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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.

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Editorial

To see … perchance to understand and act

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

We live in a period of increasingly profound and widespread planetary changes. Climate change is leading to inexorable rises in global average temperature and ever more frequent extreme climate events. Loss of biodiversity is linked to increasing fragmentation and reduction of natural habitats, changes in population distribution and the composition of ecological communities, together with the risk of mass extinctions of species. Health problems related to infectious diseases are appearing or re-appearing with increasing frequency in plants, wild and domesticated animals and humans. War as a seemingly inevitable expression of intraspecific human aggression increasingly leads to ecocidal and genocidal consequences.

These are wicked problems involving multiple intricate causal loops, non-linear processes and diminishing and increasing interactions that require an ability to study interconnections and anticipate developments. The complexity of such a scenario means there is an ever-increasing need for interdisciplinary and transdisciplinary perspectives within the intimate relationship between research and education as intersecting processes of observing, understanding, knowledge building, anticipating and acting.

Despite the fact that the ongoing planetary changes are evident for all those who wish to see and not deny them, to understand and act, governmental and intergovernmental action is still woefully inadequate, as can be seen from the latest "agreement" reached at the recent Cop29. At the same time, the scientific community cannot but continue its efforts to make its voice heard, both in terms of promoting approaches to education and research based on visions for sustainability and the potential they offer for taking action.

Each one of the papers published in this issue of our journal makes a contribution to these efforts. The authors are currently working in university-based research teams in eleven different countries within six different continents, studying a wide range of aspects of the bio-geo-chemical cycles on which all life depends and within which human activities have a massive impact, drawing conclusions that emerge from their work and proposing new directions for policy and research, and also exploring the educational visions necessary for promoting understanding and enabling action for more sustainable human trajectories

Rethinking education

Education plays a fundamental role in achieving learning outcomes capable of impacting on the planetary challenges faced. This requires a constant search for innovative approaches and methodologies that can enhance the validity and efficacy of the efforts of educational institutions from all levels of schooling through to higher education.

In "Ecoliteracy and ecopedagogy for environmental sustainability in education: In support of ecocentric, arts-based management learning", Kopnina et al. argue that conventional management approaches are failing to address the global ecological crisis of climate change, biodiversity loss and species extinction and that here is an urgent need to adopt an ecology-centred (ecocentric) ethic to support management learning. They propose arts-based ecopedagogy as a radical challenge to management learning enabling reorientation towards the praxis necessary to support transformation in learner consciousness and thus influence a future management practice. At the same time, they show how such an approach can be implemented at all age ranges, providing examples that draw upon arts-based education, ecopedagogy and ecoliteracy that focus on biodiversity.

In "Global sustainability challenges and the role of Higher Education Institutions", Wilhelm & Pilatti investigate the relationship between the sustainability performance of countries and the commitment of Higher Education Institutions (HEIs) to the Sustainable Development Goals (SDGs). They argue for the need for HEIs to more robustly integrate the SDGs into their strategies and curricula, promoting an interdisciplinary approach. Theoretically, the study enhances the understanding of the impact of HEIs on global sustainability, suggesting that their role can be maximized through a balanced and collaborative approach.

In "A learning model based on the promotion of sustainable entrepreneurship in higher education", Librado-Gonzalez et al. argue that the teaching of sustainability in higher education often focuses only on the environmental aspects, neglecting the social and economic dimensions. They describe the learning outcomes of an Action Plan which aims to raise awareness and improve students' understanding of the SDGs as environmentally and socially responsible practices.

In "Student perceptions of environmental sustainability. Insights into green campus innovations and geospatial analysis at Universitas Negeri Malang", Putra et al. study how universities are embracing green campus initiatives as a strategic response to the imperative of environmental sustainability. Their results not only reinforce the favourable influence of the university's sustainability endeavours on student perceptions but also delineate potential avenues for policy refinement and practical improvements to augment UM's sustainability trajectory.

In "The aesthetics of recycling as an entry point for innovative artwork related to environmental issues", Fayoumi examines the aesthetics of recycling as an entry point for creating innovative artwork related to environmental issues. The paper explores the relationship between art and the environment, highlighting the importance of environmental protection and sustainable processes. The study also addresses challenges in producing sustainable artwork and innovative methods for transforming old materials into usable ones.

In "Is nature conservation included in the training of teachers and educators? The contribution of the SOFIA educational platform", Lorenzi & Sangiorgio address teacher education in ecological topics, with a special focus on nature, focussing on Italy's national training platform for schools SOFIA. Their findings reveal a notable lack of attention to ecological topics, particularly nature conservation, in programmes and that terms such as "ecosystem", "ecology" and "climate change" are often used in ways that diverge from their ecological roots. They argue that the current polysemic nature of these ecological keywords complicates the identification of courses relevant to ecological topics, particularly in a sector where educational offerings are already limited.

Researching interconnected planetary problems

Research into intertwined problems involving climate change, biodiversity loss and health issues related to the spread of diseases investigates numerous aspects of challenges related to understanding the relative significance of concomitant variables and developing ways of adapting, mitigating and modifying behaviours.

In "Adaptation and mitigation actions for flood management. Application of the analytic hierarchical process in geographic information systems for flood risk assessment", Delgado Moreira & Reyna Bowen study how information can be generated that facilitates decision-making concerning adaptation and mitigation actions related to planning for flood management and assessing the risk of flooding in the Garrapata microbasin, located in Chone, Ecuador, using a multi-criteria analysis based on GIS modelling. They show how this helps build more resilient communities that are better equipped to handle flood-related disasters.

In "Airborne bacteria and fungi in coastal Ecuador: a correlation analysis with meteorological factors", Reyes Garcia & Vivas Saltos present research that starts from the premiss that air quality is of crucial significance for both ecosystem and human health to then assess how meteorological conditions affected the aerobiological concentration in Chone, Manabí, Ecuador. They show that aerobiological concentrations showed a minor influence from meteorological factors while being below allowable bounds.

In "Microplastics on the coasts of San Cristobal, Galapagos: a threat to the archipelago", Basurto Alcívar et al. study the presence and characteristics of microplastics on Mann, Lobos, Puta Carola, and Puerto Chino beaches. Their findings demonstrate the level of microplastic contamination in the Galapagos Islands, underscoring the urgent need for further research and mitigation strategies. They argue that raising public awareness and implementing responsible waste management practices are critical steps towards protecting the delicate Galapagos ecosystem from the detrimental effects of microplastic pollution.

In "The beauty industry, climate change, and biodiversity loss. Can humanity have 'stories of kindness' for an environment-healing culture?", Nguyen et al. look at how global beauty firms need to play a proactive role in directing resources toward the development of sustainable uses of biodiversity and agriculture methods. This includes advocating for the wider use of environmentally conscious sourcing of raw materials, avoiding excessive and wasteful packaging, and devoting resources to research and innovation in environmentally friendly manufacturing procedures.

In "How an age-old photo of little chicks can awaken our conscience for biodiversity conservation and nature protection", Vuong & Nguyen use an artifact was displayed in "Life History of the Amazon Kingfisher" written by Alexander Skutch and published by *The Condor* in 1957 to discuss the humanistic value of nature-related science, art, painting, and literature for humanities in the age of climate and biodiversity loss crisis.

Researching satisfying basic needs and safeguarding ecological sustainability

The current planetary changes and challenges faced all derive, whether directly or indirectly, from *homo sapiens* incapacity to recognise how satisfying basic needs such as shelter and nutrition must be compatible with safeguarding ecological sustainability.

In "Sustainable housing indicators. A statistical review of Indonesia's housing sector", Siahaan et al. present research that aims to contribute to the understanding of sustainable housing in Indonesia by assessing the sustainability index of housing indicators within a comprehensive framework and considering various factors that impact people's quality of life. They argue it is necessary to improve several indicators in each dimension that are not sustainable, such as maintenance and operating costs; safety and security; and waste management.

In "Navigating the policy landscape in Uganda: problem representations and silences towards transitioning to Agroecology as a business", Namanji explores the application of ecological principles to enhance sustainability and resilience in agricultural systems. The aim is to analyse the policy landscape in Uganda that enables or hinders the transition to agroecological practices. The author concludes that it is crucial to take a comprehensive approach to policy planning and implementation that promotes agroecology as a business, while bringing about a more resilient, environmentally friendly, and economically sustainable agricultural sector in Uganda, and recommends a more inclusive policy process.

In "Strategic mapping of food assets to enhance food security and foster circular economy in Semarang City. A sustainability perspective", Tri Martuti et al. study how a city is confronting the challenge of ensuring food security for its populace. They argue that to prevent the displacement of local farmers, the decline of local markets, and to avoid other social issues such as poverty and hunger, it is crucial for Semarang to become food independent. Their study also contributes to addressing broader food issues in Indonesia, particularly in urban settings, by highlighting the significance of strategic planning and resource mapping in achieving sustainable food systems.

In "A multidimensional analysis of food security for sustainable development. Evidence from India", Hiranya & Joshi analyse the question of ensuring access to sufficient and nutritious food as a vital component in attaining sustainable development, especially in developing nations like India. They argue that achieving sustainable development in India requires not just increasing food production but also adopting responsible food consumption practices and optimal use of current resources.

In "To graze or not to graze livestock in public forests. Insights from Mau and Aberdares forest ecosystems in Kenya", Chisika & Yeom discuss how with the growing human needs and the impacts of climate change, there is an emerging forest policy discourse on whether to allow or disallow livestock grazing in public forests. Their study used a case study research design and document content analysis to share comparative insights on the effects of forest grazing in two critical forest ecosystems in Kenya. They argue that a "win-win" arrangement should be developed to enhance the "cut and carry system" for fodder from the two forests to promote livelihoods and socio-economic empowerment.

In "Projections towards 2050: severe impact of conversion to dragon fruit crops (*Hylocereus spp.* And *Selenicereus spp.*) in the xeric forest", Reyna-Bowen & Cevallos Meza study a particular aspect of how global shifts in land usage have many impacts on ecosystem services and biodiversity by assessing the transition from 2016 to 2021 from xeric forest to Dragon fruit (*Hylocereus spp.* And *Selenicereus spp.*) agriculture. Their study shows the detrimental effects of dragon fruit cultivation and the need for quick recovery and preservation actions to lessen the startling reduction in forest cover.

Starting from how climatic variability significantly impacts agricultural sustainability and food security, in "Climatic variability and its impact on coconut production in Rocafuerte canton, Ecuador", Mendoza Ponce et al. study climate variability and its relationship with coconut production in the canton of Strong Rock. Their results show that climatic variability affects coconut production parameters related to flowering and fruiting in the studied areas.

In "Harnessing microbes: a new approach to carbon sequestration in cocoa agroforestry", Alcívar Intriago et al. study the carbon sequestration potential of fungal and bacterial strains in cocoa plantation soils in Ecuador's coastal region using a randomized complete block design. On the basis of the positive results shown, they argue that future research should focus on optimizing microbial dosages and application methods to enhance carbon capture and cocoa productivity.

Underscoring moral responsibilities

Whether as theoretical, research-based visions or narrative visions, sustainability literature can play and important role in underscoring the moral responsibilities that humans have for planetary changes.

In "An elegy for the Great Auk", her review of *The Last of Its Kind: The Search for the Great Auk and the Discovery of Extinction* by Gísli Pálsson (2024) Princeton University Press, Hawke shows how Pálsson aims to alert twenty-first century humanity to how easily extinction can happen, and the effect that extinctions have on the broader web of life, and ultimately sustainability. The book illustrates the impact of the ecocidal practices we have employed in the name of farming, agriculture, recreational hunting and seafaring, and succeeds in achieving a powerful educational and ethical impact.

As we approach the end of 2024, we must recognise that it has probably been the hottest year on record, has certainly continued a dramatic decline in wildlife populations and increase in habitat loss and degradation, has witnessed new emerging communicable disease threats in many parts of the world, and has prolonged or even intensified devastating global conflicts. In the face of this, our intention is that in 2025 our journal will continue to propose ecological interactions between theoretical, research and educational visions for sustainability based on the paramount significance of an intersectional perspective to encompass problems that are both complex and context-dependent, characterised by multiple interrelated factors and outcomes.

Original Paper

Ecoliteracy and ecopedagogy for environmental sustainability in education

In support of ecocentric, arts-based business education

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Keywords: arts-based; biodiversity; ecocentrism; ecoliteracy; ecopedagogy; education for sustainable development (ESDG)

Abstract. *The planet faces a global ecological crisis of climate change, biodiversity loss and species extinction. Conventional management approaches are failing to address this crisis. There is an urgent need to adopt an ecology-centred (ecocentric) ethic to support business education. We interweave positive and critical perspectives to question the pervasive neoliberal logic dominating business education and practice. We argue that* *the education for sustainable development goals embraced by management education, offered as* the *framework for addressing environmental concerns, fails to recognise the limits to industrial growth and remains anthropocentric and bound by economic logic. Instead, we propose arts-based ecopedagogy as a radical challenge to business education enabling reorientation towards the praxis necessary to support transformation in learner consciousness and thus influence a future management practice. We provide practice examples that draw upon arts-based education, ecopedagogy and ecoliteracy focusing on biodiversity. We propose future directions that integrate ecological and human well-being within management curricula.*

1. Introduction: Biodiversity crises and business education

The world is in a period of crisis. This crisis comprises not only the state of "permanent economic emergency" (Zizek, 2010), widening poverty, class, and gender inequality, but a crisis of climate change, biodiversity loss, and species extinction (Nilsen, 2023), which ultimately puts at risk all human systems and planetary boundaries maintaining functional biosphere integrity. Such a state prevails despite the United Nations (UN) Sustainable Development Goals (SDGs), designed two decades ago, to address such concerns. The seventeen SDGs emphasise economic and social aspects of sustainability (e.g., Crane et al., 2008), focusing on the key priorities of poverty, health, education, and inequality while addressing environmental issues in strictly instrumental terms (Westermann et al., 2020). That the planetary crisis prevails is attributable, at least in part, to the tension between SDGs' aims to improve planetary and human welfare and their commitment to economic growth (Adelman**,** 2018; Bonnett, 2007; 2023; 2024) and anthropocentric or utilitarian approach to sustainability (e.g., Adelman, 2018; Kopnina, 2020, 2021; Visseren-Hamakers, 2020). The extent of the ecological crisis within this wider planetary crisis, has been recognised through the adoption of the Kunming-Montreal Global Biodiversity Framework (GBF) developed during the UN Convention on Biological Diversity in December 2022, and revisited during the recent COP16 summit in November 2024 (CBD, 2024). This Framework has formulated an international agreement to protect 30% of ecosystems by 2030 (CBD, 2024; UNEP, n.d.). To achieve this ambition, GBF's Target 15 prescribes that businesses assess and disclose their environmental risks, impacts and dependencies through their operations, supply and value chains, and portfolios (ARUP, n.d.). Yet, while a positive step, necessitating scrutiny of commercial companies' operations (MSCI, 2023), this recent endeavour still fails to address the root causes of ecological degradation and mass extinctions, particularly land conversion for agriculture and industrial development (Dirzo et al., 2022).

According to a joinmt investigation with Carbon Brief (2024) (https://www.cbd.int/conferences/2024), more than 85% of countries reportedly missed the UN's deadline to submit new nature pledges ahead of the Conference of Parties (COP16) at the biodiversity summit held in Colombia between October 21 and November 1, 2024. Only five of the seventeen highly biodiverse countries, that together comprise 70% of the world's biodiversity, have produced new pledges for tackling nature loss (Carbon Brief, 2024). Central in discussions at COP16 was the need for corporate leaders as well as members of civil society, to re-orient themselves towards a new paradigm position, away from the capitalist and anthropocentric narrative of sustainability towards a new ecocentric narrative through education (https://www.cisl.cam.ac.uk/cop16-briefing). As one of the authors of this article is a contributor to The International Union for Conservation of Nature's IUCN Commission on Education and Communication (CEC) and *Guide to Nature-based Leadership: An Ecological Approach,* the need to increase awareness of biodiversity in education is keenly felt. Business and Management Schools (hereafter Business Schools) are positioned centrally in this paradigm shift. The potential impact of Business School education is significant given their links to local businesses and social concerns, as well as having large student numbers. However, the persistent paradigm within these Schools remains focused on capitalist principles and the preservation of the status quo (Gardner et al., 2021). This paper will discuss how Business Schools might though play a significant role in the necessary paradigm shift by adopting learning activities based on ecoliteracy and ecopedagogy. Reorientating our education could, we argue, underscore the increasingly essential role of Business Schools in fostering biodiversity-focused education. By positioning business education as a hub for ecological literacy and ecopedagogy, Business Schools should integrate not only learning about, but also *for*, biodiversity across diverse learning contexts beyond the current education focused on sustainable development informed by Education for Sustainable Development Goals (ESDG).

Education for Sustainable Development Goals (ESDG) still lacks the "technical and scientific expertise" to understand and respond to the "tensions between biodiversity and carbon reduction" (Baudoin et al., 2023, p. 756). This gap concerns the full range of environmental ethics from a management perspective (Starik, 1995; Cunha et al., 2008; Borland & Lindgreen, 2013; Nicolaides, 2017; Allen et al., 2019; Phillips & Reichart, 2000; Sayers et al., 2021; Kortetmäki et al., 2023). That Business Schools have not engaged effectively with concerns of sustainability and biodiversity loss, il illustrated in that from 2000 to 2019 in the journals produced by the Academy of Management, "there are zero articles on species decline and biodiversity". Moreover, of the 50 journals used in the *Financial Times* Research ranking of Business Schools have published only 11 (out of a total of 47,000) such articles have been published (Goodall & Oswald, 2019). The continued lack of discussion of, or engagement with, biodiversity in management journals is apparent after systematic keyword searches ('biodiversity', 'extinction', 'ecosystem').

Few matches for the business, biodiversity, and education nexus could result from selection bias: biodiversity has been a niche topic in business education. Highly rated management and business education journals feature articles that equate sustainability with sustainable development and ESD. Yet, the urgency of addressing environmental problems within business education is increasing, with calls for developing pedagogical approaches to represent non-human stakeholders (Tallberg et al., 2022) and for insights offered by such novel pedagogies as ecopedagogy (Dallyn et al., 2024), and other forms of business education. In contrast to anthropocentric approaches, ecocentrism recognises the intrinsic value of nature (Rolston, 1985) - an element missing in business education.

If we are to counter the pervasive anthropocentrism that puts "human needs and wants… above the survival and development needs of other species" (Borland & Lindgreen, 2013:173), and acknowledge nonhuman stakeholders (Starik, 1995; Allen et al., 2019; Phillips & Reichart, 2000; Kortetmäki et al., 2023), we need to challenge the dominant SDGs (Bonnett, 2007; 2023; 2024; Kopnina, 2012; 2020; 2021; Adelman, 2018; Visseren-Hamakers, 2020) to support the necessary shift in (business) education. In preparing future managers for effective practice, we argue that business education should broaden its scope to ensure that biodiversity and extinction-related investments are foregrounded.

We aim to achieve this by building on a wider range of content and pedagogical approaches in education for sustainability (EfS) within management learning. Accordingly, we assert the importance of replacing the dominant anthropocentric business education underpinned by ESDG (Torpman & Röcklinsberg, 2021; Moratis & Melissen, 2022) with arts-based business education (Cunha et al., 2008) grounded in ecopedagogy (Kahn, 2010) and ecocentric learning (Bonnett, 2023; 2024). In doing so, we acknowledge the challenges of such radical proposals (e.g., Purser, Park & Mountouri, 1995).

Ecopedagogy (Kahn, 2010), which connects the distinct fields of ecology and pedagogy, is an educational approach based on an ecological worldview, encompassing distinctive values of philosophy, ethics, culture, and society (Hung, 2021). In business education, this connection is akin to the term Paul Shrivastava (1995) has coined, that of an ecocentric management paradigm, which integrates a holistic view of the organization in balance with the environment. Philosophically, ecopedagogy focuses on the metaphysical investigation of the human-nature relationship through education, while also acknowledging *ecojustice* including criticism of human supremacism (Baxter, 2005). Ecopedagogy questions the oppressive structures and power systems, employing ecoliteracy (Orr, 1990).

Below, we discuss how an arts-based education can disrupt the tenets of neoliberal capitalist ideology by emphasising the political, critical, and transformative aspects of ecopedagogy. Arts-based teaching is still relatively new in business and management education and provides opportunities for learners to construct meaning through sensemaking (Flamand, Perret & Picq, 2022). In conjunction with an arts-based ecopedagogy, these approaches can challenge the status quo represented by the ESDG.

In what follows, we first evaluate the shortcomings of the prevailing ESDG approach to environmental sustainability through education. We then develop a framework for navigating the radical arts-based strategies that can be employed in business education to recognise non-human stakeholders and address biodiversity loss. This research is aimed at management learners and educators willing to make more deliberate choices about their practice.

2. Methodology

This study employs an interpretive content analysis approach (Ahuvia, 2001), following the methods outlined by Milne and Adler (1999) in the context of environmental disclosures, to examine the occurrence of three main pedagogical approaches – ecopedagogy, eco-literacy and arts-based learning within Business School curricula and within the business education academic literature.

Interpretive content analysis of the business education literature an approach used in studies related to biodiversity and business, for example, biodiversity accounting studies (e.g., Zhao & Atkins, 2021), corporate social responsibility (CSR) managers and biodiversity (Bedarkar et al., 2024), facilitates the identification of patterns and commonalities across organisations and over time (Laine, 2010).

To summarise the key strategies for learning about biodiversity, three researchers independently overviewed the literature on biodiversity, business, and education. Once the reading review was complete, several rounds of closer reading of the texts were carried out, and significant extracts were identified from the literature to form themes. The themes identified from the analysis were classified into several general categories, summarising the educational initiatives for biodiversity conservation within business education.

Our interpretive content analysis, we employed a list of keywords to identify these themes to evaluate the current state of biodiversity learning in Business Schools. Accordingly, we searched literature employing such terms as:

> biodiversity, conservation, preservation, protection, restoration, sustainable use, development, ecosystem, environment, ecology, ecological, environment, species, habitat, wetland, mangrove, forest, marine, coastal area, shrubland, grassland, protected area, park, garden, urban green space, lawn, beach, river, lake, stream, nature reserve, ecological restoration, and ecosystem service.

In our interpretive analysis of educational approaches and strategies, we generated descriptive codes for themes based on these terms. These preliminary codes were then iteratively refined through constant comparison and consolidation of similar codes, adhering to the principles of grounded theory applied in sustainability studies and environmental reporting (Beck et al., 2010; Hahn et al., 2023). By integrating similar codes, the researchers continuously compared new codes with existing codes and categories to determine whether they fit into the existing category structure or whether new categories needed to be created (Gioia, 2021). The themes identified from the analysis were classified to explain the current status of biodiversity within business education. For biodiversity, these categories include, for example, terrestrial and marine species conservation, protection of wetlands and surrounding ecosystems, wildlife and habitat conservation, urban biodiversity, public awareness of biodiversity,

biodiversity assessment, collaboration with stakeholders and local biodiversity custodians, and financial support allocated to biodiversity conservation.

Using these terms, we have searched business school programs (curricula and associated literature) in UK universities to ascertain how business curricula used terms in program names, syllabi, or other descriptions available online concerning biodiversity.

3. Education for Sustainable Development Goals (ESDG)

The literature search indicated that biodiversity and related terms were almost exclusively used in Business Schools concerning SDGs, especially numbers 14 and 15, life on land and under water. ESDG, a UNESCO-led initiative, is perhaps the most influential in supporting management learners across all educational levels to develop the knowledge, skills, and values encompassed in seventeen interconnected SDGs (UNESCO, 2017).

The implementation of SDGs across the business and management education landscape is tracked by a UN initiative the Principles for Responsible Management Education or PRME (n.d.), whose mission is to "transform management education and develop the responsible decision-makers of tomorrow to advance sustainable development. However, ESDGs as instigated by PRME, while propelling a "heightened focus on responsibility in curricula" (Wall et al., 2023:293) across Business Schools may be insufficient to address the current global crisis in biodiversity. As Huckle and Wals (2015) assert, "the majority of those … educational projects and programs [developed] under its [the ESDG] umbrella have failed, through … misplaced idealism, or the censoring of more critical ideas and content, to face up to current global realities" (p.492).

Our literature and curricula review provide evidence that much of the inability of business education to address the current grand global challenges lies in the fundamental limitations of the SDGs themselves. Responsibility to the environment is perceived in terms of distributing environmental risks, such as climate change and pollution, among human groups (Borland & Lindgreen, 2013). Economic growth is explicit in SDG8, and even SDGs 14 and 15, focused on life underwater and life on land, treat biodiversity as a resource and ecosystems as a service. In the policy documents SDGs 1 and 2, on poverty and hunger, are dependent on economic growth, without considering biodiversity costs. Thus, business education, even the critical literature reflecting the ESDGs, remains ultimately focused on growth, still ill-preparing managers to address these global threats despite espousing sustainability and environmental credentials within a PRME guiding framework. The introduction of market devices such as tuition fees, rankings, accreditations, and the focus on employability has positioned Business-Management Schools as "battery farm[s] growing graduates" (Cowden & Singh, 2013, 4; see also Mason et al., 2024). Moreover, evaluations of universities against the SDGs across the areas of teaching, research, stewardship, and engagement in The Times Higher Education Impact Rankings[1] are based upon self-evaluation and thus the robustness of the data might well be questioned. Submission of UK business education to this financial logic has resulted in a focus on the transactional acquisition of knowledge that is perceived to benefit individuals. Business education has therefore become an individualised instrumental experience, and levels of knowledge have become impoverished, merely consumed rather than extended. Such education does little to address the multi-faceted global crises facing us. That this is the case is further compounded by business education remaining largely "disconnected" from the necessary interdisciplinary discussions and know-how to "adequately prepare future managers and decision-makers to solve grand challenges" (Baudoin et al., 2023, p. 754).

Consequentially, the ideal held by sustainability advocates of "equity, justice and the right to life" (Alexander et al., 2022, p.976) is reserved for one species – man (*sic*). Ironically, progress in social and economic areas resulted in increased population and production, adversely impacting the environment (Slater & Hannaford, 2024). Persisting with such anthropocentrism within a key business education framework risks further degradation of our natural world. Addressing the global crises necessitates a transformational shift in the very tenets business education in the pedagogies employed. As previous studies have shown, even the more critical business education and wider business-management literature remains dominated by anthropocentrism, ignoring the nonhuman world, and perpetuating ecological injustice (Baxter, 2005), with CSR practices woefully disconnected from biodiversity (Bedarkar et al 2024). Critical scholars have noted that conventional pedagogies in business schools are oblivious to the planetary crises and are unable to address the wicked and interconnected global sustainability challenges precisely because they remain embedded in conventional paradigms (e.g., Painter-Morland et al., 2017; Adelman, 2018; Kopnina, 2020; Visseren-Hamakers, 2020; Bedarkar et al 2024).

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[1] https://www.timeshighereducation.com/impactrankings

Indeed, while education *for* biodiversity is encouraged (UNESCO, 2022), little reflection is given on *how* to address and arrest environmental decline and biodiversity loss (Greenfield, 2020). We assert the need for business education to employ novel and critical pedagogies that engage learners' emotions (Skilling et al., 2023) through ecopedagogy and ecoliteracy while concurrently, and explicitly, focussing on the current crises. We propose that arts-based learning can address these challenges.

4. Non-human stakeholders in business education

The mainstream growth paradigm needs rethinking. The need for a radical alternative is reflected in the lack of progress towards addressing ecological crises despite an increasing range of research and practice cited in business and management-focused journals, such as *Corporate Social Responsibility and Environmental Management* (e.g., Cunha et al., 2008), *Organization* (e.g., Sage et al., 2016) *Leadership* (e.g., Fotaki & Foroughi, 2022), *Journal of Environmental Management* (e.g., Kopnina et al., 2024a).

These have included the ecocentric organisation paradigm (Purser et al., 1995), ecocentric management (Cunha et al., 2008), ecocentric business (Borland & Lindgreen, 2013; Nicolaides, 2017), animal activism (Tallberg et al., 2022), sustainability leadership (Heizmann & Liu, 2018), and posthuman affirmative business ethics (Sayers et al., 2021). The plea to include nonhuman stakeholders has been made in leading environmental education journals such as *Environmental Education Research* (e.g., Kopnina, 2012; Huckle & Wals, 2015; Russell & Spannring, 2019), *The Journal of Environmental Education* (e.g., Kopnina, 2016; 2020; Warlenius, 2022; Pliushchik et al., 2024), and *Canadian Journal of Environmental Education* (e.g., Oakley et al., 2010).

Management Learning has started to address th**e** need for new, more critical, pedagogical approaches in a 2022 Special Issue (SI) edited by Lavine et al. (2022). This SI proposed meshing positive organisational scholarship and critical management perspectives to question the pervasive managerial and economic logics that dominate business education and practice. It proposed a need for ethics-first, contrarian approaches to engender systemic activism through themes for future directions including the need for a "contrarian" approach to business education and "ethics-first focus" upon both ecological and human well-being to bring about necessary "systemic activism" that recognises the multifaceted and interconnected nature of this global crisis (Lavine et al., 2022). However, this SI did not explicitly consider the biodiversity crisis nor place much emphasis on non-human stakeholders. If we are to counter anthropocentrism, we need to include non-human stakeholders. While publications in *Management Learning* increasingly focus on arts-based teaching, this didactic methodology is used to support and not question ESDG (Flamand, Perret & Picq, 2022; Moratis & Melissen, 2022). To address this, we outline three dimensions of an arts-based ecopedagogy; political, critical and transformative.

5. A political arts-based ecopedagogy

As we have proposed, the dominant management paradigm based on neoclassical economics (Herbrechter, 2023) has failed to address the global grand challenges of species extinction and environmental degradation. There is a need to reorientate business education away from capitalist logic, individualism, and performance-profit above all else (Holmes, 2023). Instead, business education should reconnect us with nature, recognising the inextricable intertwining of man (*sic*) and planet (Heizmann & Liu, 2018; Holmes, 2023; Hansen et al., 2015). To enable this, scholars have cited the need for business education to become more political (Purser et al., 1995; Ergene, Banerjee & Hoffman, 2020). Ecopedagogy recognises the politics that underlie business education and pedagogy (Dallyn et al., 2024; Shannon, 1992). It originates in the recognition that if we are to avoid further environmental and biosystem decline we need to "reconsider the ecological and systemic foundations for sustainability, and to integrate our work more closely with the natural sciences" (Whiteman et al., 2013, p. 307). Ecopedagogy is thus underpinned by principles and values of ecological integrity, recognising the "limits to growth" (Meadows et al., 1972), and promoting well-being for *all* species within the limits of planetary boundaries (Rockström et al., 2010; Whiteman et al., 2013) and planetary thresholds (Nilsen, 2023).

Several diverse ecopedagogical approaches have emerged since The Belgrade Charter on environmental education (UNESCO & UNEP, 1975) that share the ambition to identify the root causes of environmental problems to find workable, constructive solutions (Misiaszek, 2020). However, while ecopedagogy is embedded within some UK business-management curricula, it is mostly employed to address social and economic costs of climate change (for example, at the University of Glasgow[2]), rather than addressing biodiversity loss. Indeed, the business discipline and education still lack the recognition of biodiversity loss as a pivotal environmental issue (Winn & Pogutz, 2013; Kopnina et al., 2024b).

[2] https://www.gla.ac.uk/research/az/sustainablesolutions/courses/ecopedagogyforbeginnersputtingclimatechangeeducationintoaction/

As learners require critical thinking skills to challenge the SDG assumptions, we propose that learners can develop their understanding of biodiversity as part of responsible and ethical business leadership by engaging in arts-based ecopedagogy. In our education practice, the first stage in developing these skills is through ecoliteracy. Ground-breaking publications such as *Should Trees Have Standing* by Christopher Stone (1973), and, building on that, Mark Starik's (1995) *Should trees have managerial standing?* introduce learners to a perspective that is radically different from SDGs.

Reflecting on radical environmentalist films, enacting non-human stakeholders through in-class role plays, and organising class debates about complex topics like decoupling of the economy from natural resources, are other ways to engage learners in questioning the capitalist view of nature as a resource (Kopnina, 2020; Kopnina & Bedford, 2024). In teaching children, however, more comprehensive techniques and concepts can be used. Traditionally engagement with films in class would involve non-fictional documentary films to bring some points regarding biodiversity across. However, utilising a range of fiction as a form of ecopedagogy is well established in children's literature (e.g., Hawley, 2017; Rato, 2024), with a growing application in higher education (e.g., Shoaib, Mubarak & Khan, 2020). This reflects the need for ecopedagogical learning to be continuous and made relevant to concepts studied at each educational level. Through arts-based methods, higher education students can be encouraged to produce their own fiction, such as producing their own children's book that explains the concepts they have learned to a younger audience. This is an extension of our teaching practice in which students welcomed the opportunity to explain the environmental concepts they had learned to children. Through this exercise, students questioned the foundations of their knowledge given that children would not understand the business concepts they typically took for granted.

Another option is for learners to extrapolate their knowledge into a dystopian fictional narrative, play or zine. Zine production is a creative critical pedagogy that has been used in environment-related fields (e.g., Velasco, Faria & Walenta, 2020) and could be adapted to ecopedagogy. With a basis in ecoliteracy, learners can also be encouraged to be more creative in their choice of sources, such as Buckland's (2016) analysis of environmental ethical statements in thrash metal songs to challenge anthropocentrism. In experiential learning, children (and older students) may also be involved in outdoor activities, actively interacting with nature, rather than passively learning from it (Sitka-Sage et al., 2017). Thus, children and learners are encouraged through creative media to extend their current understanding of biodiversity crises.

6. A critical arts-based ecopedagogy

Significantly, ecopedagogy is based upon the Freirean principle of situating learning activities in the life experiences and concerns of learners and educators, shared through dialogue (Freire, 1970; 1973). The "dialectic between reflection and action" results in a "radical rejection of one reality, and action proclaiming a new reality to take its place" (Kuhn, 2004, p.9), ultimately resulting in "transformative action" (Giroux, 1991, p.47). Antunes and Gadotti (2005) discuss several examples of ecopedagogy from the Earth Charter and emphasise the need to educate learners to think about the Earth's identity as essential to the human condition; shape the planetary conscience; and educate for care. As such, ecopedagogy is well-placed to shift business eductaion to social learning related to business and biodiversity (Smith et al., 2020). This encourages a more reflexive and critical approach (Kahn, 2010) and thus has the potential to address the shortcomings of the conventional ESDG. The ecopedagogy approach is especially pertinent for business education because it transcends economy-centred prescriptions raising learners' critical consciousness (McCarthy & Grosser, 2023) to more radical transformative thinking beyond the boundaries of the "sustainable development" rhetoric put forward by the PRME principles. This thinking can enable the move away from sustainability-related outputs that businesses are quite good at delivering, and a move toward sustainability-related outcomes and ultimately impacts (Hahn et al., 2023).

This may be achieved, for example, by using in-class debates and role-plays (Gómez-Poyato et al., 2020; Kopnina, 2020, 2021; Kopnina & Saari, 2021) that challenge learners to embody positions radically different to those inherent in capitalist logic. In our education practice, students participate in the Shell role-play game (Kopnina & Bedford, 2024). This game invites them to decide whether to drill in the Arctic or diversify into renewable energy. The learners adopt various roles, within the executive board, and shareholders, but also involving non-human stakeholders, such as polar bears. In a separate activity, learners critique the SDGs from the perspective of a blue macaw (from the Disney Pixar film *Rio*). Dydynski and Mäekivi (2021) discussed how cartoon animals create expectations for their interactions with humans. Through this exercise, students realise that the first and second SDGs, relieving hunger and poverty, may require the expansion of productive land, with detrimental effects on these birds' habitats, as is evidenced by their endangered status in the Amazon.

Another critical thinking exercise for leraners involves creative physical conceptual maps and applying systems theory to the SDGs (Malcolm, & Skene, 2020). Learners not only link SDGs to a selected company, but to map out potential trade-offs of economic development. For example, if a company focuses on SDG 8, economic growth, how does this reflect on SDG 13, climate change? Such approaches utilise fiction and cultural resources and can provide space for critical thinking about controversial subjects such as corporate investment in family planning, targeting unwanted pregnancies and women's rights as part of the CSR strategy (Nuwasiima et al., 2017). Learners can also consider inequality between species and differences in consumption patterns in different parts of the world or across society (Zulfiquar & Prasad, 2021). The explicit engagement with SDGs and discussions of potential adverse impacts of business activities on biodiversity cultivate a deep-seated consciousness of the extinction crisis. This highlights the learners' roles as future business professionals in disrupting the "business-as-usual" trajectory by considering, for example, degrowth and dematerialisation models that include manufacturing to service shift (e.g., Fix, 2019). In the current economic system, Khmara & Kronenberg, (2018:727) reflect that strategies such as premium pricing may reduce the accessibility of products and thus "degrowth requires new incentives and disincentives to change the behaviours of both producers and consumers". There is an urgent need to study transition pathways to a sustainable degrowth system, but it needs to account for the microeconomic perspective of business management (Khmara & Kronenberg, 2018:727), and the types of thought and practice exercises that learners can participate in within teaching sessions. These exercises all support learners to see beyond the "one solution fits all approach" to CSR (Van Marrewijk, 2003, 96), through the process of socialisation that occurs through interaction at Business Schools that Wall et al. (2023, 293) referred to, "revealing the multiplicities of hidden curricula at play in a given learning environment", in this case, the "unofficial or implicit expectations, values, norms and messages conveyed" through SDGs.

7. A transformative arts-based ecopedagogy

Ecopedagogy can offer tools to operationalise degrowth (Kallis, 2011; Khmara & Kronenberg, 2018; Köves & Bajmócy, 2022), circular economy (Bauwens, 2021; Kopnina, 2021), and steady-state-economy (Daly & Townsend, 1993; Washington & Maloney, 2020). In business education, alternatives to the conventional linear (take, make, waste) production process could be spotlighted by corporate case studies that illustrate the production-to-services shift (Kopnina & Poldner, 2022). The main principles of circularity and the life cycle assessments support learners in influencing their organisations to make informed choices, including the materials needed, manufacturing, delivery, use, and disposal of the by-products, such as packaging. Learners are also made aware that material products such as food and textiles cannot be infinitely reused (Kopnina & Poldner, 2022; Kopnina et al., 2022), and that 'circularity' is limited to preindustrial or innovative designs that can only partially close the loop.

Early educational exposure to ecoliteracy could involve immersive activities, like nature-based learning, hands-on projects, and simulations of ecological systems. As learners advance, this could evolve into case studies, critical discussions, and project-based learning focused on real-world biodiversity challenges, particularly those impacted by business. Integrating these activities from primary school into higher education could nurture eco-conscious perspectives, equipping future leaders with an ingrained appreciation for sustainability and skills to address ecological challenges in the business world.

Significantly, arts-based ecopedagogy as business education should focus on decision-making and action in the present, not at a suitable future time. This is a radical challenge to capitalism's temporal focus on the future that is reproduced through conventional business education. Radical approaches to ecopedagogy will engage learners in physical projects of upcycling. For example, Delacroix's (2023) rug weaving from recycled clothes could be used to prompt a more critical discussion of SDGs. Such activities are pertinent as upcycling has been demonstrated to impact learners' attitudes towards the environment (Flowers, Rauch & Wierzbicki, 2018).

Outside of art-based pedagogies, and well-placed to be combined with them, are some activity ideas for each educational level, tailored to foster ecoliteracy and ecopedagogy include:

Primary School

1. **Nature Walks, Interaction and Keeping Journals**: Students participate in guided nature walks and document observations in journals, focusing on local flora and fauna. This helps build early awareness of biodiversity and ecosystems.
2. **Mini Ecosystem Projects**: Children create simple terrariums or small habitats, observing and learning about plant and animal interdependence.

3. **Storytelling and Art**: Reading nature-focused stories, followed by drawing or creating clay models, lets students express their understanding of biodiversity creatively.

Middle School

1. **Local Ecosystem Mapping**: Students map out the biodiversity in their local area, identifying species, plants, and habitats, and discuss human impacts.
2. **Biodiversity Poster Campaigns**: Creating posters on endangered species or ecosystems encourages students to research and communicate conservation messages.
3. **Eco-Club Initiatives**: Forming an eco-club where students participate in clean-up drives, plant trees, or engage in recycling projects instils a sense of responsibility and action.

High School

1. **Environmental Debate and Case Studies**: Engage students in debates on topics like deforestation, climate change, and biodiversity loss, using case studies to understand complex issues.
2. **Biodiversity Audit**: Conduct an audit of the school's grounds to document species, biodiversity, and waste, followed by discussions on improving ecological practices.
3. **Field Research Projects**: Students collaborate with local conservation groups or national parks to conduct field research, experiencing biodiversity work firsthand.

University and Business School

1. **Corporate Impact Analysis**: Students examine case studies of companies in extractive industries and analyse how their practices affect biodiversity, proposing ecologically sound alternatives.
2. **Sustainability Simulations and Role-Playing**: Using simulations where students take on roles (such as CEO, environmentalist, policymaker) fosters a balanced view on sustainability and business.
3. **Collaborative Projects with NGOs or Local Communities**: Encouraging partnerships to work on real-world biodiversity conservation projects integrates theory with practice and community impact.

Broader arts-based projects could include learner-designs for businesses and communities that support degrowth, engaging students in photographing established degrowth businesses (Pacholok, 2023) and promoting learner involvement in existing social projects and businesses through the curriculum. These projects should encourage learners to take a hands-on approach and get back in touch with nature and the community to engender a deeper understanding of the adverse impacts of capitalism. Building on their experience, learners would then create multi-media depictions of a future utopia and design interventions that could support the achievement of their vision.

8. Conclusions

While the existing literature is not inconsiderable in extent, its focus has been on defining ecopedagogy conceptually through thought pieces or commentaries. Few articles operationalise arts-based ecopedagogy in practice in higher education. While arts-based ecopedagogy is not without its limitations in addressing the urgent global challenges, and certainly within the context of the dominant capitalist-financial logic, it offers practical solutions that can be embedded effectively within business education to address issues of sustainability and biodiversity loss.

Conventional approaches to business education focus on individual knowledge and skill development based largely on contribution to a capitalist profit-focused growth model. Thus, despite the rhetoric of sustainability and responsibility, business education is bound by the economic-growth-driven logic. The ecological impact of these approaches is conventionally examined through the UN SDG and associated ESDG. We have acknowledged the tensions in operationalising the SDGs, recognising their significant limitations, in that learners are not encouraged to think beyond an anthropocentric world and are rarely empowered to think critically about the impacts of their leadership and practices beyond organisational, and certainly human-world boundaries.

Instead, we have proposed arts-based ecopedagogy, grounded in ecopedagogy and political, critical, and transformational learning to address the current biodiversity crisis. Failure to address this crisis places significant human and societal risks. Engaging with arts-based ecopedagogy in a flipped learning environment allows learners to adopt different positions to those of the capitalist logic supporting learners to question the status quo through taking non-human perspectives on issues, allowing us to "disrupt unjust and unsustainable divides that other us from one another and the rest of Nature" (Misiaszek et al. 2022, p.

620). In the spirit of Freire (1970, 1973), we assert that there is a need to support learners to develop not only 'critical consciousness' but also to work actively, and collectively to transform reality to see and understand the potential for collective impact that could lead to real change in future management practice where the environment is front and foremost.

However, we recognise that de-centring dominant ways of knowing and being can have the opposite effect than intended. For critical pedagogies to be effective, pedagogical spaces need to be understood by business education and educators, not places in which knowledge is gifted to others who lack this for them to bank it (Freire, 1970), but as safe spaces in which multiple pieces of knowledge can be shared. A resultant collective co-construction and co-creation of new knowledge will transform management thinking and being. This necessitates a significantly changed understanding of, and approach to, learning and indeed away from what is typically measured and accredited.

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Original Paper

Global sustainability challenges and the role of Higher Education Institutions

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Keywords: sustainability; Higher Education Institutions; Sustainable Development Goals; education; global targets.

Abstract. *This study investigates the relationship between the sustainability performance of countries and the commitment of Higher Education Institutions (HEIs) to the Sustainable Development Goals (SDGs). Using data from the Times Higher Education Impact Rankings (THE-IR) from 2020 to 2023 and the Global Sustainable Development Reports (GSDRs) from 2019 and 2023, the analysis encompasses HEIs from 114 countries. The* *methodology combined documentary and quantitative analysis to examine the impact of HEIs' commitment to the SDGs on the sustainability performance of countries. Results show a growing commitment to SDG 4 (Quality Education), SDG 3 (Good Health and Well-being), and SDG 8 (Decent Work and Economic Growth). At the same time, long-term goals such as climate change and biodiversity conservation receive less attention. Africa, Latin America, and Caribbean regions show progress and regressions, indicating ongoing disparities and challenges. Practical implications include the need for HEIs to more robustly integrate the SDGs into their strategies and curricula, promoting an interdisciplinary approach. Theoretically, the study enhances the understanding of the impact of HEIs on global sustainability, suggesting that their role can be maximized through a balanced and collaborative approach. Limitations include the short period of analysis and data variability. Future research should explore the regional impacts of HEIs and collaborative approaches to overcome barriers in implementing the SDGs.*

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1. Introduction

The climate emergency, over-exploitation of natural resources, global public health issues, and increasing inequality, both between and within countries, are recurring themes that have long demanded a significant and extensive transformation in how these challenges are addressed to ensure a sustainable future for humanity (GUNi, 2022).

Despite the various ongoing actions, the world is facing unprecedented challenges in the three dimensions of sustainability, exacerbated by the aftermath of three years of a global pandemic and multiple conflicts that exacerbate food insecurity and economic difficulties, as well as the dangerous temperature rise that is triggering extreme weather events and causing unprecedented biodiversity loss (Murray et al., 2023; Calvin et al., 2023). Contrary to global expectations, the prevalence of practices prioritizing political and economic interests over the transition toward sustainability has made challenging scenarios extremely complex (Dodman et al., 2023).

The latest Global Sustainable Development Report (GSDR), published by the United Nations in 2023, highlights the urgency of addressing significant sustainability challenges in sectors such as energy, food, and transport, emphasizing the need to promote large-scale practical implementation with emerging innovations, as well as the engagement of multiple stakeholders involved in more comprehensive system transformations (Dodman et al., 2023; Sachs et al., 2023).

Halfway to the end of the implementation period of the 2030 Agenda, all Sustainable Development Goals (SDGs) are seriously off track (Sachs et al., 2023). This scenario underscores the urgent need for transformation in established models, as well as the importance of learning from the lessons of this failure to ensure that future commitments are more effective (Dodman et al., 2023; Leal Filho et al., 2019a; Leal Filho et al., 2019b). Admitting the failure of the 2030 Agenda should not be seen as an end but as an inflection point that reinforces the need to do things differently. The lessons learned from this process are crucial for reformulating strategies that can effectively fulfill global commitments in future agendas (Weiland et al., 2021).

Among the main actors and agents of transformation, Higher Education Institutions (HEIs) stand out for their role in shaping individuals, producing knowledge, and preparing change agents for sustainability (El-Jardali et al., 2018; GUNi, 2022). The importance of education in the fate of humanity has never been more fundamental than now (GUNi, 2022), and HEIs can encourage innovative research, promote interdisciplinarity and critical thinking, and establish strategic partnerships with public and private sectors to apply solutions in real contexts (Bautista-Puig et al., 2022; UiB, 2020). Despite limitations, HEIs have the responsibility and opportunity to lead the implementation of new approaches and practices that ensure the achievement of the SDGs in future agendas. If fully realized, this potential can transform HEIs into key catalysts for advancing the global sustainability agenda.

The relevance of the topic and the commitments of HEIs to sustainability have driven the inclusion of Sustainable Development (SD) in their strategic agendas (Blasco et al., 2020). The role of HEIs in society and in preparing future generations of leaders has made stakeholders more attentive and demanding concrete results. This new positioning has intensified the scrutiny of HEIs' results concerning their commitments to sustainable development (Burmann et al., 2021; Hazelkorn, 2018), increasing the need for clear metrics and highlighting the role of rankings as classifiers and comparators.

The progress of the SDGs by the signatory nations of the 2030 Agenda is monitored through the quadrennial publication of the GSDR. The actions related to SD in HEIs have been evaluated by various global and regional rankings. Since 2019, the Times Higher Education Rankings (THE), a recognized global ranking assessing the quality of HEIs, has incorporated a specific ranking to measure the sustainability of HEIs, the Times Higher Education Impact Rankings (THE-IR) (THE-IR, 2023). This ranking is the only one that individually classifies HEIs based on their commitment to the SDGs.

This study aims to investigate the relationship between the sustainability performance of countries and the commitment of HEIs to the SDGs. The analysis will be based on the THE-IR from 2020 to 2023 and the GSDRs from 2019 and 2023. This study hypothesizes that countries with high levels of sustainability have HEIs that are more engaged and effective in implementing the SDGs.

The justification for this study is based on the urgent need to improve established models to meet sustainability demands, highlighting the role of HEIs in this process. Although the period analyzed by the THE-IR covers only four years and the GSDR data presents two temporal points (constructed over two blocks of four years), this analysis offers a current view of the influences of HEIs on the sustainability performances of countries. The methodology adopted is a mixed approach, which analyses documentary and qualitative data from the THE-IR from 2020 to 2023 and the results of the GSDRs from 2019 and 2023.

The analysis contextualizes the contributions of HEIs to the advancement of the SDGs. It explores the factors influencing these performances, offering an understanding of the dynamics between the actions of HEIs and the sustainability outcomes in their respective countries. The results highlight the impact of HEIs on the global sustainability agenda, especially in light of the challenges amplified by the recent pandemic and economic and climatic crises. This study emphasizes the strategic importance of HEIs in promoting sustainable practices and shaping future leaders committed to global sustainability.

2. The role of Higher Education Institutions in the 2030 Agenda

Established in 2015 by the UN General Assembly, the SDGs form the core of the 2030 Agenda. With 17 goals and 169 targets, this agenda guides the global development strategy until 2030, encompassing economic, social, and environmental aspects (UN, 2015; Rohrich & Takahashi, 2019). While they expand on the themes of the Millennium Development Goals (MDGs) and Rio+ Sustainable Development (SD), the SDGs require changes in governance strategies (Breuer et al., 2019; Kanie et al., 2019).

The 2030 Agenda underscores the interdependence of the SDGs (UN, 2015; Weiland et al., 2021), whose effective implementation requires policy coherence at vertical and horizontal levels, with the participation of non-state actors (Breuer et al., 2019). Challenges such as the complexity of monitoring indicators, the absence of methods to quantify some indicators, and the lack of a model to address synergies and trade-offs have led to the neglect of these synergies and trade-offs (Breuer et al., 2019; Renaud et al., 2022). Synergies occur when progress in one goal benefits others, while trade-offs arise when one goal hinders others (Breuer et al., 2019; Pradhan et al., 2017).

The need to address synergies and manage trade-offs intensifies due to complex political and economic dynamics (Kanie et al., 2017; Weiland et al., 2021). Analyses of synergies and trade-offs are essential for understanding how to implement SD strategies without compromising environmental and social goals (Pradhan et al., 2017; Renaud et al., 2022). Biocentric views, which value the integrity of all living beings, promote more ethical and inclusive SD (Keitsch, 2018; Spahn, 2018). The transition to biocentric principles implies recognizing all life forms' interdependence and ecosystem health's importance (Dodman et al., 2023).

The urgency of developing approaches that balance human needs with the protection of biodiversity and natural resources is pressing (O'Neill et al., 2018; Wackernagel et al., 2017). According to the 2030 Agenda, this could be the first generation to eradicate poverty and the last to have the chance to save the planet (UN, 2015, p.12). However, global inequalities, reflected in disparities in resources, wealth, and technology between developed and developing countries, amplify the challenges of meeting basic needs, exacerbate ecological damage, and hinder SD. These inequalities affect access to advanced technologies, robust infrastructure, and effective governance, impacting countries' SDG achievement (Renaud et al., 2022). While developed countries progress in goals like Clean Energy (SDG 7) and Quality Education (SDG 4), less developed nations face a lack of basic infrastructure and socioeconomic disparities, hindering progress in SDGs such as 3 (Good Health and Well-being) and 1 (No Poverty) (Weiland et al., 2021).

To implement the SDGs inclusively and equitably, international cooperation must support developing countries through technology transfer, adequate financing, and strengthening local capacities. This path, though promising, remains underexplored (Kanie et al., 2019). Policies addressing internal inequalities must ensure that all population segments have access to opportunities to contribute to and benefit from SD (Mejía-Manzano et al., 2023).

Improvements in resource efficiency, although urgent, are insufficient for sustainability in industrialized countries due to high consumption levels (Skobelev, 2021). It is necessary to consider a development model incorporating technological improvements, behavioral changes, and policies promoting reduced resource consumption (Eisenmenger et al., 2020).

Pursuing long-term sustainability requires evaluating the economic growth paradigm and prioritizing GDP over environmental health and social well-being (Eisenmenger et al., 2020). This model conflicts with the planet's ecological limits and does not reflect the interdependence between economic prosperity, social equity, and environmental integrity (O'Neill et al., 2018). The transition to a low-carbon and inclusive economy is imperative to align with the SDGs, challenging the continuous growth paradigm in favor of "prosperity without growth" (Kanie et al., 2017).

Ensuring adequate financial resources requires innovation in financing, public-private partnerships, and international cooperation (Schmitt et al., 2019; Weiland et al., 2021). Among the recommended possibilities, results-based financing, linking payments to the achievement of SDG targets, encourages efficiency and effectiveness (Mejía-Manzano et al., 2023); green bonds and social impact bonds mobilize private capital for sustainable investments, providing financial returns and environmental and social benefits (Leal Filho et al., 2021). Additionally, policies that directly address inequalities are necessary to ensure equitable access to SD (Renaud et al., 2022).

Amid uncertainties, the SDGs represent achievable targets and a call to action to rethink global development deeply. The choices made today will determine whether this generation will be remembered as one that bravely addressed the shortcomings and contradictions of the SDGs or as one that failed to seize the last chance to save the planet and ensure a sustainable and equitable future for all.

HEIs have an immediate and transversal role in implementing the SDGs, facing significant effectiveness and structural commitment challenges. Since the Talloires Declaration of 1990, HEIs have been recognized as centers for promoting sustainability through education, research, and sustainable practices (Gaitán-Angulo et al., 2022; Leal Filho et al., 2022). Despite efforts during the Decade of Education for Sustainable Development (2005-2014) and the Global Action Programme for ESD (2014-2019), promoted by UNESCO, the integration of SD principles into HEI curricula and administration globally remains uneven and insufficient, facing numerous challenges to achieving effective and comprehensive implementation (Leal Filho, 2018).

HEIs are responsible for training professionals and change agents committed to SD, leading research, innovation, and education of leaders engaged in this theme (Lozano et al., 2015). However, sustainability policies, curriculum updates, and green infrastructure often need more systematic engagement to promote fundamental changes toward the SDGs (De La Poza et al., 2021). Criticisms point to the superficiality of integrating the SDGs into curricula and the theoretical nature of research that rarely translates into practical or political impact (Mejía-Manzano et al., 2023). The lack of adequate organizational structures and investment in SD capacity building are significant barriers (Alghamdi et al., 2017).

To address these challenges, HEIs must increase engagement with applied research, form strategic partnerships, and adopt a pedagogical approach that empowers students as change agents (Leal Filho et al., 2018). Essential measures include incorporating sustainability into strategies and curricula, developing institutional capacities, mobilizing financial resources, and promoting a sustainable culture in all activities (Mejía-Manzano et al., 2023). Collaborative approaches, such as public-private partnerships, can contribute to financing, knowledge, technology, and innovation for SDG implementation (El-Jardali et al., 2018). By integrating the concepts of the Quadruple and Quintuple Helix, HEIs can promote multisectoral collaboration that enhances innovation and sustainability (Carayannis & Campbell, 2021).

Despite having a crucial role in promoting the SDGs, HEIs must face significant challenges to increase their effectiveness. There needs to be a more robust and structured commitment to ensuring that sustainability practices result in concrete practical and political changes. Promoting a culture of sustainability, developing institutional capacities, and mobilizing financial resources are fundamental to the long-term success of global SD strategies (Leal Filho et al., 2021). So far, HEIs have failed more than succeeded, and with substantial change, their efforts will continue to be sufficient to achieve a truly sustainable future.

3. Method

This study adopts a mixed-methods approach, combining documentary and quantitative methods with a longitudinal design, to investigate the relationship between countries' sustainability performance and the commitment of Higher Education Institutions (HEIs) to the SDGs. The research encompasses the analysis of THE-IR results from 2020 to 2023, verifying whether HEIs exert a positive and significant influence on the sustainability performance of the countries where they are located, as reported in the 2019 and 2023 GSDRs. Documentary analysis enabled extracting relevant data from rankings and reports, while quantitative analysis utilized statistical techniques to calculate means and standard deviations and identify trends and variations in SDG performance.

3.1 Criteria for identifying data sources data

Sources were meticulously selected based on their relevance and credibility in the context of sustainability assessment. The following primary sources were used:

a) Times Higher Education Impact Rankings (THE-IR): This global ranking evaluates the contributions of Higher Education Institutions (HEIs) to the SDGs using a variety of quantitative and qualitative indicators. Collected data include academic publications, institutional policies, collaborations, and the direct social impact of HEI activities. THE-IR's methodology is based on a combination of bibliometric and institutional policy metrics, allowing for a comprehensive and multidimensional assessment (THE-IR, 2023). Besides the mandatory SDG17, institutions are evaluated on the three SDGs in which they scored the highest.

b) Global Sustainable Development Reports (GSDRs) are quadrennial UN publications that assess global progress towards the SDGs, identifying trends, best practices, synergies, and challenges. The 2019 and 2023 reports provided a comprehensive view of trends, best practices, synergies, and challenges in SDG implementation (Sachs et al., 2023).

3.2 Data Collection Methods

Data collection was carried out in two main stages, ensuring the comprehensiveness and accuracy of the data used in the analysis:

THE-IR Data Collection: SDG results from 1 to 16 were extracted for all HEIs listed in the 2020 to 2023 rankings. Collected information included academic publications, institutional policies, collaborations, and the direct social impact of HEI activities. GSDR Data Collection: SDG assessments from 2019 and 2023 were extracted for the 114 countries included in the study.

The GSDR regional classification was used to group countries into regions with similar cultural, economic, and social characteristics, facilitating contextualized and detailed analysis. The GSDR regional classification includes Oceania, Eastern Europe and Central Asia, East Asia and South Asia, Latin America and the Caribbean (LAC), the Middle East and North Africa (MENA), Sub-Saharan Africa, and the Organisation for Economic Co-operation and Development (OECD).

3.3 Data processing and analysis

The collected data were meticulously processed and analyzed to ensure the results' integrity and relevance.

3.3.1 Data processing

Duplicates and inconsistencies in the collected data were eliminated, ensuring the accuracy of subsequent analyses. Means and standard deviations were then calculated to determine the percentage of HEIs that scored in each SDG, providing a clear view of trends and variations in SDG performance.

3.3.2 Quantitative analysis

Using robust statistical software, advanced statistical techniques were applied to identify trends and variations in SDG performance. The 2019 and 2023 GSDR SDG results were compared, assessing progress or regression in each region and identifying significant percentage variations highlighting regional dynamics.

3.3.3 Qualitative analysis

Secondary information was collected from the web pages of HEIs highlighted in the THE-IR ranking, supplemented by academic publications, case studies, and institutional reports, in addition to integrating HEI initiatives and projects related to the SDGs, providing a holistic view of HEIs' contributions to sustainability.

3.4 Data interpretation

Data interpretation focused on demonstrating the significance of the results and the innovative contribution of this study to the global scientific community:

3.4.1 Significance of results

Identification of the SDGs most highly scored by HEIs, through detailed analysis of their implications for global sustainability, highlights areas of significant impact, and identifies critical gaps.

Assessment of regional variations in SDG performance, highlighting specific challenges and progress achieved in different geographic and socio-economic contexts.

3.4.2 Contribution to the scientific community

Broadening the understanding of the impact of HEIs on Global Sustainability, suggesting that their role can be maximized through a balanced and collaborative approach involving multiple stakeholders.

Identification of Priority Areas for Future Research: Particularly in relation to the lowest-scored SDGs, proposing strategic directions to increase the effectiveness of HEIs in promoting global sustainable development.

4. Results and Discussion

Between 2020 and 2023, the THE-IR recorded the participation of HEIs from 114 countries, demonstrating significant global engagement in the context of the SDGs. HEIs were scored on three SDGs of their choice and SDG 17, mandatory for all. The analysis of the score distribution allows the identification of which SDGs received the most attention and effort from the participating institutions, reflecting their priorities and areas of potential more significant impact on global sustainability. Table 1 presents the average distribution of scores obtained by HEIs for each SDG during the analyzed period.

The results reveal different levels of attention dedicated to the goals. Among the most highly scored SDGs, with 12.81%, 12.62%, and 11.09%, are SDGs 4, 3, and 8, respectively. These SDGs are directly linked to the primary mission of HEIs in teaching, research, and community engagement. The high score in SDG 4 reflects the commitment of HEIs to quality education. The prominence of SDG 3 is due to the presence of health related HEIs, which positively impact communities. SDG 8 reflects the role of HEIs in promoting economic development and professional training. Prioritizing health, education, and economic growth improves the quality of life and promotes socioeconomic development, attracting funding and partnerships that facilitate the implementation of these projects.

Table 1. Distribution of scores by SDG from 2020 to 2023

Sustainable Development Goals (SDGs)	Average
1. Eradication of Poverty	5.63%
2. Zero Hunger and Sustainable Agriculture	3.19%
3. Health and wellness	12.62%
4. Quality education	12.81%
5. Gender equality	9.27%
6. Clean water and sanitation	3.08%
7. Clean and Affordable Energy	6.23%
8. Decent Work and Economic Growth	11.09%
9. Industry, Innovation and Infrastructure	6.59%
10. Reducing Inequalities	4.83%
11. Sustainable Cities and Communities	6.19%
12. Responsible Consumption and Production	4.52%
13. Action Against Global Climate Change	2.76%
14. Life in the Water	1.45%
15. Earth Life	2.06%
16. Peace, Justice, and Effective Institutions	7.68%

Source: Adapted from THE-IR (2020, 2021, 2022, 2023).

The SDGs that received moderate attention, ranging from 6.19% to 9.27%, include SDGs 5, 7, 9, 16, and 11. These goals reflect areas where HEIs have expertise and established resources. The availability of financial and human resources influences the capacity of HEIs to engage in these SDGs actively. The complexity of some goals requires interdisciplinary approaches, which are only possible with robust support structures.

The least scored SDGs, ranging from 1.45% to 5.63%, include SDGs 1, 2, 10, 12, 13, 14, and 15. These goals face more significant challenges and require more resources and expertise, making prioritization difficult for many HEIs. The complexity and global scope of these SDGs also contribute to less attention, as addressing issues such as poverty eradication and climate change requires multifaceted solutions beyond the typical reach of HEIs.

HEIs tend to prioritize goals with immediate and visible impact on local communities. In contrast, SDGs related to poverty, hunger, climate change, and biodiversity are perceived as global challenges with less tangible short-term benefits. Funding and partnerships for these areas face obstacles, as funders and partners prefer areas with direct and measurable impact, such as health and education (El-Jardali et al., 2018). Success in sectors like education and health is more easily quantifiable and communicable, while the impacts of SDGs related to environmental and social sustainability are more diffuse and long-term.

The analysis reveals that HEIs strongly focus on areas directly linked to their primary mission and have an immediate and measurable impact on local communities, such as education and health. However, it is imperative to intensify efforts and resources in more challenging and long-term global goals, such as climate change and biodiversity preservation. Striving for a more effective balance in addressing various SDGs can enhance the contribution of HEIs to promoting sustainability on a global scale.

Considering that SDG 4, directly interconnected with the other SDGs, highlights quality education as central to empowering society to face economic, social, and environmental challenges (Weiland et al., 2021), the results of SDG 4 in the GSDR of 2019 and 2023 were compared for the countries whose HEIs participated in the THE-IR. The results, by region, are presented in Table 2.

Table 2. Comparison between SDG4 results in SGDR 2019 and 2023

SGDR Regions	Average		Standard deviation		Percentage Change
	2019	2023	2019	2023	
Africa	2.67	2.67	0.58	1.15	0.0%
LAC	3.33	3.67	0.58	1.15	10.0%
East and South Asia	3.00	3.00	NaN	NaN	0.0%
Eastern Europe and Central Asia	3.33	3.00	1.15	1.00	-10%
MENA	4.00	4.00	0.00	1.41	0.0%
OECD	3.33	3.67	1.00	0.71	10.0%

Source: Adapted from United Nations (2019, 2023).

In Africa, the average performance in SDG 4 remained constant from 2019 to 2023, while the standard deviation increased from 0.58 to 1.15, indicating greater inequality among the countries. Although the average remained the same, there was a more excellent dispersion in the data in 2023, reflecting increased variation in educational performance among the countries in the region. This disparity results from the unequal distribution of educational resources and political instability in various regions. Gaitán-Angulo et al. (2022) highlight that inadequate funding for HEIs limits the expansion of effective educational programs.

In LAC, the average performance in SDG 4 increased from 3.33 to 3.67, but the standard deviation also grew, indicating uneven improvements. Some HEIs promote social inclusion and expand access to higher education, improving average indicators (De La Poza et al., 2021). However, economic instability in countries such as Venezuela and Brazil hampers education funding (Parr, 2022; Pradhan et al., 2017). In East and South Asia, the average of 3.00 remained unchanged from 2019 to 2023. The absence of a standard deviation (NaN) is due to uniform and insufficient data to calculate dispersion, preventing the calculation of variation and suggesting stability and possible stagnation in educational progress.

In Eastern Europe and Central Asia, the average fell from 3.33 to 3.00, a variation of -10%, while the standard deviation decreased from 1.15 to 1.00. Malinovskiy and Shibanova (2023) state that the post-Soviet economic transition still affects the allocation of educational resources, prioritizing traditional economic areas over educational innovation. The average remained stable at 4.00 in the MENA region, but the standard deviation increased from 0.00 to 1.41, indicating a growing disparity. Conflicts in countries like Syria and Libya harm education, while the UAE maintains high standards with proactive policies and significant investments (Alkhaldi et al., 2023).

In the OECD region, the average increased from 3.33 to 3.67, a variation of 10%, while the standard deviation fell from 1.00 to 0.71, indicating less dispersion. Authors such as Galleli et al. (2022) and Bautista-Puig et al. (2022) warn that the pressure to maintain high standards can increase inequality between elite HEIs and others. Long-term policies, consistent investments, and a stable political context have allowed OECD HEIs to improve the quality of education.

The analysis reveals that some regions maintained stability in average scores while others showed significant variations, reflecting different SDG progress and challenges. The variations in SDG 4 between countries and within the same regions highlight global inequalities in access to and quality of education. HEIs focus on areas like education and health but need to increase efforts on complex and long-term global goals, such as climate change and biodiversity conservation. A better balance among the SDGs can maximize the impact of HEIs in promoting global sustainability.

Each region faces challenges and achievements regarding the SDGs, reflecting the complexity and diversity of global socioeconomic and environmental conditions. This highlights how far humanity is from achieving a sustainable balance that "leaves no one behind." While Table 2 illustrates the variation in

SDG 4 results between 2019 and 2023, evidencing both progress and setbacks in different regions, Table 3, located in the Appendix A, provides a comparison of the results of the other SDGs for the countries whose HEIs participated in the THE-IR, offering a comprehensive view of the changes in SDG performance over the analyzed years.

The results in Table 3 show a mixed performance in Africa regarding the SDGs, with increases of 16.67% in SDGs 2 (Zero Hunger) and 7 (Affordable and Clean Energy), reflecting improvements in agricultural and energy policies. Recent studies indicate increased agricultural productivity and access to renewable energy (Li et al., 2024; Rehman et al., 2024). Conversely, there were regressions in SDGs 14 (Life Below Water) with a 28.57% decrease and 15 (Life on Land) with a 10% decrease, indicating challenges in environmental conservation. Stability in SDGs 3 (Good Health and Well-being), 5 (Gender Equality), and 6 (Clean Water and Sanitation) suggest that while conditions have not worsened, the improvements are insufficient for robust, sustainable development. Studies highlight the need for more effective policies and targeted investments to boost progress in these sectors (Blanco-Portela et al., 2017; Breuer et al., 2019; De La Poza et al., 2021).

Eastern Europe and Central Asia showed mixed performance. Reduced inequalities (SDG 10) improved by 83.33%, attributed to income redistribution policies, investments in education and health, and a favorable geopolitical context (Breuer et al., 2019). SDGs 1 (No Poverty), 2 (Zero Hunger), 5 (Gender Equality), and 13 (Climate Action) also showed significant improvements. However, SDG 15 (Life on Land) fell by 33.33%, highlighting challenges in environmental conservation due to intensive industrial practices (Li et al., 2020). SDGs 9 (Industry, Innovation, and Infrastructure) and 7 (Affordable and Clean Energy) also regressed, indicating the need for more effective policies and technological innovation. Stability in SDGs 3 (Good Health and Well-being) and 6 (Clean Water and Sanitation) suggests that while policies maintain current levels, innovation is needed for further advancements.

East and South Asia excelled in SDG 13 (Climate Action) with a 25% increase, reflecting effective environmental policies. SDGs 2 (Zero Hunger) and 11 (Sustainable Cities and Communities) also recorded significant improvements, evidencing social progress. In contrast, the region had a 75% decline in reduced inequalities (SDG 10), indicating increasing socioeconomic disparities. This decline underscores the need for more inclusive policies. SDG 15 (Life on Land) also regressed significantly, highlighting challenges in environmental conservation and sustainable resource management. Stability in SDGs 3 (Good

Health and Well-being) and 5 (Gender Equality) suggests maintenance of current conditions without progress. Weiland et al. (2021) emphasize the importance of consistent public policies to avoid regression in critical socioeconomic indicators.

LAC experienced significant regressions in Life Below Water (SDG 14) and Life on Land (SDG 15), with decreases of 37.50% and 30%, respectively, revealing ongoing problems in environmental conservation. In contrast, there was stability in Peace, Justice, and Strong Institutions (SDG 16) and progress in Responsible Consumption and Production (SDG 12), with an 11.11% increase. Stability in Good Health and Well-being (SDG 3) and Gender Equality (SDG 5) indicate maintenance of current conditions without significant advances. Zapata-Cantu & González (2021) point out that economic instability in countries like Venezuela and Brazil affects the necessary investments for environmental conservation and sustainable development. SDGs 1, 7, 9, and 10 also regressed, highlighting the need for more integrated strategies to address these challenges.

In the MENA region, SDGs 14 (Life Below Water) and 15 (Life on Land) saw decreases of 42.86% and 33.33%, respectively, due to severe environmental challenges such as poor waste management and pollution. Stability in SDG 12 (Responsible Consumption and Production) indicates the need for more effective sustainability actions. On the other hand, SDGs 5 and 3 improved, showing the effectiveness of social policies. SDGs 1 (No Poverty), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation, and Infrastructure), 10 (Reduced Inequalities), and 11 (Sustainable Cities and Communities) also advanced. However, SDGs 7 (Affordable and Clean Energy) and 16 (Peace, Justice, and Strong Institutions) regressed. The 25% decline in SDG 7 reflects difficulties transitioning to clean energy, crucial for sustainable development, while the reduction in SDG 16 highlights governance and political stability issues. Structural reforms are necessary to promote transparency, strengthen institutions, and ensure equitable resource access. Weiland et al. (2021) highlight that investments in civic education and civil society participation are essential for inclusive and resilient governance, advancing the sustainable development agenda, and contributing to more just, transparent, and participative societies.

OECD countries demonstrated stability in most SDGs, with some areas of regression. There were declines in SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) by 5% and 4.76%, respectively, reflecting persistent challenges in sustainable development. Significant regressions occurred in SDGs 3 (Good Health and Well-being), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 8 (Decent Work and Economic Growth), and 15 (Life on Land). These setbacks highlight the need to strengthen policies and investments in public health, water infrastructure, clean energy, and environmental preservation. Despite its economic and technological advantages, this region remains one of the most polluting, failing to present itself as a sustainable model (Wolf et al., 2022). SDG 5 (Gender Equality) improved by 25.93%, reflecting efforts in equity policies. Innovation and Infrastructure (SDG 9) slightly improved by 8%. Sustainable Cities and Communities (SDG 11) and Life Below Water (SDG 14) also improved, with increases of 3.13% and 9.52%, respectively.

In light of regional analyses and variations in SDG performance, it is evident that the 2030 Agenda represented a significant advance in global sustainability discussions, establishing the SDGs as a central framework for action. However, despite the progress, the integrated and collaborative implementation of the goals still needs to be improved. The excessive emphasis on economic growth (SDG 8) often undermines the essence of sustainability, neglecting social justice and environmental preservation. Rebalancing efforts to promote more equitable and resilient systems harmoniously with planetary boundaries is imperative.

The strategic pyramid of the SDGs (Figure 1), based on the environmental goals SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land), reflects the interdependence between ecosystem health and the success of the other goals. However, these SDGs are often neglected, both by HEIs and other stakeholders.

The social and economic goals, structured at intermediate levels of the pyramid, also require an approach that values the synergies and interdependencies between them. Effective implementation of the SDGs must be adaptive and contextually relevant, integrating local complexities with the global vision of sustainability.

Global collaboration, highlighted by SDG 17 (Partnerships for the Goals), is essential to overcome sustainability challenges. HEIs, by promoting partnerships and collaborative research, play a vital role in the transition to sustainable development. Addressing the contradictions and complexities of sustainable development requires a holistic and integrated approach, where SDG 17 can turn utopia into reality.

Therefore, HEIs and other stakeholders must strengthen their efforts across all SDGs, especially those linked to social justice and environmental preservation, to ensure a lasting positive impact on a global scale. Promoting sustainable development requires a careful balance between environmental, social, and economic dimensions, strongly emphasizing collaboration and innovation.

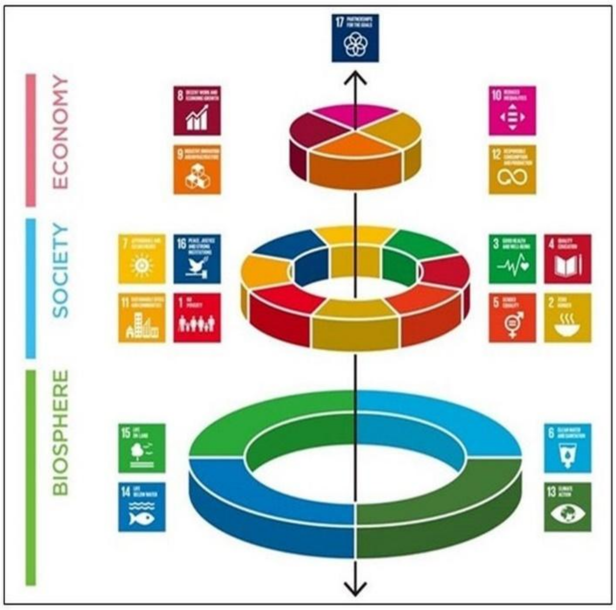

Figure 1. Strategic pyramid of the Sustainable Development Goals.
Source: Rockström & Sukhdev (2016).

5. Conclusions

This study has highlighted the significant role of Higher Education Institutions (HEIs) in promoting global sustainability, particularly in the context of the Sustainable Development Goals (SDGs). Through data analysis, it was observed that among HEIs in the 114 countries participating in the THE Impact Rankings (THE-IR), SDGs 4 (Quality Education), 3 (Good Health and Well-being), and 8 (Decent Work and Economic Growth) are the most highly scored, indicating that HEIs are intensely engaged in areas directly linked to their primary mission. However, more complex and long-term global objectives, such as climate change and biodiversity conservation, have received less attention. This proximity to and distance from different SDGs underscores the need for a better balance among the various SDGs to maximize the impact of HEIs in promoting sustainability.

Regions exhibit progress and setbacks, with varying levels of attention dedicated to the SDGs. While some regions maintain stability, others display significant variations, reflecting different levels of progress and challenges. The findings indicate a growing commitment of HEIs to the SDGs across various regions but also highlight ongoing inequalities and challenges. Regions such as Africa and Latin America and the Caribbean (LAC) have shown progress and regressions in various SDGs, indicating disparities and ongoing challenges in implementing sustainable policies. Conversely, the OECD exhibited slight stability in most SDGs, though with some areas of regression that require more robust policies and sustainable investments.

The results of this study suggest that the hypothesis that countries with high levels of sustainability have more engaged and effective HEIs in implementing the SDGs was partially confirmed. A positive correlation was observed in some regions between the sustainability performance of countries and the commitment of HEIs to the SDGs. However, this relationship is not uniform across all regions, suggesting that other factors may significantly influence the engagement and effectiveness of universities in implementing the SDGs.

Despite efforts, the necessary transformation to address global challenges remains distant. Promoting sustainable development requires a careful balance among environmental, social, and economic dimensions, strongly emphasizing collaboration and innovation. HEIs can become essential catalysts for achieving a sustainable future through strategic partnerships and integrated approaches.

Changes in development paradigms demand new knowledge and skills that HEIs can provide. However, they must also reinvent themselves to lead this transformation effectively, adopting innovative leadership, rethinking their actions, and broadly integrating capacity-building for sustainable development into their curricula, promoting research and practical engagement. This will strengthen the role of the IES in training professionals capable of reconfiguring the human presence on the planet, contributing to a more sustainable and equitable future.

This study is limited by the relatively short analysis period and the variability in available data, which may restrict the generalization of the results. Additionally, the intrinsic complexity of the SDGs and regional disparities complicate the formulation of universal conclusions. Future research should focus on studies that analyze the impact of HEIs by region and explore interdisciplinary and collaborative approaches involving multiple stakeholders. Further investigation is necessary to better understand the barriers and facilitators to implementing the SDGs across different regions.

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Original Paper

A learning model based on the promotion of sustainable entrepreneurship in higher education

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Abstract. *The teaching of sustainability has become increasingly important in higher education. However, some approaches focus only on the environmental aspects, neglecting the social and economic dimensions. The* *aim of this paper is to describe the learning outcomes of an Action Plan, which aims to raise awareness and improve students' understanding of the SDGs as environmentally and socially responsible practices. We conducted a qualitative analysis of the Challenge-Based Model methodology with more than 1,000 university students in Mexico. Using a modern methodology that immerses students in real-life scenarios, significant results were achieved on SDGs related to the environment (SDG 13), clean water and sanitation (SDG 6), ocean conservation (SDG 14), and affordable and clean energy (SDG 7). The aim is to empower and guide university youth to become catalysts for change in their communities. Participation has led to significant progress in promoting sustainability among young students. Those who participated in the Earth Day Rally and the Sustainable Entrepreneurship and SDG Bootcamp events expressed that these experiences helped them develop entrepreneurial skills, participatory and transformative leadership, creativity, initiative, communication and teamwork. In addition, 63% said they had improved their critical thinking skills by tackling challenges in teams. To effectively address the challenges of the future, it is important to fund enriching experiences for young people. These experiences can broaden their horizons and inspire them to imagine and create a more promising and sustainable future. It also encourages their commitment to the SDGs and green entrepreneurship.*

1. Introduction

In recent years, there has been considerable interest in teaching sustainability and sustainable development to younger generations. Since the establishment of the United Nations 2030 Agenda in 2015, building on initiatives such as Agenda 21 and the Millennium Development Goals, many Member States have included specific targets in their policies to mitigate social deprivation and environmental impacts on vulnerable populations (UN, 2015). This context has direct implications for higher education, where young people play a crucial role in knowledge transfer and advocacy for sustainable practices in the environmental, social and economic spheres. Transferring knowledge to younger generations increases their awareness of global issues and encourages the development of creative and innovative solutions involving the community (CEPAL, 2020). In addition, promoting good practices in sustainability can influence young people's individual choices and catalyse community action to address global challenges that disproportionately affect marginalised populations or those living in high-risk environments.

To address this issue, it is important to understand the vision of sustainability and sustainable, two approaches often used synonymously to describe sustainable development (Kopnina and Blewitt, 2014; Ruggerio, 2021). First, sustainability is based on the integration of environmental, social, economic and now institutional dimensions (Holmberg, 1992; Reed, 1997; Harris, Wise, Gallagher and Goodwin, 2001; Barbier and Burgess, 2017). Throughout history, the United Nations (UN) has played a leading role in promoting the achievement of the 169 goals of the 2030 Agenda. This leadership can be traced back to the 1987 Brundtland Commission, which defined sustainability as an approach that seeks to "meet the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 2018). In this sense, sustainability has been popularised as a development model that emphasises the efficient and sustainable use of resources. The second approach focuses on sustainable and aims to create scenarios of best practices, especially those that benefit the environment. The primary objective is to prevent the depletion of natural resources. This allows a more precise definition of the level of sustainability impact by setting specific targets as a reference (Holmberg and Sandbrook, 1992).

An integrative and inclusive perspective, it is important to adopt good institutional practices oriented towards sustainable development. In this context, higher education could implement innovative approaches, such as Challenge-Based Learning, to effectively transfer knowledge. This strategy would take advantage of creative and practical educational programs focused on sustainability and climate change, preparing the younger generation in a multidisciplinary way to face the challenges of their environment. In this sense, this document adopts the sustainability approach as the root of a learning and change-building process. Therefore, in order to promote it through this Action Plan, economic, social and environmental scenarios will be included to achieve a more multidisciplinary understanding. In this way, sustainability is intertwined with sustainable in terms of adopting best practices when proposing solutions to global issues.

However, three main challenges exist in promoting sustainability among university youth. Firstly, there's a need to understand the limits of the sustainability concept and the role of higher education (Shriberg, 2002; Thomas, 2004). Secondly, there's the perspective of both academics and the university community, which often confines sustainable development to the realm of environmental sciences (Reid and Petocz, 2005). This narrow focus can hinder a multidisciplinary approach that recognizes the interactions among people (Thomas, 2004). Thirdly, there's the challenge of adapting university curricula to current contexts, including critical perspectives on the use of non-sustainable resources across various disciplines to enrich students' education (Sibbel, 2009; Leal Filho, 2017). Many educational programs at the university level employ limited strategies to complement sustainability and circular economy education in the classroom. This highlights the need for knowledge transfer models adapted to the current context of the younger generation, where a participatory role and youth leadership would help to find concrete solutions to global issues.

In this sense, the Action Plan addressed in this document seeks to contribute to the above-mentioned challenges: Firstly, because it promotes sustainability in an inclusive way and for all, understanding the limits and the crucial role of people; secondly, because it makes it possible to displace the idea that the adoption of sustainable approaches is exclusively the domain of environmental sciences, since knowledge about sustainability is multidisciplinary and can be adopted in all actions at individual and institutional levels; thirdly, because concrete actions such as the Earth Day rallies and the Sustainable Entrepreneurship Bootcamp, based on a Challenge-Based Learning (CBL) model, can drive institutional change, pushing curricula to include a sustainability agenda in their curriculum map.

Following this argument, the aim of this paper is to analyse the extent to which the Challenge-Based Learning model promotes the understanding of sustainability among young university students. This strategy is in line with the Good Environmental Practices promoted by the Faculty of Economics and International Relations through the UABC-Yunus Centre of the Autonomous University of Baja California (UABC) in Tijuana, Mexico, which aims to promote institutional change towards more sustainable practices among students, academics and administrators, in line with UNESCO recommendations (2023).

The paper outlines a strategy involving concrete actions, such as SDG Bootcamp and rallies, designed to annually engage university students in the path towards sustainability, with a particular focus on entrepreneurship for social impact and the achievement of the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda. These actions aim to bolster the empowerment and leadership of university youth in addressing climate change and sustainability issues, intending to cultivate them into change agents within their communities.

Prior research indicates that science education on overarching topics like the environment has the potential to empower individuals to make more informed choices (Jenkins, 2003). By equipping young people with specific knowledge, they can develop confidence in articulating and defending their perspectives within society. This process contributes to the acquisition of cognitive skills, motivational patterns and personal values. An empowered individual feels capable of realizing their goals and integrating cognitive resources with affective ones, fostering a sense of agency in effecting change in the world. This agency extends from personal lifestyle choices to influencing democratic decision-making processes (Schreiner, Henriksen and Kirkeby-Hansen, 2005).

In this context, the paper is composed of the following sections: the second section discusses a theoretical review on sustainable development and the Challenge-Based Learning teaching model; the third section explores the proposed model and describes the method used for the analysis; the fourth section analyses the results, and the last section concludes with final comments and recommendations.

2. Sustainable development background

In the early decades of the United Nations (UN), environmental issues were a limited part of the international agenda. The UN focused its strategies on ensuring that developing countries managed their resources appropriately. However, in the 1970s, events emerged that raised concerns about global environmental security. These events included oil spills, such as the one that occurred in the Bay of Campeche in Mexico, where 140 million gallons of oil were spilled (Baii, Guillén and Abreu, 2017). These incidents demonstrated the need to address and analyse the environment and its degradation, becoming issues on the global agenda.

More recently, the UN has shown a strong commitment to defending the environment and has consolidated itself as a driver of sustainable development worldwide. In 1972, the United Nations Conference on the Human Environment addressed the role of economic development and environmental degradation. As a result of this event, the United Nations Environment Programme (UNEP) was established.

Throughout the 1980s, member countries continued to negotiate environmental issues, including treaties to protect the ozone layer and control toxic waste shipments. However, in 1983, the United Nations General Assembly created the World Commission on Environment and Development to ensure the economic well-being of present and future generations and to protect the world's natural resources.

In this context, the Commission presented the concept of sustainable development to the General Assembly in 1987 as an alternative to development based solely on economic growth. After learning from the experience and evidence of the impact of conventional economic growth on human development, the General Assembly convened the United Nations Conference on Environment and Development, known as the "Earth Summit", in Rio of Janeiro in 1992.

This strategy linked the scope of sustainable development to critical dimensions such as human rights, population, social development, and human settlements. The United Nations defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This approach aims to build an inclusive, sustainable, and resilient future for people and the planet (United Nations, 2018).

The fundamental milestone in the promotion of sustainable development can be found at the 1992 Earth Summit, where governments adopted Agenda 2030, a comprehensive global action plan addressing all aspects of sustainable development. These initiatives have been reflected in subsequent events, such as the 2002 World Summit on Sustainable Development and the 2012 United Nations Conference on Sustainable Development.

Following a series of actions in 2002, the document "The Future We Want" contained a set of voluntary commitments to help member countries achieve concrete results in the area of sustainable development and proposed the idea of developing a set of goals to achieve development. These precedents materialized at the United Nations Millennium Summit in 2000, where the Millennium Development Goals (MDGs) were adopted. The MDGs served as a roadmap for collective action to reduce poverty and improve the lives of the poorest people. Significant progress was made in reducing poverty, with a direct impact on the 21 targets set out in eight goals.

This scenario paved the way for the adoption of the 2030 Agenda for Sustainable Development in September 2015. This agenda aims to follow up on the MDGs and achieve sustainable development in its economic, social, and environmental dimensions (UN, 2015). The 2030 Agenda consists of 17 Sustainable Development Goals (SDGs) that are cross-cutting and can be addressed by developed, developing, or middle-income countries. The SDGs are made up of 169 targets and 230 indicators, which guide the sustainable future of economies.

The perspective of the 2030 Agenda is inclusive and comprehensive, with the intention of benefiting all people and stakeholders at the global, national and local levels. The guiding philosophy of the 2030 Agenda is based on human rights, where all people have the right to access the resources necessary to realize their full potential. However, despite the commitments made by Member States, many actions have gaps and limited implementation, especially with regard to access to information in middle-income countries such as Mexico.

In this context, establishing learning pathways with human rights focus in a multidisciplinary way can stimulate the participation of future generations in the 2030 Agenda for Sustainable Development. Given the need to transfer and democratize knowledge, higher education becomes crucial to achieve concrete results in promoting sustainability and sustainable entrepreneurship. Therefore, the inclusion of alternative and/or complementary pathways to traditional learning is required to promote sustainable development and entrepreneurship in the student community. This implies the use of different methodologies that allow the development of an inclusive learning guide.

While traditional learning serves its purpose, it can also have limitations in promoting sustainable development for a number of reasons. Firstly, its focus on static content, often centred on the memorisation of facts and concepts, tends to neglect critical skills such as problem solving, systemic thinking and informed decision making (Shapiro, 2015). Second, traditional education often lacks a connection to real-life situations. More effective learning could include practical applications and real-world contexts to make teaching and learning more relevant and effective (Selby and Kagawa, 2016). Finally, traditional education often takes place in an isolated academic environment, which limits the connection with the local community, a crucial aspect for understanding and addressing sustainability issues (Richardson and Kweku, 2011).

Addressing these limitations will contribute to the goals defined by UNESCO (2023) for higher education institutions, whose main purpose is to educate future leaders by providing them with skills and knowledge to contribute to society. Furthermore, it is essential to integrate sustainable values and attitudes into education in order to promote more conscious and responsible development (UNESCO, 2014).

Taking these into account will enable the 2030 Agenda to address the major challenges it faces. Although there has been progress and positive results in some economies, the data show that many goals have not made significant progress. This situation cannot be overlooked, as a combination of factors, such as the impact of wars in some countries and the effects of the global climate change has significantly hindered progress towards the SDGs, especially in the most disadvantaged economies.

According to the United Nations, more than half of the 140 targets set to achieve the Sustainable Development Goals are still far from being realized. Furthermore, over 30% of these targets have shown little recent progress, as reported in the Sustainable Development Goals Report (2023). Globally, the primary concern revolves around the effects of climate change (Climate Watch, 2022; EPA, 2021).

In this context, the Action Plan addressed in this document focuses on the selection of a group of Sustainable Development Goals related to the planet (SDGs 6, 7, 11, 12, 13, 14 and 15), with the aim of raising awareness among young generations about the various changes in our environment and promoting sustainability from a multidisciplinary approach and from the perspective of higher education institutions. To this end, the use of a learning model on sustainability and community intervention among young generations is proposed, which could be replicated in other universities to advance the 2030 Agenda through the adoption of good practices and collaborative work.

2. Methodology

To promote sustainability among university students, the Action Plan employs a methodology informed by the lessons learned from two major programs: the Research, Assistance, and Teaching Program for Micro and Small Enterprises (PIADMYPE), which raises awareness among young people to support entrepreneurs in vulnerable situations, i.e., those living in contexts of inequality and poverty; and secondly, the five stages of learning that students experience during their education on sustainability. Although the two main pillars of this Action Plan are the aforementioned ones, this document summarizes the second pillar and outlines specific actions for phases 2 and 3, described below:

2.1 The UABC-PIADMYPE model to promote sustainability in higher education

Conscious of the social and economic environment at the local and national levels, the UABC has distinguished itself over the last two decades for its work in community outreach and social responsibility (Mungaray-Lagarda, 2002). This achievement has been realized through the implementation and structuring of educational learning models, driven by initiatives led by academics and students to support micro-enterprises (Mungaray, Ramírez-Urquidy, Texis, Ledezma and Ramírez, 2008).

This journey began with the Research, Assistance and Teaching Program for Micro and Small Enterprises (PIADMYPE), created in 1999 as a professional social service project. In this program, students assist disadvantaged entrepreneurs and microenterprises. It has received funding from various sources, including the Ford Foundation, the Organization of American States (OAS), the National Association of Universities and Institutes of Higher Education in Mexico (ANUIES), and the Mexican Federal Government through the Ministry of Public Education (SEP), the National Council of Science and Technology (CONACYT), and the National Fund for Social Enterprises (Mungaray-Lagarda, Osorio-Novela and Ramírez-Angulo, 2022).

The primary objective of PIADMYPE was to promote the growth of microenterprises and entrepreneurship with a social and low value-added approach, using the assistance and training provided by university students engaged in social services. The PIADMYPE project began with these objectives: (1) to develop a hands-on teaching model for students of economics and related fields through service; (2) to provide free on-site business services to social microenterprises in high-poverty areas; (3) to study microenterprise development through the action research model to strengthen undergraduate programs in economics and related fields.

In 2006, inspired by PIADMYPE's action research approach and with the aim of strengthening collaboration with the microenterprise sector in a more institutional manner, the program was formalized as the Centre for Research, Assistance, and Teaching of Micro and Small Enterprises (CIADMYPE). In 2009, amidst the global economic crisis of late 2008, a partnership was established with the state government of Baja California, through the Secretariat of Economic Development, and with the federal government, through the Business Support Program known as Fondo PYME. The CIADMYPE methodology was adopted as the basis for a countercyclical public policy aimed at mitigating the effects of the crisis, particularly the massive layoffs in the maquiladoras, which, in their efforts to remain competitive, neglected their labour and social obligations (Mungaray-Lagarda et al., 2022).

With this evolution, two main objectives were established: (1) the creation of a public policy to promote the development of microenterprises; and (2) the use of the experience of the PIADMYPE project and the collaboration of university professors and students. In addition, (3) the implementation of project-based learning programs that allow students to apply their skills in formalizing and linking social enterprises with funding sources, integrating them as linkage projects in the academic structure of UABC.

In 2017, CIADMYPE became the UABC-Yunus Centre for Social Business and Wellbeing, with the aim of promoting social responsibility among students through the development of community intervention skills, inspired by the principles of Muhammad Yunus, winner of the 2006 Nobel Peace Prize. The centre's main goals are to create innovative models of service learning and to address poverty and inequality by promoting social enterprise and collaboration. From 1999 to 2023, the program has supported 13,241 microenterprises and involved 1,922 students in operational activities, contributing to their education and promoting their participation in social sustainable entrepreneurship.

Since the creation of the UABC-Yunus Centre, specific goals have been set, indicating that the PYADMYPE action research methodology will continue to guide student learning and knowledge transfer to more vulnerable populations. In this sense, with the aim of being more inclusive and aligned with the global agenda to reduce inequalities, UABC-Yunus has adopted the United Nations 2030 Agenda approach as of 2021 and joined the international Ashoka network to promote social innovation, entrepreneurship, and the training of change agents. This commitment is crucial because, through university education, students will continue to contribute to the transfer of knowledge to diverse populations, supporting entrepreneurs and serving microenterprises with a focus on sustainability and the adoption of best practices, which will help advance the Sustainable Development Goals and mitigate the effects of climate change.

In this context, following the PIADMYPE model of teaching-learning of UABC students, Figure 1 shows the UABC-Yunus intervention methodology. This program represents an educational approach that promotes students' professional development, experience, and sustainable entrepreneurial skills.

This teaching model is complemented by intervention methods in university students that encourage learning and the creation of quick solutions, such as Challenge-Based Learning (CBL). CBL is considered a multidisciplinary method that allows students to learn about the Sustainable Development Goals related to the care of the environment, ecosystems, and underwater life through innovation and creativity. It uses knowledge in an interdisciplinary way to generate learning in higher education, promoting transversal skills, knowledge, and collaboration (Gallagher and Savage, 2020).

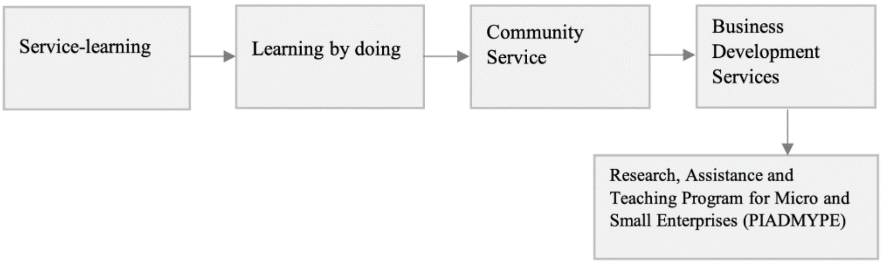

Figure 1. UABC-Yunus Centre Intervention Methodology. Source: Own elaboration

This challenge-based methodology provides real-world scenarios where students can apply the knowledge, they have acquired throughout their academic education to solve global challenges. It also fosters the development of cognitive, critical, and professional skills as students tackle real-world problems and collaborate with key stakeholders (Apple, 2010). The use of problem-based learning formats can lead to student-centred educational innovations, especially when teaching topics related to sustainability and the circular economy (Cörvers et al., 2016; Rodríguez-Chueca et al., 2020; Steinemann, 2003).

In this context, to strengthen learning through the PIADMYPE methodology and Challenge-Based Learning (CBL), students can collaborate with social enterprises, business entities, government representatives, members of academia and civil society, where they apply their knowledge in practice. Problem-based learning allows them to combine their professional skills and competencies while addressing and proposing solutions to various challenging situations.

2.2. Learning about sustainability entrepreneurship in university students

The Sustainability Learning Methodology is based on the premise that young people are essential for sustainable development (UNECE, 2022), a mandate reinforced by the creation of the 2030 Agenda for Sustainable Development. To this end, the Faculty of Economics and International Relations (FEYRI) of the Autonomous University of Baja California (UABC), through the UABC-Yunus

Center for Social Business and Wellbeing, launched a program in 2022 to promote environmental awareness among university students, focusing on topics such as the environment, water resources and the importance of the oceans. This sustainability approach is guided by the 2030 Agenda, which is based on the United Nations Sustainable Development Goals (SDGs), the common goals that humanity has chosen for itself with the agreement of all UN member states (UNESCO, 2023).

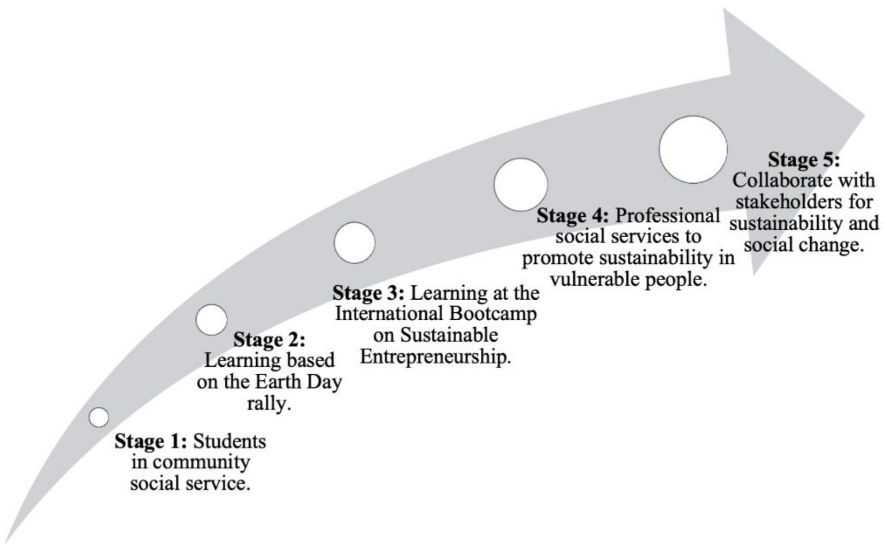

Figure 2. Steps to promote learning about sustainability and Sustainable Entrepreneurship. Source: Own elaboration.

FEYRI and the UABC-Yunus Centre strive to encourage active participation in sustainability learning and Sustainable Entrepreneurship in young people. To achieve this, five stages of learning about sustainable development have been delineated, allowing students to tailor their learning journey to their individual needs, profiles, and interests.

Stage 1. This learning stage targets students in their first to fourth semesters at the university. Students participate in a community service program named

"Sustainable Fibonacci", where they collaborate in teams (five student range) to address issues in their local environment using the Sustainable Development Goals framework. The primary objective of this initial phase is to identify opportunities for establishing Sustainable Entrepreneurship that promote social change.

Stage 2. Involves annual participation in an Earth Day rally on April 22nd, a global initiative to raise awareness about the importance of conserving natural resources. The event includes recreational and educational activities designed to promote the 2030 Agenda, with a particular focus on the Sustainable Development Goals (SDGs) related to the environment: climate action (SDG 13), clean water and sanitation (SDG 6), ocean conservation (SDG 14), and affordable and clean energy (SDG 7). Participation in this stage is open to students from different schools and disciplines, encouraging the formation of multidisciplinary teams. The event aims to help students recognize sustainable practices for environmental stewardship and provide specific information to support green entrepreneurship efforts.

Stage 3. During this phase, students have the opportunity to participate in an International SDG Bootcamp on Sustainable Entrepreneurship and the 2030 Agenda. Held annually during the summer, students collaborate in multidisciplinary teams to address real-world social challenges through sustainable entrepreneurial approaches. The bootcamp employs rigorous methodologies guided by mentors, who may include professors, international or national experts, social leaders, entrepreneurs, government officials and academics.

In particular, in this third stage, the program offers students the opportunity to test their knowledge in a multidisciplinary event, with the intention of strengthening dialogue and fostering participatory youth leadership. This is achieved by participating in an international bootcamp, where they learn about the Sustainable Development Goals (SDGs) of the 2030 Agenda and seek to respond to their implementation through sustainable ventures that encompass social, economic and environmental aspects.

This bootcamp is an initiative of FEYRI and is held annually; it brings together UABC students from various areas of knowledge, including undergraduate and engineering degrees, from the three UABC campuses: Ensenada, Tijuana and Mexicali in Baja California, Mexico. Participating faculties include the Faculty of Marine Sciences of Ensenada, the Faculty of Economics and International Relations of Tijuana, the Faculty of Engineering and Business of Guadalupe

Victoria, the Faculty of Engineering, Administrative and Social Sciences of Tecate, the Faculty of Enology and Gastronomy of Ensenada, the Faculty of Engineering and Business of San Quintin, and the Faculty of Engineering, Architecture, and Design of Ensenada.

During this process, students are fully involved and work in multidisciplinary teams. They are presented with real problems related to their community in the economic, social and environmental fields. Over the course of five days, students develop ideas for sustainable entrepreneurship and put what they have learned into practice. This process is guided by mentors, including professors from the participating faculties and/or invited national and international experts, who support the students in building their knowledge.

Stage 4. Students can carry out their professional social service to put into practice the skills developed in the previous stages, as described in Osorio-Novela, Mungaray-Lagarda and Ramírez-Angulo (2022). However, even if students have not participated in any of the stages described above, the programmes offered will provide them with training on the themes aligned with the Sustainable Development Goals, as transversal learning is promoted in all stages. In this phase of professional development, only students who have completed 60% of their credits, i.e., from the fifth to the seventh semester, are assigned to this phase.

Stage 5**.** In this learning block, students who wish to deepen their understanding of sustainable development can connect with the UABC-Yunus Centre for Social Business and Wellbeing. Similarly, students can collaborate with organisations outside the university, such as civil society organisations and government bodies, enabling them to develop their own projects. The Challenge-Based Learning (CBL) methodology is applied at all stages of the course, allowing students to engage with real-life contexts. The focus of this methodology is to use students' knowledge as one of the means to generate understanding in higher education (see Figure 3).

The five phases for learning sustainability and the PIADMYPE model, implemented through CBL, have yielded significant results among university students as they apply creativity, initiative, participatory leadership, and the execution of their projects to address real challenges in both local and national contexts. This combination of models and methodologies represents a novel educational approach, integrating traditional learning modules with real-life challenges and promoting innovative solutions that are applied in various areas (Vilalta-Perdomo et al., 2022). Moreover, students continue to show interest and active participation in understanding the UN 2030 Agenda, seeking to contribute actively, particularly to the goals related to climate action (SDG 13), clean water and sanitation (SDG 6), life below water (SDG 14), and affordable and clean energy (SDG 7)

2.3 Method

The aim of this research is to analyse how the Challenge-Based Learning (CBL) model helps young university students to understand sustainability. Using qualitative analysis, focus groups in the form of workshops and conversations were conducted with participants, and their initial learning was assessed through a survey. Following the two learning pillars mentioned above (PIADMYPE and the five-step sustainability pathway), CBL is implemented in stages 2 and 3, with annual events where students discuss concrete challenges. During these phases, real-life scenarios are created, and students experience them for five days, culminating in a pitch to an expert jury (composed of entrepreneurs, businesspeople, academics, government representatives, etc.). The interaction and development of the proposals are carried out by multidisciplinary teams, integrating fields such as exact sciences, social sciences, health sciences, environmental sciences, and administrative sciences.

Figure 3 illustrates the process of the method as implemented in the Action Plan. In stages 2 and 3, students experience the CBL methodology in teams, and then the learning is evaluated. This benefits students by allowing them to openly identify the challenge to be addressed and propose solutions to concrete societal problems (Gaskins, Johnson, Maltbie, and Kukreti, 2015).

In stages 2 and 3, students work in teams, guided by mentors (teachers, students, researchers, activists, entrepreneurs) from different fields. They are provided with information through workshops, lectures, or conferences to develop their entrepreneurial skills, teamwork, and collaboration. This allows them to engage in educational collaboration and develop a deeper understanding of the topics studied in the classroom, with the aim of identifying and solving challenges in their communities and sharing the results as a group (Johnson, Smith, Smythe, and Varon, 2009).

Incorporating this method of learning allows students to identify and solve meaningful problems, learn new ideas and tools to address them, and arrive at a solution. Furthermore, it can be applied to a wide range of curriculum content, as ideas are generated from real-world situations that need to be translated into locally applicable solutions. In this way, students can explore and deepen an aspect of the challenge and relate it to what is happening around them, thus strengthening the link between what they learn at school and what they experience outside school.

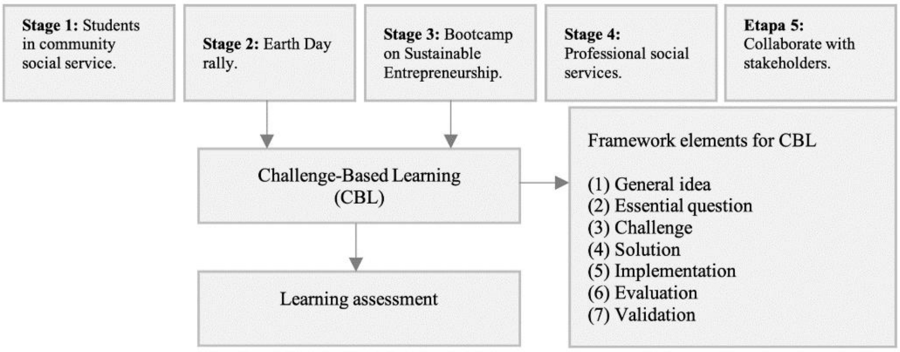

Figure 3. Integrating CBL into the sustainability learning process. Source: Own elaboration.

In this scenario, Figure 4 summarises the stages that contribute to building learning, based on the proposal of Dondi, Klier, Panier and Schubert (2021). The process involves building both individual and team skills. This includes skills for social action, where students develop empathy, solidarity, and social innovation for change. These skills will enable them to acquire essential technical skills for negotiation, entrepreneurship, social innovation, and creativity. Once these skills are acquired, students will develop socio-cognitive and linguistic skills, which in turn will foster socio-affective skills. This will enable them to take an interest in different causes and seek solutions, as well as improve communication and teamwork among students.

Following this suggestion and putting student learning at the centre, in recent years several universities have incorporated CBL methodologies with the aim of connecting with the student community and as part of an educational and didactic model. For example, one of the universities that has implemented this approach is the Tecnologico de Monterrey with its Tec21 educational model (Membrillo-Hernández et al., 2022). Similarly, it has been integrated as part of curricular activities at the TU/e Learning Centre at the University of Eindhoven, which promotes collaboration between students, industry, research and social organisations to develop, maintain and disseminate research-based CBL practices for curricular and extracurricular activities (Reymen et al., 2022). Likewise, in some European countries, it is implemented in a multidisciplinary way, combining social, natural and exact sciences (De Stefani and Han, 2022), as implemented in the stages of this analysis.

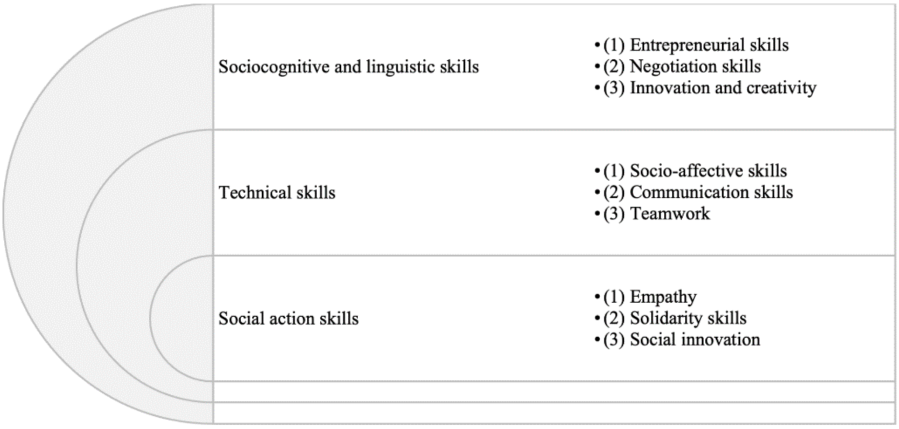

Figure 4. Learning sustainability skills through CBL. Source: Own elaboration.

2.4 The challenge

The process of implementing CBL is detailed in Figure 5. This figure illustrates how different methodologies bring students closer to the SDGs. In addition, they are presented with concrete, real-world problems to find solutions that incorporate a sustainability approach in its economic, social and environmental dimensions. Before the start of the training, students fill in a digital questionnaire to register for stages 2 (rally) and 3 (bootcamp) (see Figure 2). The registration is done in multidisciplinary teams and the questionnaire collects information about the students' profile, their knowledge about sustainability and interest in participating. After registration, on the day of the event, students are guided through a series of steps according to the CBL methodology.

Step 1: Ideation. In this phase, students familiarise themselves with key concepts of sustainability, current challenges and the role of the 2030 Agenda for Sustainable Development. In this first block, the SDGs to be addressed during the challenge are selected.

Step 2: Foundations for solutions. This step helps to define the sectors to be analysed and to propose challenges or social realities. The challenges are local or global problems applied to Baja California, Mexico. Therefore, a group of entrepreneurs, activists and academics assign students problems that reflect the social reality of their environment. Topics include clean water and sanitation, climate change, inequality in the oceans and marine life, green spaces and responsible consumption.

Step 3: Application and evaluation. Guided by business leaders, entrepreneurs and government officials, students use a variety of methodologies that incorporate aspects of the CBL methodology. Core methodologies include Art of Hosting, Design Thinking, Social Canvas and Lean Startup. These methodologies are incorporated with the intention of developing students' problem-solving and critical thinking skills. In this sense, students develop solution proposals with a focus on creating sustainable businesses, considering social, economic and environmental aspects, with mentors helping to refine and polish their ideas from a market and social perspective.

Step 4: Results and reflections. Over a period of approximately five days, the teams create a storytelling presentation of their proposed solution (sustainable enterprise), supported by a market analysis. The proposal must be sustainable and have a social impact. On the fifth day, the students present their proposal to a panel of experts, entrepreneurs, social entrepreneurs, academics and members of civil society. The teams whose proposals are socially relevant, promote good practice and are financially viable and sustainable are declared the winners of the competition.

This process promotes a holistic approach to learning, encouraging the dissemination of ideas, raising students' awareness of sustainability and helping them to develop entrepreneurial skills in teams. At the same time, it encourages the generation of ideas to create businesses with a social change focus, i.e., businesses that address the problems faced by populations living in conditions of greater inequality and vulnerability. Through real-life analysis, students can engage with different mechanisms of action that drive systemic change (Figure 5).

Figure 5 summarises the learning process of students entering stages 2 and 3 of plan of action. The figure shows the selection of SDGs to be addressed during the event, as well as the productive sector and its cross-cutting interconnection with other goals previously described. Consequently, each of the development goals is linked to a challenge that the students must address. The methods are complementary: Art of Hosting was the central methodology to generate empathy with the participants and engage their interest in the problems presented. The Design Thinking methodology helps them define users and create human-centred solutions. Lean Start-up allows them to define the proposed solution with a business approach, while Social Canvas aims to provide a sustainable approach with social impact. In this way, each of these methodologies complements the students' learning and helps achieve the elements described in Figure 4.

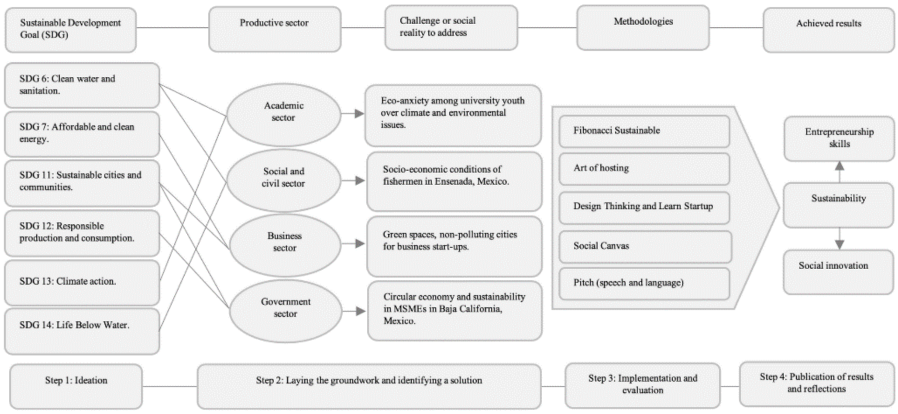

Figure 5. Implementation of CBL in phases 2 and 3 of the Action Plan. Source: Own elaboration.

4. Results

This section first presents an analysis of the diagnosis made by the participants in stages 2 and 3 of the Action Plan. This is followed by a description of the results obtained through the implementation of the methodologies and the project proposals developed by the participating teams.

4.1 Get involved and diagnose

As of 2023, the program aimed at enhancing sustainability learning has engaged just over 1,000 university students. Specifically, in Stage 2, a total of 450 students participated in an Earth Day rally to understand SDGs and green entrepreneurship, while in stage 3, the International Bootcamp on Sustainable Entrepreneurship and SDGs saw the participation of 580 students.

Table 1 summarises the number of students who have participated in the two main events organised by UABC FEYRI to promote sustainability. Both events were conducted in collaboration with other academic units, with the intention of creating synergies with other UABC faculties. In the case of the Sustainable Entrepreneurship Bootcamp, it was held in two locations to facilitate knowledge transfer and strengthen learning in a multidisciplinary and interdisciplinary manner. According to the scheme in Figure 2, stages 1, 4, and 5 have not yet been completed, so there is no specific information available to determine the impact of the Action Plan.

Table 1. Number of students learning about sustainability. Source: Own elaboration.

<table>
<tr><th>Period</th><th>Stage 2</th><th>Location</th><th>Stage 3</th><th>Location</th></tr>
<tr><td>2022-1</td><td>-</td><td rowspan="4">UABC, Tijuana-Mexico</td><td>15</td><td rowspan="2">UABC, Tijuana</td></tr>
<tr><td>2022-2</td><td>200</td><td>350</td></tr>
<tr><td>2023</td><td>250</td><td>215</td><td>UABC, Ensenada</td></tr>
<tr><td>Total</td><td>450</td><td>580</td><td></td></tr>
</table>

The results of the survey conducted at the beginning of stages 2 and 3 provide interesting data that offer an initial overview of the students' knowledge about sustainability. The demographic profile of the students who participated in stages 2 and 3, in terms of age, is predominantly young. The data shows that 48.5% of the students are between 21 and 24 years old, while 42.5% are between 17 and 20 years old. Approximately 5.5% are between 25 and 28 years old, and 3.5% are over 29 years old. In terms of gender, a large proportion of the participants are female, representing 63% of the total, while 36% are male and the remaining preferred not to answer.

In the specific case of the Sustainable Entrepreneurship and SDG Bootcamp, which is part of the third phase, student participation data, based on the university population where the academic unit is located (various UABC campuses), shows that 48.5% come from UABC, Ensenada; 14.5% from UABC, San Quintin extension; 24% from UABC, Tijuana; 6% from UABC, Guadalupe Victoria extension; 5% from UABC, Tecate; and 2% from UABC, Valle Dorado.

The distribution of students from various academic units that participated in this event is as follows: 40% from the Faculty of Oenology and Gastronomy, 22% from the Faculty of Economics and International Relations (FEYRI), 12.5%

from the School of Engineering and Business in San Quintin, 7% from the School of Engineering and Business, 5% from the School of Engineering, Administrative, and Social Sciences, 4% from the School of Marine Sciences, 4% from the School of Engineering, Architecture and Design, and 3% from the School of Administrative and Social Sciences. The remainder is distributed among other units such as the School of Natural Sciences, the School of Medicine, the School of Chemical Sciences and Engineering, the School of Accounting and Administration, and the School of Tourism and Marketing.

The participation of students from various academic units across different UABC campuses demonstrates a significant commitment to teaching sustainability as a transversal axis in higher education, especially, in events that address real-world scenarios related to environmental protection, good business practices, and government involvement. The diversity of student profiles has been fundamental in validating ideas within working teams and following the Challenge-Based Learning (CBL) methodology. Moreover, this diversity has facilitated the identification of creative and specific solutions to societal problems.

The professions that have participated in the events supported in stages 2 and 3 include economics, international relations, public administration and political science, marine science, oceanology, management, accounting, marketing, design, nanotechnology, oenology and science, among others. This diversity of disciplines enables students to take leadership roles and bring different perspectives to sustainability challenges.

Prior to the bootcamp, a short survey was administered to the participants asking about their familiarity with the SDGs. Of the responses, 63.8% of the students indicated that they had heard of the SDGs, while 36.2% had no prior knowledge of them. This provides an opportunity to transfer knowledge on these issues during the event. The students who gave a positive response reflect that they have gone through some stages of the sustainability education model, in one of its forms. In terms of detailed knowledge of the SDGs, 43% of participants said they were not familiar with any of the goals, 26% knew between 1 and 4 SDGs, 14% knew between 5 and 8 SDGs, 6% knew between 9 and 12, and 11% were familiar with more than 13 goals.

In terms of Sustainable Development Goals (SDGs) contributing to the fight against climate change and its impacts, 71% of participants identified SDG 13: Climate Action as the primary effort to mitigate climate change effects, while 23% indicated they were not familiar with this SDG, and the remaining respondents provided other responses. Another highly relevant SDG discussed during the bootcamp was SDG 6: Clean Water and Sanitation, identified by 76% of participating students.

4.2 Challenge participation

The process of transferring sustainability knowledge to young people closely follows the Challenge-Based Learning (CBL) methodology and the PIADMYPE model. In this case, Table 2 summarises the five phases that help students to learn and find solutions to social problems in a fast and multidisciplinary way. According to Apple (2010), these phases can be integrated from the ideation stage to the presentation of results. The aim of the Entrepreneurship and SDG Bootcamp is to work over five days, giving students the opportunity to present their proposed solutions to a specialised panel, mostly composed of experts in the field and including participation from the public, private, civil and government sectors.

The phases implemented in the challenge process closely follow the guidelines of the CBL method. In each phase, complementary methodologies are used to engage students and raise their awareness of the 2030 Agenda and sustainable development (Figure 5). For example, in the ideation phase, an agile methodology is used to connect students to the problem and help them define the issues they want to address during the session. In the second phase, the Art of Hosting methodology is used to identify the guiding questions by dividing participants into small groups for roundtable discussions. This is done with the aim of discussing a specific topic and exchanging ideas, and is one of the key strategies for phases 2 and 3.

This methodology is one of the main ones used in these learning phases, as it allows for reflection and the organisation of activities. It allows students to learn techniques, concepts and elements that help them to describe themselves, understand problems and transform their theoretical knowledge into practical skills (Quick and Sandfort, 2014). In addition, the method allows facilitators or "hosts" to legitimise collective wisdom, explore inquiry and experimentation, and take the group to the edge of learning (Holman, Devane and Cady, 2007).

From the data in Table 2, it can be seen that in the third stage, "Identifying a solution", methodologies are used to help students identify possible solutions. The methodologies that accompany this process include design thinking, which helps to develop entrepreneurial skills (Linton and Klinton, 2019), and Lean Start-Up, which is used to teach students about value creation in entrepreneurship and identifying markets and business models (Zott and Amit, 2024). Therefore, one of the methodologies that allows students to evaluate and propose solutions based on business creation is the Canvas Business Model, which consists of a tool that allows the concrete identification of the problem, infrastructure, capabilities and use of resources for any entrepreneurial proposal (Sparviero, 2019).

Table 2. Phases that make up the Challenge-Based Learning process.

Phase	SDGs	Target	Learning methodology	Challenges
Phase 1: Ideation	Agenda 2030 (17 SDGs)	Raise student awareness of the importance of sustainable development.	Sustainable Fibonacci	Identify social problems.
Phase 2: Build the foundation solution	▪ SDG 6: Clean Water and Sanitation ▪ SDG 7: Affordable and clean energy ▪ SDG 11: Sustainable cities and communities ▪ SDG 12: Responsible consumption and production ▪ SDG 13: Climate action ▪ SDG 14: Life below water ▪ SDG 15: Life on land	Identify guiding questions about the challenge.	Art of hosting.	Find solution to an assigned challenge.
Phase 3: Identify a solution		Research, document and develop a solution and identify the implementation steps.	Design Thinking and Learn Startup	Identify potential solutions and prototype.
Phase 4: Application and evaluation		Measure results, reflect on what has worked and what has not, and then determine if it is the right way to go.	Social Canvas and Kanban	Evaluate whether the selected solution can deliver the expected results.
Phase 5: Presentation of results and reflections		Argue and defend the chosen solution in front of experts.	Pitch	Present the solution proposal to a jury.

Source: Own elaboration. Note: The phases presented in this table correspond to the learning process delivered to university students during stages 2 and 3 of the sustainability programs.

The implementation of these methodologies, guided by the CBL and Art of Hosting approaches, facilitates the development of the participants' language skills and enables them to present themselves through a group pitch in which they outline their proposed solutions, which are mentioned below.

4.3 Proposals for solutions

The proposed solutions to the different problems analysed by the students are shown in Table 3. All participants were divided into eight teams, each of which was given one problem, and from these teams the four best solutions that met key aspects of sustainability were selected. The table only shows the solutions that performed best during the workshops and those that were presented on the pitch day, so the best solution was taken for each problem.

The proposed include the creation of cooperatives, social enterprises and public spaces with a recreational approach to preserving green spaces. During the event, for example, four proposals were presented to the participating teams. The first focused on SDGs 6 and 13, addressing the challenge of environmental anxiety among university students. Their proposed solution was to create an organisation that provides comprehensive support to young people, linking them to small actions that create positive change and contribute to the environment (see Box 3). In another case, to address the problem of transition to green areas and formalisation of micro and small enterprises in Baja California, the proposed solution was to provide advisory services to micro-enterprises that promote formalisation and the adoption of environmentally friendly practices.

Table 3. Proposed solution projects by the students.

Problem	Tackling the problem using sustainable entrepreneurship
(1) Eco- anxiety among young university students on climate and environmental issues.	Organisation that helps to generate experiences of social change in students through concrete actions that involve contributing to an action that has an impact on the environment.
(2) Socio-economic conditions of fishermen in Ensenada, Mexico.	Creation of a social cooperative to help market the fishermen's products, incorporating elements of fair trade.
(3) Green spaces, non-polluting cities for business start-ups.	Creation of Eco-parks in some areas of Baja California, Mexico. In these areas it will be possible to provide guides to promote ecotourism in areas with a high cultural and historical content.
(4) Circular economy and sustainability in MSMEs in Baja California, Mexico.	Consultancy to help formalise and transition to environmentally friendly practices.

Source: own elaboration. Note: The results of the proposed solutions to the problems correspond only to stage 3 of the Action Plan. The issues addressed are discussed in Figure 5 of this document.

In order to develop a proposed solution, each participating team worked closely with mentors who provided specialist assistance in developing proposals based on sustainability entrepreneurship. The decision to select only four of the projects created during the event helps to assess the students' learning outcomes, as these projects meet the requirements of a socially relevant enterprise that addresses a social problem and adheres to good environmental practices.

5. Discussions

Finally, a satisfaction survey was conducted among the student community that participated in the Earth Day rally events and the Entrepreneurship and SDG Bootcamp, which provided important responses for the implementation of this Action Plan. For example, among all participants, it was expressed that these experiences mainly contributed to the development and acquisition of entrepreneurial skills, participatory and transformative leadership, creativity, communication and teamwork. In addition, 63% of participants indicated that they had developed critical thinking skills while working through challenges in teams.

In this context, the impact and potential of this programme to promote sustainability as a cross-cutting theme in higher education through events that connect students with real scenarios in their environment is significant. This impact is not only educational, but also academic and social, which could make it attractive for other basic education institutions to implement. In addition, a link could be established with civil society organisations and businesses to create a model of good practice that promotes sustainability. Furthermore, the results of the proposed solutions in these phases of the Action Plan help to highlight the potential of using Challenge-Based Learning, which enables students to tackle global problems with local claims. This will be consolidated in universities as a framework for generating sustainable and innovative keys, while promoting active and multidisciplinary learning (Martínez-Acosta, Membrillo-Hernández and Cabañas-Izquierdo, 2022).

6. Conclusions

Incorporating sustainability and green entrepreneurship dimensions into learning programs becomes crucial for promoting education among university students. This initiative began in 2022 as a learning strategy within the FEYRI student community, focusing on topics related to the environment, climate change and social entrepreneurship. Aligned with the academic unit's 2020-2024 development plan, this action strategy aims to contribute to its zero waste, energy efficiency, and green campus programs. Therefore, the vision of sustainability promoted by this university is based on a multidimensional concept of development that includes environmental, social and economic sustainability (UNESCO, 2023).

This approach underscores youth as pivotal in promoting education among university students. Among the seventeen goals proposed by the United Nations, those related to the environment (SDG 13), clean water and sanitation (SDG 6), ocean conservation (SDG 14), and affordable and clean energy (SDG 7) are selected as overarching goals. Employing a methodology that immerses students in real-life scenarios, it has been observed that over a thousand university students have strengthened and developed skills such as creativity, initiative, leadership, and execution through challenges presented in both local and national contexts.

The objective of this project is to nurture the empowerment and leadership of college youth, enabling them to become catalysts of change within their communities. It is evident that the Challenge-Based model proposed in this document can serve as an effective framework for teaching sustainability to college students. A robust sustainability education model in higher education is of paramount importance, equipping students with versatile tools essential for both professional endeavours and daily life.

The participation of students from all UABC campuses in various real-world challenges has yielded significant advancements in promoting sustainability among university students. This approach emphasizes hands-on learning methods, facilitating direct engagement with the tangible challenges confronting their communities. Numerous organizations, such as the NGO Higher Youths, exemplify the empowerment of youth by advancing their education and furnishing them with employable skills through methodologies aimed at enhancing their capabilities (Green and Portelli, 2018).

To effectively address future challenges, it is imperative to conduct activities in a self-sustaining manner, which means allocating resources to enriching events for the student community. This entails allocating resources to organize meaningful events for the student community. Such an approach ensures the continued progress of the program in a sustainable manner and facilitates the dissemination of knowledge to faculties that have not yet participated. This experience can broaden students' horizons and inspire them to envision a more promising future dedicated to environmental preservation and the adoption of sustainable practices. Moreover, it fosters their commitment to the Sustainable Development Goals and the establishment of green businesses.

7. Limitations

The document can be a useful tool for promoting sustainability among university students, fostering knowledge, participation and values. However, its effectiveness will depend on factors such as available resources, cultural context, resistance to change and the ability to measure its impact. One of the main limitations of this Action Plan is the limited resources available, such as teacher training and funding for events promoting sustainability in higher education. Another limitation to the implementation of this Action Plan is resistance to change. For example, many educational institutions, communities or young people have limited acceptance and effectiveness when trying to incorporate this model into their teaching, which could mean a challenging and slow process.

In terms of impact measurement, as this document only summarises stages 2 and 3 of the Action Plan, there is no comprehensive evidence of all stages. Therefore, extending the period of analysis could help to provide a long-term perspective for evaluation and continuity. Furthermore, the document presents brief data on student learning, so it is considered advisable to include more information on the learning experiences of the students who participated in the events, as well as the related stages 1, 4 and 5 on learning about sustainability.

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Original Paper

Student perceptions of environmental sustainability.

Insights into green campus innovations and geospatial analysis at Universitas Negeri Malang

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Abstract. *A growing cohort of higher education institutions, including Universitas Negeri Malang (UM), are embracing green campus initiatives as a strategic response to the imperative of environmental sustainability. This study scrutinizes the extent of student awareness regarding UM's Green Campus strategies and employs a specified Universitas Indonesia (UI) Greenmetric indicator to map environmental features. A comprehensive survey capturing responses from 322 students across various faculties and academic levels was orchestrated to evaluate perceptions of environmental sustainability. The methodology integrated direct mapping and observational techniques, with data processing conducted via SPSS for statistical analysis and ArcGIS for polygon geometry calculations. The findings demonstrate a robust positive reception of the university's environmental initiatives, with numerous elements achieving ratings surpassing 4.0. This research highlights significant student engagement and acknowledges the university's pivotal role in nurturing a sustainable educational environment. Moreover, the study generated intricate maps delineating the spatial distribution and scope of forests, planted, and water absorption areas across UM's tripartite campuses. These cartographic outputs are posited as essential tools for policymakers dedicated to advancing green campus practices informed by the UI Greenmetric criteria. The results not only reinforce the favourable influence of UM's sustainability endeavours on student perceptions but also delineate potential avenues for policy refinement and practical improvements to augment UM's sustainability trajectory.*

1. Introduction

Environmental issues have become pressing multidimensional concerns that require immediate attention. Global warming, biodiversity loss, and pollution are tangible problems resulting from global environmental degradation (Sadono et al., 2021; Tseng et al., 2022) and must be urgently addressed (Pandya et al., 2022; Singh et al., 2016). The majority of these issues are the result of human activities (Ahmed & Wang, 2019) such as the unsustainable use of natural resources (Fuller et al., 2022), a lack of environmental consciousness and advocacy, and the increasing demands of human needs (Manisalidis et al., 2020). If unchecked, these activities will lead to continuous ecological system damage (Grifoni et al., 2022) from the environments that have been exploited and utilized (Rume & Islam, 2020).

Universities, as microcosms of urban systems, host various activities that potentially harm the environment. These activities include the use of various facilities, such as air conditioning, audio-visual learning, and laboratory, energy, vehicle, and material usage (Poluan et al., 2020; Tiyarattanachai & Hollmann, 2016) which significantly contribute to environmental issues (Anwar et al., 2020; Khan et al., 2020) and impact greenhouse gas emissions (Akadiri et al., 2012; Gammie et al., 2023). Furthermore, the construction of buildings and other facilities has led to the reduction of green areas, such as campus planted or forests (Idowu, 2012). A concept that universities must adopt to realize sustainable development is the green campus concept.

The green campus concept prioritizes the protection, management, and preservation of the environment in the long term. It focuses on minimizing negative impacts on the environment (He et al., 2020; Liziane Araújo da Silva et al., 2023) through the efficient use of resources, waste management, eco-friendly transportation, and the integration of environmental aspects into campus life (Fachrudin et atl., 2021; Partino et al., 2021). The implementation of the green campus plays a crucial role in fostering environmentally conscious campuses (Muhiddin et al., 2023; Rajalakshmi et al., 2022) and can serve as a basic reference in creating a healthy environment (Tu & Hu, 2018). The Green Campus Award is obtained based on the evaluation of categories and indicators of the UI GreenMetric (Lourrinx et al., 2019).

UI GreenMetric is a platform that assesses the sustainability programs and policies of universities worldwide. The UI GreenMetric ranking also provides insights into the strengths and weaknesses of implementing green campus and sustainable development (Tabucanon et al., 2021). Since its inception, the UI GreenMetric World University Ranking has garnered significant attention and has been improving annually (Boiocchi et al., 2023; Sari et al., 2021). The UI GreenMetric categories include setting and infrastructure (SI), energy and climate change (EC), waste (WS), water (WR), transportation (TR), and education and research (ED) (Alawneh et al., 2021; Fatriansyah et al., 2021). The Green Campus concept based on UI GreenMetric has been implemented by various universities in Indonesia (Farhan et al., 2020; Kusumaningtyas et al., 2019), including Universitas Negeri Malang (Gandasari et al., 2020).

Universitas Negeri Malang has committed to enhancing environmental management through the implementation of Green Campus. This commitment is realized in policies, management, infrastructure, and higher education activities, such as waste management strategies, smart building development, and the application of renewable energy (Puspitasari et al., 2022). Additionally, Universitas Negeri Malang also conducts outreach on sustainable campus waste management, integrates environmental knowledge and learning into specific courses across all faculties, and implements sustainable environmental programs and activities to foster green behaviours (Novianti et al., 2019). As a result, the total UI GreenMetric score of Universitas Negeri Malang has continuously increased, reaching 5900 in 2020, 6375 in 2021, and 7025 with a ranking of 32nd as a green campus in Indonesia in 2022.

However, many aspects of sustainability still need enhancement, such as evaluating policies, management, infrastructure, and environmental activities. This evaluation is not only to improve the UI GreenMetric score but also to create a sustainable and environmentally conscious campus environment (Fortes et al., 2019; Yusliza et al., 2020; Zamora-Polo & Sánchez-Martín, 2019). The implementation of a sustainable campus will have a positive impact on its community, including students who will become future policymakers. This study employs a quantitative descriptive research design to assess student perceptions of environmental sustainability at Universitas Negeri Malang (UM). The design integrates survey methodology and spatial mapping to provide a comprehensive understanding of student awareness and the spatial distribution of green campus initiatives. The study aims to address the following research questions:

1. How do students at Universitas Negeri Malang perceive and engage with the university's Green Campus initiatives, particularly in terms of their environmental concerns, participation in sustainability activities, and their satisfaction with the university's efforts in promoting a sustainable campus environment?
2. What are the spatial distributions and size of green areas (forest vegetation, planted vegetation, and water absorption) on UM campuses?

2. Methodology

2.1. *Research design*

This study utilizes a quantitative descriptive research design. The quantitative research design was conducted through surveys administered to students using forms and mapping the green areas at Universitas Negeri Malang using numerical data, particularly the spatial dimensions of green areas with the assistance of ArcGIS software. The quantitative data generated will be descriptively explained as supporting data for the implementation of the green campus concept. This quantitative approach allows the study to produce data that is not only empirical but also measurable and analysable statistically, thus providing more objective and comprehensive insights.

2.2. *Survey*

The forest vegetation, planted vegetation, and water absorption regions are critical physical aspects of the green campus. Besides physical conditions, the knowledge and implementation of the green campus concept by students are also paramount. Therefore, we conducted a survey based on: (1) concern for the environment in the present or future, (2) the role of students in supporting the environment and campus sustainability, (3) the role of the campus in supporting the environment and sustainable campus, and (4) student opinions on the environment and campus sustainability. All survey items were sourced from similar research and have been modified by the researchers according to the needs of the study. The survey utilized the Google Forms platform and involved the active participation of students from various faculties. A comprehensive survey was conducted, capturing responses from 322 students across various faculties and academic levels. The survey included both open-ended and closed-ended questions. Closed-ended questions used a five-point Likert scale to gauge perceptions on various aspects of environmental sustainability. The survey questions are presented in Appendix 1.

2.3. *Mapping*

The mapping process was methodically arranged into four stages: initial preparation, which includes the study area, Unmanned Aerial Vehicle (UAV) flight preparation, and control point design; data collection, which encompasses literature study, small-format aerial photography, and control point data; data processing, which involves stitching, georeferencing, land classification and cover, and geometry calculation; and the results, which are the outcome of the research in the form of green area maps at Universitas Negeri Malang, including forest vegetation, planted vegetation, and water absorption. The flow diagram of this research methodology is presented in Figure 1.

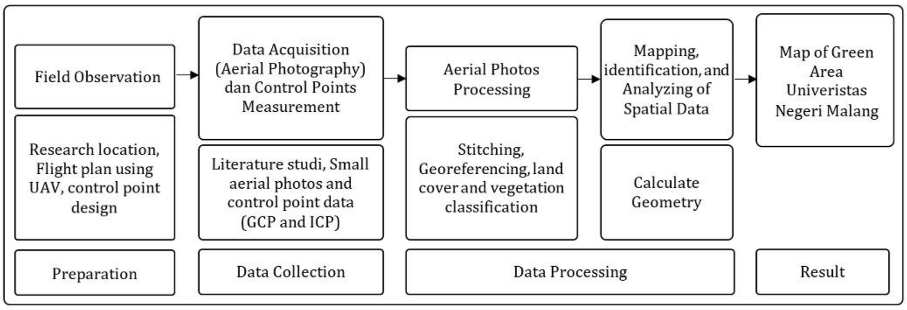

Figure 1. Research flow of Green Area Mapping Universitas Negeri Malang

1. Forest vegetation. These are defined as areas densely covered with trees and other vegetation, providing critical ecological functions such as carbon sequestration, biodiversity habitats, and microclimate regulation. The criteria for classifying an area as a forest include a minimum tree density, canopy cover percentage, and presence of native plant species.
2. Planted vegetation. These areas are characterized by landscaped spaces primarily designed for aesthetic and recreational purposes. They include lawns, flower beds, and shrubs. The criteria for planted vegetation involve the extent of cultivated land, the diversity of plant species, and the presence of recreational facilities like benches, walkways, and sports areas.
3. Water absorption. These areas are strategically placed to optimize water management on campus. These areas include vegetated swales, retention ponds, and permeable surfaces that facilitate water infiltration and reduce runoff. The catchment areas are crucial for mitigating flood risks, conserving water resources, and supporting the campus's overall sustainability goals. They also serve as practical examples for students studying sustainable urban planning and water management.

The mapping process involved capturing aerial photos using photogrammetry techniques (creating digital maps from physical objects by recording, measuring, and interpreting photos to obtain measurements and information) using UAV, due to its various advantages as shown in **Figure 2.** In this study, the UAV used was the DJI Phantom 4 Pro V2.0. The aerial photography process produced small aerial photo format images based on predetermined coordinates. The UAV photos then underwent a stitching process to produce a comprehensive map of the study area.

Figure 2. The aerial photographs taken using the UAV (a) and the images from Google Maps (a) were compared. The UAV photographs demonstrate superior quality in aspects of detail, resolution, and colour (Sadono et al., 2021).

2.4. *Study area description*

To provide a comprehensive understanding of the study area, a geographical map of Universitas Negeri Malang has been included. This map highlights the university's location within the city of Malang, East Java, Indonesia, and its spatial context relative to significant urban and environmental features. The map serves as a visual aid to illustrate the geographic scope of the research, facilitating a better grasp of the environmental and infrastructural layout of the campuses involved in the study.

The geographical location of Universitas Negeri Malang is strategically important for the implementation of green campus initiatives. The university's campuses are situated in urban areas that present both challenges and opportunities for sustainability practices. The map below delineates the specific locations of Campus 1, Campus 2, and Campus 3, providing a clear view of their spatial distribution and proximity to key urban features.

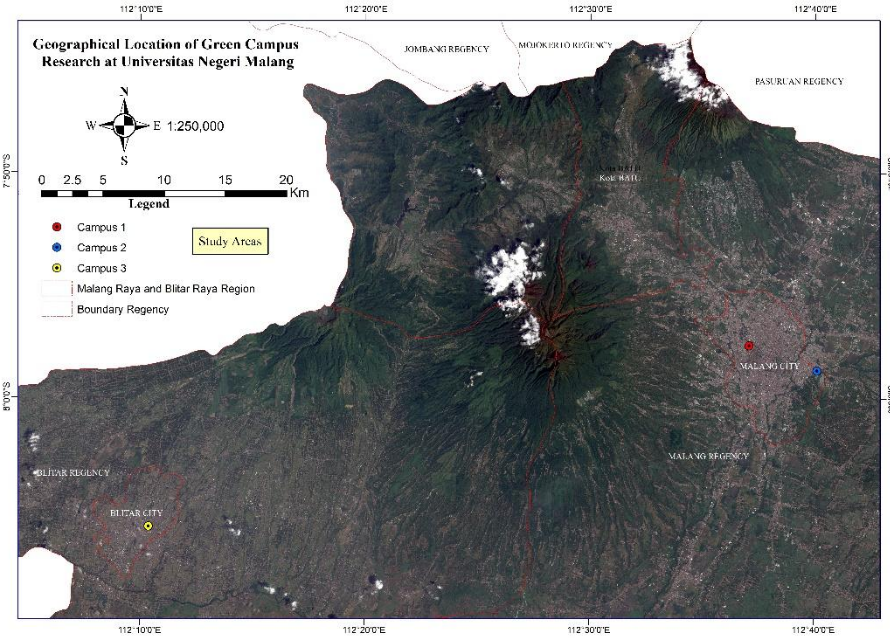

Figure 3. Geographical location of Universitas Negeri Malang Campus 1, Campus 2, and Campus 3, at East Java, Indonesia

2.5. *Types and collection of data*

The types of data used in this research include primary and secondary data. Primary data were obtained through mapping in the study area and surveys with students, and secondary data were gathered through literature studies related to and supporting the research study and documents on green campus policies at Universitas Negeri Malang.

2.6. *Data Analysis*

The mapping results will be analysed using Geographic Information System (GIS) software, specifically ArcGIS, to produce detailed visualizations of the distribution of green areas at Universitas Negeri Malang. Based on the analysis, the resulting maps are categorized into three classifications: (1) distribution and size of forest vegetation, (2) distribution and size of planted vegetation, and (3) distribution and size of water absorption. The method adopted to determine the size of each area is the calculate geometry technique using a polygonal approach. Additionally, in the data analysis process, official documents issued by Universitas Negeri Malang serve as a primary data source. Furthermore, field observations also significantly contribute to presenting descriptive data that reflects the actual field conditions. In survey data, the data analysis will employ simple statistical analysis techniques such as frequency, percentage, and ANOVA using SPSS 25.

3. Result and Discussion

3.1. *Survey*

3.1.1. Respondent information

The survey was conducted over a period of 14 days and garnered a total of 322 respondents, comprising 146 males and 176 females from various faculties and levels of study. The survey results were predominantly female, primarily at the undergraduate level (bachelor's degree), from the Faculty of Social Sciences (FIS), and the class of 2023. The frequency of respondents living on campus and those with previous experience of living on campus was shown to be very low. The survey results concerning respondent information are displayed in **Table 1.**

3.1.2. Student insight about campus sustainability and UM Green Campus

Student insights on sustainable campus practices and the UM Green Campus are categorized as in **Table 1**. The results for each category and their explanations are detailed in **Table 2**:

According to the survey results, UM students demonstrate a high level of concern for environmental issues, reflecting a deep conviction about the vulnerability of the environment and the negative consequences of human behaviour on the ecosystem. A total of 57.5% of respondents acknowledged their concerns regarding the wastage of natural resources and its impact on pollution or environmental degradation. Additionally, 34.8% of students agreed, and 29.8% strongly agreed, that current development contradicts deteriorating environmental conditions. This indicates a strong belief among students about ecological vulnerability, where the natural environment is a system that can be damaged by human activities (Amoah & Addoah, 2021; Liu et al., 2020). Human activities that prioritize economic and development factors without considering ecological implications result in various negative consequences for both current and future generations (Wang et al., 2024).

Table 1. Respondent information (N=322)

Categories	Items	Frequency (N)	Percentage (%)
Gender	Male	146	45.3
	Female	176	54.7
Level of study	Bachelor's Degree (S1)	273	84.8
	Master's Degree (S2)	4	1.2
	Doctoral Degree (S3)	36	11.2
	Teacher Professional Education (PPG)	9	2.8
Faculty	Faculty of Education	45	14.2
	Faculty of Economics	10	3.3
	Faculty of Letters	8	2.4
	Faculty of Mathematics and Natural Sciences	41	12.5
	Faculty of Engineering	20	6.6
	Faculty of Social Sciences	89	27.6
	Faculty of Sports Sciences	8	2.7
	Faculty of Vocational Studies	88	27.8
	Faculty of Medicine	1	0.3
	Graduate School Faculty	8	2.6
Class year	2019	4	1.2
	2020	11	3.4
	2021	21	6.5
	2022	105	32.7
	2023	181	56.2
Living on campus	Yes	27	8.4
	No	295	91.6
Previous experience of living on campus	Yes	26	8
	No	296	92
I know that UM adopts the Green Campus Concept	1	5	1.6
	2	11	3.4
	3	53	16.5
	4	117	36.3
	5	136	42.2
Have participated in activities with the theme "sustainability" (seminars, public lectures, etc.)	Yes	180	55.9
	No	142	44.1
Have participated in environmental action activities within the UM Campus	Yes	97	30.1
	No	225	69.9

These survey results align well with the Ecological Belief Model (EBM), which emphasizes the importance of personal responsibility and self-efficacy towards the environment (Baier et al., 2013). The EBM posits that individuals' beliefs about their ability to influence environmental outcomes play a crucial role in motivating pro-environmental behaviours (Shafiei et al., 2017). By fostering a sense of self-efficacy, individuals are more likely to engage in actions that benefit the environment, thereby contributing to broader sustainability goals (Baldwin et al., 2022; Hamann et al., 2024). This model is further supported by 43.8% of students stating that environmental factors are often overlooked due to a focus on economic factors. These results suggest that students recognize their responsibility in making sustainable decisions that enhance not only the economy but also infrastructure development for future generations (Foroozesh et al., 2022).

Table 2. Concern for the environment in the present or future

Survey Question	Answer					Average
	(1)	(2)	(3)	(4)	(5)	
I am quite concerned about the waste of natural resources and the destruction or pollution of the environment that is happening today.	8 (2.5%)	5 (1.5%)	26 (8.1%)	98 (30.4%)	185 (57.5%)	4.3 (100%)
I believe that the current economy is based on practices that will have a negative impact on future generations	19 (3.7%)	35 (6.8%)	126 (24.9%)	84 (34.8%)	58 (29.8%)	3.4 (100%)
I see that the current development is contrary to the deteriorating environmental conditions.	12 (3.7%)	22 (6.8%)	80 (24.9%)	112 (34.8%)	96 (29.8%)	3.8 (100%)
Environmental factors are often overlooked due to a focus on economic factors	7 (2.2%)	14 (4.3%)	40 (12.4%)	120 (37.3%)	141 (43.8%)	4.1 (100%)

Answers: (1) Strongly Disagree; (2) Disagree (3) Neutral (4) Agree (5) Strongly Agree.

This awareness encourages students to engage in pro-environmental actions or support green policies at Universitas Negeri Malang (Null & Asirvatham, 2023). Such support is a form of self-efficacy and an expression by students that humans can make positive changes to the environment, starting from their personal surroundings (Akhtar et al., 2022). According to the Ecological Belief Model, interventions are directed to enhance knowledge and awareness about the ecological impacts of everyday human behaviours through self-efficacy (Baldwin et al., 2022; Hamann et al., 2024). This approach is highly effective in building student character towards pro-environmental actions by understanding various negative impacts that could occur (Saulick et al., 2024). Various programs and initiatives to support the UM Green Campus, such as campaigns, workshops, and sustainability projects on campus, can encourage and strengthen sustainable behaviours (Mohamed et al., 2020). These activities not only form pro-environmental attitudes but also aid in implementing consistent behaviours that maintain a sustainable ecological environment (Castellanos & Queiruga-Dios, 2022; Ibáñez et al., 2020).

Table 3. The role of students in supporting a sustainable environment and campus

Survey Question	Answer					Average
	(1)	(2)	(3)	(4)	(5)	
Reduce the use of private vehicles and use public transportation	45 (14%)	41 (12.7%)	122 (37.9%)	62 (19.3%)	52 (16.1%)	3.1 (100%)
Car Free Day (CFD) at UM makes the campus atmosphere more comfortable	8 (2.5%)	12 (3.7%)	68 (21.1%)	83 (25.8%)	151 (46.9%)	4.1 (100%)
Car Free Day (CFD) at UM as a strategic step to support Zero Carbon Emissions in the UM campus environment	4 (1.3%)	3 (0.9%)	59 (18.3%)	82 (25.5%)	174 (54.0%)	4.3 (100%)
Using durable (non-disposable) equipment	3 (1%)	9 (2.8%)	67 (20.9%)	128 (39.6%)	115 (35.7%)	4.1 (100%)
Avoiding foods with a lot of disposable packaging	4 (1.2%)	20 (6.2%)	138 (42.9%)	91 (28.3%)	69 (21.4%)	3.6 (100%)
Turn off lights and other electronic equipment when not in use	1 (0.3%)	1 (0.3%)	26 (8.1%)	75 (23.3%)	219 (68.0%)	4.5 (100%)
Use natural light (sunlight) by adjusting the curtains instead of turning on the lights	5 (1.5%)	6 (1.9%)	59 (18.3%)	101 (31.4%)	151 (46.9%)	4.2 (100%)
Reduce the use of air conditioning by opening windows	18 (5.6%)	23 (7.1%)	91 (28.3%)	76 (23.6%)	114 (35.4%)	3.8 (100%)
Using water wisely (not leaving taps running, reporting drips and leaks, etc)	2 (0.6%)	2 (0.6%)	30 (9.3%)	80 (24.9%)	208 (64.6%)	4.5 (100%)
Save paper when printing (printing double-sided or on the back of scrap paper) or going paperless (sharing, reading, and storing documents electronically)	2 (0.6%)	12 (3.7%)	85 (26.4%)	122 (37.9%)	101 (31.4%)	4.0 (100%)
Utilize food waste into compost	60 (18.6%)	69 (21.5%)	99 (30.7%)	48 (14.9%)	46 (14.3%)	2.8 (100%)

Answers: (1) Never; (2) Seldom; (3) Sometime; (4) Often; (5) Always

The survey results illustrate an understanding and active role of students in supporting a sustainable environment. A total of 46.9% of respondents strongly agree that the Car Free Day (CFD) program enhances the campus atmosphere's comfort, improves quality of life, and contributes positively to the environment (Glazener et al., 2022). This indicates that the CFD program strengthens community and student engagement in supporting the UM Green Campus (Prasad, 2022).

Furthermore, 54% strongly agree that CFD is a strategic step in supporting Zero Carbon Emissions on campus. This shows a high level of student awareness about the relationship between campus activities, namely CFD, and the reduction of carbon emissions in the campus environment and its impact on climate change (Chandra et al., 2022). The success of CFD in motivating students to reduce reliance on personal vehicles by using environmentally friendly transportation or walking is notable (Pazhuhan et al., 2022).

Car Free Day is one of the simple programs to achieve a sustainable campus. Previous research has found that CFD is effective in reducing carbon emissions and increasing environmental awareness among students (Cirrincione et al., 2022; Perez-Lopez et al., 2021). This program restricts vehicle access to the outer ring of the campus area and requires university community members to walk. Besides having a positive impact on the environment, this program also positively affects physical activity levels (Junior et al., 2022).

Given the significant potential and strong student support for the UM Green Campus, the university can expand and enhance the effectiveness of similar programs (Ribeiro et al., 2021). Possible measures include improving infrastructure for pedestrians and cyclists, providing information and resources about sustainability benefits, and integrating sustainability education into the curriculum of each study program (Dawodu et al., 2022). This can encourage pro-environmental behaviour not just during specific events, but as part of everyday conduct (Liu et al., 2020).

On other aspects, such as durable equipment, electricity savings, and water conservation, significant results were achieved, with 35.7%, 68.0%, and 64.6% respectively. These results demonstrate a commitment to sustainable environments through waste reduction and the conservation of electricity and water (Fissi et al., 2021). These survey findings illustrate how environmentally friendly behaviours have been integrated into daily life. Additionally, the survey results reflect the level of awareness and individual responsibility towards the environment.

Although the outcomes are commendable, there remains considerable scope for improvement, especially in the consumption of single-use food packaging and the conversion of household waste into compost, which are relatively low at 21.4% and 14.3%, respectively. This indicates significant challenges for sustainable practices, influenced by lifestyle and the prevalence of hard-to-avoid plastic packaging (Dey et al., 2021).

Reducing single-use food packaging is a major issue in decreasing the amount of plastic waste. This is because most products sold are synonymous with disposable plastic packaging, from food needs to hygiene products and more (Dey et al., 2021). Programs like ecobrick production have not been maximally implemented, leading to plastic waste ultimately ending up in landfills (Mihai et al., 2022). Additionally, the use of household waste for composting has not been optimized due to various factors, such as the availability of land (Tarashkar et al., 2023).

Student awareness about the importance of using durable equipment and saving electricity reflects sustainability education. Students tend to utilize natural energy, such as sunlight or air circulation from windows, rather than using lights or air conditioners (Álvarez, 2020). According to previous research, the use of durable equipment and energy-saving activities are essential in promoting sustainable lifestyles (Al-Obaidi et al., 2022; Harun et al., 2022; Yoo et al., 2020).

Overall, the survey results are consistent with the theory of Ecological Justice, which highlights the distributive aspects of responsibility and benefits from sustainable practices at Universitas Negeri Malang. This theory emphasizes that all individuals should have equal access to maintaining and utilizing a sustainable environment (Svarstad & Benjaminsen, 2020). Survey data indicate that students support and contribute to achieving a sustainable environment, such as through the CFD program, even though there are imbalances in other practices, such as reducing disposable packaging materials and using waste for compost (Sousa, 2023).

Applying the theory of Ecological Justice in campus policy can address disparities, issues, and enhance the quality and capacity of students in achieving a sustainable environment (Martin et al., 2020). Universitas Negeri Malang can enhance awareness and infrastructure that support the reduction of plastic use and the processing of organic waste into compost (Phrophayak et al., 2024). This can provide opportunities for students, regardless of their field of study, to contribute to maintaining and enhancing environmental quality (Silva et al., 2023). This approach can also strengthen the campus community, as every individual plays a role in creating a sustainable environment (Qazi et al., 2020).

Table 4. The role of the campus in supporting the environment and a sustainable campus

Survey Question	Answer					Average
	(1)	(2)	(3)	(4)	(5)	
Environmental studies as a compulsory subject	6 (1.9%)	21 (6.5%)	99 (30.7%)	94 (29.2%)	102 (31.7%)	3.8 (100%)
Green campus seminar held by students	1 (0.3%)	4 (1.2%)	81 (25.2%)	106 (32.9%)	130 (40.4%)	4.1 (100%)
Student organizations active in the environmental field	1 (0.3%)	2 (0.6%)	59 (18.3%)	101 (31.4%)	159 (49.4%)	4.3 (100%)
Encourage the use of public and environmentally friendly transportation	0 (0%)	8 (2.5%)	58 (18.0%)	107 (33.2%)	149 (46.3%)	4.2 (100%)
Owning and using non-disposable products	2 (0.6%)	5 (1.6%)	60 (18.6%)	93 (28.9%)	162 (50.3%)	4.3 (100%)
Seminars and training or practice in recycling, energy conservation, and resources	1 (0.3%)	2 (0.6%)	50 (15.5%)	109 (33.9%)	160 (49.7%)	4.3 (100%)
Green campus campaign in the form of banners, posters, and stickers	9 (2.8%)	19 (5.9%)	67 (20.8%)	95 (29.5%)	132 (41.0%)	4 (100%)
The university has a website about the green campus	0 (0%)	4 (1.2%)	47 (14.6%)	82 (25.5%)	173 (58.7%)	4.3 (100%)
University reduces paper consumption (paperless)	1 (0.3%)	5 (1.6%)	56 (17.4%)	87 (27.0%)	173 (53.7%)	4.3 (100%)

Answers: (1) Strongly Disagree; (2) Disagree (3) Neutral (4) Agree (5) Strongly Agree.

Universitas Negeri Malang as a Green Campus University demonstrates a significant role in supporting a sustainable environment. The environmental awareness is reflected in the survey results regarding the importance of environmental study subjects (31.7%), conducting green campus seminars (40.4%), and student organization activities in the environmental field (49.4%). Additionally, UM has a UM Green Campus website that contains information about sustainable campus initiatives, from programs to annual reports. This website positively impacts students' knowledge about the green campus (58.7%), which is presented in various formats such as banners, posters, stickers, etc. (41.0%).

Integrating environmental education into the university curriculum is crucial and serves as a flagship program to achieve a sustainable campus. According to prior research, courses integrated with environmental content can enhance student awareness and engagement in environmental issues (Handoyo et al., 2021; Marpa, 2020). Moreover, the university can also provide opportunities for students to engage in environmental activities, such as organizations or seminars (Mamurov et al., 2020). This can increase environmental awareness among students through peer tutoring.

Based on Human Ecology theory, human behaviour is influenced not only by internal factors but also by external or environmental factors where individuals reside (Bubolz & Sontag, 1993). Human Ecology examines the interactions between humans and their environments, emphasizing how these interactions shape behaviours and societal norms (Nguyen et al., 2023). This theory posits that the environment, including physical, social, and cultural elements, plays a crucial role in shaping human behaviour (Michelson, 1970).

In the context of UM Green Campus, understanding campus environmental policies can influence students' sustainable behaviours (Jnr, 2021; Mohammadi et al., 2023). The Human Ecology theory complements the Ecological Belief Model (EBM) by providing a broader framework for understanding how environmental settings and social contexts contribute to the development of pro-environmental behaviours. While EBM focuses on individual beliefs and self-efficacy in driving environmental actions, Human Ecology highlights the importance of the broader environmental context and social dynamics in shaping these behaviours.

1. Campus Design and Infrastructure: Universitas Negeri Malang has implemented the green campus concept in aspects of campus design and infrastructure that support a sustainable environment and encourage environmentally friendly behaviours. Providing facilities such as waste management places, green areas, and specific pedestrian paths are examples of how UM supports the green campus program. These facilities are efforts by UM to reduce carbon emissions from motor vehicles.
2. Education and Environmental Awareness: Universitas Negeri Malang has mandated academic programs to develop curricula that include environmental studies, covering ecological issues and sustainable development. According to Human Ecology theory, an environmental education curriculum is vital in shaping social norms and individual behaviours. Moreover, environmental education can also encourage students to apply knowledge in daily life, thus having a positive impact on sustainable practices in the surrounding community and campus environment.
3. Participation in Sustainable Activities: Active student involvement, such as environmental organizations, environmental seminars, or green campus campaigns, is an important indicator in Human Ecology theory. Students

not only enhance their own awareness of the importance of a sustainable environment but can also strengthen community norms. According to Human Ecology theory, this social dynamic is crucial in shaping student identities as agents of change in a sustainable environmental context.

4. Influence of Social Environment: Human Ecology theory acknowledges the importance of the influence of other students or the social environment as shapers of behaviour. At the university level, group norms and collective attitudes towards sustainability have a significant impact in promoting environmentally friendly behaviours.

Table 5. Students' opinions on the environment and sustainable campus

Survey Question	Answer					Average
	(1)	(2)	(3)	(4)	(5)	
Environmental stewardship is important for the campus and its community	1 (0.3%)	2 (0.6%)	40 (12.4%)	88 (27.4%)	191 (59.3%)	4.4 (100%)
You are satisfied with the environmental management at Universitas Negeri Malang	5 (1.6%)	14 (4.3%)	107 (33.2%)	134 (41.6%)	62 (19.3%)	3.7 (100%)
The green spaces available at Universitas Negeri Malang are important to you	0 (0%)	1 (0.3%)	33 (10.3%)	88 (27.3%)	200 (62.1%)	4.5 (100%)
Universitas Negeri Malang provides sufficient green space to support a better quality of life	1 (0.3%)	9 (2.8%)	74 (23.0%)	110 (34.2%)	128 (39.8%)	4.1 (100%)
The energy-saving practices carried out by the Universitas Negeri Malang do support a better quality of life.	0 (0%)	1 (0.3%)	64 (19.9%)	118 (36.6%)	139 (43.2%)	4.2 (100%)
Climate change mitigation programs (greenhouse gas emission reduction) support a better quality of life	0 (0%)	1 (0.3%)	37 (11.5%)	101 (31.4%)	138 (56.8%)	4.4 (100%)
Waste management at Universitas Negeri Malang (e.g. waste segregation, waste reduction) supports a better quality of life	1 (0.3%)	4 (1.2%)	43 (13.4%)	98 (30.4%)	176 (54.7%)	4.4 (100%)
Water management (water saving) carried out by the Universitas Negeri Malang supports a better quality of life	1 (0.3%)	3 (1.0%)	42 (13.0%)	101 (31.4%)	175 (54.3%)	4.4 (100%)
Universitas Negeri Malang transportation conditions (amount of traffic, availability of public transportation, etc.) support a better quality of life	5 (1.5%)	13 (4.0%)	86 (26.7%)	100 (31.1%)	118 (36.7%)	4.0 (100%)
Environmental education at Universitas Negeri Malang (courses and academic activities related to the environment) supports a better quality of life.	1 (0.3%)	7 (2.2%)	64 (19.8%)	115 (35.7%)	135 (42.0%)	4.2 (100%)
You are satisfied with your overall quality of life at Universitas Negeri Malang	3 (1.0%)	6 (1.9%)	82 (25.4%)	142 (44.1%)	89 (27.6%)	4.0 (100%)

The survey results above demonstrate a high level of student opinion regarding campus sustainability. The majority of respondents believe that energy management practices (43.2%), climate change mitigation programs (56.8%), waste management (54.7%), and water management (54.3%) can improve the quality of life on campus. This is also supported by various environmental education activities aimed at enhancing the quality of life (42.0%). This indicates that all respondents are satisfied with the quality of the Universitas Negeri Malang campus (average rating of 4.0), reflecting their understanding of the importance of the campus environment in creating a sustainable environment.

Student perceptions of environmental sustainability at Universitas Negeri Malang show that practices and programs such as energy management, climate change mitigation, and waste management have a positive impact on improving quality of life. This is closely related to the Theory of Quality of Life, which associates individual satisfaction with various aspects of life, emphasizing the importance of sustainable environmental conditions (Fuchs et al., 2020). According to the Theory of Quality of Life, a healthy and sustainable environment not only meets basic human needs but also provides space for personal growth and well-being (Mouratidis, 2021).

The Theory of Quality of Life posits that an individual's overall satisfaction and happiness are determined by multiple factors, including physical health, psychological state, level of independence, social relationships, personal beliefs, and their relationship to salient features of their environment (Mouratidis, 2021). This theory emphasizes that quality of life is a broad, multidimensional concept that usually includes subjective evaluations of both positive and negative aspects of life. A sustainable environment significantly contributes to better physical health by reducing pollution and providing clean air and water, which is reflected in the positive feedback from UM students regarding energy management and waste management practices. These responses indicate students' recognition of the direct impact these initiatives have on their health and well-being (McCabe et al., 2010; Mouratidis, 2021). Furthermore, sustainable practices on campus, such as green spaces and eco-friendly initiatives, contribute to students' psychological well-being by creating a sense of harmony with nature and reducing stress levels. The survey results show that students are satisfied with climate change mitigation programs, which can alleviate anxiety related to environmental degradation (Fuchs et al., 2020).

The positive survey responses from UM students reflect the effective implementation of sustainability initiatives that enhance their quality of life. This alignment with the Theory of Quality of Life underscores the multifaceted benefits of a sustainable campus environment. Students' satisfaction with energy management, climate change mitigation, and waste management practices suggests that these initiatives are meeting their basic needs and contributing to a healthier, more fulfilling campus experience.

1. Energy management practices. Efficient energy use not only reduces operational costs but also minimizes the campus's carbon footprint, contributing to a cleaner, healthier environment. Students' satisfaction with these practices indicates their awareness of the long-term benefits of energy efficiency on their health and well-being (Latif et al., 2021).
2. Climate change mitigation programs. Programs aimed at reducing greenhouse gas emissions and promoting renewable energy sources play a critical role in combating climate change. The high level of student approval for these programs demonstrates their understanding of the importance of such initiatives in ensuring a sustainable future (Alhamad et al., 2024).
3. Waste management. Effective waste management practices, such as recycling and composting, reduce pollution and promote a cleaner campus environment. Students' positive feedback on waste management practices highlights their recognition of the environmental and health benefits of reducing waste and conserving resources (Zhang & Tu, 2021).
4. Water management. Sustainable water management practices, including the use of rainwater harvesting and water-efficient fixtures, ensure the conservation of this vital resource. The survey results show that students appreciate these efforts, recognizing the importance of water sustainability for their quality of life and the environment (Guo et al., 2020).

3.2. *Mapping*

3.2.1. Distribution and size of covered in forest vegetation

The distribution and size of covered in forest vegetation at Universitas Negeri Malang, encompassing campuses 1, 2, and 3, are represented in **Figure 4**. This mapping result is also supplemented with information on the size of forest vegetation (Ha) and the percentage (%) at each campus in **Table 6**. According to the mapping analysis results, the total forest vegetation at Universitas Negeri Malang is 11,618 Ha, which constitutes 22,971%. In the UI GreenMetric evaluation under the settings and infrastructure (SI) category, the indicator "total area on campus covered in forest vegetation" scored 75 and is classified in category "4".

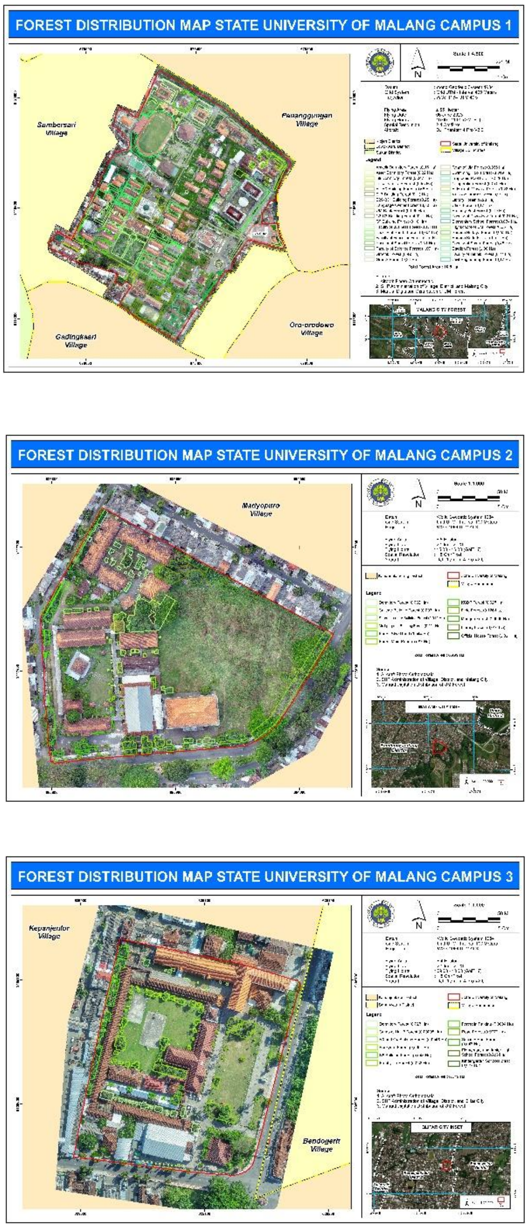

Figure 4. Map of the distribution and size of covered in forest vegetation at Universitas Negeri Malang, Campus 1 (a), Campus 2 (b), and Campus 3 (c) in 2023

The campus areas covered with forest vegetation provide various implications. Forests around the campus deliver clean and comfortable air for the campus community (Susilowati et al., 2021). Clean and fresh air can enhance the physical and mental well-being of the surrounding community (Baur, 2022). Furthermore, the presence of forests also creates green open spaces that can be utilized for various activities, such as recreation, sports, and other events (Tudorie et al., 2020). This not only provides a comfortable learning and campus life experience but also promotes a sustainable lifestyle (Menon & Suresh, 2020).

In addition to positively impacting the campus community life, the existence of forests also contributes to climate change mitigation and biodiversity conservation (Muluneh & Worku, 2022). Forests function as carbon sinks, addressing global warming and producing oxygen for other living beings (Nunes et al., 2020). Forests also serve as natural habitats and support biodiversity through the conservation of plant and animal species (Basavarajaiah et al., 2020). This is crucial for maintaining ecosystem stability and as a supportive means for conducting education and research at the university.

Table 6. Forest vegetation size (Ha) and percentage (%) based on data analysis using the calculate geometry method in ArcGIS Software

Location	Area Size (Ha)	Forest Vegetation Size (Ha)	Percentage (%)
Campus 1	45,182	10,800	23,93
Campus 2	2,937	0,499	16,99
Campus 3	2,457	0,319	12,98
Number and ratio (%)	50,576	11,618	22,97

3.2.2. Distribution and size of planted vegetation

The distribution and size of planted vegetation at Universitas Negeri Malang, encompassing campuses 1, 2, and 3, are represented in **Figure 5**.

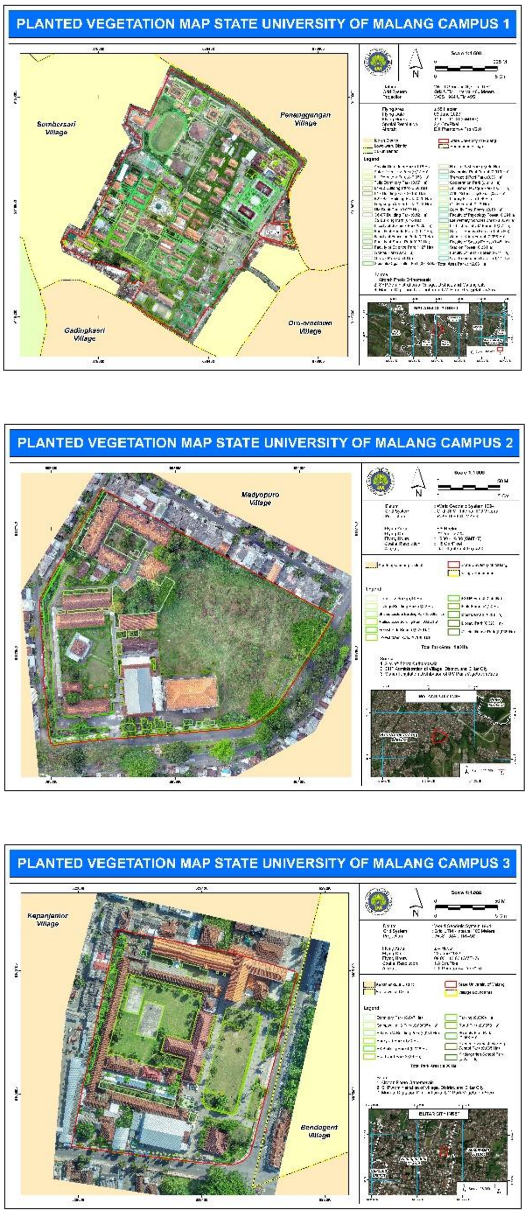

Figure 5. Map of the distribution and size of planted vegetation at Universitas Negeri Malang, Campus 1 (a), Campus 2 (b), and Campus 3 (c) in the Year 2023.

This mapping is also supplemented with information on the size of planted vegetation (Ha) and their corresponding percentages (%) at each campus in **Table 7**. According to the mapping analysis, the total planted vegetation at Universitas Negeri Malang amounts to 15,400 Ha, or 30,449%. In the UI GreenMetric evaluation under the settings and infrastructure (SI) category, the indicator "total area on campus covered in planted vegetation" scored 150 and is classified in category "4".

Table 7. Planted vegetation size (Ha) and percentage (%) based on data analysis using the calculate geometry method in ArcGIS Software

Location	Area Size (Ha)	Planted Vegetatation Size (Ha)	Percentage (%)
Campus 1	45,182	12,660	28,020
Campus 2	2,937	1,880	64,010
Campus 3	2,457	0,860	35,002
Number and ratio (%)	50,576	15,400	30,449

The implications of having planted vegetation represent and support the previous indicator, namely the presence of forests, which are interconnected. Planted vegetation provides important green open spaces for creating activity areas for the community, such as sports facilities for students, staff, and campus visitors (Tudorie et al., 2020). Besides positively impacting mental health, planted vegetation also strengthens social bonds and builds a sense of comfort and safety within the campus environment (Baur, 2022).

As areas planted with vegetation, planted vegetation also benefits the surrounding environment. Planted vegetation produces oxygen and absorb carbon dioxide, making the area around them feel cooler and helping to prevent global warming, especially in campus areas (Muluneh & Worku, 2022). This is a crucial step in maintaining environmental sustainability and protecting local biodiversity (Basavarajaiah et al., 2020).

In educational aspects, planted vegetation can create a cooling and inspiring learning atmosphere for creativity. Planted vegetation can be utilized by faculty and students as locations for outdoor learning, group discussions, and personal reflection (Dring et al., 2020). The planted vegetation at Universitas Negeri Malang positively impacts the productivity of the community through the provision of comfortable and cool green open spaces (Alnusairat et al., 2021).

Planted vegetation not only promotes community well-being but also contributes to the preservation of the environment sustainably.

3.2.3. Distribution and size of water absorption

The distribution and size of forest vegetation at Universitas Negeri Malang, which includes campuses 1, 2, and 3, are represented in **Figure 6**. This mapping is also supplemented with information on the size of forest vegetation (Ha) and their corresponding percentages (%) at each campus in **Table 8**. According to the mapping analysis, the total forest vegetation at Universitas Negeri Malang is 11,319 Ha, which constitutes 22,380%. In the UI GreenMetric evaluation under the settings and infrastructure (SI) category, the indicator "total area on campus for water absorption besides the forest and planted vegetation" scored 75 and is classified in category "4".

The presence of water absorption is closely linked with the goals of a green campus. The green campus concept is not only about greening and environmental preservation but also involves the effective and efficient management of water resources (Amanina & Ilham, 2024). Water absorptions serve as indicators that synergize with the two previous indicators, as they involve land areas that support the development of forest and planted vegetation (Pille & Säumel, 2021).

Water absorptions are capable of naturally absorbing and storing rainwater through vegetation growing on the soil. The presence of forests and planted vegetation serves not only as aesthetic features but as green infrastructure in water management (Monteiro et al., 2020). Moreover, water absorptions reduce the dependence on artificial water sources, such as clean water from wells or pipelines (Geetha Varma, 2022). These areas also positively impact the balance of the local ecosystem, including plants, animals, and microorganisms (Tolossa et al., 2020).

3.3. *Green area in UM green campus according to UI GreenMetric*

Green areas play a crucial role in enhancing the environmental quality and sustainability of the campus environment. Based on the mapping conducted at Universitas Negeri Malang, forest vegetation contributes 11,618 Ha, or about 22.971%, planted vegetation contributes 15,400 Ha or 30.449%, and water absorption contributes 11,319 Ha or 22.380%. According to the UI GreenMetric evaluation, these percentages fall within category 4, with respective weights of 75 for forest vegetation and water absorption, and 150 for planted vegetation. While these results are commendable, efforts are needed to increase the extent of green

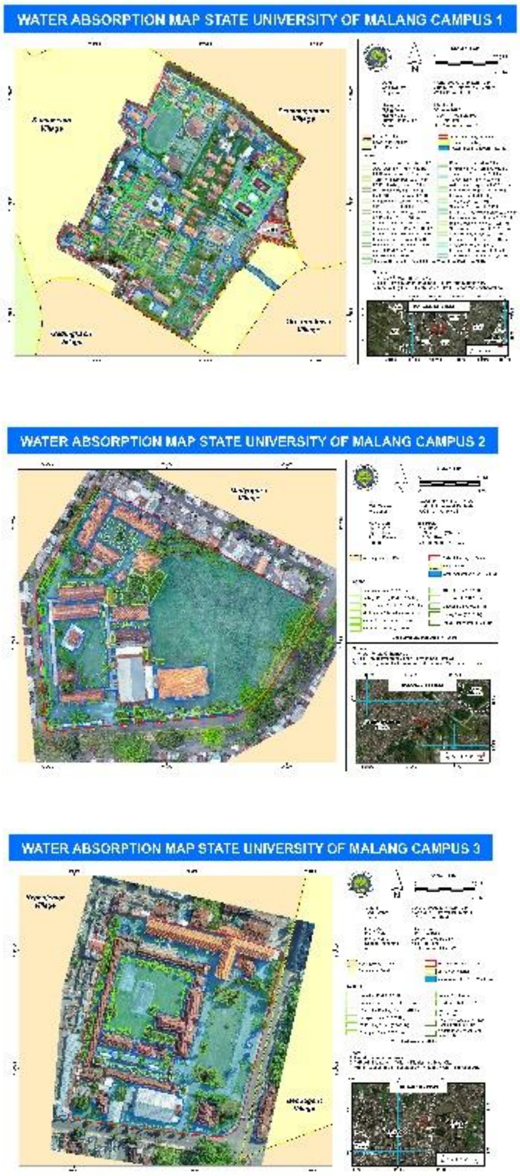

Figure 6. Map of the distribution and size of water absorption at Universitas Negeri Malang, Campus 1 (a), Campus 2 (b), and Campus 3 (c) in 2023.

areas, not only to enhance ratings and rankings but also to reap benefits and support environmentally friendly sustainable development (Abakumov & Beresten, 2023).

Table 8. Water absorption Size (Ha) and percentage (%) based on data analysis using the calculate geometry method in ArcGIS Software.

Location	Area Size (Ha)	Water Absorption Size (Ha)	Percentage (%)
Campus 1	45,182	10,720	23,726
Campus 2	2,937	0,499	16,990
Campus 3	2,457	0,319	12,983
Number and ratio (%)	50,576	11,319	22,380

Green areas have significant importance, both on small and large scales. They act as carbon sinks, reducing the adverse effects of greenhouse gases and thereby mitigating global warming (López-Pacheco et al., 2021). Green areas support air quality by absorbing pollutants and producing oxygen, creating a healthier learning environment. As educational spaces, green areas enable field studies and environmental research for both faculty and students. Green areas also help reduce stress and enhance the mental well-being of students and staff, providing spaces for relaxation, reflection, and social interaction. Furthermore, green areas enrich campus biodiversity, supporting a variety of flora and fauna by providing habitats and food (Imbar et al., 2020).

4. Conclusions

Based on the survey results, it can be concluded that students' perceptions of the UM Green Campus are rated as very good. Various points presented have an average above 4.0, while only a few points are below 4.0. In the mapping results, the green areas as per the UI GreenMetric indicators are divided into three categories: forest vegetation, planted vegetation, and water absorption, each with different criteria and evaluation weights. As a university implementing the green campus concept, it is crucial for Universitas Negeri Malang to perform mapping on the distribution and size of green areas across the entire campus. According to the mapping and calculate geometry analysis in ArcGIS, forest vegetation comprises 22.971%, planted vegetation 30.449%, and water absorption 22.380%. These results meet category 4 criteria and are considered good. However, further efforts are necessary to enhance these outcomes, not only to improve ratings but also to create an increasingly environmentally friendly campus environment.

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Original Paper

The aesthetics of recycling as an entry point for innovative artwork related to environmental issues

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Abstract. *This research examines the aesthetics of recycling as an entry point for creating innovative artwork related to environmental issues. It explores the relationship between art and the environment, highlighting the importance of environmental protection and sustainable processes. The study* *also addresses challenges in producing sustainable artwork and innovative methods for transforming old materials into usable ones. The research emphasises the role of recycling in preserving the environment and reducing pollution while promoting awareness of this issue through art. The research suggests that innovative artworks produced using recycling techniques can serve as a sustainable and innovative solution for environmental design. This research aims to promote recycling as an entry point for artists and designers to create innovative artworks, raising awareness of environmental protection and sustainable development. It seeks to enhance societal and environmental culture and study the impact of artworks in decoration and interior design on the environment. Future research can explore improving the environmental quality of homes and public buildings using recycling techniques and materials.*

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1. Introduction

Recycling has become an important focus of global interest in intersecting economic and environmental issues. It presents a substantial investment opportunity with low costs and profitable returns, making it accessible to various societal segments, particularly those unable to afford high-cost investments (Rahimi & Ghezavati, 2018). It involves processing waste materials whether household, industrial, or agricultural to reduce their environmental impact. Since the 1990s, indirect recycling, which repurposes waste into new products using the same materials, has gained prominence. This benefits consumers who cannot afford new products and plays a vital role in waste management.

Visual arts are a primary medium for expressing environmental issues. Artists can significantly raise public awareness about environmental protection by demonstrating how recycled materials can be used creatively. Recycling in visual arts involves reusing materials from daily life and subjecting them to new shaping techniques to create innovative artistic works. This practice is crucial for achieving sustainability by reducing resource exploitation, mitigating pollution, enhancing financial sustainability through raw material provision, and creating job opportunities. Socially, recycling can promote environmental awareness and job creation (Anjum et al., 2016).

Artworks, defined as creations reflecting the artist's creativity and expression, vary in forms, sizes, styles, and content. They encompass various techniques, including sculpture, painting, drawing, textile art, ceramics, and mixed media (Lucie-Smith, 2003; Sampah et al., 2024). They can reflect environmental issues and promote awareness of challenges like climate change and environmental protection (Edwards, 2022).

2. The research framework

The limited use of sustainable techniques in the art industry, specifically in the design of artistic creations, has led to increased consumption of natural resources and environmental pollution. Art is greatly affected by climate change, particularly in terms of resource availability and quality. This research focuses on how to benefit from the aesthetics of recycling in the design of innovative artistic creations in the face of environmental issues. It delves into the significance of recycling within sustainable art practices and its positive environmental impact. It emphasises the crucial role of sustainability in artistic production, particularly in light of global challenges such as climate change, and advocates for adopting sustainable methods and techniques that conserve natural resources.

The research objectives are:

1. To study the challenges of climate change and its impact on art production in general and artistic creations, and how to transform these challenges into opportunities for developing sustainable art.

2. To identify sustainable design methods, techniques, and recycled materials and how to use them to produce sustainable art creations.

3. To apply these methods and techniques in designing and producing a sustainable artistic creation and evaluate the experimental results.

The vision for sustainability presented involves showcasing how art can act as a catalyst for environmental awareness by repurposing waste into innovative artworks. An approach is proposed that not only showcases the creative possibilities of recycling but also fosters dialogue about environmental stewardship. The contribution to sustainability discourse lies in connecting the realms of recycling and art, providing insights into how recycled materials can be transformed into meaningful expressions that resonate with audiences on both aesthetic and ecological levels.

3. Theoretical and practical aspects of recycling's aesthetics

This section is divided into three parts. First, it investigates the concept of recycling and its relationship to sustainability, sustainable art, and the significance of recycling in relation to environmental issues. Second, it studies the relationship between recycling and artistic craftsmanship, investigating how recycled materials contribute to new artistic craftsmanship as well as the aesthetics of recycling's impact on artistic expression. The third part considers the obstacles that artists face while creating sustainable art. It examines works by global artists such as David Buckland, Alice Chappel, and Stephanie Kilgast and their approaches to recycling and sustainable art.

3.1 Recycling, artistic craftsmanship and the environment

Recycling can offer a way of effectively addressing environmental issues by providing a sustainable means of resource management. It repurposes old materials, reducing waste and the need for new resource extraction, thereby minimising environmental damage (Yu et al., 2019). Recycling significantly reduces carbon emissions, improves air quality, and preserves natural resources (Unescwa, 2020). By using eco-friendly and recycled materials, sustainable art merges creativity with environmental stewardship, balancing artistic expression with sustainability principles like environmental protection, social justice, non-violence, and democracy. As defined by Maja and Robin Fox, it challenges societal norms, proposes alternatives, respects cultural and biological diversity, and fosters interaction between artist and audience (Fox, 1983).

Art made from recycled materials reflects environmental and social values, encouraging change and conveying messages about sustainability. Such works engage audiences, highlight environmental challenges, and stimulate thinking about climate change (Gorsegner, 2016). Artists showcase creative transformation by reimagining recycled materials and promoting sustainable and aesthetically pleasing future visions through recycling.

According to Tadesse & Melesse (2022), handicrafts are considered an art form that encompasses artistic, aesthetic, and functional values through techniques that align with the nature of each material or medium used to produce the artwork. Materials are fundamental to an artwork's structure, embodying the artist's vision. Artists have long experimented with and recycled various materials, combining intellectual and technical innovations. In artistic crafts, materials hold both structural and aesthetic values, making them central to the production process. Consequently, recycling materials in art has become a modern trend, emphasising the reuse of recyclable materials to create innovative artworks. This trend seeks to balance artistic creativity with environmental sustainability by using recycled or biodegradable materials. Artists leverage recycled materials to communicate their vision, crafting unique works. For instance, recycled plastic sculptures highlight environmental impact, urging responsible consumption. Similarly, colourful designs crafted from recycled paper promote recycling and waste reduction and promote responsible consumption and sustainable waste management (Bahrami & Jafari, 2020; Mansour et al., 2020).

Upcycling, a practice of creatively reusing waste, has ancient roots. From prehistoric times, humans crafted tools and shelters from available materials. Today, millions worldwide, with limited resources, rely on upcycling for survival, often creating "informal housing" from discarded items (Das, 2012). Recycling encompasses processing various materials like paper, plastic, glass, metals, fabrics, clothing, and tires. Paper is converted into pulp for new paper production, while plastic is moulded into items like bottles and furniture. Glass is melted and reshaped, metals are used for cans and tools, and fabrics for carpets and apparel. Tires find new life as shoes, flooring, and furniture.

Recycling adds aesthetic value by redefining classic art in novel ways. Diverse and unique artworks repurpose materials that were previously wasted, including plastic, glass, paper, metals, and more. Recycling gives artworks new meaning and original creative ideas. The artwork has a visually appealing quality due to the different forms, colours, and textures of the recycled materials. Repurposed glass, for example, can be used to create colourful installations, and textiles can be used to make one-of-a-kind garments or provide visual coherence to artwork.

Recycling enhances artwork by transforming it into a story from recycled materials, bringing its history and unique narrative to life. This enhances the artistic and spiritual value of the artwork. Viewers can interact with the recycled artwork, learning about the materials and their transformation, fostering communication and interaction between the artist and the audience. Recycled artworks balance aesthetics and message, inspiring viewers to think and act to bring about change.

3.2 The visual artist and sustainable artistic craftsmanship

The visual artist plays a crucial role in promoting sustainable art, as they can be pioneers in using sustainable and recyclable materials in their artwork. Their role is evident in shedding light on sustainability and environmental issues and raising environmental awareness through their artistic works. Several aspects can be explored regarding the relationship between the visual artist and sustainable art.

Choosing sustainable materials

Choosing sustainable materials is key to producing sustainable artwork. The visual artist can use recycled materials such as paper, upcycled glass, or reused metals. This choice can help reduce the use of environmentally harmful materials and contribute to the preservation of natural resources.

Balancing aesthetics and sustainability

Balancing aesthetics and sustainability is an important challenge in producing sustainable artwork. The visual artist should combine artistic beauty with sustainable materials to reflect the intended message and captivate the viewers' attention. This balance can have a powerful impact on the viewers, encouraging them to think about sustainability and work towards increased environmental consciousness (Lineberry & Wiek, 2016).

Innovation and experimentation

The visual artist inspires innovation and experimentation in sustainability. By experimenting with different sustainable materials, the visual artist can create new techniques and methods for producing sustainable artwork. This encourages innovative thinking and advancements in the field of sustainable art.

Social and environmental messaging

Artists can use sustainable artwork to address social and environmental issues, like climate change. These pieces convey powerful messages, raising awareness and inspiring action for environmental preservation. They motivate viewers to engage in positive change efforts (Barrett, 2016). Adopting the concept of sustainability in visual art represents a significant shift toward environmental conservation and sustainable development. Creating sustainable artwork requires the visual artist to face challenges that may arise from working sustainably and its impact on their artistic work.

Choosing sustainable materials

Selecting sustainable materials is one of the main challenges for the visual artist. They may struggle to find materials that align with sustainability and meet their artistic needs. The artist may need to explore alternative sustainable materials such as recycled or organic natural materials.

Sustainable production techniques

The visual artist may encounter difficulties applying sustainable production techniques in their artistic work. They may need to acquire new skills and learn innovative techniques that integrate sustainability into production.

Balancing artistic message and sustainability

Visual artists face a challenge in balancing the artistic message with sustainability. They must consider how to express their artistic vision using sustainable materials and focus on sustainability-related topics.

Awareness and engagement with the audience

Visual artists face the challenge of promoting sustainability through their work, necessitating clear communication of their vision and role. Achieving sustainable art involves research, learning, and innovation to master recycling aesthetics. The article discusses global artists' contributions to raising awareness of environmental issues, highlighting art's potential to drive change beyond institutional policies.

3.3 Works by global artists

Global artists with innovative visions of recycling and sustainable art provide opportunities for creativity and artistic expression, setting clear examples and serving as role models for all visual artists concerned with environmental issues. The following renowned artist's artworks provide some significant examples.

David Buckland

David Buckland is an artist, director, writer, and curator. He is the founder and director of the international project "Cape Farewell," which brings together artists, scientists, and educators to build collective awareness and cultural response to climate change and its environmental impact. His artistic works utilise photography, video, and installations to illustrate the human impact on the environment and the challenges it faces. The "Cape Farewell" project aims to unify science and art to create positive actions in addressing climate change. Buckland uses art as a communication tool to convey his messages, collaborating with artists, scientists, and creatives to create artworks that reflect the effects of climate change, enhance awareness, and inspire action (Farewell, 2023). Buckland utilises diverse art mediums such as drawing, photography, installation, and performance to address climate change, emphasising art's role in raising awareness and driving social change. He encourages audience engagement with environmental issues and promotes collaborative efforts for engaging with sustainability.

Buckland's works are in permanent collections at the National Portrait Gallery in London, the Centre Pompidou in Paris, and the Metropolitan Museum of Art in New York. Some of his notable works include:

Figure 1. "Discounting the future" (2008).

Ice Texts series: In this work, he uses light and shadow to write messages on the ice at the North Pole.

Figure 2. "Internal combustion" (2012)

Carbon 13: In this work, he uses an old car engine and pipes to show the amount of carbon emitted by a single car per hour.

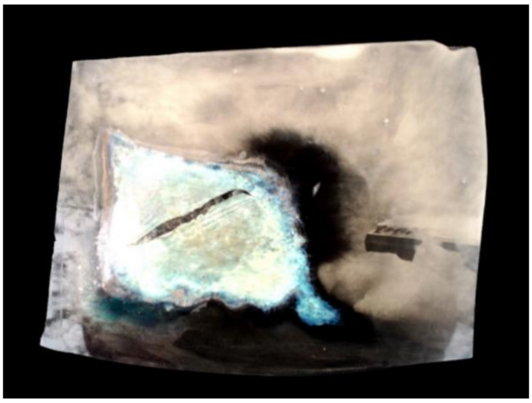

Figure 3. "Ice Shards" (2005)

Ice Shards: In this work, he uses sculpted and illuminated ice shards to create a stunning visual effect and remind viewers of the threat faced by ice due to climate change. (Figure no.3)

Source: Art, 2023; Farewell, 2023

<u>Alice Chappel</u>

Alice Chappel is a creative contemporary artist known for her sustainable and artistic works that utilise recycled materials to create unique art pieces. Her work combines her passion for art with her interest in sustainability and recycling. The artist's unique pieces, incorporating recycled materials like plastic, glass, old metals, and electronic waste, reflect artistic vision and environmental themes. Chappel's innovative techniques transform recycled materials into stunning pieces, inspiring and educating audiences about recycling and preserving natural resources (Wiguna et al., 2021). The artist has exhibited her work in international and local exhibitions, earning widespread recognition and acclaim in sustainable art. Notable works include winged insects in Figures 4, 5, 6, and 7.

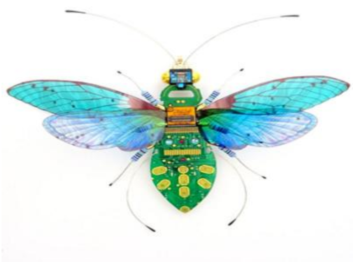

Figure 4

Figure 5

Figure 6

Source: Sayidaty, 2023

Figure 7

Stephanie Kilgast

Stephanie Kilgast is a French visual artist and painter who primarily works in the field of sustainable and environmental art. Her work focuses on recycling and using recycled materials in her artistic creations. She transforms everyday discarded objects and waste materials into colourful, innovative pieces, using materials like plastic, paper, metals, glass, and old coins. Her pioneering work aims to create a positive environmental impact and raise awareness about recycling and preserving the environment (Wiguna et al., 2021). Kilgast's art prompts reflection on the interplay between creativity and sustainability, crafting marine organism-inspired pieces from waste. Her innovative collection garners global acclaim, illustrating Art's power to convey environmental messages and promote conservation awareness.

Figure 8

Figure 9


Figure 10


Figure 11


Figure 12


Figure 13

Source: Petitplat, 2022; Sayidaty, 2023

Kilgast's works have inspired the applications of this research in the field of recycling and sustainable Art. Using recycled materials in her artistic creations, she provides a living example of how to sustainably utilise discarded materials and reimagine things that may seem useless, transforming them into innovative art pieces. Her artworks showcase innovation and creativity in recycling, using recycled materials like plastic, paper, metals, and glass (Wiguna et al., 2021). The vibrant artworks convey messages of sustainability and environmental preservation by transforming old items and waste into new creations. Her creativity highlights the aesthetic and creative potential of recycled materials, stimulating individuals to reconsider disposability and embrace recycling for environmental and economic benefits.

4. Research applications

This section describes the results of an applied experiment conducted with a group of students, utilising various waste materials such as paper and plastic, and recycling them through different artistic techniques, including heat, fusion, and additive shaping. Each shaping technique could be used individually, combined in pairs, or incorporated altogether to create a unique artistic style. This approach enriched the artworks and emphasised the aesthetics of recycling. The transformation process rendered the original raw materials, thereby foregrounding the aesthetics and underscoring the value of recycling and sustainable art. The applied works produced during the experiment are presented as follows:

First artwork

Figure 14

The artwork title is "Marine Coral". The materials used were tin plates, threads, papers, and colours. The artistic technique used for this artwork was fusion, additive, and paper pastes.

Second artwork

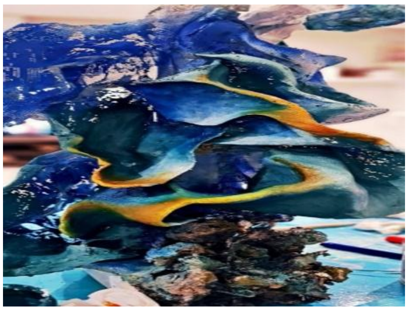

Figure 15

The artwork title is "Marine Invertebrates". The materials used were nylon plastic wrappers, paper pastes, and colours. Fusion and additives were used as an artistic technique.

Third artwork

Figure 16

The artwork title is “Fish”. The materials used were clear nylon bags, colours, heat shaping, and additives were used as an artistic technique.

Fourth artwork

Figure 17

The artwork title is "Coral Reefs". The materials used were tin plates, and fusion and additives were used as artistic techniques.

Fifth artwork

Figure 18

The artwork title is “Jellyfish”. The materials used were plastic bottle colours. Fusion and heat shaping were adapted as artistic techniques.

Sixth artwork

Figure 19

The artwork title is "Marine Invertebrates". The materials used were plastic bottle colours, and fusion, heat shaping, and additives were used as an artistic technique.

Seventh artwork

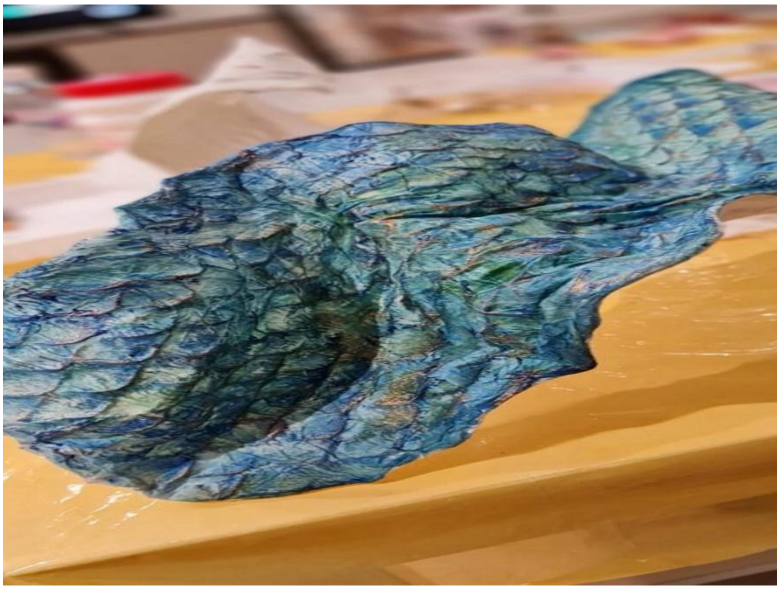

Figure 20

The artwork title is "Fish". Materials used for the artwork were metal window wires, paper pastes and colours. Fusion and additives were used as an artistic technique.

Eighth artwork

Figure 21

The artwork title is "Marine Invertebrates". Materials used were nylon bag colours, whereas fusion and additives were used as an artistic technique.

Ninth artwork

Figure 22

The artwork title is "Marine Animal Structure". Materials used metal window wires, paper pastes, colours. Fusion and additives were used as an artistic technique.

5. Discussion

The research examines the aesthetic impact of recycling as a creative approach to producing artistic creations, particularly in the face of climate change challenges. It seeks to explore how recycling can be used as a tool for artistic expression and addressing environmental and sustainability issues, as well as the artistic concept of recycling and its application in art. The research highlights using recycled materials and resources to create new and unique art pieces. It focuses on the beauty of this process and how artists can transform old and neglected materials into innovative artworks that reflect artistic and environmental value.

This aligns with existing literature on sustainable art practices and the role of art in environmental education. Previous studies have demonstrated that incorporating recycled materials in art can effectively raise awareness about environmental issues and promote sustainability. The outcomes of this study support these conclusions, revealing that students not only engaged creatively with the materials but also developed a deeper understanding of recycling and sustainability (Afriyie et al., 2022; Rahimi & Ghezavati, 2018).

The experiment conducted in the transformation of waste materials into aesthetically pleasing art pieces highlights the potential of art as a medium for environmental education. The inability to recognise the original raw materials in the final artworks emphasises the transformative power of art and the concept of reimagining waste. This finding resonates with the work of other researchers who have noted the capacity of art to shift perceptions about waste and resourcefulness (Brown & Green, 2019).

The artworks produced serve as practical examples of how artistic practice can be integrated into environmental education. The first artwork, “Marine Coral”, demonstrates the student's ability to reimagine waste materials into complex and visually appealing structures, echoing the intricate forms of coral reefs. The use of tin plates and threads in fusion processes highlights how discarded materials can gain new life and value through artistic intervention. Following this, “Marine Invertebrates” exemplifies the integration of diverse materials to mimic the delicate forms found in marine ecosystems. The choice of nylon plastic wrappers emphasises the potential to reuse common waste products in a way that is both meaningful and educational (Bertoli et al., 2022).

“Fish”, demonstrates the student's capacity to employ heat-shaping techniques to transform mundane materials into fluid and dynamic forms. The use of clear nylon bags, typically seen as waste, in the creation of an aesthetically pleasing and environmentally themed artwork underscores the educational aspect of the project. In addition, “Coral Reefs” showcases the potential of metal waste to be repurposed into intricate and beautiful art pieces. The student's ability to manipulate tin plates into forms reminiscent of coral structures highlights the versatility and creative potential of recycled materials. “Jellyfish” highlights the fluidity and transparency of plastic bottles, transforming them into organic, ethereal forms. The application of heat-shaping techniques to create the delicate tentacles of the jellyfish demonstrates the innovative use of everyday waste in art.

"Marine Invertebrates" reflects the complexity and diversity of marine life, using plastic waste to create intricate forms that mimic natural structures. The combination of multiple techniques showcases the students' ability to experiment and innovate with recycled materials. "Fish" illustrates the potential to transform industrial waste into art. The use of metal wires to create the skeletal structure of the fish emphasises the durability and versatility of recycled materials.

"Marine Invertebrates" reflects the delicate and intricate forms of marine life, using everyday waste materials to highlight the beauty and complexity of underwater ecosystems. The student's ability to transform nylon bags into detailed art pieces underscores the educational impact of the project. "Marine Animal Structure" highlights the potential of combining industrial and organic waste materials in art. The intricate design demonstrates the students' skill in reimagining waste materials as components of complex and aesthetically pleasing structures.

Ellison et al. (2018) examine projects that bring together diverse expertise from fields such as science, engineering, and the visual arts to create environmentally conscious artworks, demonstrating the creative possibilities that emerge from this interdisciplinary approach. This experimental application provides an opportunity to explore a diverse range of artists and their approaches to using recycling as a gateway to artistic creativity. It sheds light on the creative potential of sustainable materials and provides innovative responses to environmental challenges.

6. Conclusions

The research presented in this paper aims to explore the aesthetics of recycling and sustainable art in the context of climate change and its impacts. The aim has been to show how studies of this kind can contribute to understanding and developing strategies to mitigate and adapt to these impacts. Future research can concentrate on developing ways in which recycling techniques and materials in art is practiced as a significant means for addressing climate change challenges by balancing aesthetics and sustainability, integrating creativity with environmental responsibility and quality in homes and public buildings, increasing the positive impact on the environment of artworks in decoration and interior design. Supporting artists to help them create unique works that use recycled materials and embody sustainable values through promoting public participation and providing funding is essential for this development.

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Original Paper

Is nature conservation included in the training of teachers and educators?

The contribution of the SOFIA educational platform

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Abstract. *In the context of education for sustainable development, ecology can play a pivotal role in transforming human society. In this framework, the present paper addresses the training of Italian Teachers and Educators (T&Es) in ecological topics, with a special focus on nature conservation – a topic that has garnered increasing attention in recent years. The analysis centres on Italy's national training platform for schools, Sistema Operativo per la Formazione e le Iniziative di Aggiornamento del personale della scuola*

(SOFIA) – a unique platform in terms of relevance within the Italian education system. Our findings reveal a notable lack of attention to ecological topics, particularly nature conservation topics, within its training programs. We also observed that keywords such as "ecosystem", "ecology" and "climate change", used to identify courses on SOFIA, are often used in ways that diverge from their ecological roots. This issue is explored in the context of a rapidly evolving educational culture, where traditional ecological terms appear to be losing their effectiveness in identifying educational areas with a focus on ecology and nature, while acquiring different connotations altogether in other disciplines. The current polysemic usage of these keywords significantly complicates the identification of courses strictly focused on ecological topics for teachers and educators seeking their further training. This difficulty is even more significant in the context of ecological content with a special focus on nature conservation, where educational offerings are already limited. The paper concludes with a reflection on educational approaches that affect the availability of courses aimed at T&Es.

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1. Introduction

In the current geological era, recognised by many as the Anthropocene (Crutzen & Stoemer, 2000), we face huge environmental challenges such as climate change, biodiversity decline and habitat loss (Cooke et al., 2021). In recent years, the integration of the 2030 Agenda for Sustainable Development (United Nations [UN], 2015)[1] into cultural, administrative, and educational spheres of civil society, has led to a broader perception of the environment as a complex system. This transformation calls for a comprehensive understanding of the trans-scalar and inter-sectoral relationships linking both humans and nature to the global scale of environmental problems (Intergovernmental Panel on Climate Change [IPCC], 2021). For example, regional climate change is seen as strongly interconnected with global climate change. Furthermore, understanding of environmental topics is no longer being addressed solely at the governmental and

[1] https://sdgs.un.org/2030agenda. Accessed 20 June 2024.

intergovernmental level, but is also being tackled locally through awareness-raising initiatives aimed at the general public. In fact, the general public's understanding of environmental issues is crucial not only for reducing negative human impact on the environment but also for promoting Nature Conservation (NC). NC is defined here on the basis of the World Conservation Strategy - WCS, prepared by International Union for Conservation of Nature and Natural Resources [IUCN], United Nations Environment Programme [UNEP], World Wildlife Fund [WWF] (1980), that defines *Conservation* 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". This WCS definition revolves around the *living resource conservation*,[2] a key concept of the NC practices. NC topics represent a mainstream subject within Environmental Education (EE). A specific sector of EE literature that addresses the themes of NC is Conservation Education.[3] This field illustrates the many techniques available for creating effective education and outreach programs for conservation (Jacobson, McDuff & Monroe, 2015) included within the broader framework of practices aimed at sustainable development as outlined in the 2030 Agenda for Sustainable Development. Education plays a central role in this context, and all levels of governments, from local to global, are being asked to develop programs for sustainable development, including education campaigns (UN, 1992, 2015). These efforts involve investing in training, education, digital literacy, and capacity-building (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2021a). UNESCO (2021b) stresses that "one of the areas that needs significant attention is building the capacity of educators to ensure that education for sustainable development and environmental education content is effectively introduced in the various subjects, courses, and grade levels". In the framework of education

[2] According to WCS living resource conservation has three specific objectives: "to maintain essential ecological processes and life-support systems (such as soil regeneration and protection, the recycling of nutrients, and the cleansing of waters), on which human survival and development depend; to preserve genetic diversity (the range of genetic material found in the world's organisms), on which depend the breeding programmes necessary for the protection and improvement of cultivated plants and domesticated animals, as well as much scientific advance, technical innovation, and the security of the many industries that use living resources; to ensure the sustainable utilisation of species and ecosystems (notably fish and other wildlife, forests and grazing lands), which support millions of rural communities as well as major industries". https://portals.iucn.org/library/efiles/documents/wcs-004.pdf. Accessed 20 June 2024.

[3] According to its traditional definition, Conservation Education is "the study of man's intelligent use of his natural environment through the development, management, preservation, and renewal of natural resources for his material, cultural, and aesthetic needs to benefit present and future generations" (Warren, 1970).

for sustainable development, ecology plays an important role in the transformation of human society (UNESCO, 2018).

This conceptual framework also draws attention to the complexity of the interdisciplinary knowledge system involved in EE practices, specifically concerning Conservation Education. Now, this conceptual and procedural complexity could disorient teachers and educators,[4] particularly those interested in NC. In this framework, a focal key question is: what is the current situation of educational processes in schools regarding ecological topics and NC? To answer this question several factors should be considered, starting with the school curriculum.[5] UNESCO (2021b), relating to a global review of national curricula and policy documents, points out that in 2021 47% of national curricula in 100 countries had no references to climate change and only 53% included climate change at least once. According to a similar survey by UNESCO (2021a), 45% of national primary and secondary education policies and curricula, surveyed across 46 UNESCO Member States, made little-to-no reference to environmental themes such as biodiversity. Mulvik et al., (2021), in a survey targeting primary and secondary teachers, report that half of EU Member States are working on competencies for the general theme of "environmental sustainability"; however, the latter is not yet considered a systemic feature of education and training policy in the EU (European Commission [EC], 2022). In the United Kingdom, in 2020, the Climate Assembly recommended making climate change a compulsory subject in all schools.[6] In Italy, the education system has recently increased its commitment to environmental themes in formal education: in 2019 a law was passed making environmentally sustainable development compulsory for all students in primary and secondary education.[7]

Another element to consider is the focus on T&E training on NC topics. Concerning the presence of environmental issues in teacher education, UNESCO underlines a considerable variation across countries, ranging from 16% in Croatia to 82% in Colombia, and 27% in Malta and Italy (Wheeler, 2019, as cited in UNESCO, 2021a, p. 19). On top of that, training activities aimed at

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[4] Hereafter, we will refer to Teachers and Educators using the acronym T&Es.

[5] There are many definitions of "school curriculum" in the literature. For further information on this topic see Aliyeva (2016) who proposes, among others, Tyler's definition: "[The curriculum is] all the learning experiences planned and directed by the school to attain its educational goals".

[6] https://lordslibrary.parliament.uk/. Accessed 23 May 2023.

[7] *LEGGE 20 agosto 2019, n. 92, Introduzione dell'insegnamento scolastico dell'educazione civica. (19G00105) (GU n. 195 del 21-8-2019)* tr. LAW 20 August 2019, n. 92, Introduction of the teaching of civic education in schools. (19G00105) (GU n. 195 del 21-8-2019)

T&Es on environmental issues present gaps in many countries. According to a recent UNESCO survey, which conducted 1600 interviews in 93 countries, environment-related issues are debated little in teacher training programs: only 30% of pre-service and in-service training included environmental issues. Concerning climate change, nearly 95% of teachers believed that "it is important or very important to teach about the severity of climate change and its effects". However, only about 40% of teachers were confident in teaching the cognitive dimensions of climate change, and only about one-fifth of them could explain well how to reduce one's carbon footprint (UNESCO, 2021a). Considering this point, it is clearly essential to promote training initiatives for T&Es on ecological topics, in order to meet the educational needs of future generations and enable them to acquire the knowledge, skills, values and attitudes that will make them conscious contributors to sustainable development (Prisco, 2022) and NC. In various countries, several actions are thus being carried out to reinforce the training of teachers on environmental issues, so as to enable them to be agents of change.

Another aspect to be taken into account in the training of T&Es is the role of digital technologies. Information and Communication Technology (ICT), in fact, is increasingly used in scientific dissemination as well as formal and non-formal education processes (Artacho et al., 2020). For this reason, in 2016 the Italian Ministry of Education, published a National Plan for Digital Education (PNSD) to promote the use of ICT, stimulate innovation and improve teachers' digital competences (Bocconi, Panesi & Kampylis, 2020). Among ICT tools, digital platforms have become an unavoidable part of modern education (Nichols & Garcia, 2022), being increasingly used to support teaching, and learning in several disciplines, including ecology (Sangiorgio et al., 2014a, 2014b). In the school context, education platforms serve as a meeting point for the school communities involved in early childhood, primary, secondary, and initial vocational education. These platforms provide certificates of attendance that can be valuable for the careers of T&Es. One notable example on a transnational scale is the European School Education Platform, which benefits all stakeholders in the school sector by providing access to new content and teaching materials, especially related to European projects.[8]

In Italy, there is an educational platform called "Sistema Operativo per la Formazione e le Iniziative di Aggiornamento del personale della scuola

[8] https://school-education.ec.europa.eu/en. Accessed 23 July 2024.

(SOFIA)",[9] which is recognised and certified by the Ministry of Education and Merit. This platform has been the focus of our research. SOFIA was introduced by the law 107/2015 as compulsory for all Italian schools. It hosts courses and initiatives provided by accredited bodies such as universities, research centres, as well as professional and disciplinary associations linked to scientific communities. SOFIA is considered unique in terms of relevance within the Italian education system (Olivanti, Meschiari & Gastaldi, 2022) and is particularly useful for offering a comprehensive catalogue of the Continuing Teacher Education (Gentile, 2023). The importance of the SOFIA platform in Italian T&E training is testified by the fact that participants in its programs are entitled to exemptions from duty. This reflects the fact that in-service training is considered a mandatory, permanent, and integral part of the teaching profession.[10]

Procedurally, the platform is designed for in-service T&Es from schools at all levels, as well as other school system personnel. It provides a range of thematic macro-categories through which users can explore various training offerings. These courses, delivered both in-person and online, are created and managed by public and private providers across Italy that are subject to evaluation, following a ministerial directive that regulates the accreditation, qualification, and recognition of training providers.[11] SOFIA thus certifies and guarantees the quality of the training programs offered.

To ensure user satisfaction, the platform allows participants to provide feedback on individual courses via a questionnaire. Completing this evaluation is required to obtain a certificate of participation.

Given these features, we decided to explore the training opportunities available to T&Es by observing SOFIA, specifically addressing the following research question: does the SOFIA platform offer training programs for Italian in-service T&Es specifically focused on ecological topics related to NC? Additionally, we offer reflections on the future perspectives of T&E training in this area.

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[9] *Sistema Operativo per la Formazione e le Iniziative di Aggiornamento del personale della scuola* tr. Operating System for the Training of school staff; available at: https://sofia.istruzione.it/. Last accessed 30 April 2024.

[10] Directive 107/2015 art 1, comma 124.

[11] Directive 170/ 2016; https://www.miur.gov.it/web/guest/enti-accreditati/qualificati. Accessed 20 June 2024.

2. Materials and methods

To answer the research question, we have chosen to look into the SOFIA educational platform in detail.[12] On it, T&Es interested in NC or, more generally, in ecological topics can find a course catalogue organised in stable macro-categories representing specific areas of knowledge; these macro-categories are clearly labelled with titles and logos explaining the covered topics (Figures 1, 2). T&Es can access the courses of interest in two ways: by directly browsing the macro-categories or by typing keywords in the "search" field. Among the 13 macro-categories, the one titled "Conoscenza e rispetto della realtà naturale e ambientale"[13] is the most relevant for our purposes.

To address our research question, we searched for courses by keyword; then we analysed the presentation text of each course. Keywords such as *biodiversity*, *climate change*, *ecology*, and *ecosystem/s* were chosen according to UNESCO (2021a), with the addition of *nature conservation*.[14]

3. Findings and discussion

SOFIA's catalogue includes 13 macro-categories (see Figures 1 and 2). These macro-categories have a high degree of heterogeneity in terms of the number of courses per category, ranging from 1.2% (89 out of 7459 courses) for "Education in economic culture" and 20.0% (1491 out of 7459 courses) for "Teaching of individual disciplines as per regulations" (Figure 3).

The first aspect to highlight concerns the macro-category that, as suggested by the title "Knowledge and respect for nature and the environment", is dedicated to environmental knowledge and education. The presence of this macro-category suggests a general interest within the Italian training system in topics concerning "nature" and more broadly "the environment". Looking inside the "Knowledge and respect for nature and the environment" macro-category, however, it becomes clear that this interest is not reflected in the actual educational offer. In fact, the courses in this macro-category are only 3.7% (275 out of 7459) – a relatively low percentage compared to other macro-categories such as 16.9%

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[12] Our research on SOFIA was conducted in April 2024.

[13] Knowledge and respect for nature and the environment (translation by the authors).

[14] The term 'Nature Conservation' is widely recognised and likely familiar to T&Es. A quick search online reveals numerous sites that extensively use this term, including universities and governmental organisations focused on environmental issues.

(1259 out of 7459) for "School and social inclusion" and 15.7% (1172 out of 7459) for "Individual and social needs of students", both addressing social issues (Figure 3).

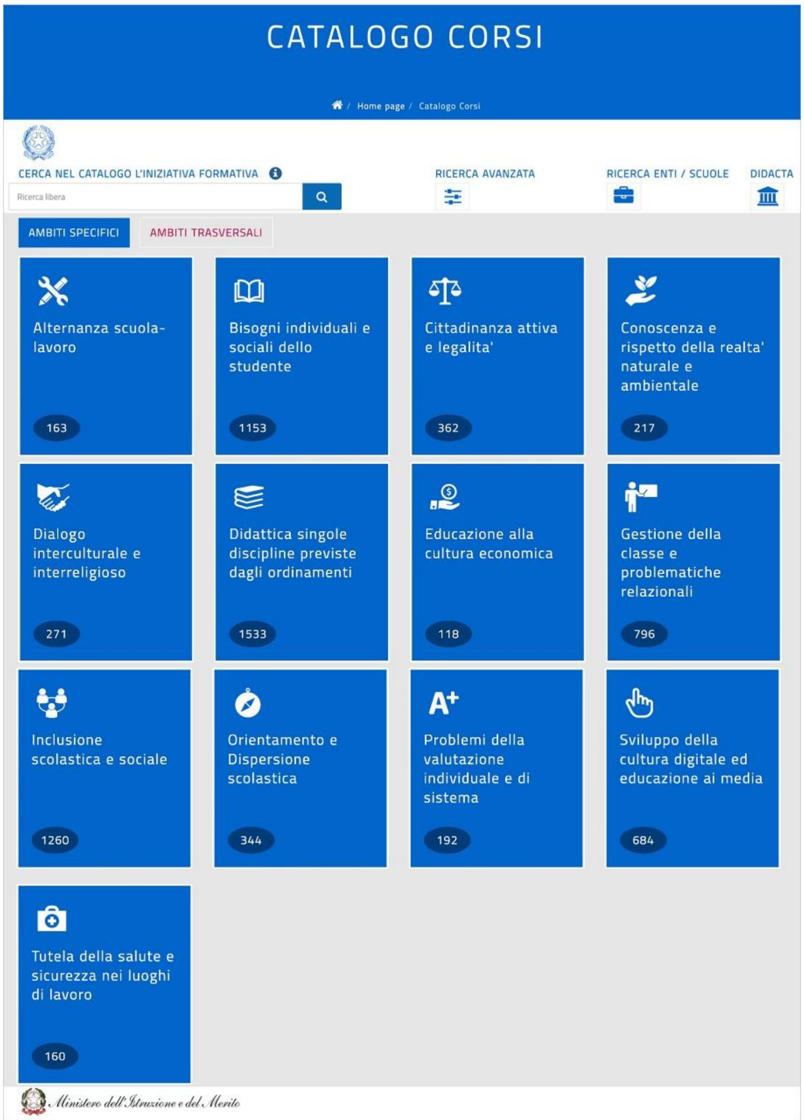

Figure 1. The SOFIA webpage indicating the courses' macro-categories (https://sofia.istruzione.it/).

Macro-categories
Work-school
Individual and social needs of students
Active citizenship and legality
Knowledge and respect for nature and the environment
Inter-cultural and inter-religious debate
Teaching of individual disciplines as per regulations
Education in economic culture
Classroom management and relational problems
School and social inclusion
Orientation and school dropout
Problems of individual and systemic evaluation
Development of digital culture and media education

Figure 2. English titles of the SOFIA macro-categories (https://sofia.istruzione.it/).

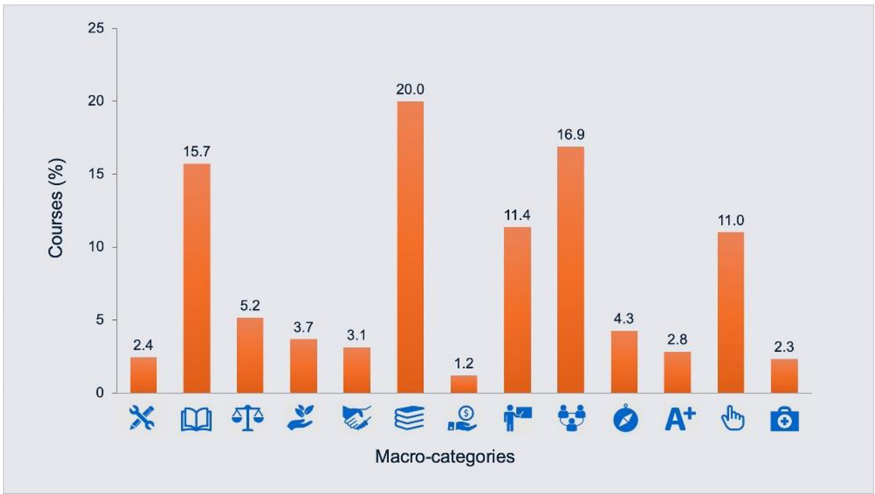

Figure 3. Percentage of courses per macro-category available on the SOFIA platform (for the full list of macro-categories, see Figure 1b).

Investigating the courses on "Knowledge and respect for nature and the environment" through the selected keywords (*biodiversity, climate change, ecology, ecosystem/s,* and *nature conservation*), one can see that little attention was given to ecological and NC topics. Specifically, the search by the keyword *nature conservation*, which is closely linked to NC issues, returned only one course within the "Knowledge and respect for nature and the environment" macro-category, corresponding to 0.4% (1 out of 275) of the available ones. Moreover, using all five keywords resulted in only 47 courses, representing 17% (47 out of 275) of the courses in this macro-category. When extending this figure to the entire SOFIA catalogue, one observes that only 0.6% (47 out of 7459) of the courses available on the platform cover these keywords. More specifically, the keywords identified 14 courses on *biodiversity*, 8 on *climate change*, 16 on *ecology*, 8 on *ecosystem/s*, and 1 on *nature conservation* (Table 1). This emerging lack of material on environmental issues in Italian T&E education aligns with UNESCO's findings (2021a), underlining a critical need worldwide to enhance teacher training in order to address urgent environmental challenges.

Observing the descriptions (*e.g.*, title, abstract, objectives) of the 47 courses, we noted that only part of them (35 out of 47) were properly concerned with ecological and NC topics, corresponding to 0.5% of all available courses (35 out of 7459). More specifically, the courses related to the keywords *biodiversity*, *nature conservation* and *climate change* (7 out of 8 for *climate change*) actually cover ecological topics. Instead, the courses found with the remaining keywords (*ecology* and *ecosystem*) turned out to address topics not relevant to ecology and applied to other disciplinary contexts. This occurred 5 times out of 16 with the keyword *ecology* and 6 times out of 8 with the keyword *ecosystem* (Table 1).

Regarding the fact that the keywords *ecology* and *ecosystem* identify courses not always aligned with ecological topics, we wish to underline a striking heterogeneity in how these terms are understood from a cultural perspective. Notably, in recent decades, both "ecology", a specific disciplinary field, and "ecosystem", a fundamental functional unit within that discipline (Odum, 1971, p. 8), have been employed in various disciplinary contexts, sometimes distant from their strict ecological meaning, exhibiting a well-known problem of lexical promiscuity in the literature (Lorenzi, 2020, pp. 161-182). For instance, the concepts "ecology of language" and "digital ecosystem" are used in linguistics; Bronfenbrenner's "ecological model of child development" (Bronfenbrenner, 1979, p. 4) is well-known in pedagogy and the term "school ecosystem" is often used in educational projects.

Table 1. Courses found on the SOFIA platform by keyword. Pertinence to ecological topics is also reported.

Keywords	Identified courses	Courses with pertinence to ecological topics
Biodiversity	14	14
Climate change	8	7
Ecology	16	11
Ecosystem/s	8	2
Nature conservation	1	1
Total	**47**	**35**

When viewed societally, the proliferation of terms rooted in various ontologies and epistemologies may still contribute to spread the ecological culture. However, in the context of this paper, their polysemic nature complicates the process of identifying courses relevant to ecological topics both within SOFIA's training offerings and more broadly on the internet.

4. Conclusions and future perspectives

As the title suggests, this paper shows what opportunities are available for Italian T&Es to receive training and updates on ecological issues specifically related to NC, as well as to learn effective teaching practices in these fields. We investigated this aspect by analysing SOFIA, the main institutional training platform in Italy. This matters because T&Es, who play an active role in educating citizens, are crucial for promoting sustainable development, ensuring that society, economy, and the natural world can thrive together. Based on what we observed, at the time of writing, T&Es interested in ecological topics, particularly those focused on NC, have very limited training opportunities in Italy provided by accredited institutions.

As a final reflection, we wish to highlight a structural aspect of this research, specifically the limited training material provided by the SOFIA platform. Its courses, in fact, do not always clearly outline their philosophical and methodological approaches, which is why these aspects were not investigated in our study.

In addition, the findings we presented reflect a snapshot in time – a limitation we acknowledge, and one that could be addressed by future research with a diachronic approach.

That being said, we believe it is desirable for SOFIA to align with international recommendations calling for increased investment in formal training programs on environmental themes. Furthermore, given that EE has been mandatory in Italian schools since 2019 (see note 7), we believe it is essential to monitor the training offerings on these topics.

In light of our findings, we think it would be beneficial for T&Es to look at the wide range of opportunities available online in the sphere of non-formal education.[15] In fact, many entities, such as scientific and environmental organisations, offer their specialised knowledge on their websites. These organisations play a crucial role in developing and disseminating scholarly knowledge and educational tools based on cutting-edge science. Therefore, they could offer significant contributions to the ecological knowledge of T&Es.

As for future research, we recommend conducting continuous assessments of the SOFIA platform to monitor the evolution of training for T&Es on NC topics, especially as academic approaches to knowledge construction continue to change. In this context, a few preliminary considerations are worth noting. SOFIA, as previously discussed, serves as a showcase for training programs offered by numerous organisations across the country, many of which are active in both scientific and humanistic research. Given that NC topics are studied and applied not only within scientific disciplines but also in the humanities – and, in some virtuous cases, through interdisciplinary collaborations – it would be valuable to track the disciplinary orientation of emerging training programs on NC topics, as well as their theoretical and methodological frameworks.

On a philosophical level, recent years have seen a flourishing of reflections on the ontological and epistemological aspects related to NC. Bianchi, Pisiotis & Cabrera (2022) highlight the emergence of new interpretations of the human-nature relationship, challenging the anthropocentric views that currently shape pivotal concepts like sustainable development. From a methodological perspective, it would be valuable to explore how educational offerings address the development of critical, problematising (Dodman, 2016), and interdisciplinary approaches (Dodman, 2016; Annan-Diab & Molinari 2017), which can be introduced in schools to equip future generations to navigate the

[15] On the meaning of the term see: European Commission/EACEA/Eurydice (2024).

complex human-nature relationship. This becomes even more significant in the context of NC, a field that is informed by diverse disciplines, ranging from natural resource management to the history of biological thought.

Continuing on the topic of disciplinary perspectives, we wish to make a few further remarks based on the observation of the increasing prominence of environmental issues across various branches of humanistic knowledge – ranging from legal to historical, philosophical, and pedagogical fields. This trend could lead to a rapid and significant ontological and epistemological transformation in the body of scholarly knowledge focused on the human-nature relationship, and more specifically, on NC. For decades now, there has been an international expansion of humanistic disciplines towards environmental topics traditionally viewed as belonging to the scientific and naturalistic realms, commonly associated with ecology. Conversely, ecology itself has increasingly incorporated elements from disciplines historically outside its scope (Costanza, 1991). In our view, this reciprocal expansion is fostering the consolidation of new interdisciplinary paradigms in environmental knowledge, which influence both theoretical and practical approaches to NC education. The interdisciplinary development of teachable knowledge is evident in many emerging teaching practices. One such example is outdoor education, which is grounded in theoretical constructs like biophilia, blending naturalistic elements with insights from environmental psychology (Barbiero, 2021).

In the early twenty-first century, the environmental humanities emerged as an academic discipline, reflecting a growing conviction that environmental problems cannot be solved by science and technology alone (a useful bibliographic source is Emmett & Nye, 2017). This development represents a cultural shift that is influencing not only academia but also the field of education in general, helping bridge the traditional divide between the sciences and the humanities. That being said, we believe it is important to consider that while the humanities' increasing engagement with environmental issues in education introduces valuable cultural perspectives, it may inadvertently contribute to a further weakening of the educational offerings in terms of ecological knowledge in the strict sense.

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Original Paper

Adaptation and mitigation actions for flood management.

Application of the analytic hierarchical process in geographic information systems for flood risk assessment

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Abstract. *In order to generate information that facilitates decision-making concerning adaptation and mitigation actions related to planning for flood management, this study assessed the risk of flooding in the Garrapata* *microbasin, located in Chone, Ecuador, using a multi-criteria analysis based on GIS modelling. The technique involved choosing conditioning factors, which included secondary data and satellite photos. These were then processed using QGIS to produce theme maps of isohyets, river distance, elevation, slope, soil texture, and land use and cover. These maps were weighted using the Analytical Hierarchy Process (AHP) to give distinct weights to each factor, producing a flood risk map that was validated with Google Earth Engine. The findings indicated that low plains spanning 12.64 km² close to the Garrapata River are at high risk of flooding as a result of heavy rainfall or overflows. This analysis shows that the use of AHP and GIS together is a useful technique for determining flood risk and providing essential data for decision-making, which helps build more resilient communities that are better equipped to handle flood-related disasters.*

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1. Introduction

Profound planetary transformations, undermining the sustainability of the ecosystems on which all life depends and involving features such as climate change, loss of biodiversity, toxic pollution and land degradation, are causing increasing instability and insecurity together with greater frequency and intensity of disasters which affect ever larger numbers of human populations together with innumerable other species. This requires adopting strategies based on a complex interaction between adaptation and mitigation actions based on trade-offs and synergies that can enhance the combined effect of both.

Floods are a particularly common type of natural catastrophe, accounting for 47% of all climatic disasters that occurred globally between 1995 and 2015 (Gran & Ramos 2019). Furthermore, flooding is one of the most difficult issues that mankind is currently experiencing due to climate change and growing urbanization (Qi et al., 2021; Rosales, 2018). Nonetheless, there are clear constraints in research, economics, and policy framework that restrict how floods are seen in underdeveloped nations (Nkwunonwo et al., 2020).

Within the limits of a drainage division, the watershed is a geohydrological unit made up of land, water, and biota (Kumar et al., 2022). Because microwatersheds are the main component of watersheds, they are therefore crucial units for planning and management on a global scale. This is because managing a region requires a thorough understanding of its social, economic, and environmental aspects, which is necessary to ensure the sustainable use of its resources and to help decision-makers in the event of natural or man-made disasters (Fenta et al., 2023; Mirzaei et al., 2023).

Floods are a relevant problem among the many studies that may be conducted at the microbasin level since surface channel overflow brought on by excessive precipitation has several negative impacts that can even result in fatalities (Mercado et al., 2020). Studies that have already been done on flood risk management in developing nations contend that not enough is known about floods, they are not well studied, and there are either no management strategies in place or they are being used insufficiently (Salman & Li 2018). Furthermore, the variables that affect a basin's or microbasin's ability to increase floods, such as land use changes, urbanization, deforestation, and climate change, must be considered (Mirzaei et al., 2023).

The severe floods of 2012 in Ecuador were estimated to have cost $238 million in economic damages (Pinos & Timbe, 2020). Subsequently, 2,268 floods were reported in the country between 2015 and 2020, with losses including fatalities, harm to crops and infrastructure, interruptions to business and education, and detrimental effects on long-term human health and well-being. Lowlands along the shore often experience flooding (Galarza et al., 2018). The province of Manabí is one of the most afflicted areas in the above-described environment; in particular, the Chone canton experiences this recurring event, which poses a serious risk of flooding. The Mosquito, Río Grande, and Garrapata microbasins comprise the Chone River sub-basin.

While this kind of event happens suddenly, Ecuador lacks a well-defined procedure for monitoring floods. While most river basins have flood early warning systems in place using basic data, only four river basins have access to detailed hydrometeorological data. Despite the importance of this data to the national system, it is well known that its operational capacity has been hampered by a lack of funding (Tauzer et al., 2019). One of the main challenges in this country is monitoring floods in order to assess the effectiveness of the safeguards put in place and pinpoint places that require further action. At the moment, floods are being tracked using satellite photos and other data, and impacted towns are collaborating to help people in need of humanitarian aid.

In light of this situation, Geographic Information Systems (GIS), which Cedeño et al. (2017) define as a collection of software and technological tools for obtaining new kinds of real-world information, have advanced to the point where multi-criteria analysis based on GIS and the hierarchical analytical process method allow for the organization and control of parameters for making complex decisions (Drawish, 2023).

The assessment of flood hazards and risk assessment has been carried out globally through the integration of GIS and multi-criteria analysis, incorporating criteria such as rainfall (isohyets), land cover, soil types, slope map, and drainage density. The primary research studies of this kind have been conducted in Greece (Karymbalis et al., 2021), Iran (Allafta and Opp, 2021), Saudi Arabia (Abdelkarim et al., 2020), India (Das, 2020), Ethiopia (Hagos et al., 2022), Egypt (Abu El-Magd et al., 2020), and Ecuador (Reyna-Bowen et al., 2017).

From the standpoint of sustainability, this study supports long-term sustainable development, fosters community resilience, and encourages responsible territorial planning in addition to enhancing flood response capabilities, thereby bringing together adaptation and mitigation actions. With the background information in mind, the goal of this study was to assess the risk of flooding in the Garrapata microbasin using a multi-criteria analysis based on GIS modelling. This was done in order to produce data that would help decision-makers plan ahead and manage the risk of this kind of event.

2. Methodology

2.1. Study area

In the Ecuadorian province of Manabí, the Garrapata River microbasin is a place of significant natural and socioeconomic value. With a total size of 147.64 km 2, this microbasin is home to a range of habitats, including tropical forests, agricultural land, and populated regions. The research area is classified as an ecological region of tropical dry forest type (Holdrigde classification) and has tropical climate features, according to Ecuador's bioclimatic map. This region is characterized by variations in the Pacific Ocean and regional mobility. According to Aveiga et al. (2023), intertropical convergence has an impact. Reyna et al. (2018) describe the yearly average meteorological parameters in the Carrizal-Chone valley: temperature of 25.6 °C, potential evapotranspiration of 1365.2 mm, and precipitation of 838.7 mm. These parameters indicate a dry season from June to December and a rainy season from January to May. The Garrapata microbasin's location is illustrated in Figure 1.

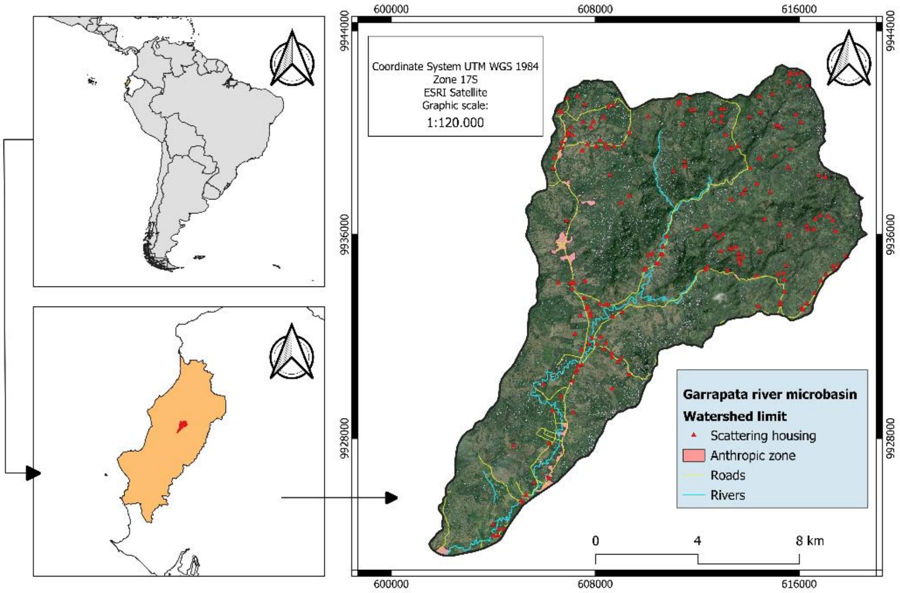

Figure 1. Geographic location of the Garrapata River microbasin, Chone canton, Manabí Province – Ecuador, specifically in Zone 17S of the Universal Transverse Mercator Coordinate System (UTM).

2.2. *Selection of the conditioning factors of floods*

By examining secondary data from government sources and pertinent agencies as well as satellite image data, thematic factors employed in this work to map flood-prone regions were identified. The Sentinel-1 satellite provided the digital elevation model (DEM), which was acquired from the website EARTHDATA (https://search.asf.alaska.edu/#/) at a resolution of 10 m. QGIS 3.36.0-1 software was utilized to analyse the DEM data in order to ascertain isohyet maps, river distance, elevation, slope, soil texture, land use, and land cover. Table 1 lists each variable's rationale, past research using it that is relevant to this study, and previous uses of the variable.

Table 1. Factors selected to represent flood hazard.

Factor	Justification	Reference
Rain	Because it increases the flow of rivers and streams, this is one of the primary causes of the overflow of bodies of water and the rise in river flow. Overflows and floods happen when the flow is greater than the channels' carrying capacity.	Darwish et al. (2023); Hagos et al. (2022); Swain et al. (2020); Cabrera & Lee (2019); Rincon et al. (2018)
Distance to the river	This is a major factor in how severe floods are since being next to a river raises the danger of flooding because riparian regions have higher water levels, are lower in elevation, and require less time to evacuate.	Swain et al. (2020); Abu et al. (2019);
Elevation	This is a crucial component to consider when assessing the danger of flooding since it affects how vulnerable towns are to flooding as well as how well the ground drains during periods of intense precipitation.	Karymbalis et al. (2021); Cabrera & Lee (2019)
Slope	This may have an impact on how water naturally drains during periods of intense rain. Water can collect in ponds and puddles on gently sloping terrain, raising the possibility of local floods. On the other hand, steeper slopes make it easier for water to flow into rivers and streams, which raises the possibility of floods later.	Hagos et al. (2022); Karymbalis et al. (2021)
Soil texture	This relates to the relative amounts of sand, silt, and clay in the soil, which greatly impacts how the soil takes in, holds onto, and releases water—all of which can impact the likelihood of floods.	Hagos et al. (2022); Cabrera & Lee (2019)
Coverage and land use	Flooding is more likely because of the altered soil's propensity to both infiltrate and hold onto water.	Nsangou et al. (2022); Hagos et al. (2022); Karymbalis et al. (2021)

By definition, floods are the outcome of several meteorological and topographic elements coming together across time and place. Consequently, every component that contributes to the occurrence of this phenomena has a distinct effect that enables the creation of a comprehensive landscape with varying degrees of flood risk sensitivity. Six parameters were considered in this study and were modelled in accordance with the AHP methodology's criteria (Figure 2).

2.3. Weighting of each factor using the AHP process

Once the thematic maps were prepared and classified, the AHP process was applied to assign different weights to each parameter. The relevance of each thematic layer in relation to the others was established by assigning weights, using the Saaty scale from 1 to 9 where 1 indicates that both elements are equally important and 9 indicates that one component is more important than the other. as detailed in table 2 (Saaty, 1980; Saaty & Vargas 1991).

Table 2. Definition of weights using AHP.

Numerical scale	Verbal scale	Description
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance of one factor over another.	Experience and judgment slightly favour one activity over another.
5	Strong or essential importance	Experience and judgment strongly favour one activity over another.
7	Very strong importance	An activity is strongly favoured, and its mastery is demonstrated in practice.
9	Extreme importance	The evidence favouring one activity over another is of the highest order of affirmation possible.
2,4,6,8	Intermediate values between two adjacent judgments	When a commitment is necessary
1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9	Inverses	This is used when the second element is greater in the criterion to be compared

Source: Adapted from (Mendoza et al., 2019)

In this research, the AHP method's first step is to compare two variables pairwise using a 6 x 6 matrix. Each theme layer's weighting was determined by the value obtained after normalizing the comparison results. A weighted sum was calculated for each row of the comparison matrix by multiplying the amount of each element by the priority assigned to each criterion. The weighted sum was then divided by the priority of the relevant criterion. Next, the mean ($\lambda_{máx}$) of the prior step's results was determined. The consistency index (CI) was calculated for each criterion, where n is equal to the number of criteria (equation 1). Subsequently, the random index (RI) was calculated as the average CI of a large sample of randomly generated comparison matrices (equation 2). Finally, the consistency ratio (CR) was established (equation 3) (Mendoza et al., 2019). The subjective evaluation is considered acceptable if the CR value is equal to or less than 0.10. However, if the CR value exceeds 0.10, the subjective evaluation is considered inconsistent and should be revised to ensure realistic results (Swain et al., 2020).

$$CI = \frac{\lambda_{máx} - n}{n-1} \qquad [1]$$

$$RI = \frac{1.98(n-2)}{n} \qquad [2]$$

$$CR = \frac{CI}{IA} \qquad [3]$$

In the second stage, each parameter was classified into subcategories and weighted using a 6x6 AHP matrix in Microsoft Excel 2016. The maximum and minimum values for each class vary from 1 to 4. In addition, normalization was utilized to calculate the weight of each class, which was then used to map flood hazard in QGIS 3.36.0-1. Isohyets, elevation, distance to river, slope, cover, and land usage are classified into four categories, whilst soil texture is classified into two. Furthermore, the flood danger index (Equation 4) is calculated by adding the weight values of all classes in each parameter to the weight values of all components. The weight of each component is multiplied by each class of the same factor to determine its overall weighting value (Hagos et al., 2022).

$$Risk\ of\ flooding = W_i X_i \qquad [4]$$

2.4. Flood risk map validation

The flood risk map generated by the AHP process was validated in a GIS environment using Google Earth Engine and Sentinel-1 data to obtain VV reference values. This allows detecting potentially flooded areas using a specific threshold (-3) (Johary et al., 2023; Singh & Rawat, 2024). The imaging period was from February 15 to February 28, 2024, since the latest flood in Chone occurred on February 22, 2024.

3. Results and discussion

The microbasin has a geographical distribution of moderate precipitation with four primary ranges: 1061 - 1076 mm/year (17.21 km^2); 1045 - 1061 mm/year (54.62 km^2); 1029 - 1045 mm/year (55.90 km^2); and 1013 - 1029 mm/year (19.83 km^2). According to Horton-Strahler, the water network consists of several channels that are categorized into two orders. The principal channel, the Garrapata River (order 2), spans 25.29 kilometres and distributes the microbasin's drainage (letter an in figure 2). The distance to the river variable illustrates that the regions most prone to flooding are those closest to the river, located in flood plains and low areas (shown in turquoise), making them vulnerable to heavy rain or overflow occurrences. Flooding is less likely in regions further from the river (in brown), as well as in mountainous and elevation areas (letter b in Figure 2).

The microbasin ranges in altitude from 29 to 794 meters above sea level. The range with the biggest size (51.78 km^2) corresponds to heights ranging from 29 to 794 meters, followed by the range of 29 to 82 meters (37.38 km^2). 36.55 km^2 have elevations ranging from 82 to 208 meters, whereas the smallest extension (21.93 km^2) ranges from 29 to 82 meters (letter c in figure 2). In terms of slope, the microbasin exhibits a wide range of terrain inclinations. The surface with a slope of less than or equal to 25% covers 143.80 km^2. The slope range of 25 to 50% covers 1.36 km^2, whereas a surface of 0.98 km^2 is within the range of 50 to 75%. The sections with a slope higher than 75% cover 2.25 km^2 of the microbasin (letter d in figure 2).

The microbasin's soil texture is mostly fine, covering 89.87 km^2 of the surface. However, near the river's banks, a medium texture (57.77 km^2) is detected, indicating bigger particles and loam-type soil (letter e in figure 2). In terms of land use, agricultural activity occupies the biggest area (114.19 km^2), with concentrations in the lowest and least sloping areas. Higher altitude regions contain remains of native forest (15.03 km^2) and secondary forests (15.79 km^2). In addition, there is a body of water and a small area (0.81 km^2) of shrub and herbaceous vegetation. The anthropic zone covers 1.79 km^2 of the microbasin (letter f in figure 2).

The first step of the AHP computations evaluates the weights and comparisons of all components using a 6 × 6 matrix with diagonal elements equal to 1 (Table 3). Furthermore, the result of the paired comparison (factor vs. factor) was adjusted to get a weighted value (Table 4).

Using the weighting in Table 4, the relative importance of each element was given to produce the flood risk map of the Garrapata River microbasin (letter a in Figure 3), which reveals interesting trends about the area's sensitivity to flooding. In this scenario, flood-prone regions (level 4) span 12.64 km^2 and are mostly located in the plains and lowlands near the Garrapata River's overflow discharge. These places are especially susceptible to flooding following heavy rain or river overflow occurrences. An area of 84.34 km^2 is distinguished as runoff plains; another 49.54 km^2 is located in level 2 (mountainous areas), and the remaining

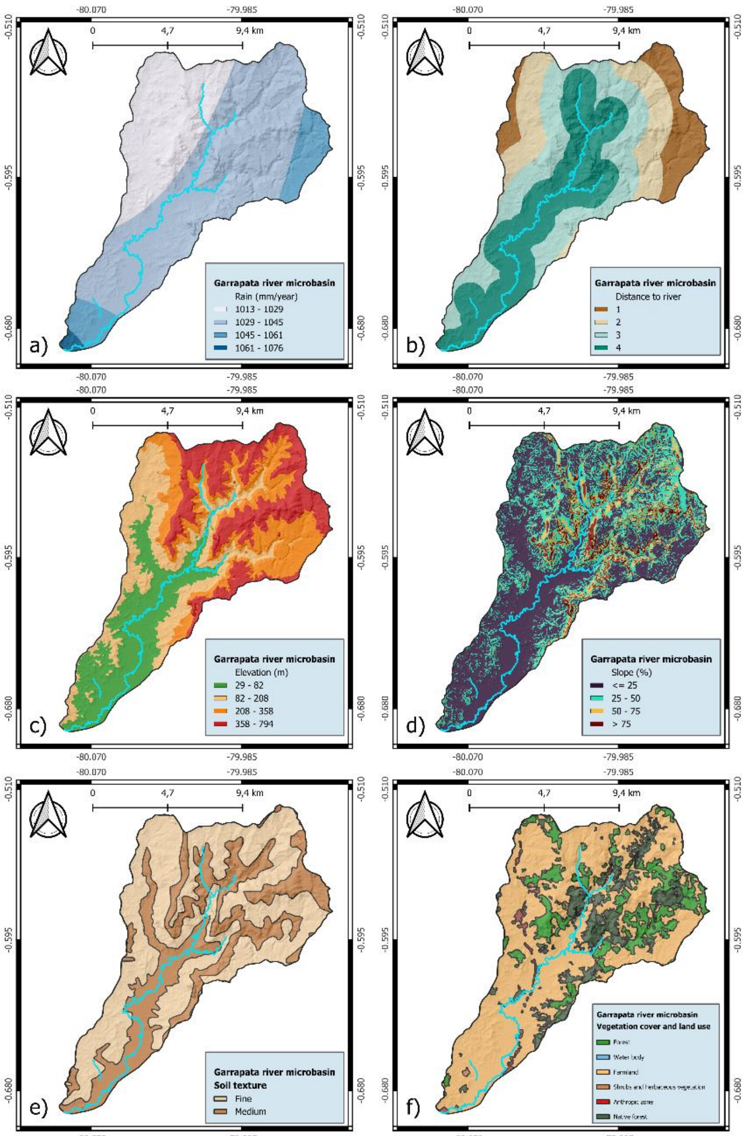

Figure 2. Factors for flood hazard mapping: a) Isohyets; b) Distance to the river; c) Elevation; d) Slope; e) Soil texture; f) Coverage and land use.

1.13 km² belongs to the most mountainous and elevated areas, which are not susceptible to flooding due to their topography and distance from the riverbed.

Table 3. Comparison matrix and relative score of factors related to flood risk.

Factor	Isoh yets	Distance to the river	Elevation	Earring	Soil texture	Coverage and land use
Isohyets	1.00	0.20	5.00	5.00	7.00	7.00
Distance to the river	5.00	1.00	5.00	5.00	7.00	7.00
Elevation	0.20	0.20	1.00	3.00	7.00	7.00
Slope	0.20	0.20	0.33	1.00	3.00	3.00
Soil texture	0.14	0.14	0.14	0.33	1.00	3.00
Coverage and land use	0.14	0.14	0.33	0.33	0.33	1.00

Table 4. Normalized values and weight of each factor according to the comparison matrix.

Factor	Pw	Weight (%)
Distance to the river	0.45	45.00
Isohyets	0.26	26.00
Elevation	0.14	14.00
Slope	0.07	7.00
Soil texture	0.04	4.00
Coverage and land use	0.03	3.00

Letter b in Figure 3 depicts the validation of the flood risk map; by superimposing the DEM derived from Google Earth Engine, a significant resemblance between the two maps is obvious; the validation flood surface measures 9.07 km², verifying the created model's accuracy. This validation confirms that the risk map created using the AHP approach and GIS accurately depicts flood-prone regions, highlighting the model's use for disaster risk planning and management.

Floods represent a danger to the built environment's economic, social, and environmental sustainability (Ekmekcioğlu et al., 2020). As a result, flood risk assessment is critical for managing this type of catastrophe, enabling the deployment of preventative, mitigation, and preparedness measures (Ma et al., 2021), as well as the integration of the AHP process with GIS. They enable for the creation of a model to assess the geographical distribution of flood-prone areas. The Garrapata River microbasin experiences more precipitation due to the

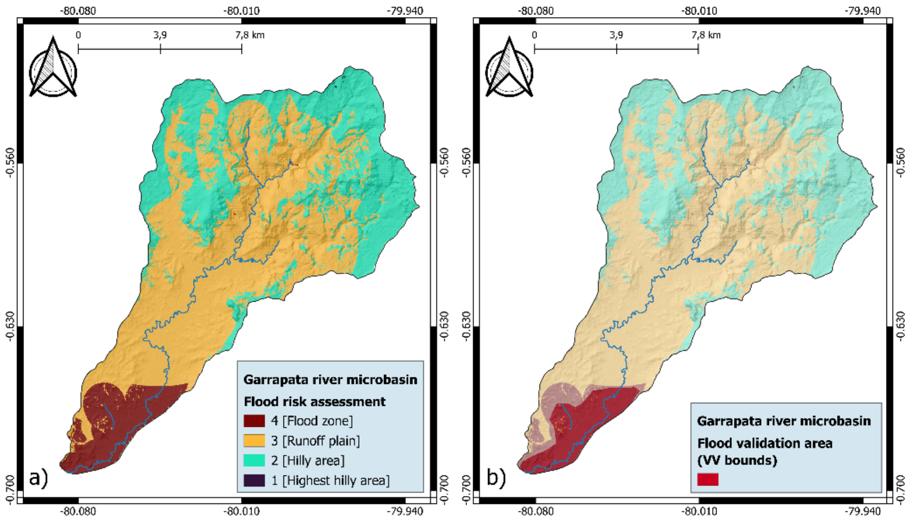

Figure 3. (a) Flood risk map of the Garrapata microbasin; (b) Validation map.

El Niño phenomenon. For example, the maximum annual precipitation level in the Chone River basin was recorded in 1982-1983, with 2855 mm, and 1997-1998, with 3352 mm, while the average annual precipitation reaches 903 mm (Rivadeneira et al., 2020). This dramatic increase in precipitation significantly raises the danger of flooding in the Garrapata River microbasin, a phenomenon that has also been identified as a critical concern posed by climate change (Rajkhowa & Sarma, 2021; Rivadeneira et al., 2020).

Recent studies have focused on areas in other parts of the world where flood management is of equal importance. Flood risk has increased significantly in Vietnam due to, among other reasons, the effect of climate change, but there is still limited research on flood risk assessment at the local level (Pham et al., 2021). In Turkey, Ekmekcioğlu et al. (2020) found that the highest flood risk districts are mainly located in the centre and highly populated areas of Istanbul, applying the AHP process to weight criteria. In China, flood risk maps were generated using the XGBoost algorithm. At the district level, it has been assessed that

40.3% of the districts are at high risk of flash floods, concentrating primarily in southern Yunnan (Ma et al., 2021).

Mujib et al. (2021) classified floodplain mapping results into five categories: poor 0.02%, low 4.26%, medium 37.11%, high 51.89%, and very high 6.72%, concluding that the AHP-GIS model's prediction is ideal for mapping flood-prone areas in Kencong district, Indonesia. Zhang et al. (2020) created a GIS-based multi-index spatial model for flood risk assessment and said that the development of this sort of study adds to future scientific efforts on flood prediction and mitigation. Similarly, Cai et al. (2021) suggest that by modifying the AHP procedure, flood risk may be properly assessed, and the results successfully applied to urban development strategy.

4. Conclusions

Flooding remains as a substantial hazard to community development over the long term and integrating adaptation and mitigation actions is essential. In this context, combining the Analytic Hierarchy Process (AHP) with Geographic Information Systems (GIS) is a potential technique to creating an accurate flood risk assessment map. This method was used in this study to determine the regions of the Garrapata microbasin that are most likely to flood. The major findings suggest that an expansion of 12.64 km² of the low parts of the microbasin and next to the bank of the Garrapata River has flooding risk (level 4). This information makes it easier to identify priority regions for the deployment of adaption measures and make educated disaster risk reduction decisions. Finally, this technology can help communities become more robust to floods and other catastrophic hydrometeorological phenomena. Several studies have demonstrated that the AHP approach is an effective technique for assessing flood risk. However, the efficacy of AHP is dependent on the quality of the expert judgment used to give weights to certain criteria. Furthermore than the validation presented in this research, other studies might compare the AHP-based map to other current flood risk maps for the Garrapata microbasin to determine its accuracy. It would be useful to know whether the study compared the AHP-based map to historical flood data for the Garrapata microbasin. Furthermore, comparing the map to flood risk maps made using other approaches may increase the validity of the results.

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Original Paper

Airborne bacteria and fungi in coastal Ecuador: a correlation analysis with meteorological factors

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Keywords: bacteria; fungi; meteorological variables; Pearson correlation.

Abstract. *Air quality is of crucial significance for both ecosystem and human health. The aim of the research was to assess how meteorological conditions affected the aerobiological concentration in Chone, Manabí, Ecuador. For five days, sedimentation in Petri dishes was used to carry out sampling at nine different points. Temperature, relative humidity, wind speed, and UV index were among the meteorological data taken from the Catholic University of Chone meteorological station and included in the analysis. Following the* *hospital (point 6), the city market (point 4) had the highest concentration of bacteria, with 301 CFU/m³ in the morning and 441 CFU/m³ in the afternoon. With values of 0.541 and 0.56, respectively, wind speed and solar radiation showed the biggest fluctuation with bacteria concentrations. With the exception of a relative humidity value of 0.023, the park (point) had the highest abundance of mushrooms and no significant associations with meteorological variables. In summary, aerobiological concentrations showed a minor influence from meteorological factors while being below allowable bounds.*

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1. Introduction

Ecosystem and human health are greatly impacted by outdoor air quality (Yin et al., 2021; Leal, 2019). Air pollution has numerous negative impacts on terrestrial and aquatic ecosystems, ranging from local and global scales, degrading the physical environment, threatening organismic health and reducing biodiversity. Airborne pollutants, which include volatile organic compounds, poisonous gases, and suspended particulates, can harm cardiovascular and respiratory health as well as induce conditions including cancer, allergies, and asthma (Ruiz-Gil et al., 2020; Leal, 2019). The World Health Organization (WHO) reports that 4.2 million die each year, across the world, due to heart disease, stroke, lung cancer, and acute/chronic respiratory disease linked to ambient air pollution (Abdul et al., 2022; WHO, 2020). Moreover, the impact extends beyond human health since certain pollutants trap heat in the atmosphere, accelerating global warming. This warming can further exacerbate air quality issues and create a vicious cycle (Keishams et al., 2022; Huh et al., 2020).

As well as affecting residents of high-pollution areas, outdoor air pollution can have an impact on an entire region or indeed the whole biosphere (Keishams et al., 2022; Huh et al., 2020). Long-distance windborne pollution can carry harmful particles and gasses, lowering air quality in isolated locations. This understanding is crucial not only for public health but also for ecosystem health. Airborne bacteria and fungi can play a role in nutrient cycling, plant-microbe interactions, and even influence the spread of plant diseases (Sangkham et al., 2021). Therefore, studying how meteorological factors influence these microbial communities can provide valuable insights into the overall ecosystems.

Human health can also be impacted by airborne microorganisms such viruses, fungus, and bacteria (Olivera et al., 2021). According to studies by Liu et al. (2018) and Madhwal et al. (2020), these bioaerosols can result in infections, allergies, and respiratory disorders. Environmental elements including temperature, humidity, and wind speed have an impact on the concentration and make-up of these microorganisms in the air (Olivera et al., 2021; Ramos & Meza, 2017). While it is true that there is several research on environmental quality in metropolitan areas conducted internationally, this subject has not yet received much attention at the provincial level (Vivas et al., 2022; Gómez et al., 2021).

Understanding the role of airborne microbes is crucial for advancing towards a sustainable future (Palladino et al., 2021). This research contributes to several Sustainable Development Goals (SDGs), notably SDG 3 (Good Health and Well-being) and SDG 11 (Sustainable Cities and Communities), emphasizing the need for managing healthy urban environments. By exploring the relationship between airborne bacteria, fungi, and the health of humans, animals, and the environment, effective strategies for improving air quality can be developed. Consequently, the research question arises: How do airborne bacteria and fungi in coastal Ecuador correlate with meteorological factors? Thus, this study aims to assess how meteorological conditions influence aerobiological concentrations in the town center of Chone.

2. Literature review

For centuries, concerns about airborne illness spurred interest in what eventually became aerobiology (Myszkowska, 2020). This field truly blossomed in the 20th century. The coining of the term *aerobiology* in the 1930s by Fred Campbell Meier, along with his innovative air sampling tool, laid the groundwork. Pioneering figures like Philip Herries Gregory further developed the field with concepts like *air spora* and studies on spore dispersal. The invention of the Hirst spore trap in 1952 revolutionized air sampling, enabling the creation of monitoring networks. Collaboration among researchers solidified with the establishment of the International Association of Aerobiology in 1972. While traditional methods like Hirst traps remain important, recent advancements like molecular techniques and real-time sensing offer more sophisticated aerobiological monitoring (Lancia et al., 2021).

Aerobiology, a vast field with over 2,122 articles on Scopus using the keyword, traditionally relied on gravimetric methods (popular in Poland around the 20th/21st century transition) but has shifted towards volumetric methods for precise particle measurement (Grewling et al., 2023). While aerobiological monitoring is carried out both indoors and outdoors, for the purposes of this research, a literature review will be conducted on the main advances in publications on outdoor monitoring.

A study conducted in Tianjin, China, revealed a diverse range of airborne fungi, with Alternaria being the most prevalent. The concentration of these fungi varies significantly throughout the year, influenced heavily by the month. However, the study found no substantial difference in fungal communities between busy urban areas and green spaces (Nageen et al., 2021).

In Seoul's elementary schools, outdoor air had a richer bacterial community than classroom air, though fungal diversity was similar indoors and outdoors. Abundant bacteria included Enhydrobacter, Micrococcus, and Staphylococcus, while prevalent fungi were Cladosporium, Clitocybe, and Daedaleopsis. Classroom air bacterial composition was uniform across rooms but distinct from outdoor air (Lee et al., 2021).

A study at Eskişehir Technical University found most departments had low to moderate levels of airborne bacteria (up to 1663 CFU/m^3). However, cafeterias had significantly higher bacterial counts, indicating a higher degree of air pollution in those areas (Bhat et al., 2022). At a public university in Islamabad, Pakistan, outdoor fungal and bacterial concentrations ranged from 280–510 CFU/m^3 and 20–100 CFU/m^3, respectively. The high outdoor fungal concentrations significantly contributed to indoor fungal buildup, as evidenced by the abundance of *Cladosporium spp.,* a plant pathogen (Hassan et al., 2021).

At the wastewater treatment plant in Lublin, Poland, the highest concentrations of total bacteria (3617 CFU/m^3) and fungi (5386 CFU/m^3) in bioaerosols were detected near the sewage pumping station, close to the aeration tanks. Pseudomonas fluorescens was found in the air around the grit chamber at 78 CFU/m^3 (Staszowska, 2022).

In Southeastern Italy during winter, Bacillus and Chryseobacterium were the only genera significantly correlated with chemical species likely associated with soil-dust and anthropogenic pollution sources, respectively. In spring, Enterobacter and Sphingomonas were the only genera significantly correlated with chemical species likely associated with anthropogenic pollution and marine and soil-dust sources, respectively (Romano et al., 2020).

Focusing on studies in America, Suehara and Pinto (2023) report that the most prevalent airborne fungi genera in Brazil are Aspergillus, Penicillium, Cladosporium, Curvularia, and Fusarium. Their findings also highlight the relationship between fungi and meteorological factors and seasonality, the sensitivity of atopic individuals to fungi, and the main nosocomial mycoses reported in the literature.

In Mexico City, Calderón-Ezquerro et al. (2021) found that the Actinobacteria phylum dominated the bacterial communities in both urban (41%) and semi-urban (42%) areas, followed by Proteobacteria, Firmicutes, Bacteroidetes, Cyanobacteria, and Chloroflexi. Interestingly, the urban environment harbored 13 unique bacterial genera, while the semi-rural area had 17.

In a public library in Colombia, Camargo-Caicedo et al. (2023) reported air fungal concentrations reaching up to 1197 CFU/m³, with an average around 150 CFU/m³, noting higher values during morning samples. Seven fungal genera were identified, with Aspergillus and Curvularia being the most abundant. The temperature ranged from 30.80 to 33.51 °C, and relative humidity from 62.61 to 64.80%. Statistical analysis revealed a significant correlation between fungal aerosol concentration and relative humidity, indicating that a 10% increase in moisture could double the fungal aerosol concentration.

In Ecuador, Vivas et al. (2021) found high bacterial concentrations, reaching up to 151,111 CFU/m³ of air, near the central market of Calceta city, with lower fungal concentrations. Significant differences were observed in monitoring frequency, with higher average concentrations of CFU/m³ and UPC/m³ on weekends. Without additional nationally relevant studies, the primary contribution of this research is its role as the first study to reveal the influence of meteorological factors on the concentration of bacteria and fungi at the municipal level in Ecuador.

3. Methodology

The research area exhibits tropical climate features as indicated by the bioclimatic map of Ecuador and is described by Holdridge as an ecological region of the tropical dry forest type. Variations in the Pacific Ocean and regional mobility characterize this area, with intertropical convergence playing a major role (Aveiga et al., 2023). According to Reyna et al. (2018), the Carrizal-Chone valley experiences 25.6 °C of annual average temperature, 1365.2 mm of potential evapotranspiration, and 838.7 mm of precipitation. Based on these facts, there is a wet season from January to May and a dry season from June to December.

The methodology proposed by Vivas et al. (2021) was employed to establish the points. Numerous elements were considered, such as crowded areas and public, urban, and rural transportation terminals found within cities. The WHO-proposed methodology was utilized by Morocho's (2021) research as a reference for determining criteria, which also took into account the emission and dispersion patterns of pollution (table 1). A total of nine monitoring sites were set up (see figure 1), where samples were taken five days a week between 1:30 p.m. and 7:00 a.m.

Table 1. Criteria for the location of monitoring points

Site rating	Description
City or urban centre	Walking or commercial zones are examples of urban locations that reflect the general exposure of the populace in towns or urban centres.
Background urban areas	Urban location that is far from sources of pollution and, hence, broadly reflective of the overall city's backdrop circumstances.
Suburban or residential areas	Location on a town or city's periphery that is residential in nature.
Places near the tracks (kerbside)	A site sample that is between one and five meters away from a major street.
Industrial	A region where long-term or peak concentrations are significantly influenced by industrial sources.

Source: Morocho (2021)

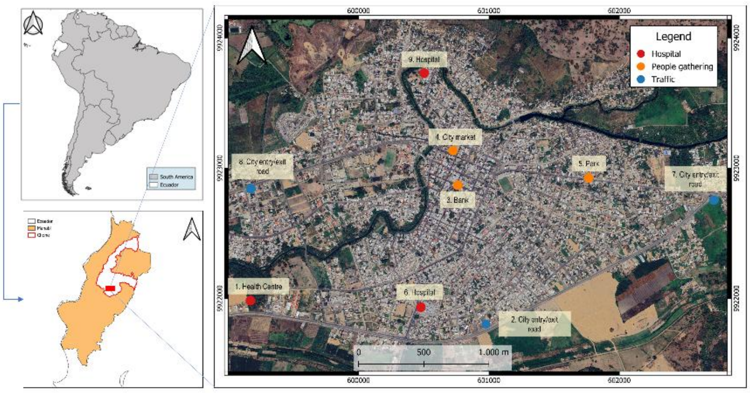

Figure 1. Geographic location of the cantonal capital of Chone.

In May 2024, sampling took place utilizing the sedimentation method in Petri dishes during a 5-day period. Nutrient agar was used to cover the boxes if aerobic bacteria were detected, whereas malt extract agar was utilized to detect fungus. The Petri dishes were left in an open position 1.50 meters above the floor and left to be exposed to the environment for half an hour. It is important to note that the approach used in the studies by Vivas et al. (2022) for exposure duration and Vivas et al. (2021) for box height served as the foundation for this process.

The samples were incubated for twenty-four hours at 35 ± 2°C. The amount of fungal and bacterial colonies was counted using the Stuart SC6PLUS counter after incubation. Stated otherwise, the number of colonies denotes the overall mean of the colonies found at the sampling locations. Equation 1 was used to calculate the concentration of colony forming units (CFU, for bacteria) and propagation units (CPU, for fungi) per m^3 of air, respectively.

$$CFU \ or \ CPU = \frac{NC \ X \ 25}{time \ (min)} \quad [1]$$

Where:

NC = number of colonies per plate

time (min) = 25

Temperature, humidity, wind speed, and UV index were among the climatic parameters that were obtained from the Catholic University of Chone meteorological station. A non-parametric analysis was used to determine the connection among these factors and the aerobiological concentration. A measure of statistical correlation used to assess the linear relationship between two variables, Pearson statistical analysis with the SPSS statistical software, according to García (2014) cited by López (2020), provides a quantitative measure of the strength and direction of a potential linear relationship between these variables.

4. Results and discussion

The mean of the meteorological parameters included for the analysis are temperature of 27.12 °C, relative humidity of 82.42%, wind speed of 0.9 m/s and UV index of 1.14 sun hours/day. Comparing the two examined timeframes, Figure 2 illustrates how the concentration of bacteria varied among the nine monitoring points in a comparable manner. On the other hand, the concentration of microorganisms increases everywhere about 1:30 (figure 2).

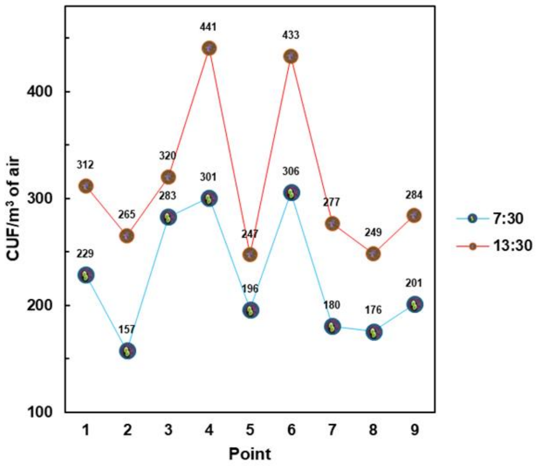

Figure 2. Data on bacteria concentrations.

The city market (point 4) stood out as one of the points with the highest densities of bacteria, as seen in the above figure. The concentration was already noticeably high in the morning at 301 CFU/m^3. On the other hand, this value sharply rose to 441 CFU/m^3 in the afternoon. This noticeable rise indicates that there is a lot more activity and social interaction in the market in the evening, which promotes the growth of germs. Food markets are known to be places where microorganisms thrive since they are the hub for a range of commercial operations that can lead to environmental issues such an overabundance of organic waste creation, according to Gómez et al. (2021). Chulquín & Rojas (2020) suggest that the current circumstances facilitate the growth and dissemination of bacteria and other harmful agents, as evidenced by the discovery by Vivas et al. (2021) of a significant bacterial concentration in the vicinity of the central market.

In point 6 (the hospital) there was a concentration of 433 UFC/m3 of air which rises raises the possibility of a connection to the higher volume of patients, guests, and medical personnel that occurs during the day. In accordance with Polytechnic University of Madrid researchers (UPM, 2023), raises the risk of nosocomial infections. As a medical facility, the hospital receives a lot of patients with different diseases, many of which are brought on by infectious agents including viruses, fungi, and bacteria (UPM, 2023). Because of their minuscule size, these microbes are easily swallowed when breathing and can spread throughout the air, raising the risk of nosocomial infections (Banchón et al., 2022). Hospital air contains a high concentration of microorganisms, which is concerning since it can spread illnesses to patients, visitors, and medical staff. Moreover, Núñez et al. (2021) state that elements like sunlight and high temperatures tend to raise the concentration of microorganisms because mid-afternoon is typically when the most daylight hours and significant temperatures are experienced.

According to Vivas et al. (2021), there are various criteria on the threshold of microbial concentration in outdoor air that is considered harmful to human health. The concentration mostly considered harmful to health is 500 CFU/m^3, in the case of fungi and bacteria. The values found in the present study are within this range, since the highest concentration recorded was 441 CFU/m^3. However, according to the limit values of microorganisms allowed by the WHO, the concentration is at an intermediate level (101 – 500 CFU/m^3 of air) (Marcillo et al., 2021), which is a cause for concern and justifies the implementation of prevention measures.

Several intriguing patterns emerged from an analysis of the correlation between climate variables and the number of germs in the air (Table 2). First, a weak negative correlation (coefficient of -0.42) was observed between the concentration of bacteria and temperature, suggesting that temperature had no effect on the number of bacteria in the air. Certain research, like Tang's (2009) study that Siller et al. (2024) mentioned, indicates that temperatures higher than 24°C may reduce the lifespan of microorganisms. However, studies like the one by Smets et al. (2016), which Yang et al. (2024) mentioned, show that bacterial growth is favored by rising temperatures. Temperature affects the dispersal of germs in the air because it encourages convective air movement, regardless of its impact on life (Miri et al., 2023).

An even weaker negative connection (coefficient of -0.05) was found for relative humidity. This indicates that the CFU concentration tends to decrease significantly as the relative humidity decreases. However, this association is extremely weak and nearly inconsequential because the coefficient of -0.05 is so close to zero. As to Guarnieri et al. (2023), an overabundance of relative humidity (RH) fosters the growth of detrimental microbes, including bacteria, viruses, and mold. Moreover, Cortés et al. (2024) claim that an excessively low relative humidity increases the risk of infection by causing dryness and irritation in the skin and respiratory system.

Table 2. Pearson correlation coefficient test for bacteria.

		Bacteria
Temperature	Pearson Correlation	-0.042
	Sig. (2-tailed)	0.692
	N	90
Relative humidity	Pearson Correlation	-0.055
	Sig. (2-tailed)	0.610
	N	90
Wind speed	Pearson Correlation	0.541**
	Sig. (2-tailed)	0.000
	N	90
UV index	Pearson Correlation	0.056
	Sig. (2-tailed)	0.601
	N	90

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

By contrast, there was a statistically significant positive association between wind speed and the concentration of airborne bacteria, with a coefficient of 0.541 and statistical significance at the 0.01 level. According to Miri et al. (2024), high winds cause bacteria to be lifted from the soil and plant surfaces into the air, which explains why the concentration of bacteria in the air increases as wind speed increases. Although the role of wind speed in the modulation and transport of bacteria has not been well investigated, Dueker et al. (2017) note that this variable is expected to increase the creation and transport of microbes from nearby bodies of water.

Furthermore, a positive association (coefficient of 0.56) was found between the UV index and the concentration of microorganisms. This suggests that more sun exposure may be linked to a higher prevalence of bacteria in the environment because there is a direct and reasonably strong relationship between the UV index and the quantity of bacteria in the air. Yet in a study conducted by Fahimipour et al. (2018), they assessed the impact of light exposure and wavelengths on the composition of the dust microbiome (in indoor environments). They found that exposure to sunlight led to a reduction in the number of some abundant microorganism groups and an apparent increase in the number of rare groups, suggesting that some microorganisms may have grown slightly in the presence of light.

The fungal concentration shows a notable increase around 1:00 p.m. at points 4, 5, and 6, with point 5 (park) recording the highest value at 87 CUP/m³. In contrast, the highest incidence of fungi at other locations (points 1, 2, 3, 7, and 9) occurs at 7:30 a.m., which follows a different pattern compared to the bacterial concentration at the two measured times (Figure 3).

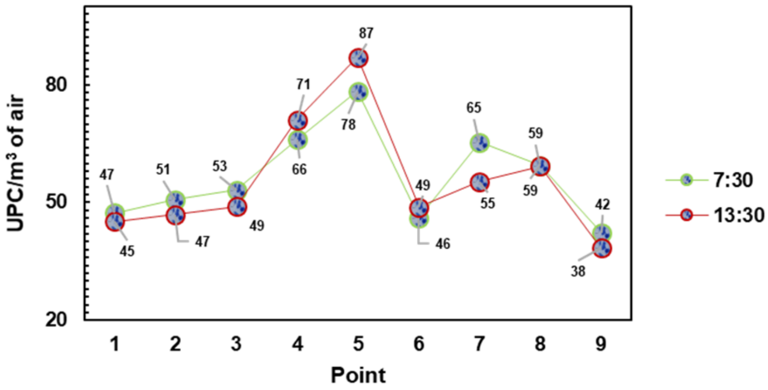

Figure 3. Data on fungal concentrations.

As opposed to the concentrations of bacteria, the preceding figure in this instance demonstrates that there is minimal fluctuation regarding the sample sites; in fact, depending on the two monitoring schedules, the concentrations may decline in certain instances or remain constant in others. The point 9 showed the biggest decline of all the locations, going from 65 to 55 UPC/m³ of air, a remarkable 10 CPU/m³ decrease from morning to afternoon. This notable variance could be attributed to a decrease in afternoon human activity or site-specific environmental variations, like variations in natural ventilation or sunlight (Marcillo et al., 2021).

This reduction is notable in comparison to other points because most locations saw minor gains or losses. One example of this is point 5 (park), which showed a notable increase of 8.6 CPU/m³ from morning to afternoon. Since vegetation is one of the primary substrates for the development of fungi, it is assumed that in urban parks, the concentrations of fungal spores in the air could be higher, as per Kasprzyk et al. (2021) since the production of fungal spores is significantly higher than that of pollen grains.

In the instance of the city market (point 4), there was a 5 CPU/m^3 variation in the concentration of fungus from the morning (66 CPU/m^3 of air) to the afternoon (71 CPU/m^3 of air). Although not as large as that of point 5, this increase is nonetheless noteworthy, and Gómez et al. (2021) attribute it to the escalation of commercial activity and the rise in afternoon population density. Conversely, point 9 (a city entry/exit road) had the lowest fungal content during both periods (42 UPC m^3 of air in the morning and 38.4 UPC m^3 of air in the afternoon). This could be because of its urban setting with fewer green spaces in addition to the rising temperatures.

Regarding the Pearson correlation between meteorological variables and fungal concentrations, the following was obtained:

Table 3. Pearson correlation coefficient for fungi.

		Fungi
Temperature	Pearson Correlation	0.018
	Sig. (2-tailed)	0.870
	N	90
Relative humidity	Pearson Correlation	0.023
	Sig. (2-tailed)	0.830
	N	90
Wind speed	Pearson Correlation	0.003
	Sig. (2-tailed)	0.978
	N	90
UV index	Pearson Correlation	-0.195
	Sig. (2-tailed)	0.066
	N	90

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

A very weak positive association, indicated by a correlation coefficient of 0.18 in the temperature variable, suggests that while the concentration of fungus tends to increase slightly with temperature, the relationship is not very strong. However, in September, there was a strong direct correlation between temperature and the total amount of fungi ($r = 0.853$, $p < 0.01$), according to a study by Nageen et al. (2023) on the seasonal change of fungal diversity in urban contexts. However, in November, the connection was inverse, meaning that the overall number of fungi decreased with increasing temperature ($r = -0.7718^*$, p

< 0.05). Likewise, Noor et al. (2019) in a similar study, found that the number of fungal spores in the air varied throughout the month of March and was related to climatic factors such as temperature, which influences the release of spores and growth. of mushrooms.

The correlation coefficient for relative humidity was 0.023, suggesting a weak positive association. This implies that there is a modest positive correlation between an increase in relative humidity and an increase in the variable under investigation. Similarly, Hass et al.'s study from 2023 found that there were negative associations between fungal spore counts and relative humidity for both Cladosporium and xeric fungi, with rho values of -0.35 ($p < 0.001$) and -0.33 ($p < 0.001$), respectively. Regarding its part, a statistically significant influence ($p < 0.002$) was identified on the number of fungal spores in the air, accounting for 1.5% of the overall change in the presence of fungal spores, in the study by Grinn and Bosiacka (2015), referenced by Núñez et al. (2021).

On the other hand, there is just a very slight positive association (0.003) between wind speed and fungal concentration. There is essentially no link between the two variables because this number is so close to zero. In contrast, the average wind speed was found to have a statistically significant influence ($p \leq 0.03$) on the number of fungal spores in the air during the study period, accounting for 1.5% of the total variation in the presence of fungal spores over a three-year period. This study was conducted by Grinn and Bosiacka (2015), cited by Haas et al. (2023). The wind helps release fungal spores and carries them through the air, expanding their dispersion and range, according to Nageen et al. (2021) by creating air currents.

However, the correlation value for UV index variable is -0.195, indicating a very weak negative link. In fact, in the study conducted by Kowalski and Pastuszkan (2018), at similar temperatures, the concentration of bioaerosols decreased with increasing sun radiation intensity, indicating that UV solar radiation negatively affects fungal spores and decreases their airborne presence. According to Noreiga et al. (2020), when administered in greater quantities, the same light wavelengths that promote spore formation in tiny amounts can completely prevent it.

5. Conclusions

Bacteria and fungi are part of airborne particles that exist momentarily and are subject to variations in concentration based on meteorological factors. Temperature and relative humidity had no discernible effects on bacterial concentrations in the research area, while wind speed and UV index demonstrated the strongest and positive connections with bacterial concentrations. The connections between meteorological factors and fungi were typically minor, with the most notable, though still weak relationship, being that of relative humidity.

The usefulness of the presented results is supported by their complete reproducibility. Future research should account for as many factors as possible in aerobiological studies. Additionally, monitoring should cover the entire season of the study area. Lastly, employing advanced techniques for identifying bacteria and fungi would enhance the specificity and accuracy of the information presented. This will make a significant contribution to monitoring the relationship between air quality and ecosystem and human health.

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Original Paper

Microplastics on the coasts of San Cristobal, Galapagos: a threat to the archipelago

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Abstract. *This study aimed to evaluate the presence and characteristics of microplastics on Mann, Lobos, Puta Carola, and Puerto Chino beaches. Water and sand samples were collected and analyzed for microplastic particles, considering factors such as size, color, and type. Each sampling point was meticulously georeferenced to track distribution patterns. Microplastics were* *extracted using a flotation process and identified using a stereomicroscope. The analysis confirmed the presence of microplastics on Puerto Chino beach, with the highest concentrations observed in the sand. Particles smaller than 1mm and 2mm were the most abundant, and blue was the predominant color. These findings shed light on the microplastic contamination in the Galapagos Islands, underscoring the urgent need for further research and mitigation strategies. Raising public awareness and implementing responsible waste management practices are critical steps towards protecting the delicate Galapagos ecosystem from the detrimental effects of microplastic pollution.*

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1. Introduction

Physical and chemical anthropogenic influences on the Earth system have reached a level comparable to that of natural geophysical processes (Steffen et al., 2011; De Souza Machado et al., 2018). As a result, human activities are among the most important drivers of ecosystem functions and threats to biodiversity (De Souza Machado et al., 2018).

Mass production of plastics began in the 1940s with the manufacture of a large number of different types (Mitrano and Wohlleben, 2020). As a result, there is growing concern about the increase in microplastics (plastic particles <5 mm) that contaminate different environmental compartments (Giráldez Álvarez et al., 2020; Rillig and Lehmann, 2020; Casso-Gaspar et al., 2022). These have increased in recent decades, with production increasing almost 200 times, reaching 320 million tons worldwide (Castañeta et al., 2020). Scientific research has shown the negative impact of plastic pollution on the oceans, as its mismanagement affects marine biodiversity (Rivera-Garibay et al., 2020).

Plastic pollution has become a global crisis, with millions of tons accumulating annually in both terrestrial and marine environments. Representing a staggering 20-30% of municipal solid waste by volume, plastic poses severe threats to ecosystems worldwide (Sumathi et al., 2016). While recycling and incineration efforts account for only 10% and 24% of plastic production respectively, the remaining 66% remains unmanaged, exacerbating the problem (Sumathi et al., 2016).

Although plastic constitutes a relatively small portion (10%) of municipal waste by mass, it accounts for a shocking 85% of marine debris, primarily originating from land-based sources (Rhodes, 2018). While ocean pollution has garnered significant attention, freshwater ecosystems are increasingly impacted by plastic contamination (Lebreton et al., 2017).

On land, the accumulation of macro and microplastics in soils and natural areas is disrupting vital ecosystem functions. These plastic particles alter soil properties, hindering plant growth and potentially impacting broader ecological processes (Rillig & Lehmann, 2020).

Ecuador, a country with a significant coastal profile made up of five provinces along the so-called sun route, contains 64% of its waste from plastics, with the highest density found on the southern beaches of the Guayas province, which are mostly dragged by river currents (Gaibor et al., 2020). In 2020, the waters contained an approximate of 112 m^3 of microplastics, compared to the 41.28 m^3 registered in 2008, of which a massive increase of 160.90 m^3 is expected by 2030 (Pinargote, 2020).

Beach debris accumulation occurs worldwide, primarily composed of 60% to 80% plastic waste (Davis and Murphy, 2015; Gaibor et al., 2020b; Watts et al., 2017). Plastic waste can be transported to beaches through various pathways, including tides, wind, land transport, or even being directly discarded by beach visitors (De La Torre et al., 2020; Honorato Zimmer et al., 2019; Lavers and Bond, 2017; Serra Gonçalves et al., 2019).

The Galápagos Islands, a highly protected UNESCO World Heritage Site renowned for its endemic biodiversity, are not immune to the growing concern of the biological and socioeconomic impacts of plastic pollution (Jones et al., 2022). A study by (Villarreal, 2017) revealed the highest microplastic volume on San Cristobal Island, covering 128.7 mm3/m3. Floating plastics carried by the Humboldt Current (extending from southern Chile to the west coast of South America, reaching Ecuador and the Galápagos Islands) are considered a significant source entering the Galápagos Marine Reserve (Jones et al., 2021; Mestanza et al., 2019; Van Sebille et al., 2015), posing threats to the aquatic system as microplastics are ingested particulate matter (Figure 1.) (Rehse et al., 2016), playing a crucial role as a disease vector in the marine environment (Kirstein et al., 2016).

Current research on microplastics in the Galapagos Islands is notably deficient. There is a critical absence of longitudinal studies to establish long-term trends, understand the specific impacts on endemic species, and accurately identify local contamination sources. Additionally, the interaction between microplastics and chemical pollutants remains largely unexplored. Monitoring microplastic pollution on beaches across space and time is crucial to understanding its ecological impacts and guiding mitigation efforts. Therefore, this study aims to evaluate the presence of microplastics on Mann, Lobos, Punta Carola, and Puerto Chino beaches in San Cristobal canton, Galápagos province (Ecuador), to determine the current level of plastic pollution.

2. Methodology

2.1 Study area

Fieldwork was conducted between September 2023 and March 2024, with sample collection focused on the southern region of San Cristóbal Canton, Galápagos Province, covering four beaches: Mann (209571.483 - 9900901.013), Lobos (209165.696 - 9900136.129), Punta Carola (209261.390 - 9901519.185), and Puerto Chino (229583.746 9897546.624) (Figure 1). A two-month sampling period was deemed sufficient to gather representative data and establish a baseline for subsequent research and management initiatives. This timeframe allowed for efficient logistical planning, resource allocation, and the implementation of robust data collection and analysis methodologies. An exploratory descriptive study was conducted with a qualitative-quantitative approach as established by Torres (2016), since sand and water sampling were carried out on the mentioned beaches in order to identify the quantity, size, and color of microplastics present in the study areas.

2.2 Sand sampling

Sand sampling was conducted along the high tide line in a 100-meter transect, consisting of four sampling points of 0.5 meters by 0.5 meters with a distance of 25 meters, following the methodology outlined by Olaya (2020). Sand samples were collected using an aluminum spoon, to a depth of 10 cm from the surface between the high tide lines, where three samples were taken in each transect and deposited in a 1 L glass Kilner jar, avoiding any presence of water (González, 2019; Horton et al., 2017).

The samples were labeled with the following information: location, date, area, coordinates, and transect number. Samples were taken every five days after the first sampling for three weeks.

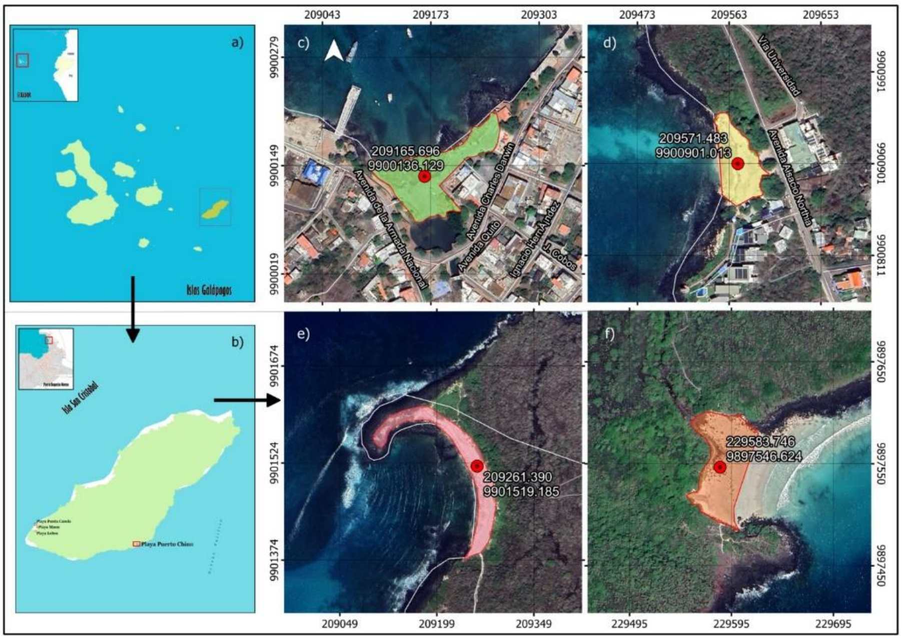

Figure 1. a) Galapagos province in Ecuador, b) San Cristobal Island, c) Lobos beach, d) Mann beach, e) Punta Carola beach, f) Puerto Chino beach.

2.3 Sampling of marine surface water

For water sampling, a 200 µm unweighted plankton net with a 200 µm mesh window and a flow meter was used, towing against the wind. GPS readings were taken at the beginning and end of each sampling point. However, due to the regulations established by the Galapagos Regulations for Maritime Tourist Transport Vessels, it was not possible to comply with the sampling protocol for microplastics on the sea surface as indicated by Gómez & Vélez (2023) and Kovač et al. (2016) at 3 of the 4 beaches. The plankton net was manually towed through the seawater surface for 2 to 10 minutes at a speed of 2 knots in duplicate.

2.4 Extraction of microplastics in sand and water samples

The density separation and flotation method proposed by Urban et al. (2020) was used to extract microplastics from sand and water samples. This method involved separating microplastics from water and sediment samples for quantification and characterization. The sieving method described by Crawford and Quinn (2017) was used as a reference for identifying microplastics in surface water. The samples were analyzed in the laboratories of the San Francisco de Quito University (USFQ) extension on San Cristobal Island.

2.5 Quantification of microplastics

Microplastics were identified using a stereomicroscope (Marine and Environmental Research Institute, 2019). Microplastics were classified by particle size (5mm, 4mm, 3mm, 2mm, 1mm), color, and type. The data obtained were used to estimate the total amount of microplastics on the beaches studied.

3. Results and discussion

The results of this study revealed the presence of microplastic particles (<5mm) on all four beaches sampled. Additionally, the presence of particles (<1mm) was observed in both sand and water (Figure 2).

Figure 2. Plastic particles (> 5mm) in sand.

Table 1 (see Appendix 1) details the results corresponding to the color, type, size, and quantities of plastic particle units (<5 mm) and (<1 mm) identified in the sand of the four beaches in San Cristobal canton.

Puerto Chino beach presented microplastics with a quantity of 37.375 units/kg, of which 0.1% corresponds to the fiber type and 99.9% to the solid type. Specifically, the distribution shows that 10 predominant microplastic color groups were identified with 31.6% blue, 22.2% green, 13.3% red, 8.7% light blue, 8.6% yellow, 7.1% orange, 3.9% pink, 2.7% purple, 1.7% black and 0.1% blue fiber (Figure 3). Recent studies have reported that the ingestion of MP by wild fish could be related to the availability, size, shape and color of plastic particles (Dos Santos et al., 2020), with blue being the preferred color for fish ingestion.

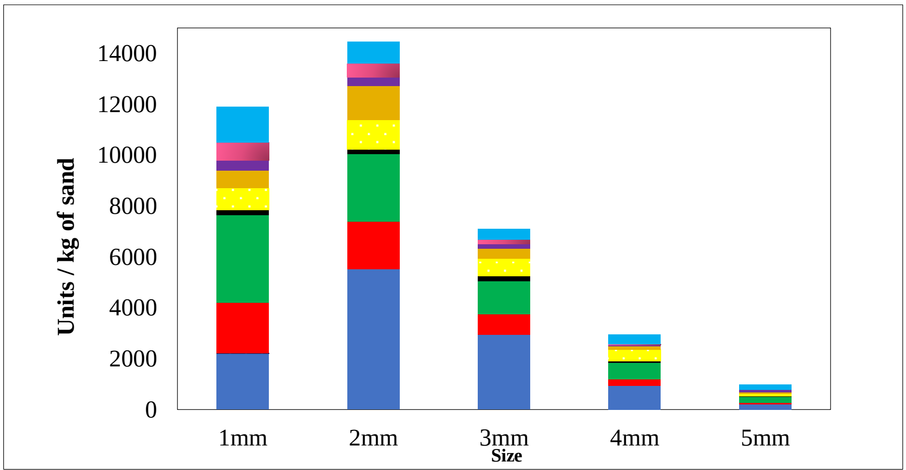

Figure 3. Microplastics identified by color and size obtained from the sand of Puerto Chino beach.

Figure 3 shows the fractions corresponding to each color of microplastics classified by particle size of <5 mm - 1 mm obtained from the sand of Puerto Chino beach. There is a higher concentration of microplastics, especially in the 2 mm and 1 mm sizes, with values of 14,450 and 11,900 units/kg of sand. Consecutively, a quantity of 7,100 units/kg of microplastics with a size of 3 mm is shown, 2,950 units/k with diameters of 4 mm. Finally, a lower presence of microplastics of <5 mm registering 975 units/kg of sand. On the Tortuga Bay beach line, the mean microplastic concentration (1–5 mm) ± SD was 74 ± 43 particles m−2. This high concentration is similar to those recorded in the Azores

Archipelago on the edge of the North Atlantic gyre (with an average of >500 particles·m−2 in the top 10 mm) (Pham et al., 2020)

In the microplastic analysis, it was determined that among the predominant colors associated with each particle size, green plastics of 1 mm (29%) and 5 mm (23%) and in the case of microplastics of 2 mm (38%), 3 mm (42%) and 4 mm (31%) blue color predominates.

Similarly, on Puerto Chino beach, a concentration of particles less than <1mm was identified equal to 500 units/kg, of which 8% corresponds to the nylon type plastic, 51% to the fiber type and 41% to the solid type. In addition, the specific distribution shows that 11 predominant color groups were identified with 38% blue fiber, 12% yellow, 12% blue, 10% red fiber, 8% red, 8% white nylon, 3% purple, 3% brown fiber, 2% green, 2% orange and 2% pink.

On Punta Carola beach, a concentration of particles (<1mm) was identified equal to 533 units/kg, of which 33% corresponds to the nylon type plastic, 44% to the fiber type and 23% to the solid type. The specific distribution shows that 8 predominant color groups were identified with 33% corresponding to white nylon, 30% to blue fiber, 14% to red fiber, 8% to green solid, 6% to blue solid, 5% to red solid, 3% to light blue solid and 2% to orange solid.

On Lobos beach, a concentration of plastic particles (1mm) was identified equal to 1,644 units/kg, of which 11.8% corresponds to the nylon type plastic, 26.6% to the fiber type and 61.6% to the solid type; identifying 10 predominant color groups with 20.9% blue fiber, 18.6% red, 14.1% purple, 12.5% blue, 11.8% white nylon, 9.1% light blue, 5.7% red fiber, 3% green, 1.9% orange, 1.9% yellow and 0.4% pink.

On Mann beach, a concentration of plastic particles (<1mm) was identified equal to 225 units/kg, of which 83.3% corresponds to the fiber type plastic and 16.7% to the solid type. In addition, the specific distribution shows that 5 predominant color groups were identified with 66.7% blue fiber, 16.7% red fiber, 5.6% purple, 5.6% light blue and 6.5% yellow.

Table 2 (see Appendix 2) details the results corresponding to the color and quantities of plastic particle units (<1mm) identified in seawater (20m from the high tide line) on the four beaches of San Cristobal canton.

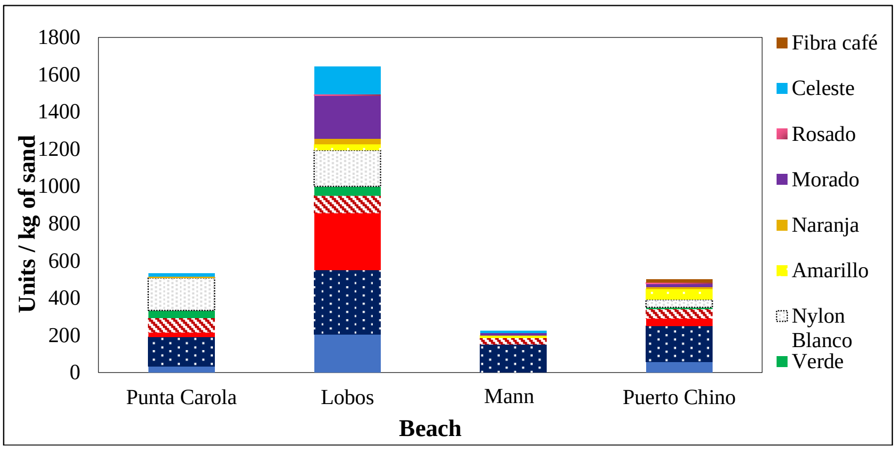

Figure 4. illustrates the fractions corresponding to each predominant particle color (>1mm) in the sand samples from the four beaches studied.

In the seawater of Puerto Chino beach, a concentration of <1mm particles was identified equal to 54 units per liter of water, of which 18% corresponds to the fiber type plastic and 82% to the solid type. In addition, the specific distribution shows that 10 shades were identified, red with 37%, yellow 25%, blue fiber 11%, orange 7%, pink 7%, blue 4%, brown fiber 4%, red fiber 3%, light blue 3% and green 1%.

In the seawater of Punta Carola beach, a concentration of particles (<1mm) was identified equal to 104 units per liter of water, of which 7% corresponds to the nylon type plastic, 63% to the fiber type and 30% to the solid type; 8 predominant hue groups were identified with 53% blue fiber, 12% blue, 10% red fiber, 10% purple, 8% red, 7% white nylon, 1% green and 1% yellow.

In the seawater of Lobos beach, a concentration of <1mm plastic particles was identified, equal to 38 units per liter of water, of which 49% corresponds to the fiber type plastic and 51% to the solid type. Likewise, 7 predominant color groups were identified with 49% blue fiber, 18% blue, 13% light blue, 10% red, 7% purple, 1% green and 1% pink.

In the seawater of Mann beach, a concentration of particles (<1mm) was identified equal to 13 units per liter of water, of which 25% corresponds to the nylon type plastic, 42% to the fiber type and 33% to the solid type. In addition, the specific distribution shows that 5 color groups were identified, with 25% green, 25% red fiber, 25% white nylon, 17% blue fiber and 8% orange in seawater.

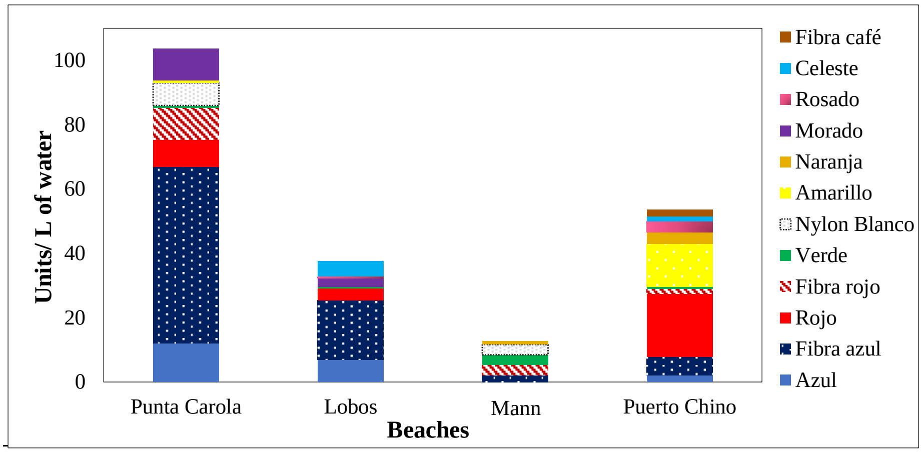

Figure 5. Plastic particle units <1mm identified by color in the seawater of San Cristobal beaches.

Plastics have become an environmental problem worldwide (Maxwell, 2021), due to the fact that tons of this polymer end up in the sea annually, causing pollution in the oceans and posing a danger to marine fauna due to its persistence and high toxicity (Barrera et al., 2023; Sánchez et al., 2022). Williamson et al. (2019) state that the environmental conditions of beaches cause the fragmentation and degradation of plastic waste into smaller sizes, eventually turning into microplastics (Lots et al., 2017).

Torrez et al. (2021) state that the ingestion of microplastics by marine species such as fish, birds, turtles, mammals and invertebrates is related to the size of microplastics available in the environment. Lusher (2015) states that in general, micrometers of plastics are easily ingested and expelled, however, nanometric plastics manage to pass through the cell membranes of species. Based on the above, there are various research works that report the presence of microplastics in the stomachs of mammals (Núñez, 2022), fish (Román et al., 2024), invertebrates (Astorga et al., 2022) and even the presence of microplastics in human placentas has been evidenced (Ragusa et al., 2021), which is why studies on plastics on beaches are sought to determine the level of contamination.

The analysis showed that the Puerto Chino beach showed the presence of microplastics in sand, with diameters of 2 mm (14450 units/kg) and 1mm (11900 units/kg). In addition, 5 color groups were identified, with blue being the predominant color for MP with diameters of 2 mm, 3 mm and 4 mm. In the research carried out by Torrez et al. (2021) on the beaches of Colima and Jalisco in Mexico, a total of 12001 microplastics were found in sand, and 12 colors were also identified, with blue being the most prevalent (45%). Olaya (2020) states that beaches are generally the areas that harbor a large amount of plastic waste.

In this study, it was determined that the largest amount of plastic particles (<1mm) in the San Cristobal canton was found on Lobos beach (1644 units/kg) in the sand samples, since the study area is an area destined for boating activities. These results differ from those achieved by Gómez & Vélez (2022) on the beach of San Jacinto, Manabi province, since microplastics were identified in various areas in this study site: fishing (1492 MP/m^2), tourist (490 MP/m^2) and area with less intervention (324 MP/m^2).

On the beaches of the coast of Peru, a microplastic study was carried out, reporting quantities of 19692 mg/cm3 on the Pozo de Lisas beach and 11358 mg/cm3 in Montecarlo (Dávila, 2021), values that are higher than those obtained on the Punta Carola beach with 104 units/L of particles (<1mm) in seawater on the island of San Cristobal, Galapagos. Acosta et al. (2022) state that microplastics are present in various environments, however, their presence is greater in saline waters in coastal areas.

In the research of Mindiola et al. (2016) carried out on three Galapagos islands (Santa Cruz, San Cristobal and Isabela), 669 MP particles were measured, determining that Santa Cruz Island exhibited the highest volume of microplastics (308706 mm3/L) and, San Cristobal Island reported a greater abundance of microplastics (34275 particles/L), the authors mention that the cause of this considerable amount of microplastics is due to marine currents according to the sampling season (October).

Regarding the coloration, it was identified that the most representative color on the beaches studied for sand corresponds to blue fiber that is generated by the breakage of cables or other activity. For its part, in the seawater samples, the predominant color was blue and blue fiber, in addition to colors such as green, red and yellow; classified as types of fiber, fragment and films that can come from plastic bags, disposable materials, among others. Mendoza and Mendoza (2020) mention that on the Mía beach in the city of Manta they found microplastics of similar colors (blue, yellow, green and red) to those identified on the beaches of San Cristobal, highlighting blue as the color with the highest percentage (40%). In addition, various types of microplastics were found: film (22%), fragment (30%) and fiber (48%).

In the investigations of Lino (2019), Torrez et al. (2021), Yagual (2023) and Ríos (2023) blue microplastics predominate significantly. Xiong et al. (2019) state that in the characterization of microplastics, the blue color will always prevail, given the abundance of blue MP that exist in the ocean. Mazariegos et al. (2021) state that this color has a high possibility of being absorbed by fish, since they can confuse their prey with microplastics. Van Sebille et al. (2021) argue that in the study carried out on the island of San Cristobal in the Galapagos, the most abundant types of microplastics are fragments (53%) and fibers (44%), while the results of Calle (2021) found fragments (49.10%) and fibers (40.75%) with white, green, orange and transparent colors. Villamar (2022) points out that in general the most frequent microplastics are: low density polyethylene (LDPE), high density polyethylene (HDPE), and polyethylene terephthalate (PET).

4. Conclusions

The findings support the modeled predictions that the Humboldt Current could be a major driver of the rate and spatial distribution of plastic accumulation in this part of the Galapagos Marine Reserve. Microplastics have a great impact on marine biota, especially on vertebrate fauna such as turtles, as well as on species included in the IUCN Red List. The prevalence of fiber-type microplastics gives us a clear idea of the failures in wastewater treatment plants (WWTPs) in countries, so research on microplastic sources is needed. The predominant particle size (<2 mm) and the predominant color is blue, associated with ease of consumption, as well as the resemblance to common prey. Appropriate conservation measures and management measures are needed to reduce the entry of microplastics into the Galapagos Sea ecosystem and protect its fragile and unique biodiversity.

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Original Paper

The beauty industry, climate change, and biodiversity loss.

Can humanity have "stories of kindness" for an environment-healing culture?

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Abstract. *Many people now recognize that the challenges of climate change and biodiversity loss are rooted in how and to what extent humans consume goods in the Anthropocene era. Consumerism has driven natural resource exploitation to its peak, and resource depletion is becoming more common. The beauty and personal care industry has an enormous market and substantial profitability, particularly in the high-income category. However, this benefit* *comes with the risk of being scrutinized, investigated, and criticized by civil society groups, environmental activists, and consumers. More than anyone else, the industry is aware of the risks of negative society appraisals, notably the consequences of consumer-led boycott activities. In this paper, we suggest that, given the current situation, global beauty firms need to play a proactive role in directing resources toward the development of sustainable uses of biodiversity and agriculture methods. This includes advocating for the wider use of environmentally conscious sourcing of raw materials, avoiding excessive and wasteful packaging, and devoting resources to research and innovation in environmentally friendly manufacturing procedures. The proactiveness would allow them to demonstrate their environmental commitment and actively give customers persuasive evidence of their social responsibility through emission reduction and biodiversity protection actions, gradually building an environmental-healing culture in the beauty industry.*

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1. The origin and expansion of the beauty industry

The world is now facing existential threats from climate change induced by anthropogenic greenhouse gas (GHG) emissions. The Global Tipping Points Report released at COP28 suggests that five major tipping points are in danger of being crossed at the current warming level, and three more will be at risk in the 2030s if the globe surpasses 1.5°C of global warming (Lenton et al., 2023). However, climate change is just one front in the current battle against environmental degradation (UNDP, 2023). Recent evidence indicates that biosphere integrity, another core planetary boundary besides climate change, has been transgressed (Richardson et al., 2023). Specific losses driven by anthropogenic impacts and climate change have and will continue to be updated, increasing in scale and scope, extending beyond insects, penguins, dolphins, whales, or corals, which are already quite familiar (Baumhardt, 2023; Chow, 2023; Fretwell, Boutet, & Ratcliffe, 2023; The Associated Press, 2023; Vuong & Nguyen, 2023; Wudu, Abegaz, Ayele, & Ybabe, 2023).

With the increasing volume of specialized scientific knowledge and widespread public information on climate change and biodiversity loss, many people have realized that the issue lies in how and to what extent humans consume products for their lives in the Anthropocene era. Consumerism has pushed natural resource exploitation to its peak, and the depletion of resources is becoming increasingly prevalent.

As part of endeavours to change human trajectories in all fields of consumption, the battle against climate change and biodiversity loss is also spreading to the beauty industry, which benefits from natural resources and biodiversity greatly for innovation and contributes between 0.5% to 1.5% of global GHG emissions (Escobedo & Lojenga, 2013; MacCarthy et al., 2020; Rocca, Acerbi, Fumagalli, & Taisch, 2022). Before delving into the contribution of the beauty industry to the current climate and biodiversity crisis and how it should change to address the issues, it is worth looking back at drivers that have led to the rapid development of the industry.

The use of beauty products did not emerge in the last few centuries but can rather be traced back thousands of years ago and linked to many cultures and societies, including Ancient Egypt, the Persian Empire, China, the Ancient Greeks, and the Roman Empire. However, access to beauty in past cultures and societies was primarily limited to elites who had sufficient income and leisure. Only until the 19th century did cosmetic products start to be used by a wider number of people due to mass production capability, advances in transportation, and increasing income brought by industrialization (Jones, 2011). One of the major barriers to the development and expansion of the beauty industry at the time was the hazardous ingredients. Thus, the invention of safer products, like Henry Tetlow's discovery of zinc oxide for face powder and Eugène Schueller's invention of modern synthetic hair dye, also helped disseminate cosmetics to more people (Jones, 2010; L'Oréal Groupe, n.d.).

Apart from the advancements in production and distribution, the social transition toward a higher consciousness of personal image was also a vital factor driving society's rising demand for cosmetics products (Jones, 2010). The technological advancements of mirror production, commercial photography, marketing, and the advent of electricity in homes and public spaces improved people's self-awareness of their personal appearance. Moreover, through the influence of ballet and theatre stars as well as the film industry in Hollywood, make-up became fashionable in the United States and Europe in the early 20th century. Taking the opportunities, entrepreneurs established many famous cosmetic firms in the present day during this period, such as L'Oréal, Elizabeth Arden, Helena Rubinstein, and Max Factor (Jones, 2023).

The enduring presence of cosmetics throughout history underscores their perceived benefits and society's ongoing demand for them (e.g., desire for attraction, reproduction, happiness, freedom, and feminine self-presentation) (Jones, 2023; Peiss, 1999). A survey conducted by the trade association Cosmetics Europe in 2022 revealed that 72% of European consumers viewed cosmetics as important or very important in their lives. This sentiment was even higher among 25-54 year-olds, with 74% considering cosmetics essential, and it peaked at 80% among women (Cosmetics Europe, 2022).

Despite the perceived benefits of beauty products, it cannot be denied that such a large number of people considering cosmetics important is largely driven by the industry's substantial investment in marketing with the aim to create additional demands for their products. In 2022, businesses in the beauty and personal luxury category spent $7.7 billion on advertising, representing approximately 1% of the total global advertising expenditure (Faria, 2023). Much of the advertising is used to generate the "unreal needs" and "conspicuous consumption" of luxurious fragrances, skincare products, and color cosmetics, which are often distinguished by intricate packaging (Galbraith, 1998; Jones, 2023).

Story-telling is a primary marketing strategy of the industry to exaggerate and create fanciful claims about the benefits of beauty products. Typically, since its beginning, the industry has continuously stereotyped beauty (e.g., global homogenization of "whiteness" as a beauty standard) and created fear over the natural processes of aging (Jones, 2010, 2023; Krozer & Gómez, 2023). Through doing so, the industry makes people, especially women, increasingly concerned about their appearance, stimulates their demand for solutions, and sells "hopes" (Tedlow, 2009). For that reason, the products promoted to address the aging and gender roles have not significantly changed in the last century, whereas marketing has continually evolved through a relentless process of linguistic innovation, constantly adapting to generational shifts (Hess, 2017). In particular, by the 1970s, language in beauty marketing had taken on a more inspirational and combative tone, using terms like "combat," "fight against," or "defy" age. In recent years, the focus has shifted, with "youthful" being replaced by words such as "renewing" and "radiant," and products are now often promoted as wellness-enhancing and environmentally friendly (Hess, 2017). Such a strategy was even heavily criticized by Anita Roddick, the founder of The Body Shop beauty retailer, in her autobiography *Body and Soul* (Roddick, 1991): "It is a monster industry selling unattainable dreams. It lies. It cheats. It exploits women. By preying on women's fears – of lost youth, diminishing appeal, and fading beauty

– the false hopes offered by the cosmetics industry can only result in misery, demoralization, and a deep-rooted sense of inadequacy" (p.9).

As "hopes" seem to have no boundaries, the success of this strategy is evident in the continued growth of the beauty market despite "little sign of either humility or even honesty in relation to customers" (Jones, 2023, p.119). By 2023, the industry had had a large market and high profits, especially in the high-income segment, with an estimated global market value of 460 billion USD and a projected annual growth rate of 6% until 2027 (The Business of Fashion & McKinsey & Company, 2023). However, given its detrimental impacts on the environment, more growth also means a higher risk of facing scrutiny, investigations, and criticism from civil society organizations, environmental activists, and consumers. More than anyone else, the industry is vulnerable to the perils of unfavourable societal assessments, particularly the repercussions of consumer-led boycott actions. The latest and future developments will only increase the pressure on businesses with products related to emissions and environmental damage, specifically biodiversity loss due to deforestation and long-term agricultural cultivation.

2. Detrimental impacts on the environment of the beauty industry

In contrast to the exaggerated and fanciful claims of the beauty industry, which are hard to validate, its various negative impacts on the environment are apparent with abundant evidence. The most obvious one is the generated waste due to extensive and wasteful packaging. Packaging is a crucial element in the business as it helps prevent the contamination of the product's ingredients, ensure the product's functionality and that the product is sealed and brand new, protect the product during transportation, etc. Since François Coty replaced pharmaceutical-style bottles with elegant new bottles characterizing artistic designs for selling perfumes, packaging has become much more important, even surpassing the ingredients across beauty categories as it has become a fundamental component in the industry's marketing strategies (Jones, 2010). Packaging is a way for the industry to attract buyers, associate the brand image with the quality of a product, and communicate the brand identity to consumers (Laurea, 2019). Most recent statistics suggest that by 2020, the industry produced around 120 billion units of beauty packaging annually, many of which were made from materials not easily biodegradable or recyclable, like plastic and glass, and ended up as waste. It is also estimated that 70% of the industry's waste comes from packaging (British Beauty Council, 2020).

As a result, the industry substantially exacerbates the global waste disposal crisis, especially the plastic pollution that adversely affects multiple geophysical processes and properties (e.g., global carbon cycle, nutrient cycle, soil properties, etc.) and worsens biological integrity (MacLeod, Arp, Tekman, & Jahnke, 2021). Specifically, ingestion of macroplastic debris has been recorded for 701 species, accounting for more than 76% of 914 studied marine megafaunal species (including birds, mammals, turtles, fish, and invertebrate species) (Kühn & Van Franeker, 2020). Another study by Gall and Thompson (2015) indicated that 17% of species affected by marine debris were listed on the International Union for Conservation of Nature Red List. Besides macroplastics, microbeads (types of microplastics) contained in some personal care and cosmetic products, like facial scrubs, body scrubs, toothpaste, etc., are also washed down drains into water sources, ultimately ending up inside marine life and humans (Okafor, 2021). The ingestion of microplastics has been reported to cause various harmful effects, including physical injuries, physiological changes, and impaired feeding, growth, reproduction, and oxygen consumption rates among aquatic species (Issac & Kandasubramanian, 2021; MacLeod et al., 2021). The pollution has reached a critical level when microplastics are now detected in cloud water at mountain summits ranging from 1300 to 3776 meters in altitude (Wang et al., 2023).

Sourcing raw materials for cosmetics production is also directly associated with biodiversity loss and GHG emissions. Palm oil is an exemplary ingredient used extensively in the cosmetics industry. Around 70% of beauty and personal care products include at least one palm oil derivative (Warn, 2021). However, its cultivation is a typical example of deforestation and an agricultural production method that disrupts the ecological balance, disturbs stable carbon reserves, and causes large-scale emissions (Qaim, Sibhatu, Siregar, & Grass, 2020; Vijay, Pimm, Jenkins, & Smith, 2016).

Due to the growing demand for palm oil-related products, oil palm plantations expanded by 0.7 million hectares annually during the 2008-2017 period (Erik Meijaard et al., 2020). A remote sensing assessment indicated that the total areas of oil palm plantations reached 19.6 million hectares by 2019, with Southeast Asia, specifically Indonesia, Malaysia, and Thailand, accounting for approximately 90% (Descals et al., 2020). The expansion of oil palm plantations resulted in widespread deforestation in Southeast Asia's tropical forests. Between 1972 and 2015, about half of new plantations encroached upon forests, while the rest replaced croplands, pasturelands, scrublands (including areas of secondary forest regrowth), and other types of land use (E. Meijaard et al., 2018).

Deforestation even happens in Borneo rainforest, one of the oldest rainforests in the world (around 140 million years old) that contains many endemic species of plants and animals, including critically endangered Bornean orangutan and Bornean rhinoceros (Leeder et al., 2016). Specifically, between 2000 and 2017, Borneo's old-growth forest declined by 6.04 million hectares (14% of the total area), primarily due to conversion to oil palm industrial plantations (Gaveau et al., 2019).

As forests are cleared, the species they contain are also negatively affected. According to Meijaard, at least 321 species listed in the International Union for the Conservation of Nature (IUCN) Red List are reported to be threatened by oil palm plantings, which is significantly higher than those affected by other oil crops. Some notable threatened species are orangutans *Pongo* spp., gibbons *Hylobates* spp., and the tiger *Panthera tigris* (Erik Meijaard et al., 2020). The species diversity and abundance for most taxonomic groups in oil palm plantations are also found to be substantially lower when compared with natural forests (W. A. Foster et al., 2011; Savilaakso et al., 2014). In certain plantations, plant diversity is less than 1% of the diversity found in natural forests. Meanwhile, mammal diversity in plantations is recorded to be 47–90% lower than in natural forests, with the level of diversity heavily influenced by the proximity to natural forests (Erik Meijaard et al., 2020; Pardo et al., 2019; Wearn, Carbone, Rowcliffe, Bernard, & Ewers, 2016). Oil palm plantations typically exclude forest specialist species, which are usually the species most important for conservation, like forest-dependent gibbons (Erik Meijaard et al., 2020).

In addition to negative impacts on biodiversity loss, oil palm plantations can lead to a predominantly negative net effect on ecosystem functions as compared to primary, selectively logged, or secondary forests. The loss of some ecosystem functions is potentially irreversible when the forests are cleared for new plantations, such as reductions in gas and climate regulation, habitat and nursery functions, genetic resources, medicinal resources, and information functions (i.e., cultural, aesthetic, and educational values of ecosystems) (Dislich et al., 2017). Xu et al. (2022), using high-resolution satellite maps, discovered that the oil palm expansion in Indonesia and Malaysia alone caused the loss of around 50.2 million metric tons per year during 2001-2015. They also observed the encroachment of oil palm plantations from low to high-biomass-density forests after 2007. In 2015, 0.12 million hectares of 395 protected areas (over 405 protected areas in Indonesia and Malaysia) were encroached by oil palm plantations.

The deforestation and drainage of peatlands for oil palm cultivation release significant amounts of carbon dioxide (Wijedasa et al., 2017). Although oil palm trees can capture high levels of carbon and their oil can be used as a renewable energy source, the carbon emissions from deforestation and peatland drainage cannot be offset by biofuel production in the short to medium term (less than 100 years) (Erik Meijaard et al., 2020; Searchinger, Wirsenius, Beringer, & Dumas, 2018). Despite the detrimental impacts of sourcing raw materials, its contribution to the beauty industry's GHG emissions is only ranked second with 30%. The majority of emissions in the beauty industry (59%) derive from consumer use of products, according to Carbon Trust's analysis (N. Foster & Retallack, 2023). Other GHG emission sources in the industry include end-of-life treatment of products (5%), transportation and distribution (5%), and manufacturing (1%).

Besides the aforementioned adverse impacts, the beauty industry is also involved in other socio-environmental problems, like poor working conditions, water pollution, animal cruelty, etc. However, the study will not delve into these aspects as its focus is on biodiversity loss and climate change, the two core planetary boundaries (Steffen et al., 2015).

3. The need for an environment-healing culture

As humanity is approaching the climate tipping points and planetary boundaries, people are increasingly more conscious of anthropogenic activities' adverse impacts on the environment and their consequences on human well-being. Such a consciousness is driving the social transitions toward a society that prioritizes sustainability. As a result, environmental protection and the reduction of negative impacts on the environment are gradually becoming standards reflecting ethical and humanistic values (Vuong & Nguyen, 2024a, 2024b).

Although beauty is hard to define, it is generally accepted by philosophers that for something – an event, a person, a behavior, an object – to be considered beautiful, it needs to attain the unity-in-diversity principle. The principle means that the diverse elements need to be organized and integrated into a meaningful whole (Diessner, Pohling, Stacy, & Güsewell, 2018). For someone's beauty to be appreciated, not only their image, actions, and values but also other information related to that person (including the personal care and cosmetic products they use) also need to be acknowledged by themselves or other people (Güsewell & Ruch, 2012; Haidt & Keltner, 2004; Vuong, 2023). Suppose consumers know that the products used for maintaining their beauty are contributors to climate change, biodiversity loss, environmental degradation, animal cruelty, and the suffering of other people. In that case, they would gradually begin to have multiple questions: whether their "beauty," which is the integration of multiple destructive elements, is true beauty; whether they still want such a beauty; and whether it is worth compromising their moral values for "hopes" and unattainable dreams of forever young. Indeed, the analysis of The Business of Fashion and McKinsey & Company (2023) indicates that the absence of ingredients that harm the environment and cruelty-free production is considered the most crucial aspect of sustainability by beauty consumers.

Besides social transitions, structural transformations also occur to restrict businesses, which causes harmful effects on the environment. In 2022, 196 countries signed an agreement to prevent and reverse biodiversity loss under the leadership of the United Nations. The Kunming-Montreal Global Biodiversity Framework is currently encouraging raw material suppliers to source plant-based materials that comply with environmental ethics and laws (Convention on Biological Diversity, 2022), for example, based on Union for Ethical Biotrade (UEBT), International Standard for Sustainable Wild Collection of Medicinal and Aromatic Plants (ISSC-MAP), FairWild Standard, Rainforest Alliance, Forest Stewardship Council (FSC), etc. Increasing pressure and legislation trends will gradually occur in countries across the globe, making it mandatory. For instance, if a product uses natural raw materials that violate the European Union's forest deforestation regulations (EUDR), that product will be banned or subject to heavy penalties. The compulsory implementation of traceability measures, which enable the identification of the geographical origins and production conditions of commodities, is increasingly prevalent.

Thus, businesses that capitalize on agricultural and wild-harvested ingredients are currently under scrutiny concerning their capacity to guarantee that these ingredients are ethically and environmentally friendly sourced. Ecovia Intelligence, a research, consulting, and training company specializing in global ethical product industries, anticipates a forthcoming surge in the adoption of sustainable regulations and strategies by beauty and personal care firms. One notable facet of this transition involves selecting raw materials that adhere to established environmental ethics criteria (Doolan, 2023). The company also assesses that this shift is no longer a prediction but has become a pressing necessity!

Some exemplary commitments can be seen so far:

- Davines Group, an Italian hair and skincare product company, partnered with the Rodale Institute to establish the European Organic Regenerative

Center in Parma in 2021. The company cultivates cosmetic ingredients using regenerative agriculture in a 17-hectare area.

- The multinational L'Occitane Group is committed to producing 100% of raw materials through regenerative and sustainable agriculture by 2025.
- Weleda, a pioneering organic skincare company worldwide, has established medicinal plant gardens with over 1,000 plant species and over 80% of plant ingredients grown according to organic farming processes.

Given the current circumstances, multinational beauty corporations must take a proactive role in allocating resources towards the development of sustainable agriculture practices. This entails not only advocating for the widespread adoption of environmentally conscious production methods but also dedicating efforts towards conducting research and innovation in the area of nature-friendly manufacturing techniques. There is a worldwide demand for a substantial proportion of profits to be reinvested into the cultivation of soil fertility, carbon sequestration, and active engagement in a collective effort to safeguard biodiversity within the Earth's ecosystem (Nguyen & Jones, 2022; Vuong, 2021). Such reinvestments can be made through schemes like Payment for Ecosystem Services, offsets, etc. (Escobedo & Lojenga, 2013).

Although the trend of transitioning from materials of fossil origin (such as oil) to renewable materials, adapting to climate change, and coexisting in harmony with nature has been theoretically determined, execution is still referred to as "a complex ecosystem of challenges" (Doolan, 2023). The main reason is that any change can entail a whole chain of consequences, which can be assessed by the complexity of the current supply chain in the industry. Moreover, greenwashing, inadequate environmental information disclosure, and lack of external verification and certification of ecological commitments hinder the industry's sustainability transformation (N. Foster & Retallack, 2023; Sangal, 2023; Tiscini, Martiniello, & Lombardi, 2022).

4. Conclusions

Despite the numerous obstacles, a consensus on the change in packaging and material sourcing is critical for the sustainability transformation within the industry. Leading brands are increasingly required to demonstrate their commitment to the environment and actively provide convincing evidence to consumers of their social responsibility through emission reduction and biodiversity conservation practices. Therefore, beauty firms' proactiveness in developing an environment-healing culture (i.e., eco-surplus culture) and subsequently educating their consumers is more ethically and responsibly sound than being forced by consumers and more aligned with the "healing beauty" message that they are trying to persuade their consumers to believe in (Vuong, 2023). This approach will also be more effective as beauty firms have better control over the transformation process (e.g., the resources, human resources, and technologies)[1] (Vuong, 2021).

Humanity has transcended the era in which the wealthy dressed themselves with the pelts of wild animals. Humanity is also leaving behind products that bring ecological destruction, albeit indirectly. Ecological destruction is also the destruction of the living environment of fellow human beings, those who may not have the resources to beautify themselves. Therefore, this type of destructive beauty can also be understood as a source of suffering for fellow human beings, not just in nature.

We end by quoting Karl Marx, as cited in the 1987 documentary film "The Story of Kindness" by director Tran Van Thuy (Wilson, 2015; Thuy, 1985):

> Only animals can turn their backs on the suffering of fellow beings and care only for their own fur (59:38)

Both the capitalist owners of beauty brands and their consumers have gradually come to understand this very well.

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[1] Even though the majority of emission in the beauty industry derives from consumer use of products (59%), the beauty products' usages were designed by the firms.

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Original paper

How an age-old photo of little chicks can awaken our conscience for biodiversity conservation and nature protection

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Keywords: artifact; climate apathy; education; artificial intelligence; humanities; art; painting; literature.

Abstract. *When discovering artifacts from ancient periods, humans often experience a deep and ineffable emotion. While studying the kingfisher as a symbolic representation of nature to restore the nature-human connection, we accidentally unearthed a valuable antique artifact in the journal: a picture of kingfisher taken nearly a century ago. The artifact was displayed in "Life History of the Amazon Kingfisher," written by Alexander Skutch and published by The Condor (1957). Inspired by the picture, we wrote this paper*

to discuss the humanistic value of nature-related science, art, painting, and literature for humanities in the age of climate and biodiversity loss crisis.

> Kingfisher knows he is quite handsome, so he often admires himself in the reflection of the pond. […] However, due to his rather eccentric personality, Kingfisher rarely communicates.
>
> In "Fragile Pride"; *Wild Wise Weird* (2024)

Sometimes, humans experience a profound and indescribable emotion when they unearth artifacts from ancient times. Scientific disciplines like paleontology and archaeology reflect our curiosity and desire to understand the natural world's past and evolutionary history. Physics also invests significant effort in exploring the origin and evolution of the universe. In social life, the study field of humanities also has journals about art history, such as the *Art History* or *Journal of Art History*. Through our shared thoughts and efforts to restore the humanities for the cause of ecological and biological conservation, we have discovered a picture of kingfishers taken nearly a century ago by A. F. Skutch in *The Condor* (Skutch, 1957). Obtaining such a vivid, genuine, and emotionally evocative image was no easy task because, for the photo to be taken, it requires the preservation capability of the scientific publication system, the skills of the photographer, the existence of the camera at the time, and most importantly, the occurrence of the precious moment in nature. This image has the power to stir the thoughts and awaken the conscience of the viewer, emphasizing the importance of a vibrant environment (see Figure 1).

1. "Naive little chicks in the kindergarten"

Unearthing this seemingly buried image, obscured by the passage of time and overshadowed by numerous contemporary interests, was not obvious and straightforward. First, this search was a continuation of our long-standing interest before, during, and after our article on connecting humanities to the ecological conservation mission through the image of kingfishers appearing in *Pacific Conservation Biology* (Vuong & Nguyen, 2023). The author (QHV) has had a deep connection with nature, especially birds since he was at a very young age. Such a connection has turned nature into a valuable source of inspiration and contemplation for his scientific activities. His social commentary book was even written with a Kingfisher as the protagonist character (Vuong, 2024). Due to this special interest, he often feels attracted to information related to kingfishers, whether it is scientific studies, literature, arts, paintings, photos, or lived experiences (Nguyen, 2024). It was this urge that led him to wander through the vast sea of information on the Internet, where he came across the remarkable image hidden in a study written in 1957 by A. F. Skutch. This is a prime example of serendipity—a conditional process shaped by one's mindset and environment, which allows for the detection and capitalization of unexpected information's values (Vuong, 2022). In other words, if Skutch's study had not been well-preserved and circulated through the Internet, and if the author had not had an interest or passion for kingfishers, this serendipitous discovery would never have occurred.

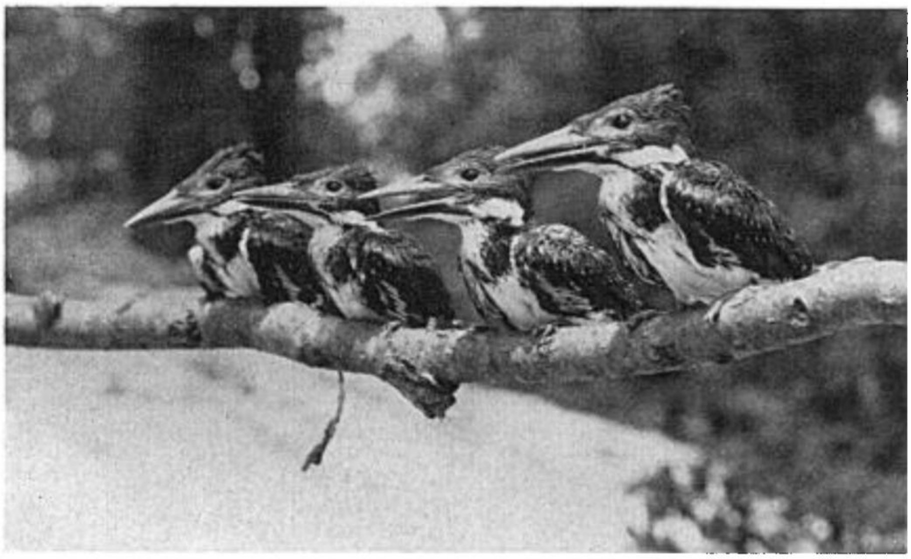

Fig. 3. Nestling Amazon Kingfishers, 18 days old; near Tela, Honduras, May 24, 1930.

Figure 1. "Naive little chicks in the kindergarten," from Skutch (*The Condor*, 1957).

Upon careful examination of the photograph, the image's name, as mentioned earlier in the caption of Figure 1, almost immediately comes to mind without the need for any linguistic refinement. The title of this 1930 photograph reflects a few details that can evoke emotions. First and foremost, one can easily recognize the innocence of the Amazon kingfisher chicks. At 18 days old, the world is entirely new and curious to them. Their eager expressions are reminiscent of children eagerly awaiting birthday cake from their family. It can be assumed that the birthday cake for these chicks is much simpler: food. At this age (18 days), they are not yet capable of hunting for food on their own. Finally, the term "kindergarten" emerges from the way the four kingfishers are lined up neatly on the branch. All four exhibit a very "uniform" appearance, but it is entirely natural, reflecting a form of social interaction that is very "non-kingfisher" characteristic (The reason for saying "non-kingfisher" will be clarified later.)

This image, along with a couple of other images in A. F. Skutch's 13-page article published almost a century ago, transcends mere biological life cycle descriptions or descriptions of kingfisher characteristics in adulthood. Although scientific information about kingfishers is crucial for enhancing our understanding of the species and developing effective conservation strategies, its monotonous language—laden with technical terms, jargon, and assumptions—does little to foster meaningful connections or inspire imagination in people's minds, either towards the species specifically or the natural world in general (Vuong & Nguyen, 2024a, 2024b). Instead, the images prompt profound reflections on the value of humanity in the battle for habitat conservation and the quest to reconnect people with the natural world harmoniously and co-existentially. This is particularly significant as human activities directly impact the loss of wild natural habitats, greenhouse gas emissions cause temperature fluctuations and disturb wildlife's long-standing growth conditions, and destructive exploitation of nature still occurs at an alarming rate (Armstrong McKay et al., 2022; Cooke et al., 2023). Species sensitive to environmental changes, such as the kingfisher, face an elevated risk of extinction due to temperature fluctuations and alternations in growth conditions, particularly among critically endangered species (Barik et al., 2022; Shifa et al., 2023; Tyler & Younger, 2022).

2. The quest for humanistic values for the cause of biodiversity and nature protection

Limiting the impacts of "anthropogenic stressors" remains challenging despite increasing awareness of its urgency among scientists and the general population. One reason is the difficulty of translating thoughts and awareness into practical action due to the persistent anthropocentrism among the public (Vuong & Nguyen, 2024a). The anthropocentric perspective positions humans as the central entity on the planet, viewing nature merely as "nothing more than matter-in-motion" without inherent values (Oelschlaeger, 1991). This mindset leads many to see humanity as superior to the natural world, prioritizing human needs and desires over the preservation of nature and environmental sustainability (Harding, 2019). Influenced by such beliefs, some even go so far as to deny the reality of climate change and the crisis of biodiversity loss (Almiron & Marta, 2019; Harding, 2019; Lees et al., 2020).

However, there is an observation to be made. If someone has been moved by the beauty of nature and has come to appreciate the value and beauty of life in the natural world, they are more likely to have sown the seeds of humanistic values that align with the quest to seek solutions to protect nature and preserve biodiversity.

It can be stated as follows: The earlier children are exposed to and appreciate the value and beauty of life in the natural world, the more opportunities they have to develop their own humanistic values. They may develop a value system incorporating those values and aesthetics as they grow into adults. The presence of nature in their retinas and the subsequent memories of a child will later create connections, recollections, and reminders of the value of the environment and ecology regularly (Reason & Gillespie, 2023). This is the ideal starting point for the quest for humanistic values for the purpose of nature conservation and biodiversity preservation (Paulsen et al., 2022; Spannring, 2017).

Now, let's return to what is referred to as the "non-kingfisher" characteristic of the image above. Kingfishers are generally known for being solitary, essentially shy, and characterized by their still, focused, perching behavior (Eliot et al., 2009; Reason & Gillespie, 2023; Renila et al., 2020; Vilches et al., 2013). Kingfishers are typically only seen as not solitary when breeding or caring for their young chicks (Morgan & Glue, 1977; Reyer, 1980). In their adult lives, they dive down to catch fish incredibly quickly, earning them the playful "royal titles" in *Wild Wise Weird* (Vuong, 2024), and their proportion of "meditation" time increases. However, the image above presents a "group activity" appearance. When viewing the image, the author himself (QHV) immediately traveled back in time to when he lined up at a kindergarten in Hanoi, waiting for his turn to receive lunch, around the mid-1970s. During this time, Vietnam had just ended the war against the United States, and while bombings had ceased, food was still in short supply.

3. Essential elements in restoring the missing bond

Art, painting, and literature. For a long time, kingfishers have appeared in various works of art and literature, even in sculptures in ancient Egyptian nobility tombs or mosaic paintings from the Greco-Roman civilization (El Menyawy, 2020; Eliot et al., 2009; Tammisto, 1985). If we consider A. F. Skutch's photograph in *The Condor* from 1957 as an antique artifact, then the connection to contemporary art, literature, and expression brings a fresh perspective to the era with a new flow of information. This has helped both authors like us receive sharing and approval from discerning readers, including editors and reviewers, as the image of kingfishers was introduced as a symbolic representation of nature (Barik et al., 2022; Vuong & Nguyen, 2023). Below is a watercolor painting of a kingfisher, seemingly coincidentally representing the Amazon kingfisher featured in Skutch's photograph (see Figure 2).

Bringing education closer to nature. High-value and long-lasting memory-preserving qualities in the image, especially after nearly a century, will permeate efforts in science communication through thought-provoking questions such as: What if this image can never be encountered again because this kingfisher species has completely disappeared, a victim of habitat loss? Such a question can also be linked to the history of human-animal relations, like the 19th-century hunt of the great auk (*Pinguinis impennis*) in the North Atlantic by British naturalists Alfred Newton and John Wolley that enlightened humankind about the existence of human-caused extinction (Pálsson, 2024). From this point, we could even delve deeper into the economic aspect of wildlife conservation by asking whether young children would prefer to spend vast money maintaining museums that preserve the remnants of extinct species and millions of dollars hoping to one day revive them or invest in conservation funds to ensure that they can continue to interact with these species and use their beauty to enrich their own imaginations (Vuong & Nguyen, 2023).

Moreover, if the photograph is shown to young children, they are likely to notice the feather tuft on the kingfisher's head. The tufts on these four chicks appear to be untidy hair even though kingfishers are exceedingly meticulous about cleaning and preening their feathers. Or conversely, it may be compared to the gelled hair of some "playboys," who spend a lot of money on their impressive hairstyles. Either way, children will find it intriguing. In any case, education becomes more natural and humane. Aren't education researchers striving to bring children closer to the natural environment? Whether or not children like it depends largely on the attractiveness of the information presented to them (see Figure 3).

AI and "serendipity." AI is a revolution, and the emergence of ChatGPT has heated up the information race. The research community is also anticipating the new role of generative AI and potentially Artificial General Intelligence (AGI) in the fight against climate change and ecosystem destruction. With the ability to create new information combinations from mountains of old information, AI

Figure 2. "Kingfisher appalled by violence": Watercolor by Bui Quang Khiem. ©2017 Quan-Hoang Vuong.

also greatly supports the harnessing of serendipity's power, a form of information processing capability that drives changes in perception and action stemming from (and having the characteristics of) demands for survival skills (Vuong et al., 2023), such as how AI is assisting drug development research (Paul et al., 2021). Similarly, in the fight against climate change and ecosystem destruction, if the power of AI is utilized appropriately and wisely, it will provide people, especially the young generations who are often referred to as "digital natives," with well-organized, concise, and overall trustworthy information that helps expand and deepen their understanding and connections with these environmental topics. Through increasing levels of interactions with AI trained by valid information prioritizing the inherent values of nature, people will be cognitively and affectively scaffolded to acculturate toward new humanistic values that focus on ecosystem protection and biodiversity conservation, like the eco-surplus culture (Vuong & Nguyen, 2024a). Simultaneously, the utilization of AI to build an eco-surplus culture will also help deal with environmental apathy, such as "who cares" attitudes (Vuong & Ho, 2024).

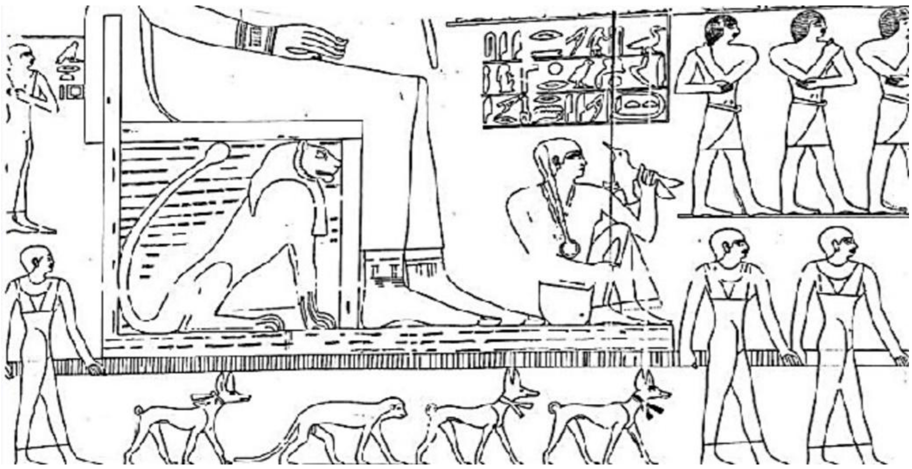

Figure 3. "A child holding a kingfisher by his left hand": Retrieved from El Menyawy (2020) under CC-BY-4.0. A scene from the tomb chapel of Wattkhethor, wife of Merruka (one of the most powerful officials during the Sixth Dynasty of Egypt) and daughter of King Teti (the first king of the Sixth Dynasty of Egypt). The Sixth Dynasty is considered the last dynasty of the Old Kingdom of Egypt, spanning 2305-2152 BC.

In general, the image of Skutch, with not only its scientific but also humanistic values, has given us an answer to the question of how much expense is justifiable for science. When science awakens humanistic values and conscience for life, the image is priceless, even when the cost of capturing it is negligible (Vuong, 2018). Furthermore, the value of publications lies in their ability to preserve, share, and expand new understanding of history and historical artifacts, making them invaluable. Value and innovation emerge from the interactions of information (Vuong & Nguyen, 2023). The information (e.g., knowledge, arts, paintings, literature) preserved through scientific publications is generally reliable and useful, often representing the distilled essence of a historical period. If this information were lost to the passage of time, the likelihood of reproducing it would be very low, almost equal to zero, and thus, so would its relevant values and innovations. And if such values and innovations have the potential to help humanity navigate and overcome the current planetary crises, the loss will be immeasurable.

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Original Paper

Sustainable housing indicators.
A statistical review of Indonesia's housing sector

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Abstract. *Sustainable housing is a concept for urban planning, the goal of which is building a living environment that is fully sufficient for today's demands and future generations' needs, addressing social and ecological issues. Sustainable housing includes sustainable building principles, which are applied to the aspects of planning, constructing, and managing living environments. This research aims to contribute to the understanding of sustainable housing in Indonesia by assessing the sustainability index of housing indicators within a comprehensive framework and considering various factors that impact people's quality of life. The research findings indicate that the sustainability index values for economic, social, and environmental dimensions show a quite sustainable range. it means that the housing is designed and built with a balanced consideration of its impact on the economy, society, and the environment. Although overall the three dimensions show sustainability, it is necessary to improve several indicators in each dimension that are not sustainable, such as maintenance and operating costs; safety and security; and waste management.*

1. Introduction

Housing sector in Indonesia plays a fundamental part in the development of the country's socio-economic welfare but the challenges are immense. The notion of the green city, which has been used in the Indonesian context, mainly illustrates the idea of green open spaces and yet does not contribute much to the enhancement of sustainability of the urban area (Zain et al., 2022). The demographic transformation across the different Indonesian parts has intensified the growth of slum areas and poor housing standards (World Bank, 2021).

Sustainable housing development is essential for achieving the United Nation's Sustainable Development Goals. The development of sustainable housing refers to the construction and operation of environmentally, socially and economically sustainable homes (Adabre et al., 2022). Sustainable housing is defined by several indicators that capture environmental, social and economic dimensions. Environmentally speaking, it involves using resources well, avoiding waste and reducing carbon footprints. Socially, it looks at making people feel safe and cared for in their neighborhoods. Economically, affordability and maintaining economic stability are its main aims. These indicators are crucial in assessing the sustainability of housing projects or policies (Ruíz & Mack-Vergara, 2023).

In recent years, Indonesia's government has introduced several initiatives that are aimed at promoting sustainable housing. Initiatives such as 'One Million Houses' program look at increasing the number of affordable homes available and simultaneously making them sustainable. Furthermore, policies that promote green building standards and renewable energy integration have been put in place to facilitate transition towards more sustainable housing practices. Nevertheless, Indonesia still struggles with achieving sustainable housing (Pane et al., 2023).

However, Indonesia still encounters challenges on sustainable housing. It is because of the obstacles that are present in Indonesia upon developing and implementing sustainable housing concepts. Demographic represents the primary challenge faced by Indonesia. This is because this country has a huge and ever-increasing population with inadequate homes for most households. According to data from Badan Pusat Statistik-Indonesia 2023 (BPS-Statistics Indonesia), the percentage of households that live in suitable homes was 63.15%. Suitable houses must satisfy four criteria; minimum floor area per capita (7.2 square meters), availability of clean water sources, adequate sanitation facilities and built resilience against hazards (Statistics Indonesia, 2023).

The second challenge faced is the lack of land availability for housing development. This has led to high housing prices, making them inaccessible to all segments of society. According to data from BPS-Statistics Indonesia 2023, 84.79% of the population own their own homes, while the remaining 15.21% are renters or temporary contract holders. Furthermore, the existing housing development has not been able to improve the quality of life for the Indonesian people. The presence of slum housing is an indicator of a decline in the quality of life. Data shows that the percentage of slum housing areas in Indonesia has decreased since 2021 and 2022. In 2021, the percentage of slum housing areas was 9.12%, and in 2022, it was 8.93%. However, some provinces still have a percentage of slum housing areas above 10.00%. Additionally, in 2023, the total percentage of slum housing areas in Indonesia was 7.94% of all households. This means that approximately 8 out of 100 households in Indonesia live in slum housing areas (Statistics Indonesia, 2023).

The objective of this research is to contribute to the understanding of sustainable housing in Indonesia by assessing the sustainability index of housing indicators within a comprehensive framework and considering various factors that impact people's quality of life. Specifically, sustainable housing indicators are considered a unified economic, social, and environmental metric. By examining the sustainability index, this review aims to highlight progress achieved, identify ongoing challenges, and propose recommendations to enhance the housing sustainable in Indonesia.

2. Literature review

Sustainable housing indicators are crucial tools for evaluating and guiding the development of housing that meets the needs of both present and future generations while balancing economic, social, and environmental factors (Piparsania & Kalita, 2022). In the context of Indonesia, a rapidly developing country with significant urbanization and environmental challenges, sustainable housing is vital for fostering long-term socio-economic stability and ecological health. Sustainable housing is a multidimensional concept that encompasses several key aspects. It is a comprehensive approach to housing development that considers not only economic factors but also social and environmental (Adamec et al., 2021).

2.1. Economic sustainability

Economic sustainability in housing projects means that the project can generate income and reduce expenses while also benefiting society and the environment (Menberu, 2023). It's crucial to consider economic sustainability alongside social and environmental sustainability for a comprehensive approach to sustainable development. Economic sustainability is significant because it ensures that the housing project can generate sufficient income and be well-maintained in the future, which is essential for both residents and the community at large (Tang et al., 2021). This includes making sure that housing is affordable, financially attainable, and economically feasible for a wide range of people (Saidu & Yeom, 2020).

2.2. Social sustainability

Social sustainability in housing means that housing must have a clear social responsibility towards residents and the surrounding community. Housing that is oriented towards social sustainability must prioritize the quality of life for residents and contribute to the quality of the environment and community (Amoah, 2023). In this context, housing must have a commitment to participate in various programs and activities that enhance the quality of life for residents and the community.

It should focus on creating inclusive, safe, and resilient communities, with access to essential services and opportunities for social integration (Hernández et al., 2023).

2.3. Environmental sustainability

Environmental sustainability plays a crucial role in ensuring housing sustainability by mitigating the environmental impact of construction practices. Environmental sustainability for housing refers to the practice of designing and building homes that minimize their impact on the environment while ensuring the well-being of both the occupants and the planet (Ruíz & Mack-Vergara, 2023). This approach involves integrating eco-friendly materials, energy-efficient systems, and waste reduction strategies into the construction process (Quidel et al., 2023).

2.4. Sustainability indicators

To evaluate sustainable housing in Indonesia, several indicators are typically employed across the economic, social, and environmental dimensions (Rahmawati et al., 2022). These indicators provide a comprehensive framework for assessing the sustainability of housing developments (Adamec et al., 2021).

1. Economic dimensions:
   a. Affordability: Measures the ability of average households to afford housing.
   b. Cost of Living: Assesses the overall cost of maintaining a certain standard of living, including housing, utilities, transportation, and groceries.
   c. Maintenance and Operating Costs: Assesses the long-term costs of maintaining and operating sustainable housing.
2. Social dimensions:
   a. Accessibility: Access to Livable Residential Buildings.
   b. Safety and Security: risk of natural disasters.
   c. Health and Well-being: Reflects the potential for indoor air pollution, such as smoking behavior.
3. Environmental dimensions:
   a. Energy Efficiency: Energy consumption per household and integration of renewable energy sources.
   b. Water Management: Water usage, recycling, and conservation practices.

c. Waste Management: Systems for reducing, reusing, and recycling household waste.

Sustainable housing in Indonesia requires a comprehensive and multi-faceted approach that integrates economic, social, and environmental considerations (Jones, 2017). By employing a robust set of indicators and theoretical frameworks, stakeholders can better understand the current state of housing sustainability and identify pathways for improvement. Overcoming the challenges and leveraging the opportunities inherent in sustainable housing will be essential for Indonesia's long-term development and the well-being of its citizens (Fitriani & Ajayi, 2022).

3. Method

3.1. Research Design

This study follows an evaluative research design, which is an approach used to assess the effectiveness, efficiency, relevance, and impact of a program, policy, or project (Bowes et al., 2023). The focus of evaluative research is to collect and analyze data to determine whether the desired goals have been achieved and provide recommendations for future improvements. In the context of this study, it allows for a comprehensive evaluation of various sustainability indicators related to the housing sector.

3.2. Research Question

1. How great is the sustainability index of economic, social and environmental dimensions in Indonesia for housing development?
2. What are the economic, social and environmental indicators that can be used to actualize sustainable housing in Indonesia?

3.3. Research Methodology

The method used in this study refers to the Handbook on Constructing Composite Indicators (CI) published by the Organization for Economic Co-operation and Development (OECD) (OECD, 2008). CI can summarize complex and multidimensional realities, making it very useful in measuring complex concepts such as sustainable housing. Therefore, the CI method can capture various aspects related to sustainable housing in a single integrated index.

It also allows for equal weighting of each component, making it transparent and data driven. This eliminates subjectivity and ensures more accurate results. Using the CI method in analyzing the sustainable housing index can provide more accurate, transparent, and easy-to-understand results, as well as enabling more effective decision-making. Here are the steps in the Sustainable Housing Index Analysis:

1. Identify and select key indicators for assessing housing sustainability.

We have identified nine (9) components of sustainable housing indicators, which can be categorized into three main dimensions: economic, social, and environmental. Here are the specific indicators under each category:

   a. Economic Indicators: Affordability, Cost of Living, & Maintenance and Operating Costs
   b. Social Indicators: Accessibility, Safety and Security & Health and Well-being.
   c. Environmental Indicators: Energy Efficiency, Water Management & Waste Management.

2. Collect relevant quantitative data from official sources such as the BPS-Statistics Indonesia, the Ministry of Public Works and Housing, as well as reports and surveys from research institutions and non-governmental organizations.

3. Normalize the data to ensure that all indicators are on the same scale, making them comparable. The normalization technique used is min-max normalization on a scale of 0-1.

Method Maximum-Minimum using the following calculation formula:

$$\mathrm{Ii} = \frac{\mathrm{x} - \min\,(\mathrm{x})}{\max\,(\mathrm{x}) - min\,(x)}$$

Where Ii is the value of a normalized indicator, x is the initial value of the indicator, and max(x) and min(x) are the maximum and minimum values of x, respectively.

4. Assign weight to each indicator based on its relative importance to housing sustainability. Determining the weight of each indicator is carried out using the Analytic Hierarchy Process (AHP) method. The Analytical Hierarchy Process (AHP) is a decision-making method developed by Thomas L. Saaty

in the 1970s. It is used to solve complex multi-criteria problems by breaking them down into simpler elements and then combining them back into a hierarchy. AHP is a decision support model that decomposes complex problems into simpler elements. It allows users to integrate subjectivity and objectivity in the decision-making process and helps identify the most important factors in complex situations. AHP allows the use of priorities for each indicator, so that it can determine the indicators that have the most influence on housing, decision-making, handling complexity, and flexibility in various applications. In this study, the weighting of the indicators is as follows:

a. Economic Indicator: 40% (0,4)

b. Social Indicator: 30% (0,3)

c. Environmental Indicator: 30% (0,3)

The determination of these indicator weights is based on the relative importance of each indicator, with the economic indicator being considered more critical in the concept of sustainable housing due to its direct impact on affordability for the community.

5. Calculate the sustainability index score for each region or housing category by combining the normalized values and indicator weights. The general formula for the index is:

$$\text{Sustainability Index} = \sum (\text{Indicator Value x Indicator Weight})$$

Furthermore, the Sustainability Index (SI) scores are split into five categories which imply the level of sustainability achieved in regard to the following scale:

$0.0 < SI \leq 0.2$: Very unsustainable

$0.2 < SI \leq 0.4$: Unsustainable

$0.4 < SI \leq 0.6$: Quite Sustainable

$0.6 < SI \leq 0.8$: Sustainable

$0.8 < SI \leq 1.0$: Very Sustainable

6. Analysis and Interpretation: Analyze the index results to identify regions or housing categories with the best and worst performance in terms of sustainability. Interpret the findings to provide insights into the factors influencing housing sustainability.
7. Formulation of Recommendations: Based on the analysis, formulate strategic recommendations to improve housing sustainability in Indonesia. Recommendations may include enhancing government policies, promoting green housing practices, and increasing public awareness about the importance of sustainable housing (OECD, 2008).

3.4. Data collection technique

Data collection in this research used secondary data collection methods. Secondary data collection techniques are used to gather information that has already been collected by someone else, in this case, the BPS-Statistic Indonesia. Secondary data is used in research because it is already available and accessible, making it easier to use without having to collect primary data from scratch, which may be difficult or costly to access. Additionally, secondary data often has higher validity and reliability because it has already been processed and checked by others, ensuring that the data used in the research has good quality. Furthermore, secondary data can have better quality and specifications because it has already been processed and checked by others, allowing researchers to use more accurate and relevant data for their research (Bowes et al., 2023).

The secondary data comes from the publication of data by BPS-Statistics Indonesia. Badan Pusat Statistik (BPS) is a Non-Ministerial Government Agency that reports directly to the President. BPS aims to become "A Provider of High-Quality Statistical Data for a Prosperous Indonesia" and its mission includes improving the quality of human resources in Indonesia, enhancing the country's productive and competitive economic structure, and promoting balanced and equitable development (Statistics Indonesia, 2023).

Data collection is done by downloading data from the BPS website[1] regarding the 2023 Indonesian Housing and Settlement Statistics Report, the 2023 Housing and Environmental Health Indicators, and the 2023 Statistical Yearbook of Indonesia. The locations sampled for this research were 34 provinces in Indonesia. All provinces in Indonesia were chosen to be able to describe the condition of Indonesia as a whole.

[1] https://www.bps.go.id/

4. Results and Discussion

4.1. General overview of Indonesia

Indonesia is a country located in Southeast Asia, comprising more than 17,000 islands. It is the world's fourth most populous country, with a population of over 273 million people. The country is known for its rich cultural heritage, diverse geography, and vibrant economy. Geographically, Indonesia is situated between the Indian and Pacific Oceans, with the equator passing through the center of the country. Indonesia has a land border with Papua New Guinea on the island of Papua, Malaysia on the island of Borneo, and East Timor on the island of Timor. Additionally, the country has a maritime border with Singapore, Vietnam, Thailand, the Philippines, Australia, Palau, and India. The country's landscape is characterized by volcanic mountains, rainforests, and coral reefs. The climate varies from tropical to temperate, with two main seasons: dry and wet.

Figure 1. Map of Indonesia

Indonesia is a federal republic with a parliamentary system of government. The country is divided into 34 provinces, each with its own governor and local government. The capital city is Jakarta, which is also the country's largest city and economic hub. Indonesia has a diverse economy, with major sectors including agriculture, manufacturing, and services. The country is a significant producer of palm oil, rubber, and coffee, and it is also a major exporter of textiles and electronics. The country's economy has experienced significant growth in recent years, driven by investments in infrastructure and the services sector.

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One sector that has a significant impact on the development of regions and the economic growth of Indonesia is the housing sector. The housing sector plays a crucial role in the Indonesian economy by impacting economic growth, welfare, and financial stability. Public housing infrastructure development can stimulate economic growth by opening isolated areas, reducing production costs, and creating new economic centers (Nurdini et al., 2021).

Housing financing policies, like the Liquidity Facility of Housing Financing (FLPP), aim to improve low-income communities' welfare and boost economic performance through reallocation of resources (Adianto & Gabe, 2022). Additionally, the housing sector's turmoil can directly affect the domestic economy and financial stability, emphasizing the importance of macroeconomic variables and inflation-targeting frameworks in managing asset prices and preventing crises. Efforts to enhance housing financing efficiency, such as through primary housing financing improvements and stable bond markets, are essential for providing affordable housing for low-income individuals and driving economic development in Indonesia (Sun & Yiu, 2021). Despite government programs addressing housing backlogs, challenges persist, necessitating strong supervision and supportive regulations.

The house has developed into a place for various basic activities, building a family, raising children, and educating and instilling cultural values. Along with the development of the Republic of Indonesia, as mandated by the 1945 Constitution, the provision of housing is directly handled by the government through the Ministry of Public Works and Housing, particularly the Directorate General of Housing. As a stakeholder in housing activities in Indonesia, we need to educate the public about the history of housing in Indonesia from various eras. Here's Historical Development of Housing in Indonesia year by year (Suparwoko, 2013):

Table 1. Historical Development of Housing in Indonesia

Year	Historical Event
1924	The colonial government facilitated Dutch government employees.
1925	Kampung Improvement Program The first program in Surabaya (Kampong Verbetering) aimed at Dutch interests, namely Empowerment.
1926	Construction of public housing. Construction of Loji, a large house owned by Dutch officials.

1932	First village improvement program (renewal program); village improvements to prevent the spread of disease from spreading to Dutch housing (bubonic plague), including by repairing drainage and providing information about healthy homes.
1950	Healthy Public Housing Congress in Bandung Healthy housing to improve welfare. Formulate minimum housing standards. Immediately form a public housing agency with the APBN.
1952	The Development Cash Foundation (YKP) targets 12,000 houses. Housing developments carried out by YKP include Tenggilis and Jemur Handayani Public Housing (PERUM) in Surabaya, as well as housing near Unmer in Malang.
1953	Dutch housing was secured by the military. Urban residents are lazy about building houses, because they are too lazy to deal with the housing affairs office. However, this does not happen in rural communities
1955	Implementation of Land and Building Tax (PBB) LPMB, a research institute on housing was inaugurated in Bandung on March 1, 1955. It also functions as the United Nation Regional Housing Center (UNRHC). Determining the structure and sanitation of house construction.
1960	MPRS Decree no. 2 / 1960: In the housing sector, you should build houses that are healthy, cheap, enjoyable and meet moral requirements. Housing arrangements are held. Construction of housing facilities by the government. Built in an industrial area
1969	KIP is implemented in Jakarta.
1972	National Housing Workshop. National Housing Coordinating Board (BKPN). National Urban Development. City Urban Development Corporation, State City Development Company. Financial institutions Real Estate was formed on May 6, 1972. KPR starts running. BIC (Building Information Center) changed to PITB (Building Engineering Information Center)
1974	REI was formed simultaneously with Perumnas.
1976	New residential areas began to appear, such as in Jakarta and Medan.
1979	KIP becomes a National program.
1984	Core houses appear. Core 16 m^2 and rooms 5 m^2
1989-2000	PT. Prosperous Board ---- Board Bank. Housing Development Focuses on Groups (P2BPK) Home loans are also provided by private banks.
2000 – Present	Construction of Rusunawa/Rusunami Self-Help Housing: BSP2S and PKP.

The main challenges faced in designing affordable housing in Indonesia involve property owners, architects, and the government. These challenges include limited floor space, high density, and poor living conditions. The history of housing development in Indonesia has gone through several stages, from the Dutch colonial period to the post-independence era. Housing development has been a priority for the government, with various institutions and programs established to improve the quality of life for residents. However, several challenges still need to be addressed, including limited floor space and poor living conditions. The current goal of housing development is not just to provide residential units but rather to ensure that the needs of housing are met, prioritizing the quality of life of the community, including affordability, environmental friendliness, and ease of access to various sectors.

4.2. How great is the sustainability index of economic, social and environmental dimensions *in Indonesia for housing development?*

Indonesia has committed to achieving sustainable development goals (SDGs) that cover three main dimensions, namely economics, social, and environmental. Furthermore, you can see the percentage indicators for each dimension of sustainability in Table 2.

Table 2. Percentage data of sustainable housing indicators in Indonesia. Source: BPS-Statistic (2023).

Indicators	Economic	Social	Environmental
Affordability (Ec1)	84,79		
Cost of Living (Ec2)	5,82		
Maintenance and Operating Costs (Ec3)	0,7		
Accessibility (S1)		63,15	
Safety and Security (S2)		16,4	
Health and Well-being (S3)		70,77	
Energy Efficiency (En1)			97,93
Water Management (En2)			96,97
Waste Management (En3)			86,29

From table 2 we can see the percentage of indicators for each sustainability dimension. Due to the unequal distribution of data on these indicators, it is necessary to normalize the data. Data normalization is essential for comparing data from different indicators. Since each indicator has its own set of basic data, it's important to bring them all to a common scale. This allows for meaningful comparisons between the indicators. The process of normalization involves transforming the data so that it falls within a specific range. In this case, we are using the Maximum-Minimum method, which scales the values between 0 and 1. A value of 0 represents the minimum value in the dataset, while a value of 1 represents the maximum value. By normalizing the data, we ensure that all variables are treated equally and can be compared with one another. This removes any biases or discrepancies that may arise due to differences in the original scales of the data.

Method Maximum-Minimum using the following calculation formula:

$$\mathrm{Ii} = \frac{\mathrm{x} - \mathrm{min}\ (\mathrm{x})}{\mathrm{max}\ (\mathrm{x}) - min\ (x)}$$

The normalized data results are in Table 3.

From Table 3, we can see that all the indicators from each sustainability dimension already have data that are normally distributed, which scales the values between 0 and 1. Next, we will perform weighting on each indicator using the AHP method. At this stage, each normalized value for each indicator will be multiplied by its dimension weight. The indicators from the economic dimension, namely Affordability (Ec1), Cost of Living (Ec2), and Maintenance and Operating Costs (Ec3), will be multiplied by a weight of 40% (0.4). Meanwhile, the indicators from the social dimension, namely Accessibility (S1), Safety and Security (S2), and Health and Well-being (S3), will be multiplied by a weight of 30% (0.3). Finally, the indicators from the environmental dimension, namely Energy Efficiency (En1), Water Management (En2), and Waste Management (En3), will be multiplied by a weight of 30% (0.3). The results of the indicator weighting are shown in Table 4.

Then we combine all the indicators for each economic, social, and environmental aspect. We repeat this process again to calculate a final sustainability index value. By looking at the aggregation results of each indicator in the economic, social, and environmental dimensions (as shown in Table 5), we can see that the sustainability index falls within a *quite sustainable* range.

Table 3. Data normalization results

Indicators	Calculation formula: $Ii = \frac{x - \min(x)}{\max(x) - \min(x)}$	Normalization result
Affordability (Ec1)	$Ec1 = \frac{84,79 - 0,70}{84,79 - 0,70}$	1,00
Cost of Living (Ec2)	$Ec2 = \frac{5,82 - 0,70}{84,79 - 0,70}$	0,06
Maintenance and Operating Costs (Ec3)	$Ec3 = \frac{0,70 - 0,70}{84,79 - 0,70}$	0,00
Accessibility (S1)	$S1 = \frac{63,15 - 16,4}{70,77 - 16,4}$	0,86
Safety and Security (S2)	$S2 = \frac{16,4 - 16,4}{70,77 - 16,4}$	0,00
Health and Well-being (S3)	$S3 = \frac{70,77 - 16,4}{70,77 - 16,4}$	1,00
Energy Efficiency (En1)	$En1 = \frac{97,93 - 86,29}{97,93 - 86,29}$	1,00
Water Management (En2)	$En2 = \frac{96,97 - 86,29}{97,93 - 86,29}$	0,92
Waste Management (En3)	$En3 = \frac{86,29 - 86,29}{97,93 - 86,29}$	0,00

Table 4. Analytic hierarchy process results

Indicators	AHP
Affordability (Ec1)	0,40
Cost of Living (Ec2)	0,02
Maintenance and Operating Costs (Ec3)	0,00
Accessibility (S1)	0,26
Safety and Security (S2)	0,00
Health and Well-being (S3)	0,30
Energy Efficiency (En1)	0,30
Water Management (En2)	0,28
Waste Management (En3)	0,00

Table 5. Sustainability Index

Dimensions	Sustainable Index
Economic	0,42
Social	0,56
Environmental	0,58

The value of each economic, social, and environmental dimension is 0.42; 0.56, and 0.58. When calculated overall, this dimension reaches a value of 1.56, indicating the highest level of sustainability. In the context of housing, this can mean that the housing sector in Indonesia has achieved a high standard in all three dimensions of sustainability. A value that is quite sustainable indicates that the housing sector has reached a relatively stable level and can meet the needs of the community and has integrated environmental and social aspects into its development process, but still has some shortcomings that need to be improved.

Table 5 shows that among the three dimensions reflecting sustainable housing in Indonesia, the economic dimension has the smallest sustainability value (0.42). This economic dimension requires serious attention and improvement from stakeholders to ensure its impact on the implementation of sustainable housing, as it has the most significant influence on the quality of life of the community. The economic dimension plays a crucial role in sustainable housing by ensuring affordability, maximizing profits, and minimizing costs while also enhancing social and environmental aspects (Ghaffar & Aziz, 2021).

Sustainable housing projects need to focus on economic sustainability to achieve multiple planning objectives, such as reducing transportation costs, improving incomes, and providing infrastructure for the poorest of the poor (Menberu, 2023). Incorporating economic sustainability in affordable housing programs is essential to address the economic, social, and environmental challenges faced in urban areas. Additionally, sustainable housing planning should consider the economic benefits derived from environmental and social sustainability, leading to significant gains at both individual and societal levels (Mironiuc et al., 2021).

By evaluating the economic sustainability of urban forms and incorporating economic considerations in housing projects, cities can achieve better economic performance, environmental quality, and social equity, contributing to overall sustainable development. Adabre & Chan (2020) presented a sustainability assessment model for affordable housing in Ghana, consisting of four indices, with household satisfaction being the most significant index. According to Hasan et al. (2024), sustainable development should also be able to generate interest in affordable housing and low living costs within residential areas. Overall, the economic dimension not only affects affordability and financial viability but also influences decision-making, policy implications, and the overall sustainability of housing projects.

Besides that, social and environmental dimensions also play a crucial role in sustainable housing by ensuring the well-being of communities. Social sustainability, often overlooked compared to environmental and economic aspects, is vital for human well-being, inclusiveness, and community benefits. It involves addressing basic human needs and integrating social and environmental aspects to meet welfare criteria (Goh et al., 2023).

Sustainable housing aims to reduce the environmental impact of buildings, which account for a significant portion of global energy consumption and resource use (Cubukcuoglu, 2022). Governments incentivize environmentally conscious practices in real estate development through tax credits and grants, promoting the construction of green buildings to mitigate carbon emissions and resource depletion (Regodon et al., 2022). By integrating green building practices, such as energy-efficient design and water conservation measures, sustainable housing not only reduces environmental harm but also contributes to long-term ecological preservation and intergenerational justice.

4.3. What are the economic, social and environmental indicators that can be used to actualize sustainable housing in Indonesia?

Next, we will analyze indicators that form the dimensions of economy, society, and environment, which can support the implementation of sustainable housing in Indonesia. This is done to identify which indicators need to be improved and enhanced so that they can support the sustainability of housing in Indonesia.

4.3.1. Economic sustainability

From Table 4, we can see some indicators of every dimension of sustainable housing in Indonesia. Among the economic dimension indicators that have higher sustainability value, affordability is one. This means that the most crucial aspect suggesting sustainability for housing within the economic dimension is affordability. The concept of sustainable affordable housing choice involves factors such as housing price in relation to income, rental price in relation to income, building type (Ezennia & Hoskara, 2019).

Having a high score for the affordability indicator of housing in Indonesia signifies that a significant portion of Indonesians can financially afford to buy or rent a home (Heylen, 2021). This translates to housing in Indonesia being relatively accessible for a large part of the population. Compared to other countries, Indonesian house prices tend to be lower. This stems from factors like cheaper construction costs, and government policies promoting affordable housing development. The Indonesian government has implemented various policies to improve housing affordability. These include subsidized housing programs, development of apartment complexes (rumah susun), and streamlined property permitting processes. Besides that, Current Indonesian mortgage rates (Kredit Pemilikan Rumah/KPR) are low. This makes home loans more accessible and affordable for the public.

However, it's important to acknowledge that housing affordability isn't uniform across Indonesia. In densely populated urban areas, house prices might still be out of reach for many. Additionally, a portion of the population lacks access to formal financial services, hindering their ability to obtain mortgages.

Therefore, the government and other stakeholders need to continuously strive to improve housing affordability in Indonesia. This can be achieved through various means:

a) Increasing Supply of Affordable Housing: Constructing more houses at accessible prices for low-income earners.

b) Providing Housing Subsidies: Offering financial assistance to low-income individuals for buying or renting a home.

c) Enhancing Access to Formal Financial Services: Assisting low-income earners in obtaining mortgages and other financial products.

d) Strengthening Housing Regulations and Policies: Implementing regulations and policies that encourage the development of affordable and high-quality housing.

Through sustained efforts, Indonesia's housing affordability can be enhanced, ensuring that everyone has access to decent and affordable housing (Adianto et al., 2021).

Next, the indicators for Cost of Living and Maintenance and Operating Costs have low sustainability values. In the context of Indonesian housing, a low score in the Cost of Living and Maintenance and Operating Costs indicator signifies that the living expenses, maintenance, and operational costs for that housing are relatively high compared to other options (Saldaña-Márquez et al., 2019).

Living expenses in Indonesia, including housing costs, significantly increase due to inflation and rising construction material prices. This makes housing costs more expensive and difficult for people to meet their basic needs. Operational and maintenance costs for housing also increase due to rising maintenance and other operational costs. This makes housing costs more burdensome for people, resulting in a low sustainability value for housing in Indonesia. Besides that, Indonesia faces resource constraints, such as water and energy shortages, which affect operational and maintenance costs for housing. This makes housing costs more expensive and difficult for people to meet their basic needs (Che-Ghani et al., 2016).

This low indicator score can negatively impact the sustainability of the housing in a few ways:

a) Increases financial burden: High living, maintenance, and operational costs can strain residents financially, and in some cases, make housing unaffordable (Fulcher et al., 2022).

b) Lowers investment value: Housing with high operational costs is less attractive to potential buyers, potentially decreasing its investment value (Garrido-Jiménez et al., 2022).

c) Increases environmental impact: High energy and water consumption can contribute to greenhouse gas emissions and pollute the environment (Shang et al., 2023).

4.3.2. Social sustainability

From a social dimension, two indicators that have a value of sustainability are Accessibility and Health and Well-being. Accessibility and Health and Well-being are two crucial indicators within the social dimension of sustainability. They reflect how well a society fulfills the basic needs and fundamental rights of its citizens and creates conditions that enable them to live healthy and prosperous lives (Leão & Neiva, 2022). Accessibility refers to the ability of individuals to access and utilize various resources and opportunities available in society. This includes access to:

a) Basic services, such as education, healthcare, clean water, sanitation, and housing

b) Economic opportunities, such as jobs, training, and entrepreneurship

c) Social participation, such as involvement in decision-making and community activities

d) Freedoms and human rights, such as freedom of expression, assembly, and religion (Fedchyshyn et al., 2023).

Health and Well-being refers to a state of optimal physical, mental, and social health that allows individuals to live meaningful and productive lives. This includes:

a) Physical health, such as being free from disease and having the physical capacity to perform daily activities

b) Mental health, such as being free from stress, anxiety, and depression, and having the ability to manage emotions and adapt to change

c) Social health, such as having positive relationships with family, friends, and community, and feeling accepted and valued (Hu et al., 2021).

These two indicators are closely linked. Good accessibility allows individuals to meet their basic needs and improve their physical and mental health. Good health, in turn, enables individuals to fully participate in social and economic life (Okitasari, 2022). There are many things that can be done to improve accessibility and health and well-being in a society. Here are some examples:

a) Developing policies and programs that promote accessibility, such as inclusive education programs, affordable healthcare, and disability-friendly infrastructure

b) Investing in disease prevention and health promotion, such as health education programs, access to nutritious food, and providing open spaces for physical activity

c) Supporting communities and organizations that work to improve accessibility and health, such as disability advocacy groups, public health organizations, and community development programs (Serano & Li, 2022).

While the Safety and Security indicator from the social dimension does not show sustainable values in housing in Indonesia. Here are several factors that might contribute to the Safety and Security indicator from the social dimension not showing sustainable values in housing in Indonesia:

a) *Infrastructure Limitations*: Indonesia has limited infrastructure, such as roads, electricity, and water, which can affect the safety and comfort of homeowners. These limitations can lead to low sustainability levels.

b) *High Crime Rates*: Indonesia has high crime rates, which can make homeowners feel unsafe and uncomfortable. These crimes can include theft, violence, or environmental crimes.

c) *Limited Public Services*: Public services like police, fire departments, and ambulances can be ineffective in addressing safety and comfort issues. Limited public services can lead to low sustainability levels.

d) *High Housing Costs*: Housing costs in Indonesia can be very high, making it difficult for some people to buy safe and comfortable homes. Limited financing options can lead to low sustainability levels.

e) *Limited Education*: Education on safety and comfort can be lacking in Indonesia, so some people may not know how to maintain safety and comfort in their homes. Limited education can lead to low sustainability levels.

f) *Government Ineffectiveness*: The government in Indonesia can be ineffective in addressing safety and comfort issues, such as high crime rates and infrastructure limitations. Ineffectiveness can lead to low sustainability levels.

g) *Community Limitations*: The community in Indonesia can be less involved in addressing safety and comfort issues, such as not following rules or not maintaining home safety. Community limitations can lead to low sustainability levels (Dixon, 2019).

To address the unsustainability aspect of housing in Indonesia, on Safety and Security indicator under social dimension that does not have a sustainable number of values, several things can be done. Firstly, it is important to improve infrastructure such as roads, electricity and water to ensure that homeowners are safe and comfortable. Infrastructure limitations may result into low levels of sustainability thus by improving infrastructure, we will enhance sustainability (Abed, 2017).

Secondly sea-based crimes such as piracy and drug trafficking require law enforcement and surveillance. The government needs to beef up its law enforcing systems as well as put in place strong surveillance systems for ensuring safety while at sea in Indonesia. This measure can help reduce crime rates and keep sea travel safe. Thirdly human resource development plays a vital role too. It would also improve the maritime safety if fishermen and sailors went through more training courses to acquire new skills. Skilled human resources are vital in keeping up with the security measures of Indonesian seas. Fourthly improvement of ship quality is crucial too. Ships operating within Indonesian boarders should meet safety standards set by the government. Enhancing ship quality can also be beneficial in guaranteeing the security during sea travel within Indonesia (Janssen & Basta, 2022).

Fifthly, international cooperation is crucial. By increasing cooperation with other countries in the region, we can develop policies and safety standards applicable to Indonesian waters. This will help maintain the safety of sea travel and promote sustainability. Sixthly, modern technology plays a vital role. Equipping ships with advanced navigation and communication systems can significantly improve the efficiency and safety of ship operations, ultimately contributing to safer sea travel and increased sustainability. Lastly, public education on home safety and comfort is essential (Gurmu et al., 2022).

4.3.3. Environmental sustainability

Subsequently, from the environmental dimension, indicators of Energy Efficiency and Water Management show sustainable values in housing in Indonesia. This statement highlights the importance of energy efficiency and water management in ensuring sustainable housing practices in Indonesia. It emphasizes the need for environmentally friendly practices in residential construction and management to achieve long-term sustainability. Energy efficiency refers to the reduction of energy consumption and waste, while water management involves the efficient use and conservation of water resources (Bellot & Fiscarelli, 2020).

The Indonesian government has taken several steps to support energy efficiency in housing. The government aims to reduce final energy consumption by 17% compared to the Business-as-Usual scenario by 2025 and reduce GreenHouse Gas emissions (GHG) by 29% by 2030. Additionally, the government has launched the Energi Transition Mechanism (ETM) Country Platform, a main coordination to promote fair and accessible energy transition, which aims to reduce carbon emissions by approximately 50 million tons by 2030 and 160 million tons by 2040 (BPS-Statistic, 2023).

The government has also set Minimum Energy Performance Standards (MEPS) for various household appliances such as Air Conditioners (AC), Light Emitting Diode (LED) lamps, rice cookers, refrigerators, and fans. This helps consumers choose energy-efficient appliances by looking at the energy efficiency label with the number of stars displayed. Furthermore, the government encourages building managers and residents to implement effective energy management, which includes having an energy manager, developing energy efficiency programs, conducting regular energy audits, and implementing audit recommendations.

The government also promotes the development of energy-efficient electronics while enhancing the industry, making energy efficiency and the industrial ecosystem part of the economic growth machine. Moreover, the government encourages public participation in building energy awareness in both work and residential environments. Residents can start saving energy by taking simple steps such as turning off lights and appliances, unplugging chargers, and setting AC temperatures between 24-27°C. Overall, the Indonesian government's efforts to support energy efficiency in housing involve various strategies aimed at reducing energy consumption, promoting energy-efficient appliances, and increasing public awareness of energy conservation.

Related to water management, The Indonesian government has taken several initiatives to support water management in housing, including setting targets for sustainable water resource management in 2024, such as 100% of housing with access to safe drinking water, 30% of housing with piped water supply, increasing national water capacity by approximately 2.3 billion cubic meters, and sustainable irrigation water supply from dams covering around 355,800 hectares (BPS-Statistic, 2023).

Additionally, the government has developed coastal defense structures and coastal protection systems to ensure the safety of the North Java Coastal Corridor and to develop water supply systems and wastewater treatment facilities at the housing and city scales. Monitoring systems have also been developed to support the control of land subsidence and groundwater extraction, as well as to enhance national water resilience. Indonesia has also initiated programs for land stability and ecosystem-based approaches to ensure the availability of clean water with sufficient quantity and quality.

The Presidential Regulation Number 37 of 2023 on the National Water Resource Policy (Jaknas SDA) has been enacted to enhance national water resilience and implement the provisions of Article 10, letter a, and Article 11, letter a, of Law Number 17 of 2019 on Water Resources. Therefore, these initiatives aim to improve access to safe drinking water that is safe, equitable, and accessible to 100% of the population, as well as to enhance water efficiency in all sectors.

If energy efficiency and water resource management have shown sustainability values, it is not the same with waste management. That happens because of several reasons:

a) *Lack of Regulatory Framework*: Waste management is often governed by less stringent regulations compared to energy efficiency and water resource management. This lack of regulatory oversight can lead to inadequate waste disposal practices and a lack of accountability.

b) *Limited Public Awareness*: Public awareness about the importance of proper waste management is often limited. This lack of understanding can contribute to the persistence of poor waste disposal practices and inadequate waste management strategies.

c) *Economic Factors*: Waste management can be a costly endeavor, especially for developing countries. The high costs associated with waste disposal and treatment can lead to inadequate waste management practices, as governments and communities may prioritize more pressing economic concerns.

d) *Technological Limitations*: Waste management often relies on outdated technologies and methods, which can be less effective in managing waste efficiently. The lack of modern and efficient waste management technologies can hinder efforts to improve waste management practices.

e) *Lack of Community Engagement*: Waste management is often seen as a community responsibility, but community engagement and participation are crucial for effective waste management. The lack of community involvement can lead to inadequate waste management practices and a lack of accountability (Pane et al., 2023).

To address the disparity in waste management compared to energy efficiency and water resource management, several solutions can be implemented, including developing comprehensive regulatory frameworks to ensure sustainability and efficiency in waste management, increasing public awareness and participation in waste management processes, deploying modern and effective technologies for waste recycling and processing, optimizing waste management costs by reducing unnecessary expenses, and enhancing intersectoral coordination among government, organizations, and academia to develop more effective and sustainable waste management strategies (Aliu, 2022). By adopting these solutions, it is hoped that waste management can be improved in terms of efficiency and sustainability, thereby reducing the disparity with energy efficiency and water resource management.

5. Conclusions

The research findings indicate that the sustainability index values for economic, social, and environmental dimensions show a quite sustainable range. If the economic, social, and environmental dimensions show a quite sustainable range in Indonesian housing, it means that the housing is designed and built with a balanced consideration of its impact on the economy, society, and the environment. Housing that shows a quite sustainable range across these three dimensions can offer significant benefits to its residents, the local community, and the environment. From economic dimensions, the maintenance and operating costs indicators have the lowest sustainability value. This suggests that maintenance and operating costs for housing in Indonesia are too high compared to the standard or average of other sectors. Next, from a social dimension, indicators of safety and security have the lowest sustainability value. This low sustainability value indicates that the level of safety and security in housing is very low. The low sustainability value of the 'Waste Management' indicator within the environmental dimension suggests that household waste is not being effectively managed. This lack of effective waste management leads to negative environmental impacts. This area requires action for promoting improvement.

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Original Paper

Navigating the policy landscape in Uganda: problem representations and silences towards transitioning to Agroecology as a business

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Keywords: Transitioning; agroecology; policy; problem-representations; silences.

Abstract. *This paper explores the application of ecological principles to enhance sustainability and resilience in agricultural systems. The aim is to* *analyse the policy landscape in Uganda that enables or hinders the transition to agroecological practices. Studied national policies and strategies included the: National Environment Management Policy; National Agriculture Policy; National Organic Agriculture Policy; Uganda National Grain trade policy; Uganda Vision; Uganda National Seed Strategy; Agriculture Sector Development Strategy and Investment Plan; as well as the Uganda Biodiversity Strategy and Action Plan. The theoretical framework outlines the principles of agroecology, showing how these are integrated or overlooked in national policies. Through a qualitative interpretive approach and documents review, I analyse the policy documents. The analytical framework applies Carol Bacchi's approach to policy analysis, to identify the problem representations, presuppositions that underlie the problem representations and silences within the problem representations that affect the transition to agroecological business systems. Results indicate that although the studied documents try to align agroecology principles, there are active silences such as promoting fragmented implementation which contradicts the principle of participation, failure of most of the policies and strategies to address soil health management, overlooking economic diversification and not integrating indigenous knowledge systems in sustainable land management. I conclude that it is crucial to take a comprehensive approach to policy planning and implementation that promotes agroecology as a business, while bringing about a more resilient, environmentally friendly, and economically sustainable agricultural sector in Uganda, and recommend a more inclusive policy process.*

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1. Overview of the importance of agroecology in sustainable agriculture

Agroecology (AE) aims at transforming food systems by applying ecological principles to agriculture, ensuring regenerative natural resources use, and ecosystem services, while also addressing the need for socially equitable food systems where people can exercise choice over what they eat and how and where it is produced. It presents a transdisciplinary field which includes all ecological, social-cultural, technological, economic and political dimensions of food systems along the value chain (FAO-HLPE, 2019). As an approach to farming, AE emphasizes the ecological principles and practices that promote sustainable and resilient agricultural systems (Altieri, 2019, 2000; Wezel et al., 2020). It integrates traditional knowledge with modern science to co-create knowledge of farming methods that are environmentally friendly, socially just, and economically viable (Altieri et al, 2012; Caporali, 2010; Utter, 2021). This overview delves into AE's significance in sustainable agriculture, exploring its key principles, benefits, and implications for global food security and environmental conservation. The outcome is an assessment of the extent to which agriculture-related policies in Uganda enable transitioning to AE: a holistic approach that aims to create resilient, sustainable, and equitable food systems while preserving natural resources, promoting biodiversity, and maintaining profitability as a business. In business terms, AE involves applying ecological principles to agricultural systems to enhance sustainability, productivity, and resilience, maintaining economic viability and social responsibility. This approach focuses on promoting biodiversity, reducing reliance on external inputs like pesticides and fertilizers, and integrating natural processes to optimize resource use. AE may involve consulting services, the sale of eco-friendly agricultural inputs, implementation of sustainable farming practices, and marketing of organic or agro ecologically produced products to environmentally conscious consumers. Overall, it aims at creating profitable enterprises while fostering environmental stewardship and social equity within the agricultural sector.

On a global scale, adopting AE has significant implications for global agriculture and sustainable food systems (Barrios et al., 2020; Tomich et al., 2011) because when sustainability, resilience, and social equity are prioritized, AE offers a transformative path towards more sustainable, resilient, and equitable food production (Altieri et al., 2012) systems. Such systems like regenerative agriculture, diversified crops, efficient distribution networks, community engagement etc. prioritize practices that conserve natural resources, reduce waste, and promote biodiversity while also being adaptable to shocks and stresses such as climate change, pandemics or economic disruptions. However, widespread transitioning to such agroecological systems requires supportive policies, investments, and capacity-building efforts to overcome any barriers.

In Uganda, the agricultural landscape is diverse and characterized by various components including crops, livestock, farming systems, agricultural regions/zones, technology and practices, as well as challenges and opportunities (Kagorora et al., 2021).

The main crops cultivated in Uganda include bananas, cassava, sweet potatoes, beans, maize, millet, sorghum, coffee, tea, and a variety of fruits and vegetables. Livestock rearing is an essential component of Uganda's agriculture, with animals like cattle, goats, pigs, sheep, poultry and fish being raised for meat, milk, eggs and other products. Crops cultivation and livestock rearing are practiced in small scale subsistence, large scale commercial, agroforestry, or mixed farming systems. These practices also occur within different regions of Uganda, each having different agricultural landscapes influenced by factors such as climate, soil types and topography. The agricultural landscape utilizes various technologies and practices leading to traditional farming methods coexisting with modern agricultural practices and technologies. While some farmers still rely on manual labour and traditional tools, others apply modern irrigation systems, mechanized equipment, and improved crop varieties. There are various opportunities and challenges facing the agricultural landscape in Uganda (Magunda, 2020). The opportunities include increasing investment in agriculture, promoting agribusiness, improving value chains, and enhancing agricultural extension services. Some challenges exist including pests and diseases, limited access to both local and foreign markets, inadequate infrastructure, climate change impacts and land tenure systems. Uganda's policy arena is tasked with taking advantage of the opportunities and addressing challenges as a way of achieving sustainable resilient food systems.

The purpose of this paper is to navigate the policy landscape for AE in Uganda and analyse specific policies related to AE and sustainable agriculture and identify silences within specific policies that need attention to bring about resilient and sustainable food systems while ensuring profitability. I do this by applying an analytical and theoretical framework to understand AE principles within a business perspective, the agricultural policies in Uganda, and the extent to which the respective policies mainstream these principles.

1. Theoretical and analytical framework

2.1 Business perspective on AE principles

According to the High-Level Panel of Experts-HLPE (2019), the 13 principles of AE include Biodiversity, Recycling, Input reduction, Soil health, Animal health, Synergy, Economic diversification, Co-creation of Knowledge, Social values and diets, Fairness, Connectivity/networking, Land and natural resource governance, as well as Participation. All these principles are drivers towards sustainable and resilient food systems. In this article, we analyse the extent to which Uganda's agricultural related policies embody these principles, as a way of transitioning to AE as a sustainable business pathway.

Biodiversity in agricultural systems implies the cultivation of a diversity of crops and incorporating agroforestry practices to enhance resilience, pest management, and soil fertility (Attwood et al., 2017). According to Dusgupta (2021), Biodiversity is a multi-faceted feature of ecosystems, including species, genetic and functional traits variations. The business aspect of biodiversity is understood through the lens of the various economic principles that emphasize the value of diverse ecosystems in economies and agricultural systems (Van den Burg, 2014). Such economic principles include ecosystem services like pollination, pest control and soil fertility which are crucial for agricultural productivity and profitability, although most of these services are largely hidden in economic discourses (Dasgupta, 2021). In addition, diverse ecosystems promote sustainability because they are more resilient to environmental stresses and shocks, reducing the risk of crop failure and financial losses for farmers. Biodiversity also reduces the need for external inputs like pesticides and fertilizers by promoting natural pest control and nutrient cycling, thereby lowering production costs for farmers (Pretty, 2008). At the policy level, there is regulatory compliance by governments and international bodies to promote biodiversity conservation in agriculture, creating opportunities for businesses to align with these policies and access funding or markets.

Recycling involves utilizing organic waste materials, such as crop residues and manure, to enhance soil fertility and productivity (Pretty, 2008; Sarkaet al., 2020; Sharma et al., 2019). By recycling these resources on farm, agroecological businesses can reduce the need for external inputs like synthetic fertilizers, saving costs and minimizing environmental impact, and enhance long-term agricultural productivity and profitability. The recycling principle of AE is similar to the *input reduction* principle which emphasizes the minimization of non-renewable inputs (Pretty, 2008).

Soil health is crucial in that healthy soils are essential for sustainable agricultural production (Kibblewhiteet al., 2008; Singh et al., 2011; Zuazo et al., 2011), and play a big role in ensuring resilience of food systems. This is in relation to the capacity of soil health to increase productivity through better nutrient availability and water retention, through reduced input costs due to practices like crop rotation and cover cropping, through enhanced resilience to environmental stresses such as drought and erosion, and through market differentiation as consumers increasingly value products grown in systems that prioritize soil health. Therefore, soil health principles have the potential to improve productivity, reduce costly external inputs, reduce the risk of crop failure and financial losses to farmers, and offer opportunities for agroecological businesses to differentiate themselves in the market.

Animal health as an agroecological principle is envisaged in business terms as providing an enabling environment for ensuring product quality such as meat, milk, eggs, which can attract effective market demand. There are reductions in veterinary costs due to investing in preventive agroecological health measures like nutrition, sanitation, and access to pasture. Recently various animal related diseases have spread especially through animal movements (Fèvre, 2006) and consumers increasingly seek products from animals raised in systems that prioritize animal welfare and health (Spain et al., 2018; Ssekyewa et al., 2022). This provides sustainable opportunities for agroecological businesses to differentiate themselves in the market.

Synergy/crosscutting issues involve optimizing interactions between different components of the farming system to enhance overall productivity and profitability (Accatino et al., 2019; Power, 2010). This helps to maximize resource efficiency since there is a systemic approach (Namanji et al., 2022) to integrating diverse crops, animals and other elements, reducing input costs, and enhancing resilience. Diverse and interconnected farming systems reduce the risk of crop failure and financial losses to farmers. At the institutional level, synergy provides avenues for interaction among different stakeholders, to co-learn and co-create knowledge towards developing sustainable food systems (Kpienbaareh et al., 2020).

Economic diversification involves expanding revenue streams beyond traditional crop or livestock production, while specialization weakens the economic resilience of farms (De Roest, et al., 2018). Economies of scope emerge with diversified farming systems especially when farmers are able to use the same inputs to produce two or more products, thereby being more efficient (Paul & Nehring 2005). This practice helps to reduce risk, enhance resilience due to complementary benefits, availability of value-added products such as processed food and agro tourism, thus generating additional income. This also happens because farmers build complementary networks and work together in Farmer Research Networks (FRNs) to transition to AE.

Co-creation of knowledge involves collaborative learning and innovation between farmers, researchers, and other stakeholders (Utter, 2021). This enhances efficiency since it allows for identification and adoption of best practices and innovative solutions, improved adaptability to practices towards changing environmental conditions and market demands, fosters innovation and development of novel solutions to complex agricultural challenges, builds social capital within farming communities, access to funding and markets, thus enabling AE businesses to thrive.

Social values and diets as a principle emphasizes the importance of cultural, social, economic, environmental, and political dimensions in food production and consumption (Barrios et al., 2020). It recognizes that food is not only about nutrition but also about cultural identity, social relationships, and ecological sustainability. In this way, it helps to meet consumer demand by producing food in alignment with social values and dietary preferences, as well as building consumer trust, with consumers who prioritize values such as environmental stewardship, animal welfare and fair labor practices. Overall, it aims to create a food system that is equitable, socially just, and environmentally sustainable, which enables AE businesses to enhance their market positioning, profitability and societal impact.

Fairness involves promoting equitable distribution of resources, opportunities, and benefits within the agricultural system. This can be done through ensuring fair prices, support to smallholders and marginalized groups, fostering social equity through fair labour practices such as fair wages and safe working conditions, promoting transparency and accountability such as fair-trade certifications and participatory decision-making processes, as well as transparent business practices, addressing issues of food insecurity and inequality, which supports new models of entrepreneurship (Dumont, et al., 2016).

Connectivity/networking involves fostering collaboration and cooperation among farmers, researchers, policymakers and other stakeholders. The High-level Panel of Experts (2019) shows that connectivity provides proximity and confidence between producers and consumers through promotion of fair and short distribution networks by re-embedding food systems into local communities. This helps to access knowledge and expertise, facilitates innovation by bringing together diverse perspectives and resources, enhances market access due to connections and partnerships along the value chain, thereby expanding sales opportunities, influencing policy and advocacy, since networks allow farmers to advocate for policies and regulations that support agroecological principles, creating a more sustainable environment for sustainable agriculture.

Land and natural resource governance involves responsible management and stewardship of land, water, and other resources, recognizing and supporting the needs and interests of family farmers, smallholders and peasant food producers as sustainable managers and guardians of natural and genetic resources (HLPE, 2019; Agroecology Europe, 2024). This helps to ensure sustainable land use, optimizing resource efficiency, mitigating environmental impacts such as soil erosion or water pollution (Thomas, 1993), as well as promoting social equity through equitable access to land, water and other resources supporting smallholder livelihoods.

Participation involves engaging stakeholders, including farmers, communities and consumers in decision-making processes and project implementation (HLPE, 2019). This practice enhances local knowledge and expertise in farming practices, leading to more contextually appropriate and effective solutions. It builds social capital and collective action for sustainable development, increases ownership and buy-in, leading to higher adoption rates and greater impact. Importantly, engaging consumers and value chain actors in participatory processes enhances market responsiveness due to a better understanding of market preferences and trends.

In relation to the highlighted principles of AE, this research assessed the level of support provided by Ugandan agricultural policies to AE as a viable business venture. This was achieved through the identification of policy clauses that either facilitate or hinder the adoption of agroecological practices. To this, we need to understand the policy framework for AE in Uganda.

2.2 Policy framework for AE in Uganda

Uganda is in East Africa and known for its rich agricultural heritage, contributing to employment, income generation, and food security for most of its population. However, over the years, Uganda has faced significant challenges in its agricultural sector, including soil degradation, low crop yields, vulnerability to climate change, and institutional challenges (Bategeka et al., 2013; Kagorora, 2021; Magunda, 2020). In response to these challenges, the government of Uganda has implemented various policies and strategies aiming at enhancing agricultural productivity, environmental sustainability and social equity. We studied the extent to which these policies enhance or disable a transitioning to AE as a business, by identifying within the policy documents the enabling clauses and silences. the Uganda Biodiversity Strategy and Action Plan (UBSAPII; NEMA,2016), the National Environment Management Policy (NEMP, 1994), the National Agriculture Policy (NAP, 2013), the National Organic Agriculture Policy (NOAP, 2018), the Uganda National Grain trade policy (2015), the Uganda Agriculture Sector Development Strategy and Investment Plan (2010/2011-2014-15), the Uganda Vision (2040), Uganda National Seed Strategy

(2014/2015-2019/2020) (Republic of Uganda, 1995; 2013; 2019; 2015; 2010; 2024; 2015) are among the policy and strategic frameworks that guide the implementation of AE practices in the country.

2.2.1 The National Environment Management Policy (NEMP) was formulated in 1994 and its revision has been ongoing since 2019. This policy is the umbrella of all policies, and it takes a broader approach by addressing all sectors that impact the environment, including agriculture. Chapters 3, 4, and 5 of the policy recognize the need for environmentally sustainable practices in agriculture and encourage the adoption of agroecological approaches to achieve this. They also emphasize Agriculture and Farming Systems, Forest Conservation and Management, Wildlife Conservation and Management, Livestock and Rangelands Management, Fisheries and Other Aquatic Resources Conservation and Management. The NEMP principles also emphasize the promotion of biodiversity conservation and sustainable use of natural resources, the integration of environmental considerations into agricultural planning, and the development of innovative farming techniques that minimize negative environmental impacts. However, the NEMP presents some silences or gaps that undermine agroecological practices and are hindering the transition to AE in Uganda.

2.2.2 The National Agriculture Policy (NAP) was formulated in 2013, and it recognizes the importance of sustainable agriculture practices, promoting the adoption of AE to achieve increased productivity, resilience, and food security. The policy emphasizes the integration of traditional knowledge and indigenous farming practices with modern scientific techniques. It also emphasizes the importance of empowering small-scale farmers, especially women and youth, by providing them the necessary skills and resources to implement sound agricultural practices. Just like the NEMP, the NAP has gaps that need scrutiny if Uganda is to achieve profitable and sustainable food systems through AE.

2.2.3 The National Organic Agriculture Policy (NOAP, 2020-2025) is among Uganda's efforts to promote organic farming through various initiatives and programs aimed at enhancing sustainable agricultural practices, improving soil fertility, reducing synthetic chemical use, and supporting small-scale farmers. The focus is also on encouraging organic certification, promoting organic farming techniques, and supporting organic agriculture through research, extension services and market development. The policy presents Uganda's efforts as aligned with broader global trends towards sustainable and environmentally friendly agricultural practices.

2.2.4 The Uganda National Grain trade policy (2015) aims to enhance the competitiveness, efficiency, and inclusiveness of the grain sector. It focuses on improving market access, promoting private sector investment, enhancing value addition, ensuring food security, and fostering sustainable production and trade practices. The policy seeks to create an enabling environment for all stakeholders involved in the grain trade, including farmers, traders, processors, and consumers, to thrive and contribute to Uganda's economic development.

2.2.5 The Uganda Biodiversity Strategy and Action Plan (UBSAPII) is a national framework designed to conserve and sustainably manage Uganda's rich biodiversity. The strategy outlines measures to conserve Uganda's diverse ecosystems including forests, wetlands, savanna and freshwater bodies as well as its rich flora and fauna. Other measures include promoting sustainable utilization of biodiversity resources, balancing conservational goals with social-economic development needs. The strategy includes provisions for raising public awareness about the importance of biodiversity conservation and building the capacity of stakeholders involved in biodiversity management. To achieve its objectives, the strategy emphasizes effective governance structures and collaboration among government agencies, civil society organizations, local communities and other stakeholders. It identifies and addresses key threats to biodiversity such as habitat loss, deforestation, pollution, invasive species and climate change. Overall, Uganda's biodiversity strategy and action plan provides a comprehensive framework for safeguarding Uganda's natural heritage while promoting sustainable development and human well-being. It serves as a guiding document for biodiversity conservation efforts across the country.

2.2.6 The Uganda Vision (2040) is a long-term development framework that outlines Uganda's aspirations and goals for social-economic transformation over the next few decades. Key elements of the vision include achieving a middle-income status and becoming a prosperous nation with high quality of life for all citizens by 2040, inclusive economic growth that benefits for all segments of society, including marginalized groups through job creation, poverty reduction, and equitable access to basic services. The country seeks to transform its economy by promoting industrialization, diversifying into higher value-added sectors and embracing modern technologies and innovation. The vision also emphasizes infrastructural development including roads, railways, energy, water supply and ICT to support economic growth, regional integration and improved living standards. Investing in education, health care, skills development and social protection to build productive workforce, enhance human capital development and ensure social well-being. In all that is envisioned, there is recognition of the importance of environmental sustainability and natural resource management to ensure long-term resilience, ecological balance, and sustainable development. It shows the importance of strengthening governance institutions, promoting transparency, accountability, and the rule of law to foster a conducive environment for development and citizen participation.

2.2.7 The Uganda National Seed Strategy (2014/2015-2019/2020) aimed at improving the seed sector in Uganda to enhance agricultural productivity and food security. Key elements of the strategy include strengthening seed quality assurance mechanisms to ensure that farmers have access to high quality seeds that are genetically pure, viable and adapted to local ecological conditions; increasing the production and distribution of improved seeds, including high yielding varieties of staple crops to small-holder farmers across the country; supporting research and development efforts to breed new crop varieties that are resistant to pests, diseases and environmental stresses, as well as improving the nutritional content and yield of potential crops; building the capacity of seed producers, extension workers, and farmers in seed production techniques, seed quality management and seed system governance; strengthening the regulatory framework for the seed sector to ensure compliance with quality standards, intellectual property rights, and seed certification procedures; promoting partnerships between government institutions, research organizations, private seed companies, farmer organizations and other stakeholders to enhance the efficiency and effectiveness of seed value chain; integrating gender considerations into seed sector interventions to ensure that women farmers have equal access to improved seeds, training and resources. Overall, the Uganda National Seed Strategy aimed at transforming the seed sector into a vibrant and efficient system that meets the diverse needs of Ugandan farmers, enhances agricultural productivity, and contributes to food security and rural development.

2.2.8 The Uganda Agriculture Sector Development Strategy and Investment Plan (2010/2011-2014-15) was a comprehensive framework aimed at promoting sustainable agricultural development and rural transformation in Uganda. The key elements of the strategy and investment plan included increasing agricultural productivity through the adoption of improved technologies, practices, and inputs including high-yielding crop varieties, mechanization, and irrigation; improving access to markets for agricultural produce and promoting value addition along agricultural value chains to increase farmers' incomes and competitiveness; supporting the development of the livestock sector through improved animal health services, breed improvement, and value chain development to enhance food security and rural livelihoods; promoting sustainable natural resource management practices, including soil conservation, water management, and agroforestry, to enhance environmental sustainability and resilience to climate change; rural infrastructural development, including roads, storage facilities, and market infrastructure, to reduce post-harvest losses, improve market access, and stimulate economic growth in rural areas; strengthening institutional capacity and coordination mechanisms within the agricultural sector to improve policy formulation, implementation, and monitoring and evaluation; promoting private sector investment and entrepreneurship in agriculture through policy reforms, incentives, and public-private partnerships to unlock the sector's potential for growth and job creation; social inclusion and gender equality through mainstreaming gender considerations and ensuring the inclusion of marginalized groups, such as women and youth, in agricultural development interventions to promote equitable and inclusive growth. Overall, the Uganda Agriculture Sector Development Strategy and Investment Plan provided a strategic framework for guiding public and private investments in agriculture, with the aim of transforming the sector into a modern, efficient, and sustainable engine of economic development and poverty reduction.

It is crucial to analyse the extent to which the selected policies harness AE as a business while maintaining environmental health and sustainable food systems. Therefore, to undertake the policy analysis, this research engaged with different approaches across social and natural sciences. The theoretical underpinning is tagged to systems theory, which provides a multidisciplinary perspective. Systems theory encourages us to integrate insights from multiple disciplines such as Economics, Ecology, Biology, Psychology, Physics, to tackle agricultural development issues instead of controlling nature with a single-minded Anthropocentric goal (Namanji et al., 2022; Ricket, 2004). Therefore, systems thinking in agricultural development calls for acknowledging the importance of interrelations of all components within the agriculture systems as they support each other. A breakdown in one component of that ecosystem results in the whole ecosystem being at standstill and in disequilibrium.

This theoretical framework was supported by clear paradigms that involved the application of interpretivism (Guba and Lincoln, 1994; Rehman & Alharthi, 2016; Tubey et al., 2015) with respective ontological, epistemological and methodological assumptions. The interpretive policy analysis helped to examine the selected policy documents, processes and outcomes through self-reflexivity, where the researcher had the capacity to read policy documents and reflect upon what is happening in Uganda's policy arena for the purpose of commentary and critique, as shown in the policy analytical framework.

2.3 Policy analytical framework for AE in Uganda

The policy analytical framework involved applying an interpretive policy analysis of the selected policies, by using Carol Bacchi's "What is the Problem Represented to be?" (WPR) approach to policy analysis (Bacchi, 1999; 2009; 2012). The aim was to critically interrogate how the selected policies defined the principles of AE and identify the policy articles that promote and those limiting transitioning towards AE, as well as policy silences (principles not mentioned).

The WPR approach is a Foucauldian influenced poststructuralist approach to policy analysis (Fischer et al., 2015; Yanow, 2015) which interrogates critically how the policy issue is problematized, the premises that representations of the problem rest upon, its effects, as well as problems that could be nested or hidden in the policy problem itself. According to Bacchi: "Poststructuralism…creates a space for questioning taken for granted concepts and categories" (2016, p.8). This approach provided space to unveil silent challenges, as it "encourages us to think about the interconnections between policy areas, and to reflect upon which issues remain unaddressed or undiscussed because of the ways certain problems are represented" (Bacchi, 1999, p. 2). Thus the policy analysis framework by Bacchi allows policy analysists to tackle any relevant of the six questions including; i) identifying the problem representations, ii) presuppositions that underlie those problem representations, iii) how the problem representations came to be, iv) silences within the problem representations, v) effects of the problem representations, vi) how the problem representations are reproduced, disseminated and defended, or how they are being questioned, disrupted and replaced.

In the context of this analysis, I critically examine how the selected policies construct problems (identifying the problem representations), the presuppositions that underlie the problem representations and the silences within those problem representations that enable or disable AE and sustainable food systems. This was done for the selected policies and strategies related to agriculture.

Accordingly, Bacchi (2012) shows problem representations as what someone proposes to do about a particular issue, and this reveals what they consider to be problematic and needs change. Thus, policy proposals implicitly contain representations of what is considered the "problem" and therefore needs change.

Presuppositions or assumptions that underpin these problem representations are the beliefs or ideas that inform how the problem is defined, and these can be normative, epistemological, ontological or in a historical context. For instance, normative assumptions refer to value judgements about what is desirable or undesirable, right or wrong. When defining a problem, policy makers and analysts often rely on implicit normative assumptions such as economic growth is inherently positive, equality is a fundamental goal, sustainability is crucial for long-term development, etc. Here I examine the policy discourses in ongoing debates around the value of AE and its related principles, and the extent to which the selected policies understood and or tried to address this aspect. Silences are what remains apparently unproblematic or unspoken about. The absence of some issues from problem representations reveals underlying assumptions.

From an interpretive analytical point of view, a close reading of the relevant policy documents and other related literature was instrumental in reaching findings. This analytical and theoretical framework provided answers to the research problem using the following materials and methods.

3. Materials and Methods

The application of a case study approach involved a purposive sample of eight pertinent documents including policies and strategies in line with AE. There were other related documents like the draft Agroecology strategy, the draft National Bio economy and Biosafety strategy, but these were excluded because they were still in draft form and not yet implemented. Following a qualitative interpretive approach (Guba & Lincoln, 1994), I identified relevant resources, utilizing the documents review method (Bowen, 2009) and following the principle of interpretivism as the nature of knowledge building to understand the studied phenomenon. Following Carol Bacchi's policy analysis guiding questions, I selected three: i) What is the problem represented to be? ii) What presuppositions underlie the problem representations, and iii) where are the silences in the problem representations? All questions were addressed in relation to the principles of AE. To add to the body of existing knowledge, I utilized stakeholder engagements by applying the soft systems methodology to obtain their opinions. All data sources formed the basis for drawing policy recommendations.

Results were analysed by applying a content analysis (Lal Das, 2008), where I created themes and flexibly decided how many concepts to include in the analysis. Thus, I identified the key words or statements to achieve the stated objectives. Levels of mainstreaming AE principles in policies were based on the extent and times a principle was directly or indirectly referred to in the policy. Data were presented in tables and figures.

4. Results

4.1 Results of enablers for and silences against transitioning towards agro-ecological business systems

There are policies that provide space in transitioning to AE although, within these policies there are silences/limitations that require attention. In this research, a random sample of 8 documents was made including Uganda Vision (2040), National Organic Agriculture policy (2020-2025), National Environment Management policy (1995), The National Agriculture Policy (2013), The National Grain trade policy (2015), the Uganda Biodiversity Strategy and Action Plan II (UBSAPII), Uganda National Seed Strategy (2014/2015-2019/2020), as well as the Agriculture Sector Development Strategy and Investment Plan (2010/2011-2014-15).

With reference to the AE principles, each policy document was analysed to identify the extent to which they promote AE as a business (number of times a specific policy addresses respective principles), mention of a specific position (enabling article towards transitioning to AE), the limiting article or silences in each policy document that need to be addressed to create space towards agroecological systems that ensure profitability and sustainable farming systems (Table 1).

The results shown in Table 1 and Figures 1 to 8 indicate the extent to which each policy document tackled respective AE principles, and Annex 1 goes further to show what was left as unproblematic within policy documents. A summary of those findings indicates the policy, the number of principles addressed and the respective times the principles were related to or mentioned.

In Figure 1, only six principles are mentioned or relatedly referred to in the NEMP. Of these, the Biodiversity and Participation principles were mostly presented in one form or another. Soil health, input reduction, economic diversification, co-creation of knowledge, networking, fairness, and building synergies were left silent.

In the case of the National Agriculture Policy (Figure 2), five principles were represented and mainstreamed by referring to them or mentioning a related subject. Those most mentioned are land and natural resources as well as participation. The policy also refers to aspects of animal health, inputs reduction and economic diversification. It remained silent about other principles which include biodiversity, soil health, recycling, co-creation of knowledge, networking, social values and diets, fairness and synergies. For Figure 3, the streaming of AE principles in the National Organic Agriculture Policy is presented. Nine AE principles are represented here, while four remained silent. Biodiversity was the most mainstreamed principle, whereas nothing was found about economic diversification, co-creation of knowledge, networking and social values and diets.

The National Grain Trade Policy only presents some 4 principles, Biodiversity, land and natural resources, participation and synergies, while it remains silent about other principles (Figure 4). The National Seeds Strategy is closely related to the grain trade policy, with the exception of it considering networking instead of synergies (Figure 5). Further analysis involved the Agriculture Sector Development strategy and investment plan. This plan was most aligned to AE with all principles addressed to some extent, except the Soil health and Recycling principles (Figure 6). It focused most on land and natural resources as well as participation.

Table 1. Problem presuppositions/AE Principles and the extent to which they are mainstreamed in selected policies and strategies: National Environment policy (NEMP), National Agriculture policy (NAP), National Organic Agriculture Policy(NOAP), National Grain trade policy (NGTP), Uganda National Seeds Strategy (UNSS), Agriculture sector Development strategy and investment plan (ASDIP), The National Biodiversity Strategy and Action Plan (NBSAP II), Uganda Vision 2040 (UV2040).

	EXTENT AE PRINCIPLES ARE STREAMLINED IN SELECTED POLICIES							
PRESUPPOSITIONS/AE PRINCIPLES	**NEMP**	**NAP**	**NOAP**	**NGTP**	**UNSS**	**ASDSIP**	**NBSAP II**	**UV2040**
Biodiversity	27	0	20	1	12	6	770	4
Soil health	0	0	2	0	0	0	0	0
Animal health	3	1	2	0	0	7	1	0
Input reduction	0	1	6	0	0	1	0	0
Recycling	4	0	2	0	0	0	3	1
Economic diversification	0	1	0	0	0	2	0	1
Co-creation of knowledge	0	0	0	0	0	4	0	1
Connectivity/networking	0	0	0	0	1	4	5	2
Social values and diets	1	0	0	0	0	2	5	0
Fairness	0	0	2	0	0	1	2	6
Land and natural resource governance/sustainable resource management	4	3	4	2	1	15	4	5
Participation	26	2	7	1	7	15	16	32
Synergy	0	0	2	2	0	9	2	0

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The National Environment Management Policy (1995)	Biodiversity	27
	Soil health	0
	Animal health	3
	Input reduction	0
	Recycling	4
	Economic diversification	0
	Co-creastion of knowledge	0
	Connectivity / Networking	0
	Social values and diets	1
	Fairness	0
	Land and natural resources governance (sustainable resource management)	4
	Participation	26
	Synergy	0

Figure 1. Mainstreaming of AE principles in the National Environment Management Policy.

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The National Agriculture Policy (2013)	Biodiversity	0
	Soil health	0
	Animal health	1
	Input reduction	1
	Recycling	0
	Economic diversification	1
	Co-creastion of knowledge	0
	Connectivity / Networking	0
	Social values and diets	0
	Fairness	0
	Land and natural resources governance (sustainable resource management)	3
	Participation	2
	Synergy	0

Figure 2. Mainstreaming of AE principles in the National Agriculture Policy.

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The National Organic Agriculture Policy (2020-2025)	Biodiversity	20
	Soil health	2
	Animal health	2
	Input reduction	6
	Recycling	2
	Economic diversification	0
	Co-creastion of knowledge	0
	Connectivity / Networking	0
	Social values and diets	0
	Fairness	2
	Land and natural resources governance (sustainable resource management)	4
	Participation	7
	Synergy	2

Figure 3. Mainstreaming of AE principles in the National Organic Agriculture Policy.

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The National Grain Trade Policy (2015)	Biodiversity	1
	Soil health	0
	Animal health	0
	Input reduction	0
	Recycling	0
	Economic diversification	0
	Co-creastion of knowledge	0
	Connectivity / Networking	0
	Social values and diets	0
	Fairness	0
	Land and natural resources governance (sustainable resource management)	2
	Participation	1
	Synergy	2

Figure 4. Mainstreaming of AE principles in the National Grain Trade Policy.

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The Uganda National Seed Strategy (2014/2015) (2019/2020)	Biodiversity	12
	Soil health	0
	Animal health	0
	Input reduction	0
	Recycling	0
	Economic diversification	0
	Co-creastion of knowledge	0
	Connectivity / Networking	1
	Social values and diets	0
	Fairness	0
	Land and natural resources governance (sustainable resource management)	1
	Participation	7
	Synergy	0

Figure 5. Mainstreaming of AE principles in the Uganda National Seed Strategy.

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The Agriculture Sector Development Strategy and Investment Plan (2010/2011) (2014/2015)	Biodiversity	6
	Soil health	0
	Animal health	7
	Input reduction	1
	Recycling	0
	Economic diversification	2
	Co-creastion of knowledge	4
	Connectivity / Networking	4
	Social values and diets	2
	Fairness	1
	Land and natural resources governance (sustainable resource management)	15
	Participation	15
	Synergy	9

Figure 6. Presentation AE principles in the Agriculture Sector Development Strategy and Investment Plan.

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The National Biodiversity Strategy and Action Plan (NBSAPII)	Biodiversity	770
	Soil health	0
	Animal health	1
	Input reduction	0
	Recycling	3
	Economic diversification	0
	Co-creastion of knowledge	0
	Connectivity / Networking	5
	Social values and diets	5
	Fairness	2
	Land and natural resources governance (sustainable resource management)	4
	Participation	16
	Synergy	2

Figure 7. Mainstreaming of AE principles in the National Biodiversity Strategy and Action Plan.

POLICY	PRESUPPOSITIONES (AE PRINCIPLES)	EXTENT OF STREAMING
The Uganda Vision (2040)	Biodiversity	4
	Soil health	0
	Animal health	0
	Input reduction	0
	Recycling	1
	Economic diversification	1
	Co-creastion of knowledge	1
	Connectivity / Networking	2
	Social values and diets	0
	Fairness	6
	Land and natural resources governance (sustainable resource management)	5
	Participation	32
	Synergy	0

Figure 8. Status of AE principles mainstreaming in the Uganda Vision.

The National Biodiversity Strategy and Action Plan II are only about Biodiversity, with scant reference to animal health, recycling, networking, social values and diets, fairness, land and natural resources, plus participation (Figure 7).

The last analysis was of the Uganda Vision 2040. This policy document has some aspects related to AE principles especially regarding participation. Other represented principles include land and natural resources, fairness, biodiversity, networking and somehow economic diversification, recycling and co-creation of knowledge (Figure 8).

Table 2 shows percentage reference to the AE principles to give another dimension on visualizing the extent to which selected policies align with these principles. It is clear that the most aligned with Agroecology principles is the Agriculture Sector Development Strategy and Investment Plan (85%), followed by the National Organic Agriculture Policy (69) and the National Biodiversity Strategy and Action plan II (69%), as well as the Uganda Vision 2040 (62%). Others fall below 50% of alignment, including the National Environment Management policy (46%).

Table 2. Percentage score of each policy or strategy in relation to addressing Agroecological Principles

Policy	Number of AE principles addressed	Percentage score	Ranking
NEMP	6	46	4
NAP	5	38	5
NOAP	9	69	2
Grain Trade Policy	4	31	6
National Seed Strategy	4	31	6
Agriculture Sector Development Strategy and Investment Plan	11	85	1
NBSAPII	9	69	2
Uganda Vision	8	62	3

Results show that all policies and strategies remained completely silent about certain AE principles. The Agriculture Sector Development Strategy and Action Plan (ASDSAP) presents more principles although it remains silent about soil health and recycling principles. On the one hand, like the ASDSAP, NOAP also presents pertinent silences, by not explicitly mentioning the principle of economic diversification, remaining completely silent about knowledge co-creation even when it talks about knowledge in the broader sense, silent about connectivity as well as social values and diets, even though it tries to address the social aspect but not from an AE business perspective. On the other hand, the NBSAPII does not explicitly mention soil health, completely silent about input reduction, economic diversification and co-creation of knowledge.

The National Environment Management Policy (NEMP) is equally silent about such AE principles as soil health, input reduction, economic diversification, co-creation of knowledge, connectivity, fairness, and synergy. The Uganda Vision 2040 remains silent about AE principles such as soil health, animal health, input reduction, synergy and social values and diets.

The NAP is silent about soil health, biodiversity, recycling, co-creation of knowledge, connectivity, social values and diets, fairness, and synergy, whereas the National Grain Trade Policy is silent about soil health, animal health, input reduction, recycling, economic diversification, co-creation of knowledge, connectivity, social values and diets, as well as fairness. Finally, the National Seed Strategy is silent about principles such as soil health, animal health, input reduction, recycling, economic diversification, co-creation of knowledge, social values and diets, as well as synergy.

5. Discussion

Results indicate that of the thirteen AE principles, land and natural resources governance/sustainable resource management and participation were cited in all policy and strategic documents. On the one hand, it should be noted that, although all policies tackle the principle of sustainable resources management, there are contradictions. For instance, in the Uganda Vision 2040, in chapter four on strengthening fundamentals for harnessing opportunities, agriculture is considered an important opportunity to achieve social-economic transformation. Although the chapter proposes efforts to attain a green and clean environment, while conserving the flora and fauna, there are contradictions in achieving this goal proposing to increase land for mechanization, investment in technology for improved seeds, breeds and stocking materials.

Moreover, the NEMP is silent about robust enforcement mechanisms to ensure compliance with regulations related to sustainable resource management, while the NAP promotes large scale farming enterprises, block farming and out grower schemes which lead to deforestation, habitat loss and soil degradation. In its implementation framework, the NAP does not provide strategies for sustainable resource use. There is more emphasis on sustainable use (e.g. for the NOAP) rather than sustainable management. While sustainable use focuses on the consumption aspect, sustainable management encompasses broader strategies for maintaining the health and productivity of a resource over time (Bansard and Schroder, 2024; Muller, 2023; Thomas,1993; Zuazo et al., 2011) and goes beyond consumption to encompass the entire lifecycle of resources to balance social, economic and environmental aspects. Although the DSIP prioritizes Sustainable Land Management, there are inadequate resources allocated for it. It still ignores the role of indigenous knowledge in sustainable land management practices, and it promotes large scale mechanized agriculture which does not favour sustainable land management. Equally, the NBSAPII is silent about unequal land distribution which undermines sustainable land management.

On the other hand, participatory approaches are necessary for creating avenues to engage value chain actors because they enhance market responsiveness due to a better understanding of market preferences and trends[1]; Guijt, 2014; Mayanja et al., 2012) and building collective action for sustainable development. Although value chains may create mistrust among actors, participatory approaches promote trust-building, information sharing and cooperation leading to improved responsiveness. Therefore, it is a plus for policies and strategies to embrace participatory approaches. However, there are active silences within respective policy statements and strategies regarding participation. For example, in the NEMP, NBSAPII, and Uganda Vision there is lack of meaningful participation from all relevant stakeholders, including marginalized groups such as women, youth, indigenous communities, and small-scale farmers. This is evident for instance in the NEMP which emphasizes the formulation of the overall environmental management policy at the highest level of government-hence not prioritizing the bottom-up approach (5.2). Superficial consultation of stakeholders without their input being genuinely considered in the decision-making processes does not reflect effective participation. In addition, in the NAP, none of the guiding principles explicitly focuses on participation, and in section 3.2 both Vision and mission of the policy do not provide for participation as an objective or strategy, implying that participation is not prioritized. The National Grain Trade Policy is silent about stakeholders' access to decision-making forums at various levels of governance from local to national level. This implies no genuine efforts to promote participation. The Development Strategy and Investment Plan Section 7.1 promotes fragmented implementation which contradicts participation.

In terms of performance, the Agriculture Sector Development Strategy and Investment Plan (2010/2011-2014-15) has emerged with the highest score of 85 percent being in position to acknowledge a range of AE principles and cross-

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cutting concerns that must be addressed in the investment portfolio. Among the aspects there are reducing land degradation, agrochemical pollution, loss of biodiversity through deforestation and wetlands, loss of biodiversity in agricultural landscapes through introduction of non-native varieties. However, in the document, component 1.6.8: emphasizes the promotion of mechanization for increased rice production. It should be noted that mechanized rice production is not environment friendly. While the strategy and investment plan embrace many AE principles, it remains silent about soil health and recycling principles.

Likewise, apart from the National Organic Agriculture Policy, all other policies are silent about soil health management which is crucial for sustainable agriculture and resilient food systems. Soil health impacts crop productivity, nutrient cycling, and water retention. Thus, sustainable soil management practices are essential for long-term agricultural resilience and holistic sustainability. Other than soil health, some studied policies and strategies like the NEMP, the NGTP, the UNSS, NBSAPII, and the UV do not explicitly address reducing excessive use of chemical inputs (such as synthetic fertilizers and pesticides), while overreliance on synthetic chemical inputs can harm soil quality, water systems and human health (Horrigan,2002; Pretty, 2008; Nadarajan, & Sukumaranm, 2021). Promoting judicious use of inputs is necessary for environmental conservation. Apart from the NAP and the UV, other policies and strategies are silent about the AE principle of economic diversification. The lack of emphasis on diversifying agricultural activities is critical because diverse agricultural practices reduce vulnerability to market fluctuations and climate shocks yet, income diversification enhances livelihoods due to production efficiency exhibited by using the same inputs to produce more than one item (Paul & Nehring, 2005). Results show that although the NOAP does not explicitly mention economic diversification, it presents various aspects that could contribute to economic diversification, such as enhancing research, technology development, dissemination, promoting organic agriculture education and training, and market development and promotion. These elements can lead to a more diverse and resilient economy by supporting different sectors and creating new opportunities within the organic industry.

However, for a more complete policy, policymakers ought to explicitly tackle all such aspects instead of leaving them ambiguous and in danger of being lost. In the case of grain policy, the lack of emphasis on creating diverse grain markets underscores the aspect of diverse markets enhancing resilience and income opportunities for grain traders. Likewise, for seed strategy, diverse seed varieties are not explicitly promoted yet they enhance resilience and adaptability. The importance of knowledge co-creation cannot be underestimated yet it is noted that other than the Agriculture Sector Development Strategy and Investment Plan as well as the Uganda Vision, other policies and strategies did not explicitly tackle this aspect, which undermines involvement of local communities and stakeholders in decision-making, and collaborative learning. Engaging farmers, researchers, and policymakers in inclusive decision-making ensures, relevant policies, context-specific solutions and effective implementation towards transformative governance (Razzaque, 2019) as well as collaborative learning (Utter, 2021).

In the analysis, it was observed that knowledge sharing, and knowledge co-creation can be misunderstood. Knowledge sharing involves the exchange of existing knowledge between individuals or groups in an organization or setting (Cabrera & Cabrera, 2002; Yang & Wu, 2008) while co-creation of knowledge involves collaborative efforts to generate new knowledge or insights through shared experiences, ideas and contributions from multiple parties and differs from passive knowledge sharing (Utter, 2021). Thus, while knowledge sharing focuses on disseminating what is already known, co-creation of knowledge goes beyond by involving all stakeholders to actively produce new knowledge together and is crucial for advancing sustainable food systems and AE businesses.

Failure to integrate environmental management across sectors (connectivity) complicates addressing environmental challenges like water scarcity and pollution which require cross-sectoral collaboration and holistic planning for effective solutions. In addition, for the NOAP, linking organic practices with broader sustainable goals is not explicitly tackled, although organic practices lead to overall environmental health and addressing these gaps represent opportunities for policy enhancement, and more comprehensive approaches to sustainable agriculture in Uganda (United Nations,2023; World Bank,2021; Ndejjo et al., 2019). Four of the eight studied policies and strategies tried to tackle the fairness AE principle, while the rest including the NEMP, the NAP, the NGTP, and the UNSS did not explicitly focus on ensuring equitable access to resources and benefits. Various studies help us understand how fairness contributes to social justice, reduce disparities, and prevents marginalization of vulnerable groups (Craig et al., 2011; Hart, 2019; Pranis, 2001). All policies and strategies ought to highlight the importance of promoting synergies between environmental conservation and agricultural development because coordinated efforts can achieve both ecological and economic goals thus maximizing positive outcomes. Among all policies and strategies, the NAP remains silent about biodiversity and the role of a biodiverse ecosystem in resilient agriculture systems. It should be noted that biodiversity supports pollination, pest control and diverse ecosystem services critical for farming (Van den Burg, 2014). Yet in the economic sense, a biodiverse agroecosystem supports farmers in diversifying their income streams, thus protecting them against market shocks.

Recycling is equally important, although the NAP, the NGTP, and the UNSS are completely silent about it. Recycling organic materials like crop residues enriches soil and reduces waste (Sarka et al., 2020; Sharma et al, 2019; Pretty, 2008). In the case of the seed strategy, seed recycling conserves genetic diversity and reduces costs. Other than the NBSAPII, the NEMP, and the DSIP, other documents are either completely silent about social values and diets or do not explicitly prioritize them. Considering cultural and dietary preferences is a crucial policy aspect since food choices are influenced by cultural norms and impacts health due to their influence on food security and nutrition. The Grain Trade Policy, the Seed Strategy and the Uganda Vision do not emphasize animal health. Ensuring healthy livestock for grain production is crucial, while healthy animals contribute to grain and seed production through manure for soil fertility, traction and general soil productivity (Duncan et al., 2016; Spain et al., 2018; Ssekyewa et al., 2022).

6. Conclusions

Findings from the analysis of policy and strategic documents highlight the importance of sustainable resource management and participation in the context of AE. These principles were consistently cited across all the studied documents. However, a closer examination reveals contradictions within these policies and strategies. While they address sustainable resource management, there are instances where conflicting goals emerge. First, the Uganda Vision 2040 recognizes agriculture as a crucial avenue for socioeconomic transformation, and it emphasizes achieving a green and clean environment while conserving flora and fauna. Yet, proposals to increase land for mechanization and invest in technology for improved seeds and breeds seem at odds with these conservation goals. Second, while the National Environment Management Policy (NEMP) acknowledges sustainable resource management, robust enforcement mechanisms for compliance with related regulations remain unaddressed. Third, while promoting large-scale farming enterprises, block farming, and out-grower schemes, the National Agricultural Policy (NAP) inadvertently contributes to deforestation, habitat loss, and soil degradation. Additionally, its implementation framework lacks specific strategies for sustainable resource use. Fourth, despite the Development Strategy and Investment Plan (DSIP) prioritizing Sustainable Land Management, inadequate resource allocation and oversight of indigenous knowledge hinder effective practices. Furthermore, the promotion of large-scale mechanized agriculture may not align with sustainable land management goals. Fifth, the National Biodiversity Strategy and Action Plan (NBSPII) remains silent on addressing unsustainable practices related to land use and resource management. In the same vein, when policies indicate emphasis on participatory approaches, there should be prioritization of meaningful participation. Lack of meaningful participation can easily cause tokenistic engagement, where stakeholders are consulted superficially without their input being genuinely considered in decision-making processes. There is room for improvement in addressing soil health, recycling and all other agroecology principles that were not explicitly tackled or those that remained completely silent in the studied policy and strategic documents. A comprehensive approach that integrates all these aspects will promote AE as a business, while bringing about a more resilient, environmentally friendly, and economically sustainable agricultural sector in Uganda.

7. Policy recommendations

Harmonize Goals. Policymakers ought to ensure coherence between agricultural development goals and environmental conservation. Mechanization and technological advancements must align with agroecological principles and sustainability objectives.

Enforcement Mechanisms. Policy statements ought to out rightly indicate strong enforcement mechanisms to ensure compliance with sustainable resource management regulations. Robust monitoring and penalties for violations are essential.

Holistic Approach. While designing policies, there should be a shift of focus from mere sustainable use to comprehensive sustainable resource management. Consider long-term health and productivity of resources, including indigenous knowledge.

Resources Allocation. Policy statements should emphasize the adequate allocation of resources to Sustainable Land Management initiatives. Recognize the value of indigenous practices and integrate them into policy frameworks.

Awareness and Education. Promote awareness among stakeholders about sustainable practices. Encourage capacity-building programs and knowledge-sharing platforms.

Agroecology Knowledge co-creation and sharing. It is necessary to involve agro-ecologists in the process of co-creating all government plans and strategies because these groups can bring on board the expertise necessary to guide and monitor effective and efficient land use to ensure sustainable productivity.

In summary, while AE principles are acknowledged, effective implementation requires addressing contradictions, enhancing enforcement, and adopting a landscape or systemic or holistic approach to resource management.

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Original Paper

Strategic mapping of food assets to enhance food security and foster Circular Economy in Semarang City: A sustainable perspective

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Abstract. *Responding to the projected 2050 global food production increase of 50%, Semarang City in Indonesia, home to 1.65 million people, is confronting the challenge of ensuring food security for its populace. To prevent the displacement of local farmers, the decline of local markets, and to avoid other social issues such as poverty and hunger, it is crucial for Semarang to become food independent. This research aims to develop a robust food information system in Semarang City by identifying and analysing urban food assets. This system will support food security, promote a circular economy, and contribute to the creation of a Food Independent City in Semarang. The study commenced with a focus group discussion involving government agencies and organizations possessing food-related data within the city. Findings reveal a diverse array of food resources, including 49 markets, 5 fruit gardens, 10 urban farms, fisheries production, rice fields, beef cattle livestock groups, and the Farmer-Owned Enterprise Lumpang Semar Sejahtera, all playing pivotal roles in shaping Semarang's food landscape. This study contributes to addressing broader food issues in Indonesia, particularly in urban settings, by highlighting the significance of strategic planning and resource mapping in achieving sustainable food systems.*

1. Introduction

Food is a fundamental need for humans that must be fulfilled every day according to its nutritional value for the body (Leandro et al., 2020; Wallace et al., 2020). Food security has long been a central concern for policymakers, evolving into a multifaceted concept addressing both immediate and long-term challenges. One dominant perspective has been the emphasis on increasing agricultural production to combat under-consumption and hunger, thereby ensuring a steady food supply (Lang & Barling, 2012). It cannot be denied that food security is very dependent on the supply of food and the availability of food (Ansar & Fathurrahman, 2018; Rusmawati et al., 2023; Santoso et al., 2021). In 2050, it is estimated that world food production must increase by around 50% in order to meet the needs arising from the increase in human population (Cervantes-Godoy et al., 2014; Food and Agriculture Organization of the United Nations (FAO), 2022). However, focusing solely on increasing agricultural production to achieve food security can lead to significant challenges, such as climate change and variability, unstable markets, and shrinking arable land resources (Hossain et al., 2020). Additionally, prioritizing large-scale industrial farming over smallholder farmers exacerbates social inequalities, deepens rural poverty, and can displace communities, leading to social unrest (Ward Anseeuw & Maria Baldinelli, 2020). Therefore, while boosting production is important, it must be balanced with environmental protection and social equity to achieve sustainable food security (Namany et al., 2020).

Achieving sustainable food security necessitates integrating practices that ensure long-term ecological balance and equitable access to resources (Berry et al., 2015; Capone et al., 2014; McKenzie & Williams, 2015). This can be effectively connected with the principles of a circular economy. The circular economy is an economic system aimed at minimizing waste and making the most of resources by reusing, recycling, and regenerating materials in a closed-loop system (Kara et al., 2022). This approach is highly relevant to food security, as it promotes sustainable practices that reduce environmental impact (Vågsholm et al., 2020). Food asset mapping complements the circular economy by identifying local food resources, strengths, and gaps, enabling communities to utilize their assets efficiently (Jensen & Orfila, 2021). Circular economy practices, including food asset mapping, reduce food waste, support local production, and enhance resource sharing (Sindhu et al., 2023). By identifying and utilizing local food assets efficiently, these practices create a more sustainable and resilient food system.

Semarang City is a metropolitan city with a population of 1.65 million people (Handayani et al., 2020; Sejati et al., 2018; Syafrudin et al., 2021). The Semarang City Government is very concerned about food availability policies for its people. This is reflected in the City Mission number 2: "Increasing the potential of a competitive local economy and stimulating industrial development, based on research and innovation based on the principles of Pancasila economic democracy", and the City Mission number 4: "Creating quality infrastructure with an environmental perspective to support the city's progress". In these two missions, the Semarang City Government really pays attention to and supports the availability and diversity of food for its people through: urban farming, hydroponic festivals, herbs and spices garden, food street festivals, vertical gardens, and others.

Despite the Semarang city government's strong commitment to achieving its food security mission, they still lack a comprehensive and representative food map to inform their policies and regulations; whereas a Food Asset Map is crucial for integrating food production assets, supply chains, population density centres, and health and nutritional data, all of which are essential for developing a robust system of food availability and security (Alisjahbana & Busch, 2017; Saurabh & Dey, 2021). Food Assets are local food infrastructure to maintain food availability and security in communities and regions, such as: agricultural production land, agricultural input production infrastructure, agricultural product processing infrastructure, retail traders (supply chain actors), sustainable food yards and families (including urban areas). farming), markets and their integration with mapping the conditions for fulfilling community nutrition (stunting levels, nutritional adequacy rates, and Expected Food Patterns - PPH) (Caro et al., 2018). Furthermore, National Development Planning Agency/Bappenas (2021) stated that the current implementation of the Food System in Indonesia is based on Food Production and Agriculture to achieve Food Security.

This research aims to fill a critical gap in the current literature on food security by developing a comprehensive and representative Food Supply Asset Map for Semarang City. Despite strong governmental commitment, Semarang City lacks such a tool to guide its policies and regulations. This study identifies and analyses urban food assets to create this map, which will enhance the city's ability to maintain food availability and security. Unlike existing studies that often focus broadly on increasing agricultural production or addressing food security at a national or global level, this research uniquely concentrates on a metropolitan context and integrates the principles of a circular economy. By mapping local food production assets, supply chains, population density centres, and health and nutritional data, this study offers a novel approach to enhancing food security policies. The focus on Semarang City is particularly significant as it exemplifies how urban areas can incorporate sustainable practices, such as urban farming and food asset mapping, to build a resilient and equitable food system. This integration of circular economy principles not only reduces food waste but also supports local production and resource sharing, providing a model that other cities can emulate to achieve sustainable food security.

2. Literature review

2.1. *Urban and peri-urban food systems in Indonesia*

The food system includes all actors and their involvement in interrelated value-added creation activities in the production, collection, processing, distribution, consumption and "waste" of food products originating from agriculture, forestry or fisheries, and the food industry, as well as the economic, social and natural environment in which the process takes place (Mantino & Vanni, 2018). Food availability is the degree to which food is consistently physically obtainable in desired quantities, shaped by the production, distribution, and exchange patterns of food goods (Carson & Boege, 2020). Food availability is determined by production in the region, in this case the city of Semarang, food trade through market mechanisms in the region, stocks held by traders and government reserves as well as food assistance from the government. Figure 1 presents urban and peri-urban food systems in Indonesia.

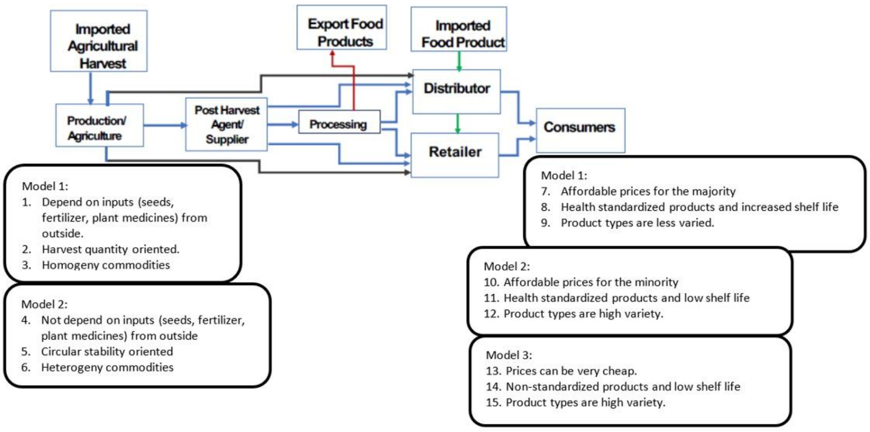

Figure 1. Urban and peri-urban food systems.

Food independence is the nation's ability to produce sufficient food to meet its needs through optimized domestic capabilities and fair international cooperation, emphasizing self-reliance and competitiveness without isolating from global partnerships (Febriani, 2023). In order to move towards a prosperous society, the focus of the development of Semarang City is contained in the Seven/*Sapta* Program, one of which is overcoming poverty and unemployment (Ahmad et al., 2019). Several poverty reduction programs in Semarang City, one of which is the food independence program (Alfisyahrin, 2021). So that in order to make Semarang City a Food Independent City, one of the ways is to support it with a food information system that can provide broad information so that each OPD has uniform data and information as a basis for preparing work programs that are oriented towards food security in Semarang City.

2.2. *Food asset mapping*

Asset mapping is a research tool utilized across various disciplines, particularly for supporting community capacity building and development (Kretzmann & McKnight, 1993) as cited in (Lightfoot et al., 2014). It has been employed to identify cultural assets (Jeannotte, 2016), health disparities and community health (Jakes et al., 2015), and both informal and formal community assets (Weng, 2016), as well as housing (Butterfield et al., 2009). The asset-based approach is now being applied to identify key food sites through food asset mapping. This tool is increasingly used by municipalities across Canada and is recommended by the American Planning Association (APA) (2007) in their Policy Guide on Community and Regional Food Planning. The APA (2007) advises planners to map the location of diverse "food assets" and enhance these assets. Additionally, there is a history of planners studying foodsheds—the total production area needed to feed an urban population (Donofrio, 2007). Food asset mapping helps in understanding foodsheds better.

The definition of food assets varies, and so does the purpose of food asset mapping. Currently, diverse stakeholders, including planners, public health practitioners, academics, and community organizations, conduct food asset mapping (Romses et al., 2017). There are several reasons for developing a food asset map. It is often used to keep track of the diverse food resources available in a city or region (Baker, 2018). Increasingly, online food asset maps help users find food sources in the city (Romses et al., 2017). Unlike culinary or gastronomic mapping, which focuses on promoting or attracting culinary tourism and mapping restaurants (Booysen & du Rand, 2021), asset mapping is primarily aimed at improving community food access and food security for equity-deserving community members.

3. Methodology

This research is conducted in Semarang City, the capital of Central Java Province. Geographically, the research area directly borders the Java Sea to the north (Figure 2). Data collection focuses on 16 sub-districts within Semarang City. The map below illustrates the research location.

The implementation of this research involved several stages, including primary and secondary data collection, data processing, database preparation, and data analysis using a spatial analysis approach to create thematic maps and perform qualitative analysis of the types of food asset sources at the research location. The systematic stages of the research activities are as follows:

Figure 2. Research Sites

1. <u>Focus Group Discussion (FGD)</u>

A Focus Group Discussion (FGD) was conducted with a total of 25 participants from various affiliations, including the Regional Development Planning Agency (*Badan Perencanaan dan Pembangunan Daerah* - Bappeda), the Agriculture Department, the Food Security Department, the Trade Department, the Fisheries Department, the Cooperative and Small and Medium Enterprises Department (Dinas Koperasi dan UMKM), Farmer-Owned Enterprises, the Obor Tani Foundation, Food Bank Indonesia, PT PLN Indonesia Power Branch Semarang, lecturers from the Culinary Department of the Faculty of Engineering from a public university in Semarang- Universitas Negeri Semarang, and representatives from small and medium enterprises specializing in processed food.

The participants were divided into three groups based on their roles: government representatives from relevant agencies and universities, producers including small and medium enterprises, farmer groups, and universities, and consumers encompassing non-governmental organizations, social media practitioners, and universities. Throughout the discussion, participants focused on several key issues, including the availability of food supply data from upstream to downstream, regulations, the implementation of existing programs, and action plans for future initiatives.

2. Secondary data collection

Institutional surveys were conducted to collect secondary data related to food asset sources. Agencies involved included Bappeda, the Food Security Service, the Maritime Affairs and Fisheries Service, and other relevant bodies managing food asset data. The goal was to obtain information on food sources, land use, food source management, and additional data to support field survey activities.

3. Primary data collection

Field surveys were conducted using a participatory method, involving key personnel at each food storage site in the research location. The information collected included the name, address, and type of commodities stored. Surveyors then conducted field surveys at each food storage site using handheld Global Positioning System (GPS) equipment to obtain Universal Transverse Mercator (UTM) coordinates. Additionally, the field surveys included documentation of the food storage facilities, types and quantities of commodities, and management and production practices. The results of the field surveys were used as the database for developing the food asset information system at the research location.

4. Supporting data collection

Interviews with managers or responsible individuals for food assets were conducted to obtain detailed information about food barns in each region.

5. Database preparation

A food asset database was developed using Geographic Information System (GIS) technology, which served as the foundation for compiling thematic maps of food assets at the research location.

Data analysis in this research employed spatial analysis to prepare a spatial database and map of food assets in Semarang City. This spatial analysis identified the distribution and accessibility of food barns. Additionally, quantitative descriptive analysis was used to assess information related to each food barn, including types of food sources, land use, management practices, and other relevant data.

4. Results and Discussions

Food is one of the fundamental human needs for maintaining life. The types of food consumed by people in a region typically reflect the types of food that can be produced or grown locally (Enthoven & Van den Broeck, 2021). This research was designed to identify the potential and capacity for food storage to support food supplies in Semarang City. To achieve this, a food supply map is necessary to provide comprehensive information regarding the food potential and conditions in Semarang City. The results of this research are as follows:

4.1. Market distribution in Semarang City

Data regarding markets, which serve as food supply providers in Semarang City, were obtained from the Semarang City Trade Office. The distribution of these markets is spread across 16 sub-districts in Semarang City. Markets in this research are categorized into three types: City Markets, Regional Markets, and Neighbourhood Markets. According to previous research, markets can be categorized based on consumer reach, physical improvements, and strategic location (Kharisma, 2014):

a. Neighbourhood Markets, serve the immediate surrounding area, selling household necessities. Semarang City has 24 neighbourhood markets.

b. Regional Markets, serve several residential areas within a sub-district, offering modern and relatively expensive commodities. Semarang City has 13 regional markets.

c. City Markets, serve the entire city and surrounding areas, offering a wider variety of goods than regional and neighbourhood markets. Semarang City has 12 city markets.

Markets are integral to the food supply chain of a region, with the buying and selling activities within them being key indicators of economic growth on local, regional, and national scales. Previous research describes market chains as networks connecting all relevant actors and transactions in the movement of agricultural goods from farms to consumers (Lundy et al., 2004). The analysis of agricultural commodity market chains includes price analysis and value addition throughout the sequence of activities from raw materials to the final product, highlighting all relevant actors and activities that directly influence the final product (Bockel & Tallec, 2016).

According to inventory data from the Semarang City Trade Office, Semarang City has 49 markets, categorized as neighbourhood, regional, and city markets. The management of these markets is divided among six regional coordinators, each managed by a respective UPTD. The regional coordinators are:

a. Johar Market Region: 5 markets

b. Karimata Market Region: 6 markets

c. Bulu Market Region: 7 markets

d. Karangayu Market Region: 9 markets

e. Jatingaleh Market Region: 9 markets

f. Pedurungan Market Region: 13 markets

The spatial distribution of markets shows that neighbourhood markets are widely spread across various sub-districts in Semarang City, whereas city and regional markets are concentrated in Central Semarang District, West Semarang District, and North Semarang District (Figure 3).

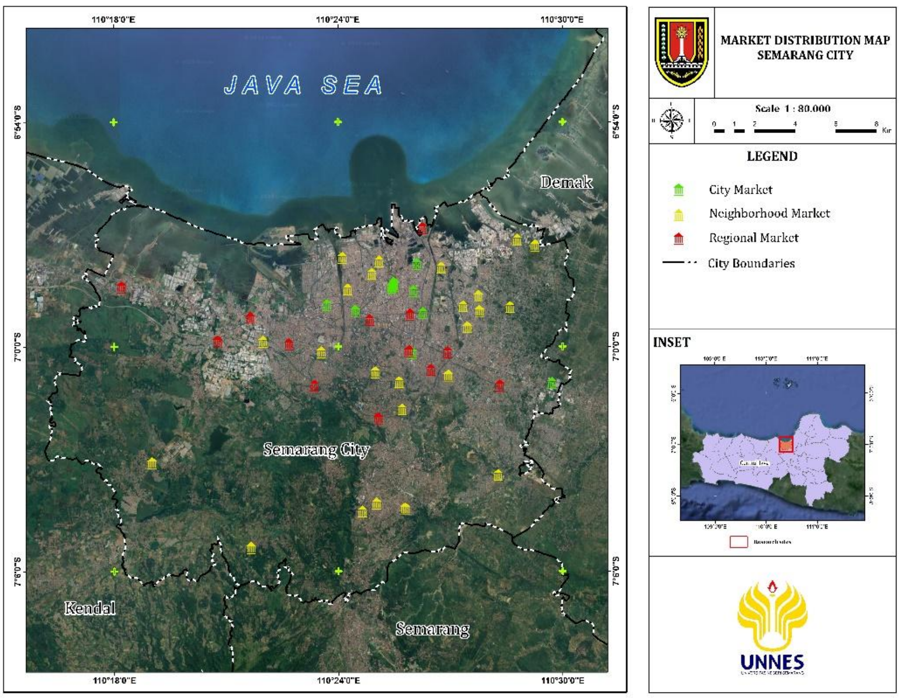

Figure 3. Market distribution map of Semarang.

4.2. *Distribution of fruit gardens in Semarang City*

Fruit is a vital component of the diet for many people. To meet the demand for fruit in Semarang City. The local government has established several fruit gardens. According to data from the Semarang City Agriculture Service, there are currently five fruit gardens located in the Gunungpati, Mijen, and Ngaliyan districts. Additionally, there is an Urban Farming Corner (UFC) on Jl. Menteri Supeno in the South Semarang District, which serves as a hub for agricultural activities.

Most fruit gardens in Semarang City are located in the upper areas, such as Gunungpati and Mijen districts. Developing a fruit orchard requires extensive land, which is more readily available in these upper areas. In contrast, the lower areas are too densely built-up, making orchard development impractical. Additionally, the upper Semarang area benefits from fertile soil due to its proximity to Mount Ungaran, which is highly conducive to agricultural and plantation activities, resulting in a high success rate for cultivation. Figure 4 illustrates the spatial distribution of these fruit gardens in Semarang City.

Each fruit garden in the research location has different crop commodities tailored to the natural resources and potential of each region. For instance, the Cepoko, Purwosari, and Wates fruit gardens primarily cultivate crystal guava and longan, while the Plalangan Fruit Garden focuses on durian. These gardens produce high-quality fruits that are popular among the residents of Semarang City, contributing significantly to the local fruit supply. According to (Mustikaningtyas et al., 2016), the Gunungpati District has the potential to become an agricultural center for organic fruit and vegetable gardens, underscoring the importance of these gardens in supporting the city's fruit and vegetable needs. The Cepoko, Purwosari, and Wates Fruit Gardens also serve as agrotourism destinations, offering educational and recreational opportunities for visitors. The Urban Farming Corner (UFC) further supports this initiative by acting as a meeting facility for farmers, hosting training sessions, discussions, and exhibitions organized by the Department of Agriculture.

The fruit gardens in Semarang City range in size from 3.2 to 10 hectares, utilizing land owned by the sub-districts. The Argo Plalangan Fruit Garden, covering approximately 10 hectares, is the largest, while the Agro Cepoko Fruit Garden spans about 3 hectares. The number of plants varies depending on the land area and the type of crops grown. For example, the Purwosari Agro Fruit Garden has the highest number of plants, with around 1,772 crystal guava, longan, and durian trees, managed by the Sumber Rejeki Farmers Group and the Semarang City

Agriculture Service. In contrast, despite being the largest in area, the Agro Plalangan Fruit Garden has the fewest cultivated plants (797 trees) due to the space requirements for durian trees, which need larger growing areas and wider spacing between trees.

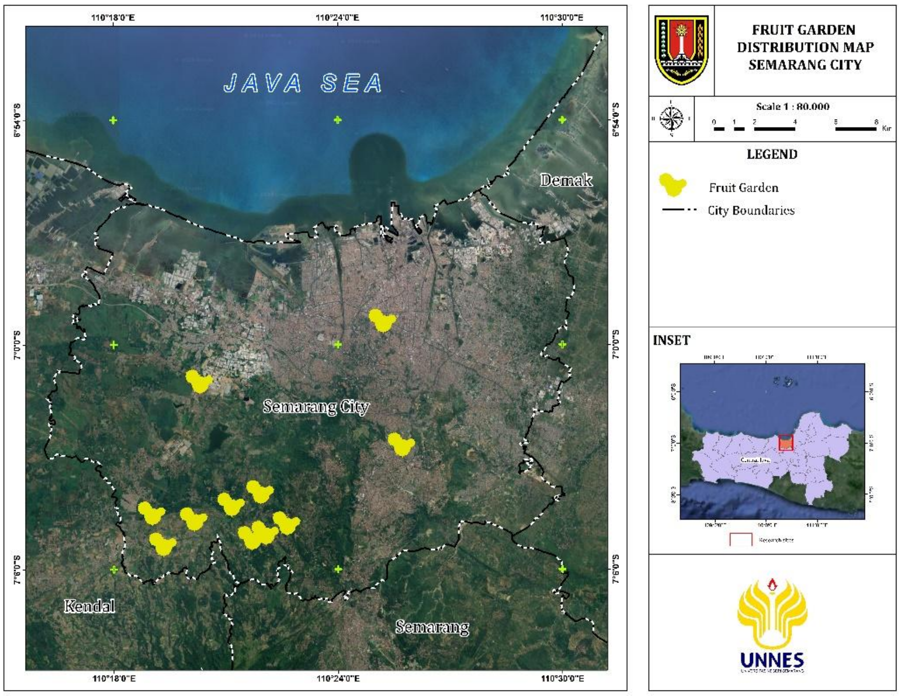

Figure 4. Fruit Garden Distribution Map of Semarang

4.3. *Distribution of urban farming activities in Semarang City*

Since 2019, the Semarang City Government has initiated the Urban Agriculture Movement to support the Mandiri Pangan Village program. To realize the government's goal of achieving food sovereignty, it is imperative to engage in food security activities across all sectors of society through the urban agricultural acculturation movement. This endeavour is reinforced by Semarang Mayor Regulation Number 24 of 2021, which outlines the Urban Agricultural Cultivation Movement in the city. According to this regulation, urban agriculture, also known as Urban Farming, involves the cultivation, processing, and distribution of food and other products through intensive plant cultivation and animal husbandry in urban and peri-urban areas. It emphasizes the reuse of natural resources and urban waste to enhance crop and livestock diversity. The objectives of the Urban Agriculture acculturation movement in Semarang City include empowering communities to strengthen food and nutrition security, utilizing land and space effectively, creating a healthy environment, and enhancing greening efforts while utilizing household waste.

This urban farming movement is implemented across all sub-districts, schools, and government offices. Although all 177 sub-districts in Semarang City are mandated to execute the urban farming program, not all have been successful in their implementation. Sub-districts serve as the foundation of government at the grassroots level and play a crucial role in supporting the city government's initiatives. Farmer groups comprising local community members have been established in sub-districts to spearhead vegetable and fruit cultivation programs. Field observations have identified 10 sub-districts in Semarang City where urban farming is being effectively and sustainably practiced, with their spatial distribution depicted in Figure 5.

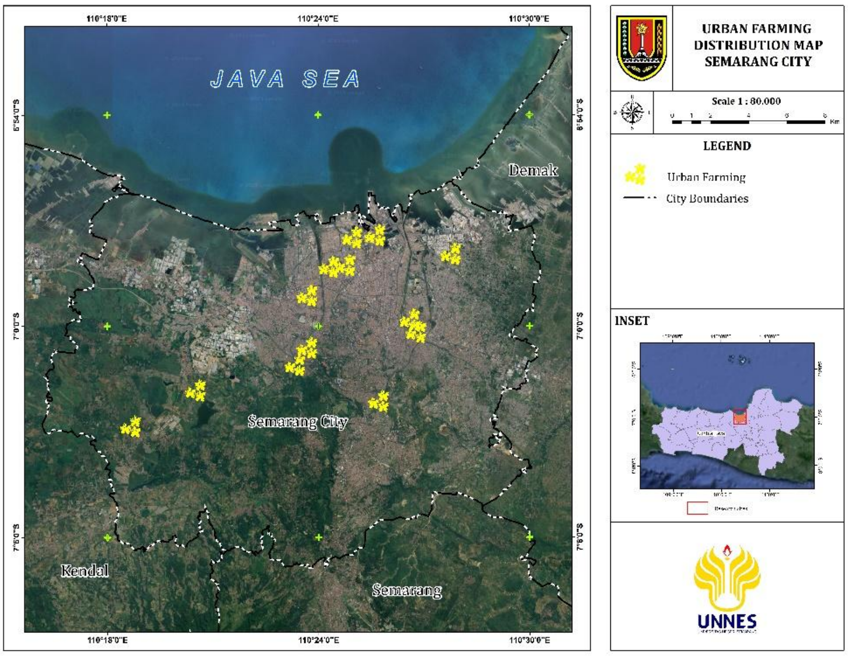

Figure 5. Urban farming activities distribution map of Semarang.

The urban farming activities that are currently continuing are mostly in the lower Semarang City area which actually has limited development space, but this is not an obstacle to the program, but rather makes the enthusiasm of KWT members to maximize the land. Based on the results of a field survey, urban farming in Tambakrejo Village has the largest development land area with an area of around 650 m², located on the banks of the Tenggang River. Urban farming in the area is managed by the Tambakrejo Farmers Group (KT) with cultivated crops in the form of vegetables and fish cultivation, where urban farming in the area is a Community Development and Empowerment (PPM) program carried out by PT Saka Energi Muria Limited (SEML) and Universitas Negeri Semarang. Next, there is Kambera urban farming with a land area of around 600 m² in Jatirejo Village with typical cultivated plants in the form of butterfly pea flowers and chilies. Furthermore, urban farming with the smallest area is in Miroto Village, Central Semarang District with a land area of around 100 m² which has cultivated plants in the form of horticultural plants.

4.4. Fisheries sector in Semarang

As a maritime country and the largest archipelago in the world, Indonesia has various kinds of coastal ecosystems and marine resources, including fisheries potential. Even though the potential and utilization of fisheries resources in fresh, brackish and marine waters is relatively high, eating fish has not yet become a culture in most parts of Indonesia. One food security that needs to continue to be improved is fish resources. As we know, fish contains good benefits for brain development. By consuming lots of fish, it is hoped that the nation's next generation will be a generation that is ready to compete with the outside world. Fish is universal to be used as food, fish can be accepted by all religions and all groups in Indonesia. Therefore, no restrictions on eating fish among communities in Indonesia. In addition, fish can be consumed by humans at almost any age (Nurphadilah et al., 2022). The coastal area of Semarang City has an area of 5,039.17 hectares or around 0.02 percent of the total area of Semarang City. Meanwhile, the length of the coastline is around 25 km, with details for Tugu District 3.5 km, North Semarang District 5.56 km, West Semarang District 8.94 km and Genuk District 7 km. Activities in this coastal area are increasingly heterogeneous, some of the people work as fishermen (Ridlo & Yuliani, 2018). Apart from marine fisheries commodities, freshwater fisheries are also a potential that cannot be ignored. With so many flowing freshwater sources, lakes, rivers and reservoirs, freshwater fisheries are also a potential source of excellent food.

Based on the results of inventory data from the Semarang City Fisheries Service, data was obtained for fisheries potential in Semarang City which currently consists of 4 types, namely pond aquaculture fisheries, marine capture fisheries, public water capture fisheries and pond aquaculture fisheries. The potential for fisheries in the Semarang City area can also be seen from the existence of Fish Auction Places (TPI) and fish markets. The largest results in fish production are obtained from fish cultivation through ponds in coastal areas with production in 2022 of 1,652.67 tons, while the smallest fisheries potential comes from capture fisheries in public waters with a production of 16.27 tons which is the result of freshwater aquaculture in the district Banyumanik amounting to 16.27 tons in 2022. Furthermore, there is only one TPI in Semarang City, namely TPI Tambak Lorok, while the fish market currently operating is Kobong Market which is on Jalan Raden Patah, East Semarang. Table 1 and Figure 6 present information regarding fisheries conditions and production in Semarang City.

Table 1. Fisheries sector production data in Semarang City 2022 in Mg.
Source: Fisheries Department of Semarang City, 2023

District	Aquaculture pond production	Fisheries production in marine water	Fisheries production in common water
Mijen	386.68	-	-
Gunungpati	601.23	-	-
Banyumanik	121.93	-	16.27
Gajah Mungkur	9.67	-	-
Semarang Selatan	16.59	-	-
Candisari	17.65	-	-
Tembalang	74.36	-	-
Pedurungan	70.63	-	-
Genuk	39.26	136.01	-
Gayamsari	67.22	-	-
Semarang Timur	10.64	57.41	-
Semarang Utara	5.19	1,920.59	-
Semarang Tengah	0	-	-
Semarang Barat	97.77	54.73	-
Tugu	26.32	832.92	-
Ngaliyan	107.53	-	-
Total	**1,652.67**	**3,001.66**	**16.27**

4.5. *Distribution of Food Crops Commodities in Semarang*

Based on data from the Semarang City Agriculture Service (2022), it shows that rice fields are classified into Sustainable Food Agriculture Land (LP2B) with a land area of around 1,625.15 hectares and ordinary rice fields with an area of 2,219.54 hectares. Most of the LP2B rice fields are in the Mijen District area with an area of 630.95 hectares, while most of the ordinary rice fields are in the

Gunungpati District with an area of around 480.88 hectares. There are three sub-districts in the Semarang City area that do not have LP2B agricultural land, but have ordinary rice fields, including Pedurungan District, Genuk District and West Semarang District, so there is still potential for existing rice fields to be converted into built-up land in line with land needs. which is increasing, especially in the lower Semarang area.

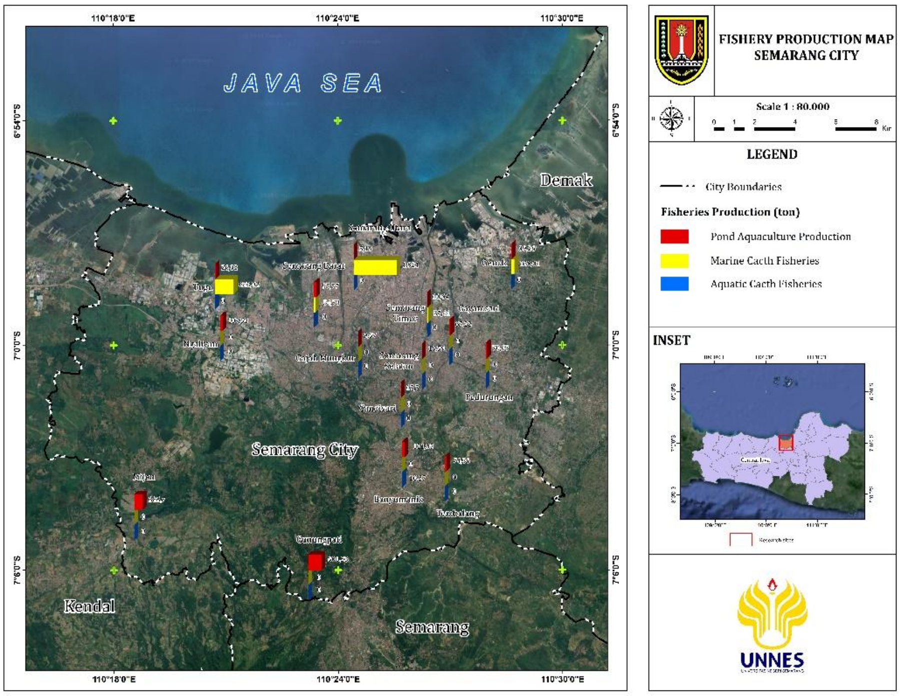

Figure 6. Fishery production map of Semarang

Food crop production in the city of Semarang is currently in 9 sub-districts out of 16 existing sub-districts. This is because some sub-districts no longer have agricultural land or plantations using built-up land, especially in the lower Semarang region. Several sub-districts that have agricultural land for cultivating food crops include: Mijen District, Gunungpati District, Banyumanik District, Tembalang District, Pedurungan District, Genuk District, West Semarang

District, Tugu District and Ngaliyan District. Figure 7 presents the spatial distribution and productivity of agricultural land in Semarang City.

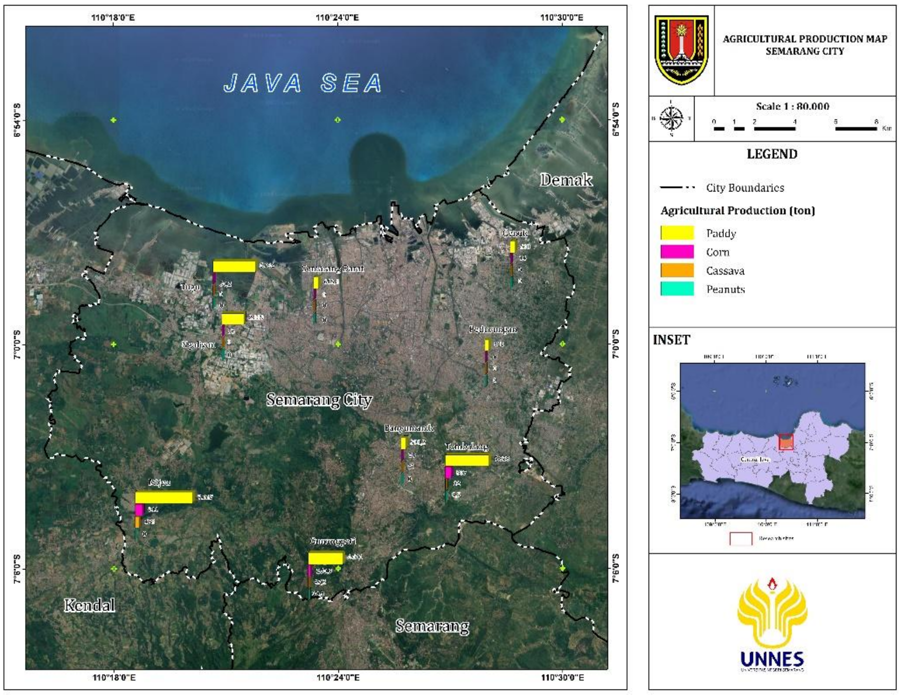

Figure 7. Agricultural production map of Semarang

Food crop commodities cultivated in Semarang City include rice, corn, peanuts, cassava, sweet potatoes, green beans, soybeans and *porang* plants with total production for all these commodities in 2022 amounting to 31,817.1 tons. The rice crop commodity has the highest production level with total production of 28,934.80 tons in 2022, with the highest production contributed by Mijen District with production of 7,666.9 tons, where Mijen District has the largest LP2B agricultural land in the Semarang City area. Furthermore, rice plants with high productivity were also produced by Tembalang District with a production of 5,828.3 tons and Tembalang District with a production of 5,641.7 tons. Furthermore, the food crop with the next highest productivity is corn with a productivity in 2022 of 2,150.24 tons, most of which is contributed by Mijen

District and Tembalang District. Table 2 presents data on agricultural land and its productivity at the research location (see Appendix A).

4.6. *Research implications*

The findings of this study have significant implications for policymakers, urban planners, and community leaders in Semarang City. By identifying a diverse array of food assets, including 49 markets, 5 fruit gardens, 10 urban farms, fisheries production, rice fields, beef cattle livestock groups, and the Farmer-Owned Enterprise Lumpang Semar Sejahtera, the research highlights the multifaceted and interconnected nature of the city's food supply network.

The policy recommendations emphasize the critical need for a holistic approach to food security that integrates diverse food assets and sustainable practices resources (Fitzpatrick et al., 2022; Leach et al., 2020; Savary et al., 2020). Policymakers should prioritize the protection and expansion of urban and peri-urban agricultural areas (Ahani & Dadashpoor, 2021; Spyra et al., 2021) identified in the Food Supply Asset Map, especially for the peri-urban area. This argument based on the fact that peri-urban agriculture (PUA) is more crucial in urban areas than in rural areas for food supply, ecology and biodiversity preservation, disaster mitigation, and recreation (Mulya et al., 2023). Uncontrolled urbanization has severely impacted food production in peri-urban areas of developing countries. In Ghana, agricultural land in peri-urban has drastically decreased over the last three decades due to residential and infrastructural development (Ziem Bonye et al., 2021). In Ethiopia, the continuous eviction of peri-urban farmers from their indigenous land for redevelopment projects has negatively affected the livelihoods of farming communities (Mohammed et al., 2020). In Indonesia context, the area of agricultural land in West Java experienced net losses from 2013 to 2020 being approximately 2.3 times larger than that from 2003 to 2013, amounting to about 1,850 hectares per year (Gandharum et al., 2022). The similar condition happens in Tegal (Mardiansjah et al., 2021); Malang (Adrianto & Ravetz, 2020); Yogyakarta(Nurcahyani & Marwasta, 2021) and Semarang which ost 31.85 km2 of agricultural land and 14.00 km2 of forest land and gained 20.13 km2 of urban land and 16.11 km2 of commercial/industrial land during 2006-2015 (Kelly-Fair et al., 2022).

The protection and expansion of urban and peri-urban agricultural areas can be achieved through zoning regulations that designate these areas for agricultural use, thereby safeguarding them from urban sprawl and developmental pressures. Simulations conducted by Domingo et al (2021) in Spain highlight the importance of zoning regulations, showing that directing growth to areas designated for urbanization projects could preserve nearly 4,200 hectares of grassland and cropland from overdevelopment and shifting growth to zones without urbanization projects could save another 3,800 hectares (Domingo et al., 2021). Additionally, offering tax incentives or subsidies for sustainable farming practices, such as organic farming and agroecological methods, can incentivize producers to adopt environmentally friendly techniques while enhancing the resilience of local food production systems (Piñeiro et al., 2020). This strategy has been proved as effective strategy in China (Bai et al., 2022) and European Union (Scown et al., 2020).

Furthermore, the study underscores the importance of fostering local food markets (González-Azcárate et al., 2023) and cooperatives that connect producers directly with consumers. Policymakers can support this by creating infrastructure and policies that facilitate the establishment and growth of farmers' markets, such as developing e-commerce for agricultural products (Muñoz et al., 2021), supporting community-supported agriculture (CSA) programs in terms of legal and regulation issues (Martinez et al., 2022), and creating local food hubs (Moragues-Faus, 2021). These initiatives not only promote economic opportunities for local farmers but also ensure access to fresh, nutritious food for urban residents. Integrating circular economy principles into these initiatives can further enhance resource efficiency by promoting practices such as food waste reduction, recycling of organic materials, and sustainable packaging solutions.

In terms of urban planning, policymakers should integrate food asset mapping data into land use planning processes. Urban planners can leverage food asset mapping data to create more effective land use plans that protect and expand urban and peri-urban agricultural spaces. By understanding the strategic value of different food assets, planners can prioritize the allocation of land and resources to areas that maximize food production and accessibility. This involves integrating food asset mapping into urban development plans (Giroux et al., 2021; González-Azcárate et al., 2023), ensuring that agricultural activities are not only preserved but also promoted in urban settings (Diehl et al., 2020). This can lead to the creation of green belts, community gardens, and urban farms that serve as vital sources of fresh produce and contribute to the city's environmental health. By incorporating green infrastructure into urban development plans, such as green roofs and vertical gardens, cities can mitigate the urban heat island effect, improve air quality, and provide additional space for food cultivation

Community leaders and local organizations can use these insights to strengthen community-based initiatives and support local food production. By fostering collaborations between different stakeholders, including small-scale farmers, local markets, and educational institutions, communities can enhance their food self-sufficiency and resilience (Guell et al., 2022). Initiatives such as urban farming projects (Clerino et al., 2023; Mabon et al., 2023), community-supported agriculture (CSA) programs (Egli et al., 2023; Tay et al., 2024), and local food cooperatives (Bijman & Höhler, 2023) can be bolstered using the data from this study. These efforts not only improve food access and nutrition but also promote social cohesion and community empowerment. Moreover, enhancing food security policies requires collaboration across government departments, community organizations, educational institutions, and private sector stakeholders. Policymakers should promote multi-stakeholder partnerships that facilitate knowledge sharing, capacity building, and collective action towards sustainable food systems. This collaborative approach can foster innovation in urban agriculture, improve food distribution networks, and strengthen community resilience in the face of climate change and economic uncertainties.

This study calls for policymakers in Semarang City to adopt an integrated and proactive approach to food security that embraces the city's diverse food assets and promotes sustainable practices. Implementing the outlined recommendations will enable policymakers to ensure a resilient and equitable food system that meets the needs of current and future generations while safeguarding the environment and enhancing community well-being. By continuously updating and refining food asset maps, researchers and policymakers can ensure that Semarang City remains well-prepared to meet the food security needs of its growing population.

5. Conclusions

The study concludes that Semarang City's food supply is supported by a diverse array of assets. These findings were obtained through a comprehensive focus group discussion with government agencies and organizations that manage food data in the city. Despite the valuable insights provided, the study has certain limitations. One major limitation is the reliance on available secondary data, which may not capture the full scope of smaller or informal food sources that also contribute to the city's food supply. Additionally, the study's methodology could be expanded to include more detailed field surveys, allowing for a more granular understanding of the food supply landscape. Future research should aim to address these limitations by employing more diverse data collection methods. Engaging a broader range of stakeholders, including small-scale farmers, local market vendors, and community organizations, can provide a more comprehensive view of the food supply network. Furthermore, future studies should investigate the resilience of these food assets to environmental and economic changes, such as climate change and market fluctuations. This would provide a more robust understanding of the sustainability and adaptability of Semarang City's food security framework. By addressing these areas, future research can contribute to the development of more effective policies and strategies for enhancing food security and sustainability in Semarang City.

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Competing Interests

The author declares that there is no conflict of interest in the conduct or publication of this research.

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Original Paper

A multidimensional analysis of food security for sustainable development

Evidence from India

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Keywords: food security; India; policy evaluation; Sustainable Development Goals (SDGs).

Abstract. *Ensuring access to sufficient and nutritious food is a vital component in attaining sustainable development, especially in developing nations like India. This study aims to comprehend the importance of food security measures in relation to Sustainable Development. We performed an analysis employing data obtained from the official Food and Agriculture Organisation databases and the National Family and Health Survey of India. This study utilises a comprehensive quantitative approach, employing graph analysis, trend analysis, and literature reviews to examine the several dimensions of food security in India. These dimensions include availability, access, utilisation, stability, agency, and sustainability. The results emphasise the importance of policy in improving food security and encouraging healthy diets, while considering the current state of affairs. This paper argues that achieving sustainable development in India requires not just increasing food production but also adopting responsible food consumption practices and optimal utilization the use of current resources.*

1. Introduction

Food aid which includes variety of programs and initiatives designed to provide food security and nutritional support to vulnerable populations, has both positive and negative effects on food security. It facilitates food security through improving production and consumption choices, but also hinders it through labor supply disincentives and dependence syndrome. Further, the impact of food security is multifaceted, influenced by food aid, environmental factors, food processing technologies, and dietary habits. Therefore, researchers are of the opinion that comprehensive studies are needed to determine the net effect of food aid on food security, incorporating multi-country and multi-program factors (Garbero & Jäckering, 2021).

The economic and social transformation after the dissolution of the USSR, changing agricultural policies, and climate change have shaped the state and changing trends of food security in Asia. Asia is the largest producer of rice, with China and India being the leading producers, and the region also produces a significant amount of vegetable oil (Iqbal et al., 2022). More than half the world's population lives in Asia, making food security a matter of paramount importance. Even though, the region has made impressive achievements in reducing poverty and hunger, driven by economic growth and rising incomes, progress has been uneven, with over 60% of undernourished people in the world residing in Asia. Similarly, in India, the issues of food security and food consumption are critical, yet they have not been thoroughly assessed. More than 40% of the population lives below the poverty line, earning less than $3.20 per day, according to the World Bank Poverty and Inequality Platform (2021). This lack of adequate nutrition and sanitation facilities contributes to high morbidity rates among this group. The demand for food in India has surged over the last decade, driven by population growth. As one of the world's most populous countries, India is expected to surpass all others by 2027. Being a major agriculture player, India is also home to 25% of the world's hungry population.

India's food security situation has been a major concern, with the country ranking 76th among 113 countries in the Global Food Security Index 2018 and 103rd out of 119 countries in the Global Hunger Index 2018. Further, India, ranks 102nd out of 119 countries on the 2019 Global Hunger Index (GHI) with a score of 30.5, indicating a serious hunger problem. The GHI score is determined by four factors: undernourishment, child wasting, child stunting, and child mortality. India's high GHI score is partly due to the prevalence of child wasting (children under five who are too thin for their height) and child stunting (children under five who are too short for their age). Although India has made some strides in reducing hunger and malnutrition, substantial work remains. With 113 other nations, India ranks 68th on the 2022 Global Food Security Index. Its performance is generally consistent throughout all four dimensions, with a peak of 62.3 in the availability dimension. The Sustainability and Adaptation pillar is where the nation really falls short, earning a score of 51.2. According to the results, India's food security is especially at risk from the effects of climate change. The root causes of food insecurity in India are diverse, including poverty, low agricultural productivity, inefficient supply chains, and inadequate infrastructure. Natural disasters like floods and droughts exacerbate the problem.

In recent years, the number of people living in poverty and hunger has increased, and food costs have risen significantly. With this backdrop, this article aims to provide a comprehensive overview of food security interventions in India, emphasizing their multidimensional nature, which is crucial for understanding the unique challenges the country faces in this area.

1.1 *Food Policy Interventions in India*

Government interventions in foodgrains markets in India have been in place for several decades, aiming to ensure remunerative prices to farmers, improve access to food for economically vulnerable people, and stabilize foodgrains prices and availability in the country. Moreover, studies have shown that food security interventions, such as the Public Distribution System (PDS) and the Mid Day Meal Scheme (MDM), have significantly contributed to poverty reduction and improved calorie intake in India. Major food policy intervention are listed in below Table 1.

Table 1. Major Food Policy Interventions in India

Year	Scheme/Programs	Objective/(s)
1940	Public Distribution System (PDS)	Launched as general entitlement scheme
1960s	Green Revolution	Self – sufficiency in Food grains (Macro level food security)
1975	Integrated Child Development Services	Includes a package of integrated services consisting of supply of nutrition, immunisation, health check-up, referral and educational services (up to 6 years through Anganwadi)
1995	Mid-day Meal	Aims at enhancing retention, attendance and improvement in nutritional levels in government schools and aided schools.
1997	Targeted Public Distribution System (TPDS)	PDS was revamped to target poor households.
2000	Antyodaya Anna Yojana	Poorest among Below Poverty Line identified for TPDS. 25kgs of food grains made available to eligible family (revised to 35kgs) at subsidized rate of 3 per kg for rice and 2 per kg for wheat.
2010-11	Rajiv Gandhi Scheme for Empowerment of Adolescent Girls (RGSEAG)	Empowerment Adolescent Girls (11-18 years) through nutrition, healthcare and life skills education
2013	National Food Security Act (NFSI)	Aim of increasing rice, wheat, and pulses output through expanding land and increasing productivity, as well as offering job possibilities and initiatives to help farmers regain confidence
2017	Zero Hunger Program	To make India free from malnutrition by 2022 and attaining "Zero Hunger"
2018	National Nutrition Mission (POSHAN)	Improvement in nutritional status of children from (0-6 years) through different target aims at reducing levels of stunting, under-nutrition, anaemia and low birth weight babies.

Source: Authors compilation from various Government database.

The PDS was introduced in the 1940s to ensure food security in urban areas and continued after independence to address food security during droughts, famines, and wars. The PDS was later expanded to include other items such as cooking oil, sugar, and wheat. Additionally, the Green Revolution in the 1960s, which introduced high-yielding varieties of crops, had significant impacts on agricultural production, biodiversity, and environmental sustainability. It led to a significant increase in food production and helped to improve the food security situation in the country. Further, food policy interventions in India such as mid-day meal scheme, TPDS, Antyodana Anna Yojana have shown positive economic implications through improved food security, potential public health benefits through poverty reduction and calorie intake. The TPDS Act also contains a number of provisions aimed at improving the efficiency of the distribution system, including the use of electronic ration cards and the establishment of a grievance redressal mechanism.

Apart from the above-mentioned interventions, Government also introduced the Pradhan Mantri Fasal Bima Yojana (PMFBY), a crop insurance scheme that provides insurance cover to farmers in the event of crop loss. The scheme has been operational since 2016, and it is currently the largest crop insurance scheme in the world. The Pradhan Mantri Krishi Sinchai Yojana (PMKSY) is a scheme that was launched in 2015 with the aim of improving irrigation infrastructure in the country. The scheme has been successful in increasing the area under irrigation and in reducing the state of waterlogging and salinity in the country. The government of India has put in place several food policy interventions in an effort to address the challenge of food insecurity in the country. However, the government's efforts to improve agricultural productivity and infrastructure have not yielded the desired results.

2. Methodology

This study is comprised of two stages. The prevalence of various food insecurity challenges, in Asia and India was compared using statistics from the World Food and Agriculture Yearbook 2023, the Food and Agriculture Organisation of the United Nations (FAO), and the National Family and Health Survey of India. This analysis examines the consumption of certain sector outputs, with a specific emphasis on food security and nutrition. Secondly, based on the output of the relevant data of food security, current scenarios are discussed in Indian context on the basis of pillars of food security namely, availability, access, utilization, stability, agency and sustainability to assess sustainable development.

3. Results

According to the National Family Health Survey (NFHS - V) data, 33.4% of women and 28.5% of men are undernourished in India. This means that nearly one-third of the population is not getting the minimum amount of food required for a healthy and active life. In comparison to the global and Asian averages, Indians have the highest proportion of undernourishment (15.3%), which is a cause for alarm.

The main reasons for high levels of undernourishment encompass a complex interplay of poverty, inadequate food security, unhealthy diets, and disruptions in the food supply chain. Millions of people in India do not have access to adequate nutritious foods, especially those rich in essential vitamins and minerals, leading to malnutrition due to low income and affordability issues. This leads to serious health related consequences, including weakened immunity, increased susceptibility to illness, and stunted growth (Tharumakunarajah et al., 2024). Furthermore, as mentioned in Figure 2, undernourishment is a significant contributor to high levels of child mortality in India, with nearly half of all child deaths in the country attributed to malnutrition. The prevalence of underweight, stunting, and wasting among children under five is alarmingly high, with rates of 32.1%, %, and 24.5% respectively

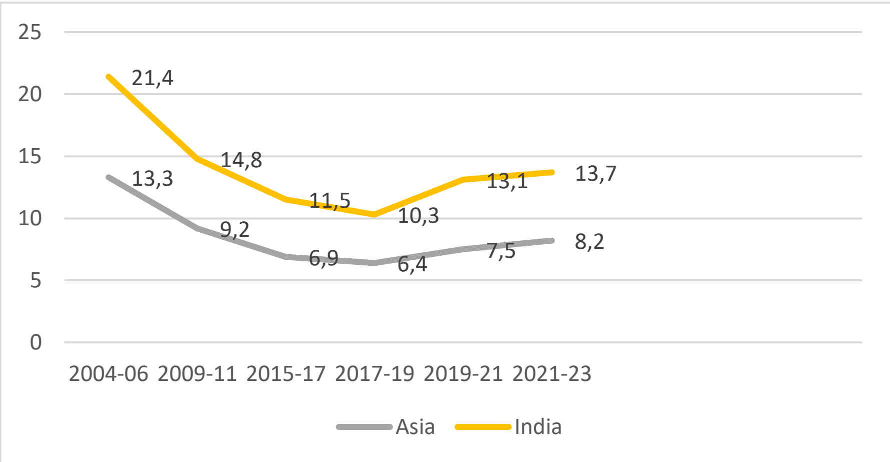

Figure 1. Prevalence of Undernourishment (in %). Source: World Food and Agriculture Yearbook, 2023.

Figure 1 demonstrates that both Asia and India made a significant reduction in undernourishment in terms of population % from the year 2004-06 to 2021-23. However, the uptrend from 2017-19 for both regions suggests that external factors such as COVID-19 may have adversely impacted the increase of food insecurity and nutritional diets. Furthermore, the prevalence of undernourishment in India is much higher compared to overall average of Asia, which highlights severe concern.

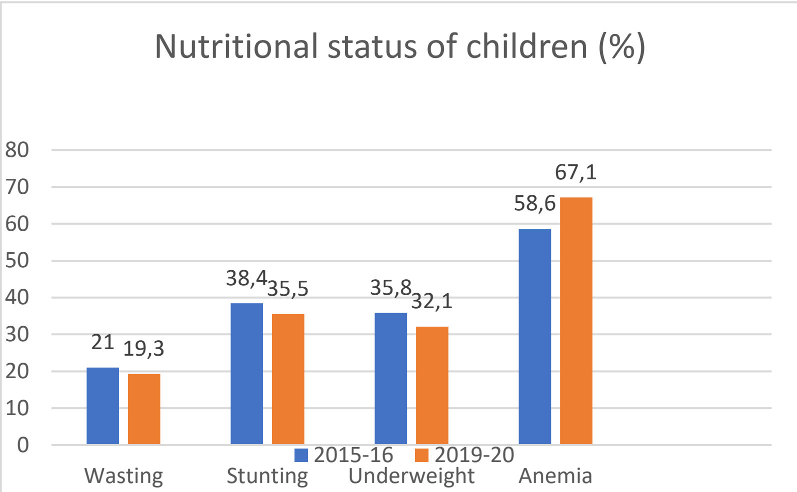

Figure 2. Nutritional status of children in India. Source: NFHS V; Wasted, Stunting, Underweight, Anaemia.

Figure 2 shows how India has reduced the percentage of wasted, stunted, and underweight children (0-5 yrs) during the last five years. However, the proportion of children who are anaemic has recently increased (9%). This is a concerning development for the country, which is due in part to the fact that anaemia affects more than half of women of reproductive age.

4. Discussions

Adopting the four pillars of food security framework namely, availability, access, stability, and utilization can lead to a more holistic understanding of food security, guiding the development of effective interventions at the national, community, or household level (Okpala et al., 2024). Further, research suggests a need for a more efficient approach which shall include agency and sustainability to dealing with the multifaceted nature of food insecurity (Clapp et al., 2022).

4.1 *Availability*

The definition of availability in food security encompasses the concept of ensuring that all people have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs for an active and healthy life (Barrett, 2010). Cereals are the most important staple food crop globally, contributing substantially to more than 50% of daily caloric and nutrient intake across the globe (Anjali et al., 2023).

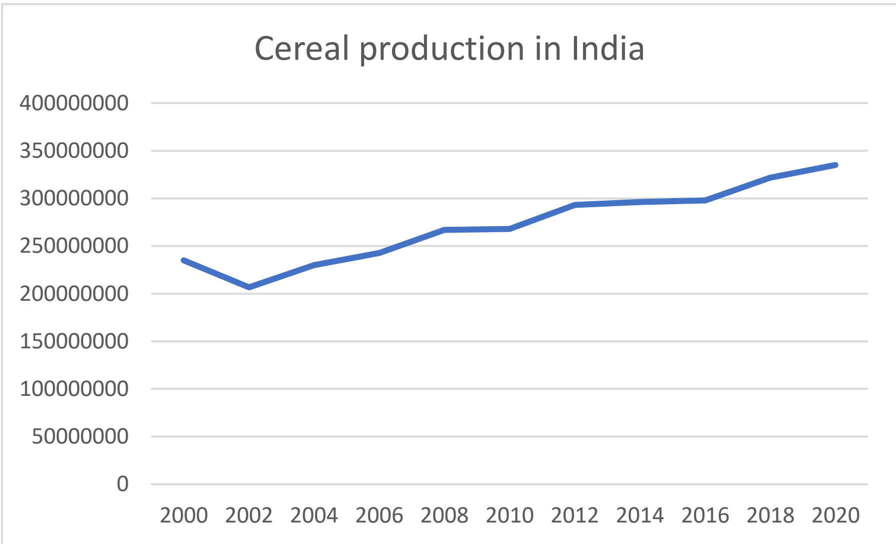

Figure 3. Cereal Production in India. Source: Food and Agriculture Organization of the United Nations (FAO, 2023).

As per data suggests from the Figure 3, , the cereal production in India is on the increasing rate. Further, the average Indian adult requires around 1798 kilocalories (kcal) per day to maintain their body weight, according to the National Institute of Nutrition (NIN).

We live in a more equal world today than we did in the previous century when it comes to food availability (Balogh & Hall, 2016). According to the data presented in Table 2, it is clear that the availability of nutrient-rich diets is steadily growing each year.

Table 2. Supply of dietary per capita in India

Year	Per capita fat Supply (in gms)	Per Capita Protein Supply	Per Capita Kilo Calorie Supply
2010	49.29	60.46	2378.80
2012	50.85	60.85	2407.44
2014	53.91	63.78	2457.91
2016	54.66	65.19	2489.46
2018	59.97	66.35	2539.40
2019	59.06	67.83	2549.85
2020	60.14	70.07	2550.00
2021	60.36	70.52	2569.00

Source: Food and Agriculture Organization of the United Nations (FAO, 2023).

4.2 Access

A fivefold strategy incorporating a life-cycle approach, reproductive health, citizen participation in national programs, women's empowerment, agricultural advancement, and better monitoring of the Public Distribution System is proposed to tackle the various factors affecting food and nutrition security in India. Moreover, The Government's National Food Security Mission has helped to improve food security for millions of people across the country. The Mission has helped to increase production of food grains, improve access to food grains, and reduce wastage.

However, there are still challenges in terms of affordability of food security. While the Government has increased production of food grains and improved access to food, the prices of food grains have also increased. Moreover, according to NFHS-V, 23% of reproductive-age women have no formal education. Furthermore, despite continuing to spend up to 28.3% of their total private final consumption budget on food and non-alcoholic beverages in FY19, many people have poor dietary practises. Their diets are severely lacking in healthy and nutritional foods such as fruits, vegetables, legumes, nuts, and whole grains.

Figure 4 shows that 70% of Indians did not have access to a healthy diet in 2020. This figure has not decreased considerably since 2017. When this figure is compared to the cost of a nutritious diet, the outcome is surprising. For example, 75% of Indians could not afford a nutritious meal in 2017, the year with the lowest cost, the highest percentage in the previous four years. Compared to the previous three years, the expense of a healthy diet was relatively modest. Due to the higher expense of a nutritious food, it comes to reason that a substantial percentage of individuals cannot afford it. As per the Centre for Science and Environment's (CSE) State of India's Environment 2022 report, consumer food price index inflation has increased by more than 300% over the past year, making a balanced diet unaffordable for even more people. This is a significant problem because a lack of access to healthy food can lead to a number of health problems.

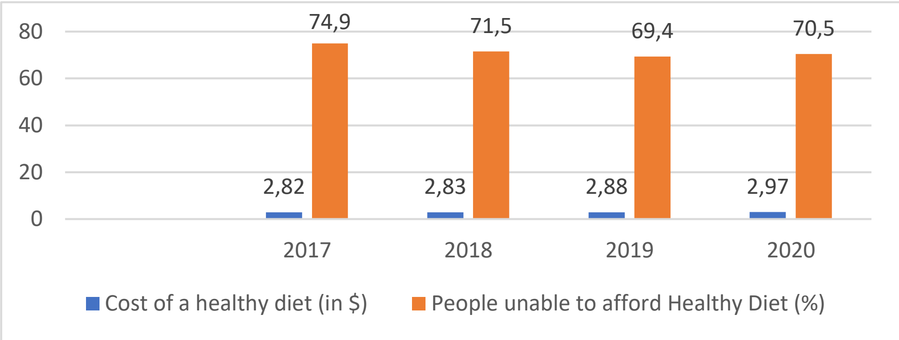

Figure 4. Affordability of healthy diet in India. Source: State of Food Security and Nutrition in the World, UN-FAO, 2022.

4.3 Utilization

Although adequate nutrition has always been a presumption of food security, the broader context that determines the nutrients in food, especially micronutrients and high-quality protein, and the ability to use that nutrient content, an additional pillar of the concept known as "utilisation" as indicated by Clap (2021). A study found that the NFSA has led to improvements in employment, calorie intake, and children's enrolment in schools among beneficiary households after three years of implementation (Satapathy et al., 2020). In addition, the Public Distribution System (PDS) has been an increasingly important tool in the fight against poverty and for better food security in India. Nevertheless, challenges in the implementation of food security programs include errors in the beneficiary list, broken delivery mechanisms, and financing costs for program implementation. The need for repairing the broken delivery mechanism and financing the program aiming to provide subsidized food to a large portion of the population are significant challenges.

4.4 *Stability*

The challenges to sustain food security in India are primarily due to rapidly increasing population, changing dietary patterns, decreasing productive land area, and the impact of climatic changes on sustainable crop production. The country's agricultural achievements have transformed it from a food importer to a potential exporter, but failure to improve agricultural practices may nullify these prospects.

Every year, millions of tonnes of food are wasted in India. According to the Food Waste Index Report, 2021, by UNEP and The Waste and Resources Action Programme (WRAP), 931 million tonnes of food waste were generated globally in 2019, with households contributing 61%, food services 26%, and retail 13%. The report estimates that Indian households alone generate 50 kg of food waste per capita per year, amounting to a total of 68,760,163 tonnes annually (UNEP, 2021). Additionally, it is noted that only 2% of the total food produced in India is processed, leading to a large portion being wasted without being consumed. The large generation of food waste (FW) is having a severe impact on the environment due to the emission of greenhouse gases (GHG) (Gustavsson et al., 2011; Venkata Mohan et al., 2017). This has exacerbated the issue of food security stability in India.

4.5 *Agency*

The purpose of agency is to end hunger and its harmful impacts by promoting process variables that enable individuals and communities to make their own decisions regarding food systems.(Clapp et al., 2022) An emphasis on agency also acknowledges that gender, racial, literacy, and other societal power disparities may hinder people's ability to have their voices heard and to take part in community and individual decisions regarding food systems. When people are unable to influence the production, distribution, and consumption of their food, food security suffers (Rocha, 2009).

The Food Corporation of India (FCI) is a crucial entity in ensuring food security in India, established in 1964 with the objective of managing minimum support price (MSP)-based public procurement operations and maintaining buffer stocks for food security. It plays a crucial role in procuring, storing, and transporting food grains on behalf of the Government of India, as well as managing the public distribution system. The FCI has a network of over 5,000 godowns across the country with a storage capacity of over 18 million tonnes. Under this system, the FCI supplies food grains to the state governments at subsidised prices. The state governments then distribute the food grains to the eligible households through the Fair Price Shops. It procures and stores food grains to safeguard against any shortfall in production.

4.6 Sustainability

The concepts of food security and food sustainability are interrelated, and a comprehensive analysis of sustainability transitions is essential to address the issues arising from conventional food systems. Govindan (2018) found that globalization and the growing world population have a significant impact on the sustainability of food production. As the world's population is expected to grow by 30%–35% over the next 60 years, with India being one of the most populous countries. This will require a 50%–75% increase in food production, particularly protein and dairy products, to meet the growing demand (Basso et al., 2024). Hence, it is essential to have a sustainable approach to food supply chains in order to limit the amount of carbon emissions produced.

5. Policy implications

Effective food security policy implementation is crucial in moving India forward with a nutritionally sensitive population. As the world population continues to grow, the demand for food will also increase. Ensuring food security for all is therefore a key challenge for policymakers. While there are many different ways to approach this challenge, one key policy implication is the need for greater investment in agriculture. This can help to increase food production and ensure that everyone has access to the food they need. In order to implement effective food security policies, it is also important to consider the social and economic factors that can influence food access and availability

5.1 Policy on health diets

If food prices continue to increase without a relative rise in wages, it will become increasingly difficult for people to afford a nutritious diet (Jha & Srinivasan, 2014; Reeves et al., 2017). If earnings drop at the same time that food prices increase, healthy diets may become unattainable for even more people (Clapp, 2014). A shift in India's agricultural policies and incentives towards investments and policies that are more nutrition-sensitive is necessary if the country is to cut down on food waste and increase efficiency across all regions. If we want those who are most vulnerable to be able to purchase healthy food, we need social protection measures that are nutrition-sensitive. It will also be necessary to implement policies that encourage people to alter their eating habits for the better (Barnhill & Bonotti, 2023).

5.2 Action on climate change

Unsustainable food production techniques contribute to climate change, which in turn threatens the long-term viability of food systems. Greenhouse gas emissions from the food industry, comprising all stages of production and consumption, account for 21–37% of global emissions, according to the IPCC (Calvin et al., 2023). Fossil fuel usage has led to a tremendous increase in worldwide energy demand and carbon dioxide emissions, contributing to climate change (Gollakota & Shu, 2023). Moreover, Climate change, characterized by rising temperatures, shifting rainfall patterns, and extreme weather events, poses a significant threat to agricultural and horticultural crop production. Additionally, increased frequency of extreme weather events, such as droughts, floods, and storms, has made agriculture more susceptible to climatic risks, leading to decreased crop productivity (Mall et al., 2017). Research indicates that climate change affects the nutritional content of foods, potentially leading to malnutrition globally. (Giulia et al., 2020). Hence, the government of India should implement measures to mitigate the impact of climate change on farming and to strengthen the agricultural sector's ability to withstand it.

5.3 Consideration of density of population

The impact of population density on the effectiveness of food security policies and programs in India is underscored by the need for a portfolio of strategies, rather than a single grand strategy, to address multiple tradeoffs at different scales. Additionally, few studies highlighted the importance of understanding interventions or environmental shocks that might affect farmers' food security status differentially, emphasizing the need for informed and equitable development (Lopez-Ridaura et al., 2018; Patel et al., 2015) . The strategies for addressing food security in densely populated regions of India should focus on crop diversification, wild fruit domestication, aquaculture, and animal foods to improve access to food, diet diversity, and nutritional security, especially for vulnerable sections of the population. Further, multisectoral interventions are required to tackle the problem of urban food insecurity in densely populated areas, including nutritional interventions combined with appropriate education, income support programs, and employment generation schemes.

5.4 Evaluation system

Food systems interventions are complex and dynamic, posing challenges for evaluation due to their multifaceted nature and lack of fit with standard evaluation methods. However, areas for future research include the evaluation of national-level policies, efforts to support women's empowerment within the food system, and the synthesis of dietary quality. The development and implementation of a holistic evaluation system should consider the ethical implications of interventions. It can be prioritized by ensuring equitable resource distribution, particularly to marginalized groups, assessing potential unintended consequences, and respecting the autonomy of local communities. This approach ensures that interventions are not only effective but also socially just, safeguarding human rights and dignity. Moreover, as researchers pointed out, multi-stakeholder engagement is critical in addressing wicked problems in agri-food businesses and public policy development (Dentoni & Bitzer, 2015). It is particularly useful in providing diverse perspectives and improving policymaking in food security. This approach would help to ensure that food policy interventions are more effective and lead to positive outcomes for all those involved.

6 Conclusions

This study laid emphasis on understanding the link between food security and Sustainable development through multidimensional analysis. It reveals a complex picture with a range of successes and failures. Further, this study asserts that attaining sustainable development in India necessitates not just augmenting food production, but also practicing responsible food consumption and optimising the utilisation of existing resources. Researchers noted that there are several ways in which food security policies can contribute to the SDGs. For example, current trends suggest that achieving zero hunger by 2030 may not be feasible without significant efforts to address food security challenges (Marcolin & Cadel, 2024). They are also integral to reducing food waste and promoting sustainable agriculture, aligning with Goal 12 of the SDGs (Responsible Consumption and Production) (Zisopoulos et al., 2017) . Furthermore, food security policies can contribute to the SDGs is by promoting sustainable agriculture practices, which can help to reduce greenhouse gas emissions and increase the resilience of local communities to climate change.

Governance plays a crucial role in conjunction with the SDGs, emphasizing the need for clear and universally applicable targets and indicators to support sustainable agriculture and food security. In order to be effective, food security policies need to be tailored to the specific needs and context of each country. They also need to be well-coordinated between different government agencies and sectors. By taking these steps, food security policies can play a vital role in achieving the SDGs and creating a more sustainable future for all.

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Original Paper

To graze or not to graze livestock in public forests.

Insights from Mau and Aberdares forest ecosystems in Kenya

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Abstract. *Forest ecosystems are important for the social, economic, and environmental well-being of many people globally. However, with the growing human needs and the impacts of climate change, there is an emerging forest policy discourse on whether to allow or disallow livestock grazing in public forests. This study used a case study research design and document content analysis to share comparative insights on the effects of forest grazing in two critical forest ecosystems in Kenya. The key documents reviewed included official government publications, policy papers, strategic plans, academic articles, relevant case studies from government websites, academic databases, international organizations, and research institutions specializing in sustainable forest management. The findings indicate that Kenya is endowed with diverse forest capital with immense potential for contributing to sustainable development. However, there is a complex interplay between livestock grazing and forest ecosystems. Insights from Mau and Aberdares indicate that livestock grazing in the two ecosystems under the current grazing system has a positive socio-economic impact. However, due to overgrazing by livestock, there are significant negative environmental impacts such as soil degradation, compaction, and erosion, reducing the forest land's ability to retain water and support plant growth, reduction in biodiversity, exacerbating the spread of invasive species, and increased vulnerability to natural disasters such as floods and landslides besides increased carbon emissions. Moreover, despite deploying several strategies to enhance sustainability, there is no adequate monitoring framework for the indicators of grazing impacts. Based on the precautionary principle, this study recommends banning livestock grazing in the two ecosystems. However, a "win-win" arrangement should be developed to enhance the "cut and carry system" for fodder from the two forests to promote livelihoods and socio-economic empowerment. These findings are critical for promoting the sustainable management of critical water towers with similar contexts in the country and enhancing the achievement of various national development aspirations, such as the aspiration to plant 15 billion trees by 2032 and a host of climate-related commitments.*

1. Introduction

Forests constitute 31% of the earth's land surface (4.06 billion ha) and are an economic and environmental lifeline for many people (FAO, 2022). However, with the growing human population, needs, and the impacts of climate change, livestock grazing in public forest ecosystems is increasingly becoming a pervasive practice globally with multifaceted and complex impacts (FAO 2018). Studies show that forest grazing, influenced by the grazing regime and species sensitivity, can significantly modify the structure, composition, and dynamics of forest ecosystems (FAO, 2018; Herrero & Thornton, 2013). It can lead to adverse long-term effects on plant communities, soil health, water quality, and, consequently, the overall provision of ecosystem services. Grazing intensity influences soil structure, function, and soil organic carbon storage capacity within livestock-plant-soil systems (Conant, 2010; Eldridge et al., 2016; Paz-Kagan et al., 2016). As a result, Abdalla et al. (2018) note that grazing degradation is becoming a global concern, with an estimated 20-35% of the world's permanent pastures affected.

On the contrary, some emerging studies increasingly advocate for forest grazing after reporting positive impacts. Wang et al. (2016) established that over the past 70 to 80 years, the Northern Great Plains grasslands had sequestered carbon and nitrogen, effectively recovering the losses incurred during widespread grassland degradation. The study notes that implementing sustainable grazing management practices after deterioration enhanced carbon and nitrogen levels in the degraded grasslands. Consequently, the grassland soils offset approximately 5.84 Mg C ha^{-1} CO_2-equivalent anthropogenic CO_2 emissions. However, this paper agrees with studies that note that the impact of grazing on forests from livestock grazing depends on many factors, such as the type of livestock, grazing intensity, plant productivity levels, and the evolutionary history of grazing (Nordberg & Röös, 2016). But, in general, from the literature review, many of the existing studies are largely regional, with mixed and inconclusive results largely based on single case study analysis. There is thus a lack of clear policy guidance on whether to continue or discontinue livestock grazing in public forests in many developing countries, necessitating the need for comprehensive, multi-site research for effective, location-specific strategies that balance livestock grazing in public forests with forest conservation goals.

Kenya has 12.13 % of tree cover and 8.83% forest cover (Kenya Forest Service [KFS] Strategic Plan 2023-2027). However, trees and forest resources in the country are increasingly under the pressure of degradation due to the rapidly growing population (GOK, 2016). To avert further degradation and loss, the country launched the National Landscape and Ecosystem Restoration Strategy for 2023-2032, which seeks to increase Kenya's tree cover to 30% by planting 15 billion trees on public, private, and community lands. It is hoped that this action will accelerate actions toward enhancing climate-reliant national economic growth and development goals within the context of many national and international development aspirations. In forest grazing, the existing forest law allows community members registered as Community Forest Associations (CFAs) living adjacent to gazette public forest areas to graze their livestock (cattle and sheep) in the public forests. But, over time, with changes in environmental and socio-economic conditions in the country, there are increasing calls for banning livestock grazing in public forests (The Star Newspaper, 2024). It has led to a raging forest policy debate amongst forestry stakeholders on whether to endorse a government policy direction that bans the grazing of livestock in public forests or not. On the one hand, the proponents of the ban argue that forest grazing reverses the gains of government-led forest ecosystem restoration efforts, increasing carbon emissions and jeopardizing the achievement of key forestry development agendas such as the presidential directive on achieving 30% tree cover by the year 2032. On the other hand, the opponents argue that besides the ecological benefits of forest grazing, such as reducing the risk of forest fires, livestock grazing in the forest was important for the socio-economic empowerment of many forest-adjacent communities. The opponents argue that instead of banning grazing, it can be transformed to become compatible with forest management in a manner that achieves the broader government environmental conservation goals and community empowerment role if the current management practices are enhanced. To contribute to the emerging discourse on whether to allow or disallow livestock grazing in gazetted public forests, unlike other studies, this paper used the case study research design to investigate two cases of forest grazing in Kenya to contribute to the current debate and provide policy recommendations on sustainability. This study used literature review and document content analysis to explore the current grazing system and identify the impacts of forest grazing on two key forest ecosystems from the theoretical background of sustainable management of forest ecosystem services. Key empirical literature and specific grazing cases in Mau forest complex and Aberdares were examined to elucidate how grazing influences public forests. Mau and Aberdares forest ecosystems were chosen for this study because they have experienced significant degradation due to illegal grazing. These forests are critical water catchment areas, and their degradation has far-reaching consequences for water availability and quality in the East African region and beyond. Moreover, few studies have been conducted on the effect of livestock grazing in water towers where Mau and Aberdares belong (Kenya Forestry Research Institute, 2023).

1.1. The impacts of livestock grazing in forest ecosystems

1.1.1. Theoretical background

The theoretical framework for understanding the impact of livestock grazing on forest ecosystems encompasses several ecological principles embodied in the concept of sustainable forest management. Grazing affects ecosystems primarily through herbivory, trampling, nutrient deposition, and the alteration of plant community composition (Sharma et al. 2024). Herbivory directly reduces plant biomass, which can lead to shifts in plant species dominance and a reduction in plant diversity (Sharma et al. 2024). Trampling by livestock and wild herbivores compacts the soil, reducing its porosity and water infiltration capacity, which can lead to increased runoff and soil erosion. Nutrient deposition through animal excreta can enrich the soil locally but may also contribute to the eutrophication of nearby water bodies if not properly managed (Crovo et al., 2021). Grazing intensity and frequency are critical determinants of its ecological impact. Light to moderate grazing can promote plant diversity by preventing any species from becoming overly dominant, a concept known as the intermediate disturbance hypothesis. However, heavy grazing often leads to vegetation degradation, soil erosion, and reduced ecosystem services, including carbon sequestration and water regulation (Crovo et al., 2021; Ren et al., 2024).

There are various sustainable forest management models in the context of forest livestock grazing. These models can balance ecological health, economic viability, and social acceptance. Forests on farmlands agroforestry systems can be adapted to integrate trees, forage, and livestock, promoting biodiversity and reducing soil erosion while providing economic benefits (Timsina, 2024). Silvopastoral systems can combine forestry and grazing, enhancing soil fertility and habitat diversity. Moreover, rotational grazing prevents overgrazing and supports ecosystem resilience. Riparian buffer zones protect water quality and aquatic habitats by restricting grazing. Community-based forest management can also be adapted to engage local communities, aligning grazing with conservation goals (Timsina, 2024). Lastly, conservation grazing, which uses livestock to manage and conserve habitats, requiring careful planning and monitoring, can also be adopted to promote sustainability. These models emphasize an integrated approach to achieve effective forest management with livestock. Together, these models leverage ecological balance, economic viability, and social acceptance, thereby supporting sustainable forest management (Timsina, 2024). Therefore, expanding on how forest policy on grazing can be improved to address specific challenges such as forest health, socio-economic empowerment, and enhancing environmental management would be valuable. For instance, forest grazing can be streamlined to highlight the practical benefits of sustainable forest management in Mau and Aberdares forest ecosystems.

1.1.2. Empirical literature review

Empirical studies have shown that grazing impacts vary widely depending on the ecosystem and management practices. This section highlights studies on the varying impacts of grazing across the world. These studies are critical in shaping the policy recommendations that will be generated from lessons learned. Existing literature on the impacts of forest grazing shows diverse results for both developed and developing countries, with some supporting forest grazing on account of positive symbiotic relationships. At the same time, some oppose it based on the negative impacts on forest ecosystems. For example, Etchebarne & Brazeiro (2016) examined that in Uruguay, livestock intervention, based on grazing regimes and species sensitivity, altered forest ecosystems' structure, composition, and dynamics, negatively impacting plant communities, soil, and water quality. This study investigated livestock exclusion effects on forest dynamics in Uruguay, focusing on tree regeneration and soil properties. Six paired grazed-ungrazed sites (4-17 years exclusion) were analyzed. Exclusion improved soil conditions by increasing leaf litter cover and reducing erosion, and tree regeneration increased, with a 20% rise in seedlings and 60% in saplings. Species composition was largely unaffected, but *Styrax leprosus* Hook. & Arn was nearly absent in grazed sites. The findings indicated livestock exclusion benefits the soil and shade-tolerant species' regeneration.

In Argentina, Trigo et al. (2020) evaluated the effects of 7-8 years of livestock exclusion on the understory plant community in Argentina's dry Chaco forest. Understory plant life forms were categorized as shrubs, succulents, and herbs. The study compared five excluded plots with five grazed plots. Livestock exclusion increased grass species richness, grass cover, and lower understory biomass while decreasing bare soil. Dominant herbs in excluded plots included *Setaria nicorae* José Francisco Pensiero. Grazed plots had *Stenandrium dulce* Nees as the dominant species. Exclusion did not significantly affect shrubs, succulents, horizontal vegetation structure, or soil hardness. The grass assemblage showed quick recovery when grazing ceased, indicating exclusion's effectiveness in recovering grass cover and promoting certain grass species. Loydi (2019) established that grazing increased bare ground, reduced plant cover, and decreased grass species richness in the seed bank while increasing shrub richness and density. Vegetation and seed bank compositions were not directly related. Shrubs and non-palatable or annual grasses, 2-year enclosures by forbs, and 12-year enclosures by perennial grasses dominated grazed areas. Herbivore removal altered vegetation and seed bank composition, suggesting controlled grazing might help maintain species and life form diversity.

In Mexico, Encina-Domínguez et al. (2022) observed that pine forest disturbances from cattle, horse, goat, and sheep grazing, especially in communal lands, led to low tree recruitment, invasive shrub establishment, species composition changes, and weed invasions. The study in Sierra de Zapalinamé, a protected mountain range, compared a 25-year grazing-excluded forest (1,200 ha) with a nearby grazed area. Analysis of forest structure, tree species richness, total understory species richness, and understory composition showed grazing altered understory species composition and reduced evenness in control plots. The study concluded that restricting extensive grazing or reducing animal numbers in ecologically valuable areas is necessary to maintain species diversity and forest structure.

Gomez et al. (2024) evaluated livestock effects on riparian forests, soil, and water in Nothofagus Silvopastoral systems across three river basins with varying stocking rates. Over three years, soil and water's physical, chemical, and bacteriological properties were assessed. The basin without livestock had the best water and riparian forest quality. Higher stocking rates caused forest degradation, reduced canopy cover, and increased water contamination from sediment, nitrogen, phosphorus, and bacteria. Water quality declined particularly during hot, dry years. Streams showed self-purification over distances greater than 1,000 m without livestock, eliminating beneficial bacteria. High stocking rates also led to increased water turbidity. To balance Silvopastoral production and ecosystem services, the study recommended excluding livestock from riparian zones, controlling stocking rates, and implementing a monitoring program to prevent ecosystem dysfunction.

In another study, Kimuyu et al. (2014) investigated understory vegetation response to 5-year spring and fall prescribed fires and cattle grazing exclusion in *Pinus ponderosa* Douglas ex Lawson stands, reporting long-term effects nearly two decades post-fire. In fall burn areas open to grazing, understory cover was 12% lower than in areas where cattle were excluded. Fire and grazing appeared to interact numerically rather than functionally, with post-fire green-up concentrating herbivores in burned areas, limiting understory response. Fall fires and grazing increased annual forbs and resprouting shrubs, while spring burns had minor effects. *C*heatgrass invasion was linked to fall burns but not grazing. The study suggested that frequent fall fires and grazing might reduce understory resilience in dry pine forests, recommending longer fire intervals, post-fire resting, virtual fencing, or burning entire pastures to mitigate these effects.

In Spain, Isabel et al. (2024) used a multiparametric soil quality index (SQI) to gauge livestock impacts on soil in the Mediterranean forest. Control areas without livestock included forest stands of varying ages, compared with areas subjected to various grazing intensities. The SQI effectively detected changes in forest ecosystems based on stocking rates. The SQI was recalibrated to create the Soil Status Index by Livestock (SSIL) for greater precision. The correlation between the indices' quality ranges suggested SSIL is a reliable indicator of livestock impact on Mediterranean forest soils.

Similarly, Candel-Pérez et al. (2024) investigated grazing's impact on soil physicochemical and biological properties and vegetation richness in Spain. Grazing significantly reduced soil water content by 53% and available water by 59%, though hydraulic conductivity remained unaffected, and soil water repellency disappeared. Grazed soils had a slight pH increase (+18%). Dehydrogenase activity increased (+100%), while basal respiration decreased (-24%). Plant species richness dropped by 34%, indicating biodiversity loss. These significant changes suggest grazing modifies overall soil quality, with certain variables serving as indicators for effective land management to mitigate degradation in Mediterranean forests.

In South America, Sandoval-Calderon et al. (2024) conducted a meta-analysis of experiments excluding livestock grazing to assess its impact on plant diversity and productivity in South American mountainous grasslands. The findings showed that herbivore exclusion increased aboveground biomass but decreased species richness and Shannon diversity. These effects intensified over longer exclusion periods and were resilient to various climatic conditions. Unlike temperate grasslands, the reduction in species richness was not linked to increased biomass, indicating different governing processes. Further research was needed to understand the factors influencing plant diversity and productivity in these ecosystems and the ecological implications of herbivore exclusion. The study noted that overgrazing was generally associated with negative ecosystem outcomes. Teague et al. (2020) demonstrated that continuous grazing led to a decline in soil health and increased erosion, while rotational grazing practices could mitigate some of these effects by allowing recovery periods for vegetation.

In the African context, a study conducted in South Africa noted a significant difference between a conventionally grazed site and one overgrazed. The conventional site had a larger CO_2 than the overgrazed site over two years. When sheep were reintroduced to the previously overgrazed site, the net emission effect difference decreased, but the overgrazed site remained resilient. These findings suggested that plant species composition and rainfall distribution were crucial factors affecting CO_2 sequestration and ecosystem status. A west African forest study that analyzed multi-annual eddy covariance data for a grazed Sahelian semi-arid savanna in Senegal established that high CO_2 fluxes were attributed to dense C4 vegetation, high soil nutrient availability, and grazing pressure. Despite high peak net CO_2 uptake, the annual budget was comparable to other semi-arid savannas due to the short rainy season. Soil data indicated a substantial increase in soil organic carbon. These findings significantly impacted the perception of the Sahelian carbon sink/source and its response to climate change (Yayneshet & Treydte, 2015).

From the above review, the studies highlight the complex interplay between livestock grazing and forest ecosystems. However, findings collectively underscore the importance of adaptive management strategies that consider ecological, economic, and social factors to sustainably manage forest livestock grazing, given the negative and positive impacts.

1.1.3. Forest grazing and sustainable forest management in Kenya

Kenya is endowed with diverse natural capital, rich cultural heritage, and immense potential for sustainable development. The country ranks among the world's richest biodiversity nations and hosts over 35,000 species, including more than 7,000 plant species and many endemic, rare, endangered, and threatened species. These resources provide critical ecological goods and services that support the country's socio-economic development. The country depends on these ecosystem services as natural capital for economic growth. Forest ecosystems, for example, are a livelihood base of over 82% of Kenya's households and offer direct employment to over 4 million Kenyans, besides contributing about USD 365 million (3.6%) to the Gross Domestic Product (GDP).

Moreover, forest ecosystems contribute more than USD 140 million worth of goods annually to other productive sectors of the economy, such as agriculture, fisheries, livestock, energy, wildlife, water, tourism, trade, and industry. In the same vein, the Water Towers Ecosystem of Kenya, which includes Mount Kenya, Aberdares, Mau Forest, Mount Elgon, and Cherangany Hills, among others, provides necessary recharge for rivers draining into several water basins and providing water for domestic use, agriculture, wildlife, and the manufacturing industry. These ecosystems interlink well with the agroecosystem, the largest contributor to Kenya's GDP at 33% directly and 27% indirectly through agro-based industries and service sector (GOK, 2016). Specifically, the agriculture sector in the agroecosystem employs more than 40% of the total population and about 70% of the rural population (GOK, 2018b). Small-holder farmers largely dominate this proportion, accounting for over 75% of the total agricultural output and over 70% of the marketed agricultural produce.

Several policy and legal reforms have been rolled out in the country to promote the sustainable management of these forests. Key among these reforms was the enactment of the Forest Conservation and Management Act 2016, which initiated a paradigm shift in forest management from the initial "command and control approach" to a "community involvement approach." In this new legal dispensation, forest-adjacent communities participate in forest management through legal frameworks that empower local communities and enhance their roles in forest governance. The Act recognizes Community Forest Associations (CFAs), which allow community members to actively engage in the sustainable management, conservation, and utilization of forest resources. These associations can enter into management agreements with the Kenya Forest Service (KFS), enabling them to participate in decision-making processes, benefit-sharing, and conservation activities. The Act also encourages the development of community-based forest management plans and supports capacity-building initiatives to enhance local knowledge and skills in forest conservation. By involving communities directly, the Act aims to foster a sense of ownership and responsibility among local populations, ensuring that forest management practices are ecologically sustainable and socially equitable. This participatory approach not only helps preserve forest ecosystems but also improves the livelihoods of the communities through access to forest resources and involvement in conservation-related economic activities. The Act allows controlled grazing within forest reserves under specific conditions outlined in management agreements between Community Forest Associations (CFAs) and the Kenya Forest Service (KFS). These agreements stipulate the carrying capacity of grazing areas, the timing and duration of grazing periods, and the communities' responsibilities. By setting these guidelines, the Act aims to prevent overgrazing and land degradation while supporting the livelihoods of pastoral communities that depend on forest resources. Additionally, the Act encourages the integration of sustainable agroforestry practices, which combine grazing with tree planting and forest regeneration efforts.

However, Kenya's natural capital, including public forests, is rapidly depleted due to various factors that have led to degradation and loss of biodiversity. They include a growing human population, poverty, inequality in access to resources and lack of regulatory capacity, changes in production and consumption patterns, human population and settlement, and environmental deterioration. These challenges threaten the livelihoods of millions of Kenyans, especially the rural poor who depend on natural resources for survival. Kenya's forest ecosystems are particularly vulnerable to grazing pressures due to high livestock densities and reliance on pastoralism. Recent studies show an emerging trend of negative impacts of livestock grazing in forest ecosystems. Grazing in Kenyan forests has been linked to forest density and carbon storage reductions. Overgrazing by livestock reduces tree recruitment and decreases tree density, affecting the carbon sequestration capacities of these forests (Cierjacks and Hensen, 2004). This impact is critical given the role of forests in mitigating climate change through carbon storage.

Moreover, studies have documented that grazing leads to soil compaction, reducing water infiltration and increasing runoff. This effect is particularly pronounced in forested areas where the soil structure is crucial for maintaining hydrological cycles (Webber et al., 2010). The loss of soil structure due to grazing has been linked to reduced plant water availability and increased soil erosion, exacerbating land degradation. However, other studies on grazing impacts on biodiversity are mixed, with impacts depending on grazing intensity. The studies show that while moderate grazing can maintain or even increase plant species diversity, heavy grazing typically reduces biodiversity. In Kenyan forests, heavy grazing has been associated with a decline in understory plant species and an increase in invasive species, which can outcompete native flora and alter ecosystem functions (Archer et al., 2017).

To avert further crisis, the Kenya Government recognizes that the sustainable management and conservation of natural capital and biodiversity is essential for maximizing the production of natural resources and sustaining growth. To this end, Kenya drew up the 10-year ambitious and visionary strategy to restore 10.6 million hectares of degraded landscapes and ecosystems. The strategy aims to increase the tree cover of the country from the current 12.13 percent to 30 percent by 2032 while restoring degraded landscapes and ecosystems. The strategy was formulated based on the principles of the Theory of Change, which calls for accelerated approaches to address the key drivers of degradation in each of the seven ecosystems to prevent, halt, and reverse landscape and ecosystem degradation. Some of the activities to achieve this goal include growing 15 billion trees, promoting sustainable agricultural practices, soil and water conservation, sustainable livelihood options, proper land use planning, and waste disposal. Implementation of this strategy is based on the principle of the "whole of government, whole of society approach," which calls for the participation and contribution of all Kenyans. It leverages technology and innovations such as the Jaza Miti App, which enables the tracking and monitoring of the trees planted across the country.

From this review, the authors opine that a complex interplay between livestock grazing and forest ecosystems in Kenya has significant ecological and socio-economic impacts. Key ecological impacts include overgrazing, diminished carbon storage and soil degradation, decreased tree recruitment, and soil compaction. Hence, there is a need for case studies to formulate robust strategies for managing the impacts.

2. Materials and Methods

2.1. Research design

A case study research design was used to investigate the effects of forest grazing on Kenyan forests. A case study approach was ideal in this study because it provides an in-depth, contextualized understanding of complex ecological and socio-economic dynamics. This research design allowed for a detailed examination of specific forest areas where grazing practices vary, facilitating a detailed analysis of their impact on biodiversity, soil health, tree regeneration, and local communities' livelihoods. The study compared different management practices and their outcomes by focusing on multiple sites, thereby identifying best practices and key challenges. The case study approach also supported the inclusion of qualitative data from local stakeholders, offering insights into community perceptions and traditional knowledge, which were crucial for developing sustainable forest management strategies. This method's flexibility in integrating various data sources ensured a holistic understanding of the multifaceted effects of livestock grazing, making it a robust and appropriate research design for this context.

2.2. Case studies

2.2.1. Aberdare Forest Reserve

The Aberdare Forest Reserve is one of the five main water towers in the country alongside Mt Elgon, Cherangani Hills, Mau Complex, and Mt Kenya. It has 19 forest stations. It covers Nyandarua, Nyeri, Muranga, and Kiambu counties and has an acreage of 103,024.930 hectares. It is gazetted under Legal Notice 48/1943 (KFS 2018). It comprises various vegetation types such as Natural forests, plantation, bamboo, bush, teazones, and moorland. It has five forest blocks: South Laikipia, Kipipiri, Nyeri, Kikuyu Escarpment, Aberdare Forest, and Aberdare National Park. The Aberdare ecosystem also designated a Key Biodiversity Area (KBA), is in the central highlands of Kenya and forms part of the eastern escarpment of the Rift Valley. This area features a spectacular landscape where lush forests, expansive grasslands, bamboo thickets, montane moorlands, and misty peaks merge to create a unique sanctuary. It includes 76,600 hectares of National Park and 108,400 hectares of Forest Reserve. As one of Kenya's five primary 'water towers,' this ecosystem serves as a catchment area for dams supplying water to Nairobi, the Athi-Galana-Sabaki River draining into the Indian Ocean, the Ewaso Nyiro River leading to Lorian Swamp, and the Malewa River flowing into Lake Naivasha. The Aberdares KBA is home to diverse wildlife, including the critically endangered Mountain Bongo. More than 300 bird species, such as the rare and globally threatened Aberdare Cisticola, Abbott's Starling, Jackson's Widowbird, and Sharpe's Longclaw, have been recorded here. Endemic species such as the Aberdare shrew, Aberdare mole rat, and the Aberdare frog underscore the area's evolutionary significance. This biodiversity hotspot is a living laboratory for scientists, providing valuable insights into ecological processes, species interactions, and the complex web of life-sustaining this remarkable ecosystem.

Despite its exceptional importance, the KBA faces numerous threats, including illegal logging, unauthorized grazing, wildlife poaching, illegal water extraction, destruction of riparian zones, forest encroachments, and climate change. There is also a looming threat from infrastructure development. In January 2024, the National Environment Management Authority (NEMA) approved the construction of a 49-kilometer road cutting through the forest to connect Nyandarua and Nyeri counties. An Environmental Impact Assessment (EIA) report indicated that 104 hectares of vegetation, including 75 hectares of bamboo, 14 hectares of forest, and 14 hectares of moorland, would be cleared for this project. Therefore, protecting this vital site requires robust collaboration among government agencies, conservation organizations, local communities, and other stakeholders. The conservation community and other stakeholders have undertaken numerous restoration initiatives due to the site's significance and uniqueness. Currently, the Conservation Alliance of Kenya, which includes 73 member organizations such as Nature Kenya, has appealed to the National Environment Tribunal to halt the road construction. The Alliance has emphasized the road's negative impact on the KBA and proposed an alternative route that would minimize effects on biodiversity while being equally effective for travel. The Aberdare Forest is a key water catchment area for several major rivers in Kenya (Kinyanjui, 2011).

2.2.2. Mau Forest Complex

The Mau Forest Complex is situated in Kenya's Rift Valley region, between latitudes 0°91' N - 1°49' S and longitudes 34°9' - 36°6' E, encompassing approximately 24,000 km². The complex borders 13 counties of Kenya, namely Baringo, Bomet, Elgeyo Marakwet, Kericho, Kiambu, Kisumu, Nakuru, Nandi, Narok, Nyamira, Nyandarua, and Uasin Gishu. The predominant land use in this area around the complex is small-holder agriculture (50.7%), followed by rangeland (23.7%) and forest (17.7%). Several rivers traverse the Mau forest complex. Key urban centers around the complex include Nakuru and Kericho. The altitude of the Mau region varies from 1000 to 3200 meters above sea level, with the highest elevations found in the central part of the study area, particularly in the northern part of Narok County and the western regions of Nakuru. Annual temperatures vary significantly by location: the highly elevated regions have low annual temperatures with minimums of 10.6°C. Meanwhile, the northern areas in Elgeyo Marakwet and Baringo experience high annual temperatures with maximums of 24.6°C. The estimated total population in the Mau region is about 4.8 million people, with Nakuru being the most populous county.

The Mau Forest Complex is vital not only for the livelihoods of the local population but also for people in the broader Rift Valley province and western Kenya (KWS, 2009). Agriculture, the predominant land use, is crucial for food security and a significant source of income, with most agricultural products being exported to other regions within Kenya. Additionally, the study area holds international importance for the tea industry and tourism. The region falls into different climate zones: equatorial tropical rainforest climates with high monthly rainfall and tropical savannah climates with dry seasons. The rainfall pattern in the study area is bimodal, with the long rainy season occurring from March to May and the short rainy season from October to December. Generally, the dry seasons span from January to March and May to September, though this varies by location. Annual rainfall is higher in the western counties (western parts of Kisumu, Kericho, and Bomet). In contrast, the northern and southeastern counties (such as Baringo and Elgeyo Marakwet) tend to be drier.

The Mau Forest Complex, Kenya's largest water tower, is crucial for the provision of critical ecosystem goods and services. However, human activities such as logging, charcoal burning, and settlement have drastically reduced their area from over 273,300 hectares in the 1990s to just over 160,000 hectares by 2018. This deforestation has diminished the forest's ability to act as a carbon sink, exacerbating climate change. Livestock grazing further reduces tree cover, impacting carbon sequestration and water regulation. Previous studies have demonstrated loss of biodiversity, changes in tree composition and richness, invasion by alien plant species, and loss of catchment services (Kinyanjui, 2011; Mullah et al., 2011; Mullah et al., 2014). Restoration efforts have focused on reforestation and controlled grazing, with mixed results due to ongoing pressures from surrounding communities (Chumo, 2016). Figure 1 shows the location of Mau and Aberdares forest ecosystems in Kenya. As the deep green color shows, both ecosystems are in dense natural forest areas.

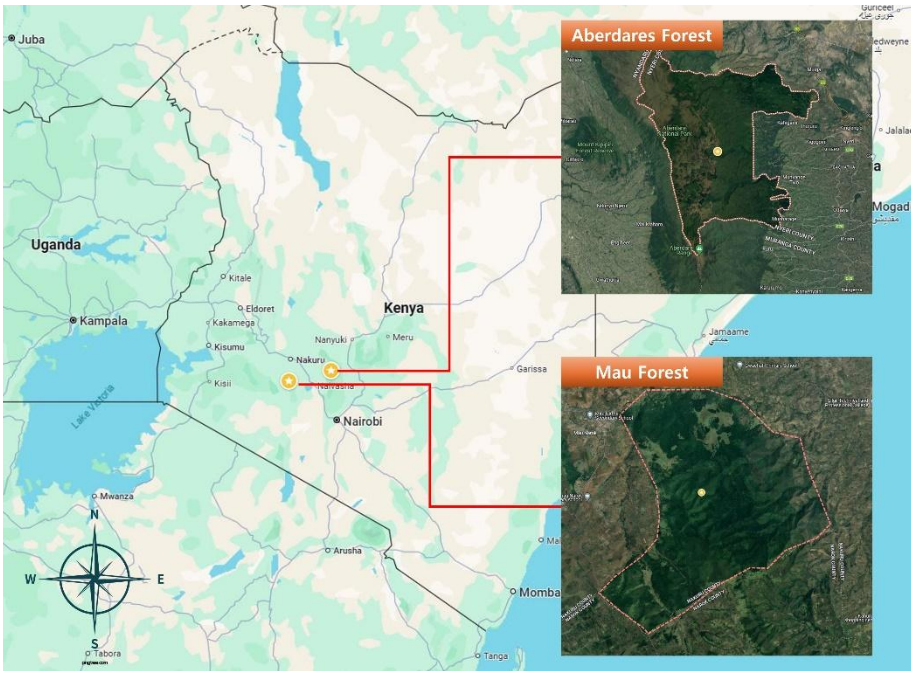

Figure 1. Location of Mau and Aberdares forest ecosystems in Kenya.

2.3. Data collection

A meticulous document content analysis process was employed to study the effects of livestock grazing in public forests. Initially, the document selection process began by defining clear criteria to ensure relevance and comprehensiveness. The criteria focused on documents that discussed environmental impacts, grazing management practices, and ecological assessments within public forest lands. A broad search was conducted across multiple databases, including academic journals, government reports, environmental assessments, and grey literature from conservation organizations. The documents analyzed included peer-reviewed articles, policy papers, environmental impact statements, and technical reports. These documents provided diverse perspectives and comprehensive insights into the effects of livestock grazing. After gathering an extensive list of potential documents, a convenience sampling strategy was used to cover different geographic regions, types of public forests, and varying grazing intensities. Both qualitative and quantitative techniques were employed during content analysis to identify recurring themes, keywords, and patterns across the documents. Initially, documents were coded manually to establish a preliminary framework through notetaking. Key concepts such as soil erosion, vegetation change, wildlife habitat alteration, and water quality were systematically examined. In total, 15 documents were analyzed and sourced from academic databases such as JSTOR and ScienceDirect, government repositories, and organizational archives. The sampling strategy ensured that the documents represented various ecological zones and management practices. The analysis yielded a comprehensive understanding of the varied impacts of livestock grazing, highlighting both detrimental effects and potential mitigation strategies. This structured and detailed approach provided robust evidence to inform public forest policy recommendations and management practices. The Key documents reviewed are shown in Table 1 (see Appendix 1).

2.4. Data analysis

The effects of livestock grazing in Kenya's public forests were explored from the perspective of sustainable forest management, as shown in Figure 2.

The sustainable forest management concept emphasizes the balance between ecological, economic, and social functions of forests, aiming to maintain their biodiversity, productivity, and regeneration capacity. In Kenya, where public forests are critical for local livelihoods and biodiversity conservation, a holistic approach is provided to evaluate grazing impacts. If not managed properly, livestock grazing could lead to soil compaction, erosion, and loss of vegetation cover, undermining the forest's ecological integrity. However, when integrated into a sustainable management plan, grazing is controlled to prevent overuse and promote regeneration. It involves setting grazing limits, rotational grazing systems, and monitoring ecological indicators. Under sustainable forest management, stakeholders can ensure that grazing practices support forest health rather than degrading it.

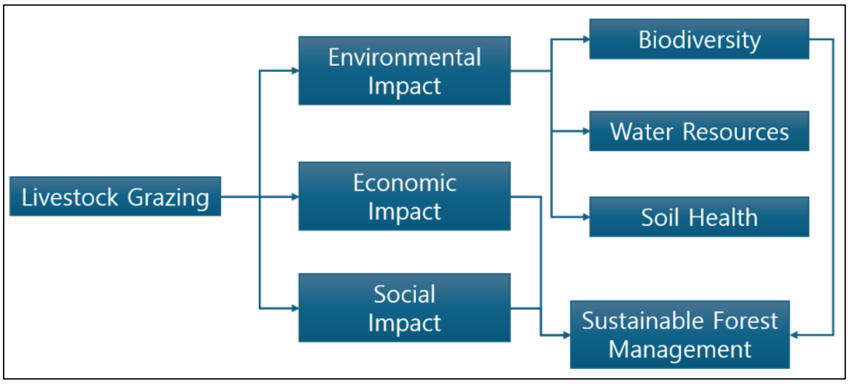

Figure 2. Conceptual framework for the effects of livestock grazing in public forests in Kenya.

Additionally, sustainable forest management promotes the inclusion of local communities in decision-making processes, recognizing their dependence on forest resources and traditional knowledge. This participatory approach enhances the effectiveness of management strategies. It fosters a sense of stewardship among local populations, ensuring the long-term sustainability of public forests amidst the pressures of livestock grazing. The effects of forest grazing were presented in three broad thematic areas: social, economic, and environmental impacts.

3. Results

3.1. The current system of livestock grazing in Mau and Aberdare public forests

The Forest Conservation and Management Act 2016 ensures the participation of duly registered Community Forest Associations (CFAs) in the conservation and management of public forests, as per Section 48(2). This participation aligns with the Constitution of Kenya's 2010 national values and principles of governance.

Furthermore, Section 49(1)(b) mandates that CFAs involved in forest management or conservation must develop and implement sustainable forest programs that respect the traditional user rights of their communities. Among these rights, outlined in Section 49(2)(d), are grass harvesting and grazing. Under Section 49(3)(b), the Chief Conservator of Forests has established rules for grazing to ensure proper implementation of this user right. These rules include forest zonation and mapping to identify suitable grazing areas and prohibit grazing in young plantations, rehabilitation zones, and ecologically sensitive areas. Each forest station must maintain a grazing register, and the land's carrying capacity determines the number of grazing animals. Grazers must obtain monthly permits, and the CFA management committee and the Forest Station Manager supervise grazing. Grazing is restricted to daylight hours, and violations of the guidelines result in penalties, including the loss of grazing rights and potential prosecution in a court of law. The Service may also withdraw grazing rights to protect biodiversity if necessary.

In Mau and Aberdares forest ecosystems, the above community-based forest management model governs grazing activities. The forest estate is zoned into various use levels in both Mau and Aberdares. Typically, these zones include conservation areas, where strict protection measures are enforced to preserve sensitive habitats and rare species, and sustainable use zones, where controlled human activities such as selective logging, non-timber forest products collection, and ecotourism are permitted. Buffer zones are also designated to mitigate conflicts between conservation and human activities. Delineating these zones involves extensive consultation with local communities, indigenous groups, conservationists, and policymakers to ensure the management plan reflects diverse interests and perspectives.

In the Mau Forest Complex of Kenya, the existing livestock grazing system is deeply intertwined with local livelihoods and resource management practices. Communities residing in and around the complex heavily rely on forest grazing for their economic sustenance, with a significant portion of households depending on it for their livestock, including cattle, sheep, goats, and donkeys. In the Aberdare Forest Complex of Kenya, the existing livestock grazing system plays a vital role in local livelihoods and socio-economic dynamics. Adjacent communities heavily rely on forest grazing as a livelihood diversification, with a significant portion of households depending on it for their cattle and sheep. Livestock keeping is an important economic activity, contributing substantially to household incomes, particularly in poorer households.

3.2. Impacts of livestock grazing in Mau and Aberdares forest ecosystems

The impacts of livestock grazing on the Aberdare Forest Ecosystem and the Mau Forest Complex exhibit similarities and differences across social, economic, and environmental dimensions. For social impact, both ecosystems see communities relying significantly on forest grazing for livelihood diversification, fostering socio-economic stability. However, while grazing activities in the Aberdares promote community cohesion, those in the Mau Complex emphasize shared resource management. Economically, livestock grazing contributes substantially to both ecosystems, with studies estimating its economic value and significant role in household income, particularly in poorer households. Nonetheless, environmental repercussions vary; overgrazing risks forest regeneration and biodiversity in both ecosystems, but its specific effects on soil carbon stocks and riparian plant diversity differ.

3.3. Strategies for enhancing sustainability in Mau and Aberdares ecosystems

Various strategies have been identified for managing the impacts of livestock grazing in forests based on the provided sources (Table 1). These strategies encompass a range of approaches to promote sustainable practices and mitigate negative effects on forest ecosystems. The National Landscape and Ecosystem Restoration Strategy 2023-2032, advocates for promoting sustainable agricultural practices and livelihood options to restore degraded landscapes and ecosystems. Similarly, the Forest Conservation and Management Act 2016 regulates grazing activities within forest areas, emphasizing the need for permits and conducting grazing that does not harm the forest ecosystem. The Forest Policy 2023 encourages adopting controlled grazing practices aligned with forest management plans to safeguard biodiversity and regeneration.

Additionally, the Aberdare Ecosystem Management Plan, 2010-2020, establishes multiple-use zones to balance ecological sustainability with socio-economic needs, permitting grazing only in designated areas. Strengthening livestock extension services, as recommended by the Report of the Prime Minister's Task Force on the Conservation of the Mau Forests Complex, 2009, aims to alleviate pressure on forests and enhance food security. Furthermore, establishing sustainable grazing thresholds (Leley et al. 2022) and education on riparian management practices (Ruto et al. 2023) contribute to forest regeneration and mitigate adverse effects on riparian plant diversity. These multifaceted strategies reflect a comprehensive approach to sustainable forest management in the face of livestock grazing impacts.

4. Discussion

Forests are important for sustainable development as they contribute to ecological stability and socio-economic empowerment (FAO, 2022a; GOK, 2018a; GOK, 2018b). However, deforestation has been severe due to agricultural expansion, livestock grazing, firewood collection, charcoal production, and forest fires (FAO 2018). Such depletion of forest vegetation is particularly severe in the key water towers in Kenya (KWTA 2014). This depletion will consequently have a major impact on other natural resource uses and sectors of the economy, such as agriculture, water resources, energy, and biodiversity conservation. Forests and woodlands, predominantly common-pool or open-access resources in the country, face widespread over-exploitation, leading to significant environmental problems, including soil erosion, soil nutrient depletion, moisture stress, deforestation, and overgrazing (Mullah, 2016). As these resources are overused, the negative effects ripple through various sectors, exacerbating environmental degradation and undermining the sustainability of essential economic activities and ecological functions (Abdalla et al., 2018).

Forest grazing is widely practiced in the water towers of Kenya. It is a crucial element of household income for many forest-adjacent communities, whose livelihoods depend on livestock and forests (Kenya Forest Service [KFS] Strategic Plan 2023-2027). A severe shortage of feed sources is the major constraint to livestock production, leading rural communities to increasingly depend on remnant forest stands. This dependency underscores the importance of sustainable forest management practices to balance the needs of local communities with the preservation of these vital ecosystems. This reliance on forest resources for grazing sustains the socio-economic well-being of communities, contributing significantly to their livelihoods (GOK, 2018b). Policies such as the Forest Conservation and Management Act 2016 further promote community involvement in forest management through mechanisms like Community Forest Associations (CFAs), empowering locals to engage in decision-making, benefit-sharing, and conservation activities related to forest resources (GOK, 2018a). Economically, forest ecosystems, including those utilized for livestock grazing, significantly contribute to Kenya's GDP, providing direct employment to over 4 million people and contributing about USD 365 million annually (GOK, 2018a). Livestock grazing in public forests supports the livelihoods of millions, particularly small-holder farmers, with forest income, including revenue from grazing, significantly bolstering household incomes, especially in rural areas where agriculture is predominant (GOK, 2018b). However, these practices also have environmental repercussions, including degradation and biodiversity loss. Studies indicate reductions in forest density, diminished carbon storage, and soil degradation due to grazing activities (Cierjacks & Hensen, 2004; Webber et al., 2010). Soil compaction and erosion, attributed to grazing, exacerbate land degradation, reduce plant water availability, and pose significant environmental challenges, particularly in forested areas. Balancing socio-economic benefits with environmental conservation is imperative for sustainable forest management in Kenya. Effective management can help ensure that forest resources continue to support the region's ecological health and the economic well-being of its inhabitants. However, it is important to conduct case studies on the location-specific impacts of livestock grazing in key water towers in the country to improve the sustainability of forest grazing management initiatives, hence the successive discussion in this study.

4.1. Impacts of livestock grazing in Mau and Aberdares forest ecosystems

When the conceptual framework (Figure 2) was applied in the case of Mau and Aberdares forest ecosystems, results showed that both Mau and Aberdares have a similar livestock grazing management system, which is community-based. The Forest Conservation and Management Act 2016 involves Community Forest Associations (CFAs) in public forest management, aligning with Kenya's 2010 Constitution. Section 49(1)(b) mandates CFAs to implement sustainable forest programs that respect traditional user rights, including grass harvesting and grazing. The Chief Conservator of Forests has established rules for grazing, such as forest zonation and mapping, prohibiting grazing in young plantations, and maintaining grazing registers. Grazing is allowed only during daylight hours, with penalties for guideline violations. Grazers must obtain monthly permits, and the Forest Station Manager supervises grazing activities. Grazing rights may be withdrawn to protect biodiversity.

The current grazing system has impacted Mau and Aberdares forest ecosystems. Results from Table 2 (see Appendix 2) indicate that livestock grazing impacts the Aberdare Forest Ecosystem and the Mau Forest Complex similarly and differently across social, economic, and environmental dimensions. Socially, both ecosystems rely on forest grazing for livelihood diversification and socio-economic stability, with the Aberdares promoting community cohesion and the Mau Complex emphasizing shared resource management. Economically, grazing is vital, especially for poorer households. Environmentally, overgrazing threatens forest regeneration and biodiversity in both areas, but its specific effects on soil carbon stocks and riparian plant diversity differ. Overgrazing in forest ecosystems, exacerbated by livestock grazing, poses several risks to forest biodiversity, productivity, and regeneration capacity. Overgrazing leads to soil degradation, compaction, and erosion, reducing the forest land's ability to retain water and support plant growth. This degradation disrupts the natural regeneration processes of forests, resulting in the loss of native vegetation and a decline in forest cover. The reduction in plant diversity adversely affects the habitat of various wildlife species, leading to decreased biodiversity. Overgrazing also exacerbates the spread of invasive species, which can outcompete native plants and further alter the ecosystem balance. The loss of vegetation and soil stability increases the vulnerability of forests to natural disasters such as floods and landslides. Overgrazing can also contribute to increased carbon emissions, as degraded forests lose their capacity to act as carbon sinks, exacerbating climate change. The negative environmental impacts of forest grazing in the two ecosystems are consistent with findings from other global reviews such as Sharma et al. (2024), Crovo et al. (2021), and Timsina (2024). Negatively altered forest structure, composition and dynamics due to forest grazing has been reported in many countries across the globe (Etchebarne & Brazeiro, 2016; Trigo et al., 2020; Loydi, 2019; Encina-Domínguez et al., 2022; Gomez et al., 2024; Kimuyu et al., 2014; Candel-Pérez et al., 2024; Yayneshet & Treydte, 2015).

To achieve sustainability, the two ecosystems have deployed several strategies. The Aberdare Ecosystem Management Plan (2010-2020) designates multiple-use zones to balance ecological sustainability with socio-economic needs, allowing grazing only in specified areas. As recommended by the Prime Minister's Task Force on the Conservation of the Mau Forests Complex (2009), strengthening livestock extension services aims to reduce forest pressure and improve food security. Additionally, establishing sustainable grazing thresholds (Leley et al., 2022) and educating on riparian management practices (Ruto et al. 2023) contribute to forest regeneration and protect riparian plant diversity. These strategies reflect a multifaceted approach to sustainable forest management amidst the challenges of livestock grazing. Authors opine that even though these strategies appear adequate in addressing the challenges of livestock grazing and promoting sustainable forest management, there is a need to review some of the strategies based on the fact that some are developed based on expired management plans such as the Aberdare Ecosystem Management Plan (2010-2020).

Moreover, there are limited studies on monitoring livestock grazing indicators in the two forest ecosystems. One of the salient features of Figure 2 is the requirement for a robust monitoring system that governs setting grazing limits, rotational grazing systems, and monitoring ecological indicators. However, in both forest ecosystems, there is a weak monitoring system for the effects of livestock grazing. A robust monitoring system for livestock grazing requires specific indicators to ensure sustainable practices and minimal environmental impact. Key indicators include vegetation cover and composition, such as baseline vegetation assessments to measure plant species types and abundance before, during, and after grazing, and vegetation recovery rates to track post-grazing recovery. Soil health indicators involve monitoring soil erosion, such as rills and gullies that indicate overgrazing, and assessing soil compaction levels, which affect water infiltration and tree root growth. Animal health and productivity indicators include regularly checking livestock weight and health to ensure grazing benefits and tracking reproductive rates as an indicator of sufficient nutrition. Carrying capacity indicators involve comparing stocking rates to the land's carrying capacity to prevent overgrazing and measuring grazing intensity. Biodiversity indicators include monitoring species richness to ensure grazing does not negatively impact ecosystem diversity and tracking specific indicator species sensitive to grazing pressure as early warning signs of ecosystem stress. Water resources indicators involve testing water quality for contamination and ensuring water availability is not depleted by grazing activities. Ecological health indicators include monitoring invasive species' presence and assessing habitat conditions. Compliance and management indicators involve ensuring all grazers adhere to permit terms and using GPS tracking and field observations to monitor grazing patterns and ensure they align with designated areas. Socio-economic indicators include assessing the socio-economic benefits to local communities from grazing activities and tracking any conflicts between grazers and other forest users or conservation goals. These indicators collectively help manage livestock grazing sustainably, maintain ecosystem health, and ensure that the rights and needs of local communities are respected. Reviewed literature agrees with these interventions and has called for prioritizing adaptive management of forest grazing based on regular monitoring and adaptive management based on these indicators are crucial for achieving long-term sustainability (Cierjacks and Hensen, 2004; Table 1; Encina-Domínguez et al., 2022; Gomez et al., 2024; Kimuyu et al., 2014; Candel-Pérez et al., 2024; Yayneshet & Treydte, 2015).

4.2. Ban or not to ban livestock grazing in Mau and Aberdares forest ecosystems?

Deciding whether to ban livestock grazing in public forests requires a comprehensive assessment of various facts. From the reviewed literature, scientific research plays a crucial role, providing insights into the ecological impacts of grazing on forest ecosystems, including biodiversity loss, soil erosion, and carbon sequestration. Additionally, ongoing monitoring and data collection efforts help track changes in vegetation, soil quality, and wildlife populations over time, offering empirical evidence of grazing impacts. Stakeholder input from local communities, environmental groups, and government agencies provides valuable perspectives on social, economic, and cultural considerations. Legal and policy frameworks guide decision-making by outlining permissible activities and regulatory measures, while economic analyses assess the costs and benefits associated with grazing. Social impact studies delve into the livelihoods and socio-economic dynamics of affected communities, while risk assessments evaluate potential environmental, social, and economic risks. By integrating these diverse sources of evidence, policymakers can make well-informed decisions that balance conservation goals with the needs of stakeholders and the broader ecosystem. In the absence of accurate scientific data on the above decision-making criteria on whether to ban livestock grazing in forests, the authors recommend applying the precautionary principle to safeguard the ecosystem integrity of the forest ecosystems. The precautionary principle is a strategy for approaching environmental management that emphasizes caution, prevention, and risk avoidance in the face of uncertainty. It advocates taking proactive action to prevent environmental harm even when scientific evidence about potential risks is inconclusive.

In the context of livestock grazing in the Mau and Aberdares forests, this principle can be applied through measures such as controlled grazing, establishing sustainable grazing thresholds, and creating multiple-use zones. These strategies aim to prevent overgrazing, protect biodiversity, and ensure ecosystem resilience, minimizing potential long-term damage to these forest ecosystems. However, having evaluated the current community-based grazing system and the grazing impacts against the yardstick for banning grazing or not, this study recommends banning livestock grazing in Mau and Aberdares forest ecosystems. Banning livestock grazing in Mau and Aberdares forest ecosystems will provide an opportunity for the natural regeneration of vegetation, enhancing forest cover and biodiversity. This regeneration will improve soil health and stability, reduce erosion, and increase forest land's water retention capacity. Removing livestock will support native wildlife, creating healthier ecosystems.

Additionally, increased forest cover enhances carbon sequestration, mitigating climate change. Whereas there is debate about forest-adjacent communities losing out on grazing livelihood, this study submits that this will not be entirely the case. The Forest Conservation and Management Act 2016 still allows communities to cut and carry forest grass as fodder for livestock from the two forest ecosystems. The cut-and-carry system of grass in public forests offers several benefits. This method involves harvesting grass from designated areas and transporting it to feed livestock elsewhere, reducing the direct impact of grazing on forest ecosystems. It prevents overgrazing, allowing natural vegetation to regenerate and maintain biodiversity. Soil health and stability are preserved, minimizing erosion and improving water retention. The system also helps control invasive species, as livestock are not directly grazing on forest flora. Additionally, it supports sustainable livestock management by providing a reliable feed source, promoting the balance between agricultural needs and environmental conservation.

5. Conclusion and policy implications

Forests are important for environmental stability and the socio-economic empowerment of millions of people worldwide. However, with the growing population and the impacts of climate change, human activities such as livestock grazing in public forests are increasingly exacerbating forest degradation. Results from Mau and Aberdares forest ecosystems have demonstrated that livestock grazing impacts the two ecosystems similarly and differently across social, economic, and environmental dimensions. Forest grazing in the Aberdares and Mau Complex provides socio-economic benefits by diversifying livelihoods and fostering community cohesion and shared resource management. Economically, grazing is essential for poorer households. However, overgrazing poses significant environmental risks, including threats to forest regeneration, biodiversity, and soil health. It leads to soil degradation, compaction, erosion, and a decline in forest cover, negatively impacting wildlife habitats.

Overgrazing also promotes invasive species spread, further disrupting ecosystems. This degradation increases the vulnerability of forests to natural disasters and reduces their capacity to sequester carbon, exacerbating climate change. Even though various strategies have been deployed to enhance forest grazing based on the negative environmental impacts, a weak monitoring system for an indicator of forest grazing, weak enforcement of grazing regulations, and the precautionary principle, this study has recommended banning livestock grazing in Mau and Aberdares forest ecosystems. While moderate grazing can be compatible with forest conservation in the two ecosystems, overgrazing degrades soil, vegetation, and ecosystem services. However, to maintain the livelihood and the positive socio-economic impacts of grazing, this study encourages the need to promote the "cut and carry" system where grass is harvested sustainably by forest adjacent communities and used for feeding livestock outside public forest ecosystems. During the ban period, efforts should be concerted to strengthen policies and enforcement mechanisms to control illegal grazing and deforestation, involving enhanced capacity and funding for forest management agencies. However, future research and monitoring are essential to understand long-term grazing impacts and develop evidence-based management strategies. Studies on livestock grazing in the Mau and Aberdares should focus on the long-term ecological impacts, including soil health, carbon sequestration, and biodiversity. Research should also explore effective management practices, community engagement strategies, and the socio-economic implications of grazing restrictions to inform sustainable land-use policies. The study on livestock grazing in the Mau and Aberdares is limited by short-term data, which may not capture long-term ecological changes. Additionally, variability in grazing practices and socio-economic factors across different communities complicates the generalization of findings.

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Original Paper

Projections towards 2050: severe impact of conversion to dragon fruit crops (*Hylocereus spp*. and *Selenicereus spp*.) in the xeric forest

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Keywords: land use change; deforestation; Dinamica EGO, *Hylocereus sp*., *Selenicereus sp*.

Abstract. *Global shifts in land usage have many impacts on ecosystem services and biodiversity. This investigation assessed the transition from 2016* *to 2021 from xeric forest to Dragon fruit (*Hylocereus spp. *and* Selenicereus spp.*) agriculture. To determine the rates of land use change and deforestation, an approach comprising multitemporal analysis, supervised classification of Landsat and Sentinel satellite images, and a transition matrix was used. Furthermore, land use changes up to 2050 were modelled and predicted using Dinamica EGO software. The study noted detrimental effects of dragon fruit cultivation and suggested quick recovery and preservation actions to lessen the startling reduction in forest cover.*

1. Introduction

A wide range of causes, including social, economic, demographic, and environmental ones, are responsible for the global shift of land usage. According to Sahagún & Reyes (2018), this shift has detrimental effects on ecosystem services and biodiversity, including soil degradation, erosion, infertility, and deforestation.

One of the primary effects of changing land use is deforestation, which is bad for the quality of the soil, water, and air (Food and Agriculture Organization [FAO], 2018). Worldwide, 420 million ha of native forests were lost between 1990 and 2020, resulting in a decrease in the percentage of forest cover from 30.8% to 32.5% (FAO, 2020). With an annual deforestation rate of over 2.6 million ha, South America, especially emerging nations, is the second area behind Africa with the largest rate of soil loss (Bruera & Ignacio, 2021).

With a rate of 39.4% during the previous 26 years and an annual loss of 60,000–200,000 ha of native forests, Ecuador presents a serious issue in terms of deforestation (Mora et al., 2016). Between 1990 and 2018, the province of Manabí, which has the ninth-highest rate of deforestation in the nation, lost 26% of its forest cover (González, 2020). One of the main reasons for deforestation in the area is the growth of dragon fruit production, a traditional agricultural practice requiring extensive maintenance (Chalán, 2019; Ruiz, 2022).

Currently, geospatial tools provide a dynamic view of vegetation cover (Montilla et al., 2017). These tools enable the creation of satellite images for multitemporal monitoring as well as the analysis of landscape fragmentation and its effects on biodiversity through temporal and spatial simulations. In the light of this, the study's goal was to examine how Dragon fruit (*Hylocereus* sp. and *Selenicereus* sp.) cultivation converted xeric forests between 2016 and 2021.

2. Methodology

2.1 Study area

The study was carried out at El Cerezo location, which is situated in the Ecuadorian province of Manabí between the cantons of Portoviejo and Rocafuerte. This region, located between 0° 55' 37.1' S and 80° 31' 16.9' W, is a component of the xeric forest, a delicate and distinctive ecosystem that supports a high level of biodiversity. This kind of woodland is found in a dry area with 300–800 mm of annual rainfall and 25 °C typical temperatures. The study area is 1,136.56 ha, of which 86.09 ha are dragon fruit crops, 382.35 ha are regions intended for new crops, and 668.12 ha are dry forest. The study area was delineated by supervised classification of satellite photos in 2021.

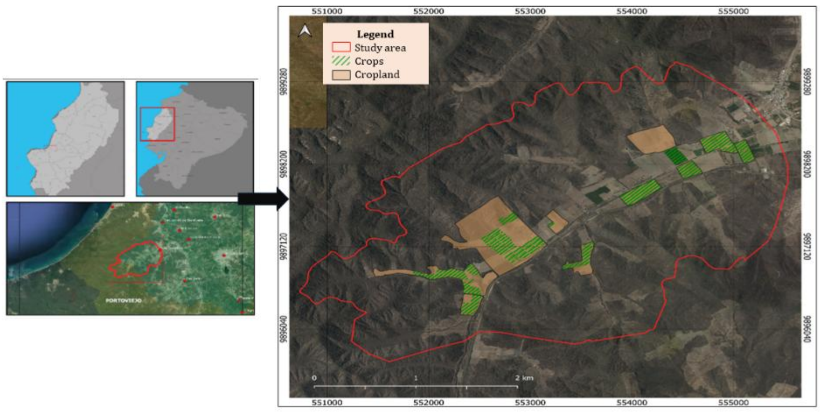

Figure 1. Location of the study area.

2.2 Crop georeferencing

During a field visit, the dragon fruit crops were georeferenced using a Garmin GPS. Following acquisition of the data, ArcGIS Pro version 2.8.4[1] was used to analyze it and produce the polygons representing the plantations that were the subject of the study. The years 2016, 2017, 2018, 2019, 2020, and 2021 were represented by the Landsat TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper), and Sentinel-2 pictures with a spatial resolution of 30x30 m and 10x10 m. These photos were acquired by using the ESPA ordering interface on the United States Geological Survey portal (USGS, 2020). However, satellite photos with less cloud cover were obtained, and the months with the least cloud cover were chosen in order to prevent data gaps caused by cloud cover (Sandoval et al., 2021).

2.3 Determination of land use change

For Landsat-8 and Sentinel-2, an RGB band composition of 6-5-2 and 11-8-2, respectively, was utilized to detect changes in land use (Rosales & Apaza, 2022). Using ArcGIS Pro's maximum likelihood technique, the satellite photos were categorized (Rufin et al., 2021). Forests, agricultural land (dragon fruit crops), crops, water features, and inhabited centers were the recognized land use types (Poveda et al., 2022). In order to detect changes in land use, the classed photos from 2016 and 2021 were finally compared.

2.4 Multi-temporal analysis and calculation of land use evolution

The categorized photos from two separate periods were compared as part of the multitemporal analysis procedure. To compute gains, coverage changes, and losses, a transition matrix (cross tabulation) was used (Reyna et al., 2017; Torres et al., 2016). The numbers that are diagonal indicate that there has been no change in coverage, whereas the values that are off-diagonal indicate a shift in coverage. The intersection tool was used in ArcGIS Pro version 2.8.4 software to do the study in accordance with Paula et al. (2018)'s approach. The average annual deforestation was calculated using equation (1) from the methodological sheet of Puyravaud (2003).

$$R = \frac{A_1 - A_2}{t_1 - t_2} \qquad (1)$$

[1] Available at https://pro.arcgis.com/es/pro-app/latest/get-started/download-arcgis-pro.htm

Where:

R: Average annual total deforestation for a given period

A1: Initial forest area (ha)

A2: Final forest area (ha)

t1: Initial year

t2: Final year

The deforestation rate and the percentage of change for each period were obtained using equation (2):

$$q = \left(\frac{A_2}{A_1}\right)^{1/(t_1 - t_2)} - 1 \qquad (2)$$

Where:

q: Deforestation rate in continental Ecuador (%)

A1: Initial forest area (ha)

A2: Final forest area (ha)

t1: Initial year

t2: Final year

2.5 Analysis of the evolution of land use change for the estimation of deforestation by 2050

Future changes in land use were modelled with consideration for the cover of vegetation. According to Soares et al. (2022), the procedure was grounded on the examination of trends, temporal and geographical phenomena, and transformation processes. Dinamica EGO software version 6[2] was utilized for this purpose, condensing the data into raster format (Pérez et al., 2020). Dinamica EGO is based on cellular automata algorithms and the evidence weights of various biophysical and socioeconomic variables identified as direct causes (Leija et al., 2021).

[2] Available at https://csr.ufmg.br/dinamica/

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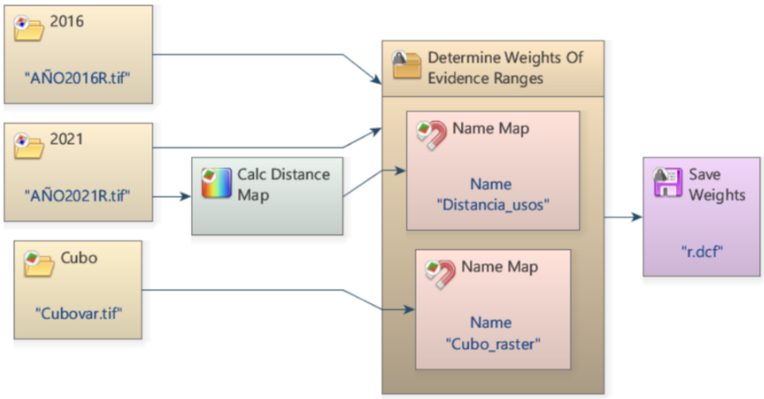

Figure 2. Categorizing variables and calculating evidence weight coefficients.

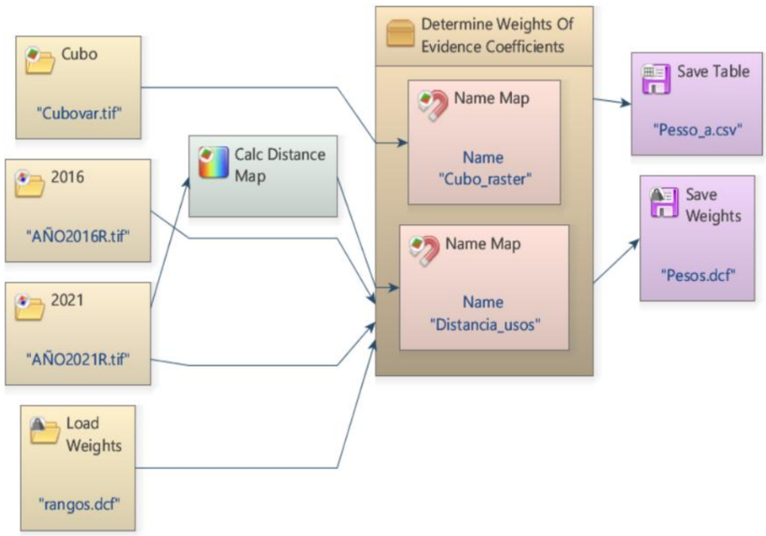

Figure 3. Evidence weight coefficient calculation.

After calculating the ranges, a model constructed in the Dinamica EGO program was used to establish the evidence coefficients (figure 3). Reyna et al. (2017) claim that the program performs a very intricate calculating method. Nonetheless, coefficients with values of 0 or negative values have no discernible effect, and the independence of the variables is a crucial need. Therefore, the independence between these variables was determined using the Cramer coefficient.

The produced findings, as shown in figure 4, will make up the projection calculation model.

Insert **Figure 4**. Projection calculation model.

In order to calculate spatial overlap at various tolerance levels, simulated and real land use change maps were compared using fuzzy similarity indices as part of the validation process (figure 5). There were two attenuation functions used in the model testing. According to what is indicated by (Rodríguez et al., 2023), the first test was conducted with the default window size of 11 pixels (330 m x 330 mq). The second test was conducted with a single pixel size of 30 x 30 m or 900 mq) increased by 15 pixels.

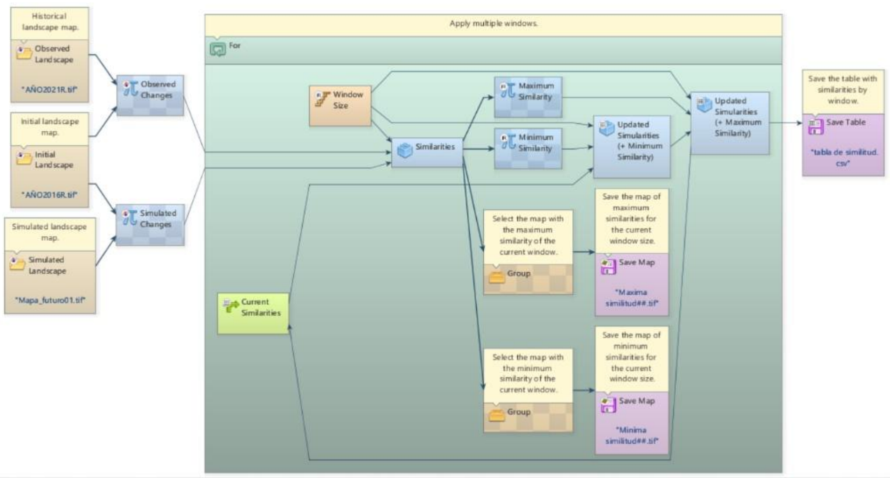

Figure 5. Prediction model validation.

3. Results and discussion

Figure 6 illustrates the change in land use from 2016 to 2021, indicating the deforestation of 245.3 ha of forest over this time. In addition, a 30.63 ha revegetation occurred in line with the rise of dragon fruit crops. There was a 41.19 ha transition to agricultural land, compared to 805.09 ha of unaltered land.

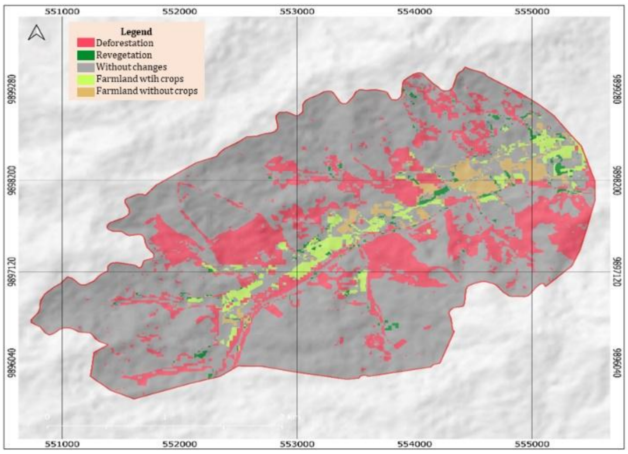

Figure 6. Land cover changes, 2016 – 2021.

Deforestation, which is mostly caused by agricultural growth, is a serious environmental problem. A number of issues, such as a lack of incentives for conservation, the growing demand for agricultural goods, and the need to increase their economic income, force communities living in or close to forest regions to convert their forests into agricultural land (World Bank, 2007). In Ecuador, deforestation is a serious problem. Estimations by Ministerio del Ambiente, Agua y Transición Ecológica de Ecuador (MAATE), the country's forest cover, which was 52% in 2009 (or around 13 million ha), decreased to 12.5 million ha by 2018, indicating an average annual net deforestation of 94,353 ha.

Between 1999 and 2018, the area of Ecuador's deforestation induced by the country's agricultural frontier expanded by 42%. In areas of one ha or less, deforestation grew by 14% between 2016 and 2018, 40% in regions of five ha and in bigger properties (areas between 20 and 50 ha), and over 80% in areas between ten and 100 ha. This growth in deforestation is regarded as a small to medium-sized deforestation agent. It is important to remember that the participation of agricultural producers, more especially, family nuclei cause the loss of forests when they move from rural to urban regions (Sierra et al., 2021).

The xeric forest in the study region is in danger of being completely destroyed due to the unchecked spread of dragon fruit, which has grown exponentially from 850 ha in 2018 to over 2,300 ha in 2022 and is predicted to reach 10,000 ha by 2025 (MAG, 2022). According to Rodríguez et al. (2021), the conversion of forests to agriculture has detrimental effects on the ecosystem, including deforestation, habitat loss, and soil degradation (FAO, 2020; Ruiz, 2022). If this monoculture is not properly maintained, it has the potential to destroy a rare and delicate environment.

The deforestation rate in the study region increased steadily between 2016 and 2020, peaking in 2019 and 2020, as seen in table 1. After that year, there is a noticeable decline, but it is still higher than the average annual deforestation rate for the years 2016–2021, which is 52,575 ha at a rate of -0.721% (keep in mind that negative numbers denote a drop in forest cover).

Table 1. Evolution of deforestation and its rate of change.

Period	Average annual deforestation (ha)	Deforestation rate %
2016-2017	31.909	-0.034
2017-2018	44.046	-0.049
2018-2019	61.336	-0.072
2019-2020	87.755	-0.111
2020-2021	37.827	-0.054
2016-2021	52.575	-0.721

Ecuador has seen a startling loss in forest cover despite having a rich biodiversity, mostly as a result of increased agricultural production. According to FAO (2020), the nation has lost a significant portion of its forest cover, with the greatest deforestation rate in South America of 1.8%, or 198 000 ha annually. Land use changes, particularly the conversion of forests into farmland, are linked to this deforestation (Loon et al., 2019). This tendency is supported by studies like those conducted in Morona Santiago by Yunda (2018) and Pastaza and Orellana by

Quezada et al. (2022), where the increase of agriculture and livestock is responsible for deforestation rates of 1% and -4.095%, respectively. The MAATE study indicates a marginal decline in the rate of deforestation from 1990 to 2016 (-0.71% and -0.66%), between 2014 and 2016, the situation worsened, with 94 353 ha of forests lost annually. Ecuador's biodiversity and ecosystems are at risk due to deforestation, which is mostly caused by the country's expanding livestock and agricultural industries. Urgent action is needed to stop this deforestation and reverse its effects.

The ecosystem and biodiversity of the Manabí province are being threatened by deforestation. Research like that conducted by Intriago & Roldán (2017) reveals concerning patterns in the Flavio Alfaro canton, where the growth of agriculture has been primarily responsible for a 29 ha (-0.01%) decline in forest cover throughout the assessed period. Similarly, Poaquiza (2023) finds that 122.88 ha of forest have been converted to agricultural land, representing an annual deforestation rate of 0.48% (16.38 ha/year) in the Pacoche Coastal Marine Wildlife Sanctuary. These findings emphasize how critical it is to go into action swiftly to halt deforestation and save the delicate ecosystems of Manabí.

It is imperative to underscore that deforestation in Manabí is intimately linked to natural elements like altitude, in addition to socioeconomic issues like agricultural growth. This link is shown in figure 7, where the distances of crops and agricultural land are represented by estimated evidence weights, which show a considerable proximity impact at a distance of no more than 100 m (X axis). The coefficients' representation is shown on the Y axis; values greater than 0 signify a larger transition from forest to agricultural land. The computed evidence weights for the distances of crops and agricultural land show a strong proximity impact at a distance of no more than 100 m, which is consistent with Osorio et al. (2015).

The research region has maximum altitudes of 280 meters above sea level (m.a.s.l.) and minimum elevations of 15 m.a.s.l., with slopes reaching up to 15%, in relation to the altitude variable. The weights of evidence determined for distances from crops and agricultural land revealed an effect of altitude at a distance of greater than 103 m, as shown on the X axis, while the Y axis depicts the coefficients in the transition from forest to agricultural soils. These statistics support Vallejo & Medinas's (2020) findings, which indicate that deforestation is more prevalent in regions with slopes of less than 20% and elevations of less than 300 m.a.s.l. It is necessary to comprehend these spatial linkages in order to put focused conservation efforts into action. Protecting places with lower elevations and slopes, where deforestation is more likely, must be given priority.

This geographical correlation demonstrates that Manabí's deforestation is focused in lower-lying areas where farming is more feasible. This aligns with the results of earlier research conducted in the area (Intriago & Roldán, 2017; Poaquiza, 2023), which emphasize that one of the primary causes of deforestation is agricultural expansion.

Figure 7. Probability of occurrence in the coverage change according to altitude.

The research area's distance to the river does not seem to be a decisive factor in deforestation. Values less than 1400 m, the closest distance to the river, have a value of 0, according to the computed evidence weights (figure 8), indicating that the distance to the river has no effect on the deforestation process. This observation is at odds with the results of Burkhardt & Scheurer (2007), who discovered that rivers that are located within 1000 m of agricultural regions contribute to deforestation by acting as sources of irrigation. In this instance, the availability of alternative irrigation water sources, like wells or rainwater collection systems, may account for the absence of association observed between the distance to the river and deforestation.

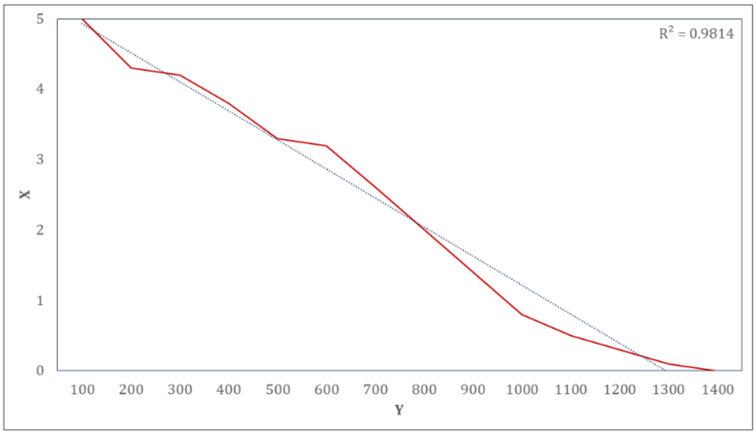

Figure 8. Probability of land cover changes according to variable distance to river.

In accordance to the aim of the study, noteworthy associations were discovered between the growth of dragon fruit farming and alterations in the land cover within the investigated region. The strongest significant connections with dragon fruit expansion are shown in table 2 between shifts from agricultural land to crops (0.4061) and from forest to agricultural land (0.6038), suggesting that these regions are more likely to be converted for this crop. These findings are in line with earlier studies by Pérez (2021); Leija et al. (2021), which show that substantial relationships are indicated by Cramer coefficients more than 0.15 and correlation values near to 1. The strong relationship seen in this instance between changes in land cover and the growth of dragon fruit implies that xeric forest degradation plays a significant role in the dynamics of this crop.

The reliability of the findings and their potential for forecasting future scenarios are supported by the geographical concordance of the computed indexes. In the same way, Caita & Castañeda (2021) draw attention to the fact that the evidence weight coefficients make it possible to determine which factors have the most effects on the system. The spread of dragon fruit farming is determined by the destruction of xeric forest, as confirmed by the greatest values of these coefficients for land cover changes in this study.

Table 2. Cramer index, transition of uses.

From	To	Cramer
Forest	Farmland	0.603841259
Forest	Crops	0.406062732
Farmland	Forest	0.0703216461
Farmland	Crops	0.700444591
Crops	Forest	0.092835845
Crops	Farmland	0.712496523

A pattern in the simulated and actual coverage at various distances is described by the data in table 3. The highest similarity is 0.9283 and the minimum is 0.8185 at a distance of 30x30 m. But as the scale goes up, the similarity goes up a lot, reaching a minimum of 0.9358 and a maximum of 0.9926, suggesting that the simulated and observed data at this size match quite a little.

Table 3. Similarity index.

Cell size (ha)	Minimal similarity	Maximum similarity
30	0.8185	0.9283
60	0.8585	0.9627
90	0.8876	0.9776
120	0.9084	0.9850
150	0.9239	0.9899
180	0.9358	0.9926

These results are closely tied to the growth of dragon fruit cultivation in xeric forests and align with the findings of Ore et al. (2021), who report that the high similarity shows that the applied simulation model is successful in capturing particular vegetation cover characteristics. These findings are crucial to comprehending the growth of dragon fruit cultivation in xeric forests. Notably, the results align with those of Espinoza (2016), who similarly assessed the degree of similarity between simulated and actual data about crop development in an urban forest area, yielding scores ranging from 0.50 to 0.90. According to his research, these data showed a good fit for the model, supporting the robustness of the findings and indicating that the model used in this study is effective at capturing the dynamics of changes in the xeric forest's vegetation cover and, consequently, the growth of dragon fruit crops in the studied area.

Since the results centre on the growth of dragon fruit agriculture in xeric woods, the comparison of the actual and simulated vegetation cover in the research region is highly important. There is a significant degree of agreement between the simulation and the actual vegetation cover in the research region, as the data show that as the cell size grows in ha, so does the resemblance between the data.

It is clear from the study region that the simulation can accurately capture the features of the xeric forest cover at a greater scale. A closer look at figure 9 reveals that the similarity between the simulated and observed cover is $R^2 = 0.9662$. This suggests that there is a significant correlation between the simulated and observed data on the expansion of dragon fruit agriculture in the research area.

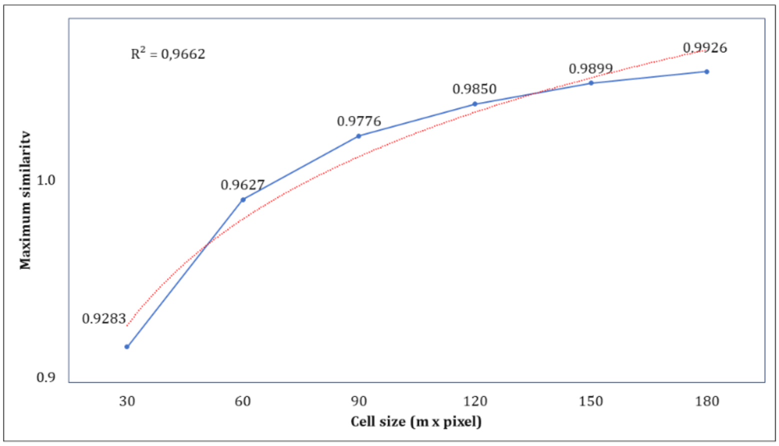

Figure 9. Validation with constant decay function.

For environmental planning and decision-making in the research area, these findings are very relevant. According to them, the models used to depict vegetation cover dynamics in the xeric forest and, therefore, in the growth of dragon fruit farming, can be more accurate and dependable when used to a larger scale. In the particular context of a xeric forest, this is crucial for the protection of this unique ecosystem, sustainable natural resource management, and the successful use of mitigation techniques against climate change.

Figure 10 shows how the land cover in the study region is expected to change in 2050. This figure's data reflect a prediction that helps us comprehend how dragon fruit production affects the xeric forest. A total of 156,874 ha of forest cover, 685,861 ha of agricultural land and 293,634 ha of dragon fruit cultivation are predicted by 2050. Figure 11 details the modifications and development of the 2016–2050 future forecast.

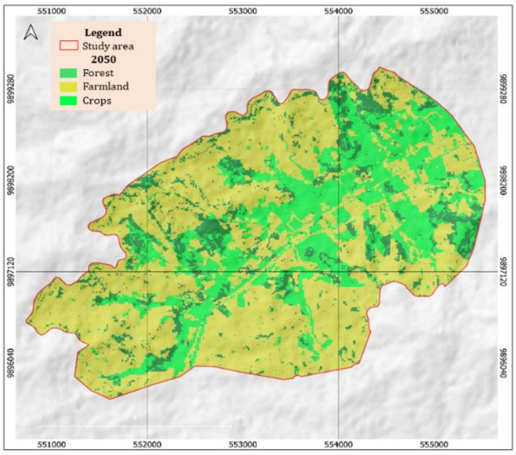

Figure 10. Coverage projection for 2050.

The projection for the year 2050, as illustrated in figure 10, indicates that agricultural land will increase by 685 ha, indicating a 79% increase; dragon fruit cultivation will increase to 293.63 ha; and forest cover will decrease to 156,874 ha, corresponding to a 77% reduction with a deforestation rate of 0.85%, losing a total of 511.24 ha. It's critical to remember that, as a forecast, the model is prone to uncertainty and might be impacted by unanticipated developments like shifting land use regulations or fluctuations in the climate. According to Torrella et al. (2018), there is a degree of uncertainty regarding the exact occurrence of deforestation due to the predictive nature of models. However, it is imperative to take into account the primary drivers of this process when devising strategies for managing forest resources and mitigating its effects. This observation is consistent with their findings.

Sierra et al. (2021) conducted a study on deforestation in Ecuador from 1990 to 2018. The study covered a research area of approximately 5,272.36 square kilometres, or 2.1% of Ecuador's continental territory, and included the Cordillera and Plains of the Central Pacific. This analysis came to the conclusion that there is a 0.9, or crucial, likelihood of changes in the area by 2030.

Consistent with what has been said thus far, Villarreal & Arteaga (2019) attribute these changes to the way agriculture affects the forest cover and speculate that the demand for resources may make matters worse. A substantial likelihood of a decrease in forest cover is associated with the development of agricultural activities and the research area's boundaries, as per the 2050 deforestation prediction model.

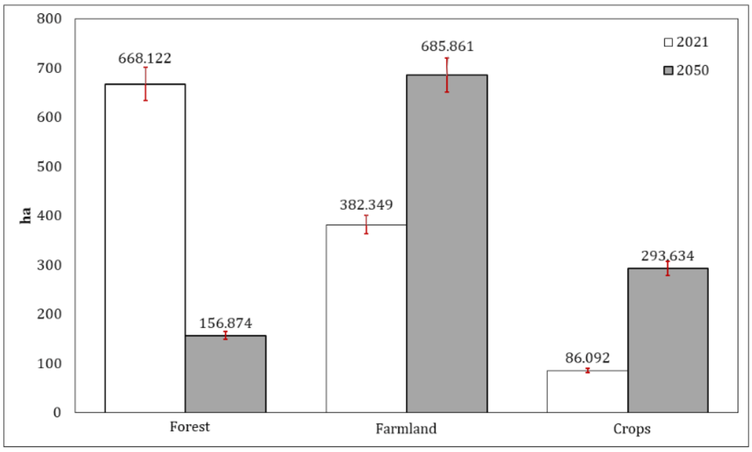

Figure 11. Changes in coverage projection 2021-2050.

4. Conclusions

The increased demand for dragon fruit has led to an alarming 52.57 ha of deforestation between 2016 and 2021 in Manabí due to the development of dragon fruit farming. This phenomenon has detrimental effects on the ecosystem, such as habitat loss and soil degradation, even if the pace of deforestation varies. Concerns regarding sustainability and biodiversity are raised by projections for 2050, which show an annual deforestation rate of 0.85% and an increase in dragon fruit to 293,634 ha. To lessen these consequences and make sure that agriculture and conservation are sustainably balanced in the area, it is imperative to put deforestation prevention initiatives into action, support environmental education, and encourage good agricultural practices.

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Original Paper

Climatic variability and its impact on coconut production in Rocafuerte canton, Ecuador

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Abstract. *The climatic variability significantly impacts agricultural sustainability and food security. This study aimed to evaluate climate variability and its relationship with coconut production in the canton of Strong Rock. The production system was analyzed using an exploratory approach with stratified random sampling, dividing the canton into two strata:*

the upper area "El Cardón" and the lower area "El Pasaje". Seven production parameters were analyzed through surveys, and two meteorological stations were installed, one in each zone. Daily data on precipitation, temperature, humidity, and evapotranspiration were collected for six months (January – June 2024) and statistically analyzed using Pearson correlation. The data were compared with NASA's 12-year historical records starting in 2010. The most produced variety was manion, yielding 846.1 kg/m² in "El Cardón" and 297.8 kg/m² in "El Pasaje." Evapotranspiration and temperature had a high positive correlation with coconut production (0.78 in "El Cardón" and 0.82 in "El Pasaje"), while humidity and precipitation had a low negative correlation. The meteorological data closely matched NASA's historical values for June. The study shows that climatic variability affects coconut production parameters related to flowering and fruiting in the studied areas.

1. Introduction

Rainfall influences 80% of agricultural land and approximately 47% of the global economy depends on agriculture, highlighting the critical role of climatic conditions in food production and economic well-being (Ortiz & Ortega, 2018). Climate variability profoundly impacts global, regional, and local levels, causing extreme events that affect agriculture and food security (Kundzewicz et al., 2020; Franzke et al., 2020). In parts of Latin America, alternating drought and precipitation periods have significant social and economic implications (Aliaga, 2020). Ecuador's coastal region, particularly, experiences high climate variability due to Pacific Ocean temperature anomalies (León et al., 2021; Velasco et al., 2023).

In Manabí, Rocafuerte canton is divided into a dry, mega-thermal tropical upper zone (62% of the territory) suitable for winter crops with 500-1000 mm rainfall from January to April, and a tropical, semi-arid lower zone with less than 500 mm rainfall in the same period. The Poza Honda canals provide year-round irrigation to the lower zone, while the upper zone relies on winter rains, facing summer drought and high temperatures (Rocafuerte Territorial Development and Planning Plan [PDOT], 2016).

Climatic variables like temperature and precipitation significantly impact coconut growth, physiology, phenology, and ecological interactions, accelerating production changes (López et al., 2018). Water deficits can cause crop loss, reduced fertilization, premature fruit drop, and seedling death, while intense rains and extreme temperatures directly reduce production (Jayalath et al., 2020). Around 60% of coconut harvesting occurs under rainfed conditions in tropical climates, emphasizing the need for careful management to ensure long-term sustainability (Hebbar et al., 2022).

The PDOT of Rocafuerte (2016) highlights coconut as an economic pillar, with an area increasing from 354.01 ha to 434 ha in 2019-2023, underscoring agriculture's role in local development. Linking agriculture to the Sustainable Development Goals of the United Nations Development Program, particularly promoting responsible production, consumption, decent employment, and economic growth, is essential.

This study introduces a novel approach to investigating the relationship between climate variability and coconut production in Rocafuerte canton. By employing a multidisciplinary framework that incorporates climatic and productive factors, this investigation aims to evaluate climate variability and its relationship with coconut production in Rocafuerte canton. Our findings are expected to contribute to sustainable coconut production by minimizing losses, enhancing productivity, and aligning with Sustainable Development Goals. This research will provide a replicable model for future studies and inform the development of effective agroclimatic policies.

2. Methodology

2.1. Study area

This study investigated the coconut production system in the rural communities of El Cardón and El Pasaje, Rocafuerte canton, Ecuador. An exploratory approach was employed to analyze the relationship between climate variability and coconut production, aiming to identify patterns, trends, and areas for further research (Miranda et al., 2020).

2.2. Sampling and characterization of coconut production areas

To identify and characterize coconut production areas within Rocafuerte canton, a two-step approach was employed. First, a stratified random sampling technique was used. The canton was divided into two ecologically distinct zones: the upper zone, "El Cardón," and the lower zone, "El Pasaje." This ensured that farms from both areas were included in the study, providing a more representative picture of coconut production across the canton. Within each zone, simple random sampling was employed to select coconut farms. This method reduces bias by ensuring each farm has an equal chance of being chosen, avoiding situations where specific areas are overrepresented in the data.

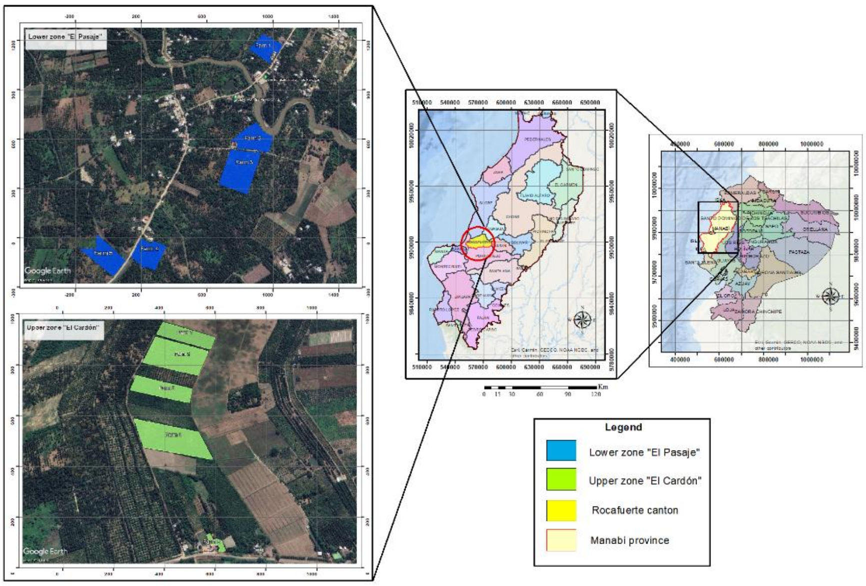


Figure 1. Location of the study area.

Second, representative farms were chosen based on key production characteristics. Reconnaissance visits guided by the Rocafuerte canton's PDOT (2016) helped identify these farms. Selection criteria included the number of coconut trees on the farm, the total area under cultivation, and the annual harvest. A standardized checklist adapted from Gámez & Negrete (2021) further facilitated the selection process.

Once the representative farms were identified, georeferencing was conducted. This process involved recording the geographical coordinates of each farm, allowing for the creation of a map that visually depicts the spatial distribution of the study areas (Gómez et al., 2022). Additionally, surveys were administered to the farm owners. These surveys, based on the work of Lechón & Chicaiza (2019), gathered data on the sociodemographic characteristics of the farmers and details on their coconut cultivation practices. This combined approach of geospatial data collection and surveys provided a comprehensive characterization of the coconut production system in Rocafuerte canton.

2.3. Determining coconut yield per unit area

An important aspect of this study was quantifying the total yield of coconuts from each farm. Researchers employed a method established by Alcántara et al. (2021) to calculate the yield per unit area. This approach expresses yield in kilograms per square meter (kg/m²). To achieve this, the total coconut production (kg) harvested from each farm was multiplied by the farm's total area in square meters (m²). In simpler terms, the total production refers to the total number of coconuts harvested, potentially multiplied by the average weight per coconut (if considered). The farm area represents the entire productive coconut-growing surface. By dividing the total production by the area, researchers obtained a standardized measure of yield that accounts for differences in farm size. This approach allows for a more accurate comparison of productivity across various farms.

$$Performance\ (kg * m^2) = \ Total\ production\ (kg)/area(m^2)\ [1]$$

Where:

- *Total production (kg):* number of coconuts harvested per farm
- *Area (m ²):* surface area of the productive coconut farm

2.4. Setting up meteorological data collection

To understand the relationship between climate variability and coconut production, the study involved installing two meteorological stations. One station was placed in the upper zone ("El Cardón") and another in the lower zone ("El Pasaje") of the canton. These wireless stations boast a coverage radius of approximately 20 kilometers and connect to computers for data storage, as described by Barona et al. (2022). This setup facilitates continuous data collection through multiple sensors, allowing for real-time recording and display of current weather conditions. To ensure optimal functionality and reliable internet connectivity, the stations were strategically placed at homes with internet access within the designated areas.

Over a six-month period spanning January to June 2024, the stations diligently collected daily data on precipitation, temperature, humidity, and evapotranspiration. This valuable information was meticulously recorded in a Microsoft Excel spreadsheet for further analysis and processing, following the methods outlined by Martínez et al. (2021). This data plays a crucial role in exploring the potential influence of climate variability on coconut production in the region.

To understand the relationships between the collected meteorological variables, a statistical analysis was conducted using Pearson correlation coefficients. This method, as described by Escobar et al. (2018), measures the linear association between two continuous variables. By applying Pearson correlation to the data from each station's database, the study aimed to gain a deeper understanding of the interplay between these climatic elements.

2.5. Comparison with historical NASA data

To investigate potential long-term trends and assess the representativeness of the collected data, the average values for each meteorological variable (precipitation, temperature, humidity, and evapotranspiration) were calculated for the six-month monitoring period (January-June 2024). These averages were then compared with historical data from NASA covering the same period for the past twelve years (2010-2024). This approach, following the methods outlined by Bernal et al. (2020), allowed for a direct comparison between the current study's findings and historical climate patterns in the region. By analyzing these similarities and differences, researchers aimed to gain a broader understanding of potential climate variability and its impact on coconut production.

3. Results and discussion

3.1. Coconut producer survey results

Interviews with coconut producers revealed that 70% reported stable crop yields over the years. Detailed findings from the production diagnosis are presented in Table 1.

The coconut producer survey provided valuable insights into the experience and practices of these individuals. A significant portion (70%) of those surveyed have been cultivating and selling coconuts for over ten years, aligning with the findings of Alcívar et al. (2021). This suggests a long-standing tradition of coconut farming passed down through generations in Rocafuerte canton.

In terms of the coconut variety, the Manilon reigns supreme, constituting 70% of the cultivated trees. This dominance is consistent with observations by Basurto et al. (2022) regarding coconut plantations in Portoviejo. However, as noted by Álava et al. (2022), the Manilon variety requires careful handling during harvest due to its susceptibility to chontaduro, a type of weevil damage.

Table 1. Summary of the productive diagnosis of coconut

Variable	Options	Percentage
Production time	More than 10 years	70%
Most used variety	Manilon	70%
Cultivated area	Between 1 ha and 2 ha	70%
Number of plants/ha	From 100 to 200 plants	40%
Number of coconuts/plant	From 1000 to 2000 coconuts	60%
Harvest time	3 to 6 times	100%
Irrigation system	Aspersion	50%
	Pumping	50%

Moving on to yield and harvest practices, a majority (60%) of producers report harvesting between 1,000 and 2,000 coconuts per harvest, with a frequency of 3 to 6 harvests annually. This aligns with findings by Khaidir et al. (2022) who reported similar harvest frequencies in Indonesia, highlighting the global practice of multiple harvests per year. Similarly, Burbano et al. (2020) reported coconut yields ranging from 1500 to 2500 coconuts per harvest, aligning with the findings of this study.

The survey also revealed details about land and palm ownership. Producer land ownership is concentrated between 1 and 2 hectares for 70% of those surveyed. In terms of palm ownership, 40% reported having between 100 and 200 coconut palms on their land. According to Woittiez et al. (2018), an optimal planting density of 120-125 palms per hectare can significantly influence both productivity and management practices.

Irrigation practices also emerged as a key finding. The survey indicates a balanced distribution of methods, with 50% of producers using sprinkler systems and the other 50% relying on pumping systems. As described by Patel & Prajapati (2020), sprinkler irrigation offers advantages like reduced water waste and improved water management compared to traditional methods.

Finally, the survey investigated the water source for coconut cultivation. Half of the producers utilize refineries as their primary water source. This finding, along with the PDOT (2019-2023) of Rocafuerte canton, suggests a reliance on various water sources, including rivers, irrigation canals, and the La Esperanza aqueduct (which supplies water stored in albarradas or reservoirs in the upper zone).

3.2. Analysis of coconut production

To calculate crop yield, we averaged the weight of 15 coconuts from each farm in both zones. This average weight was then used to determine the total production (kg) for each area.

In the lower zone, the total crop yield was 297.8 kg/m², while in the upper zone, it was 846.1 kg/m², indicating significantly higher yields in the upper zone. According to Samarasinghe et al. (2018), areas with favorable climatic conditions, such as adequate rainfall distribution and moderate temperatures, tend to have higher yields.

Hernandez et al. (2024) note that yield is a dependent variable influenced by factors such as soil quality, climate, and cultivar type. Furthermore, Khaki and Wang (2019) emphasize that crop yield is also affected by management practices and technological advancements.

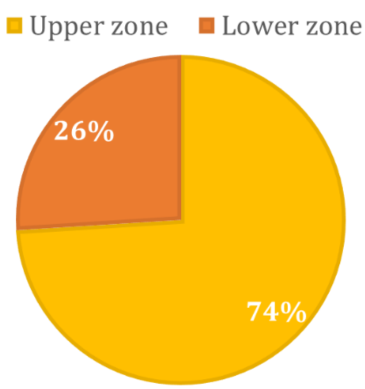
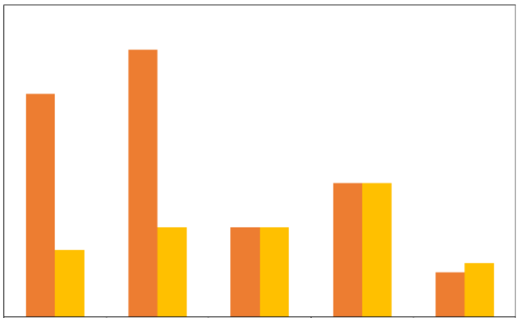


Figure 2. Crop production.

3.3. Coconut production variations between zones

It was determined that the upper zone has higher coconut production compared to the lower zone, based on the monthly number of coconuts harvested by each producer on each farm in the studied areas. Specifically, the upper zone reports a total of 9,714 coconuts harvested, while the lower zone reaches 5,543 coconuts.

Studies such as Woittiez et al. (2018) have highlighted those environmental conditions, including climate and soil quality, play a crucial role in the productivity of coconut palms. The higher production in the upper zone may be attributed to more favorable climatic conditions or soils better suited for cultivation, which could partly explain its higher yield compared to the lower zone.



	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
Upper zone	2857	3429	1143	1714	571
Lower zone	857	1143	1143	1714	686

Figure 3. Coconut crop production

3.4. Pearson correlation

To assess the linear relationships between the collected meteorological variables (precipitation, temperature, humidity, and evapotranspiration), a Pearson correlation analysis was conducted. The resulting correlation coefficients were interpreted based on the standard interpretation scale established by Montaño (2016). This scale provides guidelines for interpreting the strength and direction (positive or negative) of the relationships between the variables.

Table 2. Pearson correlation

Variable 1	Variable 2	Pearson	
		Value	Meaning
Upper zone temperature	Upper zone humidity	-0.05	Very low negative correlation
Lower zone temperature	Lower zone humidity	-0.02	Very low negative correlation
Upper zone evapotranspiration	Upper zone temperature	0.78	High positive correlation
Lower zone evapotranspiration	Lower zone temperature	0.82	High positive correlation
Upper zone humidity	Upper zone precipitation	0.23	Low positive correlation
Lower zone humidity	Lower zone precipitation	0.98	Very high positive correlation
Upper zone temperature	Upper zone precipitation	0.34	Low positive correlation
Lower zone temperature	Lower zone precipitation	0.12	Very low positive correlation
Upper zone evapotranspiration	Upper zone humidity	-0.36	Low negative correlation
Lower zone evapotranspiration	Lower zone humidity	-0.32	Low negative correlation
Evapotranspiration upper zone	Lower zone precipitation	-0.25	Low negative correlation
Evapotranspiration lower zone	Upper zone precipitation	-0.31	Low negative correlation

Temperature and humidity exhibited a strong negative correlation in both the high and low zones, consistent with Escobar et al. (2017) who reported a correlation coefficient of -0.9. This inverse relationship between temperature and humidity is detrimental to coconut flowering and fruit development as noted by Sudhalakshmi et al. (2023) and Albuquerque et al. (2020), ultimately reducing productivity.

Conversely, evapotranspiration and temperature displayed a high positive correlation in both study areas, deviating from the findings of Azevedo et al. (2019). This suggests that prolonged drought conditions, particularly in arid regions, can exacerbate water loss through evapotranspiration, leading to premature coconut drop as reported by Samarasinghe et al. (2018) and Jayalath et al. (2020). As highlighted by Maheswarappa & Krishnakumar et al. (2018), increased evapotranspiration rates amplify the water requirements of coconut palms.

Humidity and precipitation exhibited a low positive correlation in the high zone, contrasting with a strong positive correlation in the low zone. These findings diverge from Ruiz et al. (2023); Rahaman et al. (2019), who reported moderate positive correlations between these variables. Barreto et al. (2024) attributed such discrepancies to factors like water availability and soil properties (Abhinav et al., 2018; Pathmeswaran et al., 2018).

Similarly, temperature and precipitation showed weak positive correlations in both zones, aligning with Rahaman et al. (2019); Bahena et al. (2017). Wasko et al. (2019) and Das et al. (2020) emphasized the negative impact of inconsistent rainfall patterns on coconut flowering. Notably, coconut palms can experience water stress or excess independent of temperature fluctuations (Fernandes et al., 2024; Ruiz et al., 2023).

Evapotranspiration and humidity displayed a weak negative correlation in both zones, similar to the negative Pearson correlation (-0.29) reported by Yongping et al. (2019) between evapotranspiration and precipitation. High humidity levels in coastal coconut plantations can potentially buffer the adverse effects of climate change, reducing yield losses as suggested by Hebbar et al. (2020). However, while coconuts exhibit resilience to short-term drought (Godage, 2022), prolonged dry periods intensified by climate change can have lasting negative impacts on fruit production (Hebbar et al., 2022). Garcon et al. (2019) explained that the inverse relationship between evapotranspiration and humidity is primarily driven by seasonal variations, with higher evapotranspiration rates during dry periods and lower rates during the rainy season.

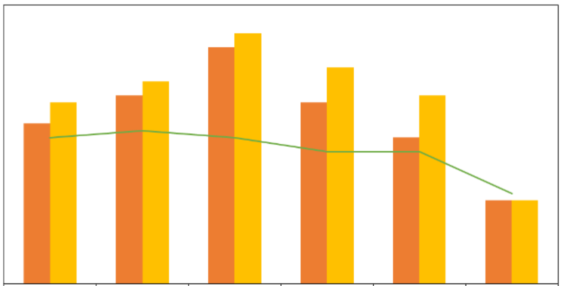
3. 4. Contrast with historical NASA data from the last 12 years

In figure 4, the average temperature in the lower zone reaches a maximum of 28.1°C in March, slightly higher than the upper zone's maximum of 27.9°C. Both zones experience a notable decrease in June, with temperatures dropping to 25.7°C. Historically, NASA data over the past 10 years shows that from January to May, temperatures remain constant between 26.4°C and 26.7°C, with a small decrease to 25°C in June, similar to the study zones. These results align with Hebbar et al. (2020), who describe optimal temperatures for coconut cultivation as ranging between 27°C and 32°C.

The study period coincided with the transition of the tropical Pacific from El Niño conditions to neutral, as reported by the Instituto Oceanográfico y Antártico de la Armada (ERFEN, 2024). This shift resulted in a gradual temperature decrease of 0.4°C between May 26 and June 26 within the study areas.

Figure 5 shows that the average humidity in the upper zone slightly exceeds that of the lower zone, peaking at 87.5% in January. In March and June, the lower zone's humidity decreases significantly to 81.8%, while the upper zone also shows a decrease in June, recording 81.9%. Historical data from the past 12 years indicate that the lowest humidity levels are in January and June, with values of

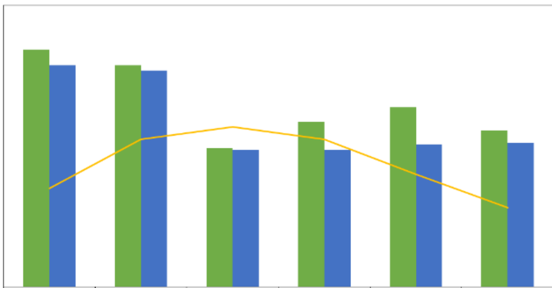
79.6% and 78.5%, respectively, and a high of 83.1% in March. A study by Alvarado et al. (2018) determined that the optimal humidity level for coconut cultivation ranges between 65% and 80%, which supports favorable yields. The study zones generally exceed this optimal range, suggesting a potential impact on coconut productivity due to higher-than-ideal humidity levels.



	JAN	FEB	MAR	APR	MAY	JUN
Upper zone	26,8	27,2	27,9	27,1	26,6	25,7
Lower zone	27,1	27,4	28,1	27,6	27,2	25,7
NASA	26,6	26,7	26,6	26,4	26,4	25,8

Figure 4. Current and historical temperature data.

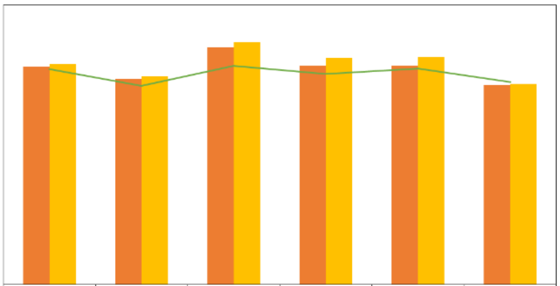
Soil moisture, a critical factor in coconut production as highlighted by Nilmini (2018), is influenced by climate, hydrology, and drainage. Coconut palms exhibit optimal growth with balanced water availability, though they can endure brief periods of water stress. However, both insufficient and excessive moisture can adversely impact yield (Zhang et al., 2022).



	JAN	FEB	MAR	APR	MAY	JUN
Upper zone	87,5	86,6	81,9	83,4	84,2	82,9
Lower zone	86,6	86,3	81,8	81,8	82,1	82,2
NASA	79,6	82,4	83,1	82,4	80,4	78,5

Figure 5. Current and historical humidity data.

Figure 6 shows that the upper and lower zones exhibit a similar trend in evapotranspiration values. In the lower zone, values range from 129.1 mm/month to 156 mm/month, while in the upper zone, they vary between 128.7 mm/month and 152.8 mm/month. Both zones reach their highest peaks in March, with 152.8 mm/month in the upper zone and 156 mm/month in the lower zone.



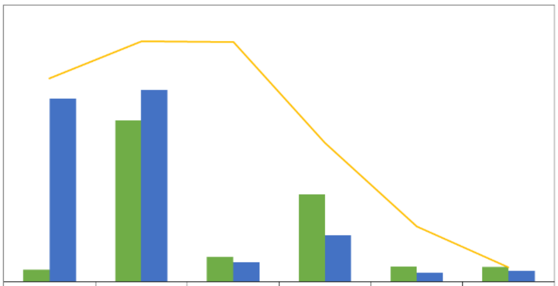
	JAN	FEB	MAR	APR	MAY	JUN
Upper zone	140,2	132,2	152,8	141,1	140,9	128,7
Lower zone	142,0	134,1	156,0	145,9	146,5	129,1
NASA	138,7	128,0	140,9	135,8	139,1	130,6

Figure 6. Current and historical evapotranspiration data

Over the past 12 years, average monthly precipitation in the study areas ranged from a low of 128 mm in February to a high of 140.9 mm in March. These values align with the evapotranspiration estimates of Azevedo et al. (2011), which ranged from 126 to 174 mm/month. Garcon et al. (2019) emphasized that evapotranspiration is influenced by factors such as plant age, climate, and soil conditions.

High temperatures, strong winds, and inadequate soil moisture can significantly elevate evapotranspiration rates, inducing water stress in coconut palms (Bappa et al., 2020; Teixeira et al., 2019). This stress can reduce coconut yields to as low as 35-70 coconuts per palm annually. Conversely, optimal evapotranspiration, characterized by a balanced water supply and atmospheric demand, can lead to higher yields of 80-120 coconuts per palm per year (Carr, 2011).

Figure 7 illustrates that the upper zone exhibits relatively low precipitation patterns during the rainy season, with 7.8 mm/month in January and 16.3 mm/month in March. In comparison, the lower zone experiences its lowest precipitation in March with 12.9 mm/month. Moving into the early dry season, the upper zone shows slightly higher values than the lower zone with 10.2 mm/month in May and 9.6 mm/month in June.



	JAN	FEB	MAR	APR	MAY	JUN
Upper zone	7,8	104,8	16,3	56,7	10,2	9,6
Lower zone	119,1	124,9	12,9	30,3	5,7	7,3
NASA	132,2	156,4	155,9	90,5	36,1	9,5

Figure 7. Current and historical precipitation data

In contrast, NASA data from the past 12 years indicates significantly higher precipitation values during the rainy season, with 132.2 mm/month in January, 156.4 mm/month in February, and 155.9 mm/month in March, gradually decreasing to 9.5 mm/month in June. The agreement among these data sources is most apparent in June, where values align closely.

The physiographic characteristics of the study areas promote orographic rainfall, contributing to precipitation in both low and high altitudes (PDOT, 2016; Alvarado et al., 2018). Optimal coconut cultivation requires monthly rainfall exceeding 130 mm (Corona et al., 2022), a threshold met in the present study. While well-drained, sandy soils and a limited dry season (no more than four months) favor coconut growth (Fernandes et al., 2024), climate change-induced rainfall reductions can negatively impact flowering and yield (Aidoo et al., 2021).

Rainfall and soil moisture are critical factors influencing coconut growth and yield, particularly in regions with pronounced wet and dry seasons. Excessive or intense rainfall during the crucial flowering and early fruit development stages can lead to reduced productivity (Rajapakse et al., 2010). Conversely, prolonged drought during nut filling can diminish coconut size and copra content (Rao, 2016). Implementing effective water management practices, such as supplemental irrigation during dry spells, is essential to optimize coconut production and mitigate the negative impacts of variable rainfall patterns.

4. Conclusions

In the upper zone "El Cardón" and lower zone "El Pasaje" of Rocafuerte canton, the predominant coconut variety is Manilón, constituting 74% and 26% of coconut production per unit area, respectively. Evapotranspiration and temperature showed a strong positive correlation with coconut production (0.78 in the upper zone and 0.82 in the lower zone), highlighting their significant influence on crop yield. Conversely, humidity and precipitation exhibited a low negative correlation across both zones. Comparing data from local meteorological stations with NASA records revealed consistent values, particularly evident in June over a 12-year period. This consistency underscores the reliability of local meteorological data for understanding climatic influences on coconut production in the region.

This study's findings are subject to limitations due to its six-month timeframe and reliance on data from only two meteorological stations, potentially limiting the representation of annual climatic variability. To enhance future research, extending the study period to multiple years and expanding the meteorological network is recommended. Additionally, investigating the influence of specific agricultural practices, management strategies, and technological advancements on coconut production under varying climatic conditions would provide valuable insights for mitigating climate change impacts.

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Original Paper

Harnessing microbes: a new approach to carbon sequestration in cocoa agroforestry

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Abstract. *This study evaluated the carbon sequestration potential of fungal and bacterial strains in cocoa plantation soils in Ecuador's coastal region using a randomized complete block design. Four microbial treatments were tested:* Trichoderma longibrachiatum *(T1),* Trichoderma reesei *(T2),* Bacillus subtilis *(T3) and* Bacillus licheniformis *(T4). All microorganisms showed high viability, with bacterial and fungal colony-forming units exceeding* 10^8 *and* 10^6 *CFU/ml, respectively.* T. longibrachiatum *and* T.

reesei *significantly outperformed the bacterial treatments in carbon sequestration (p<0.0001).* T. reesei *achieved a 29% increase in carbon sequestration after the first application, while* B. subtilis *showed an 11.25% increase after four applications, though with decreasing efficacy.* B. licheniformis *maintained* NH_4^+ *at 19.00 ppm, Zn at 5.60 ppm, Mn at 5.20 ppm, and B at 0.61 ppm, while increasing P to 66.00 ppm, K to 1.89 Meq/100ml, Ca to 19.00 Meq/100ml, Mg to 5.10 Meq/100ml, S to 50.00 ppm, Cu to 5.20 ppm, and Fe to 54.00 ppm. Future research should focus on optimizing microbial dosages and application methods to enhance carbon capture and cocoa productivity.*

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1. Introduction

Greenhouse gas emissions from agriculture, primarily from livestock methane, are a significant contributor to climate change, accounting for approximately 18% of global emissions (Belezaca et al., 2022). Latin America, including Ecuador, is a major source of these emissions, with the agricultural sector being a key contributor (SELLCA, 2024; Paccha et al., 2023). Ecuador's agricultural practices, often characterized by deforestation and excessive chemical use, exacerbate this issue (Racines, 2018; FAO, 2022). To mitigate these emissions, carbon sequestration in soil and plant biomass offers a promising strategy (Ortiz & Batioja, 2023). Forests and agroforestry systems, including cocoa cultivation, have demonstrated significant carbon capture potential (Leiva & Ramírez, 2021; Buitrago et al., 2018; Andrade et al., 2020), with soil microorganisms playing a crucial role in this process (Ahmed et al., 2019).

This study introduces a novel approach by focusing on the carbon sequestration potential of specific fungal and bacterial strains within cocoa plantation soils in Ecuador's coastal regions. Unlike previous research that broadly examines microbial impacts, our study aims to provide a detailed assessment of how Trichoderma and Bacillus strains can enhance carbon capture in this context-specific setting. By evaluating the viability and efficacy of these microorganisms, our research seeks to contribute new insights into optimizing microbial applications for improved soil health and carbon storage. The findings are intended to bridge gaps in the existing literature by offering practical recommendations for integrating microbial inoculation into cocoa agroecosystems, with the potential to enhance sustainability and contribute to multiple Sustainable Development Goals (SDGs), including climate action, life on land, zero hunger, economic growth, and partnerships for the goals.

The potential applications and positive societal outcomes of this research lie in demonstrating how specific microbial strains can enhance carbon sequestration in cocoa plantations. By providing actionable strategies for farmers and policymakers, the study aims to support efforts to reduce agricultural emissions and promote sustainable practices. Although the results are context-specific to Ecuador's coastal cocoa plantations, they offer a valuable model for similar agroforestry systems, paving the way for broader implementation and environmental benefits. Ultimately, this study evaluates the carbon sequestration potential of selected fungal and bacterial strains, contributing to the development of targeted strategies for improving soil health and advancing sustainability in cocoa cultivation.

2. Methodology

2.1. Description of the study area

This research was conducted at the Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López (ESPAM MFL), a higher education institution situated in Bolívar Canton, Manabí Province, Ecuador (0°49'8.87"S, 80°10'53.03"W, figure 1). Located at 15 meters above sea level, the region experiences a tropical climate with average temperatures ranging from 20.60°C to 31.11°C, annual rainfall of 624 mm, and relative humidity of 82.42%.

2.2. Microorganism activation

A completely randomized design (CRD) was employed for this study, with four treatments and four replications per treatment, totaling 16 experimental units. Each treatment consisted of the application of a specific fungal or bacterial strain (Table 1).

Fungal activation

Fungal strains were cultured on Potato Dextrose Agar (PDA) in Petri dishes. A sterile inoculation loop was used to transfer fungal suspensions to the plates, which were subsequently incubated in the dark at room temperature for 24 hours. Following incubation, fungal colony growth and development were assessed.

Bacterial activation

Bacteria were initially cultured in a liquid peptone water medium before being transferred to nutrient agar plates. These plates were incubated at 37°C for 24 hours under aerobic conditions. Bacterial colony growth and development were monitored.

Microorganism reproduction

To increase microorganism populations, serial dilutions were prepared according to the protocol outlined by the Ministry of Agriculture and Livestock of Ecuador (2014) and Mero (2019). Briefly, activated microorganisms were suspended in sterile water, centrifuged, and resuspended in peptone water. Serial dilutions ranging from 10^6 to 10^8 CFU/mL were prepared.

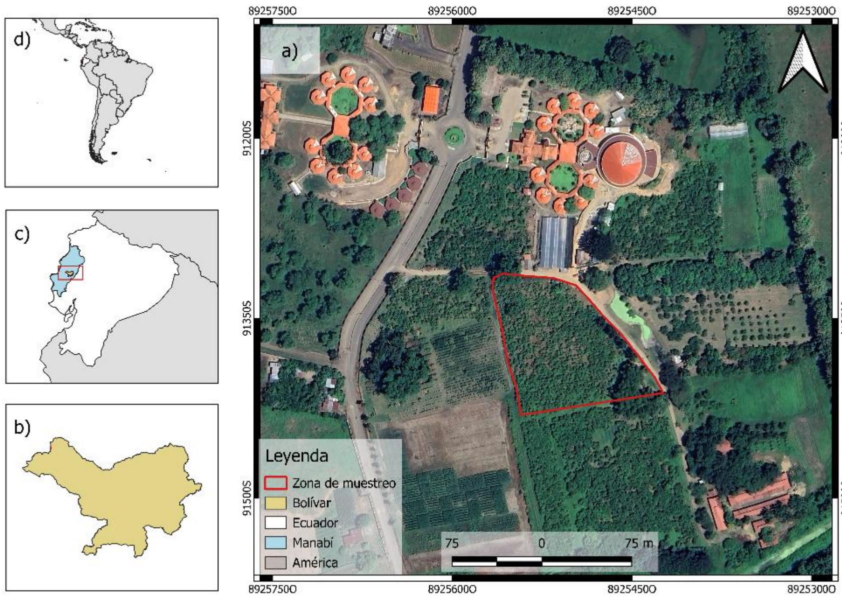

Figure 1. a) Geographic location of the sampling area, b) Bolívar, c) Ecuador, d) South America.

2.3. Soil analysis

To assess soil quality, samples were collected from ESPAM MFL cocoa plantations before and seven days after experimental treatments. These samples were submitted to the Instituto Nacional de Investigaciones Agropecuarias of

Ecuador (INIAP) for analysis of pH, organic matter, NH4, P, K, Ca, Mg, S, Zn, Cu, Fe, Mn, and B. Standard laboratory methods were employed, including potentiometry, Walkley-Black, atomic absorption, modified Olsen, micro Kjeldahl, and Yuan procedures (Table 2).

Table 1. Applied treatments.

Treatment	Code	Concentration
Trichoderma longibrachiatum	T1	1×10^8 ufc/ml
Trichoderma reesei	T2	1×10^6 ufc/ml
Bacillus subtilis	T3	1×10^8 ufc/ml
Bacillus licheniformis	T4	1×10^7 ufc/ml

Dilution concentration : 1 x 108 ufc/ml

Table 2. Parameters analyzed in the study and their classification criteria.

Parameter	Class criteria			Unit
	High	Medium	Low	
NH_4	> 30,1	12,1 - 30,0	< 12,0	ppm
P	> 15,0	8,0 - 14,0	<1,0 - 7,0	
K	> 0,4	0,2 - 0,4	< 0,2	Meq/100ml
Ca	> 4,1	2,0 - 4,0	< 2,0	
Mg	> 2,1	0,8 - 2,0	< 0,8	
S	> 16,0	5,0 - 15,0	< 5,0	ppm
Zn	> 7,1	3,1 - 7,0	3,0	
Cu	> 4,1	1,1 - 4,0	1,0	
Fe	> 41,0	21,0 - 40,0	20,0	
Mn	> 15,1	5,1 - 15,0	5,0	
B	> 0,6	0,2 - 0,6	< 0,2	
Organic matter	> 6,1	6,0 - 3,1	< 3,0	%

2.4. Carbon uptake assessment

Carbon uptake was determined by measuring soil respiration rates (CO_2 release) before and after treatment application. Laboratory analyses, including titration and CO_2 estimation, were conducted to assess soil biological activity, carbon storage, and the impact of treatments on carbon sequestration.

3. Results and Discussion

Microorganism viability

Both fungal (*Trichoderma longibrachiatum* and *Trichoderma reesei*) and bacterial (*Bacillus subtilis* and *Bacillus licheniformis*) strains exhibited high viability, consistently exceeding 10^6 and 10^8 CFU/mL, respectively. These findings align with previous research by Bolaños et al. (2014); Bampidis et al. (2023); Hernández et al. (2019); González et al. (2023).

Nutrient availability

Trichoderma and *Bacillus* application significantly enhanced soil nutrient availability. Initially low levels of NH_4, Zn, Fe, and Mn increased following treatments, with NH_4 and Zn reaching medium levels and Fe attaining high levels. These results corroborate findings by Abdelmoaty et al. (2022); Andrade et al. (2023) regarding Trichoderma's role in organic matter decomposition and nutrient release. Bacillus demonstrated a more limited effect on Mn, increasing it only to medium levels. Mg, S, and Cu levels increased to high levels with both treatments, while B exhibited variable responses. P, K, Ca, and organic matter remained consistently high. Araújo et al. (2022) support the hypothesis of increased nutrient use efficiency following microbial inoculation. Soil pH was neutralized from 6.7 to 7.3 in all treatments (table 3).

Table 3. Results of soil parameter analysis before and after each treatment.

Parameter	Pre application	T1 (*T. longibrachiatum*)	T2 (*T. reesei*)	T3 (*B. subtilis*)	T4 (*B. licheniformis*)
NH_4	8,00 L	29,00 M	22,00 M	24,00 M	19,00 M
P	66,00 H	57,00 H	57,00 H	56,00 H	66,00 H
K	0,98 H	1,79 H	1,87 H	2,00 H	1,89 H
Ca	11,00 H	18,00 H	18,00 H	19,00 H	19,00 H
Mg	1,00 M	4,10 H	5,40 H	4,70 H	5,10 H
S	15,00 M	55,00 H	60,00 H	55,00 H	50,00 H
Zn	1,00 L	5,80 M	6,10 M	6,00 M	5,60 M
Cu	2,60 M	4,80 H	4,70 H	4,40 H	5,20 H
Fe	13,00 L	54,00 H	56,00 H	46,00 H	54,00 H
Mn	3,20 L	4,80 L	4,90 L	5,80 M	5,20 M
B	0,55 M	0,98 H	0,57 M	0,30 L	0,61 M
Organic matter	7,00 H	8,00 H	7,90 H	8,00 H	7,80 H
pH	6,7 H	7,3 N	7,3 N	7,3 N	7,3 N

*H=High; M=Medium; L=Low (criteria in Table 2).

All microbial treatments significantly enhanced soil carbon sequestration ($p<0.05$) compared to the control. *Trichoderma reesei* initially exhibited the highest carbon capture rate (29.00 mg*kg-s), followed closely by *Trichoderma* *longibrachiatum*. *Bacillus subtilis* and *Bacillus licheniformis* showed lower carbon sequestration rates. These findings align with previous research highlighting the potential of *Trichoderma* species for carbon sequestration (Obando & Vélez, 2023; Conrado et al., 2019; González et al., 2023).

While *Trichoderma longibrachiatum* maintained a consistent carbon capture throughout the experimental period, *Trichoderma reesei* exhibited a slight decline after the initial peak. Both *Bacillus* species showed limited carbon sequestration capacity (figure 2). Although both *Trichoderma* and *Bacillus* species are beneficial soil microorganisms, our results indicate that Trichoderma*,* particularly *Trichoderma longibrachiatum*, is more effective in promoting carbon sequestration under the studied conditions. While Mohammed et al. (2017) reported the positive impact of these microorganisms on plant growth and disease control, our study focused specifically on their carbon sequestration potential.

The results obtained suggest that the use of *Trichoderma longibrachiatum* as a biofertilizer could be a promising strategy to increase carbon storage in agricultural soils, thus contributing to mitigating the effects of climate change. Further studies are recommended to evaluate the long-term impact of this microorganism on soil carbon dynamics and its interaction with other soil factors.

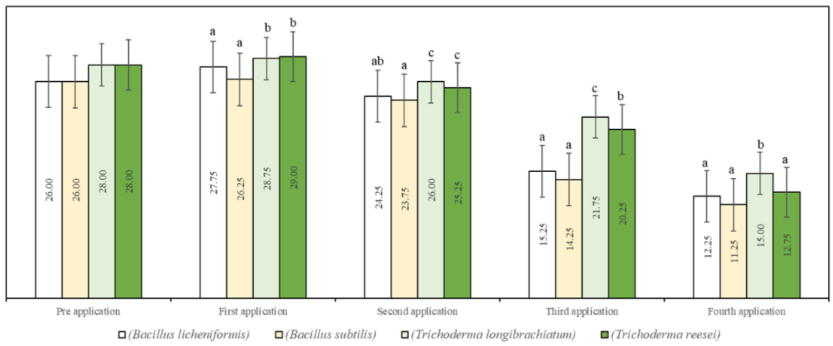

Figure 2. Carbon sequestration rates (mg CO_2-C kg^{-1} soil) among treatments over four weeks. Error bars represent standard error. Means with the same letter are not significantly different ($p > 0.05$) according to Tukey's HSD test.

Trichoderma longibrachiatum and *Trichoderma reesei* demonstrated superior carbon sequestration capabilities compared to *Bacillus subtilis* and *Bacillus licheniformis* throughout the four-week study. However, a general decline in carbon capture was observed across all treatments after the initial week. This reduction is likely attributed to factors such as plant and microbial carbon uptake, as well as ongoing soil organic matter decomposition (Pérez et al., 2021; Zamora et al., 2020).

While Trichoderma treatments showed promise in enhancing carbon sequestration, the results indicate the need for further research to optimize application rates and assess long-term effects. Additionally, exploring alternative strategies to sustain carbon capture in cocoa plantation soils is warranted. The observed decrease in carbon sequestration compared to initial levels and findings from previous studies (Ortiz, 2019; Barrezueta, 2019) suggests that cocoa agroecosystems may require specific carbon management practices to maintain soil fertility and productivity.

4. Conclusions

A comprehensive analysis of the research data indicates that Trichoderma and Bacillus strains exhibited high viability, with bacterial and fungal colony-forming units exceeding 10^8 and 10^6 CFU/ml, respectively, suggesting their potential for successful establishment in field conditions. Although microbial inoculation led to initial improvements in soil properties. Such as *Bacillus licheniformis* maintaining NH_4^+ at 19.00 ppm, Zn at 5.60 ppm, Mn at 5.20 ppm and B at 0.61 ppm, while increasing P to 66.00 ppm, K to 1.89 Meq/100ml, Ca to 19.00 Meq/100ml, Mg to 5.10 Meq/100ml, S to 50.00 ppm, Cu to 5.20 ppm and Fe to 54.00 pp, the overall impact on carbon sequestration was limited. Specifically, *Trichoderma reesei* achieved a 29% increase in carbon sequestration after the first application, while Bacillus subtilis showed an 11.25% increase after four applications, though with diminishing returns. These findings suggest that while microbial inoculation can positively influence soil health, a more holistic approach is necessary to achieve sustained carbon storage within complex cocoa agroecosystems. To optimize microbial applications and maximize their benefits, future research should focus on integrated management strategies that consider the specific conditions of cocoa plantations and the intricate interactions within the soil ecosystem.

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An elegy for the Great Auk

Review of *The Last of Its Kind: The Search for the Great Auk and the Discovery of Extinction* by Gísli Pálsson (2024) Princeton University Press

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This anthropological text covers the genealogy of the extinction of the Great Auk, a large flightless bird that made its home in the islands off the coast of Iceland until the mid-1800s. Gísli Pálsson takes the reader on a journey through time and place to capture the story. In his journeying we are introduced to Pálsson as his young self – a keen Icelandic birdwatching boy who later became an anthropologist. We also meet other scientists who had a fascination for the Great Auk (also known as the Gare Fowl), such as Alfred Newton the naturalist who, with his colleague John Wolley, penned earlier histories on the species.

Pálsson literally follows the research steps that Wolley and Newton undertook in 1858, when it was discovered that the birds were now extinct. Pálsson's main aim seems to be to alert twenty-first century humanity as to how easily extinction can happen, and the effect that extinctions have on the broader web of life, and ultimately sustainability. The brutality that these particular birds suffered is a disquieting but necessary read, if humans are ever to shift consciousness towards a more sustainable way of sharing the world.

Paradoxically, the book is both disturbing yet beautifully written and offers a broad audience (from science students to everyday citizens) a lesson about the 'discovery' of extinction. As an Icelander, and someone well acquainted with the research trail, Pálsson brings an intimate and authentic touch to this tragic exploration of one bird's extinction. In his very characteristic narrative voice that weaves facts, history and science with his own personal knowledge of the land

and its bio-cultural geography, this book is somewhat of a mystery thriller that knocks on the Icelandic door of memory, melancholia, remorse and reparation.

What we discover through Pálsson's extensive research and indeed the research that preceded him, is that the Auk's were already gone – extinct – once Wolley and Newton arrived in Iceland in the mid-1800s. They had intended to make the trip by boat to Eldey themselves, as this was the last known breeding ground for the Great Auk, but weather conditions prevented that expedition. In what was perhaps a stroke of genius, those two ornithologists instead met and spoke with the very people who participated in the 'last successful trip' to hunt the birds. These interviews spawned important historical information about who allegedly killed not only the last two Auks, but much of the whole species over time, as dictated by the lifestyle of a 'subsistence economy' (p. 154), culture over centuries, colonialism, the lure of reward from merchants, fame, and the abject vulnerability of birds that were flightless and easy to trap.

The situation for the birds became more precarious after the volcanic eruption of the Great Auk Skerry in 1830 that effectively upended their home and forced their migration to the Isle of Eldey, southwest of Iceland. Here, they became more accessible to humans, whose historic lack of insight and preservation resulted in the Auk's extinction. While the Great Auks may have been more accessible, the trip to Eldey was nothing short of intrepid and many sailors and hunters lost their lives over time in that pursuit. Others were affected lifelong by the brutal nature of the hunt.

We get excellent lessons in history and science in Pálsson's book, perhaps also some moral philosophy on injustices perpetrated by humans on nonhumans and the lexicon of extinction. It is at times an uncomfortable read, that demonstrates that in the nineteenth century the idea of mass extinction was simply unimaginable. It seems that the longevity of all species was assumed and there was no hint of danger to any one of them. Then we are told about George Cuvier's controversial 1812 publication that claimed evidence of forty-nine extinctions of vertebrates, the first known iteration in which the concept of extinction was declared as a fact (p. 5). This would have been a profound statement to make and contra to prevailing ideas about zoology and preservation of any species. Cuvier unlike many of his time, mentions women in his work and relays and acknowledges his dependence on 'fossil hunters' in order to make his scientific assessments. He particularly records the work of fossil hunter Mary Anning from Lyme Regis, who had a considerable reputation then and now for the information gleaned from fossils that contributed to the store of palaeontology knowledge and collections of artefacts. Cuvier also praises his daughter Sophia who sketched many of the birds for him. Such mentions of women in scientific work are unusual for the time. Pálsson too mentions women throughout as Icelanders, as fossil hunters, women as fishers, net menders, birdpluckers, adapting to life in the harsh climate of Iceland and providing what merchants so keenly sought (p. 112) to sell on to scientists and collectors alike. Women were also taxidermists and at times lead rowers in boats. He notes in particular Þurídur Einarsdóttir (1777-1863), who was a foreman [sic] on some of the boats and allegedly 'never lost a man to the sea' (p. 144).

We journey through the re-assembly of skin, bone and feathers by taxidermists to be displayed as curiosities at museums and in shows for entertainment. Once offshore, these re-assemblages were not always complete replicas of the bird and represent a crude moment in natural history and its commercial interconnections. In one instance, a collection of ten Auk eggs were found uncatalogued in a vault by Newton at Cambridge. Pálsson tells us squarely that in the absence of modern-day science ethics clearance in Victorian England, and any sense of moral responsibility, 'Ostensibly, the last great auks were killed for "science,"' (p. 112). Pálsson further explains the concerns of Wolley and Newton then, and our concerns now, that the extirpation and consequent loss of a species of any kind affects the whole web of life that is biosocial at its very core. 'Death piles up and spreads like fire, without necessary renewal' (pp. 198-200) he tells us in his affecting poetic tone, while drawing respectively on the work of Deborah Bird Rose (2017) and Donna Haraway (2008) who have covered similar terrain with different species and cultural geographies, and the precarity of more-than-human lives across the nature/culture spectrum.

The 'last successful trip' (in the short term) as it has been dubbed, heralded an extinction moment that would be repeated ad infinitum (in the long term) with other species, to the point where we find ourselves with several human induced mass extinctions in the twenty first century. While accounts vary, it is clear that some of those involved in that last expedition, were affected lifelong. Vilhjálmur Hákonarson owned the boat, and crewmen Jón Brandsson (1804-80), Ketill Ketilsson (1823-89), and Sigurður Ísleifsson (1821-89) went ashore to hunt the birds (p. 149). The description of this hunt is an uneasy read as are the descriptions of the massacres of thousands of birds in Newfoundland (pp. 36-39). Moreover, and deeply disturbing is that the cruel methods applied to trapping and killing the birds is an appalling testimony to what was considered normal practice at the time, with an oppressive colonial massacre mentality ever ghosting in the geopolitical background and recent past.

Upon finding a Great Auk egg, we are told that Ketill's head 'failed him' and he stopped. Why did this twenty-two-year-old stop from capturing the egg. "Was he suddenly dizzy, a coward, or was he responding as a moral being unable to do the deed?" (p. 151). Descendants of Ketill and the communities of the area, have had this story handed down to them in several iterations. Vífill Oddsson, for example, was told by his grandmother, 'never to shoot any living thing unless they could eat it'. She said of her father-in-law [Ketill] 'He was just there as a youngster. He did not kill the last bird … Ketill did not have the heart to kill birds … Indeed, his head failed him' (p. 209). Or was it instead, his head that ultimately saved him?

On Pálsson's own journey he discovers that while the birds are over 150 years gone, they have been richly memorialised. He tells us, 'Here stands a tall statue of a great Auk by US artist Todd McGrain, part of his Lost Bird Project' (p. xxvi). Could it be any more poignant than that: 'a proud bird, about my height, gazing mournfully out to sea' (p. xxvi) at Kirkjuvogur, towards its island home of Eldey.

The great tragedy highlighted in this book is that man alone claimed the lives of the last Auks on Earth. This was not the first time, and nor would it be the last time, that humans did something so reckless. But as Newton's legacy shows, remorse can yield a greater inheritance. Newton is remembered as a zoologist, but he is not remembered so much as an initiator of bird protection and the Game Park idea, and this is a mistake. Pálsson's book clearly narrates his journey post Eldey, that included a shift in consciousness and a greater understanding and reverence for lives other than humans. Others too, such as Gallivan (2012), Birkhead (2022), Nijhuis (2022) and Walliston (1921) have suggested that Newton's best work was his involvement in the Game Park idea, and having quotas set for hunting. A generation later in the United States of America, a young man called Aldo Leopold would also experience a self-transforming moment after culling wolves in wilderness as part of his job. Having killed a she-wolf, he watched the fire of life die in her eyes:

> I thought that because fewer wolves meant more deer, that no wolves would mean hunters' paradise. But after seeing the green fire die, I sensed that neither the wolf nor the mountain agreed with such a view ([1949] 2001, p. 129).

Leopold was one of the initiators of the concept of protected wilderness areas or National Parks as they are now called, in the United States of America. He was part of the re-wilding of Yellowstone National Park, to return wolves – the keystone species – to the area to balance out the ecosystems. The Great Auks would not be so lucky. Yet here we have two examples of shifts in human consciousness that led from slaughter to reparative action, prescient of what we now call deep ecology. And Ketill, once returned from the last expedition, didn't hunt birds again. He developed a strong farming community and built churches for the people, perhaps a form of amends, recalibrating his moral compass, or as one local put it 'built to memorialize the events at Eldey in 1844'.

We owe Wolley and Newton a great debt for taking the trouble to note what they and others did before and around them. Furthermore, because anthropologists such as Pálsson – provoked in part by a moral responsibility as a scientist and as a citizen of Iceland to document this genealogy – we are called again to take inventory about what ecocidal practices we have employed in the name of farming, agriculture, recreational hunting and seafaring, that no longer serve – that perhaps never served a sustainability consciousness. We are the agents of the Anthropocene, and its 'trajectory' (Steffen et al. 2015) and we have a lot to answer for. Pálsson couldn't be any clearer about that, and hence succeeds in achieving a powerful educational and ethical impact. He should be applauded for this raw, yet at times elegiac handling of the story of the last Great Auk, and it is no surprise that the book has been shortlisted for the prestigious Royal Society of London Science Book Prize, 2024.

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