0.523	0.667	1.354
Ultm	0.942	Reflective	0.960	<0.001	0.500				
WoB	0.604	Reflective	0.960	<0.001	0.500				
Corporate Sustainable Performance (CSP)						0.697	0.746	0.754	1.713
PER	0.841	Reflective	0.960	<0.001	0.375				
ROE	0.611	Reflective	0.960	<0.001	0.267				
OPM	0.992	Reflective	0.960	<0.001	0.357				

Table 1. Measurement model result

Combined loadings and cross-loadings are in line with expectations that the reflective latent variable loading, shown in brackets, will be high; and cross-loading will be low.

Standard errors (SE) were used in the multi-group analysis, with the same model but different subsamples. In research that wants to strengthen the analysis (robust) by comparing measurement models to ensure equality, use a multi-group comparison technique such as that conducted by Kock (2014a). The P value for all indicators is <0.001 indicating that the formative latent variable measurement item that has been built is correct. According to (Kock, 2014a) the recommended P value is 0.05 the value which is considered valid and meets the criteria in measuring formative latent variables. The highest VIF value as a result of this study is 3.232, which is still below the VIF threshold of 3.300 which has been recommended in the context of PLS-based SEM in the measurement of formative latent variables (Kock, 2014a). The value of Weight-loading signs (WLS) is equal to 1, all of which means that all indicators make a positive contribution to the R-squared of the latent variable. It also shows that there is no Simpson Paradox (-1) which means that there is an indication of a causality problem which indicates that the hypothetical relationship between indicators and latent variables in the model does not make sense or is inverted (Kock, 2015e; Kock & Gaskins, 2016). Effect Sizes (ES) value is the absolute value of the contribution of each indicator to the R-squared coefficient.

All indicator effects are moderate to large (ES>0.02) which means both for formative and reflective latent variables (Kock, 2014a).

Ten global fit models and quality indices are provided consisting of Average path coefficient (APC)=0.327, P<0.001; Average R-squared (ARS)=0.270, P=0.002; Average adjusted R-squared (AARS)=0.242, P=0.004. The P values for APC, ARS and AARS in this study were all in accordance with the recommendations, namely equal to or lower than 0.05; that is, significant at the 0.05 level. AVIF and AFVIF are used together as a measure of the indication of variation in collinearity. AFVIF is not sensitive to collinearity variations due to the use of a nonlinear algorithm. Meanwhile, AVIF is sensitive to the use of nonlinear algorithms. The recommended (ideally) AVIF and AFVIF values are equal to or lower than 3.3, especially in a model where most variables are measured through two or more indicators. In this study, each latent variable has three indicators. The value of AVIF 1.211 and AFVIF 1.602 in this study is lower than 3.3. PLS-based SEM algorithms in general tend to be very effective in reducing collinearity (Kock, 2022). Tenenhaus GoF (GoF)=0.307, which indicates that the explanatory power of the model is medium (>= 0.25) Wetzels et al. (2009). The value of Sympson's paradox ratio (SPR)=1,000 (acceptable if 0.7) means that at least 75 percent of the paths in the model are free from Simpson's paradox. The value of R-squared contribution ratio (RSCR) = 1,000 (acceptable if 0.9, ideally = 1) which means that the number of positive R-squared contributions in a model is 97 percent of the total absolute R-squared contribution in the model. Statistical suppression ratio (SSR) = 1,000, meaning that all paths in the model are free from statistical suppression. Nonlinear bivariate causality direction ratio (NLBCDR)=0.750 (acceptable if 0.7) which means that all paths in the model do not show the inversely hypothesized causality direction.

5.2 Latent variable coefficients

R-squared of ownership composition variable is 0.160 and R-squared of Corporate Sustainable Performance variable is 0.381. This means that the variance in the composition of ownership can be explained by the Merger and Acquisition by 16 percent, the remaining 84 percent is explained by other variables outside the model. This means that the variance of Corporate Sustainable Performance can be explained by Merger and Acquisition and the ownership composition is 38.1 percent, the remaining 61.9 percent is explained by other variables outside the model. The Adjusted R-squared coefficient is equivalent to the R-squared coefficient, with the main difference that the Adjusted R-squared corrects for a false increase in the R-squared coefficient due to the predictor adding no explanatory value in each block of latent variables. The coefficient values of R-squared and Adjusted R-squared are above 0.02, so there is no need for revision.

The composite reliability and the Cronbach's alpha coefficients should be equal to or greater than 0.7. An even more relaxed version sets this threshold at 0.6. A latent variable does not satisfy any of these criteria, the reason will often be one or a few indicators that load weakly on the latent variable. The AVE of each construct is very good, that is, above the recommended value of 0.5, it means that it meets the criteria for discriminant validity (Kock, 2014). Composite Reliability above 0.5 so that it meets internal consistency reliability). The value of Full Collinearity VIF for each very good construct is less than 3.3, which means that there is no collinearity problem in the model. The mean and standard deviation are not shown because the latent variable is standard; that is, they all have a mean of 0 and a standard deviation of 1.

	M&A	**OI**	**CSP**	**M&A*OI**
M&A	0.529	-0.345	0.499	0.455
OI	-0.345	0.667	0.148	0.019
CSP	0.499	0.148	0.754	0.488
M&A*OI	0.455	0.019	0.488	0.323

Table 2. Correlation between latent variables and square roots AVE

Table 2. Presenting the recommended criteria for discriminant validity assessment is that each latent variable, the square root of the extracted AVE is all higher than any correlation (above or below it, in the same column; or to its left or right, in the same row) involving the latent variable.

5.3 Findings and discussion

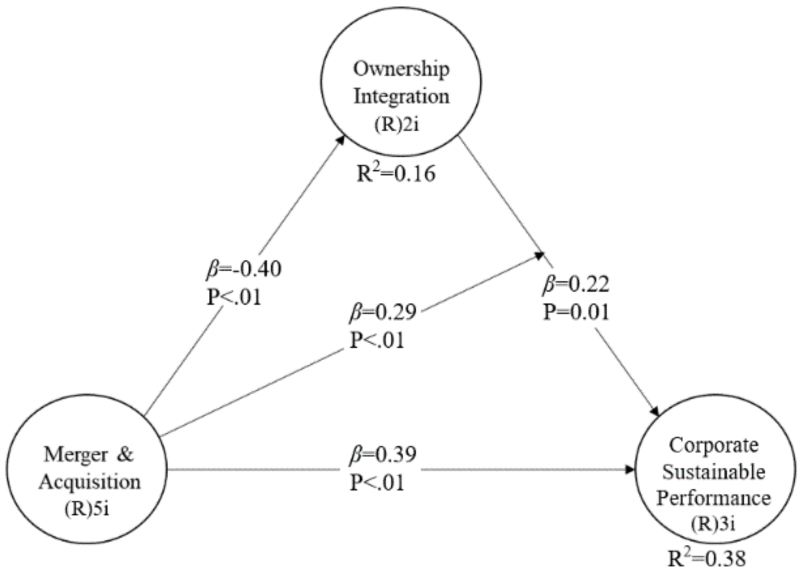


Figure 3. Conceptual model showing path coefficient, R^2 and P-value (Source: output of PLS-SEM)

The effect of Merger & Acquisition and ownership integration on corporate sustainability performance is measured using WarpPls Version 7.0. The R Square value is 0.381 which indicates that the Merger & Acquisition and ownership integration causes variations in corporate sustainability performance by 38.1 percent. In contrast, the remaining 61.9 percent can be explained by variables not examined in this study. This R Square value explains that to achieve corporate sustainability performance, it is quite dependent on Merger & Acquisition and ownership integration. For comparison, the effect of Merger & Acquisition on ownership integration is 0.106. These results indicate that the variation of Merger & Acquisition only causes variation in ownership integration by 10.6 percent. Thus, the effect of the Merger & Acquisition experience is weak on ownership integration. There are 89.4 percent of variables that are not examined that have a more significant effect on ownership integration compared to Merger & Acquisition.

 http://dx.doi.org/10.13135/2384-8677/7916

	Path Coefficient	Effect Size (f^2)	Decision
Part A: Direct effect			
Merger & Acquisition → Proprietary Integration (H1)	-0.400*** (0.096)	0.160	Rejected
Merger & Acquisition → Corporate Sustainable Performance (H2)	0.394*** (0.096)	0.197	Accepted
Proprietary Integration → Corporate Sustainable Performance (H3)	0.219*** (0.096)	0.041	Accepted
Part B: Indirect effect			
Mediating effect:			
Merger & Acquisition → Proprietary Integration → Corporate Sustainable Performance (H4)	0.307* (0.068)	0.043	Accepted
Moderating effect (H5)	0.294*** (0.096)	0.143	Accepted
Determination coefficients (R^2) and predictive relevance (Q^2) of endogeneous:			
R^2 (Ownership Integration) = 0.160; Q^2 (Ownership Integration) =0.146			
R^2 (Corporate Sustainable Performance) = 0.381; Q^2 (Corporate Sustainable Performance) = 0.468			

Table 3. Significant testing results of the structural model part coefficients.
***, ** and * indicate significant at the 0.01, 0.05 and 0.10 levels respectively. Standard errors clustered by firms are indicated in parentheses.

The path coefficient values are shown in Table 3. Part A shows the direct effect of each variable. Merger & Acquisition have a significant negative effect on Ownership Integration (β= -0.400, P-value<0.001), so hypothesis 1 is rejected. In the context of research in Indonesia, these results are in line with research conducted by Pye (2000) that as ownership grows larger it becomes difficult to achieve a well-informed and challenging corporate dialogue about decisions taken by the board in management (Pye, 2000). high concentration of ownership does not necessarily reduce agency costs (Rossi et al., 2018).

Tested using the basic Warp2 algorithm to try to identify the existence of a non-linear relationship to the linear test results, the direct effect of Merger & Acquisition has a significant negative effect on Ownership Integration which causes hypothesis 1 to be rejected. We find a U-curve relationship between Merger & Acquisition and Ownership Integration variable pairs in the estimated path coefficients in the model (Figure 4.). The Warp2 algorithm used will change (or "curve") the score of the Merger & Acquisition latent variable so that it can better describe its relationship with the ownership integration predictor variable.

This shows that the Merger & Acquisition corporate action will have a significant positive effect on ownership integration if the Merger & Acquisition value is greater than 32.84 percent, while the average value of Merger & Acquisition in the observed companies is 25.20 percent (Figure 4.)

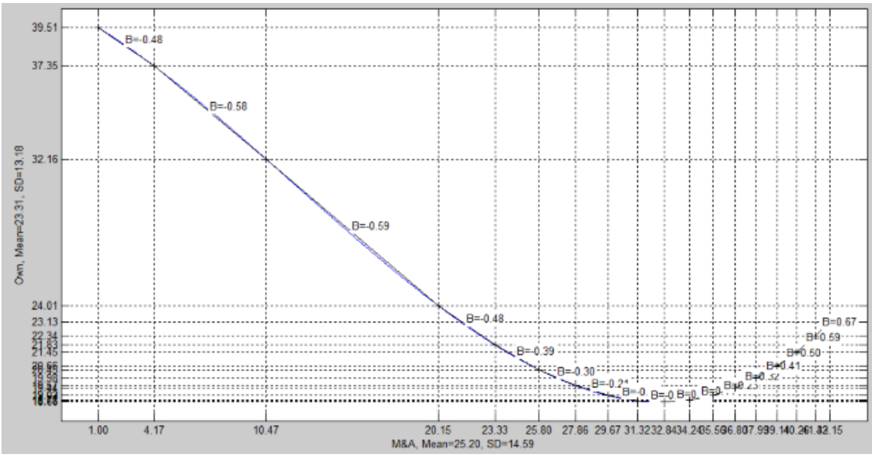


Figure 4. U-curve graph of Merger & Acquisition and Ownership Integration relationship

Merger & Acquisition has a positive and significant effect on Corporate Sustainable Performance (β = 0.394, P-value < 0.001), so hypothesis 2 is accepted. Merger & Acquisition will improve Corporate Sustainable Performance. These results are in line with research (Caiazza et al., 2021; Cui & Chi-Moon Leung, 2020; Khaled et al., 2021). This means that when a company carries out a Merger & Acquisition, the more likely it is that increasing Corporate Sustainable Performance, the company's leverage level has a positive effect on its sustainability performance and disclosure; states that highly leveraged firms tend to disclose more sustainability information to reduce the agency costs generated as a result of their higher debt levels.

Furthermore, the results of another direct influence, namely Ownership Integration, have a significant and positive effect on Corporate Sustainable Performance of =0.219 with P-value = 0.013, so hypothesis 3 is accepted. The results of this study are in line with research (Cui & Chi-Moon Leung, 2020;

Gainet, 2010; Tjahjadi et al., 2021) which states that the integration of ownership as measured by indicators increases Corporate Sustainable Performance.

5.4 Mediation analysis

In this study, the role of Ownership Integration as a mediator between Merger & Acquisition and Corporate Sustainable Performance will be tested. To explore the significant role of mediators between Merger & Acquisition and Corporate Sustainable Performance, different estimates were obtained, namely total effect, indirect effect, path coefficients, and bootstrap. In Table 3 Part B shows that there is a positive and significant indirect relationship on the effect of Merger & Acquisition on Corporate Sustainable Performance after being mediated by Ownership Integration. These results are sufficient to accept hypothesis 4.

Partial mediation occurred because the indirect effect of the independent variable on the dependent variable (β=0.307, P-value<0.10) the coefficient was smaller than the direct effect of the independent variable on the dependent variable (β=0.394, P-value<0.001) (Baron & Kenny, 1986). When tested using the Variance Accounted For (VAF) method, the results show that there is partial mediation because the VAF value is between 20 to 80 percent (VAF = 28.7 percent. Thus, Ownership Integration acts as a partial mediator of the relationship between the effect of Merger & Acquisition on Corporate Sustainable Performance.

5.5 Moderated Mediation

Moderation test is applied in this study to interpret whether the determinants of the weakness or strength of Merger & Acquisition in the relationship between ownership integration and Corporate Sustainable Performance. It is suspected that there is an interaction between Merger & Acquisition and Integration of ownership on Corporate Sustainable Performance, so the researcher has reasons to investigate moderation. In this study, Merger & Acquisition also acts as a moderator which strengthens the effect of ownership integration on Corporate Sustainable Performance (β=0.294, P-value<0.001). The moderator's role is indicated by an increase in the coefficient value of the direct relationship between ownership integration and Corporate Sustainable Performance (β=0.219, P-value=0.013). Thus hypothesis 5 is accepted.

The moderating effect can be seen from the Merger & Acquisition latent variable which is hypothesized to moderate the relationship between ownership integration and corporate sustainable performance. The 3-dimensional (3D) graph in Figure 5. shows a moderating relationship involving two latent variables, a moderating variable and a pair of variables connected through a direct link. The sign and strength of the path coefficient for the moderating relationship refers to the effect of the moderating variable on the sign and strength of the path for the direct relationship being moderated (Kock, 2022). If the path for the direct relationship moves from the low to high range of the moderating variable, then the sign of the path coefficient for the corresponding moderating relationship will be positive and the path coefficient will be relatively high; so that the Merger & Acquisition variable produces a strengthening and statistically significant moderating effect on the direct relationship between ownership integration variables and corporate sustainable performance. In this study the Merger & Acquisition moderator variable interacts with the ownership integration mediator variable in such a way that the value of the indirect effect changes depending on the moderator variable value, resulting in moderating mediation.

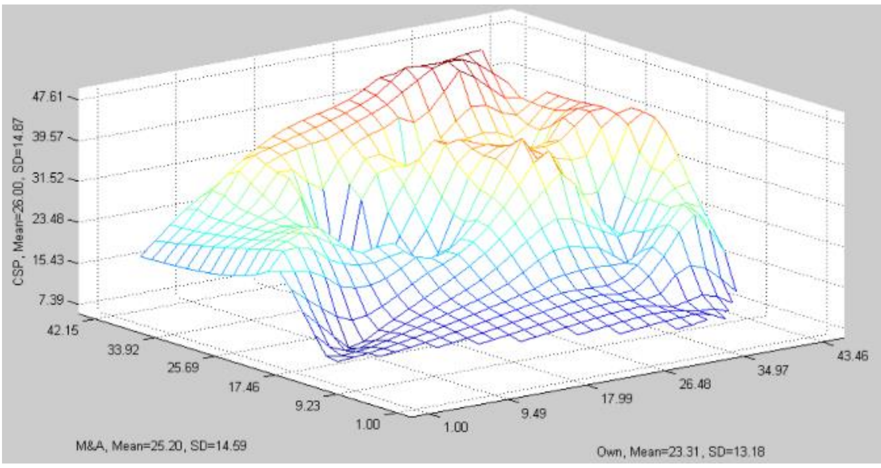


Figure 5. The moderating effect of Merger & Acquisition

The extant literature on corporate sustainable performance has been focused on the direct influence of various factors and organizational strategies. This research identified OI as a key mediator between the RM and corporate sustainable performance, which is previously limited (Adams and Graham, 2016; Brix, 2017). The examination of the mediating role of OI in the proposed model provides a novel theoretical point of view in the context of emerging economies. This is because just a very few studies have explored an intervening role of OI in various cultures (Hamann et al., 2017). Third, this study revealed that OI is an important determinant of corporate sustainable performance and its all dimensions that keep the environment clean and enhance the sustainable development; however, OI has a strong effect on the environmental dimension of corporate sustainable performance. Consequently, this research contributes to the RBV in the developing country context that OI remains a significant factor in the context of corporate sustainable performance. Finally, the research advances a better understanding that KMP is important for corporate sustainable performance. Finally, this study advances the knowledge of how OI can improve for accomplishing corporate sustainable performance by communicating and applying the knowledge into corporate strategies and operations. This empirical research, however, is the first to test the moderation of OI among RM, Ac and corporate sustainable performance. Accordingly, these results provide supplements for literature about corporate sustainable performance. Wong (2013) highlighted the significant role of KMP in influencing the OI because GI can enhance the corporate sustainable performance to fulfill the requirement of sustainable development. The current research extends the findings of Wong (2013) by exhibiting that KMP facets impact corporate sustainable performance through OI in the developing country context. In a nutshell, results revealed that all dimensions of corporate sustainable performance are the most persuasive drivers, which offer solutions to environmental degradation and cost-efficiency that provide support to sustainable development. Thus, organizations can perform effectively and efficiently.

6. Conclusions

After the M&A action, it causes a decrease in the effect of ownership integration as measured by the ultimate share ownership indicator and the presence of a female board in the company. M&A agreements, which are measured using financial indicators, make the company bigger and thus the ultimate shareholding grows bigger, making it difficult to achieve corporate dialogue and decisions taken by the board in management. In line with the concept of ultimate shareholder entrechment can affect corporate governance. We find a U-curve relationship between the Merger & Acquisition and Ownership Integration variable pairs, which means that the M&A agreement will align with the ownership integration after the M&A agreement through the point of 32.84. This reflects efforts to increase control by controlling shareholders to maximize their interests through M&A. M&A agreements, and ownership integration as measured by the presence of controlling shareholders and women on board affect corporate sustainable performance. The M&A agreement creates a stronger link between Ownership Integration and corporate sustainable performance. In this study, it was found that Ownership Integration also acts as a partial mediator on the relationship between M&A and Corporate Sustainable Performance. This research is only using the perception of corporate sustainable performance in terms of the company's finances. Future research is suggested to investigate the special case of M&A, on environmental, social, and governance as a measure of corporate sustainable performance.

References

Aksoy, M., Yilmaz, M. K., Tatoglu, E., & Basar, M. (2020). Antecedents of corporate sustainability performance in Turkey: The effects of ownership structure and board attributes on non-financial companies. *Journal of Cleaner Production*, *276*, 124284. https://doi.org/10.1016/j.jclepro.2020.124284

Andriosopoulos, D., & Yang, S. (2015). The impact of institutional investors on mergers and acquisitions in the United Kingdom. *Journal of Banking and Finance*, *50*, 547–561. https://doi.org/10.1016/j.jbankfin.2014.06.004

Baron, R. M., & Kenny, D. A. (1986). The Moderator-Mediator Variable Distinction in Social Psychological Research. Conceptual, Strategic, and Statistical Considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173

Barros, V., Verga Matos, P., Miranda Sarmento, J., & Rino Vieira, P. (2022). M&A activity as a driver for better ESG performance. *Technological Forecasting and Social Change*, *175*(November 2021), 121338. https://doi.org/10.1016/j.techfore.2021.121338

Bertrand, M., Black, S. E., Jensen, S., & Lleras-Muney, A. (2019). Breaking the Glass Ceiling? The Effect of Board Quotas on Female Labour Market Outcomes in Norway. *The Review of Economic Studies*, *86*(1), 191–239. https://doi.org/10.1093/restud/rdy032

Brooks, C., Chen, Z., & Zeng, Y. (2018). Institutional cross-ownership and corporate strategy: The case of mergers and acquisitions. *Journal of Corporate Finance*, *48*, 187–216. https://doi.org/10.1016/j.jcorpfin.2017.11.003

Cai, G., Xie, S., Xu, Y., Zeng, Y., & Zhang, J. (2019). Ultimate parent's board reform and controlling shareholder entrenchment: Evidence from a quasi-natural experiment in China. *Emerging Markets Review*, *38*(November 2018), 389–403. https://doi.org/10.1016/j.ememar.2018.11.002

Caiazza, S., Galloppo, G., & Paimanova, V. (2021). The role of sustainability performance after merger and acquisition deals in short and long-term. *Journal of Cleaner Production*, *314*(August 2020), 127982. https://doi.org/10.1016/j.jclepro.2021.127982

Carbonero, F., Devicienti, F., Manello, A., & Vannoni, D. (2021). Women on board and firm export attitudes: Evidence from Italy. *Journal of Economic Behavior & Organization*, *192*, 159–175. https://doi.org/https://doi.org/10.1016/j.jebo.2021.10.011

Chams, N., & García-Blandón, J. (2019). Sustainable or not sustainable? The role of the board of directors. *Journal of Cleaner Production*, *226*, 1067–1081. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.04.118

Cui, H., & Chi-Moon Leung, S. (2020). The long-run performance of acquiring firms in mergers and acquisitions: Does managerial ability matter? *Journal of Contemporary Accounting and Economics*, *16*(1), 100185. https://doi.org/10.1016/j.jcae.2020.100185

Dawson, J. F. (2014). Moderation in Management Research: What, Why, When, and How. *Journal of Business and Psychology*, *29*(1), 1–19. https://doi.org/10.1007/s10869-013-9308-7

Dočekalová, M. P., & Kocmanová, A. (2016). Composite indicator for measuring corporate sustainability. *Ecological Indicators*, *61*, 612–623. https://doi.org/10.1016/j.ecolind.2015.10.012

Gainet, C. (2010). Exploring the Impact of Legal Systems and Financial Structure on Corporate Responsibility. *Journal of Business Ethics*, *95*(SUPPL. 2), 195–222. https://doi.org/10.1007/s10551-011-0854-5

Geraldi, J., Teerikangas, S., & Birollo, G. (2022). Project, program and portfolio management as modes of organizing: Theorising at the intersection between mergers and acquisitions and project studies. *International Journal of Project Management*. https://doi.org/https://doi.org/10.1016/j.ijproman.2022.03.005

Gillan, S. L., Koch, A., & Starks, L. T. (2021). Firms and social responsibility: A review of ESG and CSR research in corporate finance. *Journal of Corporate Finance*, *66*, 101889. https://doi.org/https://doi.org/10.1016/j.jcorpfin.2021.101889

Gregoriou, G. N., & Renneboog, L. (2007). 1 - Understanding mergers and acquisitions: Corporate governance and regulatory issues. In G. N. Gregoriou & L. B. T.-C. G. and R. I. on M. and A. Renneboog (Eds.), *Quantitative Finance* (pp. 1–13). Academic Press. https://doi.org/https://doi.org/10.1016/B978-012374142-4.50003-8

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a Silver Bullet. *Journal of Marketing Theory and Practice*, *19*(2), 139–152. https://doi.org/10.2753/MTP1069-6679190202

Hazelkorn, T., Zenner, M., & Shivdasani, A. (2004). Creating Value With Mergers and Acquisitions. *Journal of Applied Corporate Finance*, *16*(2–3), 81–90.

Jensen, & Meckling. (1976). Theory of the Firm : Managerial Behavior , Agency Costs and Ownership Structure. *Journal of Financial Economics*, *3*, 305–360.

Khaled, R., Ali, H., & Mohamed, E. K. A. (2021). The Sustainable Development Goals and corporate sustainability performance: Mapping, extent and determinants. *Journal of Cleaner Production*, *311*(May), 127599. https://doi.org/10.1016/j.jclepro.2021.127599

Kock, N. (2014). Advanced Mediating Effects Tests, Multi-Group Analyses, and Measurement Model Assessments in PLS-Based SEM. *International Journal of E-Collaboration*, *10*, 1–13. https://doi.org/10.4018/ijec.2014010101

Kock, N. (2018). Single missing data imputation in PLS-based structural equation modeling. *Journal of Modern Applied Statistical Methods*, *17*(1). https://doi.org/10.22237/jmasm/1525133160

Kock, N. (2022). WarpPLS user manual : Version 7.0. *ScriptWarp Systems*, 1–122.

Kouaib, A., Mhiri, S., & Jarboui, A. (2020). Board of directors' effectiveness and sustainable performance: The triple bottom line. *The Journal of High Technology Management Research*, *31*(2), 100390. https://doi.org/https://doi.org/10.1016/j.hitech.2020.100390

Krishnan, H. A., Hitt, M. A., & Park, D. (2007). Acquisition premiums, subsequent workforce reductions and post-acquisition performance. *Journal of Management Studies*, *44*(5), 709–732. https://doi.org/10.1111/j.1467-6486.2006.00672.x

La Porta, R., Lopez-de-Silanes, F., & Shleifer, A. (1999). Corporate ownership around the world. *Journal of Finance*, *54*(2), 471–517. https://doi.org/10.1111/0022-1082.00115

Lestari, R. I., Wahyudi, S., Muharam, H., & Utomo, M. N. (2020). The role of monitoring and bonding mechanisms of good corporate governance towards banks performance. *Humanities and Social Sciences Reviews*, *8*(2), 328–336. https://doi.org/10.18510/hssr.2020.8237

Madaleno, M., & Vieira, E. (2020). Corporate performance and sustainability: Evidence from listed firms in Portugal and Spain. *Energy Reports*, *6*, 141–147. https://doi.org/10.1016/j.egyr.2020.11.092

Malikov, K., Demirbag, M., Kuvandikov, A., & Manson, S. (2021). Workforce reductions and post-merger operating performance: The role of corporate governance. *Journal of Business Research*, *122*, 109–120. https://doi.org/https://doi.org/10.1016/j.jbusres.2020.08.042

Manuela, W. S., Rhoades, D. L., & Curtis, T. (2016). Journal of Air Transport Management The U. S. Airways Group: A post-merger analysis. *Journal of Air Transport Management*, *56*, 138–150. http://dx.doi.org/10.1016/j.jairtraman.2016.04.022

Morioka, S. N., & Carvalho, M. M. (2016). Measuring sustainability in practice: exploring the inclusion of sustainability into corporate performance systems in

Brazilian case studies. *Journal of Cleaner Production*, *136*, 123–133. https://doi.org/10.1016/j.jclepro.2016.01.103

Naciti, V. (2019). Corporate governance and board of directors: The effect of a board composition on firm sustainability performance. *Journal of Cleaner Production*, *237*, 117727. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.117727

Nicolò, G., Sannino, G., & Iorio, S. De. (2021). Gender diversity and online intellectual capital disclosure: Evidence from Italian-listed firms. *Journal of Public Affairs*, *May*, 1–13. https://doi.org/10.1002/pa.2706

Nikolaou, I. E., Tsalis, T. A., & Evangelinos, K. I. (2019). A framework to measure corporate sustainability performance: A strong sustainability-based view of firm. *Sustainable Production and Consumption*, *18*, 1–18. https://doi.org/10.1016/j.spc.2018.10.004

Piosik, A., & Genge, E. (2020). Earnings management prior to mergers and acquisitions: The role of acquirers' ownership structures. Evidence from Poland. *Procedia Computer Science*, *176*, 1299–1311. https://doi.org/https://doi.org/10.1016/j.procs.2020.09.139

Pislaru, M., Herghiligiu, I. V., & Robu, I. B. (2019). Corporate sustainable performance assessment based on fuzzy logic. *Journal of Cleaner Production*, *223*, 998–1013. https://doi.org/10.1016/j.jclepro.2019.03.130

Preacher, K. J., Rucker, D. D., & Hayes, A. F. (2007). Addressing Moderated Mediation Hypotheses: Theory, Methods, and Prescriptions. *Multivariate Behavioral Research*, *42*(1), 185–227. https://doi.org/10.1080/00273170701341316

Pye, A. (2000). Changing Scenes in, from and Outside the Board Room: UK corporate governance in practice from 1989 to 1999. *Corporate Governance: An International Review*, *8*(4), 335–346. https://doi.org/10.1111/1467-8683.00212

Rossi, F., Boylan, R., & Cebula, R. J. (2018). Financial decisions and ownership structure as control mechanisms of agency problems: evidence from Italy. *Corporate Governance (Bingley)*, *18*(3), 531–563. https://doi.org/10.1108/CG-01-2017-0014

Tampakoudis, I., Nerantzidis, M., Eweje, G., & Leventis, S. (2022). The impact of gender diversity on shareholder wealth: Evidence from European bank M&A. *Journal of Financial Stability*, *60*, 101020. https://doi.org/https://doi.org/10.1016/j.jfs.2022.101020

Tao, Q., Li, H., Wu, Q., Zhang, T., & Zhu, Y. (2019). The dark side of board network centrality: Evidence from merger performance. *Journal of Business Research*, *104*, 215–232. https://doi.org/https://doi.org/10.1016/j.jbusres.2019.07.019

Teti, E., & Tului, S. (2020). Do mergers and acquisitions create shareholder value in the infrastructure and utility sectors? Analysis of market perceptions. *Utilities Policy*, *64*, 101053. https://doi.org/https://doi.org/10.1016/j.jup.2020.101053

Thraya, M. F. (2015). Are controlling shareholders extracting private benefits from European public acquisitions? *International Journal of Managerial Finance*, *11*(1), 80–96. https://doi.org/10.1108/IJMF-07-2012-0081

Tjahjadi, B., Soewarno, N., & Mustikaningtiyas, F. (2021). Good corporate governance and corporate sustainability performance in Indonesia: A triple bottom line approach. *Heliyon*, *7*(3), e06453. https://doi.org/10.1016/j.heliyon.2021.e06453

Trujillo, A. J., Garcia-Morales, E. E., Kabarriti, G., & Anderson, G. (2020). Do mergers and acquisitions improve firms' financial performance? The case of the U.S. generic drug industry. *Managerial and Decision Economics*, *41*(1), 10–24. https://doi.org/10.1002/mde.3074

Widjajanti, K., Prihantini, F. N., Wijayanti, R. (2016). Sustainable Development of Business with Canvas Business Model Approach: Empirical Study on MSMEs Batik Blora, Indonesia. *International Journal of Sustainable Development and Planning, 2022, 17(3), pp. 1025–1032.*

Widjajanti, K., & Widodo. (2016). Improving Organizational Innovation by Human Capital, Knowledge Sharing and Organizational Learning Base. *International Business Management, 10*(9), 1599-1609.

Widjajanti, K. (2011). Organizational transformation and the performance. of Indonesian privatized State-Owned Enterprises (SOEs). *JM international journal of HR review, 1*, 76-91.

Wonder, N., & Lending, C. (2019). Acquisitions and the shareholder base. *Managerial Finance*, *45*(10/11), 1416–1432. https://doi.org/10.1108/MF-12-2017-0502

Zhang, W., Wang, K., Li, L., Chen, Y., & Wang, X. (2018). The impact of firms' mergers and acquisitions on their performance in emerging economies. *Technological Forecasting and Social Change*, *135*(2), 208–216. https://doi.org/10.1016/j.techfore.2018.05.015.

Authors

Kesi Widjajanti, (*corresponding author*)
Department of Management, Faculty of Economics, University of Semarang, Semarang City, Indonesia kesi@usm.ac.id

Rohmini Indah Lestari,
Department of Management, Faculty of Economics, University of Semarang, Semarang City, Indonesia

Eviatiwi Kusumaningtyas Sugiyanto,
Department of Management, Faculty of Economics, University of Semarang, Semarang City, Indonesia

Funds

This research was funded by the Indonesian National Research and Innovation Agency. Therefore, the author would like to thank the institution for the financial support that has been provided.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Widjajanti, K., Lestari, R.I. & Sugiyanto, E.K. (2023) How the strategic to achieve corporate sustainable performance? The role of mergers, acquisitions and ownership integrations. *Visions for Sustainability*, 20, 7916, 301-328.
http://dx.doi.org/10.13135/2384-8677/7916

Original Paper

Fostering sustainability in China's textile industry.

The role of education for sustainable development.

Ji Jie, Tan Wee Hoe, Shi Wen Qian

Received: 10 July 2023 | **Accepted:** 14 September 2023 | **Published:** 19 September 2023

Keywords: sustainability; textile industry; education; development

Abstract. *As China's textile industry grapples with sustainability issues, education plays an increasingly important role in promoting sustainable practices. The objective of this research was to assess the impact of an Education for Sustainable Development (ESD) syllabus on the sustainability knowledge, attitudes, and behaviours of a cohort of 60 students studying textile and clothing. By employing a quasi-experimental methodology, surveys were administered to students both before and after the implementation of an ESD curriculum, with the aim of monitoring alterations in their sustainability knowledge, attitudes, and behaviours. The curriculum for ESD was customised to cater to the requirements of the textile industry, encompassing both theoretical knowledge and practical implementation. The study utilised various statistical methods such as descriptive statistics, paired t-tests, correlation analysis, and multiple regression to analyse the data. The study reveals a significant enhancement in students' sustainability knowledge, attitudes, and behaviors post-ESD curriculum. A strong correlation was established between sustainability knowledge and attitudes, and between knowledge and behaviors. Further, multiple regression analysis demonstrated that both knowledge and attitudes significantly contribute to predicting sustainability behavior. The research concludes that tailored ESD curriculums can effectively boost sustainability knowledge, engender positive attitudes, and inspire sustainable behaviors among textile and clothing students. These findings emphasize the pivotal role of education in driving sustainable transitions in the industry, providing useful insights for future ESD curriculum design.*

1. Introduction

In recent years, the global textile industry has faced increasing scrutiny due to its substantial environmental footprint, which encompasses significant resource consumption and pollution generation. The extent of this issue is amplified by the international reach of the textile supply chain, which not only exacerbates environmental concerns but also embeds complex socio-economic dynamics into the industry's operations (Milgate, 2001). At the center of this global issue stands China, the world's foremost textile producer, whose practices in the sector have far-reaching impacts, thereby spotlighting the urgent need for sustainable transformations in the industry (Franco, 2017).

Understanding the gravity of the situation in China is pivotal, given its central role in the global textile market. The country's manufacturing processes, ranging from raw material extraction to the disposal of the final product, are characterized by considerable water and air pollution, augmented energy usage, and substantial waste generation, all of which contribute to a pressing environmental dilemma(Ashokkumar et al., 2022). Hence, a critical examination of the sustainability practices within China's textile industry presents itself as a timely and significant endeavor.

In this landscape, Education for Sustainable Development (ESD) emerges as a potent tool to foster sustainable practices within the industry. Leveraging ESD can enhance the understanding and application of sustainable practices at various stages of the textile lifecycle, thereby nurturing a generation of professionals adept at aligning the industry's operations with sustainability principles (Abner et al., 2019; Leicht et al., 2018). However, the incorporation of ESD in China's textile education remains in its infancy, characterized by limited reach and unresolved questions regarding its effectiveness (Figueiró & Raufflet, 2015; Okereke et al., 2019).

This study endeavors to address this gap, aiming to unearth how ESD can be effectively integrated into China's textile education to foster a sustainable industry landscape. By delving deep into the current state of ESD in Chinese textile education and identifying potential barriers and facilitators, this research aspires to forge a path toward a more sustainable textile industry in China and, by extension, globally. Furthermore, it intends to offer valuable insights to educators, curriculum designers, and industry stakeholders, thereby making a significant contribution to the scientific community in the realm of sustainability education and industry practice (de Oliveira Neto et al., 2019).

2. Research questions and research problem

The pressing environmental issues linked to the textile industry highlight the need for sustainability education within textile programs. Specifically, the ESD approach may foster increased environmental knowledge, pro-environmental attitudes, and pro-environmental behaviors among textile students. However, empirical examination of these potential influences in the context of Chinese textile education is lacking, which this study aims to address.

2.1 Research questions

RQ1 : Can the ESD approach increase environmental knowledge (EK) in the context of Chinese textiles and apparel education?

Studies suggest that education, particularly focused on environmental impacts, can enhance learners' environmental knowledge (Karahan & Roehrig, 2015). However, the effectiveness of ESD in boosting such knowledge within the context of Chinese textile education remains unexplored.

RQ2 : Can the ESD approach enhance pro-environmental attitudes in the context of Chinese textiles and apparel education?

Pro-environmental attitudes are complex and influenced by multiple factors including environmental knowledge (Vicente-Molina et al., 2013). Research in the context of Western countries has found that certain teaching methods, such as the use of videos, can effectively foster these attitudes among textile students (Moos & Ringdal, 2012). Nonetheless, the efficacy of the ESD approach in the realm of Chinese textile education remains inadequately scrutinized.

RQ3: In the context of Chinese textile and apparel education, does the ESD approach foster pro-environmental behaviours?

According to prior research, there is a notable impact of pro-environmental attitudes on behaviours (Ahuti, 2015). The correlation between education and behaviour is intricate; however, the ESD methodology has the potential to augment pro-environmental conduct among pupils (Vicente-Molina et al., 2013). However, the scope of this impact within the framework of Chinese textile education remains ambiguous.

2.2 Objectives of the study

The principal objective of this investigation is to examine the impact of the ESD methodology on the environmental knowledge, pro-environmental attitudes, and pro-environmental behaviours of Chinese students specialising in textiles and apparel. In light of this overarching aim, the subsequent specific objectives have been delineated:

RO1: To assess the efficacy of the ESD methodology in enhancing the environmental knowledge of students specializing in textiles and apparel in China.

The primary aim is to evaluate the impact of ESD on students' comprehension of environmental concerns pertaining to the textile and apparel sector. The proposed methodology entails the assessment of students' environmental knowledge pre- and post-exposure to ESD. To investigate whether the ESD approach enhances pro-environmental attitudes among textiles and apparel students in China.

RO2: To examine the impact of the ESD approach on the pro-environmental attitudes among students specializing in textiles and apparel in China.

The secondary goal of this study is to ascertain the potential impact of ESD on the attitudes of students towards environmental sustainability. The proposed study aims to evaluate alterations in students' attitudes and emotions towards environmental concerns, with a particular focus on the involvement of the textile industry in these matters.

RO3: To explore the potential of the ESD approach in promoting pro-environmental behaviors among textiles and apparel students in China.

The third objective is to ascertain whether ESD can lead to changes in students' behaviors that align with environmental sustainability. This will involve examining the potential shift in students' actions related to the consumption, use, and disposal of textile and apparel products.

In the preparation for this study, a meticulous literature review was undertaken to set a robust foundation for the research questions and objectives, grounded in an understanding of the existing body of knowledge on the topic. The criteria established for the selection of sources were multi-faceted, ensuring a rich and current pool of references to draw upon. Firstly, relevance was upheld as a principal criterion; thus, only articles directly pertaining to sustainability education, the environmental impacts of the textile industry, and ESD were selected. To ensure the incorporation of the most recent insights and data, a preference was accorded to studies published in the last decade. Additionally, a critical emphasis was placed on the authority of the sources, giving priority to reputable journals, institutions, and authors recognized for their expertise in the relevant fields.

The geographical context of the sources was also a crucial aspect of the selection criteria. While the core focus remained on the Chinese context, the review also embraced pertinent research emerging from Western and other Asian contexts, aiming to cultivate a comprehensive perspective on the subject matter. This strategic approach to source selection was designed to fulfill several vital objectives of the literature review. It seeks to establish the existing understanding of the impacts of ESD within various educational settings globally. Furthermore, it aids in identifying the significant gaps in the present research landscape, especially in the context of Chinese textile education. Through this, the literature review offers a solid groundwork, highlighting both the potential benefits and challenges of implementing ESD in the textile sector, thereby framing the study's research questions and objectives with a well-rounded viewpoint.

3. Literature review

3.1 Sustainability in the textile industry

The textile industry has significant environmental impacts globally. The production processes involved in textiles contribute substantially to environmental degradation through water pollution, waste generation, and high carbon emissions (Ahuti, 2015). The extensive use of water and energy in the textile production processes, especially in dyeing and finishing, are critical areas of concern (Kant, 2011). Furthermore, the heavy reliance on non-renewable resources, including petroleum-based fibers like polyester, compounds these impacts (Derkach & Shuhailo, 2022). This highlights the urgent need for integrating sustainability within the textile industry worldwide.

Sustainability efforts in the global textile industry are growing but still face numerous challenges. While many companies have started to incorporate sustainable practices, such as resource efficiency, recycling, and cleaner production methods, the transition is slow and fraught with difficulties (Todeschini et al., 2017). One of the biggest challenges hampering the sustainability transition in the sector is the high cost of sustainable technologies (Murzyn-Kupisz & Hołuj, 2021). Other barriers include a lack of consumer awareness and lax regulatory laws. The scarcity of eco-friendly materials is a further problem (Hwang et al., 2022). This indicates that additional effort is required to hasten the transition to a more sustainable textile industry.

As the largest textile market in the world, China plays a crucial role in the fight for textile sustainability on a worldwide scale. The textile sector is vital to China's economy (Jasmi et al., 2019), as the country is the world's largest exporter of textile products. However, the manufacture of textiles in China has a large negative effect on the environment because of the country's strong reliance on coal for electricity, the enormous use of water resources, and the significant emissions of dye waste (Ashokkumar et al., 2022). There has been a tightening of environmental legislation in the country, but there is often a lack of application and enforcement (Derkach & Shuhailo, 2022). As a result, reducing the worldwide environmental implications of the textile sector requires a strong emphasis on sustainability within China's textile industry.

The ESD approach offers a constructive way forward for China's textile sector to include sustainability. As a comprehensive method of teaching, ESD has the ability to provide future textile professionals in China with the knowledge, attitudes, and skills required for environmentally friendly manufacturing (Luo et al., 2021). It promotes sustainable decision-making by increasing awareness of the interconnectedness of environmental, social, and economic concerns. including ESD into textile education in China can encourage sustainable advancements across the sector (Chiba et al., 2021). For the industry to promote sustainability, it is essential to examine the effects of ESD in the context of Chinese textile education.

3.2 Education for Sustainable Development (ESD)

A method of educating with the goal of fostering the information, abilities, attitudes, and values required to create a sustainable future is known as education for sustainable development or ESD. According to UNESCO, ESD is an integrated approach to learning that takes into account how social, economic, cultural, and environmental facets of human society interact with one another (Okereke et al., 2019). It aims to equip students the critical thinking abilities, comprehension of complex systems, and valuesnecessary to contribute to the creation of a more sustainable world (Köksal et al., 2017). Additionally, ESD places a focus on interactive teaching and learning strategies that inspire and empower students to alter their behaviour and take action for sustainable development (Jasmi et al., 2019). Therefore, ESD is essential in raising citizens who are concerned about sustainability.

ESD has been incorporated into a number of learning settings, including technical and vocational education. In these environments, ESD frequently focuses on giving students the information and skills necessary for sustainable industries and green professions (de Oliveira Neto et al., 2019). Technical expertise in waste management, resource efficiency, and renewable energy are included in this, as are larger competences like systems thinking and decision-making for sustainability (Figueiró & Raufflet, 2015). According to studies, including ESD into vocational and technical education can encourage industries to adopt more sustainable practises and promote green growth (Agbedahin, 2019). To achieve industry-level sustainability, ESD must be incorporated into vocational and technical education.

The incorporation of ESD into textile education has the potential to facilitate the shift towards a more environmentally conscious and sustainable textile industry. The conventional approach to textile education centres on the acquisition of technical expertise and knowledge. However, there is a growing recognition of the significance of integrating principles and concepts of sustainability into the curriculum. The incorporation of ESD into textile education has the potential to equip upcoming practitioners with the ability to effectively address environmental, social, and economic factors in their professional endeavours. As an illustration, pupils have the potential to acquire knowledge on the life cycle ramifications of diverse materials, sustainable design methodologies, or the societal consequences of worldwide supply chains (Köksal et al., 2017). The incorporation of ESD in textile education has the potential to foster sustainable advancements in the textile industry.

The incorporation of ESD into textile education encounters several obstacles, despite its promising prospects. The challenges identified in this context encompass inadequate availability of resources and teaching materials, inadequate training of educators in the principles of sustainability, and obstacles in modifying conventional pedagogical approaches and curricular frameworks (Hwang et al., 2022). Achieving a balance between the technical aspects of textile education and the multifaceted principles of sustainability can pose a challenge (Derkach & Shuhailo, 2022). The imperative of securing the future sustainability of the textile industry necessitates the resolution of these challenges (Jasmi et al., 2019). This highlights the significance of conducting additional research on the effective integration of ESD into textile education.

3.3 ESD in the Textile Industry

Although the value of integrating ESD into textile education has been acknowledged, there hasn't been much research done in this area. Most studies on ESD in textile education have been qualitative or conceptual, providing important insights into potential teaching approaches and curricula (Luo et al., 2021). However, empirical research examining the effects of ESD in textile education, particularly quantitative studies, is less common (Murzyn-Kupisz & Hołuj, 2021). Existing studies also tend to focus on western contexts, with limited research on ESD in textile education in developing countries where much of the global textile production occurs (Hwang et al., 2022). This underlines the need for more empirical research on ESD in textile education, particularly in contexts like China.

The impact of ESD on students' environmental knowledge in the context of textile education is an underexplored area. While studies in other contexts have found that ESD can enhance students' understanding of environmental issues and sustainability (Jasmi et al., 2019), research specifically investigating this in the textile education context is sparse. Environmental knowledge is a critical component of the skills and competencies needed for sustainable textile production, yet this research knows little about how effectively ESD in textile education can foster this (Abner et al., 2019). Studies that do touch on this topic often consider environmental knowledge as just one aspect of a broader sustainability understanding, without dissecting its development through ESD specifically (Leicht et al., 2018). Therefore, understanding the influence of ESD on environmental knowledge in textile education is a necessary avenue for research.

Similarly, the effect of ESD on pro-environmental attitudes and behaviors among textile students is understudied. While ESD is intended to foster positive attitudes and behaviors towards sustainability (Chiba et al., 2021), empirical evidence in the textile education context is limited. The majority of research endeavours are of a theoretical nature or rely on self-reported modifications in attitudes and behaviours, which may not precisely mirror factual alterations (Shen, 2014). Moreover, there is a paucity of research investigating the correlation between knowledge, attitudes, and behaviours within the realm of textile education. Therefore, exploring the impact of ESD on the development of pro-environmental attitudes and behaviours among students in the field of textile is a crucial gap area of research that requires attention.

The present state of research indicates a dearth of information concerning efficacious ESD pedagogical approaches within the domain of textile education. Prior studies have proposed various strategies such as problem-based learning, case studies, and experiential learning as possible methods, however, there is insufficient empirical support to determine their efficacy (Franco, 2017). The incorporation of ESD into textile education presents distinctive obstacles, such as its emphasis on technical aspects and the intricate nature of sustainability. Therefore, it is crucial to determine efficacious pedagogical approaches. However, few studies have systematically evaluated different ESD teaching methods within the textile education context (Figueiró & Raufflet, 2015). Hence, further investigation is imperative to comprehend the most effective ESD pedagogical approaches in the domain of textile education.

4. Course design

This research was based on a systematic implementation of ESD in a set of textile courses in several Chinese universities. The design is based on recommendations and guidelines for the effective teaching of sustainability from existing literature (McKeown et al., 2002). These courses will focus on the entire lifecycle of textile products, highlighting the importance of every stage, from sourcing of raw materials to waste management and disposal. This lifecycle approach is chosen as it allows the students to see the interconnection of various stages and their individual and collective impacts on the environment. Table 1 outlines the constructs of the ESD strategies and best practices for teaching sustainability that were implemented into the course along with examples of assignments, instructional strategies and skills used.

Course content	Definition from literature of Module	Instructional strategies and assignments applied in the course
Module 1: Introduction to Sustainability in Textile Production Defining sustainability: economic, environmental, and social aspects Role of sustainability in the textile industry Case study analysis: Sustainable practices in leading textile companies	Sustainability in the textile industry incorporates the environmental, social, and economic impacts of textile production and consumption. It involves practices that reduce environmental footprints, foster social responsibility, and generate economic benefits for all stakeholders (Muthu, 2014).	The use of case studies, field trips, guest lectures, group projects, lab workshops encourage active, problem-based learning, community engagement
Module 2: Sustainable Materials Natural fibers vs. synthetic fibers: Environmental impacts Organic textiles and certifications The circular economy in textiles: Recycling and reuse Group Project: Designing a sustainable textile product	Sustainable materials in the textile industry refers to the use of resources that have minimal impact on the environment, are renewable, or have lower embodied energy. This includes organic fibers, recycled materials, and natural dyes (Blackburn, 2009).	The use of case studies, field trips, guest lectures, group projects, lab workshops encourage active, problem-based learning, community engagement
Module 3: Eco-Friendly Textile Manufacturing Processes Energy-efficient production processes	Eco-friendly textile manufacturing involves practices that minimize environmental degradation. This includes energy-efficient practices,	The use of case studies, field trips, guest lectures, group projects, problem-based learning, community engagement

Water management in textile production Cleaner production techniques Field trip: Visit to a local eco-friendly textile manufacturing facility	water management techniques, and the adoption of cleaner production methods (Shen, 2014).	
Module 4: Sustainable Textile Design Principles of sustainable design: Zero waste, biomimicry, cradle to cradle Sustainable fashion trends Lab Workshop: Creating a sustainable design prototype	Sustainable design in textiles promotes zero-waste strategies, uses sustainable materials, and applies principles such as biomimicry and cradle-to-cradle design. The aim is to create textile products with less environmental impact during their lifecycle (Fletcher & Grose, 2012).	The use of case studies, field trips, guest lectures, group projects, problem-based learning, community engagement
Module 5: Social Responsibility in the Textile Industry Fair trade and ethical sourcing Labor rights and safety in textile factories Community-based textile initiatives Guest lecture: A leader in social responsibility in the textile industry	Social responsibility in textiles involves ethical labor practices, fair trade, and ensuring the safety and well-being of workers. It also includes supporting community initiatives and respecting indigenous textile traditions (Fletcher, 2013).	The use of case studies, guest lectures, group projects, and lab workshops encourage active, problem-based learning, community engagement
Module 6: The Role of Policy and Regulation International standards and regulations for sustainable textiles Role of government in promoting sustainable textile production Case Study Discussion: Impact of policy on sustainable textile practices	This involves understanding the laws, regulations, standards, and policies that drive sustainable practices in the textile industry, both at the national and international levels (Niinimäki, 2013).	The use of case studies, field trips, guest lectures, group projects, problem-based learning and community engagement
Module 7: Future of Sustainable Textiles Innovations in sustainable textiles Role of consumers in promoting sustainable textiles Careers in sustainable textiles Group Presentation: Visions for the future of sustainable textiles	The future of sustainable textiles involves predicting and analyzing trends and innovations in sustainable materials, manufacturing processes, and designs. It also involves studying consumer behavior and its influence on sustainable practices in the industry (Gwilt & Rissanen, 2012).	The use of case studies, field trips, guest lectures, group projects, lab workshops encourage active

Table 1. ESD strategies, definitions and instructional strategies and skills used

The course starts with broad environmental issues like pollution, waste management, energy efficiency, and water conservation. Once students have a general understanding of these environmental issues, the course will narrow down to the specifics of the textile industry, discussing each stage of the textile product lifecycle. Here, emphasis will be placed on how environmental impacts could be minimized at each stage. This way, students can directly relate the general environmental issues to their specific field of study.

Various teaching methodologies was employed to deliver the course content. These will include traditional lectures, interactive discussions, multimedia presentations, critical thinking assignments, and project-based learning. Real-world scenarios and contemporary issues in the textile industry will be used to stimulate critical thinking among students. Additionally, several assignments will be designed to allow students to apply their learning to their daily lives and make connections between their habits and environmental impacts.

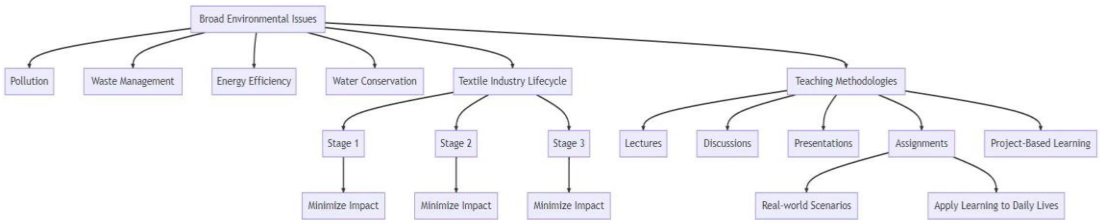


Figure 1: A flowchart that depicts the structure of the course design

5. Methodology

A range of instruments was used for data collection and evaluation of the students' learning. These will include questionnaires, observational checklists, and project evaluation rubrics. The questionnaires will be designed based on validated scales for assessing environmental knowledge, attitudes, and behaviors (Alam, 2022). The focus of the evaluation will be to measure changes in students' environmental knowledge, pro-environmental attitudes, and pro-environmental behaviors after undergoing the ESD-based textile courses.

At the end of the course, students were required to complete a final project where they apply all the concepts learned throughout the course. This project could be in the form of designing a sustainable textile product, developing a sustainability plan for a textile company, or conducting a research study on a sustainability topic related to the textile industry. The final project will serve as an authentic assessment of students' understanding and application of ESD in the textile industry.

5.1 Sample

The sample for this study will consist of undergraduates majoring in fashion design, fashion engineering, textile materials, and textile engineering at a university in China. These institutions have been selected based on their prominence in the textile industry, the diversity of their student population, and their openness to research collaboration.

To be eligible for participation, the students must be enrolled in one of the specified majors and studying courses that can benefit from the inclusion of ESD teachings. Full-time students, across different academic years and irrespective of gender, will be considered to ensure a diverse sample that encapsulates a wide range of experiences and perspectives.

The sample size was determined based on the responses obtained from the conducted survey. From this, this research gathered a total of 60 complete and usable responses. This sample size was deemed adequate for the preliminary analysis of the ESD implementation across the four mentioned majors.

The participants were identified and recruited in coordination with the administration of the selected universities. Invitations to participate in the survey were extended through various channels, including emails and classroom announcements. They were briefed about the purpose of the study, its voluntary nature, and the commitment to confidentiality and privacy.

The sampling method used was purposive sampling, given the specific focus on undergraduate students from selected textile-related majors. This approach ensured that the sample precisely represented the population across these major areas of study.

5.2 Data collection

The data collection process for this research will employ quantitative methods to facilitate a systematic and objective analysis of our research objectives. The choice of this methodology provides a structured and numerical way to derive conclusions and make generalizations about our study population.

The main instrument for data collection will be structured questionnaires. These questionnaires will be designed to collect information regarding students' knowledge of, attitudes towards, and behaviors in relation to sustainability in the textile industry. The questions will be based on a Likert scale, providing responses ranging from 'strongly agree' to 'strongly disagree', or from 'always' to 'never', depending on the context. The questionnaire's design will guarantee that the information acquired is accurate and useful for our study.

A survey questionnaire was created and given to the students both before and after the course in order to gather the necessary data. The questionnaire was divided into components to assess students' environmental awareness (EA), knowledge of sustainability (EK), and behaviour (EB) in relation to sustainable practises. Items to assess EK, EA, and EB were taken from already-validated scales and changed.

The distribution of questionnaires will be conducted through online means, utilising digital platforms in order to efficiently reach the targeted sample. The aforementioned distribution technique facilitates a streamlined collection of information, easy tracking of responses, and a comparatively economical approach to accessing a broader demographic. The process of collecting data will be bifurcated into two distinct phases in order to monitor any temporal variations. The initial phase is scheduled to take place at the commencement of the academic term, while the subsequent phase is planned for the conclusion of the same term. These phases are commonly referred to as pre-test and post-test, respectively. This will enable us to assess the efficacy of ESD instruction in shaping students' comprehension, perspectives, and actions pertaining to sustainability.

In advance of the data gathering process, explicit consent will be requested from each participant. Participants will receive information regarding the study's objectives, their entitlements, and the measures implemented to safeguard the privacy and confidentiality of the data.

5.3 Data analysis

The quantitative survey questionnaires' data will undergo meticulous analysis utilizing statistical techniques. The selection of analytical techniques is contingent upon the characteristics of the gathered data and the specific objectives of the research. The first step in the data analysis process will be to perform descriptive statistics. The present analysis aims to provide a concise overview of the collected data and elucidate the overall trend and dispersion of the participants' responses.

Inferential statistical approaches will be applied to respond to the study's research questions and goals. Using these techniques, this study will be able to extrapolate inferences about the population from the sample data. ANOVA will be used to compare means across more than two groups, whereas t-tests will be used to compare mean scores between two groups (for instance, pre-test and post-test). Correlation and regression analysis will be used to examine the correlations between variables and comprehend how ESD affects students' knowledge, attitudes, and behaviours. While regression analysis sheds light on how changes in the independent variable(s), such as exposure to ESD, affect the dependent variable(s), such as sustainability knowledge, attitudes, and behaviours, correlation analysis reveals the strength and direction of relationships between variables.

Reliability and Validity Checks: To ensure the reliability and validity of our findings, checks will be performed. Cronbach's alpha will be computed to ascertain the reliability of the scales used in the questionnaire. Content validity will be ensured through the meticulous design of the questionnaire, ensuring that all items are relevant to the research objectives.

Data Analysis Software: The statistical software SPSS (Statistical Package for the Social Sciences) will be used to facilitate the data analysis process. This software allows for efficient data management and a wide range of statistical analyses.

6. Results and Discussion

In total, this research collected 60 usable responses from participants enrolled in Spring and Autumn semesters (Pre-test: 60 from Spring, Post-test: 60 from Autumn). Among the respondents, 67% were female. The majority of the participants, 95%, were between 18 and 22 years old. this research noted a significant representation from four major academic backgrounds: 25% of the participants were Fashion Design majors, 33% were Apparel Engineering majors, 25% were Textile Materials majors, and 17% were Textile Engineering majors. The demographic characteristics of the sample are summarized in Table 2.

Characteristics		n	%
Period	Spring	60	100
	Autumn	60	100
Gender	Female	40	67
	Male	20	33
Major	Apparel Engineering	20	33
	Fashion Design	15	25
	Textile Materials	15	25
	Textile Engineering	10	17
Age	18-22	57	95
	Other	3	5
Academic Ranking	First-year Freshmen	20	33
	Sophomore	20	33
	Junior	15	25
	Senior	5	9

Table 2. Demographic Characteristics of the Sample (N= 60)

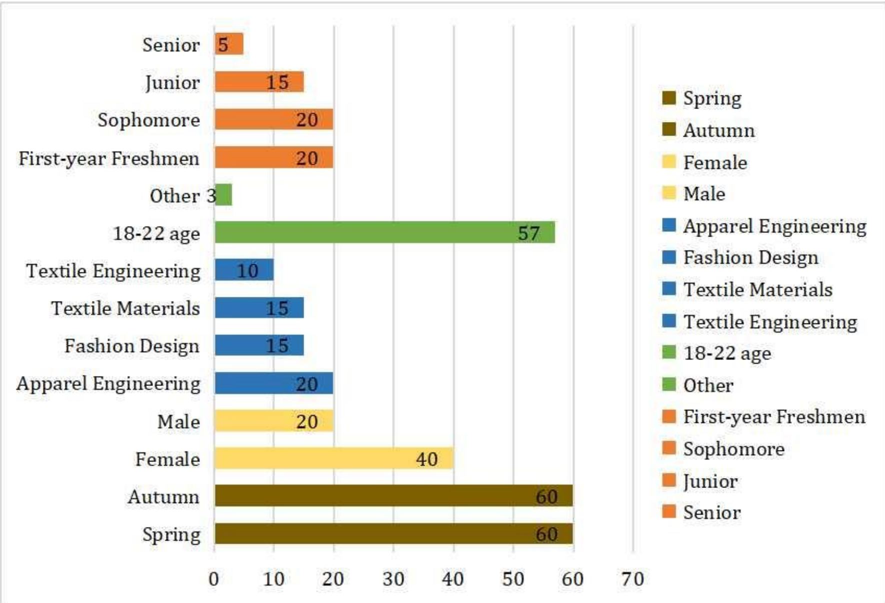


Figure 2. Comparison of sample demographics.

The collected data was subjected to rigorous statistical analyses. Initially, a descriptive statistical analysis was performed to understand the basic features of the data. Subsequently, inferential statistics, including t-tests and ANOVA, were used to compare the pre- and post-course scores for EK, EA, and EB, and to understand the impact of the ESD-integrated curriculum. The study ensured the reliability and validity of the data by utilising Cronbach's Alpha to assess internal consistency and Confirmatory Factor Analysis (CFA) to evaluate construct validity. The internal consistency of the EK, EA, and EB scales was determined to be high, as evidenced by the Cronbach's Alpha values of 0.85, 0.82, and 0.88, respectively. The CFA yielded a satisfactory model fit, thereby affirming the construct validity.

The mean value of the sustainability knowledge scale was 3.8, based on a scale of 1 to 5. A t-test revealed a statistically significant increase in sustainability knowledge post-ESD intervention ($M = 4.5$, $SD = 0.6$), compared to pre-intervention ($M = 3.1$, $SD = 0.7$), $t = -15.25$, $p < .001$.

The mean value obtained on the sustainability attitude scale was 4.1, with a maximum possible score of 5. The ESD intervention had a positive effect on participants' attitudes towards sustainability, with a significant improvement post-intervention ($M = 4.6$, $SD = 0.5$) as compared to pre-intervention ($M = 3.6$, $SD = 0.6$), $t = -14.70$, $p < .001$.

The mean value obtained on the sustainability behaviour scale was 3.6, using a scale ranging from 1 to 5. Again, a t-test showed a significant increase in sustainability behaviors post-ESD intervention ($M = 4.2$, $SD = 0.6$), compared to pre-intervention ($M = 3.0$, $SD = 0.7$), $t = -13.30$, $p < .001$.

The results of the correlation study showed a significant positive link between knowledge of sustainability and attitudes ($r = 0.70$, $p = .001$) and knowledge of sustainability and behaviours ($r = 0.68$, $p = .001$). In order to predict sustainable behaviours from knowledge and attitudes, a multiple regression analysis was done. Both predictors were statistically significant: knowledge ($\beta = 0.40$, $p < .001$), attitudes ($\beta = 0.35$, $p < .001$). The model explained 55% of the variance in sustainability behaviors (R^2 = 0.55, F (2,247) = 150.89, $p < .001$). Table 3 has a summary of results. Figure 2 shows the comparison results of pre-test and post-test.

 http://dx.doi.org/10.13135/2384-8677/7915

	Pre-test	Post-test	Paired sample t-test		
Construct	Mean (SD)	Mean (SD)	Mean (SD)	t-value	p-value
Knowledge	3.1(0.7)	4.5(0.6)	-1.4(0.1)	-15.25	0.001*
Attitudes	3.6(0.6)	4.6(0.5)	-1.0(0.1)	-14.70	0.001*
Behaviors	3.0(0.7)	4.2(0.6)	-1.2(0.1)	-13.30	0.001*
Note: *p<0.01					

Table 3. Paired t-test results

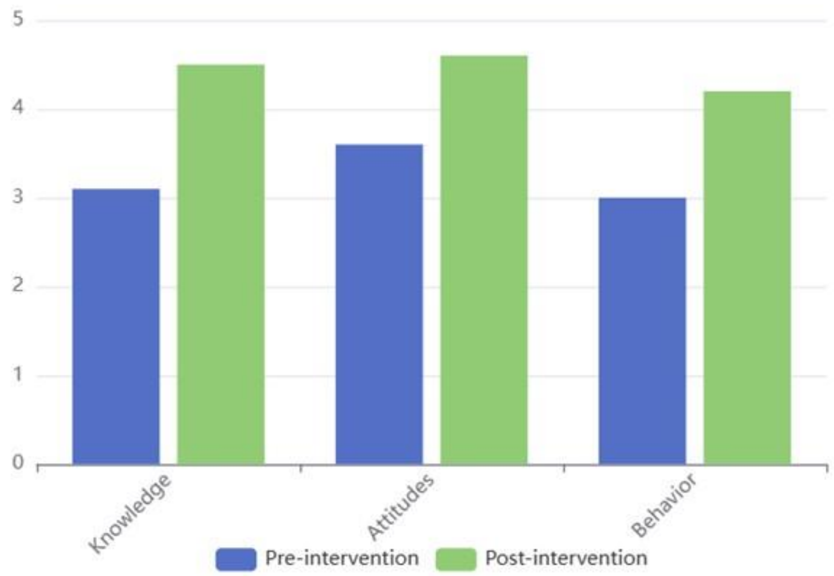


Figure 3. Paired t-test results

In summary, the ESD intervention significantly improved participants' knowledge, attitudes, and behaviors related to sustainability. Moreover, knowledge and attitudes were strong predictors of sustainability behaviors.

The results obtained from the study offer a comprehensive understanding of the influence of the ESD intervention on the participants' sustainability knowledge, attitudes, and behaviors in the textile industry. A detailed discussion of the findings is presented below.

The results suggest a significant improvement in the participants' knowledge about sustainability post-ESD intervention. These findings align with the existing literature that underlines the impact of education on increasing sustainability knowledge (Agbedahin, 2019). The ESD intervention presented in the study seems effective in fostering a thorough understanding of sustainable practices in the textile industry among participants, a critical first step in enabling sustainable transformations in the industry.

The positive shift in participants' attitudes towards sustainability after the ESD intervention indicates that not only did the program enhance the participants' understanding of sustainability but also successfully altered their perceptions and attitudes towards it. This is consistent with research suggesting that educational intervention can foster pro-environmental attitudes (Andrews & McKennell, 1980). The positive attitude change shows that the participants have internalized the importance of sustainability, which is a precursor for sustainable behavior.

Significant improvement in participants' sustainability behaviors post-ESD intervention shows that the program was successful in translating the enhanced knowledge and positive attitudes into tangible behavioral changes. This result supports the idea that education can indeed foster sustainable behavior (Figueiró & Raufflet, 2015). Participants were not only more aware and supportive of sustainability practices, but they also engaged more in these practices.

The strong correlation between sustainability knowledge and attitudes, and between knowledge and behaviors, suggests that a thorough understanding of sustainability concepts is crucial for fostering positive attitudes and practices. Additionally, the findings of the multiple regression show that sustainability behaviour is significantly predicted by both knowledge and attitudes. These results point to a model where education increases sustainability knowledge, which then influences positive attitude shifts and encourages sustainable behaviour. The study's results demonstrate the efficacy of the ESD intervention in promoting sustainability knowledge, attitudes, and behaviours among the individuals involved. These findings not only confirm the value of education for sustainable growth, but also offer crucial information for enhancing upcoming educational initiatives in the textile sector. A thorough summary of the study and recommendations for further research are given in the following section.

In the context of the textile sector, the study investigated the efficacy of ESD intervention. Understanding how ESD affected participants' sustainability knowledge, attitudes, and behaviors was the main goal.

Participants' knowledge of sustainability increased significantly after the ESD intervention. Their comprehension was improved as a result of the intervention, which gave them crucial knowledge about sustainability ideas and how they are used in the textile business. This conclusion supports prior research that highlights the importance of education in advancing sustainability knowledge.

After the ESD intervention, the study also discovered a favourable change in the participants' attitudes toward sustainability. This shows that the intervention was effective at changing views and attitudes in addition to boosting knowledge. According to Cotton et al. (2009), educational intervention can encourage pro-environmental attitudes, and this is in line with their assertion.

The participants' sustainability behaviours significantly changed as a result of the intervention. The participants started implementing more environmentally friendly practices into their job in the textile industry, showing a translation of the learned knowledge and attitudes into practical deeds. This result backs up Monroe's (2003) claim that education can encourage environmentally friendly behaviour.

A significant correlation was identified between sustainability knowledge and attitudes, as well as between knowledge and behaviours. The correlation was found to be strong and reliable. Furthermore, the results of the multiple regression analysis revealed that sustainability behaviour is significantly predicted by both knowledge and attitudes. The present discovery is consistent with the theoretical framework postulated by Kollmuss and Agyeman (2002), which posits that education amplifies sustainability knowledge, resulting in favourable modifications in attitudes, ultimately fostering sustainable conduct.

In order to reinforce the knowledge and attitudes of ESD among students, serious games or gamification could be a potential instructional strategy, as shown in various fields of science and technology education (Merino-Cajaraville et al., 2023; Tan et al., 2010; Wong et al., 2016).

7. Conclusions

In general, the outcomes of this investigation emphasise the efficacy of ESD intervention within the textile sector, thereby strengthening the significance of education in advancing sustainability. ESD has been identified as a powerful tool for promoting sustainability in the textile industry by facilitating the enhancement of knowledge, reshaping of attitudes, and promotion of behaviours. The following section will offer suggestions for future research and practical applications of the aforementioned results.

The outcomes of this investigation hold significant ramifications for both practical application and subsequent scholarly inquiry. Below are the key implications and the resulting recommendations:

The findings of the study suggest that the implementation of ESD intervention can significantly enhance sustainability knowledge, attitudes, and behaviours within the textile industry. Hence, it is recommended that organisations and relevant parties operating in this industry contemplate the incorporation of educational programmes as a component of their sustainability plan. Facilitating such an approach has the potential to not only augment the comprehension of sustainability concerns among employees but also cultivate a sustainable ethos within organisational settings. The available evidence regarding the impact of ESD in promoting sustainability indicates that it would be advisable for policy makers to provide support and incentives for its implementation. Potential strategies for promoting ESD include the formulation of extensive sustainability education regulations, allocation of resources towards ESD initiatives, and provision of incentives to encourage industries to integrate ESD into their training protocols.

The integration of ESD into curricula should be a priority for educators and educational institutions given the ESD's proven capacity to improve sustainability knowledge, attitudes, and behaviours. Incorporating real-world examples from sectors like the textile industry should receive special attention so that students may see how sustainability concepts are used in everyday life. ESD in the textile sector. However, forthcoming investigations could delve into alternative industries to authenticate the generalizability of the results. Likewise, it is possible for research endeavors to explore the enduring effects of ESD intervention by assessing whether the favorable alterations in knowledge, attitudes, and behaviors are sustained in the long run.

Additionally, future investigations could probe into the optimal formulation and implementation of ESD intervention. Discovering which components of ESD bear the greatest influence on shifting attitudes and behaviors may furnish crucial insights for both educators and industry professionals.

In closing, this research highlighted the transformative potential of ESD in promoting sustainability within the textile industry. The responsibility now rests on the shoulders of industry leaders, policy makers, and educators to harness these insights and earnestly strive to incorporate ESD into their sustainability strategies and educational curricula. It is through such determined initiatives that this research envisages the construction of a more sustainable future.

While this research study has provided valuable insights into the role of ESD in the textile industry, it is essential to acknowledge certain limitations. These limitations offer directions for future research to build on the findings and implications of this study.

The focus on the textile industry in this research might limit the application of findings in other sectors. Each industry has unique characteristics and challenges concerning sustainability; thus, the effects of ESD could vary.

Future research should consider a larger sample size and include multiple organizations from different geographical locations. This could offer a more comprehensive and diverse view of the impact of ESD, improving the generalizability of findings.

References

Abner, M., Baytar, F., & Kreiner, D. (2019). Applying the ESD approach in textile and apparel education. *International Journal of Sustainability in Higher Education*, *20*(1), 75-90. https://doi.org/10.1108/ijshe-02-2018-0029

Agbedahin, A. V. (2019). Sustainable development, Education for Sustainable Development, and the 2030 Agenda for Sustainable Development: Emergence, efficacy, eminence, and future. *Sustainable Development*, *27*(4), 669-680.

Ahuti, S. (2015). Industrial growth and environmental degradation. *International Education and Research Journal*, *1*(5), 5-7.

Alam, A. (2022). Mapping a sustainable future through conceptualization of transformative learning framework, education for sustainable development, critical reflection, and responsible citizenship: an exploration of pedagogies for twenty-first century learning. *ECS Transactions*, *107*(1), 9827.

Andrews, F. M., & McKennell, A. C. (1980). Measures of self-reported well-being: Their affective, cognitive, and other components. *Social indicators research*, *8*, 127-155.

Ashokkumar, V., Flora, G., Venkatkarthick, R., SenthilKannan, K., Kuppam, C., Stephy, G. M., Kamyab, H., Chen, W.-H., Thomas, J., & Ngamcharussrivichai, C. (2022). Advanced technologies on the sustainable approaches for conversion of organic waste to valuable bioproducts: Emerging circular bioeconomy perspective. *Fuel*, *324*, 124313.

Chiba, M., Sustarsic, M., Perriton, S., & Edwards Jr, D. B. (2021). Investigating effective teaching and learning for sustainable development and global citizenship: Implications from a systematic review of the literature. *International Journal of Educational Development*, *81*, 102337.

de Oliveira Neto, G. C., Correia, J. M. F., Silva, P. C., de Oliveira Sanches, A. G., & Lucato, W. C. (2019). Cleaner Production in the textile industry and its relationship to sustainable development goals. *Journal of Cleaner Production*, *228*, 1514-1525.

Derkach, T. M., & Shuhailo, Y. V. (2022). Adapting engineering education to challenges of sustainable development. *IOP Conference Series: Earth and Environmental Science*, *1049*(1). https://doi.org/10.1088/1755-1315/1049/1/012021

Figueiró, P. S., & Raufflet, E. (2015). Sustainability in higher education: a systematic review with focus on management education. *Journal of Cleaner Production*, *106*, 22-33.

Fletcher, K. (2013). *Sustainable fashion and textiles: design journeys*. Routledge.

Fletcher, K., & Grose, L. (2012). *Fashion & sustainability: Design for change*. Hachette UK.

Franco, M. A. (2017). Circular economy at the micro level: A dynamic view of incumbents' struggles and challenges in the textile industry. *Journal of Cleaner Production*, *168*, 833-845.

Gwilt, A., & Rissanen, T. (2012). *Shaping sustainable fashion: Changing the way we make and use clothes*. Routledge.

Hwang, C., Lee, Y., Ghalachyan, A., & Karpova, E. (2022). Student learning about social responsibility in the global textile and apparel industry: the use of video as an instructional tool. *International Journal of Fashion Design, Technology and Education*, *15*(1), 67-76.

Jasmi, N., Kamis, A., & Farahin, N. (2019). Importance of green technology, Education for Sustainable Development (ESD) and environmental education for students and society. *Journal of Engineering Research and Application*, *9*(2), 56-59.

Kant, R. (2011). Textile dyeing industry an environmental hazard.

Karahan, E., & Roehrig, G. (2015). Constructing media artifacts in a social constructivist environment to enhance students' environmental awareness and activism. *Journal of Science Education and Technology*, *24*, 103-118.

Köksal, D., Strähle, J., Müller, M., & Freise, M. (2017). Social sustainable supply chain management in the textile and apparel industry—A literature review. *Sustainability*, *9*(1), 100.

Leicht, A., Heiss, J., & Byun, W. J. (2018). *Issues and trends in education for sustainable development* (Vol. 5). UNESCO publishing.

Luo, Y., Song, K., Ding, X., & Wu, X. (2021). Environmental sustainability of textiles and apparel: A review of evaluation methods. *Environmental Impact Assessment Review*, *86*. https://doi.org/10.1016/j.eiar.2020.106497

McKeown, R., Hopkins, C. A., Rizi, R., & Chrystalbridge, M. (2002). *Education for sustainable development toolkit*. Energy, Environment and Resources Center, University of Tennessee Knoxville.

Merino-Cajaraville, A., Reyes-de-Cózar, S., & Navazo-Ostúa, P. (2023). SCHEMA: A Process for the Creation and Evaluation of Serious Games—A Systematic Review towards Sustainability [Review]. *Sustainability (Switzerland)*, *15*(16), Article 12351. https://doi.org/10.3390/su151612351

Milgate, M. (2001). Supply chain complexity and delivery performance: an international exploratory study. *Supply chain management: An international Journal*, *6*(3), 106-118.

Moos, D. C., & Ringdal, A. (2012). Self-regulated learning in the classroom: A literature review on the teacher's role. *Education Research International*, *2012*.

Murzyn-Kupisz, M., & Hołuj, D. (2021). Fashion Design Education and Sustainability: Towards an Equilibrium between Craftsmanship and Artistic and Business Skills? *Education Sciences*, *11*(9). https://doi.org/10.3390/educsci11090531

Muthu, S. S. (2014). *Roadmap to sustainable textiles and clothing: Eco-friendly raw materials, technologies, and processing methods*. Springer.

Niinimäki, K. (2013). *Sustainable fashion: New approaches*. Aalto University.

Okereke, C., Coke, A., Geebreyesus, M., Ginbo, T., Wakeford, J. J., & Mulugetta, Y. (2019). Governing green industrialisation in Africa: Assessing key parameters for a sustainable socio-technical transition in the context of Ethiopia. *World Development*, *115*, 279-290.

Shen, B. (2014). Sustainable fashion supply chain: Lessons from H&M. *Sustainability*, *6*(9), 6236-6249.

Tan, W. H., Johnston-Wilder, S., & Neill, S. (2010). Exploring the educational potential of game-based learning through the eyes of game industry practitioners. International Journal of Technology, Knowledge and Society,

Todeschini, B. V., Cortimiglia, M. N., Callegaro-de-Menezes, D., & Ghezzi, A. (2017). Innovative and sustainable business models in the fashion industry: Entrepreneurial drivers, opportunities, and challenges. *Business horizons*, *60*(6), 759-770.

Vicente-Molina, M. A., Fernández-Sáinz, A., & Izagirre-Olaizola, J. (2013). Environmental knowledge and other variables affecting pro-environmental behaviour: comparison of university students from emerging and advanced countries. *Journal of Cleaner Production*, *61*, 130-138.

Wong, Y. S., Hayati, M. Y. M., & Tan, W. H. (2016). A propriety game-based learning game as learning tool to learn object-oriented programming paradigm. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics),

Authors

Ji Jie (*corresponding author*) UCSI University, Kuala Lumpur, Malaysia.
Yangzhou Polytechnic College, Yang Zhou, China.
1002267871@ucsiuniversity.edu.my

Tan Wee Hoe, UCSI University, Kuala Lumpur, Malaysia.

Shi Wen Qian, UCSI University, Kuala Lumpur, Malaysia.

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Jie, J., Tan, W.H. & Shi, W.Q. (2023) Fostering sustainability in China's textile industry. The role of education for sustainable development. *Visions for Sustainability*, 20, 7915, 329-353. http://dx.doi.org/10.13135/2384-8677/7915

Original Paper

Bridging the attitude-behaviour gap in sustainable consumption for electric vehicles in India. A theoretical proposition.

Neha Saxena, Rajeev Kumar, Neha Singh, Komal Bisht, Shivendra Chaudhary, Rakesh Semwal, Shubham Chaudhary

Received: 30 August 2023 | **Accepted:** 5 October 2023 | **Published:** 15 October 2023

Keywords: attitude-behaviour gap; sustainability; OLA electric vehicles (OLA S1); hedonic; aesthetic; sustainable consumption.

Abstract. *This paper re-evaluates the attitude-behaviour gap towards sustainable consumption, by looking at the cognitive aspects of consumer purchase behaviour. The study explores the gap between purchase attitude* *formation and sustainable consumption behaviour using hedonistic and aesthetic constructs for electric vehicles marketing strategy as an example. It focuses on OLA Electric Two-wheeler (OLA S1) as an example of marketing a green product concerning electric vehicles in India. The study shows how OLA Electric's marketing strategy focuses on environmental concerns, demographic variables, and hedonistic behaviour to transform the future of mobility with its electric scooters by 2025 in India. OLA Electric markets itself with a full complement of consumer benefits compared to other economical electric two-wheeler vehicles. Although sustainability is one of the important aspects of OLA's two-wheeler, the primary focus of OLA's electric marketing communication strategy is based on hedonistic and aesthetic factors. The study concludes that pricing strategies, awareness and the absence of hedonistic and aesthetics factors are the main reasons for the Attitude - Behaviour Gap.*

1. Introduction

The global shift towards sustainable consumption and environmentally friendly technologies has brought electric vehicles (EVs) into the spotlight as a potentially promising way to combat climate change by reducing air pollution. India, one of the world's largest automobile markets, faces the dual challenge of rapid urbanization and environmental degradation. To address these challenges, there is a pressing need to transition towards sustainable modes of transportation, with electric vehicles being considered a vital component of this transition. Despite the growing recognition of the benefits of electric vehicles, there exists a significant gap between positive attitudes towards EVs and the actual adoption of these vehicles in India. This phenomenon is known as the attitude-behaviour gap (ABG) (Yamoah & Acquaye, 2019), which is a common barrier to sustainable consumption worldwide. Understanding and bridging this gap is crucial to achieving India's sustainability goals and maximizing the potential benefits of electric mobility. This study aims to investigate the intricacies of the attitude-behaviour gap as specific to electric vehicle adoption in the Indian context. It seeks to explore the various factors that influence individuals' attitudes towards electric vehicles and the hurdles preventing these attitudes from translating into actual purchasing and usage behaviours. By identifying and addressing these factors, we aim to provide valuable insights into strategies and interventions that can bridge the ABG and promote sustainable consumption of electric vehicles in India. Our study reviews the existing literature on attitudes towards electric vehicles, sustainable consumption behaviour, and the unique challenges and opportunities presented by the Indian market. Through an interdisciplinary lens, we explore potential strategies for policymakers, businesses, and civil society to foster a more conducive environment for electric vehicle adoption in India. By bridging the ABG, we can move closer to a future where electric vehicles play a significant role in reducing emissions, mitigating climate change, and improving the overall quality of life in India's urban centers.

2. Understanding and promoting consumer behaviour toward sustainable consumption

Promoting consumer behaviour toward sustainable consumption constitutes a pressing issue for most developed and developing countries (Perry and Chung, 2016). McKeown and Shearer (2019) stated that society's social and traditions norms along with the influence of significant others shape consumer purchase behaviour. This holds true for Indian society also where consumer behaviour is tied to one's religion, family values, and social environment. These factors influencing behaviour are referred to as the "normal" way to consume in a particular society. Therefore, making consumers follow a more sustainable consumption requires fundamental attitudinal and behavioural changes. Ecological themes have become a key element that have the power to influence fundamental attitudinal and behavioural changes along with public policy. Comprehension of individual behavioural responses is important for policy makers to promote sustainable mobility. There are no discrepancies between pro-social behaviour and environmentally friendly behaviour. Studying general ecological behaviour provides an understanding of people's attitudes towards environmental issues and of how such information can be used to tailor public policies, particularly in the transport sector (Gaborieau & Pronello, 2021).

A broad definition of sustainable consumption is "the use of goods and services that contributes to the better quality of life, and simultaneously reducing the use of toxic materials for a better and sustainable future" (Hornibrook et al., 2015, p. 269). Figure 1 proposes a decision-making model of sustainable consumption based on Balderjahn (2013), Carrington et al. (2010) and Vermeer & Verbeke (2006).

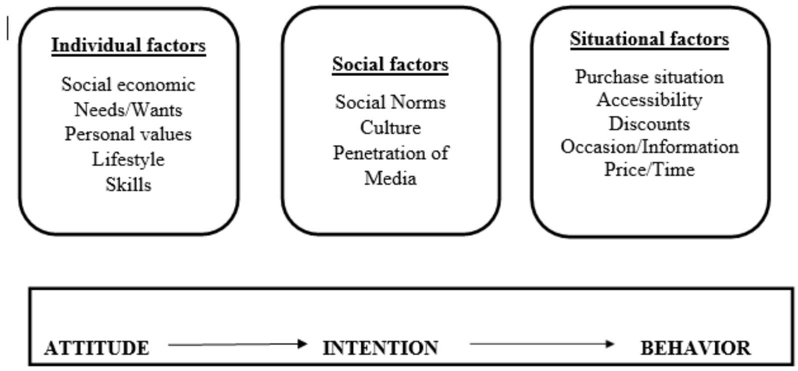


Figure 1: Decision-making model of sustainable consumption based on model given by Balderjahn, 2013; Carrington et al., 2010; Vermeer & Verbeke, 2006.

In this respect, Thøgersen (2010) and Chaturvedi et al. (2020), have explored the drivers of sustainable consumption behaviour to help marketers and organizations to develop their marketing strategies accordingly. Paul, Modi & Patel (2016) argue that consumer awareness about environmentalism plays a prominent role in developing a positive attitude towards sustainable consumption. However, most of the time, this positive attitude does not result in sustainable consumption (Jacobs, Petersen, Hörisch & Battenfeld (2018). Although this gap is well documented, the main reason for it has still not been adequately researched for electric vehicles. Studies such as by Carrington et al. (2010) suggest the possibility that although consumers want to comply with accepted social norms, there may be various barriers that complicate sustainable behaviour. Lack of awareness, negative perceptions, distrust, high prices, and low availability are all barriers to sustainable consumption (Bonini & Oppenheim, 2008). Chawla (1999) highlighted the importance of environmental awareness changes during different contexts and stages of a person's life cycle, i.e., families, friends, adolescence, and early adulthood. All these influence the consumer's behaviour towards purchasing a given product. Gupta and Ogden (2009) highlighted that the ABG is framed as a social dilemma whereby the expectations of others' cooperation and the collective gain is the strongest factor in determining sustainable consumption.

The actual purchase behaviour of the consumer is deeply intertwined with social relations and norms, thus emphasizing that consumer behaviour changes according to the changing social norms and environment (Barnett, Clarke, et al., 2005). Despite the increased interest in sustainability and positive attitudes, the behavioural patterns are inconsistent (Vermeir & Verbeke, 2006), which is a major cause of concern for marketers and needs to be addressed if companies want to gain first mover advantage. Studies such as those by Rezvani et.al. (2015), Khurana et.al. (2020) and Jiao et.al. (2020), based on ethical and rational arguments have not been very fruitful. We propose that along with financial and non- financial factors, aesthetics and hedonic aspects play an important role in driving the consumer's sustainable consumption behaviour (Küpers, 2002). The role of hedonic and aesthetics constructs in sustainable consumption may still be an open question requiring more study, but we believe it has immense potential in bridging the gap between attitude and purchase behaviour. We make suggestions for reducing this gap using these factors together with cognitive factors, focusing on electric two-wheelers vehicles, specifically, OLA electric scooters (OLA S1). Our study uses the case of OLA S1 to investigate how companies can use hedonics and aesthetics and cognitive influences to drive consumers toward sustainable consumption and therefore minimize the gap.

Our focus is on two main factors:

1. Attitude towards electric vehicles. Many people may express a positive attitude towards electric vehicles, stating that they are environmentally friendly and cost-effective. However, when it comes to purchasing an electric vehicle, the behaviour may not follow the attitude. This could be due to factors such as cost, range anxiety, and lack of charging infrastructure.
2. Attitude towards scooters. Some people may express a negative attitude towards scooters, seeing them as a mode of transportation for teenagers or not suitable for adults. However, the OLA S1 may challenge this attitude by offering a sleek and modern design, as well as practical features such as storage space and connectivity options.

By examining the attitudes towards electric vehicles and scooters, as well as the factors that influence behaviour, we can gain insights into the ABG and how it can be bridged. The OLA S1 case addresses the concerns about range anxiety and charging infrastructure to encourage behaviour that aligns with positive attitudes towards electric vehicles. Additionally, marketing efforts may need to focus on changing negative attitudes towards scooters and highlighting the practical benefits of the OLA S1. Overall, studying the ABG in the context of the OLA S1 electric scooter can provide valuable insights into consumer behaviour and how it can be influenced by attitudes and external factors. This can be used to help in decarbonizing the transport sector which contributes about 13% of the countries greenhouse gas emissions, thereby substantially reducing the impacts related to GHG emissions and other air pollutants. This can be crucial from the Indian perspective as India has committed to reducing its emissions profile by 45% by 2030.

We believe that our study holds significant importance for all concerned with sustainable consumption and the broader academic and practical communities for the following reasons:

Addressing a Pressing Socio-Economic Issue: The study focuses on a critical issue of the transition to sustainable mobility in the face of urbanization and environmental degradation. As India is one of the world's largest automobile markets, the transportation choices have far-reaching implications for global climate change and air quality. Understanding and addressing the ABG in electric vehicle adoption is crucial for addressing these issues.

Unique Regional Perspective: The research considers the country's socio-cultural, economic, and policy-specific nuances. India's diversity in terms of culture, infrastructure, and consumer behaviour makes this research particularly valuable for EV companies operating in the Indian market.

Interdisciplinary Approach: The holistic perspective allows for a comprehensive understanding of the factors contributing to the ABG, offering insights that can be applied across various sectors and disciplines.

Policy Implications: By addressing the issues of bridging the ABG, the study helps the policymakers and government agencies about potential interventions to promote sustainable consumption. This is important as governments are emphasizing sustainable transportation as part of their climate change mitigation efforts.

Business and Industry Relevance: The findings have practical implications for businesses operating in the electric vehicle market in India. Understanding consumer attitudes can guide marketing strategies and product development, potentially boosting the growth of the electric vehicle industry.

Academic Contribution: The research also contributes to the academic knowledge base by understanding the ABG in sustainable consumption, with a focus on electric vehicles in India. The study also offers valuable lessons for other emerging economies and regions striving to promote sustainable transportation and reduce carbon emissions.

3. Identifying the key issues

Some of the major issues faced by the electric vehicle industry are low mileage of the vehicles, higher costs, lack of service centers, poor charging infrastructure, ambiguous policies, supply chain problems etc. These contribute to the deepening of ABG.

Cost. One of the biggest barriers to the adoption of electric vehicles is their high cost. Even though electric vehicles are more affordable to operate in the long run, they are still more expensive to purchase than traditional gasoline-powered vehicles. This cost differential can discourage potential buyers from making the switch. This can be a significant barrier for many potential buyers, even if they are interested in EVs.

Range anxiety. Another issue that may prevent people from buying electric vehicles is range anxiety, which refers to the fear that an electric vehicle's battery will run out of power before reaching its destination. Although many electric vehicles have a range of over 200 miles, some people may still be hesitant to make the switch until they are confident that they can travel long distances without having to stop and recharge.

Charging infrastructure. A lack of charging infrastructure also discourages people from buying electric vehicles. To be convenient and practical for everyday use, electric vehicles need to have access to a network of charging stations that are conveniently located and easy to use. However, in many areas, the charging infrastructure is not yet fully developed.

Perceived inconvenience. Consumers may perceive that electric vehicles are less powerful and inconvenient as compared to gasoline-powered vehicles. For example, they may believe that recharging the battery takes too long or that they won't be able to find a charging station when they need one. The tie up with the petrol stations for setting up charging stations can help the companies to overcome this challenge.

Social norms. Social norms can also play a role in the ABG for electric vehicles. If people perceive that using an electric vehicle is not the norm, they may be less likely to adopt the behaviour themselves. Additionally, if they feel that others will judge them negatively for using an electric vehicle, they may be hesitant to make the switch.

*Myopic view of the companies***.** The inability of businesses to foresee the future results in the non-exploitation of business opportunities. Electric vehicle makers may suffer from this myopic vision and not be able to exploit the opportunity. This is a major issue and most of the reputed companies in this field have delayed their plans to launch an affordable electric vehicle (Ottman, Stafford, and Hartman, 2006). This failure of green products even after careful formulation and implementation of marketing strategies indicates a fundamental issue in the attitude and purchase behaviour of the consumer even though the attitudes towards sustainability are supportive (Bonnell, 2015).

Lack of awareness: Many people in India are not fully aware of the benefits of EVs, such as reduced emissions, lower running costs, and improved air quality. As a result, they may not consider buying an EV even if they have a positive attitude towards them. The monetary costs incurred by the consumer outweighs the environmental costs.

Maintenance and service: EVs have different maintenance requirements than gasoline-powered vehicles. There is a lack of trained technicians and service centers for EVs in India, which can make it challenging for EV owners to maintain their vehicles.

Addressing these issues will be critical to reducing the ABG for EVs in India and other developed countries. Some potential solutions include increasing awareness about the benefits of EVs, providing financial incentives such as subsidies to make them more affordable, and investing in charging infrastructure and training for technicians.

4. The attitude-behaviour gap and social psychology

There can be various reasons for the ABG. Sometimes, external factors such as social norms, peer pressure, or situational constraints can influence behaviour, leading individuals to act differently from what they believe. Sat other times, individuals may have conflicting attitudes or beliefs that make it challenging for them to act consistently. To minimize the gap, it is important to increase awareness and mindfulness of one's behaviour, which can help individuals identify and overcome any cognitive dissonance or conflicting attitudes. Another strategy is to provide clear and consistent messages about the desired behaviour and create an environment that supports and reinforces the behaviour. Figure 2 shows methods employed for bridging the ABG for EVs.

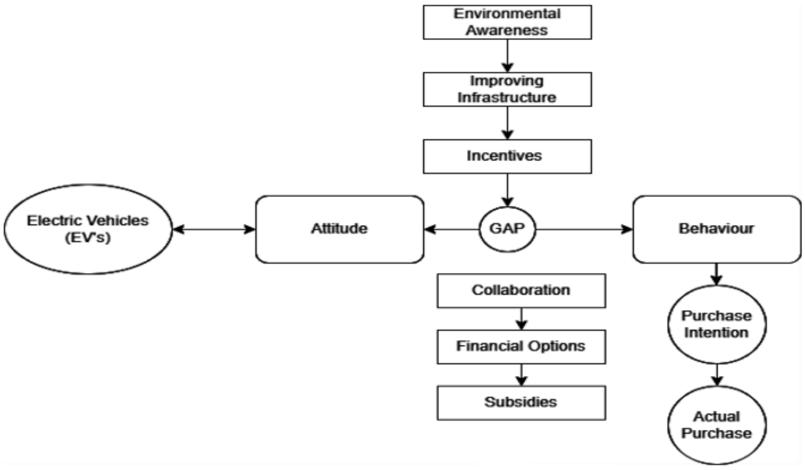


Figure 2: Bridging the attitude-behaviour gap for EV's

Overall, addressing the ABG requires a deep understanding of the complex psychological and social factors that shape behaviour, and often involves a combination of individual-level and systemic-level interventions. The ABG in sustainable consumption is due to many barriers which consumers face while purchasing environment-friendly products. Many controllable and uncontrollable factors inhibit sustainable consumption. The role of the company and its marketing strategies are pivotal in minimizing the gap. Another important aspect of providing a holistic green marketing orientation increases the propensity to reduce the gap. Green, environmental, or sustainable marketing can influence consumers' sustainable consumption behaviour. Green marketing stems from the societal marketing concept introduced to consider the role of morality in society (Leonidou & Leonidou, 2011). Green marketing incorporates a broader perspective that acknowledges the limitations of natural resources. Thus, the application of green marketing orientation decreases the gap. The green market orientations contribute to building an environment that contributes to values, culture, and knowledge. The tactical green marketing orientation has the most direct impact on the gap because the green marketing mix consisting of the 4Ps (Green Product, Green Price, Green Place, and Green Promotion) are potent tools for targeting the ABG of the customers (Norstedt & Sjölinder, 2021).

Another concern of unintentional greenwashing affects the trustworthiness of the company. The green marketing orientation reduces the risk of unintentional greenwashing. In many ways, OLA S1 efforts are not a significant departure from traditions in the two-wheeler industry. Targeting consumers with a combination of hedonic, aesthetic, and cognitive-rational approaches is very common. The only differentiating point is that OLA S1 sells the hedonic and aesthetic aspects of the electric vehicle. The company's mission to bring one million Electric Vehicles on the road by 2021 takes sustainability to a different level which would require a particular set of consumer attitudes for the adoption of the product. OLA S1 electric marketing strategy is an example of how marketing can be related to sustainable outcomes. OLA S1 is presented as a green machine to look forward to in the Indian context as an example of how aesthetics and hedonic attributes can be used to reduce the ABG of consumers for sustainable consumption. Figure 3 represents a way of managing the gap through holistic green market orientation.

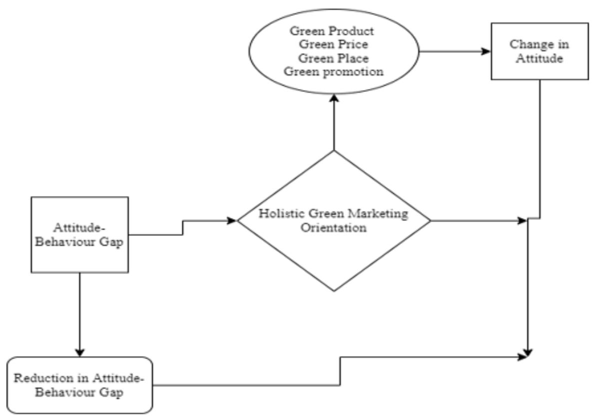


Figure 3: Managing attitude-behaviour gap through holistic green market orientation.

The theory of planned behaviour (TPB) (Ajzen, 1991) can also help us in understanding this gap in attitude and actual purchase behaviour. The theory explains the relationship between attitudes, intentions, and behaviour (Chaturvedi et al., 2020).

According to the theory, behaviour is determined by a person's intentions, which are influenced by three factors:

1. Attitude toward the behaviour itself. This refers to a person's overall evaluation of the behaviour, whether it's positive or negative.
2. Subjective norms. This refers to the perceived social pressure to engage or not engage in behaviour.
3. Perceived behavioural control. This refers to the extent to which a person believes they have control over the behaviour.

In the case of EVs the TPB suggests that the stronger a person's attitude toward the behaviour, the stronger their intention to perform the behaviour. Similarly, the more positive the subjective norms and the greater the perceived behavioural control, the stronger the intention to perform the behaviour. For EVs the TPB acknowledges that there may be factors that intervene between intentions and behaviour, such as external constraints or barriers. Thus, the theory highlights the importance of considering these situational factors in understanding behaviour. Overall, the TPB provides a useful framework for understanding the ABG for the EVs by emphasizing the role of intentions in determining behaviour, while also recognizing the impact of situational factors on actual behaviour. Below Figure 4 shows a diagrammatical representation of this.

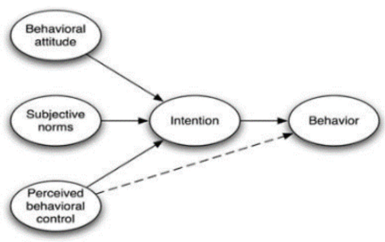


Figure 4: Theory of planned behaviour (Ajzen, 1991)

Therefore, it must be ensured that adoption of EVs is perceived to be a socially regular activity by the consumers. As and when consumer perception changes, they start developing positive attitudes resulting in correspondingly positive intentions and sustainable purchase behaviour (Cowan and Kinley, 2014). Studies by Terlau & Hirsch (2011) and Wintschnig (2021) reaffirm that there is a huge gap between attitude and behaviour for environmentally friendly products. The TPB can be instrumental in identifying the role of perceived behavioural control and behavioural and subjective norms in the adoption of Electric vehicles.

Turner (2006) contends that influencers with high appeal and credibility can also help in impacting the consumers attitudes and behaviour patterns. This will result in brand and relationship-building exercises to persuade loyal consumers to move towards green products. The only condition is that the influencers should be aware of sustainable consumption's tangible and non-tangible benefits and are aware of the best social media platforms that could be used to have the maximum impact. Subsequently, various studies contribute to the TPB. Kilbourne, McDonagh and Prothero (1997) argue that a complete transformation in the 'dominant social paradigm' impacts behavioural attitude. This term was coined by (Pirages & Ehrlich, 1974) and is described as the collection of norms, beliefs, values, and habits that form the world view held within a culture. Gupta and Ogden (2009) argue that the ABG results from a social dilemma in which the expectations and cooperation of others, along with collective gains, are the decisive factor in determining sustainable consumption. Kollmuss and Agyeman (2002) claim that the most significant influence on sustainable consumption behaviour happens when self-belief and values and social and cultural factors act synergistically. Organizations also play an important role in reducing the ABG by using brand-building and relationship-building exercises (Boulstridge & Carrigan, 2000). Moving beyond the gap means acknowledging the importance of other factors which have till now being neglected by companies and the new startups like OLA have tried to incorporate into their proposals. Factors such as hedonistic and aesthetic focus on expressed attitudes and give due importance to the element of fun (Martin, D. M. & Väistö, T. (2016). But the hedonistic and aesthetics factors also pose challenges, which are referred to as barriers to sustainable consumption which inhibits consumers from purchasing green products. Lack of awareness, perceptions, distrust, expensive products, and poor availability are some of the significant barriers to sustainable consumption (Bonini & Oppenheim, 2008). Giving importance to the common good, the essence of environmentalism, is not necessarily followed by sustainable consumption. Even after developing positive attitudes toward sustainability, frequently behavioural patterns are not coherent with these attitudes (Vermeir & Verbeke, 2006). Factors such as convenience and price still play an important role in the final product purchase.

The ABG varies depending on the product category, social norms, and convenience, pricing, and social and cultural factors. Therefore, it is necessary to move beyond the gap and rethink the role of other aspects of consumer behaviour. Hedonic and aesthetic appeals are needed to engage consumers in the consumption of sustainable products (Martin & Väistö, 2016). Figure 5 shows the various barriers to Sustainable Consumption.

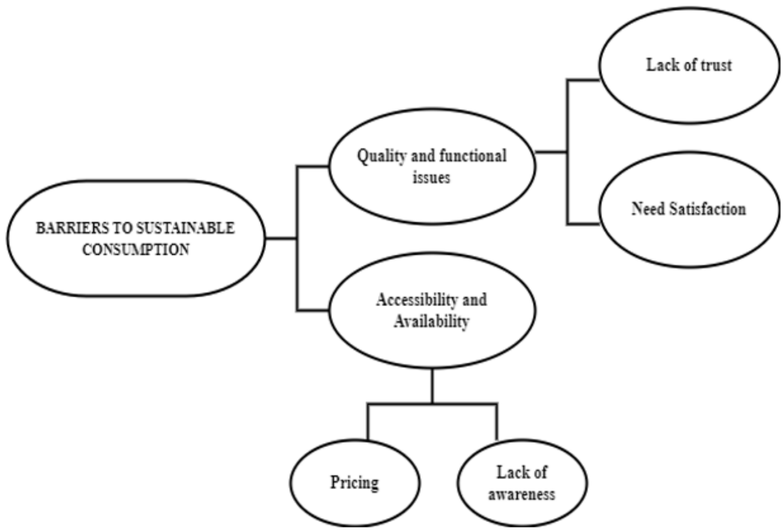


Figure 5: Barriers to sustainable consumption

5. Hedonism and aestheticism. New directions in sustainable consumption.

Hedonism and aestheticism are not new concepts in the realm of sustainable consumption, and they can play a role in promoting more sustainable lifestyles in general. Hedonism is the philosophy that posits pleasure & happiness as the ultimate goals of life. When it comes to consumption, this can mean choosing products and experiences that bring us pleasure and enjoyment while also being sustainable. For example, someone who enjoys spending time outdoors may choose to invest in high-quality, sustainable outdoor gear that they will use and enjoy for years to come, rather than cheaper, disposable products that may be harmful to the environment. Aestheticism is the philosophy that posits beauty and aesthetics as important values in life. This can apply to sustainable consumption by promoting products and experiences that are not only sustainable, but also aesthetically pleasing. For example, someone who values design and aesthetics may choose sustainable vehicles made from environmentally friendly materials that are both visually appealing and environmentally friendly. Incorporating hedonism and aestheticism into sustainable consumption can also help shift the focus from the idea of sacrifice or restriction to one of fulfillment and enjoyment. By choosing sustainable products and experiences that bring us pleasure and align with our values, we can create a more positive and fulfilling relationship with consumption that is also better for the planet. At the same time, hedonism and aestheticism should not be used as an excuse for excessive or wasteful consumption. Rather, they can be a tool for making more intentional and mindful choices that prioritize both personal enjoyment and sustainability.

Most Indian companies' EV manufacturers fail to see the importance of pleasure, joy, and excitement in sustainable consumption (Lanier & Rader, 2015). Hirschman and Holbrook (1982) highlighted the importance of hedonic consumption and affirmed that hedonic consumption lacks defining features, while involving emotive, fun, and excitement factors. Hedonic consumption is also motivated by a sense of expression and achievement. Even routine consumption can be motivated by adventure, social interaction, and altruism (Arnold & Reynolds, 2003). Therefore, hedonic consumption is characterized by "multisensory images, fantasies and emotional bursts in using the products" (Hirschman & Holbrook, 1982, p.133). An important aspect of hedonic consumption is the consumer's pleasure from the product's usage. Regardless of the product's consumption patterns, merits, and demerits, one of the important features of hedonic consumption is that it should be pleasurable. The source of deriving pleasure can be attributed to the product's design. Norman (2004) proposes the pleasurable design perspective at three levels of processing, product attributes, and product features. For example, the use of electric vehicles arises not only from their attractiveness but also from their driving pleasure, ease of use, and how futuristic it seems to be. Jordan (2000) proposed four types of product pleasures: (a) physio-pleasures which are related to senses, (b) socio-pleasures, which relate to interpersonal relationships, (c) psycho-pleasures, which relate to the emotional and cognitive reactions to product use, and (d) ideopleasures, which relate to the product attributes and personal values. Caru and Cova (2005) argue that consumers are human beings who can think and feel. Therefore, attention must be paid to the emotional experiences of customer purchases, which are deeply intertwined viewpoints and constructions of consumers' hedonic-ludic outcomes. Russell & Levy (2012) argued that repetition of activity could also provide hedonic outcomes such as traveling to exotic locations again and watching a favorite web series. Hedonic consumption brings a variety of senses, such as happiness, guilt, excitement, pleasure, and joy. Hedonic consumption affects individual satisfaction, happiness, guilt, and behaviour of subsequent purchases (Ying Liao, 2021). The hedonic and aesthetic appeals should commit to a more socially responsible consumption which is part and parcel of sustainable consumption (Soper, 2007). Aesthetics plays an important role in the consumer decision-making process as aesthetics is always in the subconscious mind of the consumers, and consumers are willing to go for an aesthetically beautiful product (Reimann, M. et al.,2010). Charters (2006) contended that aesthetic experience is also a type of hedonic consumption. Burgess et al. (2013) study focused on the purchase of electric vehicles from the utility and the environmental perspective, such as performance attributes and cost, adequate infrastructure for the charging of electric vehicles, and government policies. Consumers with pro-environmental self-identity, which fits their self-image, are more likely to have positive perceptions of electric vehicles (Schuitema, et al., 2013). Figure 6 represents the various constructs of hedonism and aesthetics and their importance in sustainable consumption.

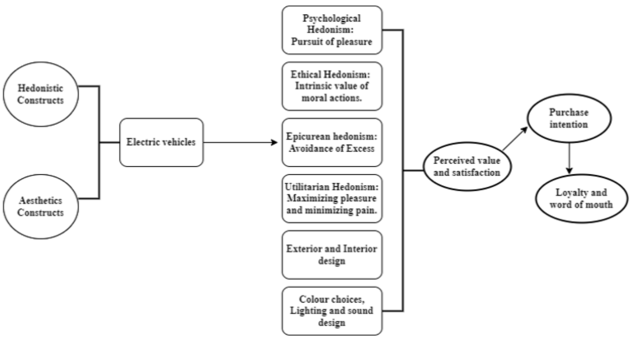


Figure 6: Constructs of hedonism and aesthetics and their role in sustainable consumption.

Our study focuses on OLA electric two-wheelers (OLA S1), which was officially launched in August 2021, started selling from the month of September and the first deliveries started in the month of December in the same year. OLA diversified into an electric vehicle business named OLA Electric Mobility (OEM) in 2019. OLA- S1 EV has considered the hedonic and aesthetic factors when designing electric vehicles. In this context of electric vehicles, the quietness and smoothness of the ride, curves, the responsiveness of the accelerator, or the sound of the vehicle can act as source of giving hedonistic pleasures to the consumers. The launch of a vehicle in multiple colors touches upon the aesthetics as refered to the appearance or visual design of a product. The shape of the vehicle, the color options available, or the design of the interior all refer to the aesthetics of the product. Aesthetics are important for electric vehicles because they can help to differentiate one vehicle from another, and they can influence a buyer's decision to choose one vehicle over another.

In creating successful electric vehicle manufacturers need to consider both hedonic and aesthetic factors in their design process. By doing so, they can create vehicles that are not only functional and efficient, but also enjoyable to use and visually appealing, and this appears to have been achieved by OLA S1. Due to effective marketing strategy and luxury positioning, OLA S1 has captured a market share of 17.45 % (as in figure 5) since its launch in August 2021 and is the third biggest electric manufacturer in India after Okinawa and Hero electric NYX. The latest technology used by OLA S1 provides consumers with the utmost in pleasurable and quality experiences. It provides motoring freedom with no additional installation, while customers can plug it into a regular wall socket overnight for a complete charge. While sustainable consumers may question the source of electric power if it is produced from burning coal, EV makers bypass this problem by providing other cleaner sources, such as wind and solar energy. OLA S1 cleaner transportation message offers an average of 75 Kms after a full charge. OLA concedes that, since the price range of its EVs is still comparatively high as compared to the fossil fuel-based vehicles, government support with respect to subsidies is important. OLA S1 provides the two-wheeler of the future and focuses on the consumers' attitudes toward sustainability. Competition in this sector is increasing because the government is promoting it, and its supportive policies such as tax incentives to owners and subsidies toward electric vehicles make it more competitive.

6. Discussion

Environmentally friendly products such as EVs provide a potentially promising path for sustainable consumption as they offer a cleaner and more energy-efficient alternative to gasoline-powered vehicles. EVs are powered by electricity generated batteries, which can be recharged from renewable sources, such as solar and wind power, thereby reducing the carbon footprint of transportation. EVs are an important source for reducing the emission of greenhouse gases that contribute to climate change. Thus, they can contribute to the reduction of air pollution and improvement in the quality of life particularly in metropolitan areas. Although consumers are slowly showing inclination towards the green products but due to some of the barriers to sustainable consumption discussed above the results are not that encouraging. Therefore, companies should think of ways to minimize the ABG in sustainable consumption. In this attempt, hedonic and aestheticist benefits can play a crucial role, and companies have begun to realize that both parameters play a vital role in minimizing the ABG among consumers. In this respect, social media have become a powerful tool for increasing consumer awareness and influencing purchase decisions (Agnihotri, R.,2020).

Our research aims to advance scientific understanding, provide practical guidance, and contribute to sustainability efforts in India and beyond. It does so by investigating a pressing issue, developing a theoretical framework, proposing actionable strategies, and fostering interdisciplinary collaboration to address the ABG in sustainable consumption behaviour. To do so we must consider the cognitive aspects of consumer purchase behaviour as follows:

1. Awareness and Knowledge. Consumers' level of awareness and knowledge regarding sustainable consumption play a crucial role in shaping their behaviour. Enhancing awareness and knowledge through education and effective communication can bridge this gap.

2. Perceived Value and Benefits. Consumers often evaluate the value and benefits associated with sustainable products or services compared to their conventional counterparts. To encourage sustainable consumption, it is important to emphasize the long-term benefits, such as reduced environmental impact, improved health, and social responsibility.

3. Behavioural Change. Breaking old habits and forming new ones can be challenging, even if individuals have positive attitudes towards sustainable

consumption. Providing reminders, creating supportive environments, and facilitating sustainable alternatives can aid in habit formation.

4. Psychological Factors. Consumers' cognitive biases, emotions, and social influences significantly impact their purchasing decisions. Understanding these psychological factors can help address the ABG. Addressing cognitive biases such as present predisposition (preferring immediate gratification) or loss aversion (fearing losses more than gains) can encourage sustainable decision-making.

5. Decision-Making Processes. Simplification of the decision-making processes and providing clear, concise, and readily available information about sustainable options can help consumers make more informed choices.

To bridge the ABG and move towards sustainable consumption, it is crucial to address these cognitive aspects of consumer purchase behaviour. By raising awareness, providing information, addressing barriers, and facilitating behaviour change, individuals can be empowered to align their attitudes with sustainable behaviours, resulting in a more sustainable society. While there are still challenges to overcome, such as the need for more charging infrastructure and improvements in battery technology, we believe the benefits of EVs are clear.

7. Conclusions

This study focuses only on sustainable consumption concerning two-wheelers using the case of OLA S1 Electric. Other modes of transport, such as Three wheelers, Four-wheelers, buses, and trucks which are very important for sustainable transportation, are not covered in the study. The reason is that in the case of trucks and buses, the hedonic and aesthetic aspects may not play an essential role in sustainable consumption, but this needs to be tested in future studies. Hence, further research work is essential to explore the role of hedonic and aesthetic in the case of heavy vehicles and how this transforms the attitudes toward sustainable consumption behaviour. As only one case of OLA S1 is used in the study, it may not represent the entire two-wheeler electric industry in India. Hence the propositions cannot be generalized. However, it will provide the necessary understanding of the impact of hedonic and aesthetic aspects in minimizing the ABG in sustainable consumption and can lay the foundation for future research. A combination of qualitative and quantitative methods can also provide a more comprehensive understanding of sustainable consumption as the behaviour of the consumer changes over time, since longitudinal studies can verify the results in a better way. Another area for future research can involve understanding the behavioural aspects of consumers which motivate them to adopt sustainable consumption patterns. This could involve studying the psychological and social factors that influence behaviour, as well as examining what interventions can encourage sustainable choices.

Future research on exploration of new technologies, such as artificial intelligence, blockchain, and the Internet of Things, can potentially be significant in facilitating sustainable consumption practices. Additionally, innovation in product design, packaging, and waste management could make an important contribution. Governments can play a critical role in promoting sustainable consumption by implementing various policy interventions, such as taxes, subsidies, and regulations. Future research should explore how supply chains can be optimized for sustainability, from raw materials sourcing to end-of-life product disposal. This could involve examining the impact of supply chain transparency, circular economy business models, and sustainable sourcing practices.

References

Agnihotri, R. (2020). Social media, customer engagement, and sales organizations: A research agenda. *Industrial Marketing Management*, *90*, 291-299.

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), 179-211.

Arnold, M. J., & Reynolds, K. E. (2003). Hedonic shopping motivations. *Journal of retailing*, *79*(2), 77-95.

Balderjahn, I., Buerke, A., Kirchgeorg, M., Peyer, M., Seegebarth, B., & Wiedmann, K. P. (2013). Consciousness for sustainable consumption: scale development and new insights in the economic dimension of consumers' sustainability. *AMS Review*, *3*(4), 181-192.

Barnett, C., Clarke, N., Cloke, P., & Malpass, A. (2005). The political ethics of consumerism. *Consumer Policy Review*, *15*(2), 45-51.

Bonini, S., & Oppenheim, J. (2008). Cultivating the green consumer. *Stanford Social Innovation Review*, *6*(4), 56-61.

Bonnell, A. (2015). Sustainability in America: Consumer attitudes toward green brands reach an all-time high. MarketResarch.com. Retrieved from http://blog.marketresearch.com/ sustainability-in-America-consumer-attitudes-toward-green-brands-reach-all-time-high.

Boulstridge, E., & Carrigan, M. (2000). Do consumers care about corporate responsibility? Highlighting the Attitude—behavior gap. *Journal of communication management*. 4(4) 355–368.

Burgess, M., King, N., Harris, M., & Lewis, E. (2013). Electric vehicle drivers' reported interactions with the public: Driving stereotype change? *Transportation research part F: traffic psychology and behavior*, *17*, 33-44.

Carrington, M. J., Neville, B. A., & Whitwell, G. J. (2010). Why ethical consumers do not walk their talk: Towards a framework for understanding the gap between the ethical purchase intentions and buying behavior of ethically minded consumers. *Journal of business ethics*, *97*(1), 139-158.

Carù, A., & Cova, B. (2005). The impact of service elements on the artistic experience: The case of classical music concerts. *International Journal of Arts Management*, 39-54.

Charters, S. (2006). Aesthetic products and aesthetic consumption: A review. *Consumption, Markets and Culture*, *9*(3), 235-255.

Chaturvedi, P., Kulshreshtha, K., & Tripathi, V. (2020). Investigating the determinants of behavioral intentions of generation Z for recycled clothing: Evidence from a developing economy. *Young Consumers*. Vol 21 (4) 403-417.

Chaturvedi, P., Kulshreshtha, K., & Tripathi, V. (2021). Investigating the role of celebrity institutional entrepreneur in reducing the attitude-behavior gap in sustainable consumption. *Management of Environmental Quality: An International Journal*, 33 (3), 625-643.

Chatzidakis, A., Hibbert, S., & Smith, A. P. (2007). Why people don't take their concerns about fair trade to the supermarket: The role of neutralization. *Journal of business ethics*, *74*(1), 89-100.

Chawla, L. (1999). Life paths into effective environmental action. *The Journal of environmental education*, *31*(1), 15-26.

Cowan, K., & Kinley, T. (2014). Green spirit: consumer empathies for green apparel. *International Journal of Consumer Studies*, *38*(5), 493-499.

Gaborieau, J. B., & Porcello, C. (2021). Validation of a unidimensional and probabilistic measurement scale for pro-environmental behaviour by travellers. *Transportation*, *48*(2), 555-593.

Gupta, S., & Ogden, D. T. (2009). To buy or not to buy. A social dilemma perspective on green buying. *Journal of consumer marketing*. Vol. 26 No. 6, pp. 376-391.

Hirschman, E. C., & Holbrook, M. B. (1982). Hedonic consumption: emerging concepts, methods, and propositions. *Journal of Marketing*, *46*(3), 92-101.

Hornibrook, S., May, C., & Fearne, A. (2015). Sustainable development and the consumer: Exploring the role of carbon labeling in retail supply chains. *Business Strategy and the Environment*, *24*(4), 266-276.

Jacobs, K., Petersen, L., Hörisch, J., & Battenfeld, D. (2018). Green thinking but thoughtless buying? An empirical extension of the value-attitude-behavior hierarchy in sustainable clothing. *Journal of Cleaner Production*, *203*, 1155-1169.

Jackson, T. (2007). Sustainable consumption. In: Atkinson, G.; Dietz, S.; Neumayer, E. (Eds.), Handbook of Sustainable Development. Edward Elgar, Cheltenham, 254-268.

Jordan, P. W. (2000). *Designing pleasurable products: An introduction to the new human factors*. CRC press.

Kilbourne, W., McDonagh, P., & Prothero, A. (1997). Sustainable consumption and the quality of life: A Macromarketing challenge to the dominant social paradigm. *Journal of Macromarketing*, *17*(1), 4-24.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental education research*, *8*(3), 239-260.

Küpers, W. (2002). Phenomenology of Aesthetic Organising--Ways Towards Aesthetically Responsive Organizations. *Consumption, Markets and Culture*, *5*(1), 21-46.

Lanier Jr, C. D., & Rader, C. S. (2015). Consumption experience: An expanded view. *Marketing Theory*, *15*(4), 487-508.

Leonidou, C. N., & Leonidou, L. C. (2011). Research into environmental marketing/management: a bibliographic analysis. *European Journal of Marketing*. 45 (1-2), 68-103.

Liao, Y. (2021). The Sources and Influencing Factors of Hedonistic Consumption. *Psychology*, *12*(4), 660-674.

Martin, D. M., & Väistö, T. (2016). Reducing the attitude-behavior gap in sustainable consumption: A theoretical proposition and the American electric vehicle market. In *Marketing in and for a Sustainable Society*. Emerald Group Publishing Limited.

McKeown, C., & Shearer, L. (2019). Taking sustainable fashion mainstream: social media and the institutional celebrity entrepreneur. *Journal of Consumer Behaviour*, *18*(5), 406-414.

Moraes, C., Carrigan, M., & Szmigin, I. (2012). The coherence of inconsistencies: Attitude–behavior gaps and new consumption communities. *Journal of Marketing Management*, *28*(1-2), 103-128.

Norman, D. A. (2004). Introduction to this special section on beauty, goodness, and usability. *Human-Computer Interaction*, *19*(4), 311-318.

Norstedt, J., & Sjölinder, F. (2021). Bridging the Attitude-Behavior Gap: A case study for how an FMCG company may decrease the attitude-behavior gap. Master's Degree Thesis. DiVA Uppsala University.

Ottman, J. A., Stafford, E. R., & Hartman, C. L. (2006). Avoiding green marketing myopia: Ways to improve consumer appeal for environmentally preferable products. *Environment: science and policy for sustainable development*, *48*(5), 22-36.

Pirages, D. C., & Ehrlich, P. R. (1974). *Ark II; social response to environmental imperatives*. Viking Press.

Paul, J., Modi, A., & Patel, J. (2016). Predicting green product consumption using the theory of planned behavior and reasoned action. *Journal of retailing and consumer services*, *29*, 123-134.

Perry, A., & Chung, T. (2016). Understand attitude-behavior gaps and benefit-behavior connections in Eco-Apparel. *Journal of Fashion Marketing and Management*. 20 (1), 105-119.

Reimann, M., Zaichkowsky, J., Neuhaus, C., Bender, T., & Weber, B. (2010). Aesthetic package design: A behavioral, neural, and psychological investigation. *Journal of consumer psychology*, *20*(4), 431-441.

Russell, C. A., & Levy, S. J. (2012). The temporal and focal dynamics of volitional consumption: A phenomenological investigation of repeated hedonic experiences. *Journal of Consumer Research*, *39*(2), 341-359.

Schuitema, G., Anable, J., Skippon, S., & Kinnear, N. (2013). The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles. *Transportation Research Part A: Policy and Practice*, *48*, 39-49.

Soper, K. (2007). Rethinking the 'good life': the citizenship dimension of consumer disaffection with consumerism. Journal of Consumer Culture 7 (2): 205-229

Thøgersen, J. (2010). Country differences in sustainable consumption: The case of organic food. *Journal of Macromarketing*, *30*(2), 171-185.

Turner, G. (2006). The mass production of celebrity: 'Celetoids', reality TV and the 'demotic turn'. *International journal of cultural studies*, *9*(2), 153-165.

Vermeir, I., & Verbeke, W. (2006). Sustainable food consumption: Exploring the consumer "attitude–behavioral intention" gap. *Journal of Agricultural and Environmental ethics*, *19*(2), 169-194.

Yamoah, F. A., & Acquaye, A. (2019). Unravelling the attitude-behavior gap paradox for sustainable food consumption: Insight from the UK apple market. *Journal of cleaner production*, *217*, 172-184.

Authors

Neha Saxena
Department of Management, International School of Business and Media Pune, India

Rajeev Kumar *(corresponding author)*
School of Management Doon University, Dehradun, India.
ranjanrajeev87@gmail.com

Neha Singh,
Department of Management, Uttaranchal University, Dehradun, India.

Komal Bisht,
Department of Management, Shri Guru Ram Rai University, Dehradun, India.

Shivendra Chaudhary,
Department of Management, Amity University, Greater Noida, India.
sschaudhary@gn.amity.edu

Rakesh Semwal,
Department of Management, Uttaranchal University, Dehradun, India.

Shubham Chaudhary
Global Market Insights Inc., Pune, India.

Funds

The paper received no funding from anywhere

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests that are directly or indirectly related to the work submitted for publication and that that may compromise or be seen to compromise the objectivity or integrity of the contents of this paper.

Citation

Saxena, N., Kumar, R., Singh, N., Bisht, K., Chaudhary, S., Semwal, R. & Chaudhary, S. (2023). Bridging the attitude-behaviour gap in sustainable consumption for electric vehicles in India. A theoretical proposition. *Visions for Sustainability*, 20, 8158, 355-377.
http://dx.doi.org/10.13135/2384-8677/8158

Original Paper

Embedding SDG 12 in consumer behaviour.

A survey of knowledge, attitude and perception for sustainable consumption

Komal Rawat, Priya Sahni

Received: 4 August 2023 **|** **Accepted:** 18 October 2023 **|** **Published:** 30 October 2023

Keywords: Sustainable Development Goals (SDGs); consumer behaviour; sustainable consumption; knowledge, attitude and perception.

Abstract. *The notion of sustainable development has led to a growing awareness of environmental issues related to human consumption. Consumer behaviour has a direct influence on the environment, regardless of whether the consumer is concerned about the environment or not. One strategy to address this issue is to continue to educate and propagate sustainable practices, particularly among younger generations. In this respect, it is necessary to* *study young people's knowledge, attitudes and perceptions. A questionnaire was used to collect the responses of 348 respondents. A random and convenient sampling method was used for data collection. For data analysis, significant statistical tools of factor analysis, correlation, and t-test were used to obtain results. The current study used the KAP (Knowledge, Attitude, and Practise) survey to explore how aims such as those contained in Sustainable Development Goal 12 can be incorporated into consumer behaviour, by assessing what the respondents "know," "feel," and "do" about the issues. While most people are aware of the existence of sustainable products, the main obstacle to sustainable consumption seems to be the lack of sustainable alternatives. It was found that awareness of consequences perceived environmental responsibility, and environmental criteria considered while making a purchase decision are important variables in influencing consumers for sustainable consumption.*

1. Introduction

Human consumption has received increasing attention as a significant environmental harm factor. Climate change is a symptom of overconsumption, which requires greater natural resource extraction, commodity manufacture, and services offered in modern society. Notions such as sustainable growth and development imply minimizing the use of natural resources and harmful materials, as well as the generation of waste and pollutants throughout all stages of production and consumption. Sustainability Development Goal 12 (SDG 12) is designed to promote more environmentally friendly consumption and production practices through a variety of measures, including particular regulations and global accords on the control of environmentally hazardous products. Individuals may play a vital role in fulfilling the sustainable development goals for sustainable consumption by buying eco-friendly products. This study tries to identify many factors that influence consumers' decisions to engage in sustainable purchasing and embed SDG 12 in consumer behaviour. The research focuses on several factors related to knowledge, attitude and practice, such as environmental issues in mass media, environment knowledge, health consciousness, awareness of consequences, perceived environmental responsibility, concern for self-image, care for green products, perceived seriousness of environmental problems, readiness to pay higher prices for green products, environmental criteria while making a purchase decision, preference for green products and social influence. A literature review was first conducted to identify recent contributions related to such factors. Subsequently t-test, factor analysis, and correlation supported by SPSS were utilized to assess the empirical validity of a number of proposed hypotheses. The study's aims to shed light on how SDG 12 might be incorporated into consumer behaviour and strategies to promote sustainable consumption, particularly in the context of the young adult market. This may help government, corporations or businesses to understand citizens and their attitudes toward environmental issues.

2. Literature review

Young (2010) investigated the purchasing process for green consumers in relation to consumer technology products in the UK. The paper concluded that incentives and single-issue labels (like the current energy rating label) would help consumers concentrate their limited efforts. Akenji & Bengtsson (2014) addressed the issue of how unsustainable production and consumption habits have been mostly responsible for environmental degradation, and proposed "decoupling" economic growth from resource use and environmental harm. Borch et al. (2015) examined the role of the Attitude-Behaviour-Choice (ABC) paradigm in shaping society's shift toward sustainability. Simões (2016) argued that Behavioural Sciences can offer important lessons and help in designing new strategies for spreading awareness about environmental harm and can help in reducing its negative impact. Khalina et al. (2017) aimed to determine customer segments in Russia based on sustainability values and barriers that can prevent Russians from choosing sustainable modes of behaviour and show the specific features of the sustainable behaviour of Russians compared to the sustainable consumption patterns described in previous research on European respondents. Jastrzębska (2017) reviewed the concept of responsible consumer and found that responsible consumers are beginning to combine two opposing roles – that of consumer, focusing on the individual needs and own benefits, and citizen, taking heed of the needs of the community (Rachocka, 2007). As citizen consumers they also support the circular economy, thereby not wasting resources, valuing such things as exchange, sharing, or other practices that build inter-personal relations, and thus social capital, a key factor in socio-economic development. Witek (2017) investigated consumers' attitudes towards sustainable labels and found that their attitudes toward sustainable labels are highly correlated but have overall and partial knowledge of them. Okur & Canan (2019) discussed consumers' attitudes toward sustainable products and their behaviour toward understanding environmental responsibility. Shiel et al. (2020) examined the various components of sustainable development and found that the concept of generativity is the main component of green consumption. The results showed a positive correlation between generativity and green consumption values, as well as between generativity and buying behavior, and generativity and prosocial attitude. Piligrimienė et al. (2020) revealed an important mediating role of the consumer engagement concept, suggesting that the application of the engagement concept in the context of sustainable consumption would allow a deepening understanding of actual consumer behaviour related to different contexts of sustainable consumption. Mainardes et al. (2021) revealed that green behaviour affects environmentally-conscious consumer behaviour (ECCB) more in the non-impacted regions and consumers are more concerned about sustainable consumption after having an environmental tragedy.

3. Research methodology

As yet, little is known about what drives young people's pro-environmental behaviour. From the literature review, it emerges that people's biospheric values and environmental self-identity evoke personal standards to act in an ecologically friendly manner, which can lead to a wide range of pro-environmental actions. Although previous studies have examined sustainable consumption, there has been little research using the KAP model for sustainable consumption in youth. Our research identifies Sustainable Knowledge Variables (SKV), Sustainable Attitudinal Variables (SAV), and Sustainable Practice Variables (SPV) as the basic categories used for understanding sustainable consumer behavior.

The study is descriptive and exploratory in nature, based on primary data using a questionnaire to collect the responses of 348 people. For the chosen sample size, a random and convenient sampling procedure was applied. The target population was young people in the age range 18-35 years. Significant findings were obtained using factor analysis, and correlation, and t-test were used to bring out substantial results. Cronbach's alpha test was used to judge the reliability of collected data. Table 1 shows the outcome of the reliability analysis conducted.

The research has the following objectives:

- To identify and analyse knowledge, attitudes, and perceptions of young people for Sustainable Consumption.

- To explore the ways in which SDGs can be embedded in consumer behaviour.
- To provide information on needs, issues, and barriers related to SDG 12 in consumer behaviour.
- To make recommendations on how to encourage young people to adopt more sustainable behaviour.

Sustainable Factors	Factors	Cronbach's Alpha
Sustainable Knowledge Variables (SKV)	Environmental issues in the mass media (SKV 1)	0.985
	Environment knowledge (SKV 2)	
	Health consciousness (SKV 3)	
	Awareness of consequences (SKV 4)	
Sustainable Attitudinal Variables (SAV)	Perceived environmental responsibility (SAV 1)	0.983
	Concern for self-image (SAV 2)	
	Care for green products (SAV 3)	
	Perceived seriousness of environmental problems (SAV 4)	
Sustainable Practice Variables (SPV)	Readiness to pay higher prices for green products (SPV 1)	0.973
	Environmental criteria while making a purchase decision (SPV 2)	
	Prefer green products (SPV 3)	
	Social influence (SPV 4)	

Table 1. Reliability Analysis

The study seeks answers to the following questions:

Q1: Is there significant variation in the desire for sustainable products regarding young people's educational level?

Q2: Is there a significant relation between awareness and making purchase decisions for sustainable products?

Q3: Is there a significant difference in factors affecting sustainable buying behavior?

4. Results

Q1: People may vary in their desire for sustainable products regarding their educational status. In this respect, the t-test calculated value (12.28155) is greater than the table value (6.388233) shown in Table 2. Thus it can be seen there is significant variation in the desire for sustainable products regarding their educational level.

	Favour for Sustainable Products	**Against Sustainable Products**
Mean	54.1488	15.4512
Variance	2887.689	235.1241
Observations	5	5
df	4	4
F	12.28155	
P(F<=f) one-tail	0.016153	
F Critical one-tail	6.388233	

Table 2. t-Test: Paired two sample for means.

Q2: The buying behaviour of consumers may be affected by the awareness level of respondents. Table 3 displays a summary of the correlations. In this respect, it was found that awareness level has a positive high degree impact (+0.957185) on the purchase decisions for sustainable products.

	Awareness of Sustainable Product	*Frequency of Buying*
Awareness of Sustainable Product	1	
Frequency of Buying	+0.957185	1

Table 3. Correlation summary

Q3: As regards significant differences in factors affecting sustainable buying behaviour, The Sustainable Knowledge Variables (SKV) and their implications on sustainable purchasing behavior are summarised in Tables 4, 5, and 6. It reveals that Awareness of Consequences (0.997) can be considered the most important knowledge factor that influences the buying behavior for sustainable products followed by environmental knowledge (.992).

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		**.701**
Bartlett's Test of Sphericity	Approx. Chi-Square	22.126
	df	6
	Sig.	.001

Table 4. Sustainable Knowledge Variables (SKV) KMO and Bartlett's Test

Sustainable Knowledge Variables (SKV)	Initial	Extraction
SKV 1	1	0.942
SKV 2	1	0.992
SKV 3	1	0.943
SKV 4	1	0.997

Table 5. Sustainable Knowledge Variables (SKV) Communalities

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
SKV 1	3.874	96.850	96.850	3.874	96.850	96.850
SKV 2	.113	2.813	99.663			
SKV 3	.012	.311	99.974			
SKV 4	.001	.026	100.000			

Table 6. Sustainable Knowledge Variables (SKV). Total variance explained. Extraction method: principal component analysis

Tables 7, 8, and 9 demonstrate Sustainable Attitudinal Variables (SAV), and it was found that Perceived Environmental Responsibility (0.995) can be considered the most significant attitude factor that influences the buying behaviour for sustainable products followed by the Perceived Seriousness of Environmental Problems (.990).

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.785**
Bartlett's Test of Sphericity	Approx. Chi-Square	20.933
	df	6
	Sig.	.002

Table 7. Sustainable Attitudinal Variables (SAV) KMO and Bartlett's Test

Sustainable Attitudinal Variables (SAV)	Initial	Extraction
SAV 1	1.000	.995
SAV 2	1.000	.962
SAV 3	1.000	.905
SAV 4	1.000	.990

Table 8: Sustainable Attitudinal Variables (SAV) Communalities. Extraction method: principal component analysis.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
SAV 1	3.853	96.331	96.331	3.853	96.331	96.331
SAV 2	.133	3.336	99.667			
SAV 3	.011	.287	99.953			
SAV 4	.002	.047	100.000			

Table 9. Sustainable Attitudinal Variables (SAV). Total Variance Explained

Sustainable Practice Variables (SPV) are listed in tables 10, 11, and 12 list. Environmental criteria while making a purchase decision (.996), Social influence (.993), and preferring green Products (.893) are important practice-related factors that motivate buyers to buy more sustainable products and Ready to pay higher prices for green products (.889) may be ignored for sustainable food.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.715**
Bartlett's Test of Sphericity	Approx. Chi-Square	19.988
	df	6
	Sig.	.003

Table 10. Sustainable Practice Variables (SPV). KMO and Bartlett's Test

Sustainable Practice Variables (SPV)	**Initial**	**Extraction**
SPV 1	1.000	.889
SPV 2	1.000	.996
SPV 3	1.000	.893
SPV 4	1.000	.993

Table 11. Sustainable Practice Variables (SPV). Communalities Extraction Method: Principal Component Analysis.

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
SPV 1	3.772	94.305	94.305	3.772	94.305	94.305
SPV 2	.209	5.213	99.518			
SPV 3	.018	.449	99.967			
SPV 4	.001	.033	100.000			

Table 12. Sustainable Practice Variables (SPV). Total Variance Explained. Extraction Method: Principal Component Analysis.

 http://dx.doi.org/10.13135/2384-8677/8015

5. Discussion

The findings of our study can be summarized as follows:

- The majority of respondents (61.5%) fall under the category of below 20,000 family income and 82.1% of respondents are between the 18-35 age group.
- It was found that lack of awareness and training (22.2), lack of assistance (11.8), reluctance to pay high prices (12.9), unsustainable thinking (19.7), and lack of sustainable alternatives to products and services (33.4) are the major barriers to sustainable consumption.
- It was found that there is a significant variation in the desire for sustainable products regarding their educational level and awareness level has a positive high degree impact (+0.957185) on the purchase decisions for sustainable products.
- Awareness of Consequences (0.997) is considered the most important Sustainable Knowledge Variable (SKV) that influences the buying behaviour for sustainable products followed by environmental knowledge (.992).
- Perceived Environmental Responsibility (0.995) is considered the most significant Sustainable Attitudinal Variables (SAV) that influences the buying behaviour for sustainable products followed by the Perceived Seriousness of Environmental Problems (.990).
- Environmental criteria while making a purchase decision (.996), Social influence (.993), and preferring green Products (.893) are important Sustainable Practice Variables (SPV) that motivate buyers to buy more sustainable products and Ready to pay higher prices for green products (.889) may be ignored for sustainable food.

On the basis of these findings, we believe that the following options or recommendations can be made for incorporating SDGs into consumer behaviour.

- *Lack of sustainable alternatives to products and services* - A key obstacle to sustainable consumption is a lack of sustainable alternatives to products and services. New startups for environmentally friendly products and services are needed to get started and work on sustainable alternatives. Companies must practice Green Marketing, particularly with regard to product labelling and packaging, in order to raise customer knowledge.

- *Awareness Programs* - It was discovered that awareness levels had a favourably high degree of influence on purchasing decisions for sustainable items. Many awareness programs may be launched at the educational level, such as at schools and universities.
- *Use zero-waste items* - It is advised that companies should use zero-waste items to improve the quality of products by investing in reusable mesh filters or reusable containers rather than plastic or paper.
- *Influential factors* - Awareness of Consequences, Perceived Environmental Responsibility, and Environmental criteria while making a purchase decision are regarded as the most significant components influencing purchasing behaviour for sustainable items. More initiatives to educate people about the implications of environmental degradation are recommended.
- *Bulk Purchasing* - Grocery stores with bulk bins reduce the need for fancy packaging and single-use plastics. If consumers prefer to purchase online, these online bulk businesses may be beneficial to sustainable behaviour.
- *Shop at zero-waste establishments* - These provide low-waste and biodegradable packaging for food, cosmetics, and cleaning items. There are other zero-waste online purchasing possibilities, similar to bulk shops.
- *Online shopping* - The conventional shopper emits almost twice carbon units in comparison to the online shopper. Ethical internet shopping will help in reducing carbon emissions, hasty delivery can negate the benefits of purchasing online by requiring additional delivery vehicles and packing.

6. Conclusions

Many consumers are not aware of what constitutes sustainable consumption and its future consequences. This study tried to identify Sustainable Knowledge Variables (SKV), Sustainable Attitudinal Variables (SAV), and Sustainable Practice Variables (SPV) that influence consumers' decisions in sustainable purchasing and identify suggestions necessary for encouraging sustainable consumption like zero waste, online shopping, bulk purchasing, awareness programs, and zero waste establishment. We believe that our research provides new methods for increasing public awareness of environmental harm and helps to lessen its negative effects so that people may comprehend environmental responsibility. We recommend the promotion of new startups for environmentally friendly products and that these companies must practice Green Marketing, particularly with regard to product labelling and packaging to increase customer knowledge. Moreover, a strong and sustainable waste control system must be developed in order to control environment-degrading consumer practices.

References

Akenji, L. & Bengtsson, M. (2014). Making sustainable consumption and production the core of sustainable development goals. *Sustainability*, 6(2), 513-529. https://www.mdpi.com/2071-1050/6/2/513

American Apparel and Footwear Association (2014). Apparel Stats. Available online: www.wewear.org/apparelstats-2014-and-shoestats-2014-reports/ (accessed on 23 March 2017).

Bhuwandeep, P. P. D. (2021). Study on Knowledge, Attitude, and Practice (KAP) of sustainable consumption behavior among college students. *Journal of Asia Entrepreneurship and Sustainability*, 17(4), 125-141. http://dx.doi.org/10.22622/jaes

Borch, A., Vittersø, G., & Stø, E. (2015). Studying sustainable change: From ABC to practice. *GAIA-Ecological Perspectives for Science and Society*, 24(2), 102-107. http://dx.doi.org/10.14512/gaia.24.2.8

Connolly, J. & Prothero, A. (2003). Sustainable consumption: Consumption, consumers and the commodity discourse. Consum. Mark. Cult. 2003, 6, 275–291. [Google Scholar] [CrossRef] https://doi.org/10.1080/1025386032000168311

Consumer Behavior (2023) https://www.economicsdiscussion.net/marketing-management/consumer-behaviour/33645

Consumers International (2023) https://www.consumersinternational.org/news-resources/blog/posts/the-importance-of-sustainable-consumption-in-a-changing-climate/

Elhoushy, S., & Lanzini, P. (2021). Factors affecting sustainable consumer behavior in the MENA region: A systematic review. *Journal of International Consumer Marketing*, 33(3), 256-279. https://doi.org/10.1080/08961530.2020.1781735

Environmental assessment of Swedish fashion consumption (2015) Environmental assessment of Swedish fashion consumption.pdf (refashion.fr)

Ha-Brookshire, J.E. & Norum, P.S. (2011). Willingness to pay for socially responsible products: Case of cotton apparel. J. Consum. Mark., 28, 344–353. [Google Scholar] [CrossRef]. https://doi.org/10.1108/07363761111149992

Harris, F., Roby, H. & Dibb, S. (2016). Sustainable clothing: challenges, barriers and interventions for encouraging more sustainable consumer behaviour. *International Journal of Consumer Studies*, 40(3), 309-318. https://doi.org/10.1111/ijcs.12257

Jastrzębska, E. (2017). The responsible consumer as an answer to new sustainable development challenges. *Economics and Environment 60.1): 9-9*

Khalina, E. V. et al. (2017). Values of sustainable development in consumer behavior: Case of Russia. *Revista ESPACIOS 38.54*.

Kostadinova, E. (2016). Sustainable consumer behavior: Literature overview. *Economic Alternatives*, 2, 224-234.

Kozar, J.M. & Hiller Connell, K.Y. (2013). Socially and environmentally responsible apparel consumption: Knowledge, attitudes, and behaviors. *Soc. Responsib. J*, 9, 315–324. [Google Scholar] [CrossRef]. https://doi.org/10.1108/SRJ-09-2011-0076

Luchs, M. G. & Mooradian, T. A. (2012). Sex, personality, and sustainable consumer behaviour: Elucidating the gender effect. *Journal of Consumer Policy*, 35, 127-144. https://doi.org/10.1007/s10603-011-9179-0

Mainardes, E. W., Espanhol, C.A. & Bastos da Cruz, P. (2021). Green consumption: Consumer behavior after an environmental tragedy. *Journal of Environmental Planning and Management* 64.7 1156-1183. *https://doi.org/10.1080/09640568.2020.1812546*

McDonald, S. & Oates, C. J. (2006). Sustainability: Consumer perceptions and marketing strategies. *Business strategy and the environment*, 15(3), 157-170. https://doi.org/10.1002/bse.524

McGovern, E. (1998). Controlling the environmental impact of transport: Traffic management schemes and their influence on consumer behaviour. *Sustainable Development* 6.1: 23-30. https://doi.org/10.1002/(SICI)1099-1719(199803)6:1%3C23::AID-SD78%3E3.0.CO;2-X

McGregor, S. (2005). Sustainable consumer empowerment through critical consumer education: a typology of consumer education approaches. *International Journal of Consumer Studies*, 29(5), 437-447. https://doi.org/10.1111/j.1470-6431.2005.00467.x

Milfont, T. L. & Markowitz, E. (2016). Sustainable consumer behavior: A multilevel perspective. *Current Opinion in Psychology*, 10, 112-117. https://doi.org/10.1016/j.copsyc.2015.12.016

Okur, N., & Canan, S. (2019). The impact of knowledge on consumer behaviour towards sustainable apparel consumption. *Consumer behaviour and sustainable fashion consumption* 69-96. https://doi.org/10.1007/978-981-13-1265-6_3

Peattie K. & Peattie S. (2009). Social marketing: A pathway to consumption reduction? *Journal of Business Research,* vol. 62, pp. 260-268. https://doi.org/10.1016/j.jbusres.2008.01.033

Peters, G., Granberg, H. & Sweet, S. (2014). The role of science and technology in sustainable fashion. *Routlegde Handbook of Sustainability and Fashion*, 181-190. https://doi.org/10.4324/9780203519943.CH18

Piligrimienė, Ž., Žukauskaitė, A., Korzilius, H., Banytė, J. & Dovalienė, A. (2020). Internal and external determinants of consumer engagement in sustainable consumption. *Sustainability*, *12*(4), 1349. https://doi.org/10.3390/su12041349

Rizkalla, N. (2018). Determinants of sustainable consumption behavior: An examination of consumption values, pce environmental concern and environmental knowledge. *International Journal of Social Science and Humanity*, 8(2), 48-54. https://doi.org/10.18178/ijssh.2018.8.2.932

Roos, J.M. (2010). The Consumer Report 2010. *Center for Consumer Science*, University of Gothenburg: Gothenburg, Sweden. [Google Scholar]

Roos, S., Sandin, G., Zamani, B. & Peters, G. (2015). Environmental assessment of Swedish fashion consumption. *Five garments–sustainable futures. Mistra Future Fashion*. [Google Scholar]

Roos, S., Zamani, B., Sandin, G., Peters, G.M. & Svanström, M. (2016). A life cycle assessment (LCA)-based approach to guiding an industry sector towards sustainability: The case of the Swedish apparel sector. *J. Clean. Prod.,* 133, 691–700. [Google Scholar] [CrossRef] https://doi.org/10.1016/j.jclepro.2016.05.146

Saunders, C. D. (2003). The emerging field of conservation psychology. *Human Ecology Forum,* vol. 10, no. 2, pp.137-149. https://www.jstor.org/stable/24706965

Sheoran, M. & Kumar, D. (2022). Conceptualisation of sustainable consumer behaviour: converging the theory of planned behaviour and consumption cycle. *Qualitative Research in Organizations and Management: An International Journal*, *17*(1), 103-135. https://doi.org/10.1108/QROM-05-2020-1940

Shiel, C., do Paço, A. & Alves, H. (2020) Generativity, sustainable development and green consumer behaviour. *Journal of Cleaner Production* 245: 118865. https://doi.org/10.1016/j.jclepro.2019.118865

Simões, F. D. (2016). Consumer behavior and sustainable development in China: The role of behavioral sciences in environmental policymaking. *Sustainability,* 8.9: 897.

Sustainable Concepts (2023) https://www.gdrc.org/sustdev/concepts/22-s-consume.html

Sustainable Consumption (2022) https://www.beeco.green/sustainable-consumption/

Sustainability Tips (2023) https://www.sustainablejungle.com/sustainable-living/sustainability-tips/

Textile Exchange. Organic Cotton Market Report. Annual Report (2016). Available online: http://textileexchange.org/wp-content/uploads/2017/02/TE-Organic-Cotton-Market-Report-Oct2016.pdf (accessed on 4 May 2017).

Trudel, R. (2019). Sustainable consumer behavior. *Consumer psychology review*, 2(1), 85-96. https://doi.org/10.1002/arcp.1045

Young, W. et al. (2010). Sustainable consumption: green consumer behaviour when purchasing products. *Sustainable development*, 18.1 20-31. *https://doi.org/10.1002/sd.394*

Witek, L. (2017). Sustainable Consumption: Eco-labelling and its impact on consumer behavior-evidence from a study on Polish consumer. No. 142/2017. *Institute of Economic Research Working Papers*. http://hdl.handle.net/10419/219964

Wonder, B. (1987). Management of environment in developing countries, *Environmentalist*, vol. 7, no. 2, pp. 111-122, THE 17 GOALS | Sustainable Development (un.org). https://doi.org/10.1177/030913338701100204

Authors

Komal Rawat *(corresponding author)*

Department of Commerce, St. Aloysius' College (Autonomous), Jabalpur, M.P. India
e.mail: komal.rawat024@gmail.com

Priya Sahni

Department of Commerce, St. Aloysius' College (Autonomous), Jabalpur, M.P. India

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Rawat, K., Sahni, P. (2023). Embedding SDG 12 in consumer behaviour. A survey of knowledge, attitude and perception for sustainable consumption. *Visions for Sustainability*, 20, 8015, 379-393. http://dx.doi.org/10.13135/2384-8677/8015

Original Paper

Environmental, Social and Governance implementation in Indonesian ports.

A qualitative approach and its impact on global sustainability

Safuan, Afzil Ramadian, Vidya Selasdini

Received: 16 October 2023 | **Accepted:** 8 November 2023 | **Published:** 18 November 2023

Keywords: Environmental, Social, and Governance (ESG); port of Indonesia; sustainability performance; qualitative research; technology and innovation; economic sustainability; environmental sustainability; social sustainability.

Abstract. *The main aim of this study is to investigate the incorporation of Environmental, Social, and Governance (ESG) concepts into the operational structure of Indonesian Ports, with a specific emphasis on Port Indonesia. The research methodology employed in this study was qualitative, involving comprehensive literature studies and analysis of secondary data sources. The* *data collection entailed compiling information from various sources, including scholarly journals, company reports, and official government documents. The gathered data underwent a thorough and systematic analysis to uncover and comprehend pertinent patterns, issues, and connections about the research subject. The results indicate that the Port of Indonesia has achieved notable progress in achieving economic sustainability, as seen by its consistent improvement in important financial indicators throughout the previous three years. Nevertheless, the findings about environmental sustainability and community engagement exhibited a heterogeneous trend, wherein specific locations showed noteworthy dedication while others showcased a need for more consistency. The data presented demonstrates a solid commitment to social sustainability, as seen by the company's concentrated endeavors to improve community involvement and promote the welfare of the local population. The Port of Indonesia has exhibited a solid dedication to Environmental, Social, and Governance (ESG) principles, specifically emphasizing economic sustainability. Despite experiencing volatility, the environmental and local participation components have displayed an overall tendency of persistent dedication toward improvement. Maintaining consistent focus on these elements and ongoing surveillance and documentation is essential to ensure long-term sustainability and uncover potential opportunities for improvement.*

1. Introduction

Indonesia holds a prominent position in global climate change, ranking as the fifth most significant contributor to cumulative carbon emissions in 2021 (Mishra, Pandita, Bhat, Mishra, & Sharma, 2022). Regarding carbon emissions, it places Indonesia below the United States, China, Russia, and Brazil. Indonesia's total carbon emissions amounted to 102,562 GtCO2. Shipping significantly contributes to carbon dioxide emissions (Mutia, 2022; Shen, Liu, & Tian, 2022). Research indicates that Indonesia accounts for 19% of carbon dioxide emissions from shipping activities within the country (Ambari, 2021; Shen et al., 2022).

Ports play a crucial role in supporting the shipping industry and hence necessitate the implementation of sustainable management practices. The Port of Indonesia, called Pelindo, is a corporate entity providing port and logistical services. Pelindo, a State-Owned Enterprise (BUMN), was officially established on February 5, 1960, and is wholly owned by the Government of the Republic of Indonesia. The legal foundation for the founding of Pelindo is articulated in the Deed of Founding No. 3, executed on December 1, 1992. Pelindo, a significant entity in the port industry of Indonesia, remains dedicated to delivering optimal services within the port and logistics domain. As of December 31, 2022, the Port of Indonesia, a renowned port company in Indonesia, has a workforce of approximately 7,204 individuals employed directly by the company. The corporation possesses a comprehensive network of offices, consisting of one central headquarters, twelve regional ports I & II, twenty-five regional ports III, and twenty-two regional ports IV (Kusumaningrum & Heikal, 2023; Pasaribu, 2023; Pelindo, 2023a).

Figure 1. Pelindo Business Regions

Port of Indonesia, a prominent port management entity, must modify its operational rules following environmental sustainability, social responsibility, and effective governance (Koroleva, Baggieri, & Nalwanga, 2020). Implementing Environmental, Social, and Governance (ESG) policies addresses concerns about carbon emission reduction, business transparency, and local community empowerment (Finger & Rosenboim, 2022; WorldSmith, 2022). Port of Indonesia faces the task of mitigating its operational footprint, enhancing transparency and accountability, and engaging local communities, all of which align with the three critical pillars of the ESG (T.-T. Li, Wang, Sueyoshi, & Wang, 2021; Senadheera et al., 2021). The imperative for Port Indonesia to improve its reputation and business performance is not solely driven by ethical considerations but also by the strategic advantages it might yield.

While numerous prior research endeavors have underscored the significance of ESG (Caldeira dos Santos & Pereira, 2022) principles in the realm of business, there exists a dearth of scholarly investigations that specifically concentrate on the port industry, particularly within the Indonesian environment. Furthermore, more literary material is needed regarding the interconnection between technology, innovation, and implementing ESG practices within the maritime industry (Nõmmela & Kõrbe Kaare, 2022). Hence, this research addresses the knowledge gap by conducting a case study on the Port of Indonesia (Lee, Lee, Lee, & Kim, 2023). The objective of this study is fourfold: firstly, to examine the implementation of ESG (Environmental, Social, and Governance) principles (T.-T. Li et al., 2021) in the operations of Indonesian Ports; secondly, to determine the effects of implementing ESG principles on the operational and financial performance of Port Indonesia; thirdly, to evaluate the role of technology and innovation in facilitating the implementation of ESG principles in Indonesian Ports; and finally, to identify opportunities for cross-sector collaboration in the performance of ESG principles in Indonesian Ports.

Moreover, the research inquiry in this particular instance encompasses the following aspects: 1) How Port of Indonesia incorporates ESG principles into its operational practices; 2) The consequences of implementing ESG principles on the operational and financial performance of Port Indonesia; 3) The extent to which technology and innovation contribute to the facilitation of ESG implementation within Indonesian Ports; and 4) The identification of key stakeholders involved in cross-sector collaboration to implement ESG practices in Indonesian Ports, along with an exploration of the mechanisms employed in such collaborations.

2. Literature Review

The significance of ESG factors is progressively growing within the contemporary landscape of the corporate sphere. Organizations that embrace ESG principles are inclined to exhibit enhanced sustainability and garner increased stakeholder esteem (Septania, 2022; Sibarani, 2023). The corporation's adherence to governmental legislation and oversight from regulators across different nations, such as Indonesia, will catalyze businesses to adopt and implement Environmental, Social, and Governance (ESG) principles within their operational frameworks. Several studies (Cherkasova & Nenuzhenko, 2022; Rau & Yu, 2023; Zheng, Khurram, & Chen, 2022; G. Zhou, Liu, & Luo, 2022) have conducted research indicating that organizations that adopt environmental, social, and governance (ESG) principles demonstrate improved financial performance and enhanced risk resilience.

ESG refers to a framework used to evaluate a company's or investment's sustainability and ethical impact. The ESG framework is employed by investors who prioritize environmental, social, and corporate governance factors when making investment decisions (Finger & Rosenboim, 2022). The assessment of the ethical and sustainability implications of investing in a firm involves the utilization of the ESG framework, which comprises three primary elements (T.-T. Li et al., 2021). Most socially responsible investors utilize these ESG factors to evaluate and filter a company's investment opportunities. One of the non-financial performance metrics encompasses environmental, social, and governance factors. The abovementioned concerns encompass ethical considerations, sustainability, and corporate governance, which entail establishing mechanisms to ensure accountability and effectively manage a company's carbon emissions (Business, 2020).

Figure 2. Three key ESG factors

3. Method

The present study employs qualitative research methods. Qualitative methods encompass a set of research approaches that prioritize comprehensive observation and seek to comprehend social events through the lens of participants' perspectives (Bernard, Wutich, & Ryan, 2016; Cissé & Rasmussen, 2022; Priya, 2021; Rashid, Rashid, Warraich, Sabir, & Waseem, 2019). The following are the procedural stages employed in this qualitative research study: 1) The process of gathering and recording information for analysis and interpretation is commonly called data collection. The data collection method involves a comprehensive review of relevant literature and analysis of secondary data sources. The process of doing a literature study entails the collection of pertinent material from a diverse range of sources, including scholarly publications, articles, corporate reports, and official documents directly related to the subject of research. Secondary data refers to information gathered and examined by researchers other than the one utilizing it. This data type encompasses various forms, including statistical data, industrial reports, and scientific publications. 2) Data analysis examines and interprets data to uncover patterns, relationships, and insights. Upon completion of data collection, the researcher will analyze the acquired information to discern patterns, themes, and linkages about the research topic. Data analysis in qualitative research includes the systematic procedures of interpretation, categorization, and synthesis of information derived from various data sources. 3) The following section presents the findings of the study. Subsequently, the data analysis outcomes are articulated through a lucid and cohesive exposition, encompassing research discoveries, interpretations, and deductions. The purpose of presenting findings in qualitative research is to communicate a comprehensive comprehension of the phenomenon being investigated and offer suggestions for enhancing the resilience and sustainability of the Port of Indonesia in response to global issues.

This study investigates various solutions that the Port of Indonesia might employ to enhance its resilience and sustainability in light of global challenges. This study examines the data using qualitative research methods to produce strategic recommendations. Nevertheless, this research is subject to certain constraints, including the time required for its completion, the potential for subjective biases to influence the findings and the extent to which the results may be applied to broader contexts. Integrating qualitative and quantitative procedures in future research endeavors can yield enhanced insights and a more holistic comprehension of the subject matter.

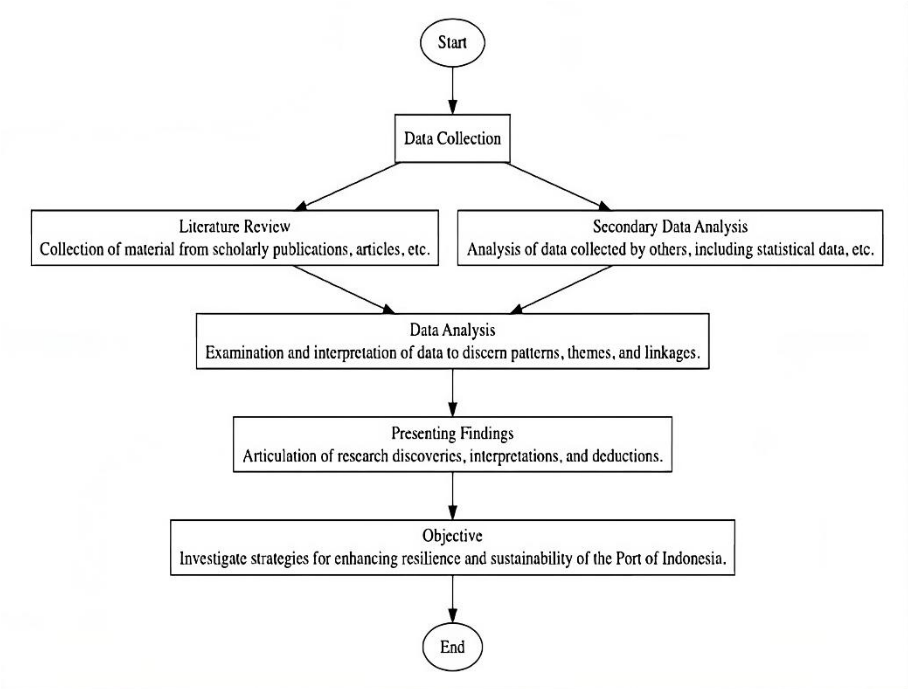


Figure 3. Research workflow

4. Results and discussion

What is the extent of Port Indonesia's dedication and effort in implementing these three primary ESG factors?

Environmental Aspect

<u>Minimize the release of carbon emissions and mitigate the impact of greenhouse gases.</u>

The Port of Indonesia has implemented electrification for its port equipment as a strategic measure to mitigate air pollution and curb the release of greenhouse gas emissions associated with port operations (Pelindo, 2023b). Furthermore, the utilization of the Onshore Power Supply (OPS) (Kizielewicz, 2023; Williamsson, Costa, Santén, & Rogerson, 2022) is implemented by Port Indonesia at various ports as a means to mitigate carbon emissions and the adverse impacts of greenhouse gases within the Port industry (Port Technology Team, 2021). The utilization of Onshore Power Supply (OPS) enables ships berthed in ports to get electrical power from land sources, resulting in a substantial reduction of exhaust emissions generated by ship engines, with reported reductions ranging from 75% to 95% (Hubla, 2022; Uly, 2022).

The Port of Indonesia demonstrates a solid dedication to mitigating carbon emissions and addressing the challenges posed by climate change (Ismadi, 2021). The Port of Indonesia has undertaken many initiatives, including establishing Green and Smart Ports, as outlined by the Port of Indonesia, to contribute to climate change mitigation (Pelindo, 2021b). The Indonesian ports have collaborated with the UK government to establish a reputable pilot project for blue carbon Fields (Sugimura et al., 2021), estimated to involve 59.6 million tonnes of (Marves, 2023).

According to a study undertaken at The Port of Rotterdam, there are ongoing efforts to mitigate the adverse effects of container ships on public health by investigating sustainable energy alternatives to minimize the environmental impact of diesel emissions from ships. One technique under consideration is Shore Side Electricity (SSE), potentially powered by offshore wind sources (Lieshout, 2019). Pelindo examines the potential of incorporating liquefied natural gas (LNG) in addition to conventional operational practices (OPS) or shore-side electricity (SSE). This consideration is supported by research conducted at Chinese ports, which demonstrates that clean energy alternatives such as solar power, wind energy, geothermal energy, LNG, and electricity are beneficial in mitigating sulfur dioxide (SO2) and carbon dioxide (CO2) emissions. (Z. Li & Cuihong, 2018).

<u>Enhancing trash management practices</u>

The Port of Indonesia has partnered with the Ministry of Environment and Forestry (KLHK) to establish a team that evaluates marine waste management practices. This collaboration aims to apply the idea of green ports throughout Indonesia to mitigate the environmental consequences associated with port operations (Rizky, 2023).

The Port of Indonesia actively participates in diverse facets of environmental stewardship, including proficiently overseeing the use of raw materials, materials, energy, water, emissions, waste, and biodiversity (Budianto, 2023). The waste management activities carried out by Port Indonesia encompass the treatment of both organic and inorganic waste. Additionally, Port Indonesia engages in collaborative efforts with relevant stakeholders to address the treatment of solid, liquid, and hazardous waste, as evidenced by the studies conducted by (Kusman, Kapita, & Mulya, 2020) and (Tangkau & Gurning, 2021).

The plastic trash recycling program has been implemented to provide fuel for fishermen and residents in the Thousand Islands. The Port of Indonesia supports this initiative and aims to enhance the well-being of individuals residing in the Thousand Islands region (Nabhani, 2021).

The Port of Indonesia actively contributes to the advancement of digital technology applications. Furthermore, apart from facilitating customer service and mitigating corrupt practices, this digital technology application also contributes to initiatives to reduce reliance on paper for office communication (Budianto, 2023). Examples of such initiatives include adopting e-office technology, utilizing QR codes as ticket substitutes, and implementing digital-based payment systems (Safuan, 2023). The digitization effort implemented by the Port of Indonesia encompasses a wide range of operational activities, including the Seaside, Terminal, Line 2, back-office functions, and customer interactions. Implementing digitalization within the port industry is of utmost importance due to its potential to enhance port services and contribute to environmental preservation by facilitating clean and efficient operating practices (Pelindo, 2021c).

Effective waste management is crucial in keeping a pristine and sustainable environment within port operations. Indonesian ports can potentially derive valuable insights from the successful waste management initiatives implemented in prominent port cities such as Helsinki, Stockholm, Tallinn, and Copenhagen Malmö Port. The research places significant emphasis on the establishment of uniform environmental regulations, the implementation of consistent measuring frameworks, and the development of robust ecological surveillance systems. Ports must give precedence to trash management and engage in spatial collaboration. (Svaetichin & Inkinen, 2017).

Enhancing energy efficiency

The Port of Indonesia has developed and constructed a Building Automation System (BAS)(Tang, Shelden, Eastman, Pishdad-Bozorgi, & Gao, 2020) and Smart Panel to implement efficiency policies in energy management. These technological advancements are intended to enhance the efficiency of the building's electrical system. Furthermore, the Port of Indonesia has devised a Remote Crane Management and Monitoring System (RCMMS) device (Y. Zhou, Fu, Zhang, Li, & Gao, 2022) to enhance energy usage profile collection efficiency and precision. The primary aim of this program is to integrate energy-efficient technology into loading and unloading equipment (Budianto, 2023). According to the Port of Indonesia, many measures were implemented, including replacing traditional lights with LED lights, optimizing equipment and machinery usage, and incorporating solar power plants (Pelindo, 2021c).

The use of electric vehicles at Indonesian ports, inspired by the practices observed at the Port of Los Angeles and the Port of Long Beach, where the objective is to achieve a 5% usage rate of electric drayage trucks for container operations, is a crucial approach to advancing sustainability. This strategy's successful implementation necessitates optimizing the combination of electric cars, charging infrastructure, and scheduling to effectively satisfy the demands of the container throughput (Wu, Zhang, & Chen, 2023). The European port industry is adopting energy efficiency strategies to mitigate greenhouse gas emissions and foster using renewable energy sources. This encompasses integrating many technologies, such as dynamic lighting, automation, eco-driving, and truck appointment systems. Transitioning towards environmentally sustainable infrastructure encompasses adopting LED lighting technology and implementing hybridization strategies—field(Sdoukopoulos, Boile, Tromaras, & Anastasiadis, 2019).

The conservation of the natural environment

During the initial six months of 2021, the Port of Indonesia undertook a substantial initiative under the supervision of the Coordinating Ministry for Maritime Affairs and Investment, wherein approximately 40,000 mangrove trees were planted as part of a comprehensive program to rehabilitate Indonesian mangrove forests. According to the Port of Indonesia, in 2022, a collaborative effort between the Port of Indonesia and the Human Initiative resulted in the planting of 2,747 trees (Human Initiative, 2022). One instance of the environmental conservation program implemented by the Port of Indonesia is the cultivation of diverse tree species, including Angsana kencana, ketapang kencana, trembesi, and mangroves. The program encompasses the principles of Social and Environmental Responsibility (TJSL). Plantation activities are conducted in many locations around Indonesia, containing a cumulative count of 608,600 seedlings (Budianto, 2023; Pelindo, 2021c).

International ports, such as the Port of Rotterdam, Port of Long Beach, and Port of Melbourne, have implemented environmental initiatives to conserve natural resources, reduce environmental damage, and foster the welfare of indigenous wildlife. Several initiatives have been conducted in the region, including the building of Maasvlakte 2, the creation of nature reserves, efforts to restore habitats, and the implementation of stormwater management systems (Baldwin, Sereno, Sayler, & Martin, 2016; Donald & Seeger, 2010; Edwards & Francey, 2008; Notteboom, van der Lugt, van Saase, Sel, & Neyens, 2020).

Social aspect

Enhance community involvement

The Port of Indonesia has assisted local communities through various projects, as exemplified by its initiatives in Kedung Asem Village and Marparan Village (Purnama, 2023). Kedung Asem Village, located in the Port of Indonesia, endeavors to promote the growth of tourism villages by enhancing the local economy by producing and promoting its exceptional goods. The development of ecotourism and mangrove tracking trails and the rise of mangrove crab cultivation is being undertaken in Marparan Village, located in the Port of Indonesia. These initiatives aim to enhance the local community's engagement with sustainable practices and economic empowerment (Media Indonesia, 2023). According to Ismadi, this program is anticipated to yield favorable outcomes for the economy, society, and environment, aligning with the principles of corporate social responsibility (Ismadi, 2021). Furthermore, the Port of Indonesia supports Small and Medium Enterprises (SMEs), precisely eight MSEs operating in batik enterprises. This initiative is undertaken to enhance the economy and safeguard the cultural heritage of batik within the community (Desfika, 2023).

Implementing the Green Port Initiative by the Johor Port Authority in Malaysia aims to facilitate sustainable operations and mitigate adverse environmental effects. The Early Learning Initiative in Dublin is dedicated to enhancing educational achievement. In California, fishing communities have undertaken a participatory strategic planning process to tackle various difficulties, such as diminished resource accessibility and environmental pressures (Richmond et al., 2019).

Enhance the overall well-being and standard of living of individuals.

In the world of education for local communities, the Port of Indonesia also participates in soft skills training and certification programs from BNSP (Akses Pelabuhan Indonesia, 2023). In addition, the Port of Indonesia provides scholarships to students of the Applied Undergraduate Study Program of Universitas Negeri Jakarta (UNJ), named the 2022 Champion Scholarship (FT UNJ, 2022). Port of Indonesia also offers an Internship Program for students throughout Indonesia who meet the requirements to be placed in Port of

Indonesia's work area throughout Indonesia (Pelindo, 2023a). The program provided by the Port of Indonesia is expected to improve the quality of life of the surrounding community.

In the North American context, port management organizations and terminal operators have been actively adopting strategies focused on assessing local communities' perceptions and engaging with the public. These efforts are aimed at cultivating and nurturing connections with the nearby communities. These practices enable port controlling bodies to enhance their strategic alignment with the needs and requirements of their local communities. Implementing such methodologies is of utmost importance in cultivating a favorable perception of the port cluster and advancing toward sustainable development (Moeremans & Dooms, 2021).

Promoting the establishment of quality and enduring employment opportunities

Fatimah anticipates that the Port of Indonesia Merger will generate 1,500 employment opportunities throughout 2021-2025 (Fatimah, 2021). It will be accomplished by implementing port development initiatives with prospective partners. The Port of Indonesia creates employment prospects and emphasizes enhancing operational performance and customer service through training and developing its internal human resources (Hajdari, Qerimi, & Qerimi, 2023). The digital-centric applied learning approach facilitates training programs that prioritize enhancing employees' talents and skills. According to Nasution and Amanda, each employee possesses an electronic wallet and a sought-after learning package available on the online learning platform (Nasution & Amanda, 2021). The expected result of improving competencies and skills is to provide the Port of Indonesia with essential capacities.

Governance aspect

Enhance the level of transparency and accountability inside corporate entities.

The Port of Indonesia is dedicated to implementing the principles of good corporate governance (GCG) within its operational framework, which encompasses the values of transparency and accountability. To enhance good corporate governance (GCG) practices across its operations, the Port of Indonesia engages in a collaborative effort with Transparency International Indonesia (TII)(Triyatna, 2022). The Port of Indonesia has partnered with the Corruption Eradication Commission to promote anti-corruption principles and prevent corrupt practices (Pelindo, 2022a).

The International Maritime Organization (IMO) created the International Ship and Port Facility Security (ISPS) Code to enhance security measures in ship and port operations. In the case of Azerbaijan, the country has accepted and implemented the ISPS Code to address and mitigate concerns related to corruption and bribery inside its port facilities (Hasanov & Alsulaiman, 2021).

Enhancing effective corporate governance practices

The Port of Indonesia has demonstrated its dedication to its stakeholders by implementing measures to prevent fraudulent behavior by its personnel, including acts such as pungli (illegal levies) and corruption. To facilitate reporting such misconduct, the Port has established a complaint channel known as the whistle-blowing system, officially named "Pelindo Bersih" (Pelindo, 2022b; Safuan, 2018). Furthermore, the use of digitization by the Port of Indonesia, as highlighted by Safuan, has the potential to mitigate corruption, pungli, and other fraudulent activities, as emphasized by the Port of Indonesia (Safuan, 2023). To achieve the objective of ensuring the provision of lawful and unencumbered operating services at ports, a Joint Integrity Pact was entered into by Pelindo and port maritime personnel (Pelindo, 2021a).

Industry 4.0 technologies, including the Internet of Things (IoT), artificial intelligence (AI), blockchain, and big data, can facilitate the utilization of real-time data, data authentication, predictive capabilities, transparency, authentication mechanisms, and structured data. These technologies could reduce the acquisition of precise ESG data and create reliable ESG reports. Consequently, they can enhance transparency and mitigate the risk of corrupt practices and bribery (Saxena et al., 2022).

Assessing the accomplishments in sustainability performance in the period 2020-2022.

The sustainability performance of the Port of Indonesia is assessed based on the outcomes of three primary ESG factors: environmental, economic and social. These factors are implemented through the adoption of the Corporate Social Responsibility (CSR) concept, specifically the triple bottom line framework, which encompasses the dimensions of Profit, Planet, and People (Gbejewoh, Keesstra, & Blancquaert, 2021; Larivière & Smit, 2022). The Port of Indonesia's sustainability performance can be observed in Tables 1, 2, and 3, as reported by (Pelindo, 2023b).

Economic aspect

Aspects	Description	Year		
		2022	2021	2020
Economics	Operating Income (Rp)*	**29.7**	**28.8**	**26.5**
	Current Year Profit (Rp)*	**3.9**	**3.2**	**2.9**
	Eco-Friendly Products (Units)	**53**	**11**	**24**
	Local Party Engagement			
	1. Number of Suppliers	**439**	**774**	**439**
	2. Contract Value (Rp)*	**6.1**	**1.9**	**1.2**

Table 1. Sustainability performance achievements in economic aspects (Pelindo, 2023a)
* (in billions)

Table 1 presents the sustainability performance accomplishments of the economic components of a corporation or organization throughout the preceding three years, specifically 2022, 2021, and 2020. During the specified time frame, there was an observed growth in operating revenue, with a rise of 8.68% from 2020 to 2021, followed by a further increase of 3.13% from 2021 to 2022. The profit for the year exhibited notable growth, specifically by 10.34% from 2020 to 2021 and by 21.88% from 2021 to 2022. In the interim, there was a significant decline of 54.17% in the quantity of environmentally sustainable items between 2020 and 2021. However, there was a substantial growth of 381.82% in the same products between 2021 and 2022. With the involvement of local parties, there was a notable rise of 76.31% in the count of suppliers between the years 2020 and 2021. However, this figure experienced a decline of 43.26% from 2021 to 2022. The contractual value of local suppliers had a notable surge of 58.33% between the years 2020 and 2021, followed by a substantial increment of 221.05% from 2021 to 2022. In general, the economic side of sustainability performance demonstrates a consistent upward trend in achievement throughout the years. The participation of local entities in this particular situation exhibits a drop in the number of suppliers involved while simultaneously seeing a notable gain in contract value.

The findings of this study demonstrate a robust association between the disclosure of ESG information and the overall value of a business. This correlation suggests that ESG disclosure can improve the financial stability and sustainability performance of 213 publicly listed ports over five years (Gavalas, 2023). This article examines the practices of ESG reporting in multinational businesses, with a specific emphasis on the involvement of financial experts in promoting its acceptability and the possible influence it may have on shareholder value. A model for implementation is presented by (Raghavan, 2022).

Environmental Aspect

Aspects	Description	Year		
		2022	2021	2020
Environment	Fuel Usage (Liters)*	**40.6**	**41.6**	**39.2**
	Electricity Usage (kWh)*	**1,284**	**539.9**	**677.5**
	Water Use			
	1. Fee (Rp)*	**40.3**	**42.7**	**40.4**
	2. PDAM (Cubic Meter)**	**489**	**556**	**1.373**
	3. Groundwater (Cubic Meters)**	**53**	**39**	**38**
	Limbah B3 (Ton)	**(206)**	**165**	**-**
	Fuel Emissions (KgCO_2eq)*	**(2.8)**	**6.6**	**-**
	Electricity Emissions (KgCO_2eq)*	**695**	**(128)**	**-**
	Environmental Cost*	**31.757**	**10.093**	**-**
	Biodiversity**	**215**	**609**	**12**

Table 2. Environmental sustainability performance achievements (Pelindo, 2023a).
* (in millions) **(in thousands)

Table 2 presents the sustainability performance accomplishments of the environmental components of a corporation or organization throughout the past three years, specifically 2022, 2021, and 2020. During the specified time frame, there was a reduction of 4.88% in fuel consumption from 2020 to 2021, followed by an increase of 2.44% from 2021 to 2022. Electricity consumption declined by 20.38% between 2020 and 2021, followed by a subsequent rise of 137.85% from 2021 to 2022. The Cost of water utilization had a 6.67% increase between 2020 and 2021, followed by a subsequent decline of 6.47% between 2021 and 2022. The water consumption of PDAM experienced a growth rate of 4.82% during the years 2020 and 2021, followed by a decline of 65.99% from 2021 to 2022. The utilization of groundwater experienced a growth rate of 2.63% between 2020 and 2021, followed by a substantial increase of 35.90% from 2021 to 2022. The quantity of B3 trash generated showed a notable increase of 165 tons between 2020 and 2021, followed by a decline of 371 tons between 2021 and 2022. The data indicates a reduction in fuel emissions of 22.58% between 2020 and 2021. However, there was a subsequent increase of 337.11% in fuel emissions from 2021 to 2022. The emissions associated with electricity experienced a substantial reduction of 92.13% between the years 2020 and 2021. However, there was a subsequent notable increase of 214.44% in these emissions from 2021 to 2022. The environmental costs significantly increased by 183.33% between 2020 and 2021, followed by a subsequent decline of 87.57% between 2021 and 2022. The biodiversity exhibited a net gain of 50.83K from 2020 to 2021, followed by a subsequent loss of 18.24K from 2021 to 2022.

The overall successes in sustainability performance of environmental factors have demonstrated consistent growth over time. However, it is worth noting that there has been a rise in Electricity Emissions. The utilization of electricity equipment by the Port of Indonesia is consistent with its operational practices. In addition to the observed decrease in biodiversity, it is imperative to prioritize future improvements.

The Port Sustainability Framework aims to establish a comprehensive framework that integrates various port sustainability activities and measures, focusing on aligning them with the Sustainable Development Goals set forth by the United Nations. The utilization of this framework has the potential to enhance the incorporation of sustainability concepts within port operations, promoting sustainable performance and mitigating the release of greenhouse gas emissions (Alamoush, Ballini, & Ölçer, 2021).

Social aspect

Aspects	Description	Year		
		2022	2021	2020
Social	Organic Employees (People)	**7.204**	**7.370**	**7.463**
	Recruitment (People)	**-**	**245**	**-**
	Education & Training (Hours)*	**330**	**241**	**2**
	BUMN TJSL Fund (Rp)*	**199**	**132**	**141**
	Consumer Satisfaction Survey;			
	1. Pelindo Regional 1**	**4.05**	**3.93**	**3.93**
	2. Pelindo Regional 2**	**4.71**	**4.69**	**4.37**
	3. Pelindo Regional 3**	**4.25**	**4.20**	**4.44**
	4. Pelindo Regional 4**	**4.06**	**4.21**	**4.52**

Table 3. Social sustainability performance achievement (Pelindo, 2023a)
*(in millions) **(on a scale of 1-5)

Table 3 presents the sustainability performance achievements of the social aspects of a corporation or organization throughout the preceding three years, specifically 2022, 2021, and 2020. During the time above frame, there was a decline of 1.25% in the number of organic employees from 2020 to 2021, followed by a further fall of 2.25% from 2021 to 2022. In the year 2021, the organization successfully onboarded a total of 245 individuals. However, it is worth noting that there needs to be more relevant recruitment statistics for the preceding year of 2020 and the subsequent year of 2022. The education and training hours saw a significant surge of 12,033% between 2020 and 2021, followed by an additional expansion of 36.93% between 2021 and 2022. The State-Owned Enterprises (SOEs) witnessed a growth of 7.04% in their corporate social responsibility (CSR) funds between 2020 and 2021. It was then followed by a significant surge of 50.76% from 2021 to 2022. The findings of the consumer satisfaction survey revealed a notable rise in satisfaction levels throughout all regions between the years 2020 and 2022, except for Region Four, where a marginal decline was observed during the period spanning from 2020 to 2021.

In general, there has been a consistent upward trend in achieving sustainability performance in social elements over the years. However, there has been a decline in the number of organic employees due to the implementation of pension and digitization initiatives. The survey findings of regional services indicate a positive trend overall, except for Regional Four, where there is a need for concerted efforts to enhance the quality of services provided. Maintaining consumer loyalty is of utmost importance.

Integrated carriers, which provide transportation services, stand to gain advantages by embracing ESG initiatives. According to studies, these activities have the potential to boost sustainability performance, mitigate ecological impact, foster societal well-being, and enhance corporate governance standards (Gavalas, 2023).

5. Conclusions

Incorporating ESG principles inside Indonesian ports have substantially influenced global sustainability. This study employs a qualitative research approach to examine the tactics used, focusing on digitization, community empowerment, and onshore electricity. These approaches facilitate the achievement of sustainable port operations and reduce the promotion of openness, accountability, and good governance, thereby mitigating corruption. The research also emphasizes the far-reaching effects of ESG principles, empowering indigenous communities to effectively govern their ecological assets and fostering sustainable behaviors that extend beyond the scope of port activities. Future research endeavors should employ a mixed-methods design, comparative studies, longitudinal studies, targeted interventions, and data-sharing practices to understand these activities better.

References

Akses Pelabuhan Indonesia. (2023). Supporting TJSL Education PT Akses Pelabuhan Indonesia Together with Pelindo Group Collaborates to Organise Soft Skill Training Programmes and BNSP Certification. Retrieved 31 August 2023, from https://aksespelabuhan.co.id/dukung-tjsl-pendidikan-pt-akses-pelabuhan-indonesia-bersama-pelindo-group-berkolaborasi-menyelenggarakan-program-pelatihan-soft-skil-dan-sertifikasi-bnsp/

Alamoush, A. S., Ballini, F., & Ölçer, A. I. (2021). Revisiting port sustainability as a foundation for the implementation of the United Nations Sustainable Development Goals (UN SDGs). *Journal of Shipping and Trade*, 6(1), 19. Retrieved from https://doi.org/10.1186/s41072-021-00101-6

Ambari, M. (2021). A New Role for Indonesia's Seaports to Reduce Carbon Dioxide Emissions. Retrieved 2 September 2023, from https://www.mongabay.co.id/2021/11/16/peran-baru-pelabuhan-laut-indonesia-untuk-menurunkan-emisi-karbondioksida/

Baldwin, T., Sereno, D., Sayler, K., & Martin, E. (2016). Port of Long Beach Middle Harbor Redevelopment: Designing the World's Most Technologically Advanced and Greenest Container Terminal. In *Ports 2016* (pp. 12–19). Reston, VA: American Society of Civil Engineers. Retrieved from https://doi.org/10.1061/9780784479919.002

Bernard, H. R., Wutich, A., & Ryan, G. W. (2016). *Analyzing qualitative data: Systematic approaches*. *SAGE Publication*. California, USA: SAGE Publication.

Budianto, K. A. (2023). Pelindo's ESG Commitment Starts with the Smallest Things: Save Paper Usage. Retrieved 31 August 2023, from https://www.trenasia.com/komitmen-esg-pelindo-mulai-dari-hal-terkecil-hemat-pemakaian-kertas

Business, M. (2020). What is ESG? Definition and meaning. Retrieved 30 August 2023, from https://marketbusinessnews.com/financial-glossary/esg-definition-meaning/

Caldeira dos Santos, M., & Pereira, F. H. (2022). ESG performance scoring method to support responsible investments in port operations. *Case Studies on Transport Policy*, 10(1), 664–673. Retrieved from https://doi.org/10.1016/j.cstp.2022.01.027

Cherkasova, V., & Nenuzhenko, I. (2022). Investment in ESG Projects and Corporate Performance of Multinational Companies. *Journal of Economic Integration*, 37(1). Retrieved from https://doi.org/10.11130/jei.2022.37.1.54

Cissé, A., & Rasmussen, A. (2022). Qualitative Methods. In *Comprehensive Clinical Psychology* (Vol. 3, pp. 91–103). Elsevier. Retrieved from https://doi.org/10.1016/B978-0-12-818697-8.00216-8

Desfika, T. S. (2023). Indonesia Port Presents Assisted MSMEs at Gelar Batik Nusantara. Retrieved 2 September 2023, from https://investor.id/business/337107/pelindo-hadirkan-umkm-binaan-di-gelar-batik-nusantara

Donald, A., & Seeger, C. (2010). Melbourne: responding to a changing climate. *Journal of Water and Climate Change*, 1(3), 220–226. Retrieved from https://doi.org/10.2166/wcc.2010.041

Edwards, P., & Francey, M. (2008). Organisational Change in Urban Stormwater Quality Management Programs. In *Low Impact Development for Urban Ecosystem and Habitat Protection* (pp. 1–10). Reston, VA: American Society of Civil Engineers. Retrieved from https://doi.org/10.1061/41009(333)52

Fatimah, I. N. (2021). PT Pelabuhan Indonesia Merger, Opportunity or Challenge? Retrieved 29 August 2023, from https://www.aeec.unair.ac.id/pelabuhan-indonesia-merger-kejar-peluang-atau-tantangan/

Finger, M., & Rosenboim, M. (2022). Going ESG: The Economic Value of Adopting an ESG Policy. *Sustainability*, 14(21), 13917. Retrieved from https://doi.org/10.3390/su142113917

FT UNJ. (2022). Champion Scholarship Year 2022. Retrieved 31 August 2023, from https://ft.unj.ac.id/str_plm/?p=153

Gavalas, D. (2023). Does sustainability reporting affect firm performance? Evidence from the port sector. *Maritime Technology and Research*, 6(2), First. Retrieved from https://doi.org/10.33175/mtr.2024.266092

Gbejewoh, O., Keesstra, S., & Blancquaert, E. (2021). The 3Ps (Profit, Planet, and People) of Sustainability amidst Climate Change: A South African Grape and Wine Perspective. *Sustainability*, 13(5), 2910. Retrieved from https://doi.org/10.3390/su13052910

Hajdari, M., Qerimi, F., & Qerimi, A. (2023). Impact of Continuing Education on Employee Productivity and Financial Performance of Banks. *Emerging Science Journal*, 7(4), 1158–1172. Retrieved from https://doi.org/10.28991/ESJ-2023-07-04-09

Hasanov, N., & Alsulaiman, M. F. (2021). Evaluating the implementation framework of the International Ship and Port Facility Security Code in the Republic of Azerbaijan. *Maritime Technology and Research*, 3(2), 185–201. Retrieved from https://doi.org/10.33175/mtr.2021.247419

Hubla. (2022). Realising Environmentally Friendly Ports, Indonesia Seriously Implementing Onshore Power Supply. Retrieved 31 August 2023, from https://hubla.dephub.go.id/home/post/read/12824/wujudkan-pelabuhan-ramah-lingkungan-indonesia-serius-terapkan-onshore-power-supply

Human Initiative. (2022). Helping Overcome Climate Change, HI Collaborates with Regional Pelindo 4 in Planting 2,747 Trees. Retrieved 31 August 2023, from https://human-initiative.org/helping-overcome-climate-change-hi-collaborates-with-regional-pelindo-4-in-planting-2747-trees/?lang=en

Ismadi. (2021). Reducing Carbon Emissions in the Maritime Sector. Retrieved 31 August 2023, from https://nusantaramaritimenews.id/berita/penurunan-emisi-karbon-di-sektor-maritim/

Kizielewicz, J. (2023). Environmentally Friendly Cruise Seaports in Northern Europe – Onshore Power Supply. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, 17(2), 357–363. Retrieved from https://doi.org/10.12716/1001.17.02.12

Koroleva, E., Baggieri, M., & Nalwanga, S. (2020). Company Performance: Are Environmental, Social, and Governance Factors Important? *International Journal of Technology*, 11(8), 1468. Retrieved from https://doi.org/10.14716/ijtech.v11i8.4527

Kusman, M. R., Kapita, H., & Mulya, E. R. (2020). Liquid Waste Management of PT Pelindo III Tanjung Emas Branch in Semarang. *Jurnal Ilmiah Wahana Pendidikan*, 6(4), 960–964. Retrieved from https://doi.org/10.5281/zenodo.4326355

Kusumaningrum, I., & Heikal, J. (2023). Evaluating The Prospects of Financial Performance After Merger at PT Pelabuhan Indonesia (Persero. *Adpebi International Journal of Multidisciplinary Sciences*, 2(2), 110–125. Retrieved from https://doi.org/10.54099/aijms.v2i2.493

Larivière, B., & Smit, E. G. (2022). People–planet–profits for a sustainable world: integrating the triple-P idea in the marketing strategy, implementation and evaluation of service firms. *Journal of Service Management*, 33(4/5), 507–519. Retrieved from https://doi.org/10.1108/JOSM-01-2022-0033

Lee, J., Lee, J., Lee, C., & Kim, Y. (2023). Identifying ESG Trends of International Container Shipping Companies Using Semantic Network Analysis and Multiple Case Theory. *Sustainability*, 15(12), 9441. Retrieved from https://doi.org/10.3390/su15129441

Li, T.-T., Wang, K., Sueyoshi, T., & Wang, D. D. (2021). ESG: Research Progress and Future Prospects. *Sustainability*, 13(21), 11663. Retrieved from https://doi.org/10.3390/su132111663

Li, Z., & Cuihong, Q. (2018). Synergistic Emission Reduction of SO 2 and CO 2 Based on Clean Energy Replacement in ports. *IOP Conference Series: Earth and Environmental Science*, 178(1), 012025. Retrieved from https://doi.org/10.1088/1755-1315/178/1/012025

Lieshout, A. van. (2019). *Viability Study of Sustainable Shore Side Electricity for Container Vessels in the Port of Rotterdam* . Retrieved from https://www.semanticscholar.org/paper/Viability-Study-of-Sustainable-Shore-Side-for-in-of-Lieshout/720028fac56d86dd30091cac765d985941efb4b8

Marves. (2023). Discussing the Value of Carbon Economy, Indonesia - UK Sign IA on UK-PACT. Retrieved 31 August 2023, from https://maritim.go.id/detail/bahas-nilai-ekonomi-karbon-indonesia-inggris-tandatangani-ia-on-uk-pact

Media Indonesia. (2023). Indonesia Port Supports the Development of Tourism Villages in East Java. Retrieved 31 August 2023, from https://mediaindonesia.com/nusantara/591403/pelindo-dukung-pengembangan-desa-wisata-di-jawa-timur

Mishra, H. G., Pandita, S., Bhat, A. A., Mishra, R. K., & Sharma, S. (2022). Tourism and carbon emissions: a bibliometric review of the last three decades: 1990–2021. *Tourism Review*, 77(2), 636–658. Retrieved from https://doi.org/10.1108/TR-07-2021-0310

Moeremans, B., & Dooms, M. (2021). An Exploration of Social License to Operate (SLTO) Measurement in the Port Industry: The Case of North America. *Sustainability*, 13(5), 2543. Retrieved from https://doi.org/10.3390/su13052543

Mutia, A. (2022). 10 countries that contribute the most carbon emissions in the world, including Indonesia! Retrieved 2 September 2023, from https://databoks.katadata.co.id/datapublish/2022/11/10/10-negara-penyumbang-emisi-karbon-terbesar-di-dunia-ada-indonesia

Nabhani, A. (2021). Caring for the Environment in Thousand Islands - Pelindo Manages Waste into Renewable Energy. Retrieved 1 September 2023, from https://www.neraca.co.id/article/147065/peduli-lingkungan-di-kepulauan-seribu-pelindo-ii-kelola-sampah-jadi-energi-terbarukan

Nasution, D. D., & Amanda, G. (2021). Pelindo merger, PMLI improves port workers' competence. Retrieved 31 August 2023, from https://ekonomi.republika.co.id/berita/r1ztri423/merger-pelindo-pmli-tingkatkan-kompetensi-pekerja-pelabuhan

Nõmmela, K., & Kõrbe Kaare, K. (2022). Maritime Policy Design Framework with ESG Performance Approach: Case of Estonia. *Economies*, 10(4), 88. Retrieved from https://doi.org/10.3390/economies10040088

Notteboom, T., van der Lugt, L., van Saase, N., Sel, S., & Neyens, K. (2020). The role of seaports in green supply chain management: Initiatives, attitudes, and perspectives in Rotterdam, Antwerp, North Sea port, and Zeebrugge. *Sustainability (Switzerland)*, 12(4). Retrieved from https://doi.org/10.3390/su12041688

Pasaribu, D. (2023). Building Sustainability Through Port Integration: A Case Study PT Pelabuhan Indonesia. *IOP Conference Series: Earth and Environmental Science*, 1188(1). Retrieved from https://doi.org/10.1088/1755-1315/1188/1/012023

Pelindo. (2021a). Realising Clean Ports, Pelindo and Port Stakeholders Sign a Joint Integrity Pact. Retrieved 2 September 2023, from https://www.pelindo.co.id/media/40/wujudkan-pelabuhan-bersih-pelindo-dan-stakeholders-kepelabuhanan-tandatangani-pakta-integritas-bersama

Pelindo. (2021b). SOE Commitment to Develop Green & Smart Port in Support of Climate Change Mitigation at COP26. Retrieved 31 August 2023, from https://www.pelindo.co.id/media/31/komitmen-bumn-kembangkan-green-smart-port-dalam-mendukung-mitigasi-perubahan-iklim-di-cop26

Pelindo. (2021c). *Sustainability Report*. Retrieved from Jakarta, Indonesia: https://pelindo.co.id/investor/laporan-keberlanjutan

Pelindo. (2022a). Collaboration between Pelindo and KPK to Improve Anti-Corruption Value Integrity. Retrieved 31 August 2023, from https://pelindo.co.id/media/130/kolaborasi-pelindo-dan-kpk-guna-tingkatkan-integritas-nilai-antikorupsi

Pelindo. (2022b). Digitalisation Prevents Corruption at Ports. Retrieved 2 September 2023, from https://pelindo.co.id/media/478/digitalisasi-cegah-tindak-korupsi-di-pelabuhan

Pelindo. (2023a). Annual Report Pelindo. Retrieved 1 September 2023, from https://pelindo.co.id/investor/laporan-tahunan.

Pelindo. (2023b). INVESTOR RELATIONS. Retrieved 17 September 2023, from https://pelindo.co.id/investor/laporan-tahunan

Port Technology Team. (2021). What is onshore power? Retrieved 31 August 2023, from https://www.porttechnology.org/news/what-is-onshore-power/

Priya, A. (2021). Case Study Methodology of Qualitative Research: Key Attributes and Navigating the Conundrums in Its Application. *Sociological Bulletin*, 70(1), 94–110. Retrieved from https://doi.org/10.1177/0038022920970318

Purnama, S. (2023). Pelindo Empowers Village Communities to Independently Manage Natural Potentials. Retrieved 31 August 2023, from https://www.antaranews.com/berita/3599655/pelindo-berdayakan-masyarakat-desa-agar-mandiri-kelola-potensi-alam

Raghavan, K. (2022). ESG Reporting Impact on Accounting, Finance. *The Journal of Global Awareness*, 3(1), 1–16. Retrieved from https://doi.org/10.24073/jga/3/01/09

Rashid, Y., Rashid, A., Warraich, M. A., Sabir, S. S., & Waseem, A. (2019). Case Study Method: A Step-by-Step Guide for Business Researchers. *International Journal of Qualitative Methods*, 18, 1–13. Retrieved from https://doi.org/10.1177/1609406919862424

Rau, P. R., & Yu, T. (2023). A survey on ESG: investors, institutions and firms. *China Finance Review International*. Retrieved from https://doi.org/10.1108/CFRI-12-2022-0260

Richmond, L., Dumouchel, R., Pontarelli, H., Casali, L., Smith, W., Gillick, K., … Suarez, A. (2019). Fishing Community Sustainability Planning: A Roadmap and Examples from the California Coast. *Sustainability*, 11(7), 1904. Retrieved from https://doi.org/10.3390/su11071904

Rizky, D. (2023). Promoting Green Port, Pelindo collaborates with KLHK to form a Marine Waste Management Assessment Team. Retrieved 2 September 2023, from https://www.trenasia.com/usung-green-port-pelindo-gandeng-klhk-bentuk-tim-penilai-pengelolaan-limbah-laut

Safuan. (2018). FRAUD AND ANTI-FRAUD IN THE PORT SECTOR. *Asia Pasific Fraud Journal*, 3, 145–152. Retrieved 16 February 2021 from https://doi.org/10.21532/apfj.001.18.03.01.17

Safuan, S. (2023). Application of Digital Technology in Indonesian Ports and Contribute to Lowering National Logistics Costs. *Jurnal Manajemen Transportasi & Logistik (JMTRANSLOG)*, 9(3), 211. Retrieved from https://doi.org/10.54324/j.mtl.v9i3.738

Saxena, A., Singh, R., Gehlot, A., Akram, S. V., Twala, B., Singh, A., … Priyadarshi, N. (2022). Technologies Empowered Environmental, Social, and Governance (ESG): An Industry 4.0 Landscape. *Sustainability*, 15(1), 309. Retrieved from https://doi.org/10.3390/su15010309

Sdoukopoulos, E., Boile, M., Tromaras, A., & Anastasiadis, N. (2019). Energy Efficiency in European Ports: State-Of-Practice and Insights on the Way Forward. *Sustainability*, 11(18), 4952. Retrieved from https://doi.org/10.3390/su11184952

Senadheera, S. S., Withana, P. A., Dissanayake, P. D., Sarkar, B., Chopra, S. S., Rhee, J. H., & Ok, Y. S. (2021). Scoring environment pillar in environmental, social, and governance (ESG) assessment. *Sustainable Environment*, 7(1). Retrieved from https://doi.org/10.1080/27658511.2021.1960097

Septania, R. C. (2022). Climate Change Impacts (Series 4): ESG Investment Trends in Indonesia. Retrieved 31 August 2023, from https://www.trenasia.com/dampak-perubahan-iklim-serial-4-tren-investasi-esg-di-indonesia

Shen, Y., Liu, J., & Tian, W. (2022). Interaction between international trade and logistics carbon emissions. *Energy Reports*, 8, 10334–10345. Retrieved from https://doi.org/10.1016/j.egyr.2022.07.159

Sibarani, S. (2023). ESG (Environmental, Social, and Governance) Implementation to Strengthen Business Sustainability Pt. Migas–North Field. *European Journal of Business and Management Research*, 8(1), 147–150. Retrieved from https://doi.org/10.24018/ejbmr.2023.8.1.1798

Sugimura, Y., Kobayashi, T., Mito, Y., Yoshihara, S., Okada, T., & Kuwae, T. (2021). The establishment and future prospects of blue carbon offset system at hakata port. *Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research)*, 77(2), 31–48. Retrieved from https://doi.org/10.2208/jscejer.77.2_31

Svaetichin, I., & Inkinen, T. (2017). Port Waste Management in the Baltic Sea Area: A Four Port Study on the Legal Requirements, Processes and Collaboration. *Sustainability*, 9(5), 699. Retrieved from https://doi.org/10.3390/su9050699

Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X. (2020). BIM assisted Building Automation System information exchange using BACnet and IFC. *Automation in Construction*, 110, 103049. Retrieved from https://doi.org/10.1016/j.autcon.2019.103049

Tangkau, D. I., & Gurning, R. O. S. (2021). Solid Waste Management Planning at Jamrud Terminal Surabaya. *Jurnal Teknik ITS*, 9(2). Retrieved from https://doi.org/10.12962/j23373539.v9i2.57356

Triyatna, S. O. (2022). Pelindo and TII Agree to Explore Collaboration to Strengthen Port Governance. Retrieved 31 August 2023, from https://www.kompas.id/baca/ekonomi/2022/10/28/pelindo-dan-tii-sepakat-jajaki-kolaborasi-perkuat-tata-kelola-pelabuhan

Uly, Y. A. (2022). Environmentally Friendly, Ships Can Use Electric Energy When Docking at These 21 Ports. Retrieved 31 August 2023, from https://money.kompas.com/read/2022/10/19/084000526/ramah-lingkungan-kapal-bisa-gunakan-energi-listrik-saat-sandar-di-21-pelabuhan?page=all

Williamsson, J., Costa, N., Santén, V., & Rogerson, S. (2022). Barriers and Drivers to the Implementation of Onshore Power Supply—A Literature Review. *Sustainability*, 14(10), 6072. Retrieved from https://doi.org/10.3390/su14106072

WorldSmith. (2022). Why ESG is Important for Corporate Sustainability? Retrieved 30 August 2023, from https://wordsmithgroup.com/id/mengapa-esg-penting-bagi-keberlanjutan-perusahaan/

Wu, X., Zhang, Y., & Chen, Y. (2023). A Dynamic Programming Model for Joint Optimization of Electric Drayage Truck Operations and Charging Stations Planning at Ports. *IEEE Transactions on Intelligent Transportation Systems*, 24(11), 11710–11719. Retrieved from https://doi.org/10.1109/TITS.2023.3285668

Zheng, J., Khurram, M. U., & Chen, L. (2022). Can Green Innovation Affect ESG Ratings and Financial Performance? Evidence from Chinese GEM Listed Companies. *Sustainability (Switzerland)*, 14(14). Retrieved from https://doi.org/10.3390/su14148677

Zhou, G., Liu, L., & Luo, S. (2022). Sustainable development, ESG performance and company market value: Mediating effect of financial performance. *Business Strategy and the Environment*, 31(7). Retrieved from https://doi.org/10.1002/bse.3089

Zhou, Y., Fu, Z., Zhang, J., Li, W., & Gao, C. (2022). A Digital Twin-Based Operation Status Monitoring System for Port Cranes. *Sensors*, 22(9), 3216. Retrieved from https://doi.org/10.3390/s22093216

Authors

Safuan *(corresponding author)*, safuan@esaunggul.ac.id
Esa Unggul University, Jakarta, Indonesia

Afzil Ramadian
Djuanda University, Bogor, Indonesia

Vidya Selasdini
Maritime Institute, Jakarta, Indonesia

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Safuan, Ramadian, A., Selasdini, V. (2023). Environmental, Social and Governance implementation in Indonesian ports. A qualitative approach and its impact on global sustainability. *Visions for Sustainability*, 21, 8448, 395-419.
http://dx.doi.org/10.13135/2384-8677/8448

Original Paper

Socio-environmental impacts of landfill site in Nduba sector, Kigali, Rwanda

Alain Nkomezi, Francine Uwimbabazi, Chunho Yeom

Received: 29 November 2022 | **Accepted:** 25 May 2023 | **Published:** 7 June 2023

Keywords: forest adoption, sustainability, socio-economic benefits, partners, sustainable development.

VISIONS for sustainability www.ojs.unito.it/index.php/visions

Abstract. *Currently, solid disposal is a significant challenge in urban cities. In particular, Kigali City generates thousands of tons of solid waste to be transported and discarded in one city's landfill on a daily basis. It has contributed to the rise of social and environmental problems near the Nduba landfill. Previous studies have emphasized types of waste (liquid and solid) but have been unable to demonstrate land use and cover change because of solid waste disposal since its establishment in 2012. The study aimed to evaluate spatiotemporal changes vis a vis the social and environmental implications of solid waste disposal in the Nduba sector. Primary data were collected within a defined study area, whereas secondary data relied on remote sensing and geographic information system (GIS) data. Images of land use/cover were used for spatial analysis and changes before and after landfill establishment. The findings of this study indicate that land use/cover has changed considerably in the last decade. For instance, the built-up area increased within the study area from 69.21 ha to 187.56 ha in 2001 and 2019, respectively. The change detection of land use/cover indicates that the size of the landfill increased by 18.79 ha in 2019. Forest land has reduced from 199.8 ha in 2001 to 104.49 ha in 2019. Even though authorities around the landfill have established a buffer of 400 m, it remains evident that the socio-environment impacts are likely to happen 1,000 m from the current landfill's boundary. Despite public and private efforts to handle solid waste on-site, residents of Nduba claimed that the landfill had substantial social and environmental impacts.*

1. Introduction

In this era of escalating impacts of climate change and global warming, waste management has become a central issue of priority for environmental protection in several countries worldwide (Khan & Faisal, 2007). However, some do not adequately plan for solid waste management in terms of collection, transportation, recycling, and suitable disposal sites (McDougall et al., 2008). Particularly developing countries lack the human and financial capital to conduct adequate studies that handle solid waste-related issues (Buenrostro et al., 2001).

It is estimated that 3.19 billion tons of solid waste are produced annually (Kaza et al., 2018). Nevertheless, the quantity of solid waste generated in developed countries is relatively high compared with that in developing countries (Ahsan et al., 2014). A global solid waste management study conducted by the World Bank in 2018 revealed that high-income countries such as the United States, Canada, and European Union member states generate approximately 34% of global waste, with only 16% of the world's population. In contrast, low-income countries account for only 5% of global waste, with only 9% of the total population (Kaza et al., 2018).

Poor solid waste practices have undermined Rwanda's sustainable development in the last decades. For instance, From 1983 to 2012, Solid Waste was disposed of in the Nyanza landfill and replaced by the Nduba landfill, currently the only city's landfill site. (Rajashekar, Bowers, & Gatoni, 2019). But, the country's target is to reach an effective waste management system with major investment projects, including the construction of the Kigali Centralized Sewerage System (KCSS) and modern landfills in all districts by 2024 (NST1, 2017).

The Nduba landfill has been described as an open dumping site (Iraguha, Remalan, & Setyono, 2022) with a lack of modern waste treatment facilities, which is causing harmful chemicals and environmental problems, including leachate and vermin (Rajashekar, Bowers, & Gatoni, 2019). Contrary to sanitary dumpsites, the facilities are designed so that waste is secluded from the environment and residential areas (Idowu et al., 2019). There is little precision in a daily estimation of the volume of waste generated in the capital city of Kigali. The previous research suggested that the landfill could accommodate 400 to 800 tons per day and reach 1,300 tons in 2030 (Rajashekar, Bowers, & Gatoni, 2019).

Kigali's rapid population and economic growth have been seen as a major cause of the increase in solid waste production (Rajashekar, Bowers, & Gatoni, 2019) and also needs infrastructure and institution capacity for proper management (Iraguha, Remalan, & Setyono, 2022). Though the City of Kigali(CoK) and sanitation body WASAC(Water and Sanitation Corporation) took a central role in Nduba landfill management, Rwanda Utilities and Regulator Authority (RURA) set guidelines, issued license and requirements for private waste collection companies. It also sets out the household's tariff for collection (Rajashekar, Bowers, & Gatoni, 2019).

There are several companies licensed to collect and transport solid waste, including for instance; Agruni, Coped, Ubumwe Cleaning, ISUKU Kinyinya, etc. (Uwajambo et al., 2017; Mukamana, 2021). Prior to solid waste collection, there was a lack of separating households' waste from biodegradable and non-biodegradable(Akimanizanye et al., 2020). It is ideal for sorting it at the source for recycling to minimize waste disposed at the site (Gahima & Bizuhoraho, 2021). The latest study suggests a potential for rising health issues such as respiratory problems, cancer, and skin disorders in landfill vicinity (Mukamana, 2021). The facility is associated with an increased risk of diseases related to poor sanitation, such as cholera, intestinal worms, and typhoid (Kabera, 2020). The same study reveals that the key issue is the safe disposal of solid waste which can affect landslides and end up contaminating groundwater.

To enhance solid waste management and decision-making processes, GIS has been an appropriate tool for setting up new landfills using multi-criteria and suitability analysis (Jimoh et al., 2019). In contrast, remote sensing is applicable to the changing detection of land use/cover over a certain period (Mugiraneza, Ban, & Haas, 2018).

Yet, in previous studies, GIS and remote sensing have not been applied to evaluate the spatiotemporal impacts of solid waste disposal. Some scholars identified and assessed challenges related to solid waste management in Kigali and quantified the volume produced daily. However, little is known about the site's suitability and potential socio-environment impacts. The study used mixed spatial analysis methods such as Geographical Information System (GIS), ERIDAS software, interviews, and questionnaire survey. Thus, this paper aims to assess the social and environmental impact of the landfill.

2. Materials and Methods

2.1. Scope of the study area

The study evaluates the socio-environmental impacts of solid waste disposal in the Nduba sector and its implications on residents and the environment. The area of the site and 1 km buffer of the site were selected as the study area. The study used the methods of Nas et al. (2009) for the four criteria, such as residential area, road networks, slope, and the combination of rivers, streams, and wetlands, as one criterion. This method is based on the boolean operation model in GIS, which enables each criterion to be weighted and ranked/scored. Criteria weights were calculated using Analtyic Hierarchical Process(AHP) method (Nas et al., 2009). Each criterion was assessed based on weight, scoring, and distance (Table 1). It was indicated that a 0 score has no constraint, a score of 5 has a strong constraint, a score of 9 is an extreme constraint, whereas a score of 10 is an extreme constraint. The score 0-4 are positive compared to those ranging from 5-10, which are negative.

Criteria	Distance	Scoring	Weight
Residential area	<1 km	10	0.20
	>1 km	0	
Road networks	<0.2 km	10	0.10
	0.2-1 km	9	
	>1 km	0	
Streams, rivers, and wetlands	<0.3 km	10	0.15
	0.3-0.5 km	5	
	>0.5 km	0	
Slope	>15%	10	0.10
	<15%	0	

Table 1: Alternative criteria for ideal landfill site. Source: Nas et al., 2009, page 496.

Residential proximity to the location of the landfill should be considered a priority when setting up a facility. A buffer distance of 1 km from the landfill to the nearest residential area. Given the sensitivity of the landfill issue, the highest weighting score of 0.20 was calculated and assigned to the residential area. Landfills are effective because of the accessibility of road networks. However, the distance from the main road should be assessed not only to indicate the accessibility of the site but also to ensure the wellness of road users. A minimum distance of 200 m is a very extreme constraint, whereas beyond such a buffer, it does not affect the surroundings.

Streams, rivers, wetlands, or other water sources near landfill facilities are exposed to the risk of water contamination. A distance of fewer than 300 m scored a very extreme constraint, whereas those above 300 m had no constraint.

Given the significance of the risk, a weight of 0.15 was assigned for the criteria. The slope of the landfill terrain was also chosen as one of the criteria for the assessment. The slope of the facility of 15% or higher increases the speed of rainwater runoff, causing the risk of waste moving from designated landfills to unsafe places (Nas et al., 2009). Therefore, less than 15% of the slope of Nduba has no constraint. Nduba is geographically located in the Gasabo district, and one of the three districts forms Kigali City. In Gasabo, the facility is located in Nduba, Gasanze, and Muremure villages, as shown in Figure 1 below.

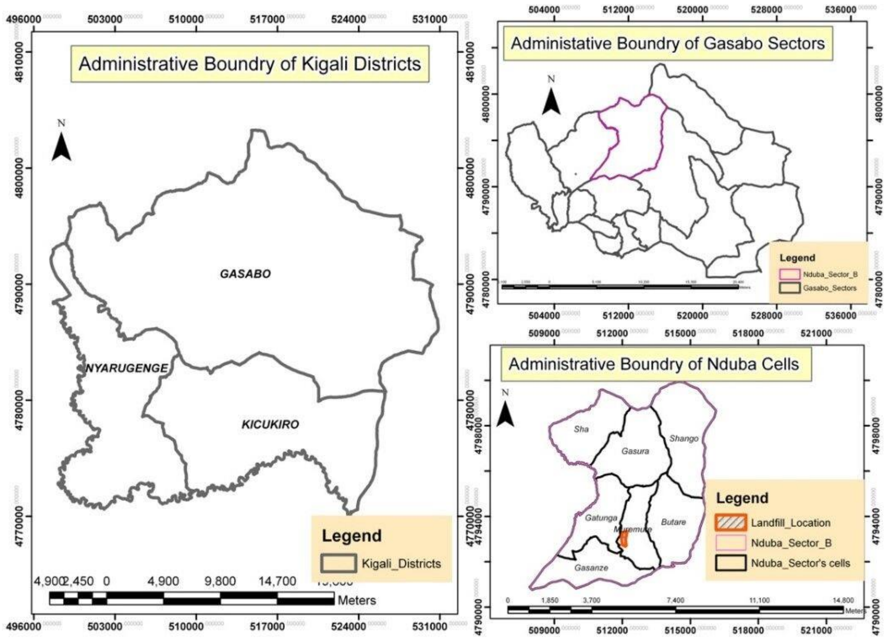


Figure 1: Geographical location of the Nduba landfill

2.2 Study design

This work consisted of data collected from various sources, both secondary and primary. Data on existing literature were used in this research. Data were also collected from public institutions in charge of utilities regulations, environment, and sanitation, including local government entities, for their direct involvement and to understand the management and operation of the landfill fully. But, the City of Kigali and sanitation body WASAC has taken a central role in Nduba landfill management. Therefore, the primary data method used key informant interviews from WASAC, COK, and DPMM-KALISIMBI. Key informants are Mr. John Mugabo from the City of Kigali (CoK), Mr. Amos Kazora Shyaka from WASAC(Water and Sanitation Corporation), and Mr. Ildebland Urayeneza from Depot Pharmacetique et Materiel Medicales-KALISIMBI were interviewed separately. Eventually, a survey questionnaire was used to gather data on the perception and feelings of residents living in the landfill vicinity (appendix).

This survey research aimed to collect Nduba residents' thoughts and feelings about the landfill. From a target population of 2,996 people residing 1 km from the site, 85 respondents were selected using a random sampling method because of their location and population distribution. The sample size was computed using the following formula (Daniel, 1999):

$$n = \frac{N*X}{(X+N-1)} \tag{1}$$

where, $X = Z_{a/2}{}^2 * p * (1-p) / MOE^2$ *and* $a = 0.05$

In Equations (1), *n* is the sample size, *N* is the population size, *Z* is the critical value for a confidence level of 95% in the normal distribution, *MOE* equals the margin of error, and *p* represents sample proportion.

A sample size of 341 was calculated from the estimated population of the Nduba sector, and the population size in the study area was 25,370. An interview included 341 households within 1km from the landfill, the average size of a household is 4.0 (NISR, 2012), and the number of heads of households (HH) to be interviewed was obtained by taking the sample size and dividing it by the average size of household (341/4=85 HH).

All the participants were interviewed from their homes and provided answers to the questions listed in the questionnaire. Respondents were selected based on the population distribution and assigned criteria. All of them were located in three cells: Muremure, Gasanze, and Gatunga. Geographic coordinates were used to provide the physical boundary of the site and the precise location of other geographical features to ensure the accuracy of the survey. Moreover, a group of public and private experts was interviewed to collect relevant information on their responsibilities in the management of the Nduba landfill. One professional staff member from CoK was interviewed in his office, and an email interview was used for an employee at the Water and Sanitation Corporation (WASAC) to respond to the questions sent to his email.

The study also used secondary data to analyze spatial features using ArcGIS 10 and ERDAS Imagine 14 in the description, mapping out, and change detection of the site to evaluate the spatial and temporal implications of solid waste disposal in eight years of its operation. Secondary data were collected based on the year of publication and image resolution (Table 2). Landsat images, orthophotos, and other spatial data of the site were used for better visualization and interpretation. Landsat images were freely downloaded from the USGS website with a resolution of 30m, whereas 10m and 25cm resolutions were used for the digital elevation model (DEM) and orthophoto, respectively. Other spatial data are accessed by public institutions such as the National Land Authority (former National Land Center), the National Institute of Statistics Rwanda, and the CoK.

2.3 Data collection

Primary and secondary data were used in this study. For the primary data, the focus was to acquire relevant field data from residents of Nduba and the authorities responsible for managing the Nduba landfill. A survey questionnaire (Appendix) was used to gather data about the attitude of government officials and Nduba residents vis-à-vis the landfill. The researcher helped respondents complete the questionnaire to ensure that all questions were responded well. Additionally, a face-to-face interview was conducted with a senior official in the (CoK), and a set of questions was sent to the email of the staff of the WASAC to make it easier to understand the entire operation of the Nduba landfill.

The study used different secondary data collected from various sources (Table 2), which allowed the authors to understand the spatial and temporal changes in the Nduba landfill over a certain period and the social-environmental implications in the vicinity.

Research techniques and methods were formulated based on the research objectives. Different methods were applied because this study has three potential research objectives. The first objective was to emphasize spatial changes during the eight years of the Nduba landfill operation. Landsat images were manipulated to reveal land use and land-cover changes. The image classification method provides a precise change in the area of interest.

The other point is that the Nduba landfill should have a systematic method of handling solid waste disposal. Therefore, the second objective was to compare the Nduba site with the ideal landfill site. The criteria for an effective landfill compared to the Nduba site were elaborated. Building on this, several spatial data, namely, building footprints, agricultural land use, elevation, and hydrological and road networks, were used and processed in ArcGIS 10 to examine the suitability of the site. Moreover, interview and observation techniques were used to collect qualitative data from the target population within 1 km of the site.

Data Type	Year	Resolution / Accuracy	Source
Landsat images	2001, 2015, 2019	30 m	Earth explorer-United State Geographical Survey
Digital elevation model	2009	10 m	National Land Authority
Ortho-photo	2009	25 cm	National Land Authority and National Institute of Statistics Rwanda
Administrative boundary	2006	-	National Institute of Statistics Rwanda
Slope, roads, and rivers	2012-2020	-	National Land Authority National Institute of Statistics Rwanda
Site boundary	2018	-	City of Kigali

Table 2: Summary of the secondary data source used in this study

Face-to-face interviews were also conducted with the CoK and WASAC employees and site workers in charge of managing the Nduba landfill to assess where the landfill has all the potential attributes of a sanitary landfill. The third objective is the handling process and socio-environmental impact. The study collected and assessed respondents' opinions using a Likert scale method. The rating scale ranged from 1 to 5 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

2.4 Data analysis

The data analysis included ArcGIS, ERDAS Imagine software, and other statistical analyses. All spatial data were analyzed using ArcGIS 10 by creating specific layers for each feature, such as slopes, road networks, hydrology, and environmentally protected areas (in shapefile format). Moreover, overlaying maps using the weighted overlay method for each criterion provides a detailed site suitability analysis. Spatial indicators of an effective landfill in comparison with the Nduba status were examined using a spatial multi-criteria analysis technique. Qualitative data were collected using interview and observation methods, and the analysis involved investigating similarities and differences regarding all defined criteria. Through research observations, notes were taken from the respondents' reactions and views.

The analysis of change detection at the site involved comparative analysis. The technique ensures that the images are classified into specific classes using the same projection system (Maina et al., 2020). In the process of change detection using ERDAS Imagine 14, at least four major steps, such as; image preprocessing, classification of an image, land use/cover, and eventually change detection, were followed (Hegazy & Kaloop, 2015). First, Landsat images were classified using an unsupervised image classification technique. The land cover and use of the study area were classified into five classes: built-up areas, trash lands, bare lands, forest lands, and grasslands. Each class shows a variation in percentage. The image types were classified using Landsat 8 OLI/TIRS C2 Level-2.

3. Results

3.1 Characterization of the Nduba site

As introduced in previous chapters, the site is located in the Gasabo District of Nduba. It is also hundreds of meters from the Nduba head office sector. The area of the landfill was 14.4 ha (1.54 km^2). However, the future site was set to extend 400 m from the actual site (Figure 2). Nearly the entire area was designated for solid waste disposal. All types of solid waste are brought in using waste trucks operated by private companies commonly known as "cooperatives." Site workers separated degradable solid waste from non-degradable solid waste at discharge points. In all three districts of Kigali, 14 private companies were responsible for transporting solid waste to the site using garbage trucks. However, the precise estimation of waste produced and transported by those companies remains unknown.

The separation of waste at the site is done not only to reduce the volume of waste but also to increase its recyclability. Construction machineries, such as excavators and bulldozers, squeeze up garbage materials simultaneously to make way for garbage truck operations.

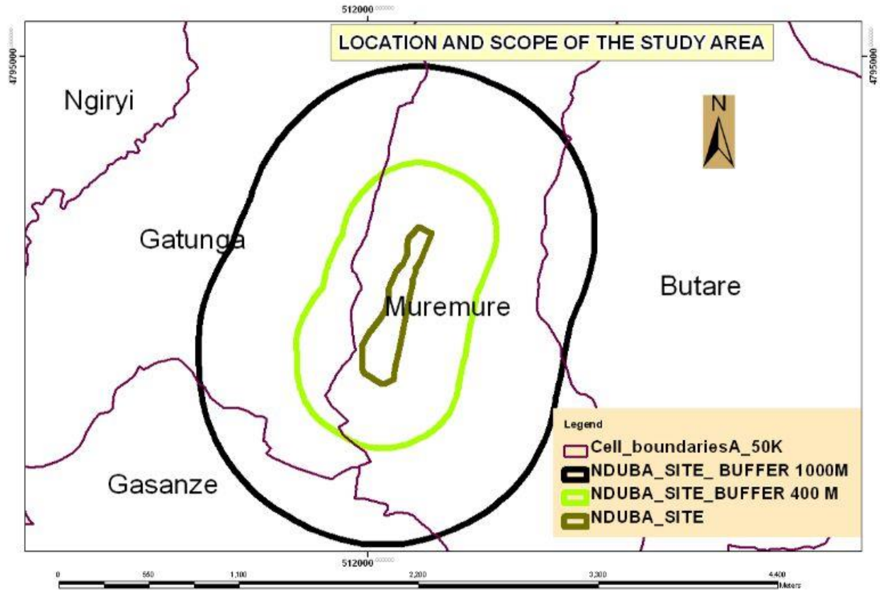


Figure 2: The Nduba landfill boundary and scope of the study

It was reported that the site was initially used as an open dumping site, similar to the same way as previous landfill in Nyanza. Subsequently, it became overloaded with the amount of waste generated in Kigali. The CoK decided to call private companies to manage and enhance sanitation and safety. In Figure 2, the site is designed with components such as main and access roads, wastewater and fecal sludge ponds, filled ponds, a stock of sorted materials, a landfill for solid wastes, leachate drains, and leachate pits.

3.2 Past and current status of the study area

3.2.1 Land use and cover

Over the past few years, land cover in the study area has changed because of the increase in human activities and the amount of waste produced in the city. Such a change can be observed when comparing its previous satellite images. Generally, the land within the study area was previously used for agricultural and residential purposes. As a countryside place, land prices seem low for low- and middle-income earners.

The land cover of the study area using Landsat images from 2001, 2015, and 2019 indicated built-up areas, forests, open land, and bare land in colors of red, dark green, green, and yellow, respectively, as shown in Figures 3, 4, and 5. The gray color indicates the trash land in the images from 2015 and 2019. It is clear that there is no trash land in the area. Instead, the land was bare in 2001. Moreover, the built-up area was relatively small compared to the years after 2001.

Three years after the establishment of the site, the 2015 satellite image shows a large garbage area. Such changes in land cover can also be seen in Gasanze and Gatunga (southwest of the study area). Forest and bare land largely changed into built-up area use of land (top left). Furthermore, between 2001 and 2015, a considerable decline occurred in the land used as forests.

For the land cover in 2019, the size of the landfill site did not change significantly compared to that in 2015. However, what is seen in the eastern part as trash land (gray color) is liquid waste disposal located outside the official boundary of solid waste. The figure for 2019 indicates that the forest zone (green) is quite close to the built-up area (red). However, a few non-residential housing units (also in red) can be seen in landfill sites used by landfill management companies.

3.2.2 Accuracy assessment of classified images

Deferential GPS was used to collect ground data for evaluation accuracy. All five physical land types were taken with their respective ground positions for comparison with the refracted colors of the image after classification. The overall classification accuracies of the images from 2001, 2015, and 2019 reached 86.00%, 87.33%, and 89.33%, respectively (Tables 3). The built-up area is highly reflected with an accuracy of more than 90%, whereas trash land remained consistent at 80% in 2015 and 2019.

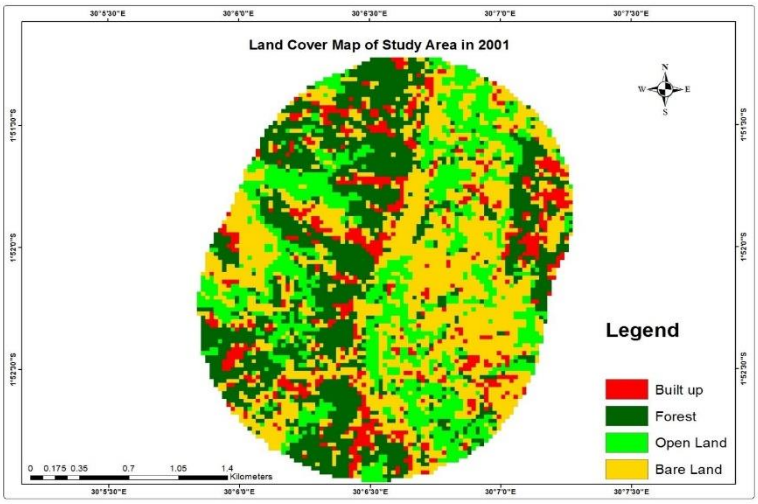


Figure 3: Land cover of the study area in 2001.

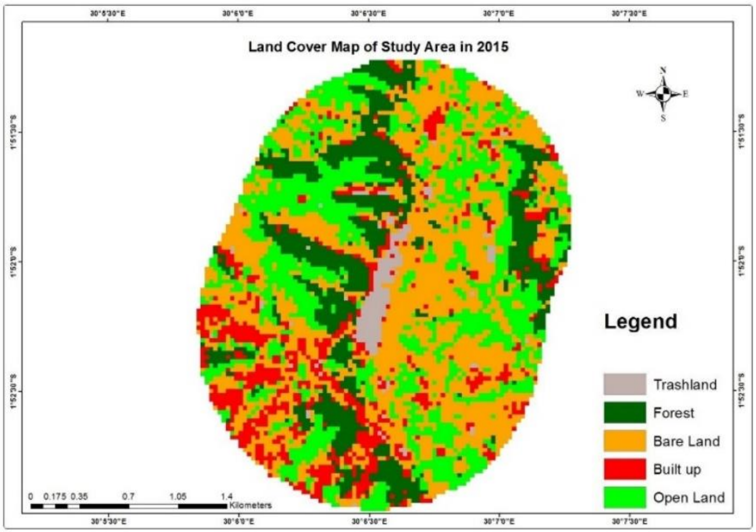


Figure 3: Land cover of the study area in 2015

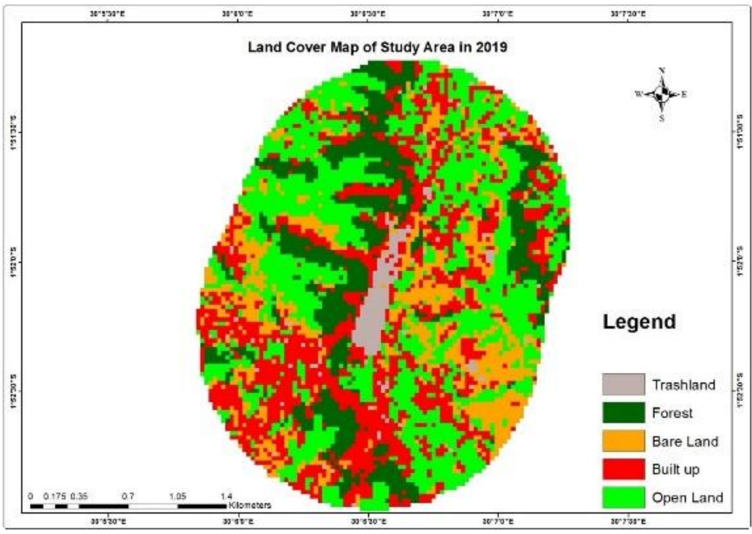


Figure 4: Land cover of the study area in 2019

3.3 Change detection of the Nduba site

Land use/cover change was assessed using the combined Landsat images of 2001, 2015, and 2019, as shown in Figures 6, 7, and 8. The technique involved changing one class to another and unchanged four land cover types. The results in Table 4 show that the land use/cover categories changed in terms of area and percentage. Trash land changed from 16.45 ha in 2015 to 18.79 ha in 2019 (a surplus of 4 ha of the actual size). The possible source of this error is more likely due to the accuracy of the image reflection. The reason for this growth is that there is no proper way to control the situation. There was a massive increase in built-up area from 69.21 ha to 187.56 ha, from 10.58% to 28.69% of the entire study area. Forests were one of the most affected land use/cover types in the study area. The reduction in the area of forest was 199.89 ha in 2001 to 104.49 ha in 2019, from 30.58% to 15.98 % of the entire area. The change in open land could be seen as an increase of 14% in the area from 2001 to 2019, whereas bare land reduced considerably by approximately 20% in the same period. During the survey, agricultural activities occupied a large area. It could be justified by the increased open land owing to fertile land.

year	Class name	Reference total	Classified total	Number corrected	Producers accuracy (%)	Users accuracy (%)	
2001	Unclassified	31	30	30	-	-	Overall Classification Accuracy = 86.00%; Overall Kappa Statistics = 0.8253
	Built-up area	28	30	24	85.71%	80.00%	
	Forest	29	30	25	86.21%	83.33%	
	Open land	28	30	24	85.71%	80.00%	
	Bare land	33	30	26	78.79%	86.67%	
	Totals	150	150	129			
2015	Unclassified	25	25	25	-	-	Overall Classification Accuracy = 87.33%; Overall Kappa Statistics = 0.8480
	Trash land	22	25	20	90.91%	80.00%	
	Forest	23	25	21	91.30%	84.00%	
	Bare land	24	25	20	83.33%	80.00%	
	Built-up area	32	25	24	75.00%	96.00%	
	Open land	24	25	21	87.50%	84.00%	
	Totals	150	150	131			
2019	Unclassified	25	25	25	-	-	Overall Classification Accuracy = 89.33%; Overall Kappa Statistics = 0.8720
	Trash land	22	25	20	90.91%	80.00%	
	Forest	25	25	23	92.00%	92.00%	
	Bare land	24	25	21	87.50%	84.00%	
	Built-up area	32	25	24	75.00%	96.00%	
	Open land	22	25	21	95.45%	84.00%	
	Totals	150	150	134			

Table 3: The accuracy assessment of the classified image of 2001,2015 and 2019

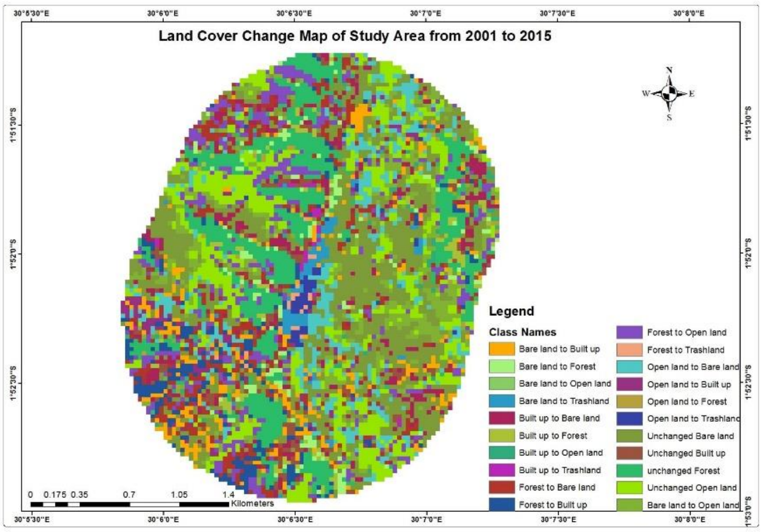


Figure 5: Land use and cover change from 2001 to 2015

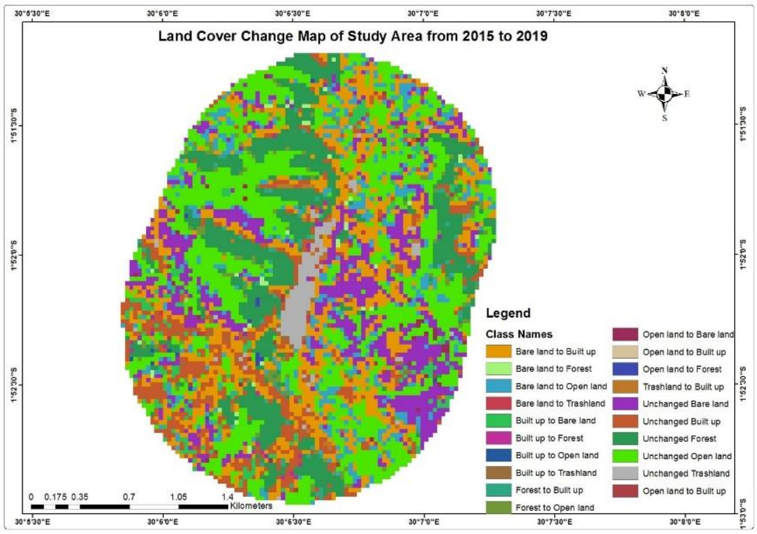


Figure 6: Land use and cover change from 2015 to 2019

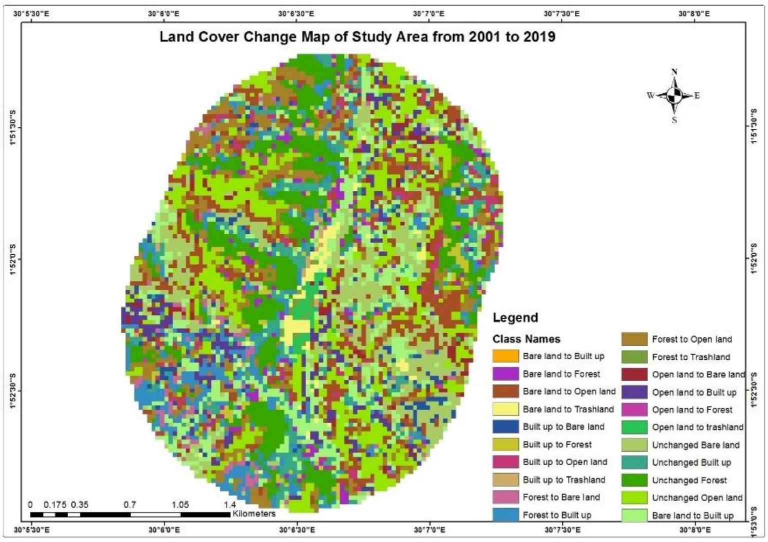


Figure 7: Land use and cover change from 2001 to 2019

Land use Categories	2001		2015		2019	
	Hectares	%	Hectares	%	Hectares	%
Trash land	-	-	16.45	2.82	18.79	3.18
Built-up area	69.21	10.58	81.9	12.53	187.56	28.69
Forest	199.89	30.58	114.48	17.51	104.49	15.98
Open land	143.55	21.95	179.28	27.42	234.54	35.87
Bare land	241.2	36.89	259.74	39.72	106.47	16.28
Totals	653.85	100	653.85	100	653.85	100

Table 4: Change detection of the study area

3.4 Spatial multi-criteria assessment of the Nduba landfill

3.4.1 Residential area

The study identified the housing units within the study area. Large concentrations of these units were identified on the east and west sides of the site, while others were scattered. Most interviewees reported that houses have three to four bedrooms in single-family housing units. Most of the respondents indicated that their land and properties were situated in the official delineation of the landfill.

Few stay there for occupational reasons. Although the site is located on the outskirts of the city, the land is used for a mix of residential and agricultural activities. Ongoing expropriation within 400 m has started since the establishment of the site. The CoK promised them to be relocated to the remaining cities in the near future.

3.4.2 Road networks and accessibility

Each waste truck took one main road passing through the Gasanze center to the Nduba landfill. A road with a width of 5 to 6 m is insufficient to allow a smooth flow of trucks and other vehicles. It has been reported that during heavy rainy seasons, some company vehicles, particularly those in old conditions, cannot be used because of poor road conditions. Another concern of the road is the heavy dust blown out toward housing units alongside the roads. Inadequate roads and safety are other concerns for pedestrians and Nduba residents. One of the interviewees stated that a number of accidents occurred because of the absence of road enforcement regulations and a lack of improved road conditions. No road accessing the site had a sewage system, as shown in Figure 9 below.

Figure 8: Garbage truck transporting solid waste to the Nduba landfill site

3.4.3 Distance to environmentally sensitive areas

Water sources were identified in the surroundings of the site. These elements present the potential and uniqueness of an area for mitigating environmental impacts. Several trees were identified near the site, and the distance from the site was ≤ 20 m. Respondents argued that old trees used as traditional medicine were cut off during site extension from 2014 to 2016 (Figure 10).

Figure 9: Trees and grassland surrounding the site

3.4.4 Slope of the Nduba landfill

The Nduba landfill is located at the top of Muremure Mountain. The slope of the study area ranges from 0.7% to 68% (Figure 11). However, the sensitivity of landfill smell and water runoff greatly impacts the Nduba community. Residents located on high slopes suffer from bad smells than those located on low slopes.

Therefore, those located in the eastern part of the site are less likely to experience bad smells and truck noise because the wind direction is east to west.

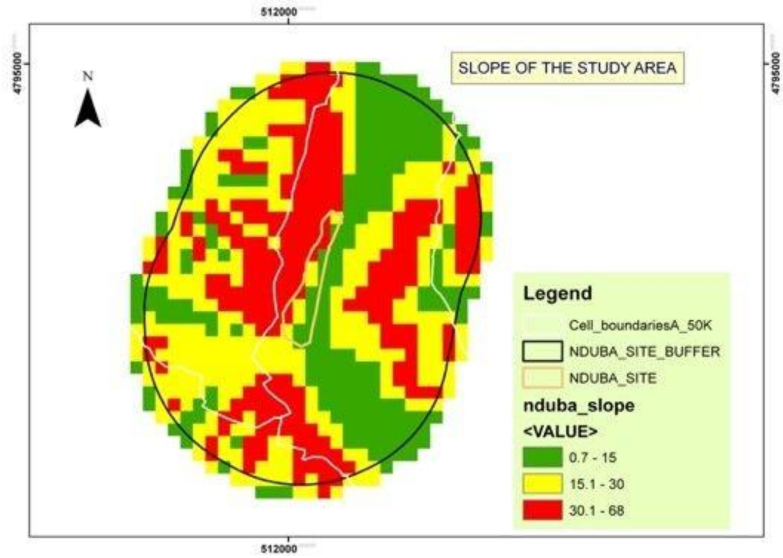


Figure 10: Slope map of the study area

The interviewees located on the western side of the landfill urged that the situation became unhealthier during the rainy season. Those identified were found in the Gasanze and Gatunga cells. Water runoff often carries solid waste from a site to its neighborhood. Precipitation also presents other challenges for accelerating waste leakage toward residential compounds. Despite this concern, landfills have no retaining facilities to block solid waste leakage and other materials (Figure 12). The sloping terrain of the view side of the Gasanze and Gatunga cells is steep compared with any other side of the landfill. During the rainy period, the soil covering the dumped material could slide downward, leaving garbage uncovered.

Figure 11: Layer of laterite soil covering the solid waste

3.5 Suitability analysis of the site

Different spatial criteria were investigated to determine the suitability of the site. The spatial attributes presented in Table 1 were used with weighted overlay methods. The produced suitability maps reveal the interconnection between criteria ranging from unsuitable to most suitable within the study area (Figures 13 through 16). The findings showed that almost the entire site boundary was located in the least suitable area. However, additional attributes could be important for the analysis and indicate that the site is not suitable for its location.

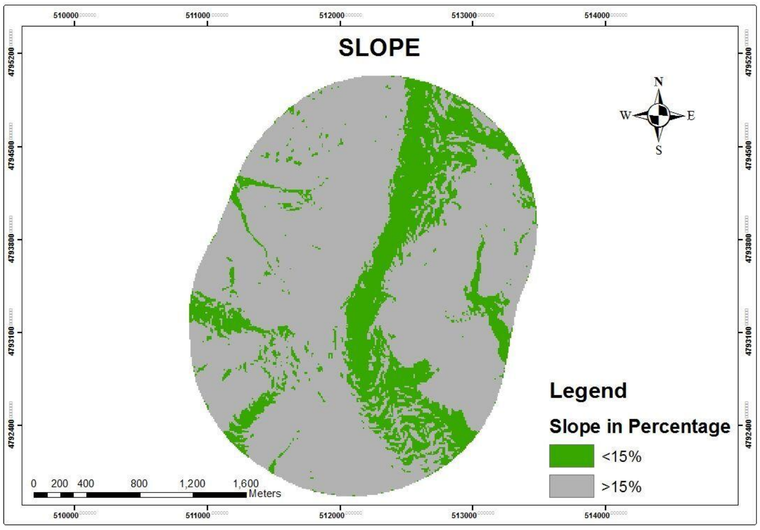


Figure 12: Slope analysis of the landfill

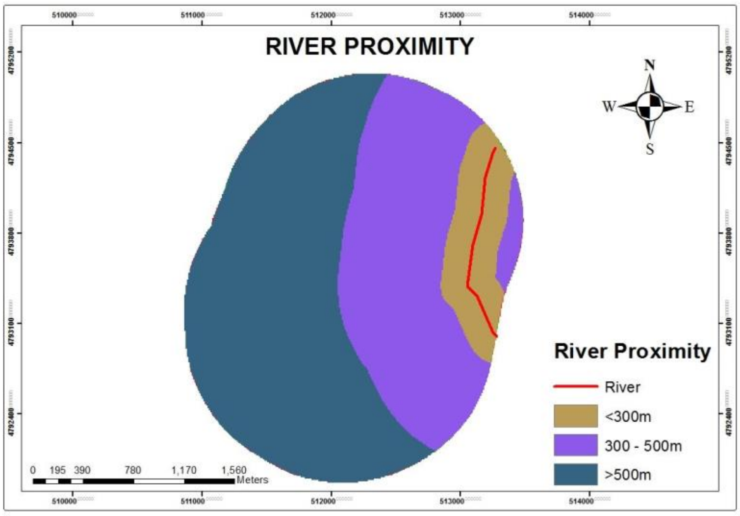


Figure 13: Suitability analysis of the river vis-à-vis the landfill

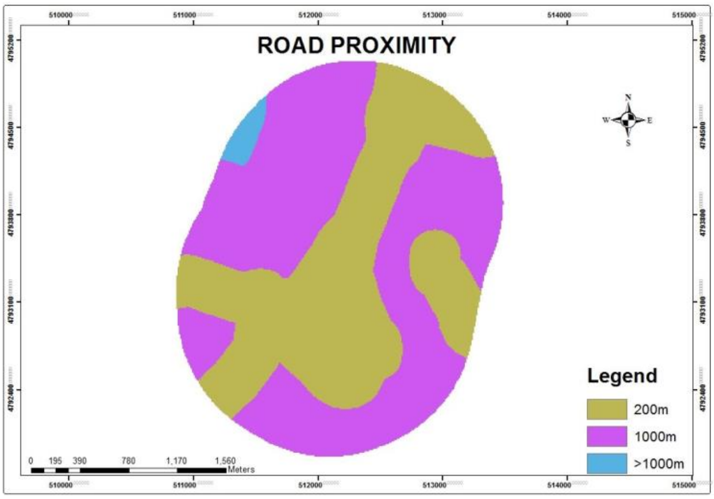


Figure 14: Suitability analysis of the road vis-à-vis the landfill

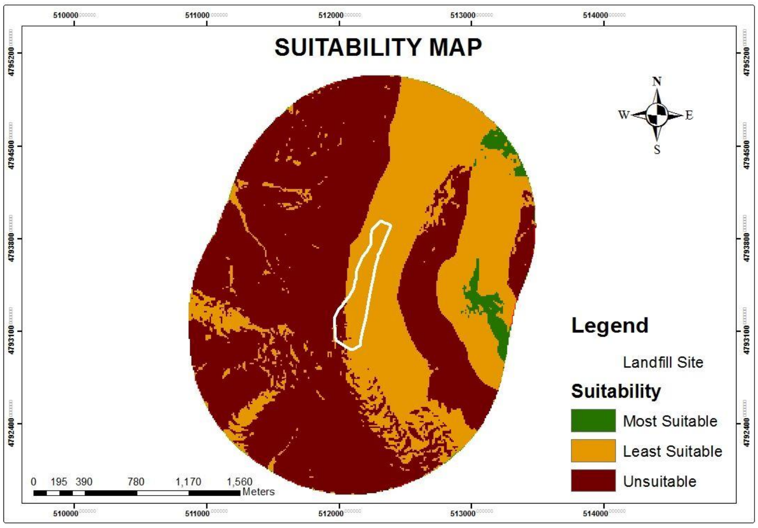


Figure 15: Suitability analysis map of slopes, rivers, and roads

3.6 Summary of the overall results from the interview and field survey

3.6.1 Solid waste handling process in the Nduba site

The study aimed to determine the process used to handle solid waste in a Nduba landfill. Depot Pharmaceutique et Materiel Medical Kalisimbi(DPMMK) is a company in contact with the CoK, which manages solid waste on-site. A semi-structured interview with Urayeneza Ildebrand, an employee of the company, reported that 70 to 100 garbage trucks discharge solid waste daily. All trucks came from different private companies transporting waste. More than 165 people are employed on-site, five are permanent, and the others are responsible for sorting solid waste.

In practice, the sorting process starts when garbage trucks offload waste. The bulldozer pushes solid waste into discharge zones that are specified on-site. The workforce starts sorting out the garbage for further use, mostly organic waste. Materials, such as plastic bags, bottles, and non-degradable items, are stored in the designed area. The other materials were separated for recycling purposes. The remaining materials are flattened under the laterite soil when sorting is performed using bulldozers and compactors. Each vehicle must be recorded and directed to a discharging point to avoid inappropriate disposal and facilitate garbage trucks at the landfill entry point. Poor waste management appears to be associated with waste collection companies, particularly services that are sometimes irregular due to limited trucks(Akimanizanye et al., 2020).

3.6.2 Role and responsibility of the CoK and WASAC

As mentioned earlier, the CoK and WASAC are public institutions responsible for managing landfills. However, CoK (which authorized this study was responsible for managing solid waste). Among them are contract management and regular on-site inspections. Mugabo John, an employee in the CoK in charge of solid and liquid waste management, stated that the site has a periodic inspection plan conducted by an inspection team working daily on site, and the CoK and WASAC coordinate it. The inspection team evaluated its performance using the daily reporting system for solid waste disposal. However, because of the confidentiality of these reports, such data were unavailable for this study. These results reflect those of Rajashekar, Bowers, & Gatoni(2019), who also found that the whole system of SWM operations remained challenging to be understood, especially in the public institutions listed above and private waste collectors who work together. Little access to data on-site also remains an issue. The contracted company that operates the facility would first request approval from the City of Kigali to collect or share data.

The CoK is also in charge of awarding a contract to a private company to operate all site work. However, the company's responsibility was limited to the internal activities of the landfill site. The expropriation of residents located 400 m from the site was an ongoing activity before the establishment of the site. It is estimated that approximately 500 households and landowners have been expropriated to date.

3.6.3 Ideal landfill attributes compared to the Nduba site

Another objective of this study was to compare typical sanitary landfills and the Nduba landfill. The interview was conducted in the WASAC, the institution in charge of sanitation in the Nduba landfill. Assessment using several indicators includes the following: master plan and zoning regulations, weather conditions, water quality, accessibility of covering materials, impact on environmentally sensitive areas, and future expansion plan of the site (Walsh & O'Leary, 2002).

To compare the Nduba site with an ideal landfill site, Amos, a WASAC staff member, was interviewed on May 15, 2021, via his email. He revealed that the facility complied with the current master plan and zoning regulations. He also affirmed that the site was accessible to waste trucks under different weather conditions. However, it has been suggested that there is potential contamination of groundwater quality, and the landfill smell is uncontrollable. The interviewee strongly affirmed whether the site had access to soil-covering materials. He further confirmed that the site strongly impacts environmentally sensitive areas. However, he strongly agrees that there is space for the future expansion plan of the site.

Despite the score of each of the seven indicators assessed, five met the criteria, whereas three failed to meet the conditions of an ideal solid waste disposal facility. Thus, it is evident that the performance of the Nduba landfill is relatively high in accessing soil, which is used to cover the landfill's solid waste. With the newly revised Kigali Master Plan of 2020, the site respects its regulations. However, this document does not indicate the future expansion zone. The results also suggest that the odor of the landfill was controlled and did not reach nearby residents. However, the performance in protecting environmentally sensitive areas, providing sufficient site space for future expansion, and avoiding groundwater contamination are deficient in the Nduba landfill.

3.6.4 Community perspectives on the Nduba landfill

Nduba residents raised several issues that need to be addressed by the authorities and companies in charge of managing the site. Most informants responded that it is unpleasant to inhabit close to the site, with 91% saying that it is uncomfortable to live near the landfill. Landfill smell is inevitable for a community reach; according to the respondents, it goes beyond the study area. Residents residing in Kibungo Village in Muremure reported experiencing a bad smell and immense flies, locally known as "*amasazi*" from the site. Moreover, 89% of the respondents confirmed the same issue. In accordance with the present results, a previous study has demonstrated that accumulation and poor waste management affect rats, flies, and other insects, likely to cause infectious diseases (Kabera, 2020). Gatunga residents, who were most exposed to waste leachates, expressed concerns about the possible contamination of Nyabagendwa stream water sources.

The lack of a secure fence at the site has been regarded as another critical challenge to retaining garbage on-site. The intruders, looking at whether they could find valuable items on-site, played an essential role in scattering waste out of the official boundary. Without being precocious, some waste materials can harm human health when they are not appropriately handled.

The site has also become a feeding site for wild dogs, endangering the safety of Nduba residents and their livestock. According to the respondents, several cases have been identified of dogs that attack and kill farmers' livestock. Despite local government efforts to resolve these issues, they have been hunted down and killed. However, the approach is far from successful because the problem has not been resolved.

When asked whether residents in the vicinity of the site were being relocated for their willingness, they responded that they had never known anyone who left their neighborhood to go and live in other places because of the landfill issue. No one has left for such a reason; however, few people are coming to dwell in the area, as confirmed by six respondents. As presented in Table 7, the built-up area has remarkably increased around trash land in the past years. The study found that more than 70% of the respondents have been living in Nduba for the last four to seven years.

They pointed out several reasons for the pulling factors. One explanation is that land is cheap compared to inner-city land. Second, the land was acquired for mixed-use (residential and agriculture), reasonably practicable in peri-urban areas, and in some cases, for commercial purposes (buying and selling), houses, and land. Another reason highlighted is that before 2013, Kigali had no master plan, which was somehow an opportunity for many, mostly with low income, to construct their house without any requirement or restriction. The suggested solutions from Nduba residents to prevent this situation are more oriented toward reinforcing government regulations. Others suggested that the case will be complicated if nothing is done soon because relocating people is not a long-lasting solution without considering groundwater contamination and air pollution.

Regarding how they perceive the landfill, nearly 60% felt it was not good and did not bring anything good to them apart from being hindered by its presence. Others suggest that the facility contributes to their livelihood, with 20% urging that it provides employment opportunities for low-income earners. Previous spatial analysis indicates that many people have moved within a few kilometers of the landfill decade. This growth is another concern in safety and planning. These results suggest that those who live at 400 m and outside tend to be exposed to landfill impacts. A comparison of the findings with those of Akimanizanye et al. (2020) confirms that rain contributes to solid waste slides toward residential areas located 400 m from the landfill. These results also match those observed by Tumwizere et al. (2017) suggested that the leachate generated from the landfill site ended up in the surrounding environment and could contaminate groundwater quality.

What emerges from the results reported here is that;

a. Using satellite images, the landfill site has grown in size over the last decades.

b. Even though authorities around the landfill have established a buffer of 400 m, it remains evident that the socio-environment impacts are likely to happen 1000 m from the current landfill's boundary.

c. The results indicated poor waste handling at the site, from waste collection to disposal.

d. The survey results indicated that residents nearby the site are more exposed to health risks and consequences.

4. Conclusion and Recommendations

The study mainly investigated the spatial changes in a landfill site that occurred before and after its establishment. However, such changes have led to social and environmental impacts on the surroundings of the site. These impacts were assessed using multiple criteria and Landsat imagery. The change detection findings provide insights into land use and cover changes. The overall results of the change detection show that forests and bare lands dramatically decreased, whereas trash land, built-up areas, and open land increased until 2019.

Dumping useless material underground is seen as an "*inefficient*" way of handling solid waste (McDougall et al., 2008). It is a common method of solid waste disposal in Nduba facilities. Three potential objectives of this study were considered in the data analysis. The primary objective was to focus on spatial changes before and after landfill establishment. The results indicate that there has been a significant change in trash land, built-up areas, forests, open land, and bare land in recent years.

The second objective of this study was to assess solid disposal based on the attributes of an ideal landfill. The findings demonstrate that the site scored low in affecting groundwater quality and environmentally sensitive areas. Regarding spatial attributes, the results revealed that the site leachates downward the Gatunga and Gatunga cells in the slope area. Accessibility to the site is narrow, and road conditions are poor. The lack of a drainage system for rainwater runoff can damage the site's main road and lead to road accidents. In addition, the report provides comprehensive suitability of combined criteria, such as road and river proximity, as well as the slope of the Nduba site. Given the limited resources, data availability, and scope of the study, it is worthwhile to investigate the suitability of the site. Additional attributes from different datasets, such as temperature, weather conditions, and soil type, are critical in landfill suitability analysis.

The third objective of this study was to focus on the handling process, human resources, and equipment used after the on-site discharge of solid waste. The findings indicate that waste is separated using human hands, and heavy construction machines assist in covering the remaining materials with laterite soil. Eventually, this mechanism was found to be inappropriate. For instance, in the rainy season, the leaching of protected materials occurs downward in residential areas.

Before this study, it was difficult to identify who was more or less affected by landfills. Therefore, this study suggests that a buffer of 400 m from the landfill to the residential area is insufficient. The buffer could be extended above 400 m, considering the significance of socio-environmental implications. Some residents consider landfills a source of financial opportunity for their livelihood. However, the implications of landfills can lead to socio-environmental damage. The CoK had affirmed that there was a plan to improve the facility to a modern level.

The interview results from the CoK, WASAC, and perceptions of Nduba residents demonstrated that solid waste disposal poses risks and challenges for the people of Nduba. The distance between landfills and residential areas is not sufficient to avoid harm. Much effort from public institutions is required to maintain waste inside landfills. Considering the significance of this issue, the safety of waste materials should be a priority in landfill management.

The physical boundary between the current and future expansion of the site needs to be demarcated to ensure the sustainability of the site. For instance, the outflows of waste material need to be retained, particularly on the side of the Gasanze and Gatunga cells, to avoid landfill leachates. The increase in built-up areas surrounding landfills could lead to environmental degradation. Trees must be protected because they are more exposed to waste chemicals. A buffer zone between the landfill and other land use activities was established to ensure the safety of materials from landfills. A new fence enclosing the site could prevent intruders and wild animals from penetrating the landfill.

It is essential to invite public participation at an earlier stage of any project that significantly impacts their lives. It is not the case for the Nduba residents. Before setting up a landfill site, a feasibility study could be a decisive tool in deciding whether to go with the project. In the case of the Nduba landfill, regulatory agencies should provide cost and benefit analysis, considering the cost related to expropriation and environmental costs to avoid a costly project. The lack of projection and data availability on landfill lifespan is crucial and can lead to underestimating socio-environmental consequences. Based on the CoK projection, the Nduba landfill is at 80% of its total capacity. It demonstrates that the available space is to continue creating layers of solid waste dumped inside the existing boundary.

Regarding landfill odor, WASAC affirmed that it was controlled; however, it was not disagreed with by some respondents in Nduba. It draws more attention to investigating this matter to explore the cause and who is affected in the area. It provides a safe working environment for site workers. An emergency preparedness office is required at the site to react in the event of an accident. The office could also be equipped with health experts and medical tools to examine the health effects of the landfill and those who are exposed to risks.

To increase the well-being of people residing near landfills, planting trees in the buffer zone decreases air pollution and the risk of respiratory diseases and increases clean air. Another advantage of afforestation is that it protects the soil in slope areas from land sliding during the rainy season.

Ongoing expropriation at 400 m from the site boundary started before landfill establishment. It means that some people did not receive compensation. As one respondent mentioned, since the expropriation started, he did not have the right to use his land, nor did he receive his promised money for his immovable properties. Fair and equitable compensation of residents' properties is recommended to ensure that resettled people will continue to improve their living conditions.

This study has found that, generally, a 400 m buffer is not enough for the safest of the community of Nduba. It is recommended to conduct research on which extent would be suitable for any human activities and environment to avoid landfill impacts in the near future. Since the landfill is considered an open dump site, furth work is needed to understand the implications of air pollution and leachates fully. The findings of this study have a number of important implications for future practice when selecting a landfill site. A further study could quantify the amount of waste produced, separated and non-separated, and assess the landfill site's long-term effects.

Acknowledgment

Thanks to CoK, WASAC, and DPMM KALISIMBI for their valuable contribution during data collection.

References

Ahsan, A., Alamgir, M., El-Sergany, M., Shams, S., Rowshon, M., & Nik Daud, N. (2014). Assessment of Municipal Solid Waste Management System in a Developing Country. *Chinese Journal of Engineering, 2014*, 1-11.

Buenrostro, O., Bocco, G., & Cram, S. (2001). Classification of sources of municipal solid wastes in developing countries. *Resources, Conservation and Recycling, 32*(2001), 29–41.

Chen, X., Geng, Y., & Fujita, T. (2009). An overview of municipal solid waste management in China. *Waste Management, 30*(2010), 716–724.

Daniel, W. W. (1999). *Biostatistics: A Foundation for Analysis in the Health Science.* New York: John Wiley & Sons.

Gahima, E., & Bizuhoraho, T. (2021). Sanitation for Sustainable Development in Informal Settlements in Kigali City,Rwanda: A synthesis of the evidence to inform policy and practice. Ielādēts 2023. gada 6. May no https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3788840

Garrod, G., & Willis, K. (1998). Estimating lost amenity due to landfill waste disposal. *Resources, Conservation and Recycling, 22*(1998), 83-95.

Ghose, M., Dikshit, A., & Sharma, S. (2005). A GIS based transportation model for solid waste disposal : A case study on Asansol municipality. *Waste Management, 26*(2006), 1287–1293.

Hegazy, I. R., & Kaloop, M. R. (2015). Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. *International Journal of Sustainable Built Environment, 2015*(4), 117-124.

Idowu, A. I., Atherton, W., Hashim, K., Kot, P., Alkhaddar, R., Alo, B. I., & Shaw, A. (2019). An analyses of the status of landfill classification systems in developing. *Waste Management, 87*(2019), 761-771.

Iraguha, F., Remalan, A. H., & Setyono, P. (2022). Assessment of current solid waste management practices, community perception, and contributions in the City of Kigali, Rwanda. *Earth and Environmental Science, 1016*(2022), 1-13. doi:10.1088/1755-1315/1016/1/012056

Jimoh, R., Chuma, V., Moradeyo, A., Olubukola, O., Sedara, S., Yusuf, A., & Jimoh, A. (2019). GIS Based Appraisal of Waste Disposal for Environmental Assessment and Management in Mainland Area of Lagos State, NG. *International Journal of Environment and Geoinformatics, 6*(1), 76-82.

Kabera, T. (2020). Solid Waste Management in Rwanda: Status and Challenges. *Research Gate*, 287-297. doi:10.4018/978-1-7998-0198-6

Khan, S., & Faisal, M. N. (2007). An analytic network process model for municipal solid waste disposal options. *ScienceDirect, 28*(2008), 1500-1508.

Maina , J., Wandiga, S., Gyampoh, B., & Charless, K. (2020). Assement of Land Use and Land cover change using GIS and Remote Sensing: A Case Study of Kieni, Central Kenya. *Journal of Remote Sensing & GIS, 9*(1), 1-5.

Makarichi, L., Techato, K.-a., & Jutidamrongphan, W. (2018). Material flow analysis as a support tool for multi-criteria analysis in solid waste management decision-making. *Resources, Conservation & Recycling, 139*(2018), 351-365.

McDougall, F. R., White, P. R., Franke, M., & Hindle, P. (2008). *Intergrated Solid Waste Magement: A Life Cycle Invintory.* John Wiley & Sons.

Memon, M. A. (2010). Integrated solid waste management based on the 3R approach. *J Mater Cycles Waste Management, 12*(2010), 30-40.

Mugiraneza, T., Ban, Y., & Haas, J. (2018). Urban land cover dynamics and their impact on ecosystem services in Kigali, Rwanda using multi-temporal Landsat data. *Remote Sensing Applications: Society and Environment, 13*(2019), 234–246.

Mukamana, J. (2021). *Iot based toxic gas detection and level of landfill.* Kigali: University of Rwanda.

Narayana, T. (2008). Municipal solid waste management in India: From waste disposal to recovery of resources? *Waste Management, 29*(2009), 1163–1166.

NISR. (2012). *Fourth Rwanda Population and Housing Census.* Kigali: National Institute of Statistics of Rwanda .

NST1. (2017). *7 Years Government Programme: National Strategy for Transformation(NST1).* Kigali: Goverment of Rwanda.

OAG. (2016). *Performance Audit Report on Management of Solid and Liquid(Sewage)Waste in City of Kigali.* Kigali: Office of the Auditor General.

Rajashekar, A., Bowers, A., & Gatoni, S. A. (2019). *Assessing Waste Managment services in Kigali* . jerry-can ltd. Kigali: International Growth Centre.

REMA. (2017). *Rwanda: State of Environment and Outlook Report 2017.* Kigali: Rwanda Environment Management Authority.

Robert, J., & Anderson, M. (1963). The Public Health Aspects of Solid Waste Disposal. *ational Solid Waste Research Conference,. 79*, lpp. 93-96. Chicago: Public Health Reports.

Sterner, T., & Bartelings, H. (1998). HouseholdWaste Management in a Swedish Municipality: Determinants of Waste Disposal, Recycling and Composting. *Environmental and Resource Economics, 13*(2010), 473–491.

Sumathi, V., Natesan, U., & Sarkar, C. (2007). GIS-based approach for optimized siting of municipal solid waste landfill. *Waste Management, 28*(2008), 2146–2160.

Tumwizere, P. R., Hategekimana, F., Niyibizi, A., & Senthil, K. (2017). Assessment of Leachate Effects on Groundwater and Soil from Nduba Land Fill in Kigali, Rwanda. *International Journal of Engineering Research in Africa, 33*, 68-75. doi:10.4028/www.scientific.net/JERA.33.68

Walsh, P., & O'Leary, P. (2002. gada 1. May). *Waste 360.* Ielādēts 2021. gada May no Waste 360 Website : https://www.waste360.com/mag/waste_evaluating_potential_sanitary

Weng, Y.-C., & Fujiwara, T. (2011). Examining the effectiveness of municipal solid waste management systems: An integrated cost–benefit analysis perspective with a financial cost modeling in Taiwan. *Waste Management, 31*(2011), 1393–1406.

Zaman, A. U. (2016). A comprehensive study of the environmental and economic benefits of resource recovery from global waste management systems. *Journal of Cleaner Production, 124*(2016), 41-50.

Authors

Alain Nkomezi
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea.
zindeghe@gmail.com

Francine Uwimbabazi
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea.
uwyfrancy03@gmail.com

Chunho Yeom (*corresponding author*)
International School of Urban Sciences, University of Seoul, 02504 Seoul, Korea.
chunhoy7@uos.ac.kr

Funds

This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2020S1A5C2A01092978).

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Nkomezi, A., Uwimbabazi, F., & Yeom, C. (2023) Socio-environmental impacts of landfill site in Nduba sector, Kigali, Rwanda. *Visions for Sustainability*, 20, 7161, 421-453. http://dx.doi.org/10.13135/2384-8677/7161

Original Paper

Fishing industries' oily wastewater biodiesel performance

Holanda Teresa Vivas Saltos, María Belén Cedeño Vargas

Received: 14 March 2023 | **Accepted:** 13 May 2023 | **Published:** 4 June 2023

Keywords: biodiesel, performance, quality, sustainability

Abstract. *In the context of developing biodiesel as an alternative energy source for replacing fossil diesel, this study aimed to assess how physicochemical factors affected the efficiency of the process for producing biodiesel from oily residues in fishing industry effluent. The oil extracted from the grease traps was initially characterized for the stabilization of the process's influential parameters, obtaining viscosities of 38 mPa/s, densities of 0.93* *g/ml, and saponification indices of 260.40 mg KOH/g. It was then necessary to neutralize the oil and dry it to reduce the oil's acidity to 0.97% and its humidity to 0.03%, in order to meet the conditions for subsequent transesterification. This led to the conclusion that T7 (80 ºC, 9:1, and 0.8%) was the best treatment. It produced a 94% performance of biodiesel extraction and had the following properties: acidity of 0.39 mg KOH/g, viscosity of 2.7 mPa/s, ashes of less than 0.02%, density of 883.7 kg/m3, flash point of 120 ºC, and cetane index of 41. However, it had a high water content.*

1. Introduction

Finding alternative energy sources is currently necessary due to the non-renewability of fossil fuels and their detrimental effects on the environment (Pasha et al., 2021). In this regard, biofuels have emerged as one of the most promising choices in recent years (Mishra & Mohanty, 2022). In terms of environmental, economic, and social sustainability, it is important to keep in mind that biofuels have both benefits and drawbacks. On the one hand, their main drivers globally are the reduction of greenhouse gas (GHG) emissions, energy security, and rural development (Canabarro et al., 2023). On the other hand, there are concerns about rising biofuel production include pressure on food costs, the possibility of increased GHG emissions from both direct and indirect land use change, and the potential of higher food prices.

Second generation raw materials are used to address some of these issues. However, the economic sustainability of some second-generation biofuels is still debatable in the current economic climate, partly because of the low price of oil (Chen et al., 2021). Some of the main benefits of biodiesel produced sustainably include: i) it reduces the life cycle greenhouse gases by an average of 74%; ii) it reduces hydrocarbon emissions by 67%; and iii) it returns 4.56 units of renewable energy for every unit of fossil energy used to produce biodiesel (Canabarro et al., 2023).

One of the widely used types of biofuel made from animal and vegetable fats, is biodiesel, which is regarded as an appealing replacement for fossil diesel. Biodiesel is utilized all over the world in its purest form (100%) denoted by B100 or in blends with petrodiesel as 5% (B5), 20% (B20), and 80% (B80) (Ameen et al., 2022). It is biodegradable, non-toxic, renewable, and devoid of benzene and sulfur (Knothe & Razon, 2017). These advantages have led to the production of 36 billion liters of biodiesel in 2017 and an estimated 9% rise through 2027 (OECD/FAO, 2018). In Europe, rapeseed and used cooking oil are the main feedstocks for biodiesel production. Argentina, Brazil, and the US also produce significant amounts of biodiesel, primarily from soybeans. Malaysia and Indonesia use palm oil. Biodiesel production more than tripled between 2008 and 2018, from 12 to 41 billion liters (Jarunglumlert et al., 2022).

Reviewing production methods and technologies, or how and what methods are used to optimize the processes that imply the rational use of agricultural inputs, involves analysis of the efficiency in the production of biofuels in Latin America. Forestry, organic waste, and technologies used in the production of first- and second-generation biofuels are among those reviewed (Acharya & Perez, 2020). Trindade et al. (2022) have analyzed in particular the method of turning oil into biodiesel with regard to the effectiveness of the procedure.

Alkali-catalyzed transesterification of fresh vegetable oils is the most popular and financially viable way of producing biodiesel on an industrial scale. However, using fresh edible oils as a feedstock account for more than 80% of the cost of producing biodiesel (Moya et al., 2019). Therefore, using alternate and less expensive sources of lipids, such recovered grease trap waste, is the main approach to lowering the cost of biodiesel manufacturing (Pasha et al., 2021). In this way, the utilization of oily waste products from the fishing industry ties renewable energy production to sustainability.

Large fishing industries have been established in the city of Manta, Ecuador, leading to significant environmental issues (Marn et al., 2015), including wastewater with high BOD levels, fish particles, and foams with oily characteristics from a variety of daily activities (Cedeño et al., 2020). 49% of these residues are made up of oils and fats (Trindade et al., 2022). Medina et al. (2020) classify this waste as of great interest because it is considered an alternative energy source capable of meeting the needs of the industry as such. Oily scums are typically collected in grease traps and placed in metal reservoirs for transfer to landfills.

In the light of these developments, the objective of this study is to assess the impact of physicochemical factors on the efficiency of the process for producing biodiesel from oily byproducts of the fishing industry. The utilization of a product from wastewater discharges during the processing of tuna gives the research considerable environmental significance, whereby this waste gets transformed into useable material (Mishra & Mohanty, 2022).

The proposed hypothesis focuses on proving whether the influence of temperature, molar ratio, and catalyst concentration increases the performance of the process in the extraction of biodiesel from oily residues. This enables verifying the quality of the biodiesel, so as to contribute to a cleaner production by fishing companies that have committed themselves to protecting the environment through supporting Objective 7 of the 2030 Agenda on Sustainability for the realization of accessible and clean energy.

2. Materials and Methods

This study uses an experimental design to examine the effects of temperature, molar ratio, and catalyst concentration on the biodiesel production performance made from oily waste collected in grease traps at a tuna firm in Manta canton, Manabi province, Ecuador.

According to Lopez et al. (2015), vacuum filtering through a quantitative filter paper no. 40, which can retain up to 25 m suspended particles, must be done if the acid value is less than 1%. It is advised to heat the oil to 80 °C to reduce viscosity.

By using the technique of discrete particle sedimentation and vacuum filtering through a quantitative filter paper no. 40 (capable of keeping suspended solids as small as 25 m), the initial composition of the material entering from the grease traps was separated. The biodiesel was heated to 80 °C before filtering to reduce viscosity (Onur et al*.,* 2018); The extracted oil was then evaluated using parameters such as density, viscosity, acidity index, and saponification index (Jarunglumlert et al*.,* 2022). This allowed the oil to be corrected and its quality to be improved through neutralization, washing, drying, dehydration, and filtering processes (Wang et al*.,* 2022). The following physicochemical analyses needed 1,000 cm^3 (1 liter) of the extracted oil:

- Moisture is determined by weighing the biodiesel after heating it to 105 °C in a stove and then putting it in a desiccator. The difference in weight is used to measure the amount of water or humidity contained in the sample.
- Viscosity: The volume of a liquid flowing by gravity through a calibrated glass capillary viscometer was measured in order to determine the

kinematic viscosity of the products obtained, both transparent and opaque.

- Density at 20°C:

$$\rho \frac{m_{v2} - m_{v1}}{v}$$

ρ = Density

m_{v2} = End mass

m_{v1} = Initial mass

v = Volume

- Acidity index:

$$Acidity\ index = \frac{V * N * 40 * 56{,}11}{P}$$

V = Volume of alkali solution (mL)

N = Normality of the titrated solution

P = Sample weight (g)

40 = Molecular weight of $NaOH$

56,11 = Molecular weight of KOH

- Saponification index:

$$IS = \frac{[(v_1 - v_2)EQ * N]}{m}$$

v_2 = Volume of hydrochloric or hydrogen sulfide used

v_1 = Volume of hydrochloric from blank test

N = Normality of the hydrochloric or hydrogen sulfide (0.5)

m = Mass of sample analyzed

EQ = Chemical equivalent KOH (56.11)

The oil treated in the previous activity was then transesterified using the equipment and methodology suggested by Valencia et al. (2018), which involves using a three-way balloon on a heating system (heating plate) with constant temperature control and a cooling system to prevent the volatilization of methoxide. As a result, the experimental units were processed under the conditions specified in the experimental design (Table 1), obtaining biodiesel samples as a result.

Treatments	Temperature	Molar ratio (MR)	Catalyst concentration (CC)	Amount of oil
T1	60 °C	6:01	0.80%	50 cm^3
T2	60 °C	6:01	1.30%	50 cm^3
T3	60 °C	9:01	0.80%	50 cm^3
T4	60 °C	9:01	1.30%	50 cm^3
T5	80 °C	6:01	0.80%	50 cm^3
T6	80 °C	6:01	1.30%	50 cm^3
T7	80 °C	9:01	0.80%	50 cm^3
T8	80 °C	9:01	1.30%	50 cm^3
				400 cm^3

Table 1. Approach to the experimental design corresponding to a 2^3 factorial arrangement, i.e., three factors (temperature, molar ratio and catalyst concentration) with two levels (high and low).

Subsequently, the biodiesel performance percentages of each treatment were calculated using the following equation (Gheewala et al*.,* 2022). The treatment with the best performance was characterized according to the proposed physical and chemical parameters (Gholami et al*.,* 2020).

$$\%\text{Performance} = \frac{\text{Biodiesel weight (g)}}{\text{Oil sample weight (g)}} \text{X}100 \qquad [1]$$

Inferential statistics were employed in the statistical analysis, and InfoStat, R-project[1], and SPSS software were used. This provided a better depiction of the descriptive and visual data. In addition, the analyses of residues, confirmation of

[1] Software used to evaluate the interaction effect and the response Surface.

the assumptions of normality, Shapiro-Wilk test, analysis of variance, and Tukey's test were performed.

3. Results and Discussion

The grease trap oil had the following characteristics: a humidity of 0.40%, a viscosity of 38 mPa/s, and it was within the ASTM-D445 standard's maximum allowable limit of up to 50 mPa/s. The findings of the oil density examination were 0.93 g/ml, and the oil's saponification index was 260.40 mg KOH/g. Additionally, an acidity of 3.63% was obtained. Therefore, it was essential to correct this parameter through the neutralization process, in which NaOH was added in accordance with the dosage established by Arenas et al. (2021), reducing the acidity to 0.97%. In this way, the necessary parameters were met prior to the application of the transesterification process (Table 2).

Parameter	Units	Oil obtained	Maximum limit	Treated oil
Moisture	%	0.40	0.05	0.03
Kinematic viscosity at 40 °C	mPa/s	38	50	
Density at 20°C	g/ml	0.93	0.96	
Acidity percentage	%	3.63	0.98	0.977
Acidity index	mg KOH/g	11.08	1.24	2.977
Saponification index	mg KOH/g oil	260.40	Not reported	

Table 2. Physicochemical characterization of the extracted residual oil.

According to the rules of the experimental design, the purified oil was put through the transesterification process at two levels for each variable being studied: temperature (60 and 80 °C), molar ratio (6:1 and 9:1), and catalyst concentration (0.8 and 1.0%). The volume of each treatment was converted to a percentage of the process' performance in relation to the volume of the initial oil, as in equation 1.

In contrast to the study by Kara et al. (2018), which obtained a 99.1% performance from fish residue oil using a 9:1 molar ratio and a 1% catalyst concentration, Figure 1 shows that the T7 treatment (9:1 molar ratio and 0.8% catalyst concentration) presented the best percentage of process performance with 94% in biodiesel extraction. The least successful treatments were discovered in T2 with 72.67% and T6 with an average of 65.3%. T5 was consistently found with an average of 89.33%; Q3 attained 84%; and the following figures exhibit commonalities between T1, T3, T4 and T8 with their respective averages of 80.67%, 84%, 80%, and 79.33%.

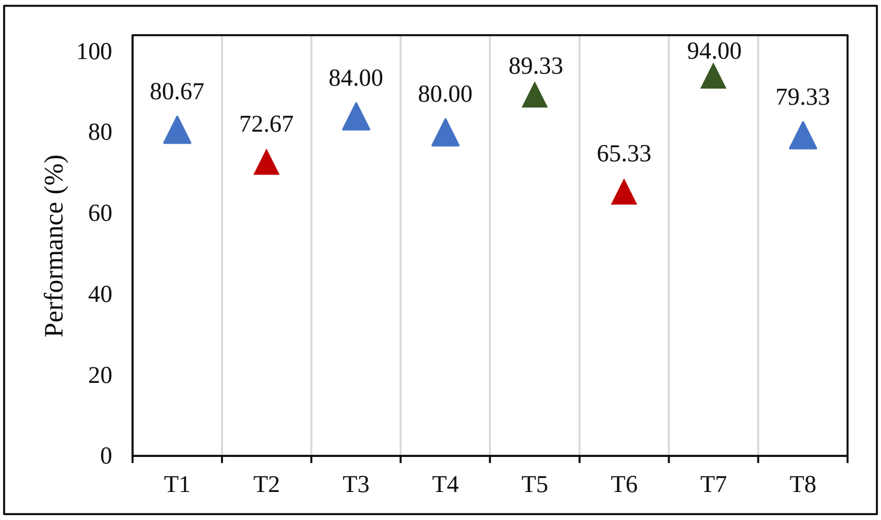


Figure 1. Comparison of the performance obtained according to the treatments.

The major impacts of the variables temperature (A), MR (B), and CC (C) exhibit significance between the levels used, with a p value less than 0.05, according to the analysis of variance of the components employed and their interactions (Table 3).

Temperature and MR (AB), temperature and CC (AC), and MR (alcohol/oil) and CC (BC) interactions were all carried out. It was discovered that the interactions between temperature and MR (AB), temperature and CC (AC), and MR and CC (BC) all showed a p value less than 0.05, presenting statistical significance. The interactions between temperature, MR, and CC (ABC), on the other hand, have a p-value of 0.114, indicating that their interactions do not provide significant means.

F.V	SC	DF	CM	F	P-VALUE
Model	1696	7	242.29	63.2	0.0001
MAIN EFFECTS					
A: Temperature	42.67	1	42.67	11.13	0.0042
B: Alcohol/oil molar ratio	322.67	1	322.67	84.17	0.0001
C: Catalyst concentration	962.67	1	962.67	251.13	0.0001
INTERACTIONS					
AB	24	1	24	6.26	0.0236
AC	266.67	1	266.67	69.57	0.0001
BC	66.67	1	66.67	17.39	0.0007
ABC	10.67	1	10.67	2.78	0.1147
Error	61.33	16	3.83		
Total	1757.33	23			

Table 3. Analysis of variance of the performance of the process.

Figure 2 illustrates the interaction effect between molar ratio (MR) and catalyst concentration (CC), which results in an 89% performance when the CC is low and the MR is high. In his research Avellaneda (2010) came to the conclusion that there must be a balance between the proportions of MR and CC, indicating having acquired a performance of 88.51% when combining MR 9:1 and CC of 0.8%, a figure that is close to 89% performance of the procedure obtained in the current analysis.

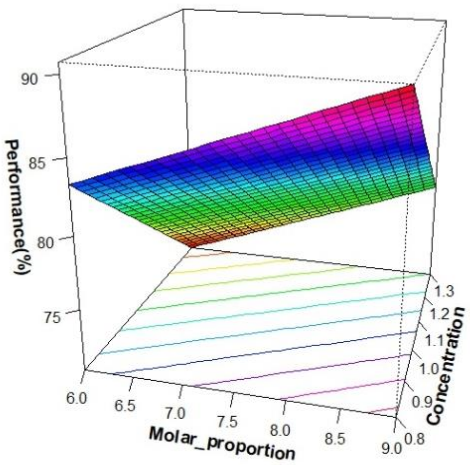


Figure 2. Response surface for biodiesel performance of the process in relation to the CC and MR.

An average performance of 86.7% (Figure 3) was achieved when temperature and MR interacted, emphasizing the high levels of temperature (80 °C) and MR (9:1), comparable to the condition described by Gómez et al. (2022), who attained a performance of 77.89% at 56 °C and a MR of 135:1.

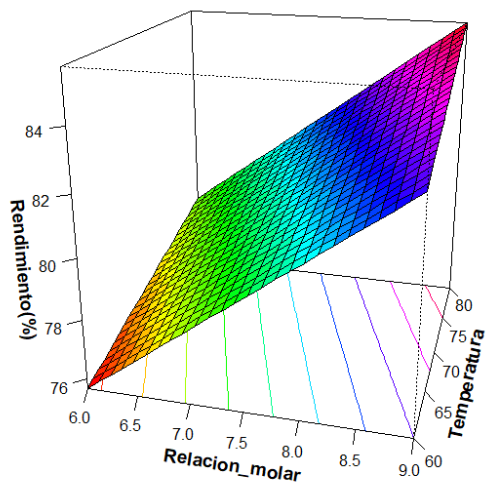


Figure 3. Response surface for process performance in relation to temperature and MR.

In the lowest concentration settings (0.8%), at the highest temperature (80 °C), the temperature and CC interaction effect showed an average performance of 91.67% (Figure 4). Caro et al. (2017) note that it is desirable to apply a CC of less than 1% and attribute this to saponifying materials that are created in excess of a catalyst (NaOH) and causing a deterioration in the performance of the process. Furthermore, Gomez *et al.* (2022) discovered that a temperature rise promotes performance at low catalyst concentrations, while a temperature increase has a detrimental impact on biodiesel performance when employing high catalyst concentrations.

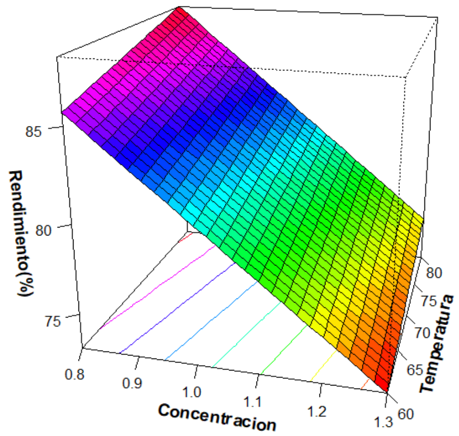


Figure 4. Response surface for process performance in relation to CC and temperature.

The treatment T7 (Temperature 80 °C, 9:1, CC 0.8) provided an average performance of 94.00% throughout the biodiesel extraction process, according to the results of the Tukey test for the treatments examined (Table 4).

TREATMENT	Mean	n	E.E	Group				
				1	2	3	4	5
T6 (1,3.6:1.80)	65.33	3	1.13	A				
T2 (1,3.6:1.60)	72.67	3	1.13		B			
T8 (1,3.9:1.80)	79.33	3	1.13			C		
T4 (1,3.9:1.60)	80.0	3	1.13			C		
T1 (0,8.6:1.60)	80.67	3	1.13			C		
T3 (0,8.9:1.60)	84.0	3	1.13			C	D	
T5 (0,8.6:1.80)	89.33	3	1.13				D	E
T7 (0,8.9:1.80)	94.00	3	1.13					E

Table 4. Tukey's test of the applied treatments.

The treatment T7 (Temperature 80 °C, 9:1, CC 0.8) provided an average performance of 94.00% throughout the biodiesel extraction process, according to the results of the Tukey test for the treatments examined (Table 4).

Additionally, a significant interaction between the factors AB, AC, and CB was discovered (Figure 5) when non-parallel lines were present in their relationship. This resulted in a demonstration of the prevalence of the levels of each factor specified in T7 (80 °C, 9:1, and 08%) and highlighted their greater influence on the efficiency of the biodiesel production process.

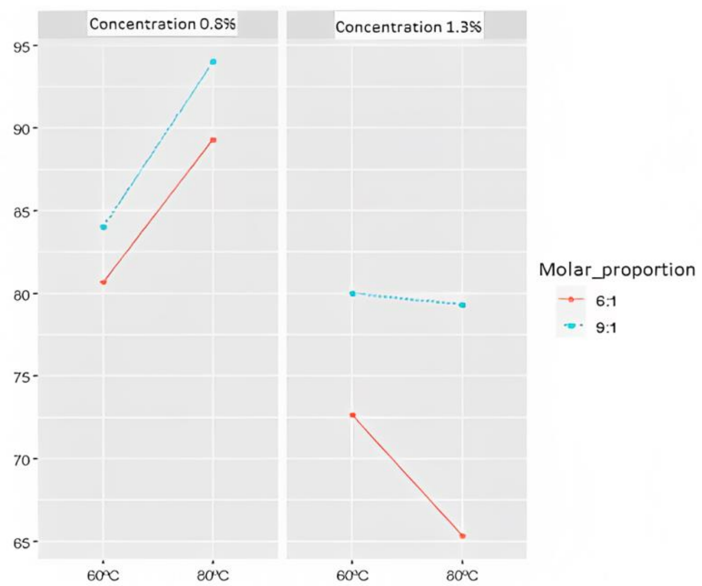


Figure 5. Interaction of the variables used to obtain the performance of the process.

The magnitude of the effects caused by the variables and any potential interactions are expressed in Figure 6, which shows that the CC variable is crucial for determining the percentage of biodiesel extraction. A surplus causes saponification, while a negligible portion results in a conversion deficit (Gomes et al., 2018). Similar results are obtained when the variable C, temperature, and factor B (molar ratio) are combined. Finally, the combination of factors A*B*C.

did not have a bigger impact on the performance percentage than factor A (Temperature).

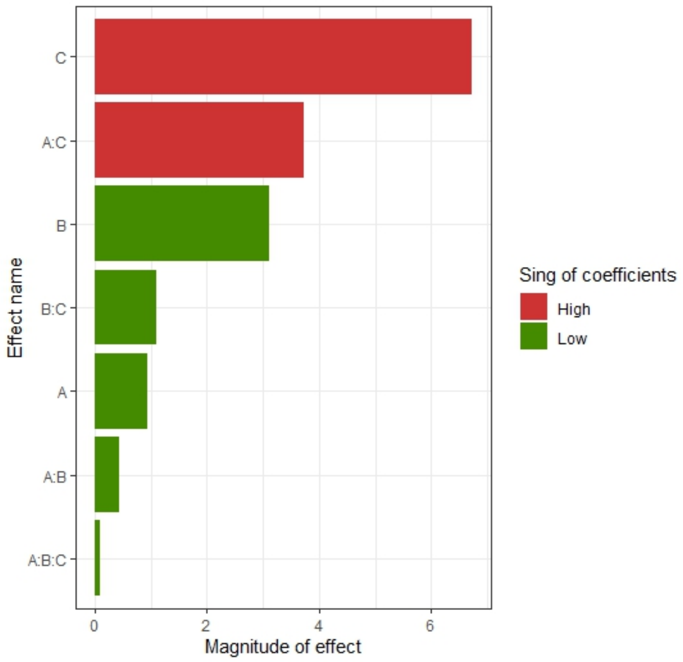


Figure 6. Pareto diagram of process performance. (A: Temperature; B: Molar ratio and C: Catalyst concentration).

The volume of the effect of the catalyst concentration is consistent with that reported by López et al. (2015), who found that the amount of catalyst used affects saponification because of the presence of sodium and its electronegative power. Rahman et al. (2022) also investigated the effect of the amount of catalyst and found that using a concentration close to 0.5% results in a higher performance of biodiesel.

The biodiesel with the greatest performance percentage (T7) is characterized in Table 5, and its density of 883.7 kg/m3 is within the acceptable range for a biofuel (biodiesel), which is between 860 and 900 kg/m³ (ASTM D6751 and EN14214).

The water content value was 560 mg/kg, which is more than the 500 mg/kg upper limit. Murcia et al. (2013) discovered comparable values of 516 mg/kg in biodiesel made from waste oils. However, they made the point that high levels of water content result in issues with corrosion and the development of microbes in the engine. Brahma et al. (2022) advise utilizing a vacuum evaporation method instead since it allows for higher water extraction without harming the final product.

The findings of Table 5 showed that the extracted biodiesel's acidity index was 0.392 mg KOH/g of oil, complying with the set parameters (which are a maximum of 0.5 mg KOH/g), and that the ash value correlated to 0.02%, meeting the specifications for the manufacturing of biodiesel. Furthermore, the described biodiesel's viscosity was measured at 2.7 mPa/s, which, in accordance with the criteria of Table 5, falls within the permitted range of 3.5 to 5 mPa/s (EN14214).

Parameter	**Unit**	**Biodiesel**	**Specification**	
			LOW	**HIGH**
Density a 15 ºC	kg/m³	883.7	860	900
Ash	%(m/m)	0.015		0.02
Water content	mg/kg	560	--	500
Acidity	%	0.27		
Acidity index	mg KOH/g	0.392	--	0.5
Kinematic viscosity 40 ºC	mPa/s	2.7	3,5	5
Flashpoint	ºC	120	120	--
Cetane index	-	41.62	49	--
Calorific power	MJ/kg	34.4		

Table 5. Physical-chemical parameters of the biodiesel with the best performance.

It was discovered that the extracted biodiesel had a flash point of 120 ºC (ASTMD6751), values that are acceptable for a biodiesel. Moreover, Avellaneda (2010) adds that a biofuel benefits from keeping high levels of flash point.

On the other hand, the biodiesel displayed a cetane index of 41.62, which is below the suggested threshold of 49.00 (ASTM D 976-06). According to

Montenegro et al. (2012), attaining a low cetane index leads to the possibility that excessive noise and ignition problems exist, while Basto et al. (2021) affirm that mixing up to 20% v/v of this additive with diesel is recommended to raise this parameter without affecting the quality metrics.

4. Conclusions

In terms of biodiesel yield, several conclusions were reached as a result of the quantitative research methodologies used to evaluate the impact of physicochemical variables on the effectiveness of the process for producing biodiesel from oily residues in wastewater from fishing industries. The best treatment was found to be achieved with the temperature conditions at 80 °C, alcohol/oil molar ratio of 9:1, and catalyst concentration of 0.8%, presenting a process yield of 94%. The physicochemical characterization of the biodiesel extracted from the grease traps, presented a density (883.7 kg/m^3), ashes (0.015%), and acidity index (0.392). The characterization of the biodiesel extracted from the grease traps, presented a density (883.7 kg/m3), ashes (0.015 %), acidity index (0.392 mg KOH/g), kinematic viscosity (2.7 mPa/S), point of inflammation (120 ºC) and calorific power (34.4 MJ/kg), conditions that meet the specifications for producing biodiesel. Thus, the research hypothesis where the variables Temperature (A), Molar ratio (B) and Catalyst concentration (C) were used for biodiesel extraction demonstrated a significant effect on biodiesel yield.

Thus, this study has shown that it is possible to produce biodiesel from oily residues in wastewater from the fishing industry. The significance of the findings emerges not only through how they relate to and confirm previous research that has already been published, but also through the way they provide a standard for the management of oily waste from fishing enterprises throughout the Ecuadorian Coast.

As a replacement for imported fossil diesel that improves air quality, biodiesel also has economic and environmental advantages (Mizik & Gyarmati, 2021). Oily byproducts from the fishing industry are a free raw material, thereby offering a key component of sustainability within the production process of biodiesel in terms of such features as renewability, biodegradability, and carbon neutrality (Yusoff et al., 2020). Through providing a promising solution to the problem of the management of fishing industry waste, an important contribution can also be made to reducing air pollution and mitigating the greenhouse effect.

References

Acharya, R., & Perez, R. (2020). Role of comparative advantage in biofuel policy adoption in Latin America. *Sustainability, 12*(4), 1411. https://doi.org/10.3390/su12041411

Ameen, M., Ahmad, M., Zafar, M., Munir, M., Mujtaba, M., Sultana, S., Rozina, El-Khatib, S., Soudagar, M., & Kalam, M. (2022). Prospects of catalysis for process sustainability of Eco-green biodiesel synthesis via transesterification: A state-of-the-art review. *Sustainability, 14*(12), 7032. https://www.mdpi.com/2071-1050/14/12/7032

Arenas, E., Villafán-Cáceres, S. M., Rodríguez, Y., García, J. A., Masera, O., & Sandoval, G. (2021). Biodiesel dry purification using unconventional bioadsorbents. *Processes (Basel, Switzerland), 9*(2), 194. https://www.mdpi.com/2227-9717/9/2/194

Avellaneda, F. (2010). Producción y caracterización de biodiesel de palma y de aceite reciclado mediante un proceso batch y un proceso continuo con un reactor helicoidal. Tarragona, ES. [Tesis doctoral, Universidad Rovira I Virgili]. Departamento de Ingeniería Química.

Basto, L., Millán, S., Medina, L., Mora, L. & Caballero, Y. (2021). Estudio del biodiesel obtenido a partir de aceite de *Sacha inchi (Plukenetia volubilis Linneo). Rev. Bio Agro, 20*(1). https://doi.org/10.18684/bsaa.v20.n1.2022.1585

Bockey, D. (2019). The significance and perspective of biodiesel production – A European and global view. *OCL, 26*(40). https://doi.org/10.1051/ocl/2019042

Brahma, S., Nath, B., Basumatary, B., Das, B., Saikia, P., Patir, K., & Basumatary, S. (2022). Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production. Chemical Engineering Journal Advances, 10(100284), 100284. https://doi.org/10.1016/j.ceja.2022.100284

Canabarro, N., Silva, P., Nogueira, L., Cantarella, H., Maciel, R., & Souza, G. (2023). Sustainability assessment of ethanol and biodiesel production in Argentina, Brazil, Colombia, and Guatemala. *Renewable and Sustainable Energy Reviews, 171*(113019). https://www.sciencedirect.com/science/article/pii/S1364032122009005#bib21

Caro, J., Castellanos, L., Romero, F., & Ruiz, M. (2017). Generación de Biodiesel a partir de residuos de aceites, utilizando un reactor con PLC para la automatización del proceso. *Rev. Energía Química y física, 4*(11),16-27. https://www.ecorfan.org/bolivia/researchjournals/Energia_Quimica_y_Fisica/vol4num11/Revista_de_Energ%C3%ADa_Qu%C3%ADmica_y_F%C3%ADsica_V4_N11_3.pdf

Cedeño, D., Loureiro, J., Delgado, M., Delgado, C., y Fajardo, P. (2020). Evaluación de un humedal artificial aireado en efluente de una planta de tratamiento de aguas residuales de la industria atunera, Manta, Manabí, Ecuador. *Revista Científica*

Multidiciplinaria Mikarimin, (6). http://45.238.216.13/ojs/index.php/mikarimin/article/download/1933/1268

Chen, C., Chitose, A., Kusadokoro, M., Nie, H., Xu, W., Yang, F., & Yang, S. (2021). Sustainability and challenges in biodiesel production from waste cooking oil: An advanced bibliometric analysis. *Energy Reports, 7*, 4022–4034. https://www.sciencedirect.com/science/article/pii/S2352484721004510

Dey, S., Reang, N. M., Das, P. K., & Deb, M. (2021). A comprehensive study on prospects of economy, environment, and efficiency of palm oil biodiesel as a renewable fuel. *Journal of Cleaner Production, 286*(124981). https://www.sciencedirect.com/science/article/abs/pii/S0959652620350253

Faurani, S., Hendrowati, T., Sanusi, A. (2018). Indonesia Growth of Economics and the Industrialization Biodiesel Based CPO. *International Journal of Energy Economics and Policy 8*(5), 319–334. https://www.econjournals.com/index.php/ijeep/article/view/6590/3959

Gheewala, S., Jaroenkietkajorn, U., Nilsalab, P., Silalertruksa, T., Somkerd, T., & Laosiripojana, N. (2022). Sustainability assessment of palm oil-based refinery systems for food, fuel, and chemicals. *Biofuel research journal, 9*(4), 1750–1763. https://www.biofueljournal.com/article_161905_d488d7a123049f8d095f610da164d9b1.pdf

Gholami, A., Pourfayaz, F., & Maleki, A. (2020). Recent advances of biodiesel production using ionic liquids supported on nanoporous materials as catalysts: A review. *Frontiers in energy research, 8*. https://www.frontiersin.org/articles/10.3389/fenrg.2020.00144/full

Gomes, M., Santos, D., Morais, L., & Pasquini, D. (2018). Purification of biodiesel by dry washing and the use of starch and cellulose as natural adsorbents: Part II – study of purification times. *Biofuels,* 1–9. https://doi.org/10.1080/17597269.2018.1510721

Gomez, E., Nabarlatz, D., & Avellaneda, F. (2022). Obtención de biodiésel por transesterificación *in situ* a partir de semillas de *Jatropha curcas L. Revista UIS Ingenierías, 21*(2), 21–38. https://revistas.uis.edu.co/index.php/revistauisingenierias/article/view/12861/12364

Jarunglumlert, T., Bampenrat, A., Sukkathanyawat, H., Pavasant, P., & Prommuak, C. (2022). Enhancing the potential of sugarcane bagasse for the production of ENplus quality fuel pellets by torrefaction: an economic feasibility study. *Biofuel research journal, 9*(4), 1707–1720. https://www.biofueljournal.com/article_161901_74239f5663ea4845e4ba28a0d1a53252.pdf

Jeswani, H., Chilvers, A., & Azapagic, A. (2020). Environmental sustainability of biofuels: a review. *Proceedings. Mathematical, Physical, and Engineering Sciences, 476*(2243), 20200351. https://royalsocietypublishing.org/doi/10.1098/rspa.2020.0351

Kara, K., Ouanji, F., Lotfi, E., Mahi, M., Kacimi, M., & Ziyad, M. (2018). Biodiesel production from waste fish oil with high free fatty acid content from Moroccan fish-processing industries. *Egyptian Journal of Petroleum, 27*(2), 249–255. https://doi.org/10.1016/j.ejpe.2017.07.010

Knothe, G., & Razon, L. (2017). Biodiesel fuels. *Progress in Energy and Combustion Science, 58*, 36–59. https://doi.org/10.1016/j.pecs.2016.08.001

López, L. Bocanegra, J. & Malagón, D. (2015). Obtención de biodiesel por transesterificación de aceite de cocina usado. *Revista Ingeniería, 19*(1).155-172. http://www.scielo.org.co/pdf/inun/v19n1/v19n1a08.pdf

Marín, J., Chinga, C., Velásquez, A., González, P. y Zambrano, L. (2015). Tratamiento de aguas residuales de una industria procesadora de pescado en reactores anaerobios discontinuos. *Rev. Ciencia e Ingeniería Neogranadina, 25*(1).

Medina, E., Ruíz, M., Morales, J. & Cerezal, P. (2018). Evaluación del perfil de ácidos grasos de Isochrysisgalbana mediante el uso de métodos ácidos y alcalinos de transesterificación. Informador Técnico. *Rev. Dialnet. 83*(1). http://doi.org/10.23850/22565035.1574

Mishra, R., & Mohanty, K. (2022). Pyrolysis of low-value waste sawdust over low-cost catalysts: physicochemical characterization of pyrolytic oil and value-added biochar. *Biofuel Research Journal 36*, 1736-1749. https://www.biofueljournal.com/article_161904_18244f8757458091e8e6ab8c41c8b4b7.pdf

Mizik, T., & Gyarmati, G. (2021). Economic and sustainability of biodiesel production—A systematic literature review. *Clean Technologies, 3*(1), 19–36. https://www.mdpi.com/2571-8797/3/1/2#B36-cleantechnol-03-00002

Montenegro, M., Sierra, F. & Guerrero, C. (2012). Producción y caracterización de biodiesel a partir de aceite de pollo. *Rev. Informador Técnico, 76*(1), 62-71, Colombia.

Moya, R., Tenorio, C., & Oporto, G. (2019). Short rotation wood crops in Latin American: A review on status and potential uses as biofuel. *Energies, 12*(4), 705. https://doi.org/10.3390/en12040705

Murcia, B., Chaves, L. y Rodriguez, W. (2013). Caracterización de biodiesel obtenido de aceite residual de cocina. *Rev. Colomb. Biotecnol, 15*(1), 61-70.

OECD/FAO. (2018). *OECD-FAO Agricultural Outlook 2018-2027*. Paris; Rome: OECD Publishing; FAO. https://www.fao.org/3/i9166en/i9166en.pdf

Onur, A., Ng, A., Batchelor, W., & Garnier, G. (2018) Multi-Layer Filters: Adsorption and Filtration Mechanisms for Improved Separation. *Frontiers in Chemistry, 6*. https://www.frontiersin.org/articles/10.3389/fchem.2018.00417/full

Pasha, M., Dai, L., Liu, D., Guo, M., & Du, W. (2021). An overview to process design, simulation and sustainability evaluation of biodiesel production. *Biotechnology for Biofuels, 14*(1), 129. https://doi.org/10.1186/s13068-021-01977-z

Rahman, M., Mondal, A., Hasan, M., & Sultana, M. (2022). Biodiesel production from a non-edible source of royna (Aphanamixis polystachya) oil. *Energy, Sustainability and Society, 12*(1). https://doi.org/10.1186/s13705-022-00360-6

Trindade, S., Nogueira, L., & Souza, G. (2022). Relevance of LACAf biofuels for global sustainability. *Biofuels, 13*(3), 279–289. https://doi.org/10.1080/17597269.2019.1679566

Valencia, J., Saavedra, S., Porras, O., Bermúdez, C., & Gonzales, J. (2018). Obtención de Biodiésel a partir de aceite y semillas de *Jatropha curcas*, utilizando catalizadores inmovilizados y transesterificación in situ asistida por ultra sonido. *Revista ESPACIOS, 39*(16), 24-41. https://www.revistaespacios.com/a18v39n16/a18v39n16p24.pdf

Wang, J., Xia, A., Deng, Z., Huang, Y., Zhu, X., Zhu, X., & Liao, Q. (2022). Intensifying biofuel production using a novel bionic flow-induced peristaltic reactor: biodiesel production as a case study. *Biofuel research journal, 9*(4), 1721–1735. https://www.biofueljournal.com/article_161903_0a8370cc9b93502d73c43ada134e15fa.pdf

Yusoff, M., Zulkifli, N., Sukiman, N., Chyuan, O., Hassan, M., Hasnul, M., Zulkifli, M., Abbas, M., Zakaria, M. (2020). Sustainability of Palm Biodiesel in Transportation: A Review on Biofuel Standard, Policy and International Collaboration Between Malaysia and Colombia. *BioEnergy Research, 14*. https://link.springer.com/article/10.1007/s12155-020-10165-0

Authors

Holanda Teresa Vivas Saltos (*corresponding author*)

Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López, Calceta, Manabí, Ecuador

teresa.vivas@espam.edu.ec

María Belén Cedeño Vargas

Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López, Calceta, Manabí, Ecuador

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Vivas Saltos, H.T., & Cedeño Vargas, M.B. (2023) Fishing industries' oily wastewater biodiesel performance. *Visions for Sustainability*, 20, 7413, 455-474. http://dx.doi.org/10.13135/2384-8677/7413

Position Paper

Artificial space debris and Kessler syndrome.
A limitation for humankind.

Adrià Harillo Pla

Received: 1 July 2023 | **Accepted:** 27 August 2023 | **Published:** 4 September 2023

Keywords: debris; evidence; Kessler syndrome; philosophy of knowledge; space debris.

Abstract. *Space debris is an unuseful material moving in space. This debris can be both natural and artificial. This paper focuses on the currently increasing quantities of artificial debris and the ensuing series of problems. The main aim is to highlight the importance of one of these issues – the Kessler Syndrome – from a philosophical perspective. The Kessler Syndrome presents a situation in which, without a reduction of artificial debris in space and especially on Earth's orbit, humans will see their possibilities to keep exploring the universe reduced. If this Kessler Syndrome becomes a reality, human knowledge will be predictably self-limited due to the current lack of responsibility. As well as examining this theoretical hypothesis, this paper considers ways of promoting a sustainable future for space exploration, and thereby human knowledge.*

1. Introduction

Space debris is an unuseful material moving in space and can be both natural and artificial. This paper will focus on the currently increasing quantities of artificial debris. This debris implies a series of problems. The main aim of the text is to highlight the importance of one of these issues from a philosophical perspective, as well as that of the sociology of expectations. The specific issue referred to is the Kessler Syndrome. The Kessler Syndrome presents a situation in which, without a reduction of artificial debris in space, and especially on Earth's orbit, humans will see their possibilities to keep exploring the universe reduced. The lack of clear agreements on who is responsible for managing this debris maximizes the relevance of the situation.

The main hypothesis is that, if this Kessler Syndrome becomes a reality, it will imply a consequent reduction of human's ability to build new knowledge of the cosmos, and this limitation will be due to the current lack of responsibility. By applying the path initiated by the sociology of expectations, we can imagine the future shape of its development as a consequence of its performative power (Van Lente, 2012, 2021). Therefore, this paper intends to present the importance of establishing expectations which are coherent with sustainability when exploring the space.

Understanding society as a large group of people who live together in an organized way, making decisions about how to do things and sharing the work that needs to be done, requires establishing a set of principles and criteria that promote sustainability. That is, paraphrasing Brundtland (1987), exploring space in a way that meets the knowledge needs of the present generation without compromising the ability of future generations to meet their knowledge needs.

The structure of the paper is based on three points. In the first step, we examine what artificial space debris is, and what its current status is. Secondly, we consider arguments to show that this context involves a limitation for the sustainability of human's knowledge. Finally, we look at the main, as yet unsuccessful, attempts to solve this issue that have taken place thus far. This third point will be dealt with in the context of keeping on reflecting and researching about this issue and ensuring that it is not abandoned.

Through a deductive *methodology* we develop a theoretical hypothesis in a coherent and plausible way. As a consequence, the results will be of a conceptual nature, and not experimentally or empirically proven.

One of the limitations of the paper is that the premises involving space data used to reach the conclusion are based on official and public data. Nevertheless, due to the nature of the topic, this means recognizing that the latest data reflect the economic or geopolitical conflict of interests among the different agents involved. As a consequence, some data might not be fully updated or accurate.

This limitation connects to the nature of our methodology. This article is based on documentary research and any sort of field research or experimental research regarding artificial space debris that has been done by agents and institutions with higher resources and knowledge of the different necessary tools.

As a consequence, the premises used to demonstrate the hypothesis presented as true, false, or null are based on the testimony of experts in the area and their authoritative explanations. The assumption is that they collected and reflected reality accurately through scientifically based statements (for example, based on mathematic calculations), their direct evidence (for example, the astronauts), and their direct evidence through the devices used to collect the data (for example, from aerospace observatories).

2. Artificial space debris. Definition and current status.

2.1 What it is

Debris can be defined as "broken or torn pieces of something larger" (Cambridge Dictionary, n.d.). Talking about space debris, we can refer to natural debris or artificial debris. Natural debris is that one generated by, for example, parts of comets or asteroids. On the other hand, artificial debris is the one with a human origin (Johnson & McKnight, 1987).

Artificial space debris concerns pieces from spacecraft which are still in space and did not burn up in the atmosphere or land again on Earth. As a consequence, one part of this debris stays in space, particularly on Earth's orbit (Wild, 2021).

The material of this debris is differentiated, depending on its origin as well as its size. The size of this artificial space debris ranges from less than one millimetre to more than ten centimetres in diameter.

2.2 Where we are

Humans have shown interest in launching objects into space since the moment in which they acquired the skill of walking on two feet and using their eyes to look in front of them and up to the sky. Nevertheless, the nineteen forties were the origin of what we understand nowadays as space exploration, since the first rocket was launched beyond the stratosphere in that period (Bright & Sarosh, 2019). Since that moment, being present in space has had significant relevance: economically, military, ideologically, and logistically. As a consequence, more and more artificial objects have been launched into space with different purposes (Cadbury, 2006; Hardesty & Eisman, 2007). According to data provided by the European Space Agency (2022), 6180 rockets have been launched in the world since 1957.

This has led to in an increase of artificial space debris and the beginning of accidents caused by artificial objects in orbit. The first accident took place in 2009, generating more than 2300 fragments of new debris (ESA, n.d.). As a consequence, although it is true that much artificial space debris falls back to the Earth (approximately once a day), a significant amount of those objects remains in space (Wild, 2021).

This increase in the artificial objects in space has taken place due to the combination of different factors. One of them concerns the technical improvements that have taken place over the years, which has led to better capacities at a reduced price when talking about space exploration (Coopersmith, 2012; Harrison et al., 2017). This has allowed a higher number of national initiatives to be present in space in the form of Space Agencies, although not all of them have launch capabilities (ESPI, 2019).

The second factor is the emergence of new private agents in this activity. Indeed, the motivations and agents driving space exploration have extended well beyond traditional scientific objectives. Space tourism, with the intent of enabling individuals to experience the environment of space first-hand, is one example. Through ventures like Virgin Galactic, Blue Origin, SpaceX, or Sierra Space, companies aim to make space travel accessible to at least some civilians, thereby opening up a new realm of human experience and pushing the boundaries of adventure (Chang, 2015; Webber, 2013).

Furthermore, the expansion of space-based communications infrastructure has become a pivotal motivation. In an increasingly interconnected world, satellites and space-based networks facilitate global communication, data transmission, and the navigation systems that underpin modern society. Companies like SpaceX have embarked on ambitious projects to deploy massive satellite constellations, such as Starlink, with the goal of providing widespread high-speed internet coverage to remote and underserved regions around the globe. Another private agent who has shown interest in this is Amazon, with its Project Kuiper (Harris, 2019).

Moreover, there are private companies that provide services and technologies related to space exploration that can be utilized by military organizations. These private agents provide tools such as satellites for reconnaissance, surveillance, and communication that enhance a nation's ability to gather intelligence. Although the information regarding specific companies' involvement with military space exploration can sometimes be limited due to security and confidentiality concerns, the existence of companies such as Lockheed Martin or Northrop Grumman is well known (Hughes-Wilson, 2016, pp. 180–198).

In addition, the exploration of space is nowadays used for many other purposes, including advertisement, or meteorological services, such as Red Bull Stratos, and The Weather Company from IBM.

As a result of this synergy between public and private agents with multifaceted motivations, an expanding array of players, from established industry giants to innovative start-ups and small investors, continue to contribute to the dynamic and evolving landscape of space exploration (Hotz, 2012; Space Capital, 2022).

This new context statistically increases the chances of new accidents and the consequent increase of artificial space debris has not as yet led to significant solutions. And it is precisely because of this that the Kessler Syndrome exists.

2.3 The Kessler syndrome

According to space agencies such as the NASA and the ESA, in the middle and long-term the amount of artificial space debris will increase, as well as the accidents caused because of it. In fact, according to the ESA, "it is however expected that in the future collisions will become the dominant source of space debris" (ESA, n.d.; Space.com, 2015).

This context, in which the impact between different kinds of debris is the main source of new debris, implies a series of issues. One of them is constituted by the fact that some of this debris falls down into the Earth. Indeed, the quantity of debris returning to the Earth is estimated to be one piece a day, falling mainly into water since that is the nature of the majority of Earth's surface (Wild, 2021). This issue involves two risks. The first is the impact of this space debris and the damage caused when it does not fall into the water. Although legally, if a piece of debris falls onto your property you must receive compensation, according to the 1967 Outer Space Treaty or the 1972 Liability Convention, there are many situations that are not contemplated (Aganaba, 2021). Even when falling into seas or oceans, contamination is another big risk for the planet and its inhabitants. Nevertheless, this does not only involve the space debris fallen there. The South Pacific Ocean Uninhabited Area is informally known as the spacecraft cemetery. It is the part of the ocean where, regularly, space debris and other space instruments which are not useful anymore are thrown. This action is exacerbated by the lack of national legal duties (De Lucia & Iavicoli, 2019). As a consequence, space debris can originate security and contamination issues when on Earth.

The second issue is the fact that the average speed of debris impact in orbit, is 36001 km/hour (Wild, 2021). Any sort of crash at that speed is highly damaging and potentially lethal. Although Space Agencies have developed and keep researching ways to travel in outer space in a safer way, scientific research and its applications are by no means as fast as the speed of the debris creation. (Garcia, 2021)

As a consequence, we are in a context in which:

1. Space Agencies and private parties are sending more objects to outer space than ever.

 http://dx.doi.org/10.13135/2384-8677/7874

2. Those objects generate debris, which can return to the Earth or stay in orbit.
3. When on Earth, that debris involves security and contamination issues.
4. When in orbit, the orbit already has natural debris, which is being naturally increased.
5. At this speed, artificial space debris impacts will be the main source of new artificial space debris.
6. At this speed, and with the current resources, artificial space debris is highly damaging and/or lethal in case of impact.

Thus, it follows that, if there are no changes in points 1 to 6, space exploration will become increasingly damaging and/or lethal.

Although the term Kessler Syndrome has never had a univocal definition, its origin can be tracked from 1978, when Kessler and Cour-Palais (1978) published an article in which they warned about this situation and predicted that random collisions between space debris would generate more random collisions, generating new debris, and so on.

This broke with the idea that space debris was not significant or big enough to be considered harmful. At the same time, they concluded that the way to avoid this escalation of events would be to reduce the non-operational artificial objects in orbit.

On one hand, this conclusion could seem to pose a false dilemma, since it is a future projection and does not take into consideration further discoveries and solutions. However, other studies conclude that this seems to be a real and not a false dilemma (Finkleman, 2014).

Nonetheless, the original article was key to putting this issue on the agenda. In fact, the term Kessler Syndrome became increasingly well known when the issue was taken up by popular magazines. Kessler extended his research and published a new contribution in 1981 (Kessler, 1981), while the most widespread publication of this issue for the general public, took place in 1982 (Schefter, 1982). The topic is still being developed and researched by different authors (Krisko, 2007; Madi & Sokolova, 2020).

3. A limitation for humankind

For the purposes of this paper, humans are considered to be rational entities. This does not mean that they are always rational, nor that their rationality does not know boundaries (Chater & Oaksford, 2010; Jonathon & Over, 1996; Mele & Rawling, 2004; Simon, 1990). At times, cognitive biases, or individual will, can change that (Chater & Oaksford, 2010). Moreover, sometimes humans actively create, write, and enjoy fiction. Nevertheless, humans have the skill of thinking rationally.

Someone who attends to, for example, a film about science fiction, rationally knows that the story is not real. Nor does its director pretend to present that story as true. The background is a rational understanding of the world. This understanding is mixed with creativity, unrealistic ideas, and a sense of excitement, but humans understand rationally the context. When this is not so, then there is an issue (BBC, 2021; Pearson, 2012).

When thinking about human passions, creativity, unrealistic or unprovable ideas, rational understanding also plays a key role. To be able to distinguish between what is true and what it is not, and to agree on what is real knowledge against what it is a belief or an opinion, we need evidence (Lanz, 1932; Stevenson, 2003).

According to Arp, Barbone and Bruce (2019), this evidence can come from seven different sources:

1. Direct evidence using our empirical skills.
2. Indirect empirical evidence through a device or tool which is reliably calibrated.
3. The testimony of others in whom we trust.
4. The testimony of experts in that specific area.
5. Authoritative explanations.
6. Logical or mathematic entailment.
7. Logically sound or cogent arguments.

Although our direct evidence using our empirical skills can sometimes be inaccurate, we all are familiar with this type of evidence. We use it every day. When we wake up and we hear the coffee machine, we conclude that the coffee is ready. When we see it is raining, we decide to take an umbrella. The same thing happens when humankind is trying to obtain evidence regarding how space is.

Different cultures have different words to refer to humans sent into space to obtain information about it. In English the most common terms are astronaut and cosmonaut. The origin of the word astronaut comes from *astron* + *nautes*, meaning "star + navigators". The term cosmonaut comes from *cosmos* + nautes meaning "universe + navigators". Independently of the language used to refer to them and the eventual differences of perspective they convey, humans have been sending other humans into space since April 12, 1961, when Yuri Gagarin travelled around the Earth in the spacecraft Vostok 1 (Kohli, 2017). On April 8, 2022, the private spacecraft Axiom Mission 1, crewed by Michael López-Alegría, Larry Connor, Mark Pathy, and Eytan Stibbe, was launch number 605 for human space travel (Margetta, 2022).

Although it is true that our empirical senses have some limitations, and it is not a trustworthy method of evidence in absolute terms, generally it is a source considered to be so, unless the contrary is proven (Hume, 1817; Russell, 1935). That is why still today we keep sending humans into the space, in order to obtain knowledge, and deliver it to future generations.

However, and if there are no significant changes in the context previously described, it will become too dangerous to send humans into outer space, or even impossible. This will involve the impossibility of obtaining evidence through these direct empirical senses. Thus, we can posit that:

1. If there are no changes, human direct exploration could become more dangerous and/or lethal than ever.
2. That danger could render direct human exploration no longer viable.
3. Direct empirical senses are a source of evidence.
4. Evidence is necessary for knowledge.

If there are no changes, it follows that human knowledge would be predictably self-limited due to the current lack of responsibility, although there are other sources of evidence.

Another way to obtain evidence is through a device or tool which is reliably calibrated. Although this kind of empirical evidence is mediated, it can be of high value. Space Agencies have been launching robots that, employing their sensors, cameras, and technological tools, can provide mediated empirical experiences. These robots can have different shapes and specific functions, and two of the most popular are Curiosity or Perseverance.

According to NASA, the calculated costs of sending a robot into space are lower than sending a human into space. NASA calculates these reduced costs taking in consideration that the robot does not need to sleep, eat, or go to the bathroom. At the same time, they can, generally speaking, last in space a longer time than a human. No less important, robots can do research in some conditions that humans could not. There is also a further factor which NASA considers when doing the calculations and must be reconsidered. According to NASA, "Sending a robot to space is also much cheaper than sending a human. [...] They can survive in space for many years and can be left out there—no need for a return trip!" (NASA Space Place, 2021).

Independently of future factors, such as if the costs will be reduced, or if it will become mandatory to make those robots return, the cost of producing them and keeping them in space are very significant. For example, Curiosity's and Perseverance's cost was about 2,9 and 3,2 billion US Dollars each, adjusted to 2021's inflation (McCarthy, 2021; NASA, 2012, p. 6).

These costs are too high to be spent regularly. They can be spent, but not without having some statistical security that those robots will be able to provide us the expected indirect evidence through their systems and tools. As a consequence, if the situation does not change, it will predictability be too expensive or even impossible to keep sending artificial tools to get indirect evidence to expand our knowledge regarding the space. Thus, we can posit that:

1. If there are no changes, human indirect evidence through well-calibrated devices could become more highly dangerous and/or expensive than ever.
2. That risk and its related costs could make human indirect exploration not viable.
3. Indirect evidence through well-calibrated devices and tools are a source of evidence.
4. Evidence is necessary for knowledge.

If there are no changes, it follows that human knowledge would be predictably self-limited due to the current lack of responsibility, although there are other sources of evidence.

Although it is true that, on many occasions, we base our knowledge on the people we trust, in the case of space exploration, this has to be relativized. The reason is that not everybody who we trust are experts in all the domains. I can trust my father to provide me some information regarding my childhood, but I would not trust him if he is trying to explain to me how to decipher the DNA of the biggest jelly fish from the ocean. The reason for that is simply that although he has all my trust as a person, he does not have enough specific knowledge regarding DNA, or jelly fishes, or the ocean's wildlife to be considered an expert. In consequence, his statements regarding this topic must not be considered evidence. Precisely, this confusion, called Inappropriate Appeal to Authority, is one of the main origins of misinformation (O'Connor & Weatherall, 2019; Vraga & Bode, 2020).

At this point, it is important to highlight that an expert only has authority if he can be proven wrong through falsifiability. Trusting someone as an expert, without falsifiability, is dogmatism (Popper, 2002). When talking about space, like in any other scientific field, experts can as well fall into the trap of misinformation (West & Bergstrom, 2021). Nevertheless, every source of legitimate expertise comes solely from authoritative explanations which are sound or cogent, and based on solid evidence. Because of this, it is possible to identify the scientists and channels that are not promoting knowledge through authoritative methods and evidence. After their identification, this category in the specific field or topic is removed by the scientific community. (Gunaydin & Doğan, 2015; Hopf et al., 2019; Obradovic & Barcus, 2020)

Due to this fact, when we have knowledge regarding space, this is based on the statements provided by people who we consider experts in the field. It is based in their authoritative explanations, and this is what makes us trust them. However, if these experts see reduced their capacity to recollect evidence regarding their field of study, those authoritative explanations will become weak, reducing the trust in their expertise. Thus, we can posit that:

1. We get evidence from people who we consider trustworthy.
2. We consider trustworthy some people regarding only some specific topics.
3. We consider these people experts in those specific topics.
4. That expertise comes from their authoritative explanations regarding the specific topic.
5. To provide authoritative explanations, previous evidence is needed.
6. If there are no changes, it could become highly harmful and/or lethal and/or expensive than ever to recollect the primary evidence.
7. Without primary evidence, there is no authoritative explanation, nor expert, nor reasonable trust.

If there are no changes, it follows that human knowledge would be predictably self-limited due to the lack of current responsibility, although there are other sources of evidence.

It must be added that experts regarding space still can provide evidence through logical or mathematic entailment and also through logically sound or cogent arguments. This appears to be accurate, and this could be done from a rational perspective. It could be done if the entailments and arguments are sustained in premises established in general scientific laws or in data obtained in the past. Nevertheless, this still involves a limitation.

If data obtained in the past cannot be regularly tested, and it is not subject to falsifiability, the knowledge already obtained will potentially not evolve. This is because some kinds of new knowledge, theories, or tools, will not be able to be applied. As a consequence, the new knowledge developed about space will not be able to be tested through different methodologies. A context in which natural or field experiments are limited leads to the sole possibility of laboratory experimentation. Nevertheless, due to the nature of the object studied, this opportunity does not seem to be realistic. Not even in the very long term. Due to this fact, the evidence and potential knowledge that could still be obtained would be too weak to be considered a solid scientific paradigm (Christensen, 1994; Kuhn, 2012). Thus, we can posit that:

1. As humans, we can get evidence from logical and mathematic entailments.
2. We can also obtain evidence from sound and cogent arguments.
3. Although this can be useful, the impossibility of obtaining new data through direct senses or tools correctly calibrated implies a limitation in obtaining new available data.
4. This also implies the impossibility of carrying out natural and field experiments.
5. Due to the nature of the object, laboratory experiments are not possible.
6. Through solely logic, mathematics, or argumentation, the knowledge obtained is weaker than it could be if tested.

If there are no changes, it follows that human knowledge would be predictably self-limited due to the lack of current responsibility.

4. Unsuccessful solutions

4.1 The legal situation

One could reasonably think that this is not a real issue, since probably, after Kessler's contribution, and with the current information available, there are already effective regulations and tools to reduce this debris. One could reasonably think that, since human beings are aware of the future, in the present, a solution is already existing precisely to avoid the potential situation of danger. Nevertheless, this is not the case.

Space Agencies would be legally responsible if a piece of debris felt into your property. At the same time, much of the artificial debris that falls back down to Earth lands in the ocean. The situation is no different regarding the debris still in space. Legally, governments are responsible for their airspace. But their airspace finishes after 100 kilometres vertically from their borders, in Kármán line.

This means that beyond the Kármán line governments do not have any legal responsibility for the debris accumulated there. Moreover, the Fédération Aéronautique Internationale (FAI) requested the International Astronautical Federation (IAF) to reduce the Kármán line to 80 kilometres. (FAI, 2018). This is the line where regulatory bodies divide Aeronautical and the Astronautical responsibilities (FAI, 2017; Haley, 1963; Lyall & Larsen, 2013; Reynolds & Merges, 2021) and a reduction implies even less space with national legal responsibility. In this context, some governments, but not all of them, decided to transfer responsibility to Space Agencies, without, however, obtaining the expected results (Munoz-Patchen, 2018; Sachdeva, 2013).

Currently the situation concerning artificial space debris and the Kessler Syndrome presents analogies with other areas of environmental challenges. Antarctica, for example, is also subject to a lack of international legally binding agreement, which has led to environmental crises. Since Antarctica is a vital component of the global climate system, a lack of intervention and unsustainable practices can result in cascading effects on other parts of the world, demonstrating the interconnectedness of Earth's systems (Rintoul et al., 2018). Another example is marine plastic pollution with its direct environmental impact due to the lack of an international legally binding agreement. As with artificial space debris, lack of intervention and increasingly unsustainable practices can result in water circulation crises, as well as other issues. The water circulation generated by islands of plastics such as the Great Pacific Garbage Patch and the North Atlantic Garbage Patch can impact ocean circulation patterns, potentially altering heat distribution and influencing climate-regulating processes such as thermohaline circulation (Miron et al., 2021).

4.2 Examples of attempts

Since the responsibility for reducing artificial space debris was transferred to the Space Agencies, and, depending on its altitude, the debris needs between a few years and more than a century to disappear, some Space Agencies started thinking in ways to address this issue. To achieve this objective, NASA created the Orbital Debris Program Office at the Johnson Space Center in Houston (Wild, 2021).

However, this commitment has had little success thus far and the quantity of space debris is increasing.

In this respect, the Chinese satellite SJ-21 has applied a pragmatic, but not long-term solution. This satellite has been seen taking debris and simply reallocating it in another place (Pardo, 2022). ESA is planning to launch ClearSpace-1, developed by the École Polytechnique Fédérale de Lausanne, by 2025. This will be a robotic tool with arms to collect multiple objects, but it is not yet operational (EPFL, 2015; ESA, 2019). Indeed, during its first attempt, ClearSpace-1 is expected to take only one single object. (Devlin, 2019). Kounotori, from the Japan Aerospace Exploration Agency, is trying to collect debris using a fishnet system, but is encountering important problems, such as the difficulty of collecting tiny pieces of debris (Phys.org, 2016). The same idea is also being tried out in partnership between public institutions and private ones, such as SpaceX, as in the example of the mission RemoveDebris, which has not yet been able to resolve the issue of the space debris in a significant way (Clark, 2018).

Others have thought of methods to reduce the impact of the artificial space debris without the need of having to travel there. On paper, this proposal seems the most interesting, since it could reduce the problem without involving a hazard for spacecraft and astronauts, although it does not mean that this activity will not have other externalities. Nevertheless, this hypothetical solution, has not yet (Phipps et al., 2012) been implemented.

Thus, we may consider our main hypothesis — if the Kessler Syndrome becomes a reality, human knowledge will be predictably self-limited due to the lack of current responsibility — as logically demonstrated. Moreover, following the sociology of expectations, imaginations of the future shape its development as a consequence of its performative power (Van Lente, 2012, 2021). Expectations shape social behaviour, interactions, and outcomes. This includes technological outcomes. Therefore, it is important to advocate for a future in which technological innovations, economic systems, political processes, and cultural practices, are aligned with developing sustainable expectations regarding cosmos exploration. This will have an impact at many levels, including human ability to gather knowledge via evidence.

5. Conclusions

Artificial space debris is made up of "broken or torn pieces of something larger" with a human origin that are not useful pieces anymore. Many of these pieces are in orbit or in space, while others fall back to Earth. Pieces that fall back into Earth involve a security and an environmental risk, while those remaining in the space could make space exploration highly hazardous and expensive.

Moreover, natural debris is continuously being generated, as well as artificial debris constantly increasing. Technological innovation and price reduction are making space exploration more accessible and frequent. At the same time, there are previsions that in the near future collisions between the already existing debris will be the main source of new space debris.

Humans can be defined as rational. To have rational knowledge, humans need evidence. Evidence can be obtained from different sources that can be classified as: direct evidence using our empirical skills; indirect empirical evidence through a device or tool which is reliably calibrated; the testimony of others in whom we trust; the testimony of experts in that specific area; authoritative explanations; logical or mathematic entailment; and logically sound or cogent arguments.

Due to the current situation, direct and indirect empirical evidence could become too expensive or hazardous to take place. And without direct and indirect empirical evidence, authority, trust, and expertise are built upon a less solid base. Logical or mathematical entailments, and logical arguments, can still be a solid source of evidence regarding space. Nevertheless, the absence of direct or indirect exploration inevitably limits the available data, and its falsifiability through field or natural experimentation.

At the same time, there is a lack of legal responsibilities for the regulation of artificial space debris and scientific trials to modify the situation have not thus far been successful. Because of this, if there are no changes in this situation, human knowledge about space will be self-limited due to the lack of responsibility. Therefore, it becomes imperative to consider sustainable management of Earth's orbit as a common resource, fostering cooperation and responsible practices to prevent exacerbating the problem of space debris. Achieving this goal will require a multi-faceted approach and collaboration among various stakeholders, both at a public and at a private level.

Examples of this collaboration should include the establishment or reinforcement of international binding agreements to govern space activities. These agreements could outline guidelines for satellite design, launch procedures, and end-of-life disposal, ensuring that all entities operating in space adhere to responsible practices. National space agencies, international organizations like the United Nations, and private companies could collectively contribute to the development and enforcement of these regulations.

Identifying the key actors in this endeavour is crucial. Governments, as primary space agencies and regulators, could play a pivotal role in creating and enforcing regulations. Private companies, particularly those involved in launching rockets and deploying satellites, must be obliged to adhere to these guidelines. Organizations such as the International Telecommunication Union (ITU) and the Space Data Association (SDA) could facilitate coordination and communication among the already existing satellite operators to minimize the risk of collisions and debris generation.

Certainly, competing interests over Earth's orbit exist, fuelled by the belief that the potential benefits of space activities are vast and varied. Conflicts might arise between nations vying for orbital slots, companies aiming to secure prime positions for their satellite constellations, and those advocating for conservation of the orbital environment. Balancing these interests will necessitate diplomatic negotiations, transparent allocation mechanisms, and compromise.

A possible development is the establishment of quotas for new rocket launches and satellite deployments. These quotas must be scientifically determined, considering the capacity of the orbital environment to accommodate additional objects without escalating the debris problem. The specific timeline for implementing such quotas will depend on a thorough assessment of the current state of orbital congestion and the rate of space activity growth.

In conclusion, transforming Earth's orbit into a sustainable common space requires global cooperation, comprehensive regulations, and the active involvement of governments, international organizations, and private industry. By establishing guidelines, allocating resources responsibly, and addressing conflicting interests, we can mitigate the impact of space debris and ensure that future generations can continue to explore and benefit from the vast frontier of space. Sustainability science must advocate for the responsible stewardship of this shared resource to enable a brighter and more sustainable future for space exploration, and thereby human knowledge.

References

Aganaba, T. (2021, May 22). If a satellite falls on your house, space law protects you—But there are no legal penalties for leaving junk in orbit. *Washington Post.* https://www.washingtonpost.com/science/if-a-satellite-falls-on-your-house-space-law-protects-you--but-there-are-no-legal-penalties-for-leaving-junk-in-orbit/2021/05/21/e4700468-b8a7-11eb-a6b1-81296da0339b_story.html

Arp, R., Barbone, S., & Bruce, M. (2019). Introduction. In R. Arp, S. Barbone, & M. Bruce (Eds.), *Bad Arguments: 100 of the Most Important Fallacies in Western Philosophy* (pp. 01–34). John Wiley & Sons.

BBC. (2021, November 1). Japanese man in Joker costume injures 17 in knife attack on Tokyo train. *BBC News.* https://www.bbc.com/news/world-asia-59103664

Bright, M., & Sarosh, C. (2019). *Earth from Space.* BBC Books.

Brundtland, G.H. (1987) Our Common Future: Report of the World Commission on Environment and Development. Geneva, UN-Dokument A/42/427. http://www.un-documents.net/ocf-ov.htm

Cadbury, D. (2006). *Space race: The epic battle between America and the Soviet Union for dominion of space.* HarperCollins.

Cambridge Dictionary. (n.d.). Paralympic. In *Cambridge Dictionary*. Cambridge University Press. Retrieved February 17, 2022, from https://dictionary.cambridge.org/us/dictionary/english/paralympic?q=Paralympic

Chang, Y.-W. (2015). The first decade of commercial space tourism. *Acta Astronautica, 108*, 79–91. https://doi.org/10.1016/j.actaastro.2014.12.004

Chater, N., & Oaksford, M. (2010). Human rationality and the psychology of reasoning: Where do we go from here? *British Journal of Psychology*, *92*(1), 193–216. https://doi.org/10.1348/000712601162031

Christensen, L. B. (1994). *Experimental Methodology*. Allyn and Bacon.

Clark, S. (2018, April 1). *Eliminating space junk could take step toward reality with station cargo launch – Spaceflight Now.* Spaceflight Now. https://spaceflightnow.com/2018/04/01/eliminating-space-junk-could-take-step-toward-reality-with-station-cargo-launch/

Coopersmith, J. (2012). Affordable Access to Space. *Issues in Science and Technology*, *29*(1), 57–62.

De Lucia, V., & Iavicoli, V. (2019). From Outer Space to Ocean Depths: The “Spacecraft Cemetery” and the Protection of the Marine Environment in Areas Beyond National Jurisdiction. *California Western International Law Journal*, *49*(2), 345–390.

Devlin, H. (2019, December 9). European Space Agency to launch space debris collector in 2025. *The Guardian*. https://www.theguardian.com/science/2019/dec/09/european-space-agency-to-launch-clearspace-1-space-debris-collector-in-2025

EPFL. (2015, February 12). *Cleaning up Earth's orbit: A Swiss satellite tackles space junk*. https://actu.epfl.ch/news/cleaning-up-earth-s-orbit-a-swiss-satellite-tackle/

ESA. (n.d.). *About space debris*. ESA. Retrieved March 23, 2022, from https://www.esa.int/Safety_Security/Space_Debris/About_space_debris

ESA. (2019, December 9). *ESA commissions world's first space debris removal*. ESA. https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

ESA. (2022, March 3). *Space debris by the numbers*. ESA. https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers

ESPI. (2019). *Evolution of the Role of Space Agencies* (No. 70; 81). European Space Policy Institute.

FAI. (2017, August 1). *100km Altitude Boundary for Astronautics*. FAI. https://www.fai.org/page/icare-boundary

FAI. (2018, November 30). *Statement about the Karman Line*. FAI. https://www.fai.org/news/statement-about-karman-line

Finkleman, D. (2014, January). The Dilemma of Space Debris. *American Scientist*, *102*(1), 26.

Garcia, M. (2021, May 21). *Space Debris and Human Spacecraft* [Text]. NASA. http://www.nasa.gov/mission_pages/station/news/orbital_debris.html

Gunaydin, G. P., & Doğan, N. Ö. (2015). A Growing Threat for Academicians: Fake and Predatory Journals. *Eurasian Journal Of Emergency Medicine*, *14*(2), 94–96. https://doi.org/10.5152/jaem.2015.48569

Haley, A. G. (1963). *Space Law and Government*. Appleton-Century-Crofts.

Hardesty, V., & Eisman, G. (2007). *Epic rivalry: The inside story of the Soviet and American space race*. National Geographic.

Harris, M. (2019, May 1). The race to build a space internet available to anyone, anywhere. *New Scientist*. https://www.newscientist.com/article/mg24232280-700-the-race-to-build-a-space-internet-available-to-anyone-anywhere/

Harrison, T., Hunter, A., Johnson, K., & Roberts, T. (2017). *Implications of Ultra-Low-Cost Access to Space*. Rowman & Littlefield.

Hopf, H., Krief, A., Mehta, G., & Matlin, S. A. (2019). Fake science and the knowledge crisis: Ignorance can be fatal. *Royal Society Open Science*, *6*(5), 190161. https://doi.org/10.1098/rsos.190161

Hotz, A. (2012, October 16). Felix Baumgartner completes world's highest skydive – coverage highlights. *The Guardian*. https://www.theguardian.com/sport/2012/oct/16/felix-baumgartner-space-jump-recap

Hughes-Wilson, J. (2016). *On Intelligence: The History of Espionage and the Secret World*. Hachette UK.

Hume, D. (1817). *A Treatise of Human Nature* ... John Francis Neylan.

Johnson, N. L., & McKnight, D. S. (1987). *Artificial Space Debris*. Orbit Book Company.

Jonathon, St. B. T. E., & Over, D. E. (1996). *Rationality and Reasoning*. Psychology Press. https://doi.org/10.4324/9780203027677

Kessler, D. J. (1981). Sources of Orbital Debris and the Projected Environment for Future Spacecraft. *Journal of Spacecraft and Rockets*, *18*(4), 357–360. https://doi.org/10.2514/3.57828

Kessler, D. J., & Cour-Palais, B. G. (1978). Collision frequency of artificial satellites: The creation of a debris belt. *Journal of Geophysical Research: Space Physics*, *83*(A6), 2637–2646. https://doi.org/10.1029/JA083iA06p02637

Kohli, M. (2017). *Yuri Gagarin*. Prabhat Prakashan.

Krisko, P. (2007). The predicted growth of the low-Earth orbit space debris environment—An assessment of future risk for spacecraft. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, *221*(6), 975–985. https://doi.org/10.1243/09544100JAERO192

Kuhn, T. S. (2012). *The Structure of Scientific Revolutions: 50th Anniversary Edition* (I. Hacking, Ed.; 4th ed.). University of Chicago Press.

Lanz, H. (1932). Review of Knowledge, Belief and Opinion [Review of *Review of Knowledge, Belief and Opinion*, by J. Laird]. *The Journal of Philosophy*, *29*(3), 78–80. https://doi.org/10.2307/2015315

Lyall, F., & Larsen, P. B. (2013). *Space Law: A Treatise*. Ashgate Publishing, Ltd.

Madi, M., & Sokolova, O. (Eds.). (2020). *Space Debris Peril: Pathways to Opportunities*. CRC Press.

Margetta, R. (2022, April 15). *NASA Coverage Set for Axiom Mission 1 Departure from Space Station* [Text]. NASA. http://www.nasa.gov/press-release/nasa-coverage-set-for-axiom-mission-1-departure-from-space-station

McCarthy, N. (2021, February 26). *Chart: This is how much each of NASA's Mars missions have cost*. World Economic Forum. https://www.weforum.org/agenda/2021/02/mars-nasa-space-exploration-cost-perseverance-viking-curiosity/

Mele, A. R., & Rawling, P. (Eds.). (2004). *The Oxford Handbook of Rationality*. Oxford University Press.

Miron, P., Beron-Vera, F., Helfmann, L., & Koltai, P. (2021). Transition paths of marine debris and the stability of the garbage patches. C*haos: An Interdisciplinary Journal of Nonlinear Science*, *31*(3), 033101. https://doi.org/10.1063/5.0030535

Munoz-Patchen, C. (2018). Regulating the Space Commons: Treating Space Debris as Abandoned Property in Violation of the Outer Space Treaty. *Chicago Journal of International Law*, *19*(1), 233–259.

NASA. (2012). *Mars Science Laboratory Landing* (p. 61) [Press Kit]. NASA. https://mars.nasa.gov/internal_resources/823/

NASA Space Place. (2021, February 5). *Why Do We Send Robots To Space?* NASA. https://spaceplace.nasa.gov/space-robots/en/

Obradovic, B., & Barcus, A. (2020). Fighting fake science: The key role of scientists. *Hemijska Industrija*, *74*(4), 231–237.

O'Connor, C., & Weatherall, J. O. (2019). The Misinformation Age: How False Beliefs Spread. In *The Misinformation Age*. Yale University Press. https://doi.org/10.12987/9780300241006

Pardo, E. (2022, February 9). *Chinese "space cleaner" spotted grabbing and throwing away old satellite | DW | 09.02.2022*. Deutsche Welle. https://www.dw.com/en/chinese-space-cleaner-spotted-grabbing-and-throwing-away-old-satellite/a-60658574

Pearson, M. (2012, July 21). Gunman turns "Batman" screening into real-life "horror film." *CNN*. https://www.cnn.com/2012/07/20/us/colorado-theater-shooting/index.html

Phipps, C. R., Baker, K. L., Bradford, B., George, E. V., Libby, S. B., Liedahl, D. A., Marcovici, B., Olivier, S. S., Pleasance, L. D., Reilly, J. P., Rubenchik, A., Strafford, D. N., & Valley, M. T. (2012). Removing Orbital Debris with Lasers. *Advances in Space Research*, *49*(9), 1283–1300. https://doi.org/10.1016/j.asr.2012.02.003

Phys.org. (2016, December 9). *Japan launching "space junk" collector*. Phys.Org. https://phys.org/news/2016-12-japan-space-junk-collector.html

Popper, K. R. (2002). *Conjectures and Refutations: The Growth of Scientific Knowledge*. Routledge.

Reynolds, G. H., & Merges, R. P. (2021). *Outer Space. Problems of Law and Policy.* (2nd ed.). Routledge.

Rintoul, S. R., Chown, S. L., DeConto, R. M., England, M. H., Fricker, H. A., Masson-Delmotte, V., Naish, T. R., Siegert, M. J., & Xavier, J. C. (2018). Choosing the future of Antarctica. *Nature*, *558*(7709), Article 7709. https://doi.org/10.1038/s41586-018-0173-4

Russell, B. (1935). The Limits of Empiricism. *Proceedings of the Aristotelian Society*, *36*, 131–150.

Sachdeva, G. S. (2013). International Code of Conduct for Activities in Outer Space: An Exercise in Futility. In *Outer Space: Law, Policy and Governance: Law, Policy and Governance*. KW Publishers Pvt Ltd.

Schefter, J. (1982, July). The growing peril of space debris. *Popular Science*, *221*(1), 48–81.

Simon, H. A. (1990). Bounded Rationality. In J. Eatwell, M. Milgate, & P. Newman (Eds.), *Utility and Probability* (pp. 15–18). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-20568-4_5

Space Capital. (2022). *Space Investment Quarterly* (Q4 2021; p. 13). Space Capital.

Space.com. (2015, January 13). *Space Junk Threat Will Grow for Astronauts and Satellites* [Fox News]. Fox News; Fox News. https://www.foxnews.com/science/space-junk-threat-will-grow-for-astronauts-and-satellites

Stevenson, L. (2003). Opinion, Belief or Faith, and Knowledge. *Kantian Review*, *7*, 72–101. https://doi.org/10.1017/S1369415400001746

Van Lente, H. (2012). Navigating foresight in a sea of expectations: Lessons from the sociology of expectations. *Technology Analysis & Strategic Management*, *24*(8), 769–782. https://doi.org/10.1080/09537325.2012.715478

Van Lente, H. (2021). Imaginaries of innovation. In B. Godin, G. Gaglio, & D. Vinck (Eds.), *Handbook on Alternative Theories of Innovation* (pp. 23–36). Edward Elgar Publishing. https://doi.org/10.4337/9781789902303.00010

Vraga, E. K., & Bode, L. (2020). Defining Misinformation and Understanding its Bounded Nature: Using Expertise and Evidence for Describing Misinformation. *Political Communication*, *37*(1), 136–144. https://doi.org/10.1080/10584609.2020.1716500

Webber, D. (2013). Space tourism: Its history, future and importance. *Acta Astronautica, 92*(2), 138–143. https://doi.org/10.1016/j.actaastro.2012.04.038

West, J. D., & Bergstrom, C. T. (2021). Misinformation in and about science. *PNAS*, *118*(15), 01–08. https://doi.org/10.1073/pnas.1912444117

Wild, F. (2021, June 7). *What Is Orbital Debris?* NASA Educational Technology Services. http://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-orbital-debris-58.html

Author

Adrià Harillo Pla,
Independent scholar, Manresa, Spain;
ORCID: 0000-0002-4005-9643
adria.harillo@gmail.com

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The author does not work for, consult, own shares in, or receive funding from any company or organization that would benefit from this article. The author has disclosed no relevant affiliations that could involve a conflict of interests.

Citation

Pla, A.H. (2023) Artificial space debris and Kessler syndrome. A limitation for humankind. *Visions for Sustainability*, 20, 7874, 475-496.
http://dx.doi.org/10.13135/2384-8677/7874

Position Paper

The liberating theology of a planet's beneficence: a possibility

Shé Mackenzie Hawke

Received: 8 May 2023 | **Accepted:** 7 August 2023 | **Published:** 23 September 2023

Keywords: Creation; idolatry; anthropocene; love; liberation theology; eco-theology; reverence.

Abstract. *Current climate crises could be considered an end of times as we have known them, requiring the human species as stewards of Creation, to make revolutionary changes to how the planet has been mis treated. Are we – the people of the twenty-first century Anthropocene age – also capable of a "Copernican revolution [evident] in Paul's thinking" (Witherington 2005, p.*

40) to see the planet as sacred and through Christ's wisdom as part of divine Creation? Do the peoples of the world have the capacity to re-store the planet through this reverential prism? Or – disassociated from our source – are we set at rapid speed to a catastrophic end, driven by neo-liberal greed and post-modern "idolatry" (Inc. 11: 61 in Behr), dressed up as the necessary economics of late capitalism? It seems that the worries of Athanasius (On the Incarnation) in the early Christian Church (4th C) are as relevant today as they were then, even if the context differed.

---

1. (R)evolutionary thinking

Oh Lord how manifold are your works!
In wisdom you have made them all;
The earth is full of your creatures
(Psalm 104: 24)[1]

The Pauline corpus illuminates the centrality of Christ in the Gospels by considering how:

> (1) Paul's storied world is reshaped around the Christ event, and (2) How Paul's hermeneutic at handling the Old Testament, Mosaic Law, God, eschatology, Adam, and a plethora of other subjects, changed once he began to look at these topics through the eyes of Christ (Witherington 2005, p. 28).

Paul not only reconsidered life and faith through the Christ event. His Copernican revolution was set against a backdrop of harsh physical conditions and geo-political tensions, in which, as Witherington suggests in 2 Thessalonians, "he and his converts believed they were living in the end of times" (2006, p. 236), lending an eschatological tone to his experience of the Christ event and its promised salvation. Yet Paul was also aware of the ongoing role of nature as Creation: "We know that the whole creation has been groaning in labor pains until now; and not only the creation, but we ourselves…" (Romans 8, 22-23). Current climate crises could be considered both an "end of times" as we have

---

[1] All Biblical references come from the New Revised Standard Version 1989 Nashville: Thomas Nelson.

known them, and a "difficult birth" towards a new ecological consciousness. Such labour pains require the human species as stewards of Creation, to make revolutionary changes as to how we have mis treated the earth, and not fully gestated our consciousness towards its miraculousness. Are we – the people of the twenty-first century Anthropocene age – (both diverse in spiritual beliefs and endeavours as well as spirit-less) also capable of a "Copernican revolution [evident] in Paul's thinking" (Witherington 2005, p. 40); to see the planet as sacred and through Christ's wisdom as part of divine Creation? Do the peoples of the world have the capacity to re-store the planet through this reverential prism? Or – disassociated from our source – are we set at rapid speed to a catastrophic end, driven by neo-liberal greed and post-modern idolatry dressed up as the necessary economics of late capitalism? Through an intentional and indeed necessary inter disciplinary lens, this paper examines post-modern idolatry in the context of the climate change epoch in which we find ourselves against the reverential instructions of both the First and New Testaments, and subsequent critique of those instructions.

The Anthropocene Epoch is characterized by the human impact on the environment and awareness of that impact. According to Hawke and Palsson (2017), Ingold and Palsson (2013), and Steffen *et al.,* (2007), the Anthropocene, and its great technological and industrial acceleration, began post WWII and heralds the greatest degradation of the planet in living history. Steffen *et al.* (2007, p. 618) say: "To develop a universally accepted strategy to ensure the sustainability of Earth's life support system against human- induced stresses is one of the greatest research and policy challenges ever to confront humanity". It also constitutes a moral responsibility to recognise the full providence of Creation. The future, if there is one as we understand it, will rely on mitigation strategies along with intelligent partnership with the natural body of the planet, as "a part of nature" rather than being "*apart* from nature" (Hawke 2022). In his letters to the Romans Paul said "Welcome one another, just as Christ has welcomed you", (Romans 15, 7); we too are re-called to welcome the God-given earth and embrace rather than exclude (Volf 1997) this life that we have exoticized and turned into "Other", and receive the knowledge offered, by sharing rather than over-exploiting its gifts. We can take some of our cues from the prophet Joel, who affirmed that God' s graciousness is applied to the whole of Creation: "Do not fear, you animals of the field, for the pastures of the wilderness are green, the tree bears its fruit, the fig and the vine give their full yield" (Joel 2, 22). [2]

This paper foregrounds the challenges and contributions posed specifically by eco-theology as liberation praxis, and our co-evolved relationship with life, that is – nature, culture and spirit. It may therefore be more appropriate to apprehend this work as Liberation Spirituality rather than through the more accepted Liberation Theology. In any case, Liberation Theologians such as Moltmann (1994); Sobrino (2008); Goizueta (2008), and Karkkäinen (2003), inform a more inclusive and gracious understanding of how a planet revived and revered, may continue to serve not only humans but all of Creation, through the beneficence of a living and breathing theo-spirituality. Eco-theology through a Liberation Theology optic further de-centres the human, and emphasises an embrace of the natural world as an equal partner in a web of relations, over whom we are instructed by God to guardian not dominate, this "carefully ordered creation" (Bauckham 2012, p. 5). This brings the dialectic of "stewardship or domination" (Rose 1992, p. 26) into acute focus.

Questions are posed throughout this article to discover whether current humanity can co-exist with its same and different selves, and the ecology that sustains it, and enact the "Copernican revolution of thinking", evident in Paul's thinking, and the broader understanding of Liberation Theology. This liberation movement came into being through the abject disavowal by oppressive colonial and political regimes towards whole peoples who were considered exploitable because of difference in race, ethnicity and beliefs, and who had a bounty of natural resources and land, that as history has narrated was turned over to cash cropping. Imperialist oppression and ecological destruction are co-implicated, as history as narrated; when war is waged on a people, the environment also suffers, repeating the "impiety and lawlessness" (*Inc.* 11, in Behr 2014, p. 61) that so troubled Athanasius. Although he was troubled for different reasons, it is not unreasonable to suggest that our common ecological disasters are born of earlier and more widespread lawlessness, and echo the warning in Deuteronomy, that curses will prevail if the commandments are not adhered to, for example: "Cursed will be your basket and your kneading bowl. Cursed shall be the fruit of

[2] Throughout Christianity's emergence we have seen several moments of sublime praise for nature as God's creation, for example Hildergard of Bingen's veneration of nature in her *Book of Divine Works* (1987) and St Francis of Assis's *The Canticle of the Creatures* that equally and inclusively honours 'brother son, … sister moon and stars, and wind'. See also Barbiero (2016).

your womb, the fruit of your ground, the increase of your cattle and the issue of your flock" (Deut 28, 17-18). The very motivation of development from the military-industrial complex being profit based, with little regard for what physical environments can produce, or indeed what is considered "natural law" in spiritual and cultural communities differently expressed, further ignores God's original blessing of nature and people rightly, treated. Yet the tension between the expansion and evangelisation of Christianity through colonialism (and the associated environmental and cultural destruction) from which by necessity ecumenical Liberation Theology was eventually spawned, remains complex and unforeclosed. Not to mention that true evangelization is as much about renewal and liberation of the soul, as it is about ethical and political practices that get in the way of such a realization, as discussed below.[3]

2. Liberation and oppression

Assassinated Archbishop Romero from El Salvador, detailing the plight of his suffering people under the totalitarian regime of the time, said, "People in the way get killed" (Sobrino 2008, p. 85); which included himself in 1980. He supported the people through human rights abuses that are only now finding justice, and provided a voice from liberation theology that has followed, in all areas of the world so troubled. So too it seems that nature is in the way of progress – natural and indigenous species of flora and fauna, overworked and poisoned to be replaced by more cashable produce.[4] Forcing people to change from traditional subsistence lifestyles into cash cropping has exponentially marginalised those in the developing world (most especially women), while simultaneously polluting and destroying their natural resources, some of which are deemed ontologically sacrosanct. Equally concerning in the developed world, is an enthusiastic and at times obsessive push towards economic growth and mono-cultures, irrespective of the reserves nature has to provide us with. We are now urgently called to a radical re-thinking of ecologically sustainable process, an "ecodemocracy" (Kopnina *et al.* 2021) of sorts, and a tectonic shift in thinking and believing in what we think and believe, and how well we share or do not share our best thinking with the world.

[3] See the *Evangelii Nuntiandi* from Pope Paul VI (1975) for a larger discussion on this.
[4] All that Sobrino, Romero and other Liberation Theologians teach, can be transposed on to how nature, women, the working and under-class and Indigenous First Nations People are treated under oppressive regimes. See Batstone *et al.* (1997) for deft and extensive elaboration of these ideas.

A more recent example of enforced shift from subsistence and original faith, and from one way of life into numerous others (not just one other) is narrated poetically, by Kathy Jetñil-Kijiner in *Iep Jaltok: Poems from a Marshallese Daughter* (2017) regarding the dispossession of the Marshall Islands people due to rampant nuclear testing by America in the 40s and 50s in the Pacific Ocean. Apart from having their own religious traditions, the Islanders – whose dwelling place is spread out among the shallow atolls of the Pacific – were converted by earlier waves of colonialism and its embedded Christianity, including from Portugal, Spain, Germany, Japan and eventually America. These influences eroded some specific cultural and traditional lifestyle and beliefs. Yet despite the machinations of colonial imbued Christianity impacting their traditions, the people of the Marshall Islands have adapted to a bicultural sense of faith, in which their love and guardianship of their land and waters is made clear despite the environmental challenges they now face.

The de-naturing of their traditional life was further compounded by their forced removal to other islands because the Marshall Islands archipelago had become too radioactive to be hospitable. "Having inherited the fallout of nuclear testing (as cancers and environmental death), having been dispatched to a safer island home, having buried elders and young relatives, Jetñil-Kijinier draws the reader on to the next catastrophe, climate change" (Hawke 2017, p. 83). In her poem "Two Degrees", she prophecies that climate change and oceanic rise in temperature and level, will wash the "crumbs of the pacific off the table" (Jetñil-Kijiner 2017, pp. 74-76), constituting the next wave of extreme change, in which Marshallese will increasingly become climate change refugees. The greater world would be wise to heed this abject warning of peril.

A similar history of disavowal of religious and spiritual traditions, people and nature appears with the story of Nuclear Testing in Maralinga, Australia at the same time. Australia, and its already colonized and Christianized Indigenous people, suffered firstly from the initial impacts of colonization (disease and massacre), and later by the forced removal of their children by white governmental policy. Further, because Indigenous Australians did not consider the land something to be owned but more over something to be protected by human guardians, the way was left open to colonial interpretation that Australia now belonged to the British Crown[5]. The British carried out their nuclear testing

[5] See for example: "The Apology" from Prime Minister Kevin Rudd February 13, 2008, to those Australians for further elaboration of Australian colonial policy and its changes over time. As postcolonial scholars widely note, colonialism and environmental

in this remote place Maralinga from 1956-1963, in the Woomera, South Australia, home to remote Indigenous people from the Anangu Pitjantjara and Yankunytjatjara clans and their spirituality. These communities now also suffered from nuclear fall-out, and their 60,000-year-old belief systems were virtually expunged in the process. Reparative justice with those communities was slow to evolve, as once again oppression of the "Other" proliferated. The travesties of these examples and the "othering" imbued in them, while exotic in a European landscape, are easily transferable to the degradation of the earth and minority groups in Europe. One only has to count the number of refugee deaths from ill-fated crossings of the Mediterranean Sea, to recognize the parallel dilemmas of people fleeing war, oppression, strife, environmental damage and famine in their home countries. The case of the Lampedusa refugee haven off the coast of Italy will yield its own stories in time.

In 2019-2022 as planet Earth and its peoples braced itself against the outbreak of COVID-19, many asked if this might be the crisis to finally embrace the whole world and all its peoples and not exclude the marginal, but rather embrace all life, and welcome new ness over the threshold. Towards the end of the twentieth century, Volf questioned the possibility of dissolving "exclusionary polarities" (1996: 99) that might better respect cultural and spiritual traditions that differ from dominant perceptions primarily from the West. Twenty years later the jury is still out on this. The question remains open: "can we manage full *in-corp-oration* of Others and of nature" (Hawke 2018, p. 195) or are we so hard-wired that even global tragedy cannot shift us towards ecological and cultural sustainability and integration? The recent invasion of Ukraine by the Russian Putin regime, suggests we are still challenged by inclusivity and embrace, investing instead in fear of the "other" inherited perhaps from former conflicts.

Solidarity with the poor, sick, marginalised and overthrown, must, by necessity then, extend to a solidarity with the poor and denatured state of the planet's ecology. This calls for the assembly of "a fresh sustainability logic [in which reverence is embedded] … that cultivates connectivity, and adaptive capacity" (Hawke and Palsson 2017, p. 235) between the biosocial constituents, and their spiritual/traditional/religious agency. "Biosociality" (Palsson 2013), gestures towards the engagement between biological and socially diverse worlds, rather than operating out of Cartesian dualisms that render culture more valuable than nature. This dangerous Cartesian optic (that earnestly guards the threshold of opposites), whether it pertains to the nature/culture divide or a

degradation have always gone hand in hand. See for example: Potter (2019) in the Australian context and Boff (1995) for a more global analysis.

geopolitical/theological divide, makes a communion of entanglement problematic and a potent life-giving spectrum of relationality unrealizable, because, "The welcome over the threshold or a membrane to a new life and habitat is less likely, not only because of physical conditions but because of the psycho-social and geo-political conditions that govern host/age and welcome" (Hawke 2018: 198). How might we host nature more inclusively and respectfully and embrace a "collective eco-literacy" (Freire 2004, p. 18)? To this end it could be argued that, "Liberation theologies are the manifestation not only of a [positive] postmodern condition but also the praxis of a new "theological paradigm" (Batstone *et al* 1997, p. 260), in which ecology pleads for an equal voice.

For holistic restoration and reconciliation between the earth and its peoples to become possible, and for the mission of Jesus to be fully expressed, "From creation-in-the-beginning to continuous creation …[meaning] God sustains what he has created" (Moltmann 1997, p. 97), the Old Testament once again proves instructive. God "watches over the world once he has created it, in order to preserve it from the chaos by which it is unremittingly threatened" (97), chaos unleashed by humans, which in self-reflection may help us re-consider our rank in Creation. Afterall we humans were only created on the 6th day along with a vast array of other creatures arguably made from dust (Genesis 2). Yet we are clearly directed to understand the specific patterning decreed by God, a cosmic patterning in which humanity is merely one actor in a vast production: "And God said, … Let the earth bring forth living creatures of every kind" (Genesis 1, 24) … Then God said, "Let us make humankind (Genesis 1, 26) … then there was evening and there was morning, sixth day" (Genesis 31).

3. Re-visiting the Old to restore the New

You save humans and animals alike, O Lord.
(Psalm 36:6)

The challenge for our climate changing times appears to be to restore g/local ecological respect, awe and wonder, and the grace of God's gifts to us in the generations that preceded the life of Jesus Christ, but which deeply informed his mission, and our current apprehension of the same. Understanding the genealogical development of Judaism intertwined with the agrarian culture of the Middle East, perhaps enables a learning from the past to envision a future, truer to God"s intention. The notion of a sacred commons and the confluence of all life on earth comes into play as the historico-theological cartography of God's mission is unfurled and better understood.

This web of interconnection is set up clearly in Genesis, as Bauckham explains, "The fundamental relationship between humans and other creatures is [precisely] their common creatureliness. In Genesis 2, 7 God forms the first humans from the earth, just as he does all living creatures, flora and fauna" (2012, p. 4). Theocentric creation[6] is predicated on the notion that "The human dominion is not granted so that humans may violate that order and remake creation to their own design" (Bauckham 2012, p. 6). On the contrary, it is patterned to be ever in relation, to be biosocial or further, theo-bio-social.

> In his hand is the life of every living thing, and the breath of every human being (Job 12, 10).

This analysis of eco-theological perspectives locates responsibility for the planet to be in in relationship with its peoples, not as separate from the people. Along with *Genesis* the *Book of Psalms* (in which humans and nature praise God and Creation), *Deuteronomy*, and *Job* from the Old Testament, are equally instructive. Some New Testament excerpts from Matthew (5, 5; 10, 29-31), and Luke (12, 6-7) are further advanced by the example of Paul's conversion as it might apply to a global conversion in favour of ecology, rather than an ongoing committal to ecocide.

For example, in Deuteronomy we are told, "If you pay heed to the Commandments which I give you this day, and love the Lord your God and serve him with all your heart and soul, then I will send rain for your land in season" (Deut 11, 13-17). Deuteronomy throws some clues as to how to care for God, each other and all that is created and sustains us. It also directs us to share the bounty with "the Levites resident in your towns, as well as the strangers, the orphan and the widows among you" (Deut 16, 11).[7] Here the message is clear that equitable sharing of everything and respect for the sacrifice of animals is also to be acknowledged.

---

[6] Bauckham (2012) points out the horizontal rather than vertical construction of the world, meaning that life was created 'alongside', rather than 'on top of'. In such a schema there is a promise of equality.

[7] See for example, Ruth (1-4) the Moabite stranger who cared for her widowed Israelite mother-in-law Naomi and was rewarded by God for her honour. Here, I note Rev Dr Jeanette Mathews and her expertise on exilic theology and its relationship to environmental and other concerns. See her paper: Mathews (2019).

Bauckham (2012, 65) interrogates in depth, the lengths that the Israelite's went to, to ensure proper care and distribution. He details those parts of the law that mitigate against poor animal husbandry, animal suffering (*tzaar baalei hayim*) and hunting that is needless. Further, and drawing on Leviticus, there are laws centring on the actual treatment of the land, and the requirement to leave fields fallow every seventh year, "to rest the earth" (84). "Six years you shall sow your field, and six years you shall prune your vineyard, and gather in their yield; but in the seventh year there shall be a sabbath of complete rest for the land, a sabbath for the LORD" (Leviticus 25, 3-4). This sabbatical year not unlike the Sabbath day, instructs humans and their labour also to rest. Jewish people are also instructed to take a sabbatical year to study the First Testament and to otherwise rest from their labours. Both Bauckham (2012) and Rose (1992) point to the significance of "resting" the earth especially in recent and current times. There is wisdom in the intention to engage in a year of reflection, to regain consciousness of the power of creation – and the God that created it.

Jewish festivals often invoke respect for nature, such as "Pesach, Shavuot, Succoth … and the festival of trees" (Bauckham 2012, 85). Similar injunctions and decrees from the Old Testament apply to water, "a vital reality, but like trees, also referred to in allegorical terms – *mayim chayim,* living waters … beginning with the very first Psalm" (Bauckham 2012, 86): [8]

> They are like trees,
> planted by streams of water,
> which yield their fruit
> in its season,
> and their lives do not wither.
> In all they do,
> they prosper. (Psalm 1, 3)

When Jesus began to teach through the art of the parable, the wisdom of the past was augmented in the everyday agrarian world of the New Testament; in the very Galilean-ness of the communities he was preaching to. Drawing on Rabbinic tradition and local geography, Jesus further advanced the ecological intentions laid down in the Old Testament by wedding them to the human concerns of the time. Ironically it is those very concerns that still trouble us today, such as war, power, famine, and fear of the "other", whoever "they" may be. Yet as Paul reminds us there is possibility that we can learn from our trials, "we glory in

---

[8] See The Chumash, the first five books of the Bible for this detail that is beyond the scope of this paper.

tribulations, knowing that tribulation waketh patience" (Romans 1, 3). Historically and in the present day, we, as a species, are implicit in creating the very situations that create peril and cause global concern, in a state of almost forgetfulness of history repeating itself. Despite the best intentions of many, humans have been waging war on each other for millennia, provoked by tensions of the times, wounding more than perceived enemies, but the very ground that supports life.

4. Why Galilee

Blessed are the meek for they shall inherit the earth
(Matt 5, 5)

Bauckham (2012: 64-70) unpacks the "micro ecologies of Galilee" that spawned Judaic beliefs. I proffer that Jesus chose to preach between lower Galilee (Nazareth), the valley and (lakeside and Capernaum) and upper Galilee (Caesarea and Philippi), because of the rich influence this small but diverse environment had on his life and evolving mission. Deeper questions remain if we follow this trajectory. Was his teaching in these locations to re-enforce in the human imagination the pivotal role of nature in everything, in all life, something that was harder to do by preaching in big cities?

Perhaps, but let us take it further than that and also consider the particular reverence Jesus had for small things. "Jesus never uses the superiority of humans to animals in order to make a negative point about animals" (Bauckham 2012, p. 97), and it could be argued that for his ministry, the city and its learned men had no superiority over the humble life and lands of Galilee. As Foulcher also suggests, Jesus "embodiment of 'love and humility'" (2015, p. 23) and his humbling from divine son to incarnate crucified man, also demonstrates this approach.

Jesus is strategic in his oration and embodiment, in which he becomes the speaking body for all bodies. He designed arguments that "depend more on the idea that, humans and animals are all creatures of God" (Bauckham 2012, p. 97) rather than further verticalizing an already hierarchical arrangement of difference in which the dialectic of servility and honorable humbling is uselessly propagated. This method serves to remind that "humans are not the priests of creation" (Bauckham 2012, p. 150), rather, they are guardians operating within a horizontal continuum.

Sustenance and recovery of Earth's actual and sacred character is an ongoing imperative in such a continuum. This is evidenced in more modern times through the creation of organisations such as the Jewish National Fund for example, "established in 1902 … to renew and redeem the land. It is significant … that its Hebrew name, *Keren Kayemet*, is a quotation from the Mishnah, written 1,700 years earlier" (Rose 1992, p. 84). Everything is connected and blessings are regularly invoked, to re-iterate connection and reverence. The people of Israel, across time, plant trees in commemoration of everything as well as to visibly commit to survival and sustainability, and to "cherish biodiversity by conserving species" (Rose 1992, p. 25) according to their own patterning and God given purpose. The New Year for Trees Festival, *Tu Bi Shevat,* "on the fifteenth day of the month of Shevat, when the winter ends in Israel" (Rose 1992, p. 15), amply demonstrates this cherishing. As Rose suggests, "Blessings hallow nature, and respect the environment, the work of the Creator" (Rose 1992, p. 17). Trees are not only there anthropocentrically for humans, but for all life, as the oxygenators that they are, whether they bear actual fruit or not.

The narrative of the sparrow told in the Gospels of Luke (12, 6-7) and Matthew (10, 29-31) also demonstrates Jesus' concern for all creatureliness, not unlike Deuteronomy's instruction about preservation and longevity that is more eco-centrically inclined: "you shall not take the mother with the young"(Deut 22, 6-7), only take what is needed and leave the possibility for a future with what you leave behind. The lessons here are about respectful discernment in what is taken from nature to sustain human and other forms of life.[9]

Sparrows, for example, represent the smallest bird in the market and the message in both Luke and Matthew is clear. "Are not five sparrows sold for two cents? Yet not one of them is forgotten before God" (Luke 12, 6). They should be affordable for all, and no one should hunger. And indeed, the sacrificial life of the sparrow is acknowledged. The parallel point that Bauckham (2012, p. 92) makes here is that Jesus chose as his disciples, not the elevated credentialed merchants and wise men or the eagles and the hawks of the city world, but the

[9] The recent example of the fish of Venetian canals is acute. During the first COVID-19 lockdown, multitudes were seen swimming freely without pollution and silt stirred from the bottom of the canals. The case of the small species of pangolins is also acutely relevant here. Rather than being cherished as their unique small selves, the species has suffered from an exotic commoditisation that not only robs it of respect and life, but has contributed to a discourse of the genetic transmission of COVID-19 through re-combination. Scientists compared genome sequence data from SARS-CoV-2 and related bat and pangolin viruses and proved that the new coronavirus likely jumped from an animal host into humans (Andersen *et al.*, 2020). While it is useful to understand 'genetic re-combination' these very understandings inadvertently demonise the smallness of bats and pangolins. Did we fail in our duty of care to small creatures?

sparrows of the world, the mostly working-class fisherman (that were the Apostles), to disseminate his salvific message.

5. Conclusions

But ask the animals, and they will teach you, or the birds in the sky,
and they will tell you; or speak to the earth, and it will teach you.
Which of all these does not know that the hand of the Lord has done this?
(Job 12, 7-9)

Fast forward to the currency of the degradation of the planet through our self-evolved climate change crisis and forgetfulness for divine instruction, as much as abject mis-management. In his exegesis on Matthew Fox, Bauckham explains: "The Paschal mystery is the Christian story of the passion, resurrection and ascension'. Fox proposes that for our age of ecological destruction, "the appropriate symbol of the Cosmic Christ who became incarnate in Jesus is that of Jesus as Mother Earth, crucified and rising daily"[10] (Bauckham 2012, p. 197). Does this daily crucifixion of the earth, and suffocating of the air and waters, represent our human ego-centric failure to uphold canonical laws of preservation and respect for all God's creatures, in which the humility of the earth is over looked? Bauckham goes some way toward answering this challenge:

> This rejection of human embedded-ness in nature and of the mutual interrelations between human history and the rest of nature, in favour of an assumed interdependence of and supremacy over nature, is of course, the ideological root of the present ecological crisis (Bauckham 2012, p. 111).

For Berndtson (2010), this crisis pre-supposes a need for a "respiratory philosophy", in which the vitalising breath is pivotal to all life as well as thinking, and inhaling the breath of life, is not a simple act of taking in air, as much as it is a conscientious inhaling of life. There is something very pneumatological in sharing the airs with other species created by God and through the embodied act of "knowing" breath. The conscious connection between thinking/knowing, breathing and doing seems holistic if not theo-ontological. As Paul also implies "As God's chosen ones, holy and beloved, clothe yourselves with compassion, kindness, humility, meekness and patience" (Colossians 3, 12). Conscientious

[10] See Bauckham's (1988) exegesis on Mathew Fox's *The Coming of the Cosmic Christ: The Healing of Mother Earth and the Birth of a Global Renaissance,* particularly Chapter 21 "Jesus Christ as Mother Earth Crucified and Resurrected" (pp. 145-149) from where this is gleaned, and Bauckam (1994).

 http://dx.doi.org/10.13135/2384-8677/7497

sharing the airs of planetary life then and all elements, is arguably a humble sharing of love.

The mis-alignment of human capacity for humility and the humility of the earth, in which sharing the elements of creation is precariously situated, continues to present great challenges not just to the humble yet noble earth, but also to the Christian context as narrated by the parables of the New Testament and the Judaic ecological living world that preceded it. Rich historical and theological contributions and practices have aided in the preservation of God's creation. There is also a mounting body of evidence to the contrary, aided and abetted by capitalism and the perils of colonial domination, and economically driven development that post-modernism and neo-liberalism has dangerously and further advanced (Mendieta, in Batstone *et al.,* 1997), and the damage it has left behind.[11]

6. Sustaining consciousness for a future on Earth

The conceptual and hermeneutical tools of Liberation Theology and a broader eco-theology have been employed here through the solidarity of suffering on the cross of Jesus, and a humble earth that is daily crucified. The "proleptic forms of the postmodern" (Mendieta, in Batstone *et al* 1997, p. 260) world have indeed revealed themselves in the increasing fragmentation and disenfranchisement of marginalised people, and nature. There is a call for politics, theology and environmental sociology, and cultural studies to recognise all the world's people as human (Mendieta 16) and as their own cultural selves, and nature as its own generative self, towards a receptivity of what the Ecclesiology, "from below" (Karkkäinen 2003: 180) offers us. The forgetting of our origins and degradation of our own lives, that is apparent in the Anthropocene era, doesn't change the fact that "God forgets nothing that he has created" (Moltmann 1994, p. 104).

Contoured by history and deep time inheritance evident in the ministry of Jesus, this paper has analysed current practices that degrade people, places, nature and things, and proffers that there is some small hope that, "By calling into question those systems and the religious, intellectual, and ideological structures that

[11] All Abrahamic religions honour the earth and its providence (and paradoxically, all have fought religious wars). The focus of this paper has been Judaism and Christianity. Please visit the Qur'an, for equivalent discourse on human preservation of nature, for example: "And Allah has sent down rain from the sky and given life thereby to the earth after its lifelessness. Indeed, in that is a sign for a people who listen." Qur'an, 16:65

validate them, we move closer to changing them" (Karkkäinen 2003, p. 16). When we, the human governors of the planet become more cognizant of a g/local suffering that draws God "irrevocably near to this world, that he is a God, 'with us' and a God 'for us' " (Sobrino 2008, p. 231), we are perhaps in with a chance. Moltmann suggests, "God's preservation of the world doesn't belong only to the realm of nature. It is already part of the realm of grace" (Moltmann 1994, p. 97). Can we then change our perspective as Paul did and embrace atonement and reparative revolution, and know grace? How does the planet in the grip and aftermath of COVID-19 in the twenty-first century, nourish grace and share it, and will we do it in time?

Sustainability and ecological consciousness have been issues for Christianity and the world long before the climate change crises of the Anthropocene. "Christology begins as receptivity to God's self gift in Jesus Christ", as Goizuetta points out: "It all started with God" (2008, p. 91), and to continue that mission do we perhaps find ourselves at a time and place in which we "re-habilitate humility" (Foulcher 2015, p. 31) and find grace. Against the quietude of our recent earthly COVID-19 circumstances, perhaps Psalm 96 offers hope, and something of the future that is on offer if liberation of the earth and nature unfolds in equal measure to the liberation of human life:

> Let the heavens rejoice,
> let the earth be glad
> let the sea resound and all that is in it.
> Let the fields be jubilant, and everything in them;
> Let all the trees of the forest sing for joy. (Psalm 96, 11-12)

Acknowledgements

The author thanks the peer reviewers for astute and generous critique and comments. The paper is dedicated to the late Professor Will Steffen (ANU, Australia) for his inspiration of all things earthly, and his support of my inter disciplinary ecological research.

References

Andersen, K.G., Rambaut, A., Lipkin, W.I., Holmes, E.C., & Garry, R.F. (2020). The proximal origin of SARS-CoV-2. *Nature medicine*, *26*(4), 450-452.

Athanasius. *On the Incarnation*. (*Inc 11*). In John Behr, (2014) [1996] New York: St Vladimir's Seminary Press.

Barbiero, G. (2016) Francis of Assisi and the Wolf: Nonviolence as a moral value of biophilia. *Visions for Sustainability* 5, 28-31.

Batstone, D., Mendieta, E., Lorentzen, L.A. & Hopkins, D.N. eds. (1997). *Liberation Theologies, Postmodernity and the Americas.* London and New York: Routledge.

Bauckham, R. (1988). Jesus Christ as Mother Earth Crucified and Resurrected. in *The Coming of the Cosmic Christ: The Healing of Mother Earth and the Birth of a Global Renaissance.* San Francisco: Harper, pp. 145-149.

Bauckham, R. (1996). The New Age Theology of Matthew Fox: A Christian Theological Perspective. *Anvil* 13 (2), 115-126.

Bauckham, R. (2012). *Living with Other Creatures: Green Exegesis and Theology.* Milton-Keynes: Paternoster.

Berndston, P. (2010). The Inspiration and the Expiration of Being: The Immense Lung and the Cosmic Breathing as the Sources of Dreams, Poetry and Philosophy, in Karel Novotn´y, Taylor S. Hammer, Anne Gléonec, and Petr Specián, (eds.) in *Thinking in Dialogue with Humanities: Paths into the Phenomenology of Merleau-Ponty,* Bucharest: Zeta Books, pp. 281-293.

Boff, L. (1995). *Ecology and Poverty: Cry of the Earth Cry of the Poor* Maryknoll: Orbis Books

Boff, L., & Boff, C. (1987). *Introducing Liberation Theology.* Kent: Burns and Oats.

Boff, L., & Elizondo, V.P. (1995). *Ecology and Poverty Cry of the Earth, Cry of the Poor.* Maryknoll: Orbis Books.

Bohache, T. (2008). "A Crucified God for a Crucified People". Latin American Liberation Christology. In *Christology from the Margins.* London: SCM Press, pp. 81-102.

Foulcher, J. (2015). *Reclaiming Humility: Four Studies in the Monastic Tradition.* Ohio: Cistercian Press.

Francis of Assisi (1224) *The Canticle of the Creatures*. http://franciscanseculars.com/the-canticle-of-the-creatures/

Freire, P. (2004). *Pedagogy of the Oppressed.* Boulder: Paradigm Publishers.

Goizueta, R.S. (2008). The Christology of Jon Sobrino. In Stephen J. Pope (ed.) *Hope & Solidarity: Jon Sobrino's Challenge to Christian Theology.* Maryknoll. NY: Orbis Books, pp. 90-104.

Hawke, S. (2017) review of *Iep Jaltok: Poems from a Marshallese Daughter***.** Kathy Jetñil-Kijiner. Arizona, USA: University of Arizona Press. In *World Literature Today; Lives Interrupted/Migration Stories* Sep-Oct 2017: 83.

Hawke, S. (2018) Graft versus Host: Waters that Convey and Harbors that Reject Liminal Subjects – Towards a New Ethics of Hospitality. In Tomaž Grušovnik, Eduardo Mendieta, and Lenart Škof (eds.). *Borders and Debordering: Topologies, Praxes, Hospitableness.* Lanham, Boulder, New York, London: Lexington Books, pp. 193-215.

Hawke, S. (2022). A part *of* Nature or apart *from* Nature. A case for bio-philiation. *Visions for Sustainability*, 18, 125-144.

Hawke, S. & Palsson G. (2017). Water Futures, Biosociality, and Other-Wise Agency. *ANUAC* 6 (1): 233-252.

Hilderagd of Bingen (1987) *Book of Divine Works*. Matthew Fox (ed.). Rochester, VT: Bear and Co.

Holy Bible (1989) New Revised Standard Version. Nashville: Thomas Nelson.

Ingold, T. & Palsson, G. eds. (2013). *Biosocial Becomings: Integrating Social and Biological Anthropology*. Cambridge: Cambridge University Press.

Jetñil-Kijiner, K. (2017). *Iep Jaltok: Poems from a Marshallese Daughter***.** Tucson: University of Arizona Press.

Kärkkäinen, V.M. (2003). *Christology: A Global Introduction*. Grand Rapids: Baker Academic.

Kopnina, H., Spannring, R., Hawke, S., Robertson, C.D., Thomasberger, A., Maloney, M., Marini, M., Lynn, W., Muhammad, N.Z., Santiago-Àvila, F.J., Begovic, H., & Baranowski, M. (2021). Ecodemocracy in Practice: Exploration of Debates on Limits and Possibilities of Addressing Environmental Challenges within Democratic Systems. *Visions for Sustainability* 15: 9-23.

Mathews, J. (2019) Led through Grief: Old Testament Responses to Crisis. *Stellenbosch Theological Journal* 5 (3), 621-642.

Moltmann, J. (1994). *Jesus Christ for Today's World*. Minneapolis: Fortress Press.

Pope Paul VI (1975) *Evangelii Nuntiandi*. https://www.vatican.va/content/paul-vi/en/apost_exhortations/documents/hf_p-vi_exh_19751208_evangelii-nuntiandi.pdf

Potter, E. (2019). Contesting Imaginaries in the Australian City: Urban planning, public storytelling and the implications for climate change. *Urban Studies* 57 (2), 1536-1552.

Qur'an, 16:65

Rose, A. (1992) *Judaism and Ecology* (ed.). New York and London: Cassell.

Rudd, K. (2008) *The Apology* (February 13, 2008) https://info.australia.gov.au/about-australia/our-country/our-people/apology-to-australias-indigenous-peoples

Sobrino, J. (2008). *No Salvation Outside the Poor: Prophetic-Utopian Essays*. Maryknoll: Orbis.

Steffen, W., Crutzen,P.J. & McNeill, J.R. (2007). The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature. *Ambio,* 614-621.

Volf, M. (1996). *Exclusion and Embrace: A Theological Exploration of Identity, Otherness and Reconciliation*. Nashville TN: Abingdon Press.

Witherington, B. III. (2005). Jesus as the Alpha and Omega of New Testament Thought, in R. N. Longenecker (ed.), *Contours of Christology in the New Testament.* Grand Rapids: William B. Eerdmans, pp. 25-46.

Witherington, B. III. (2006). *1 and 2 Thessalonians: A Socio-rhetorical Commentary.* Grand Rapids: William B. Eerdmans.

Author

Shé Mackenzie Hawke, Department of Gender and Cultural Studies, University of Sydney, Australia.
she.hawke@sydney.edu.au

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The author hereby states that there are no financial or non-financial competing interests.

Citation

Hawke, S.M. (2023) The liberating theology of a planet's beneficence: a possibility. *Visions for Sustainability*, 20, 7497, 497-514. http://dx.doi.org/10.13135/2384-8677/7497

Caterina Lorenzi e Franca Sangiorgio

Conserving Nature.

The contribution of ecological research to education

Elisabetta Falchetti (1948-2022), to whose memory this special section is dedicated

visions for sustainability
PUBLISHED TWICE A YEAR
AT THE SUMMER AND WINTER SOLSTICES

Special Section - Winter Solstice
21 December 2023

Guest Editors

Caterina Lorenzi lorenzi@uniroma2.it
Department of History, Culture and Society, Tor Vergata University of Rome, Italy.

Franca Sangiorgio franca.sangiorgio@unisalento.it
Department of Biological and Environmental Science and Technologies, University of Salento, Lecce, Italy.

Citation:

Lorenzi, C. and Sangiorgio, F (Eds.). (2023). Special Section "Conserving Nature. The contribution of ecological research to education". *Visions for Sustainability*, 20, 515-587.

Conserving Nature.

The contribution of ecological research to education

Caterina Lorenzi, Franca Sangiorgio

We are pleased to present this special section of *Visions for Sustainability* concerning the contribution of ecological research to education within the framework of nature conservation. Our aim is to spark reflection on the new frontiers of environmental education applied to nature conservation. Given the complexity of environmental issues, we believe that it is important to pay special attention to formal, non-formal and informal environmental learning contexts. Examples of places with a strong ecological vocation include natural parks, natural science museums and the many agencies that promote scientific culture dissemination, which offer citizens the opportunity to participate in tailored educational projects. Virtual contexts, such as online resources from organisations that build and disseminate ecological knowledge, can also be effective in broadening the cultural and professional horizons of all those involved in Environmental Education.

The editors, Giuseppe Barbiero and Martin Dodman, conceived this special section as a way to examine how ecological research specifically contributes to Environmental Education – a topic which may be of specific interest to educators and trainers working on ecological and environmental subjects.

The Earth's ecosystems are experiencing high pressures, including habitat change, exploitation, pollution and invasive species, which have been recognized as the most important anthropogenic causes of biodiversity loss (IPBES, 2019). The recent Conference of the Parties (COP 27) of the United Nations Framework Convention on Climate Change (UNFCCC) stressed that current climate plans are insufficient and more ambitious actions are needed.[1] Global

[1] https://www.un.org/en/climatechange/cop27 accessed 22nd November 2022.

climate and regional human pressures, from the tropics to the Antarctic, are jointly causing the erosion of biodiversity (Bergstrom et al., 2021). It is therefore undeniable that nature conservation processes and the diffusion of knowledge about environmental degradation and restoration are crucial.

Nature conservation practices have ancient origins and were regulated internationally as early as 1980, when governments, non-governmental organisations and experts all over the world were involved in drawing up a global conservation document. *World Conservation Strategy. Living Resource Conservation for Sustainable Development* was commissioned by the United Nations Environment Programme (UNEP) together with the World Wildlife Fund (WWF) and prepared by the International Union for Conservation of Nature and Natural Resources (IUCN). In this document, *conservation* is defined as "the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations". The purpose of the World Conservation Strategy is described as the achievement of three main objectives: 1. to maintain essential ecological processes and life-support systems; 2. to preserve genetic diversity; 3. to ensure the sustainable utilisation of species and ecosystems (IUCN, 1980). Later, Harrison and Burgess (2000) proposed a definition of nature conservation that refers more specifically to the importance of wilderness: "nature conservation is about ensuring that the widest possible number of habitats and species persist through time". More recently Hambler and Canney (2013) offer a more effective, albeit concise, definition: "conservation is the protection of wildlife from irreversible harm".

Over the years, conservation items have become a mainstream political issue. The publication of *Report of the World Commission on Environment and Development: Our Common Future* (also known as Brundtland Report) in 1987, and the United Nations Conference on Environment and Development (UNCED) (also known as the "Earth Summit"), held in Rio de Janeiro in 1992, are recognized as milestones for the understanding and preservation of natural ecosystems. Since then, conservation has usually been a legal requirement, within a complex and interconnected network of national and international treaties, conventions, statutes, regulations and laws. Within this framework, the Convention on Biological Diversity (CBD, 1992), signed by many governments, is of relevant importance. Here, *biological diversity* is defined as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, including diversity within species, between species and of ecosystems".[2]

An international organisation that has been working for the past twenty years to provide policy-relevant knowledge to tackle the loss of biodiversity and degradation of ecosystem services is the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2012). IPBES builds on previous initiatives carried out in the field of biodiversity, outstanding examples of which include the Global Biodiversity Assessment (GBA, Heywood, 1995) and the Millennium Ecosystem Assessment (MA, Millennium Ecosystem Assessment, 2005). It is an independent intergovernmental body established by various States to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being, and sustainable development.[3]

For many decades, by seeking to achieve nature conservation goals, ecologists and biologists have devoted considerable research efforts to identifying and determining sites that best capture a significant range of diversity (Gaston, 1996). In Italy, for example, on February 16, 2022, the European Commission approved the latest (fifteenth) updated list of Sites of Community Importance (SCIs) for the three biogeographical regions of interest to Italy: Alpine, Continental, and Mediterranean.[4]

However, the complexity of nature conservation processes needs to offer articulated solutions. It is not enough to identify key sites for conserving biodiversity *in situ* (Harrison & Burgess, 2000). There has to be a synergistic space where research findings are interpreted and applied in on-the-ground contexts in ways that acknowledge and integrate with social, political, and economic milieus (Ardoin et al., 2020).

Within this framework, the role of environmental education becomes crucial. The growing body of research foregrounding environmental education and related disciplines such as environmental psychology, the history of ecological thought and behaviour, environmental sociology, etc, "moved away from suggesting a linear path from environmental attitudes to knowledge to action, now emphasising a dynamic, complex ecosystem of relationships that influence

---

2 https://www.cbd.int/ accessed 5th January 2023.

3 More details about IPBES and other relevant national and international organisations are reported in Lorenzi & Sangiorgio paper in this special issue.

4 https://www.mite.gov.it/pagina/liste-dei-sic accessed 5th January 2023.

behaviour rather than earlier ideas derived from an information-deficit perspective" (Ardoin et al., 2020).

In this special section we present three original papers that specifically focus on the future of environmental education, exploring new ways of acquiring knowledge and skills by forming partnerships with schools and institutions that promote the dissemination of ecological culture and building multidisciplinary teams.

In the paper titled *"Introducing children in the primary school to the concept of ecosystem services"* Rota N., Canedoli C., Fava M. & Padoa-Schioppa E. focus on the concept of biodiversity conservation and the related concept of ecosystem services as they are understood at school age. The authors highlight the need to encourage greater environmental sensibility compared to the past, in relation to the increasing effects of the environmental crisis. One project discussed in this paper, aimed at developing children's sensitivity to environmental issues, is based on the use of the concept of ecosystem services as a teaching tool in primary school. The authors note a positive change in children's perception of the environment after this project based on ecological content, which could be the starting point for an increased sensitivity of children towards nature and ecosystem services.

In the following paper, titled *"Urban vegetable gardens and composting as tools for primary schools' students understanding of the EU Green Deal"*, Vicente M.M., Leitão R., Quintino V., Pombo P. & Rodrigues A. M. address the importance of ecological knowledge, aimed at nature conservation and the sustainable use of natural resources, in urban design and management practices, also stressing the importance of ecological training for all operators in the field of education. This article offers a contribution to the Green Deal strategies with a pilot project called "Nutrients Boomerang", as part of the environmental education activities of a National Agency for scientific and technological culture in Portugal (Fábrica Ciência Viva). The authors emphasise the importance of making primary school students aware of natural resources depletion and highlight a change in children's behaviour after the project activities, fostering conscientious behaviour in young students towards a more sustainable world.

With their contribution entitled *"Sustainable food consumption in nature conservation processes. Educational considerations",* Bartoccioni F., Lorenzi C. & Sangiorgio F. highlight the connection between nature conservation and food consumption within the educational framework. The subject of an agricultural production that respects natural ecosystems is currently very relevant, as it is being tackled by international agencies such as FAO and IPCC, focusing on the double link between biodiversity conservation processes and sustainable agriculture in a virtuous circular process. In this context, the adoption of sustainable eating habits, strongly relying on educational processes, is indispensable.

The special section ends with a note by Guida F. & Da Milano C. in memory of Elisabetta Falchetti, a highly influential researcher whose death has left a big hole in the community involved in environmental education and science dissemination.

We wish to deeply thank the authors who have contributed to this section and our special thanks go also to the editors of *Visions for Sustainability* for hosting it.
As a further reflection, we would like to draw readers' attention to the importance of encouraging all those working in Environmental Education, especially young researchers in ecology with an interest in educational issues, to solicit more attention to it from all ecological and environmental organisations. Particular emphasis should be placed on the literature reviews because this is a complex and interdisciplinary field of research. In this regard, Gutierrez et al. (2022) report that the literature reviews on Environmental Education, including Sustainability, have seen a marked increase in quantity and scope in recent decades, but still tend to have diverse and somewhat provisional research objectives. Moreover, strengthening the capacity of educators and trainers to become learning facilitators for Education to Sustainable Development (ESD) is one of the priority action areas of the Global Action Programme on ESD. There is an urgent need to build the skills of educators, as well as trainers and other agents of change, in relevant issues related to sustainable development (UNESCO, 2014).

References

Ardoin, N.M., Bowersd, A.W., Gaillard, E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation*, 241, 108224. https://doi.org/10.1016/j.biocon.2019.108224

Bergstrom, D.M., Wienecke, B.C., van den Hoff, J. Hughes, L., Lindenmayer, D.B., Ainsworth, T.D., Baker, C.M., Bland, Bowman, D.M.J.S., Brooks, S.T., Canadell, J.G., Constable, A.J., Dafforn, K.A., Depledge, M.H., Dickson, C.R., Duke, N.C., Helmstedt, K.J., Holz, A., Johnson, C.R., McGeoch, M.A., Melbourne-Thomas, J., Morgain, R., Nicholson, E., Prober, S.M., Raymond, B., Ritchie, E.G., Robinson, S.A., Ruthrof, K.X., Setterfield, S.A., Sgrò, C.M., Stark, J.S., Travers, T., Trebilco, R., Ward, D.F.L., Wardle, G.M., Williams, K.J., Zylstra, P.J., Shaw, J.D. (2021). Combating ecosystem collapse from the tropics to the Antarctic. *Global Change Biology*, 27, 1692-1703. https://doi.org/10.1111/gcb.15539

Gaston, K.J. (1996). Biodiversity – latitudinal gradient. *Progress in Physical Geography*, 20, 466-476. https://doi.org/10.1177/030913339602000406

Gutierrez-Bucheli L., Reid, A., & Kidman, G. (2022). Scoping reviews: Their development and application in environmental and sustainability education research. Environmental Education Research, 28, 645-673. https://doi.org/10.1080/13504622.2022.2047896

Hambler, C., & Canney, S.M. (2013). *Conservation*. Cambridge University Press, second edition.

Harrison, C., & Burgess, J. (2000). Valuing nature in context: the contribution of common-good approaches. *Biodiversity and Conservation* 9, 1115-1130. https://doi.org/10.1023/A:1008930922198

Heywood, V.H. & UNEP (1995). *Global Biodiversity Assessment*. Cambridge University Press, published for UNEP

IPBES (2012). Plenary of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services First session. Bonn, Germany. https://ipbes.net/document-library-catalogue/resolution-establishing-intergovernmental-science-policy-platform

IPBES (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Díaz, S., Settele, J., Brondízio E.S., Ngo, H.T., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Roy Chowdhury, R., Shin, Y.J., Visseren-Hamakers, I.J., Willis, K.J., & Zayas C.N. (eds.). IPBES secretariat, Bonn, Germany. 56 pages. https://ipbes.net/global-assessment

IUCN-UNEP-WWF (1980). *World Conservation Strategy: Living Resource Conservation for Sustainable Development*. https://portals.iucn.org/library/efiles/documents/wcs-004.pdf

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-Being: Synthesis*. 160 pages. Island Press ISBN: 9781597260404

United Nations Educational, Scientific and Cultural Organization - UNESCO (2014). *Roadmap for Implementing the Global Action Programme on Education for Sustainable Development*. Available at: www.unesco.org/open-ac-cess/terms-use-ccbyncsa-en

UN Secretary-General World Commission on Environment and Development (1987). *Report of the World Commission on Environment and Development: Our Common Future*. New York. 374 pages. https://digitallibrary.un.org/record/139811

Authors

Caterina Lorenzi

Department of History, Culture and Society, Tor Vergata University of Rome, Italy.

Franca Sangiorgio *(corresponding author)*, franca.sangiorgio@unisalento.it

Department of Biological and Environmental Science and Technologies, University of Salento, Lecce, Italy.

Citation

Lorenzi, C., Sangiorgio, F. (2023). Conserving Nature. The contribution of ecological research to education. *Visions for Sustainability*, 20, 8880, 517-523.
http://dx.doi.org/10.13135/2384-8677/8880

Original Paper

Urban vegetable gardens as an environmental education tool for promoting primary school students' engagement in EU Green Deal strategies

Mariana Marques Vicente, Ricardo Leitão, Victor Quintino, Pedro Pombo, Ana Maria Rodrigues

Received: 28 August 2022 **|** **Accepted:** 17 December 2022 **|** **Published:** 22 December 2022

Keywords: sustainable cities; organic farming; hands-on; composting.

Abstract. *The Green Deal is a European Commission initiative to promote zero net emissions of greenhouse gases by 2050 in the European Union. Its multiple strategies, including circular economy and agriculture, should impact on all citizens. Environmental Education programs are powerful tools to improve literacy in sustainability concepts, namely those included in the*

Green Deal strategies, and to foster environmental attitudes. A hands-on pilot project "Nutrients Boomerang" was developed and implemented as part of the Environmental Education strategy of a Portuguese science centre, Fábrica Ciência Viva, to assess its applicability in a primary school environment. The project included the implementation of an outdoor model area, focusing on urban vegetable gardening and composting, complemented with workshops on biodiversity, circular economy, and organic farming, targeting primary school students and teachers. This pilot project was implemented from January to September 2021 and, in its final months, was also organized in a way to include the students' families, given their willingness to introduce parents and grandparents to the activities they had been doing. This pilot project showed its suitability to be replicated in primary school outdoor green areas and to promote hands-on activities aiming to inform people about the European Union Green Deal policy and foster a more conscientious behaviour in young students towards a more sustainable world.

1. Introduction

Climate change has potentially negative consequences across the globe, including sea-level rise, climate instability, and increased frequency and/or intensity of droughts, floods, and wildfires (IPCC, 2018). The impact on forests and oceans could, directly or indirectly, place at risk of extinction every one of the eight million species existing on the planet (European Commission, 2019). The Mediterranean region is particularly sensitive to such alterations and is considered a climate change hotspot (Michaelides et al., 2018). This pressures Southern European countries to search for solutions to increase resilience and resource sustainability. Sustainability is seen as the paradigm where environmental, social and economic perspectives come together for the development of a just and prosperous future (UNESCO, 2012). The Rio Declaration mentions (UN, 1992) 27 broad principles for sustainable development, including equity among generations, gender equity, peace, tolerance, poverty reduction, environmental preservation and restoration, natural resource conservation, and social justice

(Agbedahin, 2019). Closely associated with sustainability is the concept of Circular Economy, which recently gained relevance on the European policy agenda (European Commission, 2020). Geissdoerfer et al. (2017) define Circular Economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. According to the authors, such a system should be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (Geissdoerfer et al., 2017). For the European Commission, a circular economy could be decisive in reaching the 2050 Green Deal goals while guaranteeing competitive European economies and decoupling economic growth from resource use (European Commission, 2020).

Scientific research can bring awareness of the problems faced by mankind while contributing with solutions. Science outreach enhances the positive contributions of scientific research by reaching the public and helping to change behaviours. In agriculture, for example, consumer choices can influence the market and so have a significant contribution to agro-biodiversity preservation (Botelho et al., 2018). In a circular bioeconomy, it is essential that public behaviour contributes to closing resource circuits, minimizing the extraction of natural resources, and ensuring that most products are recycled or composted at the end of their lives (Tan, 2021). In this sense, the European Commission states that schools, training institutions and universities are well placed to engage students, families, and the overall community in pursuing the required changes for a successful transition towards no net emission of greenhouse gases by 2050 (European Commission, 2019).

Environmental Education (EE), a discipline of science outreach, has become more relevant in the past forty years with an increasing number of research studies and with a focus on outdoor education, education for sustainable development and environmental literacy, among others (Rickinson, 2001; Stern et al., 2014; Ardoin and Bowers., 2020). According to the North American Association for Environmental Education's (NAAEE, 2022) EE "is a process that helps individuals, communities, and organizations learn more about the environment; develop skills to investigate their environment; and make intelligent, informed decisions about how they can help take care of it. It has the power to transform lives and society. It informs and inspires. It motivates action. EE is a key tool in creating healthier and more civically engaged communities" (p. 000) The creation of new patterns of behaviour in individuals, groups, and society was included in the outcomes of the EE by the Intergovernmental Conference on Environmental Education (UNESCO, 1977). In order to be effective in helping acquire new knowledge, and changing attitudes and behavior-related outcomes, EE program design is of major relevance (Heimlich, 2010), particularly to target behavioural outcomes. Active participation, Hands-on observation and discovery, Place-based learning and Outdoor instruction are some of the program characteristics that are associated with the best practices and outcomes (Stern et al., 2014).

With a strong influence in EE, Education for Sustainable Development (ESD) is now considered interdisciplinary and transdisciplinary, given that all disciplines, individually and/or collectively, can be involved with it (Agbedahin, 2019). According to UNESCO, ESD empowers learners to make informed decisions and take responsible actions for environmental integrity, economic viability, and a just society, for present and future generations, while ensuring respect for cultural diversity (UNESCO, 2018). ESD has recently gained visibility with the United Nations Decade of Education for Sustainable Development (2005-2014) and is currently part of Sustainable Development Goal 4 and a key enabler of all the other goals (UN, 2015). Educational communities teaching sustainability should thus integrate into the curriculum each of the three components of sustainability, environment, society, and economy, reflecting current knowledge and respecting local contexts and national goals (UNESCO, 2012).

Schoolteachers can have a strong influence on their students' behaviour and should be a privileged target for EE and ESD sessions. To become efficient, teachers must have the opportunity to acquire knowledge, part of it coming from ecological research, as well as teaching methodologies (Chatzifotiou, 2006). Gardens and green spaces inside schools are natural stages for EE and ESD sessions and can be improved to serve as models, allowing proximity to relevant subjects, such as biodiversity and sustainable food systems, benefiting from a daily presence in students' lives (Ferguson et al., 2019; Cortegano et al., 2021).

The main goal of this study was to develop a pilot EE/ESD program focused on circular economy and the sustainability of the food system following the European Commission Green Deal guiding principles and targeted at primary school students and teachers. This EE/ESD program was named the "Nutrients Boomerang" project and was composed of a physical area and a series of planned sessions. By promoting waste management and sustainable consumption habits, it aimed to achieve the target of public awareness of natural resource depletion and the need to make a transition to a circular bioeconomy. It was also expected to allow for a gradual transition, through behavioural adoption of a sustainable food system from production to consumption, towards fairer societies in balance with nature and potentially be used as a model for primary school EE and ESD programs. It could jointly contribute to the fulfilment of national, European, and international commitments assumed by Portugal in the field of sustainability. The main objectives were:

1. Implement a Pilot model (name used throughout this work) of circular bioeconomy, based on four components: composting, drip irrigation, organic garden, and a resulting attractive urban green space landscape
2. Develop and streamline a set of EE/ESD sessions, supported by the Pilot model, within the subjects of sustainable production and conscious consumption.
3. Assess its replicability on primary school grounds by promoting a group of sessions with both students and teachers.
4. Contribute to literacy in environmental, biological resources conservation and sustainability, through the presentation of Green Deal strategies.
5. Promote circular economy attitudes, fostering citizens' behaviour to separate urban bio-residues and so contribute to achieving European Commission goals while ensuring adequate management of urban waste.

2. Materials and methods

The "Nutrients Boomerang" project was developed as part of an ongoing EE program at Fábrica Ciência Viva Science Centre (FCCV). This Science Centre is part of the University of Aveiro, Portugal, and supported all stages of the project implementation. The project included components that related to each other during the sessions with the primary school students: the Pilot model and the Environmental Education/Education for Sustainable Development (EE/ESD) Strategy. The Pilot model was named "Botanic Garden", and the EE/ESD strategy, supported by the Pilot model was developed for the educational sessions with the students. This strategy was also designed to reach other audiences, such as families and the public in other devoted sessions.

2.1. The pilot model "botanic garden"

The Pilot model included four components: i) composting, including the biotechnology for nutrient recovery from materials classified as urban bio-residues and the use of the resulting compost as an agricultural fertilizer; ii) the drip irrigation system, consisting of a reservoir to collect and store rainwater from gutters and a drip irrigation system to distribute and optimize the water resources; iii) the organic garden, designed using ecologically-based solutions in order to stimulate biodiversity and ecosystem services, as an alternative to the use of pesticides, inspired in the European Regulation for Organic Agriculture (European Council, 2007); iv) an urban green space landscape, the global sensitive effect of the previous three components as a social benefit, providing a cultural, recreational and educational space through the citizen's contact with nature.

2.1.1 Composting

To implement this component three types of composting technics were used: the horizontal pile - to set the raised garden beds, the vertical bin - to collect urban bio-residues and complete the landscape, and the vermicompost - to be used in the EE/ESD sessions.

Horizontal pile

The horizontal pile was built on the location of the future vegetable garden by piling up gardening bio-residues over the bare ground. The pile was covered with a tarpaulin (an old canvas) in order to minimize the loss of water through evaporation. The gardening bio-residues consisted of a mixture of dry leaves from deciduous trees, crushed twigs, and fresh-cut grass from city gardens, with an ideal Carbon/Nitrogen ratio for a composting process (Chojnacka et al., 2020). It consisted of about 5 tons of material collected during January 2021 and was offered by a local gardening company. The compost pile was turned over 3 times during a 3-month period (January to March) and the resulting mature compost, weighing about 1 ton, was used for the construction of the raised beds in the circular and rectangular vegetable gardens. The 5 tons piled on the ground, at a single moment had the optimal volume to generate heat, due to the biological activity (essentially bacterial decomposition), warming the pile during the first days. Although not measured, it was predicted that the temperature at the centre of the pile reached 60 to 70 ºC (De Corato, 2020).

Vertical bin

The vertical bin was built with used wood pallets for a final volumetric capacity close to 1.5m^3. It was filled with approximately 50kg of urban bio-residues collected from a city restaurant, 150kg of dry straw and 300kg of fresh grass cuts. After 6 months of maturation (January to June), the volume reduced to about

$0.5m^3$. During this process there were moments where methane and ammonia odours were perceived, which were solved with the addition of dry straw to balance moisture. No disturbance to the neighbourhood was created at any time, since the compost was always located far from the buildings and in an area of strong aeration. Also, a net was placed inside the bin to prevent the entry of micro-mammals, such as small rodents, attracted by food residues. In urban areas, both issues are of great relevance for the success of the experiment.

Vermicompost

The vermicomposting was created exclusively for the EE/ESD sessions to demonstrate how it is possible to compost without a garden space. Moreover, this system supported the activities related to the nutrients cycle by providing compost as well as earthworms and small insects for observation with a magnifying glass. It was a simple system composed of 3 plastic boxes, 45 cm long, 25 cm wide and 25 cm high, all with covers. The boxes were placed on top of each other, in a pile, and the top two were perforated to allow the passage of the earthworms between the boxes. The system was constructed in March and started with the earthworms in the middle box. After 2 months (May) all earthworms had migrated to the top box, the bottom box collected liquid from the decomposition process and the middle box saved the resulting compost (fertilizer). The vermicompost was used in workshops 1 and 2, when the earthworms were fed from the top box during the EE/ESD sessions and the students could touch, smell, and observe them with a magnifying glass inside a Petri dish box.

2.1.2. Drip irrigation system

The Drip irrigation component included a rainwater collection and storage system, consisting of a 1 m^3 reservoir, connected to the gutter of the building, and the irrigation strips for the circular and rectangular vegetable gardens. The reservoir was installed with a slope gradient that would provide irrigation by gravitational force through the drop-by-drop system. It was necessary to apply water filters to the gutter water collection tube to prevent residues in the lower gauge piping of the drip system.

2.1.3. Organic garden

The organic garden component consisted of an organic food production vegetable garden, inspired by the European Regulation for Organic Agriculture (European Council, 2007). It was created in an overlooked outdoor area of FCCV with compacted soil covered with weeds (Figure 1).

Figure 1. The outdoor space in Fábrica Ciência Viva Science Centre where the project was installed.

Due to the high degree of compaction of the soil, the vegetable beds were manually aerated with a broad fork. The cultivated area was distributed in two distinct gardens: a circular garden inspired in a "mandala", with vegetables, flowers and aromatic plants in a circular geometrical arrangement, and a rectangular garden with the purpose of supporting the circle (Figure 2).

The Circular Garden

The shape of this garden alludes to the subject of circular economy in urban areas. It was designed to be aesthetically attractive, combining flowers, aromatic plants and vegetables. Several agroecological techniques and practices were used in its implementation and maintenance, such as intercropping and consociating of plants, crop rotation, organic fertilization and mulching (Wezel et al., 2014). No synthetic inputs of any kind were used in accordance with the EU regulation for organic agriculture (European Council, 2007). The spatial arrangement of the

Figure 2. Setting up the rectangular and the circular organic gardens, the composting vertical bin and the reservoir for the irrigation system.

plants considered their height and strata (e.g., herbaceous, shrubby, and arboreal), the natural succession of their life cycles (e.g., annual, perennial), the consociations of proximity between the various plants for crop protection (e.g., pests and diseases biocontrol, natural insect repellent plants), and pollination services stimulation through autochthonous flowers and aromatic plants (Staton et al., 2019).

The circular garden was built with a radius of 3 m, occupying 18 m^2 of the total 40 m^2 available area. The 18 m^2 area was divided into 3 vegetable beds interspersed by 2 paths. The vegetable beds were 0.8 m wide, the same as the paths, with a perpendicular path of 0.8 m at the base, joining all the paths (cf. Figure 2 and Figure 3). The area corresponding to the circular garden was filled with compost from the horizontal pill in March. Immediately after, commercial compost was added to the vegetable beds to a height of 20 cm, creating a "raised bed" effect. The paths were covered with wood chips to the same height (cf. Figure 3). This technique was inspired by the bio-intensive organic market gardening micro-farms (Jeavons, 2008), which are gaining popularity in urban and peri-urban areas around the world. The plantation was initiated in March 2021 and took place every month thereafter.

Figure 3. The Circular Garden.

The Rectangular Garden

The rectangular garden was designed to be used as a backup for the circular garden and provide extra space for the cultivation and exploration of biodiversity for the EE/ESD sessions. It also served as a wind barrier to protect the circular garden, and to stimulate the appearance of pollinators and pest and disease control species. In addition, it provided a visual barrier, hiding materials no longer used and stored for years at the back of this outer space. This garden comprised four straight vegetable beds, 80 cm wide and 4 m long, separated by 60 cm wide paths, covered by woodchips. A pair of nets supported by four wooden posts were positioned along the 1st and 2nd vegetable beds, to support the growth of taller plants (cf. Figure 2). The two gardens were created at the same time, followed the same timeline and compost application framework, and used the same "raised bed" technic. The rectangular garden also followed the same bio-intensive organic market gardening techniques used in the circular garden, but it was set with higher plant densities and less diversity to facilitate management.

2.1.4. Urban green space's landscape

The Pilot model was conceived to promote cultural ecosystem service aesthetics through the final landscape, by replacing bare ground with a pleasant space to observe, learn and be involved in nature. The Urban green space landscape was the result of the implementation of the first three components of the Pilot model (Figure 4). It resulted from the transformation of an unused outer area in the FCCV, into an aesthetic and productive "garden", both from agroecological and educational points of view, fully aligned with the FCCV target audience and activities. The model also allowed the FCCV to implement activities in the outer space of the building, which had never been attempted before, due to the lack of suitable projects.

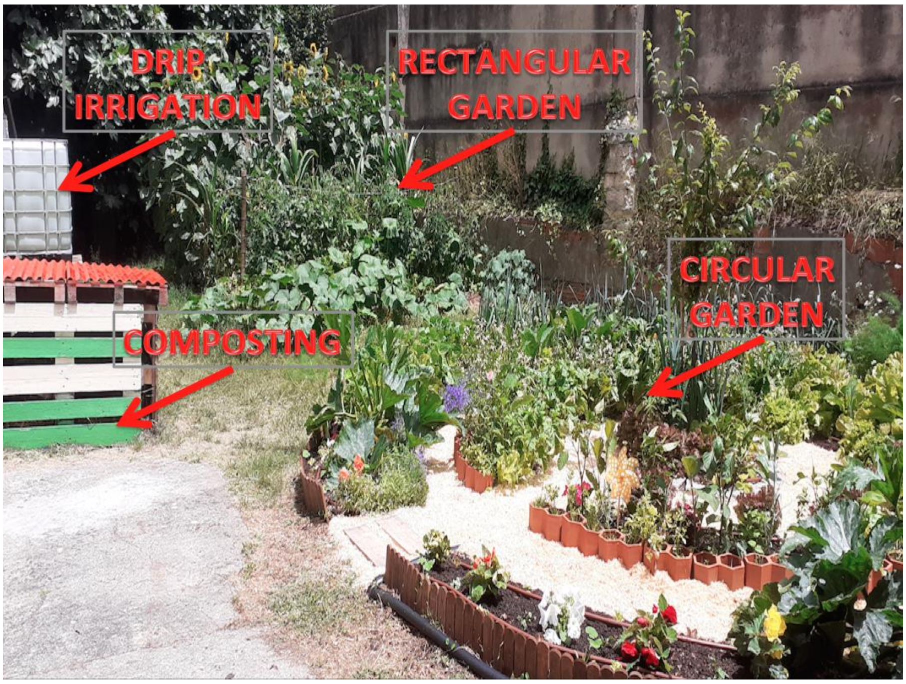


Figure 4. The Pilot model, showing all four components, the composting, the drip irrigation system, the circular and rectangular organic gardens, and the resulting urban green space's landscape. Photography taken in May 2021, close to the beginning of EE/ESD sessions.

2.2. The environmental education/education for sustainable development strategy (ee/esd)

Running as interconnected with the Pilot model, an EE/ESD strategy was elaborated, targeting primary school students. The EE/ESD strategy consisted of a series of workshop sessions held at the Pilot model area promoting a close connection with its four components. The workshops (WSs) covered four main subjects: composting, ecosystem services, biodiversity and local circular economy. Each WS was accompanied by corresponding European Strategy documentation, named "Farm to Fork", "Biodiversity", "Circular Economy" and "Green Deal", as a support of the science outreach goals. Each WS contained several hands-on activities, such as games, scavenger hunts, magnifying glass observations and gardening (Table 1). Didactic materials were developed for each activity in cooperation with the FCCV designers. Each activity had a predicted duration and goals, namely the concepts that students should incorporate and the expected results.

For the Composting workshop (WS1), a portable vermicomposting was created and kept alive and a didactic flyer on composting was prepared. Buckets with holes at the bottom and a lid on top were given to students and used to show how to do a domestic garden composter in order to motivate the students to continue this action at home with their own urban bio-residues. In this first WS, students should make a sowing in yogurt pots and transplant seedlings to the “Botanic Garden” using compost.

In the Ecosystem services workshop (WS2), students use hand magnifying glasses and binocular microscopes to explore soil and compost macrofauna, especially earthworms. To help earthworm observations, legend anatomy cards were created and placed close to the living invertebrates. Real nest-boxes and an insect hotel were also presented to improve the concept of ecosystem services as nature-based solutions in replacement of pesticides.

The Biodiversity workshop (WS3) comprises two games. One game includes a poster of a tree (Tree poster) and several cards with species (Species cards), aiming to demonstrate how a single tree can represent a complex ecosystem with several ecological niches and how species relate to each other as a community. The other game focuses on discovering the “Botanic Garden”. It includes several cards with species pictures on the face side and agro-botanic information in the reversal side. Students are expected to search for different species and mark the plant with a small flag with its name. At the same time, children harvest a leaf, a flower and fruit to smell, to taste and fully feel the plant they were looking for.

To complete this WS, students transplant flower and aromatic plants close to the vegetables already growing, transplanted in the first WS. They are then stimulated to take care and promote their growth.

In the final workshop, Local circular economy (WS4), students prepare ice creams after harvesting strawberries from the “Botanic Garden”, which they took care of in the previous WS. A synergy is set with the FCCV chemistry workshop, "Kitchen as a Laboratory", and part of the WS occurs indoors. At the end of this workshop, students should understand how urban bio-residues can be transformed into food, flowers, and a pleasant space, while enjoying a meal at the “Botanic Garden”.

3. Results

3.1. The pilot model

By the end of May 2021, the circular and rectangular gardens were fully cultivated, and all the components of the Pilot model were operational and ready to be used for the EE/ESD sessions. The drip irrigation was the most expensive and time-consuming component of the Pilot model to set up, but it allowed for saving time and to being water self-sufficient throughout the project. The nets added along the 1st and 2nd vegetable beds in the rectangular garden, allowed the cultivation of climbers and plants with higher strata and served as an additional windbreak. A dense plantation of sunflowers in the 3rd vegetable bed also provided a hiding effect of the unwanted rusty objects in the background area. At the beginning of the EE/ESD sessions, around 44 plant species were present in the circular garden and 11 species in the rectangular garden, for a total of 51 plant species. The number of species varied slightly over the duration of the project, with some plants being removed and others planted during the sessions. To better organize the available planting space in the circular garden, it was organized as shown in Figure 5, with 3 vegetable beds according to the rings (1, 2 and 3, from the outside to the inside), ring 1 was sub-divided in four quadrants (a to d, from left to right) and ring 2 in two halves (a and b, from left to right).

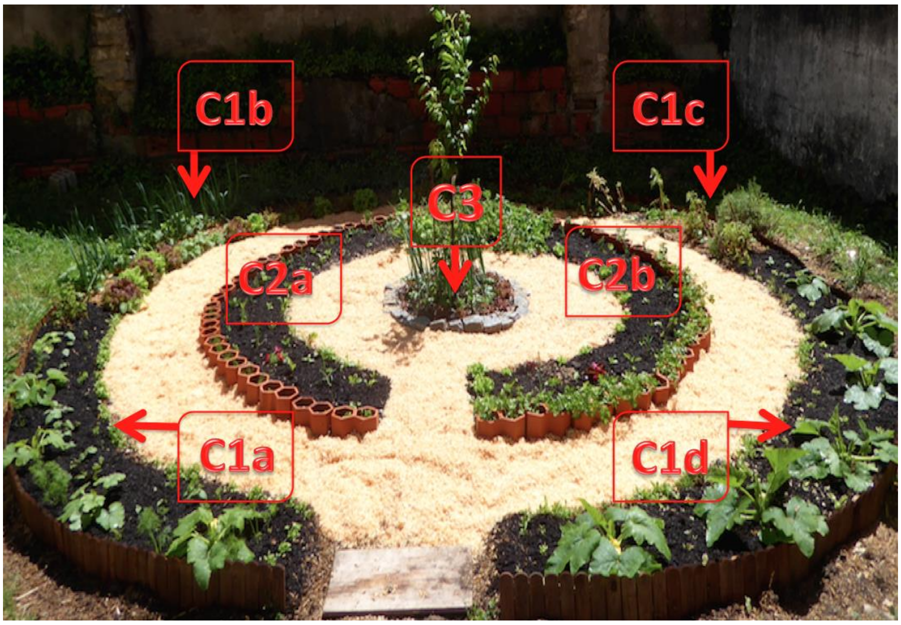


Figure 5. Organization of the circular garden by segments of plant consociation. C - circular garden; 1 to 3 - ring numbers; a to d - plants consociation segments. Photography taken in April 2021.

The species to be planted in the circular garden were chosen and combined according to, firstly, the height strata, life cycle, the ecological niche occupied and pollinators' attractiveness, and secondly, to pests' repellence and Nitrogen fixing ability (Fabaceae family), whenever possible. The plant species used included annual vegetables, flowers, aromatic plants, cereals, shrubs, and a fruit tree (Table 2). The combination of plant species, particularly in the circular garden, had the dual purpose of promoting better agronomic conditions for plants to thrive and at the same time serving as practical examples of ecosystem functions and services for EE/ESD sessions. During the project period, the two gardens produced a total of approximately 180 kg of vegetables, mainly lettuces, tomatoes, spinaches, courgettes, and eggplants (cf. Table 2). Maintenance activities were constant during the project with transplants required to replace old plants and those used in the EE/ESD sessions, as well as the plants removed by cleaning activities, to keep the Pilot model colourful and attractive for the audience of the EE/ESD sessions or others (Figure 6).

Figure 6. A public session to present the "Nutrients Boomerang" project to the academic community.

3.2. The environmental education/education for sustainable development strategy

The EE/ESD sessions started in June 2021 and lasted until September 2021 (Table 3). They took place in two distinct moments according to the target audience. The first moment was during June and consisted of the 4 chained WS, one per week, targeted to a fixed group of 14 primary school students. The group was divided in half with each WS having on average 7 students, except for WS4, which reunited the group (Table 3). In total, 7 workshops were conducted in this series. This group of students completed all the 13 activities planned in the EE/ESD strategy (cf. Table 1). Every WS lasted approximately one hour. All the workshops took place in the Pilot model area, except WS4, which was also conducted in another FCCV facility. Although no questionnaires were used to assess the efficacy of the EE/ESD sessions during the WSs, it became clear that some activities were more attractive to students than others. According to the monitors' perception, the students were more committed to activities 5 and 11 (cf. Table 1), which included transplantation actions, whereas exploring activities

6 and 7 generated more curiosity from the students. Activity 10, with the harvest and tasting of plants, created a highly sensitive impact with children enthusiastically exchanging experiences with each other. Activities 5 and 11 could be considered the most difficult for students, while the time available for activity 9 was short. In this activity, the ecological niche game, and the possibility of exploring nest boxes and insect hotels, generated lots of questions from the children and they showed great interest in sharing personal stories. Activity 13, in collaboration with the FCCV chemistry laboratory, was very well received by the children and very effective for them in grasping the concept of a circular economy.

In a second moment, the workshops targeted families and the public and took place from June to September 2021. These sessions were not initially planned in the EE/ESD strategy but were decided later to extend the project to different target audiences, taking advantage of the Pilot model already in place. For these sessions, a new model of WS was presented, the “Nutrients Boomerang” workshop. This single one-hour duration WS aimed to resume the “Nutrient Boomerang” project and consisted of a selection of activities retrieved from WSs 1 to 3. A total of 11 sessions/WSs were conducted, and the audience varied from 1 to 16 persons per workshop, in a total of 104 participants (cf. Table 3). Although involving children and adults with different levels of ecological literacy and knowledge in sustainable development, the WSs were seen as effective sessions for the purpose of transmitting environmental awareness and circular economy concepts.

4. Discussion

The Project’s development focused on including as much as possible what is currently considered to be “state-of-the-art” or “best” practices in EE (Stern et al., 2014; NAAEE, 2022). Students and teachers were actively involved in the educational experience for all the time (Active Participation), while, by planting and manipulating the multiple living life forms (e.g., worms), all EE/ESD session activities have a Hand-on component. The “Nutrients Boomerang” project is intrinsically in line with the particular attributes of a place, using nature and agroecosystem as the context for learning (covering both “Place” and “Outdoor” practices). During the workshops, monitors asked questions and facilitate students’ pursuit of answers. Still, students were stimulated to freely inquire and explore the area (Guided inquiry and Pure inquiry) (Stern et al., 2014).

In this project, the Pilot model (physical area) was concurrently built with (and for) the workshop sessions of the EE/ESD strategy. We consider this to be one of the projects' strengths. With this co-development strategy, we looked for an optimal "fit" between the area students were using with the activities they were enrolled in and the concepts transmitted. We expected, in this sense, to increase the probability of positive outcomes, make workshop sessions more fluid, and improve students' engagement in the Green Deal strategy.

The Green Deal is stringing influencing European policies and, as such, European citizens' lives (Ortega-Gil et al., 2021). In order to address the current environmental crisis, citizen actions are at the centre of EU initiatives. The Green Deal prioritized participation and citizen engagement more than any other previous environmental program (Hadjichambis, 2022). It is, though, mandatory to introduce the theme to primary students (and teachers) as part of EE/ESD programs.

This project opens the door to many potential EE/ESD sessions that can be developed in the primary school environment once the Pilot model is established there. It can be converted into a "toolbox" concept and be implemented in primary schools. The detailed and systematic information presented in Tables 1 and 2, such as vegetable species organization and WS activities characterization, allows for its replication outside Fábrica Ciência Viva. With some investment it could easily be developed as a framework for every school to implement, both the physical space of the Pilot model and the workshops of the EE/ESD sessions. Moreover, once implemented, new models of workshops can be developed, and even be adapted to the particularities of each school. By continuously accompanying the activities, students´ teachers get involved in workshop dynamics and are capacitated to implement and further adapt future EE/ESD sessions in each particular school context. The "Nutrients Boomerang" project can also include other science disciplines, physics, chemistry, or mathematics, promoting outdoor science outreach activities connected with nature and so better describe not only biology's concepts but also from other disciplines (Orsini et al., 2013). For these purposes, the plant combinations in the circular garden were design to be easily simplified to accommodate less skilled personnel, including students that could be actively involved in implementing and maintaining the gardens. By simultaneously contributing to safe, healthy, and green environments in schools, we believe this project can have a positive effect on the health of teachers and students, as noticed by Nogeire-McRae et al. (2018). Either by giving them responsibility, care of the gardens or by promoting the consumption of vegetables and legumes, there are evident external benefits that transcend the original EE/ESD educational purpose of this type of project.

By choosing primary teachers as a target audience for EE/ESD, projects such as the "Nutrients Boomerang" are actively contributing to the up-skilling of Europe's workforce as required by the Green Deal (European Commission, 2019). And by doing so, primary students will indirectly also have the possibility to develop the skills they need to adapt to new future processes throughout their life and to the ecological transition Europe is facing.

Although a formal evaluation was not implemented at this stage, based on the monitors´ perception, we can extrapolate that the other goals of the "Nutrients Boomerang" project were also achieved. Besides the resort to the EE "state of the art practices" already described, the use of nature-rich pedagogical approaches and the incorporation of movement and social interaction between students and between students and monitors also make us expect greater effectiveness in reaching the aimed at outcomes (Ardoin and Bowers., 2020). From a subjective point of view, monitors could appreciate a change in children's behaviour throughout the sessions, from a repulsion or aggressive attitude towards the small animals they found in the "Botanic Garden" during the first workshops, to holding them in their hands, such as a small caterpillar, a butterfly or an earthworm, and looking to these organisms with affection and delight during the final workshops. The vibrant spontaneous stories told by the primary school students, during the last EE/EDS sessions, also valued different subjects. Some of the students became more sensitive to nature conservation, frequently seeking the attention of the monitors to the various living animals they encountered in the soil and in plants and extolling their beauty and fragility. Other students revealed a greater tendency towards sustainability, for example, by describing personal episodes of how they managed to reproduce parts of the Pilot model at home or in their school or showing a special interest in how it was possible to "transform" their waste into strawberries at their home balcony, replicating the experience with their parents and grandparents. We believe the success of changing the perception of something disgusting (or indifferent) into affection (to be cared for), results from the proximity permitted by "hands-on" activities. This was accomplished with the "touching", "smelling", "tasting" and intense "feeling" that simultaneously involve all sense organs, week after week, in continuous sessions.

The sessions of the "Nutrients Boomerang" project workshop for the families, with an occasional calendar, were perceived by the monitors as having more environmental awareness impact than educational. Although with a general positive acceptance by the families, all monitors pointed out that the 60-minute duration was insufficient to accomplish the programmed activities. In the future, it will be possible to open up the activities program into two complementary workshops and give more opportunities for families to be involved in EE/ESD sessions.

Acknowledgments

All activities were enrolled in Fábrica Ciência Viva's facilities, owned and managed by the University of Aveiro, in partnership with Ciência Viva – National Agency for Scientific and Technological Culture. Thanks are due to FCT/MCTES for the financial support to CESAM (UIDP/50017/2020+UIDB/50017/2020+LA/P/0094/2020), through national funds. The authors thank the Biology Department of the University of Aveiro and Fábrica Ciência Viva's staff. All students, teachers and families participating in the activities enrolled in the project are acknowledged.

References

Agbedahin, A. V. (2019). Sustainable development, Education for Sustainable Development, and the 2030 Agenda for Sustainable Development: Emergence, efficacy, eminence, and future. *Sustainable Development*, 67, 669–680. doi:10.1002/sd.1931

Ardoin, N. M., & Bowers, A. W. (2020). Early childhood environmental education: A systematic review of the research literature. *Educational Research Review*, 31, 1–16. doi.org/10.1016/j.edurev.2020.100353

Botelho, A., Dinis, I., Lourenço-Gomes, L., Moreira, J., Pinto, L. C., & Simões, O. (2018). The role of consumers in agrobiodiversity conservation: the case of traditional varieties of apples in Portugal. *Agroecology and Sustainable Food Systems*, 42, 796–811. doi:10.1080/21683565.2018.1426669

Chatzifotiou, A. (2006). Environmental education, national curriculum and primary school teachers. Findings of a research study in England and possible implications upon education for sustainable development. *The Curriculum Journal*, 17, 367–381. doi:10.1080/09585170601072478

Chojnacka, K., Moustakas, K., & Witek-Krowiak, A. (2020). Bio-based fertilizers: A practical approach towards circular economy. Bioresource Technology, 295, 1–11. doi:10.1016/j.biortech.2019.122223

Cortegano, M., Dias, R. C., Guedes Vidal, D., & Seixas, P. C. (2021). "Mertola, a lab for the future" as a transformational plan for the mediterranean semi-arid region: A learning case based on landsenses ecology. *International Journal of Sustainable Development and World Ecology*, 28, 612–621. doi:10.1080/13504509.2021.1920059

De Corato, U. (2020). Agricultural waste recycling in horticultural intensive farming systems by on-farm composting and compost-based tea application improves soil quality and plant health: A review under the perspective of a circular economy. *Science of the Total Environment*, 738, 1-22. doi:10.1016/j.scitotenv.2020.139840

European Commission (2019). *Communication from the Commission: The European Green Deal*. COM(2019) 640 final, Brussels.

European Commission (2020). *Communication from the Commission: A new Circular Economy Action Plan - For a cleaner and more competitive Europe*. COM(2020) 98 final, Brussels.

European Council (2007). *Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation* (EEC) No 2092/91

Ferguson, B. G., Morales, H., Chung, K., & Nigh, R. (2019). Scaling out agroecology from the school garden: the importance of culture, food, and place. *Agroecology and Sustainable Food Systems*, 43, 724–743. doi:10.1080/21683565.2019.1591565

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy A new sustainability paradigm? *Journal of Cleaner Production*, 143, 757–768. doi:10.1016/j.jclepro.2016.12.048

Hadjichambis A. C. (2022). European Green Deal and Environmental Citizenship: Two Interrelated Concepts. *Environmental Sciences Proceedings*, 14, 1–4. doi.org/10.3390/environsciproc2022014003

Heimlich, J. E. (2010). Environmental education evaluation: Reinterpreting education as a strategy for meeting mission. *Evaluation and Program Planning*, 33, 180–185. doi:10.1016/j.evalprogplan.2009.07.009

IPCC (2018). Summary for Policymakers. In Masson-Delmotte, V., P. Zhai, H.-O.Pörtner, D.Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X.Zhou, M.I.Gomis, E. Lonnoy, T.Maycock, M. Tignor, and T. Waterfield (Eds) *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. World Meteorological Organization, Geneva, Switzerland.

Jeavons, J. C. (2008). Biointensive Sustainable Mini-Farming: II. Perspective, Principles, Techniques and History. *Journal of Sustainable Agriculture*, 19, 65–76. doi:10.1300/J064v19n02_07

Michaelides, S., Karacostas, T., Sánchez, J. L., Retalis, A., Pytharoulis, I., Homar, V., et al. (2018). Reviews and perspectives of high impact atmospheric processes in the Mediterranean. *Atmospheric Research*, 208, 4–44. doi:10.1016/j.atmosres.2017.11.022

NAAEE (2022). *Environmental Education Programs: Guidelines for Excellence*. Washington, DC: North American Association for Environmental Education. https://eepro.naaee.org/eepro/resources/guidelines-excellence-series

Nogeire-McRae, T., Ryan, E. P., Jablonski, B. B. R., Carolan, M., Arathi, H. S., Brown, C. S., et al. (2018). The Role of Urban Agriculture in a Secure, Healthy, and Sustainable Food System. *BioScience*, 68, 748–759. doi:10.1093/biosci/biy071

Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: a review. *Agronomy for Sustainable Development*, 33, 695–720. doi:10.1007/s13593-013-0143-z

Ortega-Gil M., Cortés-Sierra G. & ElHichou-Ahmed C. (2021). The Effect of Environmental Degradation, Climate Change, and the European Green Deal Tools on Life Satisfaction. *Energies*, 14, 1–14. doi.org/10.3390/en14185839

Rickinson M. (2001) Learners and Learning in Environmental Education: A critical review of the evidence. *Environmental Education Research*, 7, 207-320, doi.org/10.1080/13504620120065230

Staton, T., Walters, R. J., Smith, J., & Girling, R. D. (2019). Evaluating the effects of integrating trees into temperate arable systems on pest control and pollination. *Agricultural Systems*, 176. doi.org/10.1016/j.agsy.2019.102676

Stern, M. J., Powell, R. B., & Hill, D. (2014). Environmental education program evaluation in the new millennium: what do we measure and what have we learned? *Environmental Education Research*, 20, 581–611. doi.org/10.1080/13504622.2013.838749

Tan, E. C. D. (2021). Circular Bioeconomy Concepts-A Perspective. *Frontiers in Sustainability*, 2, 1–8. doi:10.3389/frsus.2021.701509

UN (1992). *The Rio Declaration: Report of the United Nations conference on environment and development* - Volume I Resolutions Adopted by the Conference. A/CONF.151/26/Rev.l (Vol. I). United Nations publication. Sales No. E.93.1.8

UN (2015). Resolution adopted by the United Nations General Assembly on 25 September 2015. *Transforming our world: the 2030 Agenda for Sustainable Development*. A/RES/70/1.

UNESCO (1977). *Intergovernmental Conference on Environmental Education Final report*. Organized by UNESCO in Cooperation with UNEP, Tbilisi, USSR, 14–26 October 1977.

UNESCO (2012). *Education for Sustainable Development Sourcebook*. United Nations Educational, Scientific and Cultural Organization, Paris, France.

UNESCO (2018). *Issues and trends in education for sustainable development - Education on the move*. A. Leicht, J. Heiss and W. J. Byun (Eds). United Nations Educational, Scientific and Cultural Organization, Paris, France.

Wezel, A., Casagrande, M., Celette, F., Vian, J.-F., Ferrer, A., & Peigné, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development*, 34, 1–20. doi:10.1007/s13593-013-0180-7

Authors

Mariana Marques Vicente, Departamento de Biologia e CESAM, Universidade de Aveiro, 3810-193 Aveiro, Portugal. mmv@ua.pt ***Corresponding author***

Ricardo Leitão, Centro de Ecologia Funcional, Universidade de Coimbra, 3000-456 Coimbra, Portugal.

Victor Quintino, Departamento de Biologia e CESAM, Universidade de Aveiro, 3810-193 Aveiro, Portugal.

Pedro Pombo, Fábrica Centro Ciência Viva, Universidade de Aveiro, 3810-171 Aveiro, Portugal.

Ana Maria Rodrigues, Departamento de Biologia e CESAM, Universidade de Aveiro, 3810-193 Aveiro, Portugal.

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors have declared no conflict of interest.

Citation

Vicente, M.M., Leitão, R., Quintino, V., Pombo P. and Rodrigues, A.M. (2022) Urban vegetable gardens as an environmental education tool for promoting primary school students' engagement in EU Green Deal strategies. *Visions for Sustainability*, 20, 6994, 525-547. http://dx.doi.org/10.13135/2384-8677/6994

Original Paper

Introducing children in the primary school to the concept of ecosystem services

Noemi Rota, Claudia Canedoli, Martina Fava, Emilio Padoa-Schioppa

Received: 28 August 2022 | **Accepted:** 17 March 2023 | **Published:** 25 March 2023

Keywords: natural capital; primary education; environmental education; cultural services.

Abstract. *The respect for Earth and life in all its diversity and the protection of the integrity of the environment are two of the fundamental principles declared in the Earth Charter 2000, which aims to build a just, peaceful, and sustainable global society. Due to the increasing effects of the environmental crisis, there is a need for a greater environmental sensibility and consciousness, and one path to reaching this goal passes through environmental education* *projects with children. Here we carried out a project for the involvement of children in environmental-related issues, using as a teaching tool the concept of ecosystem services (ES). The project aims to develop in children a sensitivity towards the environment, good social and civic competence, and make them more aware of environmental issues through the discovery of their territory. The topic of ES was introduced through a storytelling approach, and we described in a simplified version six ES, asking children to point out in the city map where they found these services in their town. The 17 children taking part in the project were 9 years old, we tested the considerations obtained with questionnaires appropriate to their age and level of comprehension, to evaluate the acquisition of new information and long-term knowledge. Then videos of urbanized and degraded environments in our territory were shown, and afterward, children were asked to make a proposal for the recovery of a degraded area in their town. Children had the chance to put into practice their proposal with an outdoor activity for recovering a forest in their town. After one year, a meeting with the children took place and they were asked to fill out a questionnaire regarding the project, and the consequences it had for their lives. The results highlighted that the majority of children remember this project with a positive feeling and had an improved competence and critical sense regarding the environment and ecosystem services.*

---

1. Introduction

1.1 Children and environmental education

Currently, children grow up in a context saturated with environmental issues and threatened by human activities (Melia, 2003). Thus, generally, children that are aware of environmental issues have a perception characterized by pessimism, a feeling of sadness, and a sense of helplessness about the future of the planet (Barraza, 1999; Strife, 2012; Iliopoulou, 2018). Educators should help children in developing a critical but positive environmental awareness (Piske et al., 2021). There is evidence that through a nature-based education program, with the experience of an intellectual, emotional, and sensory perception of the environment, children develop an awareness of places and the living organisms that surround them and develop a sensibility toward them (Collado et al., 2020). There is a growing number of studies that relate nature-based education and the development of personal environmental stewardship (Kuo et al., 2019). Environmental citizenship is one of the goals set by the 2030 European Strategy, which can be achieved through an appropriate model of environmental education (Monte & Reis, 2021), developing the necessary skills and values to approach the upcoming environmental changes (Hadjichambis & Reis, 2020). Education at the early stages of life represents a useful tool to achieve proper environmental citizenship, thus primary education is an appropriate life stage to develop a long-term environmental awareness and sensitivity (James Farmer, Doug Knapp, 2007; So & Chow, 2019).

Teachers have a role in this development, being responsible for providing an adequate education background to develop environmental sensitivity (Boca & Saraçli, 2019; Türkoğlu, 2019), correcting misconceptions, and influencing children's conception of the environment (Lwo et al., 2017; Yalcin & Yalcin, 2017). Dewey (1954) stressed the necessity to create a new education to change and improve society, an education based on direct experience, open dialogue, cooperative learning, and critical and democratic thought development, all of which is still today an open topic. Tiziano Fratus, defining *Puer Radix* (Fratus, 2013), stated that children have an inherited curiosity with which they observe the natural world around them, and they are also inclined to take care of it. The *Puer Radix* needs help to come outside and needs to be motivated and guided by parents, teachers, and educators encouraged in taking care of a piece of landscape, the garden of the house, or the tree on the lawn in front of the school. We approached the children's sensitivity towards the environment through an educational project in primary school, using different methodologies and Cultural Ecosystem Services (CES) (MEA, 2005) as an educational tool. In particular, we used CES because of its intrinsic relationship with the non-material context, leading children to an intellectual but emotional perception of the environment and raising awareness of ecological issues (Maraja et al., 2016).

1.2 Ecosystem services as an educational tool

Ecosystem Services (ES) are defined as the benefits that people derive from the environment (MEA, 2005; Costanza et al., 2014). This concept highlights the strict relationship between natural capital and human well-being. There has been an increasing interest in the concept of ES since its first appearance in 1981 (Costanza et al., 2017), reaching a broader audience every year. The evaluation of ecosystem services can be used as a tool to protect biodiversity and reduce the exploitation of natural resources performed by human activities. There are four categories of ES (MEA, 2005), while for our study we focused only on the category of Cultural Ecosystem Services (CES), which are defined as the non-material benefits that we obtain from ecosystems. ES can be seen as an emerging issue to encourage and strengthen positive environmental attitudes in children and educate them on sustainability topics (Almers et al., 2021). We used CES as a learning topic and tool for increasing environmental awareness and sensitivity in children, mostly because of the connection to the emotional sphere. The CES categories encompass values such as aesthetic, religious, recreational, education, and sense of place (MEA, 2005; Haines-Young, 2018), which can be easily understood by primary school children.

The main aim of this project was to introduce children to the concept of ES as a tool to discover nature, enhance their knowledge of it, intervene concretely in developing active citizenship and discover their territory. This topic was proposed to the students both as an environmental concept and a tool for developing an interest in respect for the environment. The project was divided into four phases, which resume the four main questions that we asked children: 1.What is Nature for you? 2. How is the environment where you live? 3. What does Nature do for us? 4.What can we do for the nature?

2. Materials and methods

The project was realized with a class of the primary school Rita Levi Montalcini in Torbole Casaglia (BS), a small town of approximately 6500 inhabitants in the low plain of North Italy called Pianura Padana and encompassing the Po Valley, the geographical area that coincides with the river basin of Po.

The class participating in the project comprised 17 9-year-old students (12 males and 5 females), from primary school with diverse socio-economic backgrounds. The teacher was a trainee teacher at the University of Milano Bicocca, Faculty of Primary Teacher Education, and an active and inclusive teaching methodology was used to introduce children to the concept of ecosystem services and to put them in contact with nature. The work was organized according to the cooperative learning method (Gillies and Ashman, 2003) whereby each student has to collaborate in groups, has a role, and contributes to the project. To do this, it was essential to encourage the improvement of the mediation competence to face and solve conflicts in the groups, a very important feature of active citizens (Colombo & Passerini, 2013).

The project was developed through five meetings and two outdoor trips. To introduce the topic of nature to the class, every meeting started reading a chapter of the story “Magical Tree-Castle” (Hill, 1998) and ended with a discussion in the class. The story served as an introduction to create a positive interaction between the teacher and the students, establishing a relaxed and confident relationship, and also representing symbolically that they were starting their work together. The teacher was present during all the stages of the project, to help and support children during the assignments. The first meeting was an introduction to nature and biodiversity, in which children had to think about what nature represented to them. We took as a reference area the neighbourhood of the school, focusing on the Po valley and Pianura Padana. The children were asked to express their ideas and opinions about the word “Nature” through brainstorming (Bezzi and Baldini, 2006). The children were told that no judgment on the opinions of others was allowed, which was a key statement to allow children to freely express their thoughts and increase children's participation. After the brainstorming, the class was divided into 4 groups, language difficulties and disabilities were taken into account during the creation of groups in order to apply the peer tutoring principle (Barnard, 2002). We assigned each member of the group a role, to empower all the children concerning the outcome of the project. The four roles chosen were: 1. *the clock*, that controlled the time expiry, 2. *the writer*, that wrote the proposals of the team, 3. *the voice controller*, that was responsible for the loudness of the team, 4. *the representative*, that directly interfaces with the teacher. Thus, each group had the task of creating an acrostic with the word “nature” to explain how they perceive nature and its elements (Fig.1), choosing from the words of the brainstorming activity.

The second and third meetings were about the question “How is the environment where you live?”. The topic was split into two meetings due to the need for reflecting on theoretical knowledge of geography and learn new concepts. The second meeting was a plenary session about the environment of lowlands and their representation in the Italian context. We focused on Pianura Padana and Po Valley, its biodiversity, and the nature-related resources. During the third meeting, we tested the new knowledge from the previous lesson through a questionnaire. We organized a workshop where each group recreated a small model of Po Valley, using stone, sand, clay, soil according to the typical natural environment. The children were very enthusiastic and curious about this activity because they could directly experience natural elements and apply practically what they had studied in the previous meeting.

Figure 1. Example of an acrostic created during the first meeting of the project. The acrostic is composed by “Nascosti nellA Terra Umida Respirano Animaletti” (Hidden in the moist soil little animals breathe).

The concept of ES was introduced during the fourth meeting. This part was related to the third question (“What does Nature do for us?”). To simplify the concept of ES to children, we used as examples areas in the town that they already knew, such as parks and green areas. A questionnaire about Torbole Casaglia was submitted to the class, which aimed to understand how much children knew about the territory and its peculiarities. Then, we introduced the Millennium Ecosystem Assessment (MEA, 2005) definition in a simplified version to make it more comprehensible to children. We defined ES as all the benefits that *the Earth gives us without asking anything back*. Hence, the children had to think about some examples and share them with the whole class. Then some videos were shown to them about the nature of the neighbourhood. The peculiarity of the territory is the presence of karst springs, which were introduced as a concrete example of ES that they studied. Successively they discovered the CES through some simple definitions readjusted concerning the age and comprehension skills of students (Tab.1), for instance the heritage value was readjusted using the term “memory” and was mostly focused on direct experiences of children instead of identification with the culture and history of the place. We divided the class into the groups of the past meetings to carry out an activity regarding ES using a crowdmapping approach. Crowdmapping is a methodology that leads to the visual representation of individual perception and value of the city (Hennig, 2019). Students mapped the CES, and the teacher introduced them to their city map. This activity helped children to raise their awareness regarding the city in which they live, with the possibility of adding a specific value to different areas. We gave the children a city map of Torbole Casaglia and they had to identify and highlight places in the map that were considered sources of CES and identify which one of those previously presented (Tab.1). At the end of the activity, it was very important to discuss with the whole class the results of every group and the issues that emerged.

CES explained to children	CICES V5.1 CODE	Simple descriptor (CICES V.5)
Recreational places where you can have fun	3.1.1.1	Using the environment for sport and recreation using nature to help keep fit
Community and Friendship places where you can meet with relatives and friends	3.3.X.X	Other
Well-being places where you can do sports and relax	3.1.1.1 3.1.1.2	Using the environment for sport and recreation; using nature to help keep fit Watching plants and animals where they live; using nature to de-stress
Beauty and Creativity places that you visit because are beautiful and that inspire your creativity	3.1.2.4 3.3.X.X	The beauty of nature Other
Memory places that remember you moments of your life	3.1.2.3	The things in nature that help people identify with the history or culture of where they live or come from
Environmental Education places where you can learn something about Nature and how to take care of it	3.1.2.2	Studying nature (Characteristics of living systems that enable education and training)

Table 1. Example of descriptions of CES and the related ecosystem service CODE (Classification CICES V.5)

During the last meeting, we wanted to reply to the question "What can we do for Nature?". We showed a video during the meeting about the "O_2 Wood", an artificial wood created 20 years ago by the municipality to plant greenery in the town. In the video, we explained the necessity of recovering that area, showing both natural elements (such as trees and blooms) and elements related to the abandoning and degradation of the area, such as domestic garbage. After the video, we explained to children that the abandoning of the area was causing a depletion in the provisioning of ES. The children agreed to take action and wrote a letter to the Mayor of Torbole Casaglia (S1, Supplementary Materials) explaining their concern about the “O_2 Wood”. The letter was written using the cooperative learning approach, whereby the children were divided into groups, then each group made its proposals to recover the “O_2 Wood” and presented them to the others. The proposals were summarised in the letter, and some drawings were added. We organized a trip to the Mayor’s office, where children brought and personally read the letter to the Mayor. The Mayor agreed with some of the children’s ideas and decided to help them, also involving the civil protection volunteers, which is a corps of national volunteers that take action to defend life, settlements and the environment from damage by natural hazards. Afterwards, a trip to “O_2 Wood” was organized to put into practice what was proposed by the class and clean the area, also with the help of civil protection volunteers. Furthermore, since only a small number of students had already been to the area, the trip was an opportunity for many to discover a new environment in the town.

During the project, the assessment of the children’s learning and their work was carried out by the teacher with the evaluation of practical activities, questionnaires, and discussions. Also, we used the self-assessment method to make the children aware of their changing perceptions of the studied topics and a later follow-up assessment, which consisted in administrating a questionnaire to children after one year, to investigate the long-term knowledge acquired.

3. Results and discussion

3.1 The concept of nature and CES

To achieve the main aim of the project, in particular the use of CES as a tool to improve the knowledge and perception of nature, it was necessary first to introduce children to the general concept of nature (Torkar and Krašovec, 2019) and to improve their knowledge of the environment surrounding them. The teacher reported that the first answers to the question “What is Nature for you?” were quite vague and sometimes not relevant, some examples were the words “agriculture” or “irrigation” which did not fully match the assignment. For this reason, the teacher concentrated initially on this part of the project and helped children to think about nature more broadly, trying to enhance their intrinsic naturalistic intelligence (Gardner, 1983) through storytelling and outdoor activities. This approach introduced the children to new words related to nature, such as “beauty”, “roots”, “bark”, and “freedom”. The expression of these words emerged in the acrostic activity, where children cooperatively shared their feelings, choosing the best words to create the acrostic.

In particular, regarding CES, the activity of crowdmapping ("What does nature for you?") was fundamental for the application of the new definitions learned about ES. The children were asked to tell stories, sensations, and personal experiences about some environments that they already knew. Moreover, the children were supposed to put all these feelings and perceptions into a map, and with this we sought to deepen their awareness of their town, going beyond their general knowledge of the areas, and adding a personal description. A total of 28 areas were indicated by the children for the provision of the CES identified in the project (Tab.1). The recreational service, which is linked to leisure moments of play and enjoyment, emerged as predominant (Fig.2), resulting in the most recognized component of the city map with a percentage of the 36% of the total (10 areas).

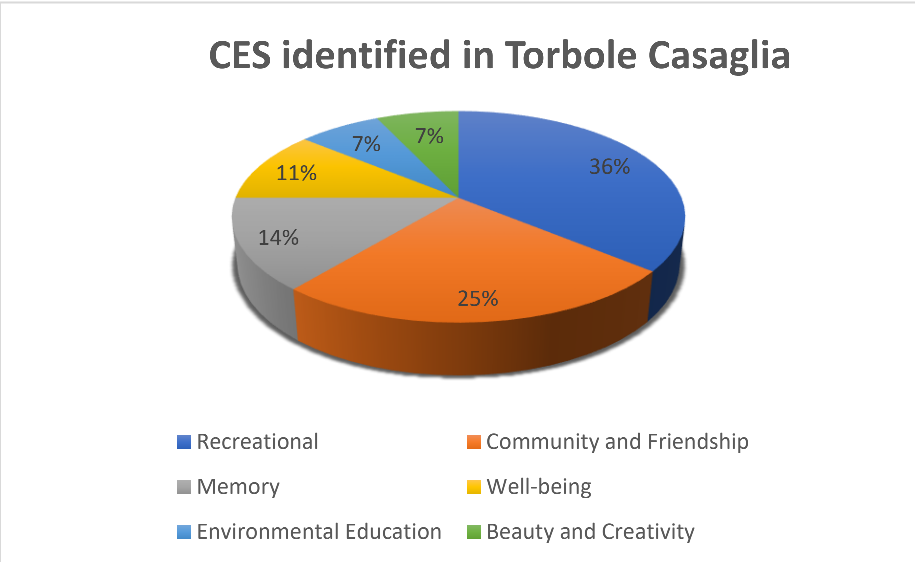


Figure 2. Results of the crowdmapping in terms of percentage of identifications of CES on the city map

This was identified in all the places where children usually play together, such as public Parks and green areas. Next, the children recognized the community and friendship service, described as the places to meet friends and to share moments, as the second most represented (7 areas) with a percentage of 25% of the total, highlighting places linked to their social life such as public parks and the oratory. The memory value, which is the service related to memories of the past and emotions linked to a special place, was identified in the city with a percentage of 14% (4 areas). The well-being value, described as places where children could relax and do sports, resulted only in 11% of areas (3 areas) belonging to this category, including the sports field, cycle, and jogging paths. Both environmental education and beauty and creativity had the lowest scores (2 areas), reaching 7% of the total. It is interesting to note that the "O_2 Wood" was recognized as a place related to the educational service instead of recreational, underlining the feeling of children about the activity carried out in recovering the degraded area and learning about the neighbourhood. The beauty and creativity value was perceived in the cycling and jogging paths. Thus, activities related to leisure and recreational values were those most recognized by children, while the aesthetic value of the study area and educational values were the least considered. From the results, it emerged that children understood the ecosystem services concept and that they feel nature like a special place where they can have fun, with family and friends.

The children showed greater recognition of services in which they could concretely recognize themselves in activities, such as playing or meeting with friends, while more reflective and abstract services had lower values. The most important result here was the efficiency of using CES as tool to develop in children new environmental perceptions, that went beyond their prior knowledge of nature, only related to personal experiences. In fact, as emerged from the crowdmapping, the most perceived service related to nature is the recreational service, but other services less linked to concrete and practical experience were identified and mapped. The high values for the recreational services could be due to the relation with nature that children had experienced prior to the project.

Thus, nature and green areas of the town, were explored mostly for recreational purposes. The fact that the aesthetic value of nature, for instance, was not highly evaluated was not surprising, as the aesthetic value is highly dependent on experiences, learning and social support (Van Wieren and Kellert, 2013). Thus, for the development of the aesthetic value of the environment, we suppose that children needed to have prior experience a contemplative view of nature. Another explanation of this result could be related to the age of children in our class. According to Rejeski (1982), children develop a sense of nature in steps related to the age, and by 9-10 years children develop a playful attitude towards nature, having internalized physical actions as mental actions. We assumed that these abstract values will be developed during the early adolescence, when the capacity of reflecting on their own thoughts and be more separated from the concrete thinking develops (Rejeski, 1982). Despite the low score, the educational value emerged in the crowdmapping, and it mapped as related to a green area. This result was interesting because it suggested that children were developing a new perception of the natural areas of the town that went beyond the recreational value, but that was more related to the new experiences and knowledge acquired during the project.

Thus, we can affirm that the children appreciated the activity and the use of CES was a tool for developing a new perception of the surrounding environment. Children are important elements of society, being future citizens and decision-makers, and for this reason they need to be motivated and included in these sorts of activities to raise their awareness of their surroundings and to participate in city development (Hennig, 2019).The results were discussed in the classroom and some issues emerged related to the understanding of a city map and the legend. The children enjoyed observing their town through the map, finding their houses, and discovering how many places they had never been to, even though some children stated they had difficulties in recognizing places through the map. After the discussion, the children were followed during a second round of crowdmapping to avoid any kind of bias, which led to the results here presented. Moreover, they themselves suggested some improvements to the activity, such as the use of a dictionary in case of difficult terminology, and more detailed explanations of the assignment. Hence, we discussed the perception of the city after the crowdmapping and the children confirmed having a new perception of the city related to a better knowledge of the green spaces and new feelings and emotions, based on the CES studied. CES was a useful tool to create new perceptions of the green areas and to first introduce new concepts, such as the active approach to nature. Using this tool, we could introduce the part aiming to promote active citizenship, to reconsider their view of nature and of themselves within it, where human beings depend on nature for the provision of many essential services for survival and well-being, and for this reason it is necessary to intervene in the protection of nature.

3.2 Cooperative learning and active citizenship

Since the activities were carried out using cooperative learning, we asked the children during the discussions their opinion regarding this methodology. Children were enthusiastic about this way of working, and many students stated that doing assignments together motivated them to carry on the activity having more fun (Mueller and Fleming, 2001). Through cooperative learning it was possible for them to work in groups, be together with their classmates, and also be more autonomous than during a normal class. In the beginning, working in groups and cooperating was at times disorienting for the children, but after a while they started to work together effectively on the assignment. There was then an improvement in the independence and individual sense of responsibility, and these together led to the children becoming more autonomous in each activity. Sometimes arguments inside the groups happened, and during a subsequent discussion a children stated that "I have learned that if you argue you cannot complete the assignment, you need to be patient", and another stated that "to respect your turn is very important to work peacefully". These statements demonstrated a good capacity for self-control and respect for each other's work, even though sometimes the teacher had to intervene to stop the arguing.

From the individual self-assessment (S2, Supplementary Materials) at the end of the project, it emerged that almost half of the students found difficulties in working in groups. Building their own personal point of view is indispensable for children to assess competences acquired and gives them the chance to develop an awareness of the personal learning experience, results, skills, and weaknesses (Bouffard et al. 2009). Asking students to participate in the assessment changes their position from passive to active, carrying out an assessment process that normally involves them only in a passive way. Hence, the student is active, and has responsibility and power. The teacher has only to decide the rules of the assessment and share them with the class. The self-assessment by children showed that particularly in the first part of the project, there were some conflicts that they did not know how to face, and difficult moments in which they felt confused and not considered by the rest of the group. Once they understood how to work together and exchange points of view with each other, their interaction became increasingly more positive. Social competence is a fundamental point of growth on which it is necessary to work from childhood to prepare children to enter society and to promote social cohesion.

Furthermore, knowledge in children emerges in different ways, and the direct interaction with nature leads to the development of knowledge through senses, emotions, and experiences, representing a tool for arousing environmental awareness (Veselinovska et al., 2010). The trip to the "O_2 Wood" represented the chance to act and put into practice the new knowledge acquired during the more theoretical parts about nature ("What is nature for you?") and their town ("How is the environment where you live?"). Children could enjoy the experience of the wood, its elements and act for its safeguarding. This is a fundamental point in Environmental Education (EE) as a tool to guide individuals to more sustainable behaviours during their lives (Michelsen & Fischer, 2017; Collado et al., 2020). EE works through the development of Environmental Attitudes (EA) and Environmental Behaviours (EB) using direct experience and overcoming the incentives and punishment strategy (De Young, 2000). Moreover, many authors stated that the outdoor experience of nature is far more effective than exclusively indoor lessons for encouraging EA and EB, being an opportunity to explore nature directly (Braun & Dierkes, 2017; Lekies et al., 2015; Evans et al., 2007). In this way, during the project the children had the chance to build a theoretical background regarding nature and their town through plenary sessions and also going on an outdoor trip where they could explore and directly experience nature. In particular, during this part of the project, we aimed to develop in children active citizenship during the proposal and application of strategies to recover the "O_2 Wood". Furthermore, children in this age group (9-10 years old) were traditionally considered by scholars as holders of a passive perception of humans in nature, perceiving that man does things in nature and not to nature (Rejeski, 1982), while during the project we successfully developed an active perception in the children, which resulted in a pro-active attitude, whereby they proposed many implementations for the "O_2 Wood" to improve the quality of the environment and had direct field-based experience enabling them to take action and safeguard green spaces.

3.3 Later assessment

Eventually, a questionnaire administrated one year later was used as a follow-up assessment the learning path offered to the students and the influence of what they learned. From the results some positive aspects emerged. All 17 students remembered well the project of the "O_2 Wood", 50% of the students visited again the "O_2 Wood" after the project with family and friends, whereas 40% did not return and 10% did not remember. 60% of those that visited the "O_2 Wood" again stated that they did it for fun, and 40% stated that the purpose was relaxing. All of those who took part in the project said they appreciated the experience conducted together and also the entire learning path undertaken before the "O_2 Wood" trip. Moreover, analysing the open question in the questionnaire, some further elements emerged. The children emphasized an appreciation for working together, highlighting the fun of a project structured in working groups and not individually, cooperating to achieve a common purpose. They underlined in the later questionnaire (S3, Supplementary Materials) their desire for respecting the planet as something that all humans have to do, expressing an ethical responsibility of everyone. Moreover, the children autonomously made many statements regarding the need for taking care of the planet and the strict relationship with our well-being, also expressing the bidirectionality of the relationship human nature, as stated by C. "I have learned that nature needs us and so do we”. Based on the results obtained from the later questionnaire, we can assume that children started developing during the project both an environmental sensitivity, which leads them to the feeling of a need for intervention and recognition of natural elements, and an active citizenship approach, by understanding what the environment needs, making proposals, acting, and expressing a shared desire for taking care of nature. Considering the results obtained, we can affirm that children’s perceptions of nature changed as the project progressed and in terms of the lasting impact the experience had. Thus, we can infer that attention to and care of nature are acquired skills, dependent on children prior knowledge of nature and personal experiences (Burgess and Mayer-Smith, 2011), but open to being developed through an appropriate educational program and outdoor experiences.

4. Conclusions

From the results of the project emerged that there was a positive change in children's perception of the environment. The cooperative learning method was highly appreciated by the children and helped to facilitate the lessons and maintain the interest of the class. Also, the teacher adopted a collaborative approach during all the activities, aiming to obtain thoughts and perceptions that emerged from each meeting. The project characteristics of self-assessment, discussion, and cooperative working are fundamental to developing children’s curiosity, also promoting inclusivity and active cooperation from each student. The most challenging concepts were proposed through plenary sessions, to facilitate learning and the consequent activities. The main aim of the project was the development of knowledge and sensitivity towards nature, and the active role of children, who through the project could develop a long-term sensitivity to the environment and a renewed perception of their city and its CES. The project is a step in the direction of developing lifelong learning skills, in line with the eight competencies identified in 2006 by the European Parliament and the Council of the European Union for lifelong learning (European Parliament, 2006), using teaching methodologies in schools that allow children to directly experience and discover for themselves, thereby making possible the development of lasting, conscious and meaningful learning.

References

Almers, E., Askerlund, P., Samuelsson, T., & Waite, S. (2021). Children's preferences for schoolyard features and understanding of ecosystem service innovations–a study in five Swedish preschools. *Journal of Adventure Education and Outdoor Learning*, *21*(3), 230–246. https://doi.org/10.1080/14729679.2020.1773879

Barnard, R. (2002). Peer tutoring in the primary classroom: A sociocultural interpretation of classroom interaction. New Zealand Journal of Educational Studies 37(1), 57-72.

Barraza, L. (1999). Children's drawings about the environment. *Environmental Education Research*, *5*(1), 49–66.

Bezzi, C., & Baldini, I. (2006). *Il brainstorming: pratica e teoria* (Vol. 1). FrancoAngeli.

Boca, G. D., & Saraçli, S. (2019). Environmental education and student's perception, for sustainability. *Sustainability (Switzerland)*, *11*(6), 1–18. https://doi.org/10.3390/su11061553

Bouffard, T., Vezeau, C., Roy, M., & Lengelé, A. (2011). Stability of biases in self-evaluation and relations to well-being among elementary school children. *International journal of educational research*, *50*(4), 221-229

Braun, T., & Dierkes, P. (2017). Connecting students to nature–how intensity of nature experience and student age influence the success of outdoor education programs. *Environmental Education Research*, *23*(7), 937–949.

Burgess, D. J., & Mayer-Smith, J. (2011). Listening to children: Perceptions of nature. *Journal of Natural History Education and Experience*, *5*, 27.

Collado, S., Rosa, C. D., & Corraliza, J. A. (2020). The effect of a nature-based environmental education program on children's environmental attitudes and behaviors: A randomized experiment with primary schools. *Sustainability (Switzerland)*, *12*(17). https://doi.org/10.3390/SU12176817

Colombo, G., & Passerini, E. (2013). *Imparare la libertà*. Salani.

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., & Grasso, M. (2017). Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosystem Services*, *28*, 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, *26*(1), 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

De Young, R. (2000). New ways to promote proenvironmental behavior: Expanding and evaluating motives for environmentally responsible behavior. *Journal of Social Issues*, *56*(3), 509–526.

Dewey, J. (1954) Il mio credo pedagogico. Antologia di scritti sull'educazione*,* Firenze*, La Nuova Italia*, 3-31.

Evans, G. W., Brauchle, G., Haq, A., Stecker, R., Wong, K., & Shapiro, E. (2007). Young children's environmental attitudes and behaviors. *Environment and Behavior*, *39*(5), 635–658.

European Parliament (2006), Recommendation of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning *OJ L 394, 30.12.2006, p. 10–18*

Fratus, T. (2013). *Il sussurro degli alberi. Piccolo miracolario per uomini radice*, Ediciclo.

Gardner, H. (1983). *Frames of the Mind: The Theory of Multiple Intelligences*. Basic Books.

Gillies, R., & Ashman, A. (2003). *Cooperative learning*. Taylor & Francis.

Hadjichambis, A. C., & Reis, P. (2020). Introduction to the conceptualisation of environmental citizenship for twenty-first-century education. *Conceptualizing Environmental Citizenship for 21st Century Education*, Environmental Discourses in Science Education, vol 4. Springer, Cham.

Haines-Young, R., & Potschin, M. B. (2018). Common international classification of ecosystem services (CICES) V5. 1 and guidance on the application of the revised structure. http://www.cices.eu.

Hennig, S. (2019). Child-and youth-friendly cities: How does and can crowdmapping support their development? *Articulo-Journal of Urban Research.*

Hill, D. (1998). *The Magical Tree-Castle*. Mammoth.

Iliopoulou, I. (2018). Children's thinking about environmental issues. *Educational Research*, *60*(2), 241–254.

James Farmer, Doug Knapp, G. M. B. (2007). An Elementary School Environmental Education Field Trip: Long-Term Effects on Ecological and Environmental Knowledge and Attitude Development. *The Journal of Environmental Education*, *38:3*, 33–42. https://doi.org/10.1080/00139254.1971.10801578

Kuo, M., Barnes, M., & Jordan, C. (2019). Do experiences with nature promote learning? Converging evidence of a cause-and-effect relationship. *Frontiers in Psychology*, 1–9. https://doi.org/10.3389/fpsyg.2019.00305

Lekies, K. S., Yost, G., & Rode, J. (2015). Urban youth' s experiences of nature: Implications for outdoor adventure recreation. *Journal of Outdoor Recreation and Tourism*, *9*, 1–10.

Lwo, L. S., Fu, J. H., & Chang, C. C. (2017). The ecological worldviews and local environmental concerns among secondary school teachers. *Journal of Baltic Science Education*, *16*(5), 706–722. https://doi.org/10.33225/jbse/17.16.706

Maraja, R., Barkmann, J., & Tscharntke, T. (2016). Perceptions of cultural ecosystem services from urban green. *Ecosystem Services*, *17*, 33–39. https://doi.org/10.1016/j.ecoser.2015.11.007

MEA. (2005). *Ecosystems and human well-being* (Vol. 5). Island press United States of America.

Melia, J. (2003). Silent Scourge: Children, Pollution, and Why Scientists Disagree. *Bmj*, *327*(7414), 568.

Michelsen, G., & Fischer, D. (2017). Sustainability and education 1. In *Sustainable development policy* (pp. 135–158). Routledge.

Monte, T., & Reis, P. (2021). Design of a pedagogical model of education for environmental citizenship in primary education. *Sustainability (Switzerland)*, *13*(11). https://doi.org/10.3390/su13116000

Mueller, A., & Fleming, T. (2001). Cooperative learning: Listening to how children work at school. *Journal of Educational Research*, *94*(5), 259–265. https://doi.org/10.1080/00220670109598761

Piske, E. L., Garcia, N. M., & Yunes, M. A. M. (2021). Environmental educational practices in the training of childhood educators, *Language and Technology 14*(1), e25698–e25698.

Rejeski, D. W. (1982). Children look at nature: Environmental perception and education. *The Journal of Environmental Education*, *13*(4), 27-40.

So, W. W. M., & Chow, S. C. F. (2019). Environmental education in primary schools: A case study with plastic resources and recycling. *Education 3-13*, *47*(6), 652–663. https://doi.org/10.1080/03004279.2018.1518336

Strife, S. J. (2012). Children's environmental concerns: Expressing ecophobia. *The Journal of Environmental Education*, *43*(1), 37–54.

Torkar, G., & Krašovec, U. (2019). Students' attitudes toward forest ecosystem services, knowledge about ecology, and direct experience with forests. *Ecosystem Services*, *37*(August 2018). https://doi.org/10.1016/j.ecoser.2019.100916

Türkoğlu, B. (2019). Opinions of preschool teachers and pre-service teachers on environmental education and environmental awareness for sustainable development in the preschool period. *Sustainability (Switzerland)*, *11*(18). https://doi.org/10.3390/su11184925

Van Wieren, G., & Kellert, S. R. (2013). The Origins of Aesthetic and Spiritual Values in Children's Experience of Nature. *Journal for the Study of Religion, Nature & Culture*, *7*(3).

Veselinovska, S. S., Petrovska, S., & Zivanovic, J. (2010). How to help children understand and respect nature? *Procedia - Social and Behavioral Sciences*, *2*(2), 2244–2247. https://doi.org/10.1016/j.sbspro.2010.03.316

Yalcin, F. A., & Yalcin, M. (2017). Turkish Primary Science Teacher Candidates' Understandings of Global Warming and Ozone Layer Depletion. *Journal of Education and Training Studies*, *5*(10), 218. https://doi.org/10.11114/jets.v5i10.2225

Authors

Noemi Rota, University of Milano-Bicocca, Department of Earth and Environmental Sciences, Piazza della Scienza, 1-20126 Milan, Italy. rota.noemi@gmail.com
Corresponding author

Claudia Canedoli, University of Milano-Bicocca, Department of Earth and Environmental Sciences, Piazza della Scienza, 1-20126 Milan, Italy.

Martina Fava, University of Milano-Bicocca, Department of Earth and Environmental Sciences, Piazza della Scienza, 1-20126 Milan, Italy.

Emilio Padoa-Schioppa, University of Milano-Bicocca, Department of Earth and Environmental Sciences, Piazza della Scienza, 1-20126 Milan, Italy.

Authors' contributions

Writing—review and editing, N.R., methodology, C.C., E.PS; investigation, M.F.; data analysis, N.R, C.C., E.PS.; supervision, C.C., E.PS. All authors have read and agreed to the published version of the manuscript.

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors have declared no conflict of interest.

Citation

Rota, N., Canedoli, C., Fava, M., and Padoa-Schioppa, E. (2023) Introducing children in the primary school to the concept of ecosystem services. *Visions for Sustainability*, 20, 6960, 549-566. http://dx.doi.org/10.13135/2384-8677/6960

Original Paper

Sustainable food consumption and Nature conservation processes.

Educational considerations

Flavia Bartoccioni, Caterina Lorenzi, Franca Sangiorgio

Received: 15 March 2023 | **Accepted:** 1 June 2023 | **Published:** 9 June 2023

Keywords: biodiversity; environmental education; Sustainable Consumption and Production (SCP); sustainable development; sustainable diets.

Abstract. *The topic of an agricultural production that respects natural ecosystems is currently very relevant, as it is being tackled by international agencies such as FAO and IPCC, focusing on the double link between* *biodiversity conservation processes and sustainable agriculture, creating a virtuous circular process. In this context, the adoption of sustainable eating habits, which heavily relies on educational processes, is indispensable. Our contribution describes the relationship between nature conservation and food consumption within a sustainability framework, while also reflecting on the potential impact of educational projects on sustainable food consumption items through a literature analysis. To minimize the impact of food consumption on nature, we propose some considerations on Sustainable Consumption and Production (SCP) environmental education concerning: the potential of SCP nodes in the environmental conceptual education network; the potential of SCP environmental education in the framework of food availability; the pro-environmental behavior research concerning SCP.*

1. Introduction

We live in the age of the Anthropocene, a historical phase where our planet is particularly marked by environmental and humanitarian emergencies with broadly anthropogenic origins (Crutzen & Stoemer, 2000). As highlighted by the scientific community, climate changes have caused and are still causing widespread adverse impacts to nature and people, which is why there is an international call for urgent enforcement actions (IPCC, 2022). Even if climate change plays an increasingly important role in the decline of biodiversity[1], its main driver is human use of land primarily for food production: human activity has altered about 70% of ice-free lands. This has had severe consequences for animals and plants, because when land is converted for agriculture, some species may lose their habitat and face extinction (United Nations, 2022).[2] The

[1] "Biodiversity or biological diversity means the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems". This is the main definition of "biodiversity", given by the UN in 1992 in "Convention on Biological Diversity" (UN, 1992; https://www.cbd.int/convention/).

[2] United Nations, Climate Action, 2022. https://www.un.org/en/climatechange/science/climate-issues/biodiversity, accessed February 2023.

increasing impact of climate change is also threatening the viability of rural agricultural livelihoods, posing unprecedented challenges and disrupting migration patterns; the World Bank has estimated that climate change could force 216 million people in six world regions to migrate by 2050.[3]

The environmental system and the anthropic system are inextricably interconnected. The quantity and quality of relationships that support the structures and processes of both indicate the complexity of the natural-human macrosystem. Industrial activities geared toward production supporting human well-being (e.g., the food industry) can paradoxically greatly reduce not only biodiversity but also the very human well-being they strive to achieve. Environmental and social changes can, in fact, result in cascading negative impacts on the production processes themselves. The *Intergovernmental Panel on Climate Change* – IPCC (2022) highlights both the strong interaction between the natural, social and climate systems and the widespread adverse impacts on nature and people of human-induced climate change. The evidence of these negative processes supports the emerging trend in national and international government documents to transition human society towards Sustainable Development.

A commonly accepted definition of Sustainable Development was reported in the World Commission on Environment and Development report (Brundtland, 1987) as "development that ensures that the needs of the present generation are met without compromising the ability of future generations to realize their own needs". In this paper, we describe the logical links between two central concepts of sustainable development processes: food consumption and nature conservation. We then reflect on the possible impact of educational programs on sustainable food consumption.

2. Sustainable food consumption and production pattern

As reported by Ahmed & Shanks (2019), relevant strategies to achieve Sustainable Development are those supporting sustainable consumption and production of human food. The concept of sustainable diet is addressed and expressed in various ways in the literature (Auestad & Fulgoni, 2015; Steenson & Buttriss, 2020). An inclusive definition was provided by the FAO (2011):

---

[3] Food and Agricultural Organization of the UN (FAO) 2022. https://www.fao.org/rural-employment/resources/detail/es/c/1599229/, accessed February 2023.

> "Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy, while optimizing natural and human resources".

The key components of a sustainable diet are clearly represented in FAO 2012 (Figure 1).

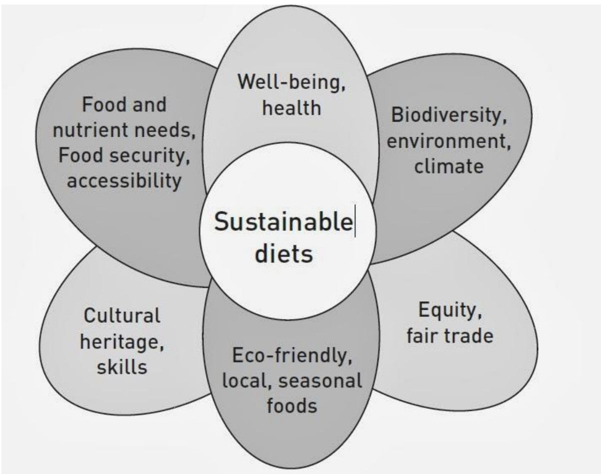


Figure 1. Schematic representation of the key components of a sustainable diet (FAO, 2012).

A preliminary clarification should be made concerning the extremes of the consumption-production relationship. In business terms, the outcome of a production process is the "product". It represents the *fulcrum* around which all of a company's activities revolve, including production, research, innovation, marketing, distribution, sales, communication, and promotion (Foglio, 1997). In other words, the product represents the concreteness of the company's philosophical choice. Sustainable development production strategies could be incorporated into the complex production process *via* proper ecological choices of raw materials, processing procedures and packaging. A product achieves a significant market penetration if it meets the consumer's needs (Foglio, 1997).

Thus, it is clear why consumer choices are seen as central in strengthening sustainable production.

The patterns of consumption and production were discussed by the United Nations Conference on Environment and Development (Rio de Janeiro, 1992). Chapter 4 of Agenda 21 states: "... the major cause of the continued deterioration of the global environment is the unsustainable pattern of consumption and production, particularly in industrialized countries …", claiming that "... sustainable development will require both efficiency in production and changes in consumption patterns; … in many cases this will require reorientation of existing production and consumption patterns that have developed in industrial societies and are in turn emulated in much of the world." Furthermore, the Rio Declaration on Environment and Development[4], approved by the United Nations during the UNCED in Rio de Janeiro (1992), established a link between development and sustainable consumption. Principle 8 states: "To achieve sustainable development and a higher quality of life for all peoples, States should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies" (UNCED, 1993). In the last thirty years, the concern over Sustainable Consumption and Production (SCP) patterns has been acquiring national and international prominence. Many environmental issues, interpreted within a systemic view, have been linked to the SCP, as evidenced by the long series of international conferences related to on-going climate changes and SCP matters (Wang et al., 2019).

A systemic link between SCP and sustainable development issues is clearly detectable in "The Agenda 2030 for Sustainable Development" of the United Nations (2015), an action plan aimed at fostering global sustainable development by 2030. This document, consisting of 17 Sustainable Development Goals (SDGs), focuses attention on SCP, particularly in Goal 12 (*Responsible Consumption and Production - Ensure sustainable consumption and production patterns*), but also in Goal 14 (*Life below water - Conserve and sustainably use the oceans, seas and marine resources for sustainable development*), and in Goal 15 (*Life on land - Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*).[5] It should be remembered that 2030 Agenda has become from the very beginning, a milestone tool for

[4] The *Rio Declaration on environment and development* adopted 27 principles to guide the future development. These principles define the right of people to development, and their responsibilities to safeguard the common environment.

[5] United Nations, 2015. https://sdgs.un.org/goals, accessed February 2023.

international discussions focused on defining problems and resolutions related to the three pillars of sustainable development: environment, society and economy. A valuable contribution to these global efforts has been already given since 2016 by the Group of Twenty (G20)[6] through adapting the G20's Action Plan to the 2030 Agenda for Sustainable Development, aimed at contributing to the Agenda's goals (OECD & UNDP, 2019). Thus, the increasingly ambitious challenge of being able to meet the food needs of the world's population, which will supposedly reach 9.7 billion people by 2050 (UN, 2017), necessarily requires the implementation of proper strategies to ensure sustainable food security, conservation of natural ecosystems, reduction of food loss and waste.

Food loss and waste are considered huge problems in the SCP framework and many initiatives have been carried out to reduce them (FAO, 2019a; Cattaneo et al., 2021). Already in May 2015, under the Presidency of Turkey, the G20 agriculture ministers highlighted the extent of food loss and waste reduction as "a global problem of enormous economic, environmental and societal significance" and encouraged all G20 members to strengthen their collective efforts to prevent and reduce food loss and waste. The FAO, through a 'Technical Platform on the Measurement and Reduction of Food Loss and Waste', assesses this process at a regional and global scale and supports countries in taking action to prevent and reduce the problem.[7]

Over time, SPC has increasingly become a holistic concept, referred to integrated models designed to achieve optimal control of both natural ecosystem limits and all the stages of a product's life cycle, from production to transportation to consumption. This concept is closely related to pressing global issues, such as climate change containment and mitigation, biodiversity preservation, the availability of water as a primary resource, food and nutrition security, and the right to food.

Since SPC refers to a complex Coupled Human-Natural System (HNS),[8] food production and consumption can be influenced by multiple aspects: availability,

[6] The Group of Twenty (G20) is the premier forum for international economic cooperation. It plays an important role in shaping and strengthening global architecture and governance on all major international economic issues. https://www.g20.org/en/about-g20/

[7] https://www.fao.org/platform-food-loss-waste/en/ accessed April 2023

[8] For literature concerning systemic vision applied to Coupled Natural-Human Systems see Pickett, et al (2005); for the more commonly used Coupled Human and Natural Systems (CHANS) concept, see Liu et al. 2021

accessibility, and choice of food resources, which in turn are influenced by geography, demographics, income, socio-economic status of the population, urbanization, religion, culture, globalization, and not least consumer attitudes (Kearney, 2010). In this framework, *consumption*, as a component of the coupled SCP conceptual system, has become increasingly important over the years as a driver of production quality within a sustainable vision. This aspect emerged in 1995 when, at the "Oslo Ministerial Roundtable Conference on Sustainable Production and Consumption" the concept of sustainable consumption was defined as: "an umbrella term that brings together a number of key issues, such as meeting needs, enhancing the quality of life, improving resource efficiency, increasing the use of renewable energy sources, minimizing waste, taking a life cycle perspective and taking into account the equity dimension. Integrating these component parts is the central question of how to provide the same or better services to meet the basic requirements of life and the aspirations for improvement for both current and future generations, while continually reducing environmental damage and risks to human health" (Norwegian Ministry of the Environment, 1995).

In recent years, as pointed out in the FAO report (2019b) *The State of the World's Biodiversity for Food and Agriculture*, there has been a growing interest in practices and approaches compatible with biodiversity conservation, although levels of coverage and protection are often still inadequate. Furthermore, the report indicates that 80% of the 91 observed countries use one or more biodiversity-friendly practices and approaches such as organic farming, integrated pest management, conservation agriculture, sustainable soil management, agro-ecology, sustainable forest management, agroforestry, diversification practices in aquaculture, an ecosystem approach to fisheries and ecosystem restoration. This suggests that a movement towards cultural innovation is now underway.

3. Food biodiversity and public health

In the past few decades, scientific literature has often shown significant evidence of the growing costs of global food diets on natural ecosystems, social systems, and public health (see, for example, Verbeke, 2007). Natural ecosystems provide the human population with numerous resources and services, with food playing a very important role. The term *Biodiversity for Food and Agriculture* has been used by the FAO (2019b) to refer to plants and animals (wild and domestic), and microorganisms that provide direct benefits to human beings such as agriculture products, livestock, animal feed, fuel, fiber, as well as indirect benefits through the processes supporting food production, thanks to the myriad of organisms

 http://dx.doi.org/10.13135/2384-8677/7419

called "associated biodiversity". Examples of "associated biodiversity" include pollinators, predators of crop pests, the vegetation of hedgerows and field margins, and the invertebrates and microorganisms that help maintain soil and its fertility. Plants, animals, and microorganisms also provide other invaluable services to human beings, such as soil fertilization, air and water purification, and crops and livestock pest and disease control.

The dependence of human beings on nature is of course clearly visible in the area of food production. The growing concern around the loss of agro-biodiversity has fueled global efforts to improve conservation actions through a number of international documents and agreements. The Convention on Biological Diversity (CBD 1992) aimed at halting the loss of plant and crop diversity. The 2002 Global Strategy for Plant Conservation (GSPC) already required the conservation of at least "70% of the genetic diversity of crops and other major socioeconomically valuable plant species" (Galluzzi et al., 2010). Instead, our diet is currently based on a limited number of species, which has profound effects on the same species and the ecosystems. In this respect, the FAO highlighted that "While more than 6000 plant species have been cultivated for food, fewer than 200 make substantial contributions to global food output, with only nine accounting for 66 percent of total crop production in 2014". Global livestock production, on the other hand, is based on about 40 animal species, with only a small group providing the vast majority of meat, milk and eggs, while 26% of the 7745 reported local livestock breeds is threatened with extinction (FAO, 2019b).

Similarly, the percentage of stocks fished at biologically unsustainable levels has increased since the late 1970s, from 10% in 1974 to 35.4% in 2019. On the other hand, the fraction of fishery stocks within biologically sustainable levels has decreased to 64.6% in 2019 (1.2% lower than in 2017). Global consumption of aquatic food (excluding algae) has increased of 3.0% (average annual rate) since 1961, compared with the population growth rate of 1.6%. The per capita consumption of aquatic food grew from an average of 9.9 kg in the 1960s to a record high of 20.5 in 2019 (FAO 2022).

Finally, according to the director of IUCN's Biodiversity Group (IUCN, 2014)[9], the growing food market is placing unsustainable pressure also on numerous

[9] Global appetite for resources pushing new species to the brink - IUCN Red list, 2014; https://www.iucn.org/content/global-appetite-resources-pushing-new-species-brink-iucn-red-list, accessed February 2023.

protected species such as Pacific tuna (*Thunnus orientalis*),[10] Chinese pufferfish (*Takifugu chinensis*),[11] American eel (*Anguilla rostrata*),[12] and Chinese cobra (*Naja atra*),[13] making it increasingly necessary to place restrictive limits on the sampling of these species and to implement appropriate measures to protect their habitats.

These patterns of production and consumption inherently lead to a reduction in global biodiversity, but the loss of biodiversity should not be understood merely as the loss of an asset to be protected for its ethical and intrinsic value. From a purely utilitarian and anthropocentric perspective, less biodiversity also means, for example, that plants and animals are more vulnerable to pests and diseases, ultimately leading to reduced livelihoods and negative impacts on human health. Indeed, our diet relies on a dwindling number of species, both plant and animal, which, together with factors such as overfishing, deforestation, uncontrolled mining, changes in land use and management, pollution, population pressure and climate change, threaten food security for the entire world population (IUCN, 2014).[14]

We can contextualize these threats geographically. Africa is mainly affected by poaching and overexploitation, and Central Asia and Europe by deforestation, land-use change, and agricultural intensification. Overexploitation, pests, diseases, and invasive species, on the other hand, are increasingly common in Latin America and the Caribbean, while the Near East and North Africa are increasingly affected by overexploitation, and Asia by deforestation (FAO, 2019). The knowledge of indigenous and local peoples about the specificity of local

---

[10] *Thunnus orientalis* has most recently been assessed for The IUCN Red List of Threatened Species in 2021, listed as Near Threatened under A2bd criteria. https://www.iucnredlist.org/species/170341/170087840, accessed February 2023. (For more information about IUCN Red list criteria see https://www.iucnredlist.org/resources/categories-and-criteria).

[11] *Takifugu chinensis* has been assessed for The IUCN Red List of Threatened Species in 2011, listed as Critically Endangered under A2bd criteria. https://www.iucnredlist.org/species/170341/170087840 , accessed February 2023.

[12] *Anguilla rostrata* has been assessed for The IUCN Red List of Threatened Species in 2013, listed as Endangered under A2bd criteria. https://www.iucnredlist.org/species/170341/170087840 , accessed February 2023.

[13] *Naja atra* has been assessed for The IUCN Red List of Threatened Species in 2011, listed as Vulnerable under A2d criteria. https://www.iucnredlist.org/species/170341/170087840 , accessed February 2023.

[14] Global appetite for resources pushing new species to the brink - IUCN Red list, 2014; https://www.iucn.org/content/global-appetite-resources-pushing-new-species-brink-iucn-red-list , accessed February 2023.

biodiversity and its sustainable management, which has developed through daily observation handed down from generation to generation, is currently considered a valuable resource (FAO, 2012). Many culinary traditions using local food resources exemplify this concept by protecting the land through sustainable production. One paradigmatic example is the well-known Mediterranean diet,[15] whose nutritional properties and environmental and social values are recognized all over the world. The Mediterranean diet, inspired by local culinary traditions, includes knowledge and practices that respect local biodiversity at all stages of production and consumption (Dominguez & Barbagallo, 2007). For the FAO (2011), the Mediterranean diet "is more than just a set of foods, it promotes social interaction because the common meat is the basis of social customs and festivities shared by a given community; it is grounded in respect for the environment and biodiversity and ensures the preservation and development of traditional activities and crafts related to the fishing and farming communities of the Mediterranean" (FAO, 2012). In 2010, UNESCO [16] nominated the Mediterranean diet for inscription on the Representative List of the Intangible Cultural Heritage of Humanity[17], describing it as follows:

The Mediterranean diet constitutes a set of skills, knowledge, practices and traditions ranging from the landscape to the table, including the crops, harvesting, fishing, conservation, processing, preparation and, particularly, consumption of food. The Mediterranean diet is characterized by a nutritional model that has remained constant over time and space, consisting mainly of olive oil, cereals, fresh or dried fruit and vegetables, a moderate amount of fish, dairy and meat, and many condiments and spices, all accompanied by wine or infusions, always respecting beliefs of each community. However, the Mediterranean diet (from Latin *diaeta*, Greek δίαιτα "way of life") encompasses more than just food. It promotes social interaction, since communal meals are the cornerstone of social customs and festive events. It has given rise to a considerable body of knowledge, songs, maxims, tales and legends. The system is rooted in respect for the territory and biodiversity and ensures the conservation

[15] The term "Mediterranean diet" was coined in 1951 by Americans Ancel Keys, a physiologist at the University of Minnesota, and Margaret Haney, his wife and a biologist at the Mayo Foundation (Moro, 2014; Dixon, 2015).

[16] UNESCO - Commissione Nazionale Italiana per l'UNESCO; https://www.unesco.it/it/patrimonioimmateriale/detail/384, accessed February 2023.

[17] The Mediterranean diet was definitively inscribed by UNESCO on the Representative List of the Intangible Cultural Heritage of Humanity in 2013; https://ich.unesco.org/en/RL/mediterranean-diet-00884, accessed February 2023.

and development of traditional activities and crafts linked to fishing and farming in the Mediterranean communities of which Soria in Spain, Koroni in Greece, Cilento in Italy and Chefchaouen in Morocco are examples.

The Mediterranean diet is also considered a balanced dietary regimen for the prevention of numerous chronic-degenerative diseases (Bosetti et al., 2013; Toledo et al., 2013; Tsivgoulis et al., 2013; FAO et al., 2022).

4. Education and information programs

Despite the growing interest in environmental protection and sustainable development among Western consumers, substantial behavior change is still rare (Richter & Klöckner, 2017). In this framework, as well established by the educational literature, Environmental Education plays a central role in promoting environmentally sustainable behavior (e.g., Hungerford & Volk, 1990).

Environmental Education, in general, is about cultural interactions guided by principles of environmental ethics. By building ecological knowledge, sharing environmental values and promoting environmental awareness, Environmental Education aims to develop pro-environmental attitudes and skills (Ardoin et al., 2020). In other words, implementing new educational processes concerning SCP could equip citizens with the necessary knowledge and skills to become active, informed and engaged participants in promoting sustainable and biodiversity-friendly consumption and production patterns.

Below we propose some considerations concerning three questions related to SCP environmental education.

1. On the potential of SCP nodes in the environmental conceptual education network. SCP environmental education is a complex process. From an educational and training point of view, it could be useful to identify some systemic themes to highlight the multiple relationships emerging in the overall SCP conceptual structure. Some themes, in fact, can be seen as effective conceptual nodes within the complex educational conceptual network. The "reduction of food loss and waste" is a good example of an effective conceptual node in the SCP educational network. It can be seen as an educational vector that could facilitate the achievement of more general environmental educational aims such as improving food security and nutrition,

reducing greenhouse gas emissions, alleviating pressure on water and land resources.

2. On the potential of SCP environmental education in the framework of food availability. SCP environmental education, if practiced as a stable and continuous process well integrated within civil society, could help future citizens and policymakers make informed food choices in view of rapidly changing environmental and social situations that strongly and quickly affect the availability of sustainable food.

3. On pro-environmental behavior research concerning SCP. To minimize the environmental impact of food consumption, it is crucial for Environmental Education research to focus on identifying barriers to pro-environmental behavior concerning SCP. Two areas requiring further exploration are identified here. The first concerns SCP literacy (Richter & Klöckner, 2017) and, more generally, ecological literacy that fosters pro-environmental behavior (Orr, 1992; Jordan et al., 2009; McBride et al., 2013). SCP literacy applied to sustainable food choices should be strongly supported by an appropriate information campaign about the relevant aspects. For example, it seems to be crucial to provide consumers with accurate information about SCP Environmental Certifications and their ability to track sustainable production. In this regard, businesses, such as restaurants or markets, are starting to provide information about the sustainable products they offer, also joining sustainable labeling programs or certified platforms (Dolmage et al., 2016). The second concerns the multitude of psycho-sociological factors that affect both environmental attitudes and the so-called "attitude-behaviour gap".[18] The question of what shapes pro-environmental behavior should be of particular interest for SCP environmental education. Kollmuss & Agyeman (2002) analyze the main factors that have been found to impact pro-environmental behavior, whether positively or negatively. These include demographic factors, external factors (e.g., institutional, economic, social and cultural influences) and internal factors (e.g., motivation, pro-environmental knowledge, awareness,

[18] It is in fact observed that attitudes towards sustainable consumption quite often deviate from actual consumption behaviour. This inconsistency is called "attitude-behaviour gap" or "attitude-intention-behaviour gap". For further information see Terlau & Hirsch, 2015.

values, attitudes, emotion, locus of control, responsibilities and priorities). In this regard, Richter & Klöckner (2017) draw attention to motivational, situational, and socioeconomic factors, while Molinario et al. (2020) focus on the importance of childhood. There appears to be a correlation between childhood nature experiences, exposure to pro-environmental social norms during childhood experiences, and the development of connectedness with nature and biospheric values in adulthood.

5. Conclusions

Numerous questions still need to be addressed regarding the broader concept of SCP, particularly in relation to food. There is certainly a need to promote dietary behaviors anchored to local traditions that protect the environment and human health, as is the case with the Mediterranean diet.

The complexity of the SCP system requires multiple interventions to maintain high product quality in terms of sustainability. These interventions include the adoption and dissemination of specific certifications, the sharing of information about best practices, and the adoption of citizen science practices to make people active agents of societal changes in favor of sustainable approaches (Vorley, 2018). Concerning the importance of local dissemination, as underlined by the FAO et al. (2021), it would be useful to create multi-stakeholder platforms, also relying on already existing consumer networks, in order to facilitate discussions and support decision-making and planning processes at the local level. These platforms could be used to explore and agree on common strategies to improve territorial food systems.

The adoption of sustainable food behaviors is closely linked to understanding the ecological dynamics that support biodiversity protection. Therefore, it is essential to encourage educational experiences concerning sustainable food, human health protection and biodiversity conservation. In this regard, many platforms with educational purposes are available on the web today (Fiore et al, 2014; Sangiorgio et al., 2017), using innovative pedagogical tools such as serious games, to engage citizens and promote effective educational practices (Sangiorgio et al., 2014; Ouariachi et al., 2018).

References

Ahmed S. & Byker Shanks C. (2019). Supporting sustainable development goals through sustainable diets. In: *Good Health and Well-Being*. Filho W.L., Wall T., Azul A.M., Brandli L., Gökcin Özuyar P. (eds). Springer Cham. https://doi.org/10.1007/978-3-319-95681-7

Ardoin N. M., Bowers A. W., Gaillard E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation,* 241, 108224. https://doi.org/10.1016/j.biocon.2019.108224

Auestad N. & Fulgoni, V. L. (2015). What Current Literature Tells Us about Sustainable Diets: Emerging Research Linking Dietary Patterns, Environmental Sustainability, and Economics. *Advances in Nutrition*, 6 (1), 19-36. https://doi.org/10.3945/an.114.005694

Bosetti C., Turati F., Dal Pont A., Ferraroni M., Polesel J., Negri E., Serraino D., Talamini R., La Vecchia C., Zeegers M.P. (2013). The Role of Mediterranean Diet on the Risk of Pancreatic Cancer. *British Journal of Cancer,* 109, 1360-1366. https://doi:10.1038/BJC.2013.345

Brundtland, G. (1987). *Report of the World Commission on Environment and Development: Our Common Future*. United Nations General Assembly document A/42/427

Cattaneo A., Sanchez M.V., Torero M., Vos R. (2021) Reducing food loss and waste: Five challenges for policy and research. Food Policy, 98, 1-9. https://doi.org/10.1016/j.foodpol.2020.101974

Crutzen P. J. & Stoermer E. F. (2000) The "Anthropocene". *Global Change Newsletter*, 41, 17-18

Dixon, J. L. (2015). *Genius and Partnership. Ancel and Margaret Keys and the Discovery of the Mediterranean Diet*. Joseph L. Dixon Publishing. New Brunswick, NJ USA. E-ISBN: 968-0-9862955.

Dolmage K. M., Macfarlane V., Alle J. (2016). Understanding sustainable seafood consumption behavior: an examination of the Ocean Wise (OW) initiative in British Columbia. *Ecology and Society*, 21(2), 586-597. http://dx.doi.org/10.5751/ES-08491-210226

Dominguez L. J. & Barbagallo M. (2007). Dieta mediterranea e longevità: ruolo dell'olio extravergine di oliva. *Giornale di Gerontologia*, 55, 231-238

Fiore N., Montinaro S. V., Sangiorgio F., Lorenzi C., Basset A. (2014). The Scientific Research Game: moodle as a game platform and a social community system. *Proceedings of EDULEARN14 Conference, Barcelona, Spain* ISBN: 978-84-617-0557-3

Foglio A. (1997). *Il marketing agroalimentare. Mercato e strategie di commercializzazione*. Franco Angeli, Milano

Food and Agriculture Organization of the United Nations - FAO (2011). Biodiversity and Sustainable Diets. United against hunger. *Report of International Scientific Symposium,* Rome 2010. Burlingame, B., Dernini, S., (eds.)

Food and Agriculture Organization of the United Nations - FAO (2012) Sustainable diets and biodiversity. Directions and solutions for policy, research and action. *Proceedings of International Scientific Symposium,* Rome 2010. Burlingame, B., Dernini, S., (eds.). E-ISBN 978-92-5-107288-2

Food and Agriculture Organization of the United Nations - FAO (2019a). *The State of food and agriculture. Moving forward on food loss and waste reduction.* Rome. ISBN: 978-92-5-131789-1

Food and Agriculture Organization of the United Nations - FAO (2019b). *The State of the World's Biodiversity for Food and Agriculture*. Bélanger J. & Pilling D. (eds.). Rome. ISBN: 978-92-5-131270-4

Food and Agriculture Organization of the United Nations - FAO, International Fund for Agricultural Development - IFAD, United Nations International Children's Emergency Fund - UNICEF, World Food Programme - WFP & World Health Organization - WHO (2021). *The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all.* Rome, FAO. https://doi.org/10.4060/cb4474en

Food and Agriculture Organization of the United Nations - FAO (2022). *The State of World Fisheries and Aquaculture. Towards blue transformation*. Rome. https://doi.org/10.4060/cc0461en

Galluzzi G., Eyzaguirre P., Negri V. (2010). Home gardens: neglected hotspots of agro-biodiversity and cultural diversity. *Biodiversity Conservation,* 19, 3635-3654 https://doi.org/10.1007/s10531-010-9919-5

Hungerford H. R. & Volk T. L. (1990). Changing learner behavior through environmental education. *The Journal of Environmental Education*, 21(3), 8-21. https://doi.org/10.1080/00958964.1990.10753743

Intergovernmental Panel on Climate Change - IPCC (2022) *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Pörtner H.O., Roberts D.C., Tignor M., Poloczanska E.S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., Rama B. (eds.). Cambridge University Press, Cambridge, UK and New York, NY, USA. doi:10.1017/9781009325844

Jordan R. C., Singer F., Vaughan J., Vaughan J., Berkowitz A. R., Berkowitz (2009). What should every citizen know about ecology? *Frontiers in Ecology and the Environment*, 7, 495-500. doi:10.1890/070113

Kearney J. (2010). Food consumption trends and drivers. *Philosophical Transaction of the Royal Society B.*, 365, 2793-2807. doi.org/10.1098/rstb.2010.0149

Kollmuss, A. & Agyeman J. (2002). Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, 8, 239-260. doi:10.1080/13504620220145401

Liu J., Dietz T., Carpenter S.R., Taylor W.W., Alberti M., Deadman P., Redman C., Pell A.,

McBride B. B., Brewer C. A, Berkowitz A. R., Borrie W. T. (2013). Environmental literacy, ecological literacy, ecoliteracy: What do we mean and how did we get here? *Ecosphere*, 4, 1-48. https://doi.org/10.1890/ES13-00075.1

Molinario, E., Lorenzi C., Bartoccioni F., Perucchini P., Bobeth S., Colléony A., Diniz R., Eklund A., Jaeger C., Kibbe A., Richter I., Ruepert A., Sloot D., Udall A.M. & Bonaiuto M. (2020). From childhood nature experiences to adult pro-environmental behaviors: An explanatory model of sustainable food consumption. *Environmental Education Research*, 26(8), 1137-1163. https://doi.org/10.1080/13504622.2020.1784851

Moro E. (2014). *La dieta mediterranea. Mito e storia di uno stile di vita*. Il Mulino. Bologna. ISBN-13: 978-8815248183

Norwegian Ministry of the Environment (1995). *Oslo Ministerial Roundtable Conference on Sustainable Production and Consumption* 6-10 February, 1995. Oslo, Miljoverndepartmentet

Serious Games and Sustainability. Encyclopedia of Sustainability and Higher Education

Organisation for Economic Cooperation and Development - OECD & United Nations Development Programme - UNDP (2019). *G20 contribution to the 2030 Agenda. Progress and way forward*

Orr DW. 1992. *Ecological literacy: education and transition in a postmodern world*. Albany, NY: SUNY Press. ISBN-13 978-0791408742

Ouariachi T., Gutiérrez-Perez J., Olvera-Lobo M. D. (2018). Serious Games and Sustainability. *Encyclopedia of Sustainability and Higher Education.* W. Leal Filho (ed.). https://doi.org/10.1007/978-3-319-63951-2_326-1

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M. (2005). Biocomplexity in coupled natural human systems: a multidimensional framework. *Ecosystems,* 8(3), 225-232. https://doi.org/10.1007/s1002-004-0098-7

Richter I. G. M., Klöckner C.A. (2017). The Psychology of sustainable seafood consumption: a comprehensive approach. *Foods*, 6(86), 1-14. https://doi.org/10.3390/foods6100086

Sangiorgio F., Lorenzi C., Fiore N., Montinaro S., Basset A. (2014). An international online competition to stimulate student's interest on ecological issues. Research Game: an innovative tool for teachers and students. *SCIentific RESearch and Information Technology*, 2, 109-116. DOI 10.2423/i22394303v4n2p109

Sangiorgio F., Gjoni V., Fiore N., Tarantino D., Basset A. (2017). An international online competition to stimulate student's interest on ecological issues. *SCIentific RESearch and Information Technology*, 7, 35-42. DOI 10.2423/i22394303v7n2p35.

Steenson, S. & Buttriss, J.L. (2020). The challenges of defining a healthy and 'sustainable' diet. *Nutrition Bulletin,* 45, 206-222. doi:10.1111/nbu.12439

Terlau W., Hirsch D. (2015). Sustainable Consumption and the Attitude-Behaviour-Gap Phenomenon-Causes and Measurements towards a Sustainable Development. *International Journal on Food System Dynamics*, 6, 159-174. https://doi.org/10.18461/ijfsd.v6i3.634

Toledo E., Hu F. B., Estruch R., Buil-Cosiales P., Corella D., Salas-Salvadó J., et al. (2013). Effect of the Mediterranean diet on blood pressure in the PREDIMED trial: results from a randomized controlled trial, *BMC Medicine*, 11, 1-9. http://dx.doi.org/10.1186/1741-7015-11-207

Tsivgoulis G., Judd S., Letter A. J., Alexandrov A. V., Howard G., Nahab F., Unverzagt F. W., Moy C., Howard V. J., Kissela B., Wadley V. G. (2013). Adherence to a Mediterranean Diet and Risk of Incident Cognitive Impairment. *Neurologia*, 80, 1684-1692. doi: 10.1212/WNL.0b013e3182904f69

United Nations (1992). Convention on Biological Diversity (CBD). Rio "Earth Summit"

United Nations Sustainable Development (1993). Report of the United Nations Conference of Environment and Development, Rio de Janeiro, 1992. *Vol. I Resolutions adopted by the Conference*. United Nations Division for Sustainable Development. Annex I: Rio Declaration on Environment and Development. Annex II: Agenda 21. ISBN92-l-100498-5

UNESCO (2010) Fifth Session of the Intergovernmental Committee (5.COM) – Nairobi, Kenya, 15 to 19 November 2010

United Nations - UN (2015). Transforming our world: the 2030 Agenda for Sustainable Development. *UN General Assembly*. UNESCO Publisher

United Nations - UN (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables*. Working Paper No. ESA/P/WP/248

Verbeke W., Vanhonacker F., Sioen I., Van Camp J., De Henauw S. (2007). Perceived Importance of sustainability and ethics related to fish: a consumer behavior perspective. *Ambio*, 36(7), 580-585. doi: 10.1579/0044-7447(2007)36[580:piosae]2.0.co;2

Vorley, B. (2018). *Citizen-generated evidence for a more sustainable and healthy food system. Sustainable Diets for All.* (SD4All) project. The Hague and London: Hivos and International Institute for Environment and Development. ISBN: 978-1-78431-560-3

Wang C., Ghadimi P., Lim M.K., Tseng M.L. (2019). A literature review of sustainable consumption and production: A comparative analysis in developed and developing economies. *Journal of Cleaner Production*, 206, 741-754. https://doi.org/10.1016/j.jclepro.2018.09.172

World Commission on Environment and Development - WCED (1987). Our Common Future. *WCDE Report*. Oxford University Press

Authors

Flavia Bartoccioni *(corresponding author)*
Department of History, Culture and Society, Tor Vergata University of Rome, Italy.
flaviabartoccioni@gmail.com

Caterina Lorenzi
Department of History, Culture and Society, Tor Vergata University of Rome, Italy.

Franca Sangiorgio
Department of Biological and Environmental Science and Technologies, University of Salento, Italy.

Funds

This research received no specific grant from any funding agency in the public, commercial, or no-profit sectors.

Competing Interests

The authors hereby state that there are no financial or non-financial competing interests.

Citation

Bartoccioni, F., Lorenzi, C., & Sangiorgio, F. (2023) Sustainable food consumption and Nature conservation processes. Educational considerations. *Visions for Sustainability*, 20, 7419, 567-584. http://dx.doi.org/10.13135/2384-8677/7419

Elisabetta Falchetti
(1948 – 2022)
For the culture of sustainability

Maria Francesca Guida, Cristina Da Milano

Elisabetta Falchetti was a reference point for all those approaching the boundaries of knowledge and relationships between disciplines such as Ecology, Art Sciences, Museology, Education and Neuroscience within a sustainability framework. Her worldview was contagious and stimulated anyone she met along her path to play an active role in her life. With the European Centre for Cultural Organisation and Management (ECCOM), we met precisely on the ground of this common commitment. She was deeply convinced of the need for profound social transformation to promote justice, equity, gender equality, well-being, quality of life and sustainable communities. Her gaze and attention were constantly addressed to local communities, especially those marginalized or discriminated against, to create opportunities for cultural life participation, to encourage creative interaction and exchange. She always supported and felt the need for a new cultural and social museology more focused on the needs of communities. The emerging social museology must reflect on certain social priorities and experiment new strategies to create "contact zones" (Clifford, 1997). The metaphor, which she loved so much and has guided many of our reflections, takes inspiration from systemic structure of living systems. The spaces that in the various structures represent borders and contiguous areas, such as those between cells, organs, populations, biotic communities, ecosystems, guide reflection on the importance of boundaries (Da Milano, Falchetti & Guida, 2019). In those contact zones it is possible to develop constructive relationships between environment and culture, new narratives and visions, social representations. This process can encourage multi-, inter- and trans-cultural approaches.

For Elisabetta Falchetti, Ecology was the science that can integrate narratives and visions that spread systemic thinking. Feudozzo's experience (L'Astorina et al., 2021)[1] represented a moment of reflection on this issue to help build new ethical-social attitudes and horizons (Falchetti & Guida, 2021).

A fundamental element for her was the role that *imagination* plays in the processes of transformation and change. In one of her latest contributions, she said "people's imaginative capacity must be nurtured. In fact, only with a fervent imagination does it become possible to build a sustainable perspective for the future and to identify strategies to pursue it" (Guida & Falchetti, 2021).

She leaves us with many things to reflect on but also with things still to be imagined and told.

References

Clifford J., (1997). *Routes. Travel and translation in the late twentieth century*, Harvard University Press, Mass

Da Milano C., Falchetti E., Guida M.F. (2019). *Intercultural Rehearsals*, Editrice bibliografica, Milano

Falchetti E., Guida M.F. (2021). Mapping steps along a pathway to evaluate an experiential transdisciplinary approach to professional learning for ecological researchers, *Visions for Sustainability*, 16, 5773, 121-140, http://dx.doi.org/10.13135/2384-8677/5773

Guida M.F., Falchetti F. (2021). *Immaginari per il cambiamento, Visioni e pratiche artistiche per Taranto*, Pontecorboli Editore, Firenze

[1] "Cammino of Feudozzo" (CaFe), conceived and carried out within the framework of the Italian Long-Term Ecological Research network (LTER Network), a five-day meeting which constituted a further step in a process of constant research into constructing new ways "to be a researcher" and of communicating ecology by the scientific research community.
For more information https://www.cnr.it/en/event/16451/in-cammino-nel-tempo-dell-ecologia-i-cammini-della-rete-lter

L'Astorina, A., Bergami, C., De Lazzari, A., Falchetti, E. (Eds.). (2021). Special Issue "Scientists moving between narratives towards an ecological vision". *Visions for Sustainability*, 16, 3-142.

Authors

Maria Francesca Guida *(corresponding author)*, guida@eccom.it

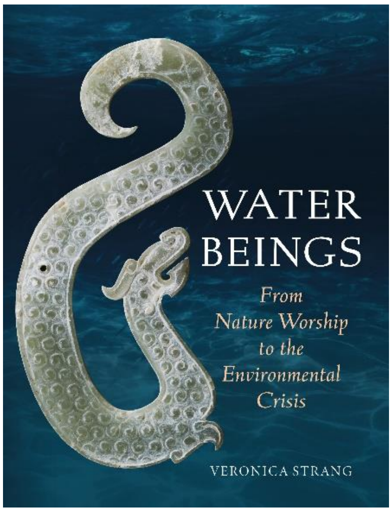
Cristina Da Milano

European Centre for Cultural Organisation and Management – ECCOM, Via Buonarroti, 30, 00185 Roma https://www.eccom.it/en/

Citation

Guida, M.F., Da Milano, C. (2023). Elisabetta Falchetti (1948–2022). For the culture of sustainability. *Visions for Sustainability*, 20, 8882, 585-587.
http://dx.doi.org/10.13135/2384-8677/8882

Veronica Strang
Water Beings:
From Nature Worship to the Environmental Crisis.
Reaktion Books, 2023



Shé Mackenzie Hawke

Serpent gods rose up out of primal seas to create worlds (p. 7).

In the transnational and fluctuating world that we inhabit, water remains a constant, if in flux, complete with its deities and magicians, totems and cycles ever narrating a cosmic story. Strang takes us on an intercultural artistic adventure through the waters of history, iconography, mythology, art, science, geo-politics, and hydrology. To produce a book of this calibre requires complete dedication, rigour, and passion. By her own admission, Strang is obsessed with water, this book is a brilliant outcome of obsession that extends her earlier work in *The Meaning of Water* (2004).

Strang's strenuous efforts to collect and cohere images and text is obvious and worthy of high praise. Her particular interest in water beings such as serpents, that 'swim in the vast aquifer of scholarly material' (p.9) is both anthropologically and archaeologically stunning as well as artistically rewarding. The book is produced on glossy paper with full colour images of artefacts that would certainly not have their full effect in a black and white academic book.

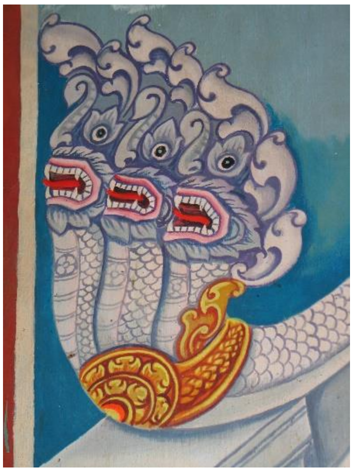
Ceramic tile screen, Behai Park, Beijing 1756
© Veronica Strang

Kungoni Centre, Malawi
© Veronica Strang

The eleven sections of the book are broken up into "Beings", such as, "Original Beings" in chapter two, and "Transformational Beings" in chapter eleven. No "being" is without its worth of space on the page. As a self-defined "waterist", (Hawke 2014), arguably as obsessed with water as Strang, I find the book both extraordinary and necessary, and a call to realise that while water and water beings are ubiquitous, as she narrates in her first chapter "Being Ubiquitous", they are also endangered by climate crises and an evident loss of elemental and reverential consciousness among the humans that dominate the earth. Aside from the rich historical research, the book explains how we have navigated away from a water reverence or understanding towards g/local environmental crises wrought from human industrial will.

Every few pages she takes the reader to a different part of the planet to talk about a particular water theme, deity artefact, admixture, or historical note. For example, in chapter seven "Travelling Beings" she consults ancient Greek philosophers such as Thales (624-546 BCE) who argued that while water was "rain, hail and dew" (p.135), it is transformative when mixed with earth. And Anaximander (610-546 BCE), who imagined an indeterminate element that was the primary form matter from "an all-engulfing sea" (p. 135), the *apeiron.* Cosmic inter-elementality has its place.

The vital message is for a renewed realisation that water is everywhere and can embody "sentience and agency", as well as going about its own sense of work, while simultaneous endangered. Strang draws on several First Nations narratives and creation stories to set forth this argument about water's critical place in our lives, both physically and psychically. The reader moves on a spectrum between worlds from artefacts and images both ancient and new, such as the Plate 27 Mural of Mwali and Thunga at Kungoni Centre, Mua Mission, Malawi (p. 52) and its story, to the narratives of the "Maori water serpent beings" (*taniwha)* that have contributed to legal debates about the water personhood of the *Te Awa Tupua*/Whanganui River (p. 234) in Aotearoa/New Zealand (Marama Muru-Lanning, 2010). This sovereignty was initialised in 2017 with the river being described as sacred and "an important tribal ancestor" (p.234). Similar quests have taken place elsewhere in the world, where First Nations people have argued not only for the right to cultural connection with water bodies and beings, but for the waters' actual ancestral authorship of knowledge, as in the case of "Yoongoorrookoo, an ancestral serpent being" from The Martuwarra Fitzroy River in Australia's Kimberley region.



Temple mural, Ho Chi Minh City, Vietnam © Veronica Strang

Taniwha Devonport 2018, © Veronica Strang

She also notes the confluences and challenges in different world views and their approach to water. Here the preservation, values and life of water are cross referenced, with "indigenous activists, campaigners for social and ecological justice, nature worshipping religious groups, legal activists, and scholars" (p. 237). Sharing aquatic ecosystems with humans and non-humans alike – "a pan-species democracy" (p.239) is fraught with political tension over who speaks for whom and what and where. Advancing the earlier thoughts of Benedict Anderson's *Imagined Communities* (2006) Strang calls for "re-imagined communities, in which the notion of community is extended to include all of the living kinds that a river catchment contains" (P. 238), and for her purposes the mythical water beings that inhabit those spaces.

In chapter eight, "Supreme Beings", Strang presents a critique of how narratives change over time and how "visual representations undergo transformations in form and meaning as belief systems adapt to new social and political realities" (p. 142). Here she unpacks the shift from polytheism to monotheism particularly through the Old Testament (Genesis) to the new Christianity that would see the "Christian God take over all of the responsibilities of [not only] earlier religions" (p. 142) but also all pre-existing water deities. She explains with the detachment of a critical observer that some water traditions and beliefs from old religions and cults, such as Paganism, were conflated with the more modern Christianity to express and endorse new purposes and "theological insights" (p. 142). The later onslaught of science and the Enlightenment Era brought further challenges to water, as industry and its pollutants bent the river to its own purpose.

These are just some examples of where the author takes the reader, emphasising along the way how fluid readership is, and how much of a text, that is, any water course or being, is also broadly understood. In her final comments in the chapter called "Turning the Tide", Strang offers insights into how we adapt, cohere and re-purpose values and beliefs around water and its sustainable future. As she says:

Today, in a world urgently in need of a change of direction, the stories that water serpent beings tell, and their capacities to represent alternative visions of human and non-human relations, may be the most crucial role they have ever had (p. 228).

This interdisciplinary visual story is a wonderous homage to water, and water beings that also calls us to re-imagine and re-embody water and its place in all life.

References

Anderson, B. (2006). *Imagined Communities: Reflections on the origin and Spread of Nationalism*. Verso

Hawke, S. (2014). *Aquamorphia: Falling for Water*. Interactive Publications

Marama Muru-Lanning. (2010). "Tupuna Awa and Te Awa Tupuna: Competing Discourses of the Waikato River". PhD Thesis, University of Auckland

Strang, Veronica (2004) *The Meaning of Water* Routledge