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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. Particular 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.

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Editorial

Interspecific and intraspecific relationships in vision and action.

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

When founding our journal, we took inspiration from Donella Meadows' assertion: "Vision without action is useless. But action without vision does not know where to go or why to go there. Vision is absolutely necessary to guide and motivate action. More than that, vision, when widely shared and firmly kept in sight, brings into being new systems" (Meadows et al., 1972, p.102).

Just over twenty years later, while affirming that "vision is the most vital step in the policy process", Meadows was, however, led to make the following statement: "Environmentalists have been especially ineffective in creating any shared vision of the world they are working toward – a sustainable world in which people live within nature in a way that meets human needs while not degrading natural systems" (Meadows, 1994, p.1).

Nearly another thirty years have by now passed, and, despite increasing and widespread awareness of the unsustainability of human trajectories and the urgency required in envisaging alternatives that enable acting to build new sustainable trajectories, it is clear that the shared vision Meadows considered essential is far from being achieved and the action (to be) taken is far from being concerted.

Visions can involve diverse ways of seeing, imagining, and representing the past, the present and the future. In each case, what we see depends on how we see, what viewpoints we (are able to) adopt and what they allow or oblige us to see. Visions are thus as much a question of what we cannot see as what we can see. This may consist of envisioning what sustainability (or unsustainability) is, what is unsustainable in our current world and way of being, what a sustainable world might be, and how human beings can act towards achieving and maintaining it.

Scientists, policymakers, and policy implementors all have vital roles to play in defining visions that can both globally encompass the multiple, interwoven aspects involved in such a complex construct (idea and edifice) as sustainability and also help underpin and deliver actions to realize it in practice. All the papers in this issue deal with an aspect, either related to theoretical or research visions, of the multi-faceted relationship between ideas and action, or ideas-in-action in a range of diverse geographical locations that encompass four different continents.

Each one of the first four papers offers a particular perspective on the interspecific relationships characterizing the dialogue between *Homo sapiens* and nature and the intraspecific relationships characterizing the dialogue between members of *Homo sapiens*, both of which are fundamental components of visions and actions for sustainability.

In "A review of worldviews beyond sustainability: Potential avenues for human-nature connectedness", Fitzpatrick argues that, although there is increasing awareness of worldviews as leverage points for transformative change, deeper understanding of the nuances between worldviews and how they frame complex human-nature relationships is needed. Her paper proposes a review of current literature on how sustainability can be conceptualized across diverse worldviews, as both a narrative and visual "map". She aims to connect transdisciplinary concepts through concrete examples, highlight gaps, and critically reflect on limitations and potentialities in dealing with the complex relationship between worldviews and sustainability, systems change and transformations.

In "Intergroup selection as a way to peace and sustainability", Giraldo-Suárez and León Rodríguez examine the relationship between a demand for resources that exceeds the ability of the biophysical system to regenerate itself and the concomitant risk of violent conflicts. They propose a theoretical vision based on the intersection between approaches to sustainability transition, complexity economics, and peace through a vision of complex systems. Their aim is to show that, by promoting cooperative behaviours through intergroup selection processes, progress can be made toward sustainability and the emergence of peace as a stable behaviour.

In "Biophilic design of building façades from an Evolutionary Psychology framework: Visual Attention Software compared to Perceived Restorativeness" Berto, Barbiero and Salingaros analyse how built environments that integrate representations of the natural world into façades and interiors benefit occupant psychophysiological well-being and behaviour. They assert that the biophilic quality of buildings does not depend exclusively on their being "green", but also upon "organized complexity" in their structure. Through an exploratory study they compare quantitative and qualitative approaches in the perception of biophilic design of building façades and demonstrate how higher perceived restorativeness and preference match a higher degree of biophilic design corresponding to a building where vegetation is integrated in an organic structure. They argue that exploring organized complexity is fundamental for understanding human responses to architecture.

In "Sustainable development through aesthetic expertise? Results and reflection on an experimental case study on arts-science policy intervention", Heinrichs and Hoernemann present a prospect for arts-social science collaboration in the context of sustainable development. By uniting conceptual and methodological perspectives of sensory, arts-based sustainability science and artistic inquiry and intervention, they explore a new approach for collaboration between arts, social science, and policymaking. They describe an experimental case study in order to show how their model of arts-social science-policy intervention can provide aesthetic expertise by co-creating scientific and artistic insights and developing creative options for sustainable development at the local level.

It is evident that the survival of life on our planet as we know it today depends on forests and the essential ecosystem services, such as carbon sequestration, biodiversity conservation, and the protection of water resources that they provide. At the same time, forests continue to be destroyed and plundered. The next two papers deal with different aspects of envisaging what sustaining forests entails and acting coherently in this respect.

In "Citizens' willingness to pay for private forest certification in Kenya", Chisika and Yeom examine the question of the management of private forests through certification in the context of promoting sustainable development. Their study draws on a literature review and data from online survey questionnaires to gather information on citizens' willingness to accept or pay for this. Various steps government has taken to support forest certification seem to have contributed to the high level of willingness to pay or accept private forest certification among study respondents who were already consuming certified products. At the same time, the authors argue that there is a need for increased education and awareness on private forest management certification, further studies on the type and market share of certified products from private forest that are consumed, and formulation of regulations for operationalizing incentives for private forestry development.

In "When a Good Policy Goes Bad. An analysis of framings and silences in Uganda's 1995 National Environment Management Policy and effects on forest conservation", Namanji analyses why, even nearly three decades after an ambitious policy for forest conservation and management was introduced, Uganda still experiences large scale loss of forest resources. The author examines how the problem of forest and biodiversity loss is represented in the NEMP and the ways the policy has been disseminated, defended, or contested. The paper concludes that the basic problem still to be addressed are the active silences such as corruption and ignorance that underlie environmental injustices and are worsening forest degradation.

Eventual developments in the current consumption-based growth model at the heart of our planet's interconnected economies and any vision for changing the future of our way of life depend on ways of enabling sustainable human access to energy. India has recently become the country with the world's largest population, and this means that such questions are of critical global significance as well as crucial for the work of scientists and policymakers in that country.

In "Decentralization to decarbonize the Indian economy", Shankar and Bukya consider the question of renewable energy in terms of how energy generated at the centralized level has significant shortcomings and the need for a shift to decentralized energy. The authors demonstrate how the Indian government has taken several initiatives to increase domestic manufacturing capacity, particularly for solar PV, electric vehicles, and batteries. The paper analyses achievements reached through various renewable energy schemes and also projections related to India's ambition of net zero through a policy of decentralized use of renewable energy technologies.

In "Demystifying the economic and energy potential of Building-Integrated Photovoltaics in achieving India's intended Nationally Determined Contribution", Shankar and Bukya look at programmes in India for promoting clean energy, enhancing energy efficiency, and developing resilient urban centres. They examine the need to use renewable energy sources optimally to meet the energy requirements of buildings in smart cities and how limited rooftop space in an urban environment can be overcome by using building-integrated photovoltaic modules as a source of clean energy on the vertical portion of building facades.

In "An experimental approach towards cost benefit analysis of 850kW solar PV plant", Kumar, Bukya, Shankar, Garg and Gowtham consider how solar photovoltaic cell technology can generate renewable power and reduce reliance on non-renewable energy sources. Their study focuses on Manipal University Jaipur (MUJ), situated in Jaipur, Rajasthan, a solar energy hotspot. They describe a performance assessment of 850 kW installed capacity on a hostel building-mounted solar photovoltaic power plant aimed at obtaining better designing, operation, and maintenance characteristics of the system. They also conduct cost-benefit analysis of 850 kW solar power plants, considering the impacts of various economic parameters.

Understanding human behaviours and developing strategies for promoting behavioural change is another key aspect of envisaging a sustainable world. In "The role of place attachment in defining a relationship between green awareness and conservation commitment and environmental responsible behaviour of university students in India", Javed and Kour examine the role of place attachment in defining the relationship between Green Awareness, Conservation Commitment, and Environmental Responsible Behaviour. Through data collected from the top ten awarded universities in the field of following green and sustainable practices by the government of India, they show how green awareness among students can positively influence their conservation commitment, leading to adopting environmental responsible behaviour, while place attachment moderates the overall relationship.

Transportation accounts for about a quarter of global CO2 emissions and this means that changing behaviours to envisage and promote sustainable transportation has come to be seen as a fundamental goal. In "What drives consumers' sustainable mobility behaviour? An empirical investigation of Delhi consumers", Garg, Kumar and Mittal explore motives and obstacles towards a cleaner, safer, and affordable mobility system. Their study incorporates additional variables (environmental knowledge, government actions, personal norms, and product attributes) into the extended Theory of Planned Behaviour. Through collecting data from a sample of 440 Indian consumers, they demonstrate a significant positive impact of the product attributes, perceived behavioural control, attitude, environmental knowledge, and personal norms on the behavioural intentions of consumers to adopt sustainable mobility behaviour, while social norms and government actions are not found to affect the consumer's sustainable mobility intentions. They also suggest a mix of strategies that can be taken into consideration by producers, marketers, and policymakers to encourage the consumers' sustainable mobility behaviour.

In "Bibliometric analysis of the transformation in air logistics operations in terms of digitalization and sustainability", Yavas and Ozkan-Ozen consider how air logistics processes can incorporate technologies and applications enabled by digitalization in terms of environmental, social, and economic sustainability impacts. Through conducting a literature review and a bibliometric analysis using VosViewer software, they propose five potential research areas for developing the field. Their study aims to contribute to digital and sustainable air logistics research by identifying current trends, revealing gaps in knowledge, and envisaging future research directions.

The relationship between human consumption patterns and the use of residues deriving from food production processes has become a central aspect of circular economy visions and policies for sustainability. In "Evaluation of the physical properties of banana pseudostem for textile application" Delgado Moreira, Vidal Zambrano, and Delgado Villafuerte examine banana cultivation residues and evaluate the physical properties of banana pseudostem for textile application. In their study, three banana species were subjected to treatments following steps of cutting, cleaning and transport of the pseudostem, and extraction, combing, drying and storage of the fibre obtained. Costs of production of the artisanal extraction of banana fibre were calculated. The authors conclude that the fibre obtained from the species studied has appropriate physical properties and costs for sustainable textile application.

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Position Paper

A review of worldviews beyond sustainability

Potential avenues for human-nature connectedness

Haley Fitzpatrick

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Keywords: mental models; awareness; knowledge system; systems-thinking; indigenous knowledge; complexity.

Abstract. *Although there is increasing awareness of worldviews as leverage points for transformative change, deeper understanding of the nuances between worldviews and how they frame complex human-nature relationships is needed. This review paper aims to synthesize current literature on how sustainability can be conceptualized across diverse worldviews. A quantitative database search was used to review peer-reviewed English-speaking scholarship. A qualitative content analysis was conducted to identify key knowledge themes and shared concepts. The results indicated overwhelming support for human-nature connectedness expressed uniquely across six identified knowledge themes. Shared concepts were found across each of these knowledge types and illustrated through a matrix of examples from the literature. This review paper synthesizes and connects transdisciplinary concepts through concrete examples, highlights gaps, and offers future research directions around activating reflexivity on worldviews. It also provides critical discussion on the limitations of conducting a literature review on the vast and complex topic of worldviews and sustainability. The combination of these contributions could provide readers with an entry point in expanding their own worldviews, as a supportive process to the larger-scale systems change needed for sustainability transformations.*

1. Introduction

"Can we transform our societies rapidly and generate an equitable, inclusive, and sustainable world?" Vogel and O'Brien echo this urgent question raised by many (2021: p. 1). To better address this challenge, scholars are increasingly calling for greater awareness on the deep leverage points for transformative action: underlying values, beliefs and mental models (Hornsey & Fielding, 2020; Woiwode et al., 2021). These social phenomena form the basis of *worldviews*, or the overarching philosophies that guide our ideologies, decision-making and actions (Du Plessis & Brandon, 2015; Rousseau & Billingham, 2018). However, reductionist and modernist scientific worldviews have shaped sustainability discourse for decades, which tend to reproduce the same systems that distance humans from nature (Abram et al., 2020; Boetto, 2019). Consequently, there is growing research on greater (re)awareness and adoption of worldviews that consider humans as part of the bigger web of life, such as Indigenous wisdom, Eastern spirituality or systems-thinking perspectives (Du Plessis & Brandon, 2015; Shrivastava et al., 2020; Spannring & Hawke, 2022; Tadaki et al., 2017).

However, literature on worldviews and sustainability tends to remain siloed within specific disciplines and research streams, which can be challenging for a broader audience to access. This contrasts recent calls for greater transdisciplinary and plural forms of knowledge as a means for mobilizing transformative change (Caniglia et al., 2020; Fazey et al., 2020). Furthermore, deeper understanding of the nuances between worldviews and how they frame complex human-nature relationships is urgently needed (van Opstal & Hugé, 2013).

Therefore, this literature review aims to close this gap by offering a synthesized overview of how sustainability can be conceptualized across diverse worldviews. This paper is intended for a transdisciplinary audience to gain broad awareness on current discourse in peer-reviewed academic literature as well as critically reflect upon the limitations of such objective. Worldviews on sustainability are highly complex, constantly evolving and derive from diverse cultures, disciplines, and practices. This review offers just one perspective into this complexity, and the limitations around the scope of reviewed literature, methodology and the author's own worldview are critically discussed in the paper.

The paper is outlined as followed: first, a theoretical framing of worldviews is used to guide the reading of this paper (Section 2). Second, the methodology is explained (Section 3). Third, the results are organized into four sections: an overview of the overarching theme of human-nature connectedness (Section 4.1), six key knowledge themes that have diverse interpretations of human-nature connectedness (Section 4.2), shared concepts across these different knowledge themes (Section 4.3) and (un)learning pathways needed for transitioning to worldviews beyond sustainability (Section 4.4). Finally, the results, gaps, and limitations, including a self-reflection of the author's own worldview, and future research directions are discussed (Section 5).

2. Theoretical Framing

Worldviews: ways of understanding multiple interpretations of sustainability

Worldview is commonly understood as the "lens" or "glasses" in which reality is understood (Gale et al., 2019; McIntosh, 2007; van Egmond & de Vries, 2011). Others describe worldviews as the cognitive structures or frameworks to collect, analyze and generate meaning from information gained from the world (Abi-Hashem, 2017; Hedlund-de Witt, 2013; Mascolo, 2014). Although other terms can be used in place of worldview, there are important distinctions to be made. For example, systems-thinking literature commonly uses “mental model” as a synonym, yet scholars argue that this represents the mechanisms and decision-making processes *under* the umbrella of worldviews (Laininen, 2018; Luthe, 2016; Senge, 1999). Similarly, the term “ways of knowing” is commonly used to refer to the diversity of practices needed to advance sustainability transformations, yet is not necessarily synonymous with worldview (Goldstein et al., 2015; Meighan, 2021). Many scholars advocate that worldview is the most comprehensive term to describe these ideas, which includes related concepts like perspective, mindset or mental model (Boik, 2020; Rousseau & Billingham, 2018; van Opstal & Hugé, 2013). Building off Gabora and Merrifield, this paper defines worldview as a dynamic and flexible process in which understandings of reality are continuously gained through both individual and collective interpretation of knowledge, beliefs, values and norms (2012).

Worldviews are critical to sustainability transformations as they represent the deepest leverage areas for change (Davelaar, 2021; Lam, Martín-López, et al., 2020). To better understand how they function, scholars have attempted to quantify and measure worldviews based on frameworks such as the Cultural Worldview (CW) scale (Choi & Fielding, 2016), the Ingelhard-Welzel cultural map (Inglehart & Welzel, 2005) and the Worldview Inquiry Framework (Rousseau & Billingham, 2018). Within sustainability discourse, there has been an effort to classify worldviews to understand different positions on sustainability and relationships with nature, i.e., organized as a range of “ideal-typical” worldviews from “traditional,” “modern,” “post-modern,” and recently, “ecological” (Du Plessis & Brandon, 2015), “integral” or “holistic” (Cayre et al., 2018; Gale et al., 2019; Hedlund-de Witt, 2013). Research suggests that modern worldviews (supporting rationality, predictability and logic) and reductionist scientific worldviews (emphasizing simplification of complex phenomena), have contributed to the artificial separation of humans from nature (Ives et al., 2018; Latour, 2015), exploitive capitalism, and colonialism (Gram-Hanssen et al., 2022; Whyte, 2020). Paradoxically, it has also guided much of the sustainability discourse in the last decades (Laininen, 2018; Moore, 2017). While efforts to reconnect humans with nature are nothing new - from the Bishnoi environmental activism in the 1700s, to the more recent environmental movements of the 1960s and 70s, and the 1987 Brundtland Commission’s proposal for sustainable development – we are more disconnected now than ever (Ives et al., 2018). Recently, more widespread agreement is emerging that reductionist worldviews which oversimplify human-nature relationships are not sufficient to fully understand and address the complexity of global environmental change, and the urgent social-ecological crisis we face today (Guterres, 2021; Herrfahrdt-Pähle et al., 2020; Thiermann & Sheate, 2020).

In response, researchers from sustainability science, humanities, design and more are advocating for "ecological" or "regenerative" worldviews that expand beyond modernist interpretations of sustainability (Du Plessis & Brandon, 2015; Kambo et al., 2016; Liobikienė & Poškus, 2019). However, different disciplines and cultures have various understandings of what constitutes such worldviews needed to advance sustainability transformations. Researchers highlight the urgent need to cross-connect between these diverse approaches, ways of knowing and paradigms (van Opstal & Hugé, 2013). Some have interpreted this by proposing an integral worldview that attempts to merge different ontological perspectives and values together (De Witt et al., 2016; van Egmond & de Vries, 2011). Yet this overemphasis on classification and integration of predefined worldviews oversimplifies the complexity of multiple understandings of sustainability that are needed to decolonize and build inclusivity in addressing the social-ecological crisis (Caniglia et al., 2020; Lima & Partidario, 2020). Instead, further research is needed to negotiate the nuance of how sustainability is framed across a wider range of worldviews (van Opstal & Hugé, 2013).

To contribute to this effort, this review paper aims to synthesize current peer-reviewed literature on how sustainability can be conceptualized across diverse worldviews, as both a narrative and visual overview (Figures 1 & 2). This paper strives to act as a learning tool for a broad audience, including practitioners, educators, and students, to help expand our own worldviews by simultaneously acknowledging distinct differences and broader consensus in how sustainability is expressed. Within these broader aims, the following research questions have guided the paper:

1. What is the current state of knowledge about worldviews and sustainability and how limited are we in knowing this? What are we able to understand through established quantitative review methods and literature within academic databases and what is missing from this discussion?
2. Instead of focusing on "ideal-typical" worldview typologies, what nuances can we learn about plural understandings of sustainability by looking at relationships between diverse knowledge themes and concepts shared between them?

3. How could (un)learning processes help us gain more awareness of our own worldviews (and limitations) and evolving human-nature connectedness?

3. Methodology

An iterative, multi-step approach was used to conduct this literature review (Table 1). First, an initial database search was conducted using broad keywords (Step 1) and the abstracts were coded for general themes and gaps (Step 2). Then, a subsequent database search was conducted with specific keywords that reflected the gaps identified from the first search (Step 3). Finally, all relevant abstracts from both searches were coded together using revised codes (Step 4). The following section describes this process in detail.

Methodology Overview

Step 1: First Database Search
Keyword: "sustainab and worldview" in SCOPUS and WoS
Reference screening via PRISMA Flow Diagram (Appendix B)

Step 2: Initial abstract coding - Qualitative Content Analysis (n = 789)
Broad themes and gaps identified for next iteration of keyword searches

Step 3: Second Database Search
Keywords: "regenerative" and "sustainab," "relational thinking", "care" and "post-human*", "mindfulness" and "sustainab" in SCOPUS and WoS *Reference screening via PRISMA Flow Diagram (Appendix B)*

Step 4: Qualitative Content Analysis of combined abstracts from all keyword searches (n= 877) with full text articles assessed (n = 89)

See Appendix A for list of SCOPUS and WoS excluded subject areas.
See Appendix B for PRISMA Flow Diagrams for each keyword search.
See Appendix C for list of codes and codings.
**The term "posthuman" was substituted for "sustainability" to specify the research streams more adequately around care ethics*

Table 1. Overview of the four-step methodology for conducting this literature review. Keyword search period was from January 2021 to June 2021, with articles ranging from 1992 – 2021, with 82% published between 2011-2021 and 56% published between 2016 – June 2021. (Appendixes can be downloaded as pdf files at: https://www.ojs.unito.it/index.php/visions/article/view/7309)

A quantitative database search within SCOPUS and Web of Science (WoS) of peer-reviewed English-speaking literature was used to survey current academic discourse on worldviews and sustainability. Both SCOPUS and WoS are considered comparable tools for detailed cross-disciplinary analysis (Martín-Martín et al., 2021) and WoS also includes grey literature, or non-peer reviewed articles, books, conference proceedings, dissertations, etc. (Godin et al., 2015). The first keyword search of "worldview" and "sustainability" acted as the primary baseline search (Step 1). The well-established PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analysis) flow diagram was used to provide transparency and replicability for the literature selection process (Moher et al., 2009), which is included in Appendix B. This first keyword search included an extensive amount of healthcare literature such as nursing, pharmacy, and biomedical engineering, which focus on patient/healthcare provider worldviews and sustainable practices in healthcare management. Since these topics fell outside the paper's scope, they were excluded (See Appendix A). After combining references from SCOPUS and WoS and removing duplicates, a total of 946 abstracts were screened in this first database search (See Appendix B).

Keyword searches through quantitative databases were chosen in the attempt to grapple with the vast and diverse discourse on worldviews and sustainability, which also highlights important limitations. This methodology, as well as the PRISMA process, are widely accepted within scientific research. However, these approaches also illustrate the limitations of what kind of knowledge can ultimately be included in a literature review, which is further reflected upon in the discussion section of this paper. Furthermore, as discussed in Section 2, some authors may use different terms to describe the concept of worldview, such as "mental model" or "way of knowing." Many other terms could also be appropriate descriptors, considering the highly diverse contexts in which worldviews can be understood. However, this review paper aims to capture a broad overview of peer-reviewed, English-speaking literature with a specific conceptual lens. Therefore, the term "worldview" was chosen as the primary keyword to pair with "sustainability," as it is well-established within the literature to describe how sustainability is conceptualized by different cultures and disciplines (A. De Witt et al., 2016; Du Plessis & Brandon, 2015; Laininen, 2018).

Furthermore, despite the broad keyword search of "worldview and sustainability," most of the reviewed literature stems from sustainability science, social-ecological systems research, social sciences and to a lesser degree, the humanities. The English-speaking and Western/Westernized scholarship provides a limited knowledge of how worldviews are conceptualized and disseminated. The discussion section expands upon these limitations and which methodological practices could be adopted in the future for communicating a more diverse body of knowledge on worldviews.

After Step 1, the first keyword search process, a qualitative content analysis (QCA) (Mayring, 2019) through MAXQDA software was conducted to screen abstracts for initial themes and gaps (Step 2). A starting list of codes was informed by broad literature scanning, conference participation and peer group discussion before the database searches to identify a rich picture of concepts related to worldviews and sustainability. From this initial list, the codes "regenerative," "relational thinking," "care" and "mindfulness," represented the smallest percentage of the total codings within these abstracts (less than five codings), yet also represent some of the emerging research themes within sustainability science (Gibbons, 2020; Thiermann & Sheate, 2020; West et al., 2018, 2020). These codes were then used to perform a second database search (Step 3) excluding the word "worldview" to scan for literature that was not captured in the first search. Finally, a second round of QCA (Step 4) was conducted with all screened abstracts (n = 877) using a refined list of codes (Appendix C). During the coding process, there were several instances where large groups of articles were deemed irrelevant, even after the refined database searches. For example, when coding abstracts, over 50 texts were irrelevant because a remote-sensing software called "Worldview-3" was prompted in the initial database search but wasn't filtered out in the refined search since these articles were within environmental science disciplines.

Codes and codings were cross-checked in a pre-tested approach by a "sounding board" of scholars within the author's professional network. Eight experts were invited to engage in this "sounding board" for discussing the themes, concepts and codings identified in the database searches. Both semi-structured and informal brainstorming discussions over the course of eight months were conducted with the following eight international and multi-cultural experts: 1.), writer and educator in regenerative design 2.) environmental historian 3.) an Indigenous food specialist and member of a First Nations tribe 4.) ecologist and sustainability scientist 5.) landscape planner 6.) social and human geographer 7.) sustainability entrepreneur 8.) systemic designer. These individuals were invited because their expertise aligned with key themes within the reviewed literature. The main objective of these conversations with individuals from diverse cultures, practices, and disciplines was to expand and healthily challenge the author's own worldview. Although these experts did not contribute to the data collection, analysis of the results or writing of this paper, this "sounding board" process stimulated important metalevel reflexivity for the author, inspiring the paper aims and worldview critique in the discussion section.

Finally, 6% of the references included in this paper are non-peer reviewed literature, falling into the category of grey literature. These include books and dissertations sourced from WoS as well as seminal books cited within the peer reviewed literature. These were included to accurately support citation credit and reinforce key themes and concepts found during the QCA.

4. Results

4.1 Overview

Overall, the results of the reviewed literature overwhelmingly suggest that human-nature connectedness is at the core of how sustainability is conceptualized across worldviews. This was the most frequently coded theme (included in 145 abstracts) within the QCA (Figure 1) and corroborates broader calls for reconnecting to nature as a fundamental aspect for mobilizing sustainability transformations (Ives et al., 2018; Riechers et al., 2021). Various terms such as "human-nature relationship," "interrelationship," "human-nature connectedness," and "interconnectedness" were used interchangeably in the literature to describe this theme as the core of healthy, livable futures (Braito et al., 2017; Dacks et al., 2019; Diver et al., 2019; Kaaronen, 2018). In this sense, worldviews that support deep human-nature connectedness go *beyond* sustainability: instead of only preventing additional harm, the focus must shift to restoring past damages to promote participatory, regenerative processes to nurture all life systems (Capra & Luisi, 2014; Gibbons, 2020; Wahl, 2006).

As illustrated in Figure 1, this overarching theme of human-nature connectedness was expressed differently across six key knowledge themes identified from the literature: Indigenous knowledge; local, place-based knowledge; systems thinking; spiritual, religious knowledge; subjective, inner knowledge and relational thinking (Section 4.2). Within and across these diverse knowledge themes, three shared concept clusters were synthesized based on the QCA codings: 1. Holism and complexity, 2. Well-being, regeneration, and resilience, and 3. Awareness and reflective mindsets (Section 4.3). Each of these three concept clusters contain important nuances on how sustainability is conceptualized differently across the six knowledge themes and are described through specific examples in Figure 2. Furthermore, the results also suggest critical (un)learning pathways needed for transitioning to worldviews beyond sustainability, as a possible precursor for transformative action (Section 4.4).

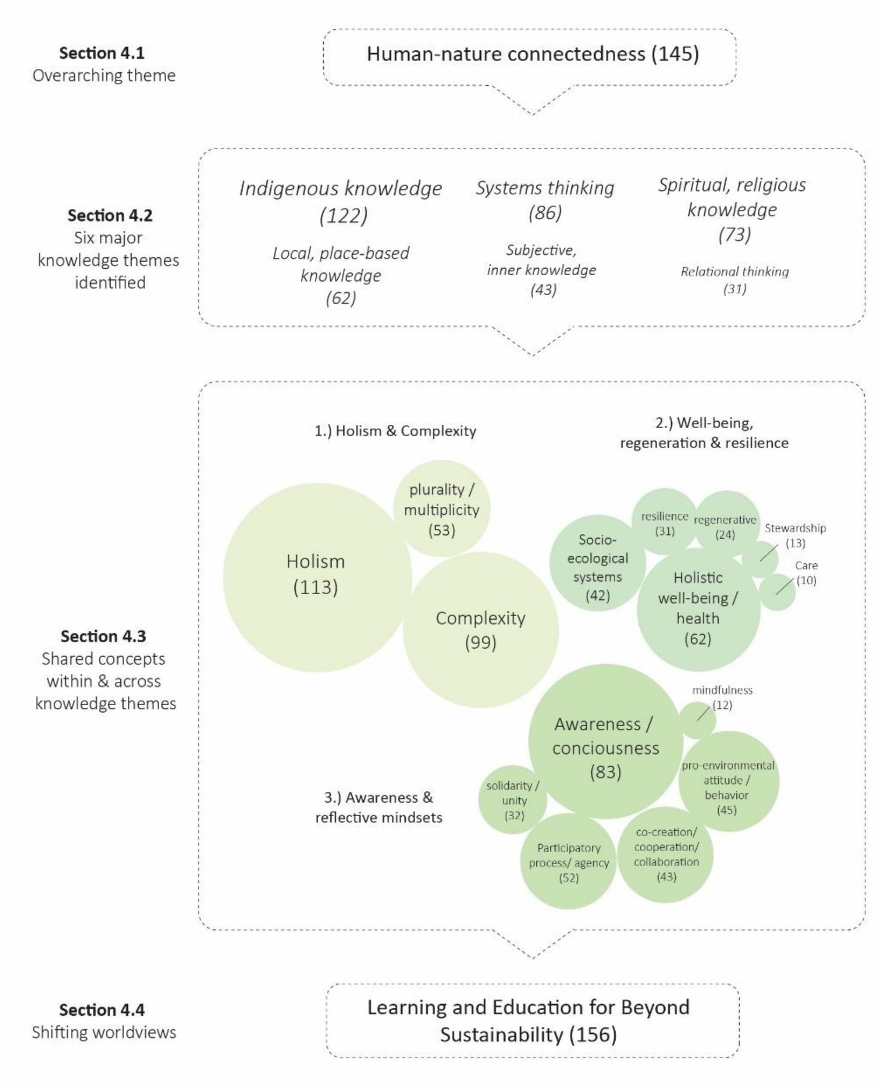

Figure 1. The results are structured through four sections. Each number corresponds to the coding frequency of a knowledge theme or concept that was found during the QCA. For example, there were 86 papers that discussed systems-thinking, 99 papers that discussed complexity, etc. Circle size and font size are proportional to different frequency ranges (1-15, 15-35, 35-55, 55-75, 75-100, 100+). Figure 1 can be downloaded as high-resolution PDF file at: https://www.ojs.unito.it/index.php/visions/article /view/7309

Likewise, much of the concepts used in the following sections are loaded with different meanings depending on discipline or cultural worldview. For example, a wide range of terms were used in the literature to describe worldviews that both support and contrast deep human-nature connectedness (Table 2). Similarly, many new worldview classifications were proposed (Table 3). These results validate the points raised in Section 2, that there is a tendency within sustainability discourse to overclassify and oversimplify worldviews as "sustainable" or not. This raises critical questions of how much language, new frameworks and other forms of communication either contributes to greater plurality or potentially causes further confusion and polarization, which is elaborated on in the discussion section of this paper.

Terminology used to support and contrast human-nature connectedness

Contrasting terminology	*Supporting terminology*
Colonial (30)*	ecological (59)
Western (25)	Indigenous (49)
mechanistic (24)	environmental (43)
modernist (23)	integrative (36)
reductionist (14)	holistic (25)
anthropocentric (13)	New Environmental Paradigm (14)
technocratic (12)	organic (14)
Dominant Social Paradigm (11)	eco-centric (12)
traditional (11)	sustainable (12)
individualistic (7)	egalitarian (8)
rationalist (4)	post-humanist (7)
Dominant Western Worldview (2)	eco-spiritual (5)
	biocentric (5)

** Numbers reflect frequency within coded abstracts*

Table 2. Terms identified within the reviewed literature that were used to contrast and support human-nature connectedness. The numbers correlated with the frequency in which the terms appeared in the coded abstracts.

"Ideal-Typical" worldview classifications used in the literature

Humans & nature disconnected	→		*Human-nature connectedness*	Reference
Fatalist	Hierarchical	Individualist	Egalitarianist	(Chuang et al., 2020; Ekener et al., 2018)
Pragmatist	Post-Positivist	Constructivist	Transformative	(Hakkarainen et al., 2020)
Traditional	Modern	Ecological Intensive	Holism	(Cayre et al., 2018)
Traditional	Modern	Post-modern	Integrative	(de Witt, 2014; van Egmond & de Vries, 2011)
Traditional	Modern		Post-secular	(Gale et al., 2019)
Modernist	Post-modernist		Integral	(O'Brien & Noy, 2015)
Defying	Non-inclusive		Inclusive	(Coscieme et al., 2020)
Technocentrism	Sustaincentrism		Ecocentrism	(Whyte & Lamberton, 2020)

Table 3. Classifications used by scholars to conceptualize the degree of human-nature connectedness based on different "ideal-typical" worldviews. Some authors referenced four worldviews types while others used only three.

4.2: Six identified knowledge themes

During the QCA, six broad knowledge themes were identified. The terms used to describe each knowledge theme were derived from the literature: for example, as illustrated in Figure 1, there were 122 abstracts referencing "Indigenous knowledge," 86 abstracts discussing "systems-thinking," etc. These knowledge themes are not meant to be mutually exclusive, but rather demonstrate relationships between different ways of reasoning based on shared concepts (Figure 2). Some knowledge themes intersect more than others, depending on disciplinary or cultural origin. For instance, as shown in Figure 2 and Section 4.3, Indigenous knowledge and local, place-based knowledge contain the most overlap in how concepts are described. Similarly, spiritual and religious knowledge is often referenced as a dimension of Indigenous knowledge. However, authors also discuss ideas from Western religions and non-Western spirituality that are not specified as part of Indigenous knowledge. Overall, subjective and inner knowledge is discussed with less context specificity and is referenced primarily within environmental education, environmental psychology, and sustainability science. Relational knowledge is primarily situated within literature from the humanities, often based on ideas found in Indigenous knowledge. In contrast, the literature on systems-thinking is significantly positioned through a Western, scientific lens, specifically from social-ecological systems research, environmental sciences, and sustainability science. Even though there is significant overlap within systems thinking and relational thinking, scholars have been recently unpacking the differences and potential implications for sustainability transformations (Raymond et al., 2021; Walsh et al., 2020; West et al., 2020).

Indigenous knowledge

The reviewed literature reflects the increasingly urgent and long overdue call within academia to recognize Indigenous and traditional ecological knowledge as fundamental in reshaping the narratives around sustainability (Belfer et al., 2017; McPherson et al., 2016; Ranta, 2018). Many Indigenous authors use Indigenous as an umbrella or "placeholder" term to encompass non-colonized ways of knowing and being from non-migratory ethnic cultures (Stewart, 2018). In general, Indigenous worldviews are grounded in a deep, place-based understanding that all beings are holistically and intrinsically interconnected (Gray, 2016; Russell & Ens, 2020). However, the depth of Indigenous knowledge has yet to reach a widescale representation in peer-reviewed sustainability literature (Belfer et al., 2017). Scholars highlight one reason for this gap is the inability to translate much of Indigenous wisdom into Western, English-speaking formats (Belfer et al., 2017; Lacombe, 2010; Tafoya, 2020). Others argue that maintaining the globally dominant Western paradigm has been at the expense of legitimatizing many other realities, like Indigenous knowledge (Boetto, 2019; dos Martins, 2010; Kochetkova, 2005). Furthermore, Indigenous knowledge is still largely considered a way to confirm scientific evidence, rather than being intrinsically valuable in itself (Belfer et al., 2017).

Local, place-based knowledge

Local, place-based knowledge is often discussed in relationship with Indigenous knowledge as an approach to decolonize dominant sustainability paradigms (Opoku & James, 2021). Some authors consider Indigenous and local knowledge (ILK) as a "body of thought that embraces all knowledge systems and legitimizes ILK holders" (Chilisa, 2017: p. 814). Others define ILK as a situated and adaptive collective identity shared across social and spatial networks (Lam, Hinz, et al., 2020). Scholars also discuss local knowledge as a perspective that intertwines place, culture and nature (Beilin & Bohnet, 2015; Briggs et al., 2019). Yet Lam et al. reiterate that local knowledge lacks comprehensive definitions and positioning outside the realm of Indigenous knowledge (2020). Despite the ambiguity of the concept, much of the literature highlights the need to reconnect with and further legitimize local, place-based and traditional knowledge sources as pathways towards sustainability (Lukasiewicz et al., 2013; Timoti et al., 2017).

Systems-thinking

Systems-thinking is a way of reasoning that aims to understand the relationships and interactions between parts and whole (Amissah et al., 2020). There are different interpretations of systems-thinking that are linked to different disciplines, derived from complexity sciences, cybernetics, general systems theory and systems dynamics (Buchanan, 2019; Midgley, 2016). However, the dominant perspective within the reviewed literature considers systems-thinking as a holistic understanding of reality, where complex interactions between components and environments are open, continuous, and self-regulating through feedback loops (Dori et al., 2019; Melo, 2020). Many authors also consider systems-thinking a way of decision-making and taking action within uncertain and complex change processes (Monat & Gannon, 2015; Reynolds & Holwell, 2020). Systems-thinking is recognized as a core approach in understanding the complexity of sustainability transformations, based on historical concepts like Miller's living systems concept and Lovelock and Margulis' Gaia hypothesis (Mang & Reed, 2012; Yablokov et al., 2017).

Spiritual, religious knowledge

A notable amount of the literature calls for greater recognition of the role of spirituality and religion in conceptualizing sustainability, especially with regards to values (Gray, 2016; Ives & Kidwell, 2019). Most of this literature remains at a conceptual level discussion and is often connected to inner or subjective knowledge (Grenni et al., 2020; Woiwode et al., 2021) and Indigenous knowledge (Gould et al., 2021; Russell & Ens, 2020). Although much of the literature related to spirituality and sustainability is limited to Judeo-Christian contexts, some scholarship focuses on "Eastern" philosophies as an alternative to reductionist worldviews (Dong et al., 2010; Zidny et al., 2020). Several scholars expand beyond "Eastern" as a blanket term and discuss ways in which Buddhist (Brown, 2018 and Song 2020), Confucian (Liu & Constable, 2012; Mok, 2020; Sjöström, 2018), and Taoist (Alterado, 2015) practices can enhance multiple understandings of sustainability. For example, within Daoism and the Ilokano concept of cosmic self, silence is a critical practice for communicating between self and the cosmos, in which the "inner voice" of nature can be heard (Alterado, 2015).

Subjective, inner knowledge

Although less represented within the literature, there are calls for greater research on the subjective and inner dimensions of sustainability (Hakio & Mattelmäki, 2019; Horlings, 2015; Ver Steeg, 2020; Wamsler & Brink, 2018). Scholars emphasize the importance of valorizing personal experiences of sustainability (Marujo et al., 2019; Tillmanns, 2020) and the need to better negotiate how subjective and objective realities could come together (Eckersley, 2016; Steelman et al., 2019). Increasing self-awareness is seen as a key practice to help individuals make sense of their place within a holistic system (Biberhofer et al., 2018; Hakio & Mattelmäki, 2019). Similarly, interactive sharing of individual experiences can help reframe "otherness" as an opportunity to connect, rather than divide (Steelman et al., 2019). Others highlight the conundrum of how little attention personal experience and place-based, local knowledge is considered within the design of environmental policies (Lukasiewicz et al., 2013). Much of the reviewed literature on the inner dimension references ancient concepts that have been continually practiced in non-Western communities, such as mindfulness, derived from the Zen practice of Mahayana Buddhism (Ericson et al., 2014). Mindfulness is considered a growing practice within sustainability education and climate change adaptation (Geiger et al., 2020; Wamsler et al., 2018) as well as pathways for linking pro-environmental attitude and behavior and reducing consumption (Grabow et al., 2018).

Relational thinking

A small amount of the reviewed literature reflects the emerging emphasis on relationality in sustainability discourse. Relationality's growing popularity has resulted in different and often misaligned meanings (Walsh et al., 2020). Nonetheless, relational perspectives consider reality as an assemblage of entities that are continuously evolving through embodied and interconnected experiences (Alexander, 2016; West et al., 2020). Relationality has been predominately positioned within social science and humanities research to describe non-anthropocentric perspectives that give agency to non-human entities (Haraway, 2015; Latour, 2015) yet much of the philosophies are based on ancient concepts across Indigenous knowledge (Panelli, 2010; Whyte, 2020).

Overall Theme: Human-nature connectedness

Identified knowledge theme	Shared concepts within & across knowledge themes: 1.) Holism & Complexity	2.) Well-being, regeneration & resilience	3.) Awareness & reflective mindsets
Indigenous knowledge	All beings are holistically interconnected and continuously evolving in embodied relationships (Gray, 2016; Russell & Ens, 2020).	Holistic well-being is practiced through sacred Indigenous cosmologies and intergenerational knowledge transfer (Diver et al., 2019; Gould et al., 2021).	Human needs are guided by "kinship" or "kincentric" awareness to strive for harmonious interactions with all aspects of nature (Kimmerer, 2012; Boehnert, 2018; Russell & Ens, 2020).
Local, place-based knowledge	Local and place-based knowledge is a situated understanding of holistic, biocultural diversity (Briggs et al., 2019).	Well-being is informed by placed-based, emergent process rather than predetermined meanings (Tadaki et al., 2017; Peçanha Enqvist et al., 2018).	Relationships with place are active rather than passive: it is a moral responsibility to care for the surrounding environment (Chapin et al., 2011).
Relational thinking	Relationality is a way of understanding the reciprocal betweenness of human and non-human actors (Akama, 2014; Alexander, 2016).	Relational caretaking of nature is considered a virtue and one that gives meaning back to self (Riechers et al., 2020; Pascual et al. 2017).	Critical reflection through relational processes expand awareness of the many ways agency can be expressed, especially in non-human entities (Barrett et al,. 2017; Tillmanns, 2020).
Systems thinking	Complex interactions between components and environments are open, emergent, continuous and self-regulating through feedback loops (Dori et al., 2019; Melo, 2020).	Social-ecological systems resilience is measured by the extent of adaptive and transformative capacities to support continued "human well-being" (Folke et al., 2016).	Systems thinking can be considered as a practice or state of mind to continuously re-align human goals with that of the rest of nature (Mang & Reed, 2012; Reed, 2007).
Inner, subjective knowledge	The inner self and the broader world are interconnected as a complex and dynamic entanglement of actors" (Aedo et al., 2019).	Flexible and adaptive capacities can lead to increased resilience and deliberate engagement in sustainability transformations (Gram-hanssen, 2019; Luthe & Wyss, 2015).	Making a connection between one's inner understanding of self and outer behaviors can lead to greater awareness of one's role within the world (Hakio & Mattelmäki, 2019; Biberhofer et al., 2018).
Spiritual, religious knowledge	Wholeness with the cosmos is emphasized through consciousness of self, transformative capacity and "radical complexity" (Kohler et al., 2019; Gray, 2016).	Concepts like dark green religion and deep ecology consider the well-being of all life forms as philosophical and sacred practice (Conty, 2019; Koehrsen, 2018).	Revitalizing spiritual aspects like enchantment, awe and wonder within the cosmos can help build empathy for other species (Taylor et al., 2020; de Witt, 2014).

Figure 2: Within the overarching umbrella of human-nature connectedness, each knowledge theme (systems-thinking, spiritual, religious knowledge, etc.) has diverse interpretations of shared concepts: 1. Holism & complexity; 2. Well-being, regeneration, and resilience, 3. Awareness & reflective mindsets. This is illustrated through a matrix of 18 examples from the literature. (Figure 2 can be downloaded as high-resolution PDF file at: https://www.ojs.unito.it/index.php/visions/article /view/7309)

Relational perspectives can be effective in reframing human-nature connectedness as "process ontologies" rather than fixed states (Hertz et al., 2020).

4.3 Shared concept clusters

The following section describes how the three shared concept clusters are manifested across the six knowledge themes. Developed from the QCA results, the matrix in Figure 2 illustrates the co-occurrence of three concept clusters, six knowledge themes, and the overarching theme of human-nature connectedness through 18 examples from the literature. The relationships between these themes and concepts are further elaborated on the following sections.

Holism and Complexity

In addition to human-nature connectedness, holism and complexity are identified as key conceptualizations of sustainability across the six knowledge themes. Indigenous knowledge contains the most expansive understandings of these concepts, in which the entirety of an individual (spiritual, intellectual, physical, emotional) is interconnected with all other living and non-living entities through evolving relationships (Sharma & Kanta, 2021; Stewart, 2018). Metaphors and stories are often used to understand the complexity of these interactions, reconcile conflict, and reevaluate priorities (Fonseca-cepeda, 2019; Timoti et al., 2017). Like a metaphor, the concept of place in both Indigenous and local knowledge is considered a contextual manifestation of complex human-nature interactions (Lam, Hinz, et al., 2020).

Within the discourse on spirituality and religious knowledge outside a specified context of Indigenous knowledge, scholars discuss the need for more holistic philosophies that connect a "consciousness" of self with the broader cosmos (Kohler et al., 2019). For example, the Confucian concept of *qi*, or the holistic force that brings harmony to all life, can offer a pathway for individually and collectively reconnecting to nature (Mok, 2020). Similarly, texts focusing on subjective and inner knowledge advocate for more awareness of the complex relationships between self and broader realities (Aedo et al., 2019). Some conceptualize this as the noosphere, or the evolving interactions between human consciousness and broader anthropocentric activity (Grachev, 2018).

Likewise, systems-thinking perspectives are based on complexity and part-to-whole relationships (Espinosa et al., 2008; Sterling, 2003). Yet within the literature, systems-thinking is considered more as a tool to address complex challenges, such as the ice-berg model and leverage points perspectives

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(Davelaar, 2021; Fischer & Riechers, 2019) which contrasts the more embodied ways of understanding complexity in Indigenous knowledge (Heke et al., 2019). While some authors suggest that the basic principles of systems-thinking are similar to Indigenous knowledge such as emergent and open part-to-whole relationships; (Ali et al., 2021), others argue that systems-thinking ultimately tends to abstract complex understandings of reality, whereas Indigenous knowledge and some forms of local knowledge cannot be truly understood outside lived experience (Goodchild, 2021).

This connects with recent debate on the nuances between systems-thinking and relational knowledge (Walsh et al., 2020; West et al., 2020). Some authors argue that relational worldviews differ from a systems-approach in that there is less emphasis on the entities themselves, and rather greater focus on the betweenness of reciprocal processes (Akama, 2015; Latour, 2017; Stenseke, 2018). For example, systems-thinking literature describes complex adaptive systems as autopoietic, or self-organizing, in which their own components are continually reproduced over time (Onori & Visconti, 2012). However, relational thinking is supported by a sympoietic process, or the collective process of being and becoming through togetherness (Collett et al., 2020; Haraway, 2015) which is also substantially present in Indigenous knowledge.

Well-being, regeneration, and resilience

In addition to the complex and holistic dimension of human-nature connectedness, the literature broadly describes the normative aspects of these relationships as well-being (Laininen, 2018; Strunz et al., 2019). Well-being is considered both a subjective, values-based concept as well as a functional metric in maintaining healthy social-ecological systems (Salonen & Konkka, 2015). Well-being is broadly described through a sense of collective equity and inclusivity (Paulson, 2017) cultural values (Towler et al., 2019), a focus on degrowth and ecospirituality (Lestar et al., 2020; Paulson, 2017) and multi-species well-being (Parsons et al., 2017; Rupprecht et al., 2020; Treves & Lynn, 2019).

Many scholars describe the active role humans have in contributing towards holistic well-being (Chapin, Power, et al., 2011; Peçanha Enqvist et al., 2018; Weller, 2014). Within sustainability science, this concept is commonly regarded as stewardship (Mathevet et al., 2018). Although the term itself was underrepresented within the literature, the concept is present across several knowledge themes, which relates to broader calls to expand siloed understandings of stewardship (Chapin, Pickett, et al., 2011). For example, from the literature concerning spiritual and philosophical perspectives, Arne Næss's deep ecology principles (Lie & Wickson, 2011) and Aldo Leopold's "land ethic" (Hourdequin, 2017; Keong, 2016; Mayer, 2018) both recognize human's responsibility to respect nature's own agency.

These ideas of moral obligation and care for nature are also deeply present within Indigenous knowledge, yet have a greater emphasis on reciprocity (Abram, 1996; Akama, 2014). In contrast to Western concepts of scarcity and competition, Indigenous perspectives emphasize the abundance that nature offers – gratitude is seen as an intrinsic motivator for "giving back" (Coscieme et al., 2020; Diver et al., 2019; Kimmerer, 2012). For example, caring for the Waipā river (in what is now called New Zealand) acts as the spiritual, cultural, and ecological core of the Maniapoto tribe's identity and well-being (Parsons, et al., 2017).

This relates to how relational understandings of multi-species equity, egalitarianism, and collaboration are discussed within the literature (Alberro, 2020; Haraway, 2015; Plumwood, 2001). Inspired by Indigenous knowledge, relational caretaking of nature is considered a virtue and gives meaning back to self (Pascual et al., 2017; Riechers et al., 2020). This is often described as care ethics, "caring for" and "caring about" nature (Bellacasa, 2011; Dooren, 2014; Moriggi et al., 2020).

On the other hand, authors tend to describe systems-thinking with a more indirect relationship to well-being. Systems-thinking is not intrinsically normative, yet it has the potential to contribute towards more regenerative cultures that support emergent, healthy human-nature networks (Duarte Dias, 2018; Mang & Reed, 2012; Swat et al., 2019). Broadly speaking, regenerative cultures are based on context specific "living systems" or "whole systems" that actively aim to restore past damages and reconcile separation from nature (Capra, 1996; Cole, 2012; Gibbons, 2020). This corresponds to how place-based knowledge considers regeneration as evolving and interlinked processes across temporal and spatial scales, rather than preconceived outcomes (Benne & Mang, 2015). For instance, the "satoyama" Japanese biocultural landscapes are specific contexts in which humans are active participants in regenerating water cycles, rice production, fish habitat and social belonging to the land (Chakroun et al., 2020).

Furthermore, the literature also discussed aspects of social-ecological systems research and resilience as key dimensions of conceptualizing sustainability (Jones & Comfort, 2018; Rogers et al., 2020; Zanotti et al., 2020). The literature defines social-ecological systems (SES) as the resilient and continuous interaction of biophysical and social factors (Everard, 2020). SES resilience is measured by the extent of adaptive and transformative capacities to support continued "human well-being" (Folke et al., 2016). Despite the holistic lens, authors argue that the historically anthropocentric focus in SES research has excluded the agency of non-human actors (Contesse et al., 2021). Likewise, scholars advocate for more place-based and biocultural emphasis on SES resilience indicators (Dacks et al., 2019; Zanotti et al., 2020) and the inclusion of more subjective dimensions like emotion, consciousness or agency (Reid & Rout, 2018). For example, authors highlight how Indigenous knowledge intrinsically incorporates these aspects by conceptualizing resilience as a flexible and participatory process that weaves mind, body and spirit with broader non-human networks (Salmón, 2000; Timoti et al., 2017).

Finally, the literature also emphasizes social and cognitive dimensions of resilience as important adaptive capacities in supporting holistic, regenerative societies (Luthe & Wyss, 2015; Marschütz et al., 2020). Within the discourse on inner and subjective knowledge, scholars argue that more effective processes are needed to accept uncertainty and prepare for change, rather than only reacting to it (Bartels et al., 2020; Rawluk et al., 2019; West et al., 2020). Communities with high levels of flexibility and diversity are more prepared for deliberate engagement in shaping sustainability transformations, which increases resilience (Gram-hanssen, 2019; Luthe & Wyss, 2015). Such a process can be cultivated by building personal and collective trust to maintain a sense of purpose, regardless of external factors (Eriksson & Lindström, 2014; Laininen, 2018; Woiwode et al., 2021). Similarly, mindfulness practice has become a recognized way of building mental resilience, by channeling emotions like empathy and compassion during both periods of disturbance and stability (A. H. de Witt, 2016; Gómez-Olmedo et al., 2020; Wamsler, 2018).

Awareness and reflective mindsets

In line with building cognitive resilience, there is substantial emphasis on the need to cultivate the awareness of human-nature connectedness, as the first step towards expanding worldviews (Ruiz-Mallén & Heras, 2020). Across the different knowledge themes, awareness and critically reflective mindsets are broadly framed as key competencies for reconciling relationships with nature (Aedo et al., 2019; Laininen, 2018; Thiermann & Sheate, 2020).

Within the literature on inner and subjective knowledge, scholars support critical reflection and awareness as core skills for adapting in times of uncertainty, such as dealing with discomfort and lack of control (Aedo et al., 2019). Specifically within mindfulness research, compassion and present-state awareness are emphasized as pathways to reconnect to nature (Doran, 2013; Ives et al., 2020; Siqueira & Pitassi, 2016).

Likewise, scholars consider spiritual and religious concepts like enchantment, awe and cosmic wonder as ways to revitalize empathy for other species (A. H. de Witt, 2014; B. Taylor et al., 2020) and support opportunities for greater belonging (Allevato, 2018; Johnston, 2018). Awareness and agency are often described together within the literature. For example, spiritual well-being with the environment is based on active participation (Aniah & Yelfaanibe, 2018) and "ecosophy" principles advocate for achieving ecological harmony through the combination of consciousness and action (Drengson et al., 2011; Lie & Wickson, 2011). Yet authors also discuss the limitations of religion and pro-environmental attitudes in that they don't necessarily lead to transformative behavioral change (Corral-Verdugo & Frías-Armenta, 2016; Ives & Kidwell, 2019; Nash et al., 2020). On the other hand, scholars argue that philosophies like degrowth, anti-materialism and frugality within the eco-spirituality discourse are effective pathways towards transformative action (Koehrsen, 2018; Lestar et al., 2020).

Such entanglement between awareness and agency is strongly represented within the literature on Indigenous knowledge. Human needs are guided by "kinship" or "kincentric" awareness of all other non-human needs as a collective process in maintaining harmony with nature (Kimmerer 2012; Boehnert 2018; Russell and Ens 2020). Similarly within relational thinking, authors describe how engaging in multi-species care practices can cultivate a greater sense of "biophilic consciousness" and willingness to share resources (Fernández-Herrería & Martínez-Rodríguez, 2016).

Similarly, scholars describe how human activity adapts to accommodate the needs and inherent agency of a particular place, such as with Indigenous fishing practices (Diver et al., 2019). In terms of local and place-based knowledge, the literature discusses place as both a physical territory and a "terrain of consciousness" in how to live appropriately in that particular environment (Lynch, 2016; B. Taylor, 2000).

Although much of the systems-thinking literature tends to focus on problem-solving complex issues, it can also be considered a practice or mindset to re-align human goals with that of the rest of nature (Mang & Reed, 2012; Reed, 2007). Rather than seeking control, awareness of the whole through question-based rather than answer-directed approaches can help people adapt appropriately to new contexts as they arise (Senge, 1999; Wahl, 2016). Ultimately, such reorientation towards a culture of questioning requires shifting the dominant, solution-oriented worldviews through processes of learning (Barrett et al., 2017).

4.4 Redefining worldviews through (un)learning

In addition to these six predominant knowledge themes and shared concepts throughout, a substantial portion of the literature centers around reframing both students' and educators' worldviews through various methods and pedagogical models. While much of the texts concentrate on specific contexts outside the scope of this paper, there are several aspects that are useful to communicate: the types of learning that can help shift detrimental worldviews towards those that support greater human-nature connectedness.

Scholars advocate that learning should receive greater attention within sustainability transitions research as it is the foundation for understanding the complexity of variables involved (van Mierlo et al., 2020). Different learning types can be used to shift unsustainable, materialist outlooks towards holistic worldviews based on curiosity, creativity, and compassion (Geiger et al., 2020; Ives et al., 2020). For example, the most supported types for reframing worldviews are social and transformative learning (Bjerkan & Ryghaug, 2021; Pel et al., 2020; Yee et al., 2019). Both of these methods encourage critical reflection for determining how new knowledge shapes one's own worldview and drives behavioral change (Boström et al., 2018; Lange, 2004, 2019). In relational scholarship, reflexive learning can help recognize the plurality of ways in which agency is expressed, especially in non-human entities (Aedo et al., 2019; Barrett et al., 2017; Tillmanns, 2020).

Likewise, within much of the literature related to Indigenous and local knowledge, scholars are increasingly advocating for more context specific, place-based learning. Community-based, participatory, and experimental learning within local and outdoor settings raises awareness about how different worldviews co-exist and helps to transcend artificial binaries between humans and nature (Herman et al., 2021; Paulus, 2016; Sumida Huaman et al., 2019). These types of "life-place learning" (Thayer, 2003) or "learning in place" (Williams et al., 2018) offer opportunities to rediscover traditional ways of knowing and "un-learn" destructive and exploitive assumptions based on dominant, reductionist worldviews (Laininen, 2018).

5. Discussion

This review paper offers readers an overview of current peer reviewed literature on different knowledge themes and concepts that constitute worldviews beyond sustainability. From the subjectivity of inner or spiritual knowledge to the objective ideals of systems-thinking in sustainability science, each of these knowledge themes can have a role in reconnecting ourselves with nature and engaging within sustainability transformations. The following sections unpack the relationships between gaps and limitations, discuss the results, offer the author's self-reflective worldview, and suggest future research avenues.

5.1 Research Gaps

Despite the vast amount of literature reviewed, there are noteworthy gaps within the research around worldviews and sustainability. Technocentric and socio-technical perspectives on sustainability, especially within transitions research, were lacking. For example, there was almost no mentioning of core concepts like scaling-up and out technological innovation, despite the broad keyword search of "worldview and sustainability." Additionally, subjective interpretations of sustainability such as mindfulness and inner spirituality were primarily situated within education for sustainability and strategies to reduce consumption, lacking association with broader and more diverse contexts. Only a few texts discussed spiritual and philosophical perspectives from Confucianism, Buddhism, and Taoism, even though concepts found within these practices are relevant to the discussion around worldviews and sustainability. Also lacking were more detailed posthumanism and ecofeminism perspectives, beyond general references to seminal texts. Likewise, there was almost no mentioning of design-based or artistic perspectives. Although there was substantial discussion of Indigenous knowledge within the literature, it is critical to highlight the underrepresentation of non-Western, non-academic, and non-English speaking voices. Even though authors can attempt to communicate Indigenous knowledge through peer-reviewed articles, dominant Western methodologies and formats can exclude embodied and non-written forms of knowledge (Parsons et al., 2017).

These gaps relate to the objectives of this review paper: to understand what kind of discourse is being included on worldviews and sustainability within peer reviewed literature in the academic system and how this can expand awareness on the limits of what can be known about worldviews.

5.2 Methodological Limitations

The established methodology of quantifiable keyword searches in peer-reviewed databases represented an accessible choice for the author to scan a large amount of literature within a defined scope, considering time, language, and resource constraints. However, this accepted scientific method limits the diversity of knowledge that could be included in such a review. While this method can function well for specific topics within defined disciplinary boundaries, the complexity of worldviews and related transdisciplinary concepts around sustainability challenges the effectiveness and appropriateness of quantitative databases searches. What do these broadly accepted methods say about our own worldviews as researchers, and the academic system at large? The peer-review publication process itself requires certain kinds of worldviews based on certain credentials achieved through certain institutions. Knowledge-holders who do not conform with these standards tend to be excluded, despite the growing focus for more transdisciplinary and participatory approaches for academic research.

While this review paper represents only a small window of knowledge, this can act as a starting point in gaining awareness of the limitations of how worldviews are discussed within the academic system. This also relates to the author's own worldview and inherent limitations.

I am a trained architect, teacher, and systemic design academic who values self-reflection and self-exploration. I also identify as a Western, white person in a privileged position to contemplate these ideas. Both the subconscious and conscious understanding of my own worldview limits what I can understand about other worldviews. For example, my position within a design institution has influenced the choice to explore both the value and limitations of quantitative research methods, like database searches. I aim to continuously acknowledge my privilege, my limitations and expand my worldview to be as inclusive as possible, especially by actively engaging with and learning from others who hold identities and worldviews that are different than my own.

For future research with greater funding and institutional support, the author strongly advocates for expanding on the vastness of worldviews and sustainability by involving an equally wide range of practitioners and non-academic partners, especially from non-Western contexts like the Global South and members of Indigenous communities. Likewise, disseminating such knowledge through a broader selection of formats outside of peer-review articles, such as podcasts, artistic performances, or visual didactics, can help expand the worldviews of all involved.

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5.3 Discussion of results

Considering these limitations, a main observation of the reviewed literature is both the broad consensus on human-nature connectedness as an overall dimension of sustainability and the disciplinary and cultural differences in how this theme is conceptualized. Generally, the primary tensions lie in striving for factual, quantifiable measures of sustainability versus understanding sustainability through collective/individual perceptions and embodied, lived experiences. For example, most literature on resilience from a systems-thinking perspective remained in the "out there" context and did not link between research related to cognitive resilience, such as mindfulness. Maintaining the evidence-based and quantifiable outputs of science is needed to guide some aspects of sustainability transformations, like calculating climate change effects on social-ecological systems. Yet other knowledge themes like relational thinking or local knowledge could help operationalize intangible dimensions for place-based and culturally specific future resilience pathways. Likewise, Indigenous knowledge offers many learnings for how resilience can be understood as a multi-dimensional, spiritual, reciprocal, and embodied practice. Finally, activating the cognitive dimensions of resilience capacities like mindfulness is critical for being able to cope with complex change processes like sustainability transformations.

This example illustrates that none of these knowledge themes necessarily have more value over the other in how resilience is conceptualized. Instead of trying to reconcile or forcibly converge such different perspectives together, perhaps an appropriate pathway would be to understand the depth and range of where knowledge themes conflict and how they are connected. For example, as presented in the results, at a micro level authors describe holism differently from a system-thinking or Indigenous knowledge perspective (abstracted versus embodied understandings). Yet at a macro level, both these knowledge themes, and the others identified in the reviewed literature, share an awareness of a common whole – that humans are part of the broader web of life. Thus, commonalities and differences depend on the degree and scale in which they are understood. Assessing concepts like holism from diverse worldviews can help reframe cultural or disciplinary boundaries as zones of connection, rather than separation. Therefore, it could be highly beneficial to cultivate more collective and inclusive processes of unpacking which knowledge themes are useful when and for what on purpose, context and actors involved.

5.4 Future research avenues

These examples represent a clear challenge – the ripple effects of reductionist thinking prevents us from being able to holistically work with different ways of knowing and operationalizing plural notions of sustainability. This could be a key direction for future research, with transdisciplinary practices like systemic design offering potential pathways to engage with this challenge. For example, scholars within systemic design are exploring how the intersections between science, design and real-world practice can be used to inform more effective strategies and methods for intervening in complex systems change (Luthe et al., 2021). Relatedly, greater attention is needed in how sustainability knowledge is validated within academic discourse and society at large. Are we able to accept that phenomena exist, even if we cannot prove its validity? For example, it was only until recently that the natural sciences have begun to legitimize "unproven" knowledge that Indigenous communities have known for millennia, such as the genetic interlacing of tree communities (Mitchell, 2018).

This also relates to a key issue in how sustainability is communicated within the reviewed literature. The results show that there is a need to clarify what sustainability is attempting to address, which relates to the ambiguity of the term itself. The normalization of "sustainability" has ironically diluted the urgency required within sustainability transformations. "Sustainability" is arguably the most generic term to reach a broad audience. Yet it acts only as an entry point towards deeper discussion: it is not sufficient to describe the complexity of human-nature connectedness. On the other hand, as shown in Tables 2 & 3, an array of different descriptors that communicate very similar ideas can lead to public confusion and apathy in reconnecting with nature. Thus, future research could explore the ways in which a plurality of worldviews can flourish while simultaneously be communicated through a common language to accelerate solidarity and action. For example, the framing of "traditional" worldviews can be confusing. Many authors use "traditional" ways of knowing to describe Indigenous epistemology, which is holistic and integrative. However, this does not align with the "ideal-typical" worldview classifications of traditional-modern-post-modern-integrative, where "traditional" stems from a Judeo-Christian set of values based on a monotheist reality where humans are managers of nature (Conty, 2019) (see Table 3). For future research, it would be useful to do a comparative analysis on how misleading words like "traditional" shape perceptions of human-nature connectedness.

Relatedly, additional future research on socio-political ideologies of diverse worldviews in relationship to sustainability would be valuable, such as ecofeminism and its emphasis on activism and emotionally equipping people to confront interconnected social and ecological injustices (Bell et al., 2021). Likewise, future pathways for broadening worldviews and encouraging greater engagement in sustainability perspectives could include more artistic and creative perspectives. For example, many two-dimensional representations of complex social-ecological systems, such as text or system maps, are limited in their capacity to activate deep emotional and lived experiences of those systems. Expanding awareness and participation in performative and embodied experiences (such as theater, artistic ceremonies, serious games, mindful outdoor movement, etc.) could help expand understandings of how interactive and creative "warm data" (Bateson, 2018) can contribute to (un)learning processes for shifting worldviews. This could also be a future avenue for relating to emerging posthumanism research on embodied processes, specifically around connecting technological, biological and philosophical dimensions of human and non-human relationships through collective "doing-making-thinking-creating" (Taylor et al., 2023).

Activating a culture of questioning: building adaptive capacities to engage in the complex web of life

Even though sustainability science is advocating for more solutions-oriented research to bridge the knowledge to action gap (Tengö & Andersson, 2021), it is critical to recognize that this derives from a modernist worldview rather than the process-oriented approaches found in Indigenous knowledge or relational thinking (Hertz et al., 2020). Concrete short-term actions are needed to address the urgent issues at hand, but this should not hinder the parallel need to develop greater capacities to engage with emergent processes that prepare us for change - rather than only responding to its effects. Institutions themselves must cultivate the conditions for change to emerge, for example, confronting the underlying worldviews that drive academic reward systems. We need more holistic worldviews that are based on critical reflection and questioning – to learn and understand our roles in the complex systems we inhabit and continuously reframe them as new contexts arise (Wahl, 2016). Such worldviews can invite different ways of approaching decision-making in uncertain conditions – when data is evolving, unknown or can never be known, we can still take more iterative, processes-oriented actions that can more easily adapt when new knowledge is produced.

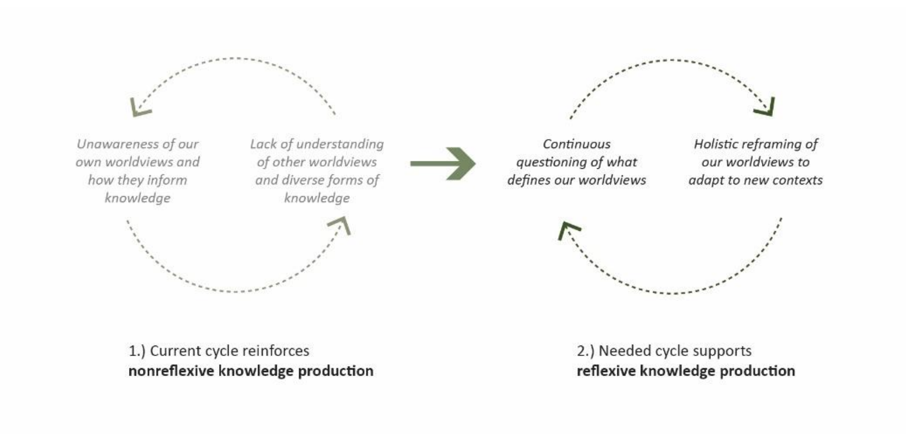

Figure 3: Within the current academic system, detrimental cycles of nonreflexive knowledge production continue to be reinforced through the lack of awareness of both one's own worldview and diverse worldviews (cycle 1). Transitioning towards a culture of continuous questioning can lead to greater adaptation and holistic evaluation of worldviews, supporting reflexive knowledge production (cycle 2). (Figure 3 can be downloaded as high-resolution PDF file at: https://www.ojs.unito.it/index.php/visions/article /view/7309)

This relates to an interesting challenge in generating this paper. The format of a literature review itself highlights the limitations of the academic system – papers on worldviews from scholars that align with certain worldviews have been reviewed through this author's own worldview. As much as we try to maintain a level of objectivity and replicability within the current academic system, detrimental cycles of nonreflexive knowledge production and dissemination continues to be reinforced, at the expense of non-compliant forms of knowledge (Figure 3). We can transition from this nonreflexive cycle towards a reflexive cycle by taking the time to question actively and collectively what a worldview is, how it is used in a particular context and who's worldviews are predominately voiced. This greater awareness can lead to the continuous practice of jointly reframing our worldviews on a systemic level to begin to unravel the hegemonic structures of validating knowledge. Such a process could potentially help us unlock the artificial barriers that have been preventing us from deeper connection between ourselves, each other, and nature.

Ultimately, readers are invited to thoroughly question this review paper– by doing so doesn't make it any less valid – instead, such practice invites opportunities to fully embrace the complexity, imperfection, and uncertainty of our worldviews as plural, dynamic constructs.

6. Conclusion

This review offers a detailed synthesis of an extensive amount of literature on diverse worldviews of and beyond sustainability. Research across sustainability science has increasingly advocated for greater understanding of the root causes that shape our behaviors, systems, and societies – our worldviews. While reductionist and modernist worldviews continue to dominate much of global sustainability discourse, the reviewed literature reveals a growing emphasis on the urgent need to transition towards worldviews that support deep human-nature connectedness. This paper contributes to sustainability discourse by providing an overview of current literature from different research streams, disciplines, and cultures. The results are synthesized into a collection of identified knowledge themes (Indigenous knowledge, systems-thinking, relational thinking, inner/subjective knowledge, spiritual/religious knowledge, and local/place-based knowledge) that have diverse conceptualizations of shared concept clusters: 1. holism and complexity, 2. well-being, regeneration, and resilience and 3. awareness and reflective mindsets. Likewise, key gaps from the results include a lack of emphasis on culturally diverse understandings of spiritual and inner dimensions of sustainability; an absence of a common language in describing worldviews of human-nature connectedness; and a lack of processes to holistically connect across different worldviews without oversimplifying or reinforcing detrimental power structures.

Instead of relying on outdated interpretations and furthering the distinction between ways of knowing, greater attention should be focused on the interconnectedness of ideas, theories, and methods: each has something to contribute towards a livable future for humankind and inspiring a reconnection to the broader web of life. This also suggests the need for critical awareness of when conflicting worldviews become obstacles towards human-nature connectedness. While some worldviews may "only" limit the degree of human-nature connectedness, others can also produce significantly detrimental social-ecological effects. Sustainability transformations require a systemic, societal shift in how we conceptualize our relationship with the biosphere, which requires both an individual and collective responsibility to critically reflect upon and broaden our worldviews. The plurality of knowledge themes presented in this review, coexisting in rich complexity, invites readers from all walks of life to actively participate in reframing, questioning and continuously designing their own worldviews, as a part of the larger scale systems-change needed for sustainability transformations.

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Note about Figures and Appendix

Figures 1, 2 and 3 and Appendixes A, B and C can be downloaded from the respective separate pdf files at this link: http://dx.doi.org/10.13135/2384-8677/7309

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Original Paper

Intergroup selection as a way to peace and sustainability

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Abstract. *Due to an increasing demand for resources that exceeds the biophysical system's ability to regenerate itself (Wackernagel et al., 2021), environmental resources are under stress, and society faces uncertainties related to their scarcity and climate change that can lead to violent conflicts.*

This context raises questions about mechanisms to understand the phenomenon and adapt. Therefore, Fisher and Rucki's (2017) approach becomes relevant: economic development, ecosystem functioning, peace, and conflict management are necessary components of sustainability, but how they work together is not well understood. To address this issue, a theoretical path is proposed based on three approaches: sustainability transition, complexity economics, and peace from a vision of complex systems. By promoting cooperative behaviors through intergroup selection processes, progress can be made toward sustainability and the emergence of peace as a stable behavior.

1. Introduction

Due to an increasing demand for resources that exceeds the biophysical system's ability to regenerate itself (Wackernagel et al., 2021), environmental resources are under stress, and society faces uncertainties related to their scarcity and concomitant crises such as climate change. This context has led to conflicts that raise questions about mechanisms to understand and adapt. One of the current mechanisms that seeks to improve human conditions in this environmental context is the Sustainable Development Goals (SDGs) proposed by the United Nations (United Nations, 2023).

These goals aim to establish an agreement between society and its inhabitable world to ensure human well-being. One of these objectives is peace, as violence and insecurity have a destructive effect on a country's development, which in turn affects its capacity for sustainable economic growth (United Nations, 2023).

The absence of peace has significant costs for nations, not only in terms of suffering for their population but also in economic terms, delaying progress and access to well-being. In 2019, the economic impact of violence was estimated at 14.4 trillion dollars, equivalent to five dollars per person for each day of the year. Therefore, in the context of peace, redirecting these resources could significantly improve the well-being of large numbers of people (Institute for Economics & Peace, 2021).

Although the Sustainable Development Goals (SDGs) recognize peace as imperative for sustainable development, the term itself remains conceptually and operationally vague (Fisher et al., 2021). Furthermore, Fisher and Rucki (2017) note that there are only superficial understandings of how the drivers of any component of sustainability (economic development, ecosystem functioning, and peace) work. While it is known that environmental quality affects economic development and that access to resources affects the probability of conflict, these relations require a deeper understanding of feedback processes within the system they comprise. As these dynamics are intertwined, less disciplinary and broader approaches are required.

We propose a theoretical path based on the complex adaptive system (CAS) approach, which offers mechanisms that favor peace as an emergence from economic, social, and environmental interactions. To achieve this goal, we investigated environmental, social, and economic perspectives that work jointly. Therefore, research has been carried out on systemic approaches starting from each disciplinary field.

This study goes beyond systems understood as a certain number of interacting elements (Bertalanffy, 1986) and complex systems in which the interacting parties present an emergency (Newman, 2009). Instead, it delves into complex adaptive systems characterized by having a large number of agents that interact, adapt or learn (Holland, 2006), modifying their structure or behavior in response to external changes or to the emergence that they themselves create.

Starting from environmental approaches, research has delved into complex adaptive systems (CAS), where the sustainability transition is circumscribed. From different perspectives, the Sustainability Transitions Research Network (STRN) seeks to create a path in which society can combine economic development and social well-being with a reduction in pressure on the environment (Brauch & Oswald Spring, 2016). One of the approaches used by this current is related to CAS, in which the system presents an adaptation through a complex and non-linear response to external disturbances that can be considered an input of the system but from a multilevel perspective (Grin, 2016). For example, a response to climate change that occurs at a high level of system aggregation affects individual agents' decisions.

From an economic approach, the concept of a complex adaptive system in the economy has been investigated. This approach moves away from a mechanistic notion of equilibrium and emphasizes that people are not gears in a machine but that human behavior co-evolves with the environment. In this environment,

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cooperation and competition, the formation and dissolution of alliances, and the emergence and dissolution of structures generate systematic changes in the goals pursued. This implies permanent changes that maintain microdiversity and generate emergent phenomena. Therefore, the economic system is unstable, evolutionary, and complex (Gomez & Gubareva, 2021).

From this approach to complexity economics, rationality is inductive. Arthur (2015) raises it as beliefs or hypotheses adapting to the aggregate environment they jointly create. After some initial learning, hypotheses or mental models adapt to each other. Agents compete for survival against other agents' ideas or mental models. This is a system that is both evolutionary and complex.

Following this perspective, the multi-level selection mechanisms in the evolutionary process proposed by Wilson (2016) were analyzed, which provided clues to identify behaviors at the agent level that transcend to higher levels of system aggregation. For this, the consideration made from complexity economy is relevant when accepting that human behavior is ambivalent and is influenced by both selfish instincts and authentic social practices (J. Spangenberg & Polotzek, 2020). From this perspective, sustainability contains social dilemmas that imply taking charge of a common good, such as the environment in which particular and common interests are intertwined, which is therefore determined by cooperation and/or competition actions.

In this sense, Bowels and Gintis (2002) suggest that cooperating implies deciding better for beneficial behaviors in groups to coevolve. His studies identified that cooperative behaviors benefit the members of a group, allowing those made up of highly cooperative individuals to dominate in intergroup conflicts. In this direction, Cottey (2018) suggests that cooperation can prevent conflict, since it thrives in environments where individualism, competition, and accumulation are present by showing a severe attitude towards losers.

As already mentioned, mental models are dynamic by adapting to each other. In this sense, Mebratu's (1998) contribution is relevant when proposing that sustainability is an epistemological resource for the desired future. Therefore, it is dynamic and subject to society's realities and expectations over time. Under this consideration systemic approaches from the social sciences were investigated to understand the emergence of peace.

In this context, the sustainability approach of Fisher and Rucki (2017) becomes relevant, according to which sustainability is the process of maintaining the progress achieved in the dynamics of desirable systems while other dynamics are actively changed, modified, or improved to bring the system closer to the objective of social justice and human well-being. For this reason, economic development, the functioning of ecosystems, and peace and conflict management become necessary components of this sustainability.

From this approach, in which these authors have researched, together with Coleman, the relations of conflict, development and environment from a complex systems approach, Coleman defines sustainable peace "as existing in a state where the probability of using destructive conflict and violence to solve problems is so low that it does not enter into any party's strategy, while the probability of using cooperation and dialogue to promote social justice and well-being is so high that it governs social organization and life" (Coleman, 2016, p. 150).

Although peace is complex and idiosyncratic, when operationalizing it, it was identified that positive intergroup reciprocities in this type of peaceful society far outweigh negative intergroup reciprocities (Coleman et al., 2020). From this concept, his studies have found that in contexts of stable peaceful societies the central dynamics responsible for the emergence and maintenance of sustainable peaceful relationships in societies are the thousands or millions of reciprocal intergroup interactions that occur daily between members of different groups. In those communities, peace depends on the degree to which the most positive interactions outweigh the negative ones. If the positives outweigh to a significant extent the negatives, the probability of maintaining peace will be greater. This finding constitutes a significant contribution to identifying how, from simple behaviors in a system, sustainable peace emerges as a pattern at a high level of aggregation, in which cooperative behaviors have a determining role.

Finally, some examples of self-organized cooperative behaviors originating in complex systems were identified to propose a theoretical path from economic relations to implement mechanisms to promote peaceful behaviors and thus contribute to sustainability framed in healthy ecosystems, economic development, and peace. In this way, it contributes to the Sustainable Development Goals, particularly peace.

This paper is structured as follows. The first section describes the context in which the phenomenon to be investigated is situated, indicates how it has been poorly studied, and presents a general conceptual framework for complex systems. The second part focuses on the theoretical proposal developed from three disciplinary approaches from the sciences of complexity: transition to sustainability, the economy of complexity, and peace as an emerging pattern of interactions in social systems. The theoretical elements taken from these approaches are used for the construction of the theoretical proposal of sustainability and peace. The proposal is shown in section three. Finally, section four presents conclusions.

2. Environmental conflict: Intersystemic vision

This section examines some dynamics identified in the literature that show how peace is affected by behaviors in different systems. Then it is shown how these connections are weakly studied.

2.1 Problem context

Understanding peace as a phenomenon that gravitates around inter-systemic relationships requires considering the ontology of ecological economy. This presents the environment as a meta-system that includes the social system of which the economy is a subsystem, forming a nested order (Spangenberg, 2016).

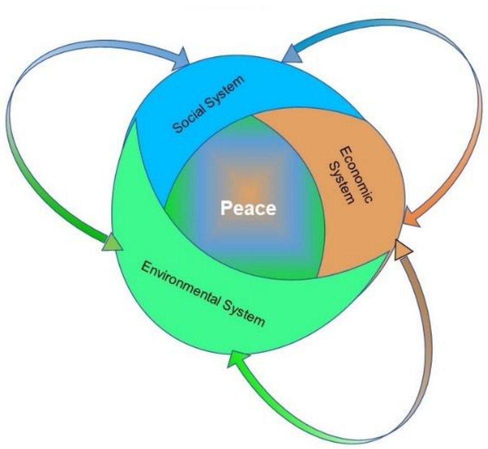

Figure 1: Peace as intersystemic emergence

In Figure 1, the three systems (economic, social, and environmental) are represented as independent but cohesive simultaneously, and, from a more aggregate perspective, they form the metasystem. At this level of abstraction, dynamics between those systems in different directions are symbolized, and peace (or its absence) emerges from these.

The dynamics found in the literature show that behaviors are not strictly assignable to a single system; on the contrary, it is evident that, in some cases, they can operate simultaneously, among themselves, or with feedback mechanisms. Some of these dynamics to consider are:

- The continuous expansion of the human sphere (Scheffran, 2016) increases demand and puts pressure on natural and ecosystem resources.
- Different economic growth rates, combined with different rates of technological growth, contribute to the emergence or maintenance of conflicts in the social system. This situation results from a tendency to carry out activities at levels not previously experienced by society or to acquire a certain degree of influence or control over a wider expanse of space or a more significant number of people (Choucri & North, 1972, cited in Stephenson, 2016).
- Unsustainable processes exacerbate the environmental crisis, which affects infrastructure and ecosystems (U.S. Global Change Research Program, 2017), as well as social destabilization, which can generate violent actions due to scarcity of resources, such as drinking water or food (Brauch, 2016).
- Economic processes like world transport, trade, and financial markets are also subject to climate change. Financial transactions and information on prices represent virtual transactions, which link environmental events in short periods. If there is an effect in a place due to the weather, there may be production losses or bankruptcies of companies, which are reflected in the stock market and spread through global networks and markets (Scheffran, 2016).
- In areas affected by the conflict, an inefficient administration of income prevails, including those that come from natural resources (Naciones Unidas, Pacto Global, 2010).
- In periods of conflict, more significant environmental threats have been found due to increasing deforestation processes, inappropriate land use, return of the displaced population without proper planning, and great dependence on the primary sector, with significant impacts on the environment (Hochschild, 2015; Suárez et al., 2017).

As can be seen, these problems are not confined to a single system or a single level but rather present a multi-scalar structure. For example, natural disasters in a particular region can undermine the legitimacy and ability of states to protect their citizens from harm. If the agriculture of a developing country suffers significant effects, the livelihood and existence of many people are at stake. Loss of life, income, wealth, jobs, health, family, or friends causes unrest that threatens the social contract and undermines the political order. Some of these processes occur slowly and contribute to social and political stability erosion, while others arise quickly and exceed communities' problem-solving and adaptive capacity.

Another example is that change in temperatures and rainfall accentuates human migrations and brings security problems, which is a factor of conflict. Thus, the stronger the impacts and the more subsystems are involved, the more difficult it will be for societies to face the consequences (Scheffran, 2016). Moreover, the interdependencies between the environmental and social ecosystemic dimensions generate complex cascading and combined effects (de Coning & Krampe, 2021). Therefore, given these global interdependencies, destabilizations anywhere cannot be ignored.

These behaviors reflect the interactions between individuals and their environment, as well as between individuals themselves. This implies that decisions are made based on the expectations and reality of the environment, which has been subject to change from previous decisions. However, these decisions continue to transform both the environment and the individuals themselves in continuous feedback processes that are retroactions (Florez & Thomas, 1993).

Given that individuals have different preferences, dilemmas may arise from these interactions, which even occur over time, because previous decisions or events may condition a present decision and, in turn, impact the future. Hence, analyzing these phenomena must consider the capacity for learning, adaptation, and evolution to respond to the uncertainty that all future times bring.

In a way, the dominant epistemological approach in economics has influenced these interactions of individuals. Adam Smith[1]´s reflections suggest that the human being acts for his egoism and society satisfies his needs by achieving individual benefits (Smith, 1994). This conception that each agent acts for his

[1] "Man in most circumstances claims the help of his fellow men, and in vain can he hope for it only from their benevolence. He will achieve it with greater certainty by interest in his favor, the egoism of others, and by making them see that it is advantageous for them to do what he asks. Whoever proposes a deal to another is making one of those propositions. Give me what I need, and you will have what you want is the meaning of any offer. Thus, we get most of the services we need from others. It is not the benevolence of the butcher, the brewer, or the baker that procures our food but the consideration of their own interest. We do not invoke his humanitarian sentiments but his selfishness; nor do we speak to them of our needs, but of their advantages" (Smith, 1994, pp. 45-46).

interest has persisted in economic models; the nature of economic theory has been influenced by this premise (Sen, 2007a). Economic well-being has been dominated by the utilitarian tradition, which considers interpersonal aggregations; the common welfare would be the total sum of all utilities of people involved (Sen, 2007b). The concept of utility raised by Bentham refers to the property or tendency of any object to produce benefit, advantage, pleasure, good, or happiness or prevent pain, evil, or unhappiness (Bentham, 1780).

Starting from the utility as a unit of account in which the greatest happiness minus any related penalty is sought, there derives a constituted cost-benefit relationship. In the economic model, this rationality translates into what someone is willing to pay for that utility. In this way, economic well-being is assumed to be linear. That is, the well-being of all is the sum of individual well-being. From the point of view of the logic of utility, this would be the most significant benefit for each individual who provides the goods or services at the lowest possible costs, which results in a dominant competitiveness model that promotes mass consumption, putting more significant pressure on environmental resources. From this perspective, many business models are based on constant product increases; thus, the culture of consumption is stimulated by ensuring changes in fashion, technological trends, and short product life cycles (Göpel, 2016).

Given these complex relationships, it has been identified that in international policy instruments such as the SDGs that represent an interconnected and integrated approach to development and sustainability, the links between environmental, economic, and social dimensions goals are not explicit enough to strengthen policy integration. Social and ecological justice is narrowly understood on the agenda and is limited to redress and access (Fisher et al., 2021). Similarly, the links between environmental sustainability studies and sustainable peace are known but must still be clearly identified (Stephenson, 2016). However, this type of problem could be addressed by systemic frameworks that welcome the overlap between areas of knowledge, as presented below.

3. Systemic approaches

Flórez and Thomas (1993) suggest that Comte's positivism of the 19th century, in which information is the only basis of knowledge, and this is only obtained from the study of the phenomenon whose objective reality is best determined in experimental isolation, implied a reductionist vision of the universe, which focused on disconnected objects and a disciplinary separation. That means the sciences were developed close to themselves by feeding the various scientific fields less and less and, therefore, offering scientific, individual, restricted, and fragmented explanations. However, in the second half of the XX Century, more holistic visions emerged, which began to break through with traditional reductionism. There, the «system» emerged as a key concept in scientific research (Bertalanffy, 1986).

The subject of this research is not only circumscribed in a system but in a complex and adaptive one that concerns several disciplines. In the literature, there is no univocity in the technical definition of a complex system (Cumming *et al.*, 2013; Newman, 2009) but at least there is some consensus that it is a system of parts that interact and display emergent behavior (Newman, 2009). Cumming et al. (2013) suggest that complex systems exhibit behaviors that include, but are not limited to, properties to alter system states that maintain different regimes; the ability to process information and respond to it; the presence of feedback loops that regulate or amplify trends, regularly resulting in multiple equilibria; and, once the system ends up in a steady state, it can be highly resistant to change, and considerable shocks are needed to switch to another regime. This phenomenon is known as a lockdown (Arthur, 2013). These feedbacks make it difficult to distinguish cause from effect. At this complex system level, the agents' interactions generate an emergence, which is not found in the interacting elements. In addition, there are delays in time and space, discontinuities, thresholds, and limits. For this reason, adding the behavior of small units to obtain the aggregate result is impossible (Costanza *et al.*, 2013).

As already specified in the introduction, complex adaptive systems (CAS) are those “systems that have a large number of components, often called agents, that interact, adapt or learn” (Holland, 2006, p. 1). One of the distinctive elements of these systems is that individual "adaptive" agents continually change their environment instead of following a fixed response behavior to external stimuli (BenDor & Scheffran, 2019). These agents can then adapt to their external environment, which includes other adaptive agents, changing rules as experience accumulates. Agents learn from their environment and modify their behavior by altering the system itself (Holland, 1996).

However, complex systems, particularly adaptive ones, present characteristics that allow a better understanding of environmental problems since they allow a richer perspective on possible sudden and abrupt changes in ecosystems and a better evaluation of responses to alternative policies (Gomez & Gubareva, 2021). In the next section, three theoretical approaches from the sciences of complexity are presented, one focused on the environmental system, another on the economic system, and another on the social system that gives rise to peace. From these theoretical instruments a mechanism that unfolds a simple behavior on individuals that boost patterns that favor environmental sustainability and peace is provided.

3.1. Environmental sustainability

As can be identified in the conceptual elements of complex adaptive systems, these are dynamic and transform and adjust themselves. Hence, the need to consider the idea of sustainability not as something static but rather it is modified according to changes that occur in the environment, since, to some extent, they may be affected by anthropogenic actions. This environment gives rise to values from which elements of judgment are established to determine what is most convenient for society.

Sustainability is a way of "being" in the present with a view to the future, which invites broader, more holistic, and dynamic thinking. In this way, as Fisher and Rucki (2017) propose, sustainability becomes a process to maintain the progress achieved in the dynamics of the desirable systems, while other dynamics are actively changed, modified, and improved to bring the system closer to the future objective of social justice and desired human well-being. In this sense, the approach of Mebratu (1998) to sustainability, who observes it as an epistemological resource on the desired future, becomes relevant.

Considering the above, it is found that the field of study of the transition to sustainability is a systemic research paradigm focusing on a long-term and large-scale transformation of the dominant trajectory of carbon-intensive development, leading to environmental deterioration with implications such as climate change. This approach embraces sustainable development, human security, and sustainable peace studies. It has contributed to promoting strategies, policies, and long-term proactive measures, to further sustainable development objectives that contribute significantly to sustainable peace as the possible result of the long-range transition of production, consumption, and governance systems (Brauch & Oswald Spring, 2016).

From this line of study, since 2009 a new discourse has been presented by the Sustainability Transition Research Network (STRN), which has focused on the problems of energy, water, transport, and food from different scientific perspectives in the way in which the Society could combine economic and social development with the reduction of pressure on the environment. Scholars in this field consider that sustainability problems, being ambiguous and complex, require transformative changes at the system level that imply economic changes in both production and consumption (Brauch & Oswald Spring, 2016).

The sustainability transition approach is systemic. It is the scenario in which long-term transformation processes are carried out at different scales and, essentially, in the established socio-technical system, which seeks to change to more sustainable modes of production and consumption (Markard et al., 2012). In this framework, transitions are emergencies of interactions between social groups with myopic views and different strategies, interests, and resources, in which social groups try to find their way through searching and learning. In this journey, controversies, debates, and even power struggles can arise (Geels, 2020).

This focus moves at three levels, mainly:

• Niches: corresponding to a new structure of a small group of agents that emerges within the system and aligns with a new configuration. Usually, this new alignment is an emergent property of the system (Mesjasz, 2016).

• Sociotechnical system: referring to scientific knowledge, engineering practices, and process technologies that are socially integrated. They are linked to the expectations and skills of technology users with broader institutional structures and infrastructures (Markard *et al.*, 2012). The path of a transition to sustainability implies changes in different aspects of the technical-material, organizational, institutional, political, economic, and socio-cultural regimes, which leads to the emergence of new products, services, and business models that replace or complement those that already exist (Mesjasz, 2016). Nevertheless, it is also necessary to change the financing and administration of the system, as well as changes in governance, institutions, and value systems for the transformation towards a globally more sustainable society, which contributes to peace, freedom, material well-being, cooperation, care, and environmental health (Brauch & Oswald Spring, 2016).

• Environment: corresponding to the macro level, consisting of deep structural trends (Morone, 2018). These are long-term exogenous trends (Grin *et al.*, 2010). On this scale, individuals and nature are most acutely connected. Therefore, the composition and configuration of the environment profoundly affect and are affected by human activities (Wu, 2013). An example is climate change.

Under mostly moderate situations, the system maintains a certain balance between stocks, flows, and agents, which could be an attractor due to internal structures generated over time. However, in the case of strong external disturbances, the agents induce non-standard responses through constant fluxes in the flow, reinforcing their own responses. This can move the system away from the stable state in which it finds itself, focusing on another attractor. That is, moving to another stable structure that implies a deep structure change, which constitutes a transition (Grin, 2016).

Those non-standard responses can be considered niches, comprising clusters undermining the socio-economic regime. Subsequently these niches are absorbed or combined with the undermined regime, which changes its structure to a new regime. This change of new structure has altered the higher level of aggregation of the environment, which again induces changes in the agents, leading to niche competition (Grin, 2016).

Here, the main challenge is identifying and overcoming structural barriers such as market conditions, regulations, technologies, and consumer routines to move in the desired direction. Hence, transition management aims to experiment, develop and learn about the potential of different innovations, such as technologies, practices, products, or organizations, with the potential to materialize strategic vision and become new, and more sustainable structures (Loorbach *et al.*, 2010). However, it is necessary to consider that each context shows a different historical beginning of dependency on the past; thus, what is proposed in one niche may not work in another one (Costanza et al., 2013).

These behaviors imply the presence of multiple feedback loops, which lead to non-linearity and the emergence of large-scale patterns, impossible to examine in the individuals who create them. In this way, CAS has an amplifying effect related to non-linearity (Paravantis, 2016), which is essential to understand environmental issues from the point of view of economics. Therefore, the transition to sustainability offers a systemic epistemological resource that allows an understanding of how technical or social innovations arise and how they operate in a dynamic that, according to its objective, can transcend the socio-technical system and be framed toward sustainable behaviors, where peace is an indispensable component.

Next, theoretical elements that show how the economy can be perceived as a Complex Adaptive System are presented, and how cooperative behaviors are identified inquiring into evolutionary dynamics mechanisms that can favor peace.

3.2. Complexity economics

In this section, from the CAS perspective, we present a view of the economy and examine the rationality of its agents. Subsequently, cooperative behaviors from evolutionary mechanisms are presented, deployed in the socio-technical system of which the transition to sustainability speaks, and how those behaviors favor peace as a stable emergent.

3.2.1 The economy as a complex adaptive system

The perspective of complexity economics allows for a systematic analysis of the interactions between heterogeneous agents at different scales. Complexity economics views the economy as a complete system and part of a larger dynamic system with which it coexists, interacts, and evolves. Composed of several agents without perfect foresight who interact through various social networks. Patterns then emerge from these micro-behaviors at macro levels (Foxon et al., 2013), which can include peace. In this sense, Arthur (2013), defines the economy as:

> a vast and complicated set of arrangements and actions among consumer agents, firms, banks, investors, government agencies that buy, sell, speculate, trade, export, import, offer services, invest in firms, strategize, explore, forecast, compete, learn, invent, and adapt. It is a massive parallel system of behaviors that concur, form prices, markets, trade agreements, institutions, industries (p. 2).

The complexity approach allows one to ask how agents' actions, strategies, or expectations could react (endogenous changes) to the patterns they create. One way to model this is to assume that economic agents form individual beliefs about the situation they are in, and continually update it. They adapt or reject and replace the actions or strategies based on what they explored (Arthur, 2013). Consequently, it is evolutionary in nature to the extent that heterogeneous agents (or heterogeneous expectation strategies) continuously adjust to the overall situation they create together, and from there, they adapt within an "ecology" created by all. Evolution arises naturally from the construction of the model itself, not needing to be added as a complement. This approach advocates more for explaining and understanding the phenomenon (Wagner, 2012).

Complexity science proposes the existence of a middle level in economics, which can trigger events at other scales. The phenomenon at this level arrives, stays for some time, and then disappears (Arthur, 2013); this meso-level redefines a solution in economics. Therefore, focusing the attention of macro-observations on micro-interactions is to recognize the different levels of the phenomenon, reflecting a bottom-up orientation towards a macro theorization (Wagner, 2012). The rule systems are the essential connections in the economic system, and these rules are mesoeconomic and finite in nature, not micro or macroeconomic. The rule systems are structures, and complexity theory warns that as circumstances change, they will become obsolete and degenerative if they are not adapted or replaced by new rules. So, if a rule is regarded as something static that arises for its useful properties at one point, it will tend to be useless in other circumstances (Foster, 2005). From the economics of complexity approach, this impermanent meso-level is the equivalent of the socio-technical system mentioned in the sustainability transition field.

Thus, the economic system presents a multisystemic nature that drives its dynamics. At the micro level are the agents; at the meso level, the rules; and at the macro level, the system as a whole. This representation implies that the economy constantly creates and recreates itself, to the extent that it produces new elements, sometimes technologies and institutions, which establish new structures as it evolves (Arthur, 2013). Due to these relationships between agents and between agents and networks, properties not found at the micro level (agents) arise at the macro level. Consequently, the system cannot be known, even if there is a precise understanding of its parts, since the level of aggregation is not only the sum of the behavior of the individuals (Fernández et al., 2004) but also the space in which patterns emerge.

At the micro level, the economic system is made up of many heterogeneous agents without perfect foresight but capable of learning and adapting over time. Their interactions occur with only some of the other agents in the space (Rosser & Kramer, 2000). For this reason, no global controller or competitor can exploit all the economic opportunities (Rosser & Kramer, 2000). These interactions can occur with or between networks and generate dispersed interactions (Foxon et al., 2013), whose hierarchical organization is transversal to many tangled interactions (Rosser & Kramer, 2000). Among these heterogeneities, there are asymmetries between levels that lead to their ability to interact being subject to the way the environment is structured. Economic networks appear within the conformation of these structures, constituted in dynamic entities in which the formation and elimination of links occur to form a configuration that influences economic results. Therefore, relationships matter, and the type of collective behavior that emerges is much more than the sum of its parts (Wilson et al., 2016). As a consequence, how agents interact at the micro level, determines what at the macro level is observed.

3.2.2 Agents' rationality

Economic agents use past knowledge and experience through simple decision-making heuristics to make sense of problems. Thus, they continuously update their internal model. This means they constantly adapt, discard, and replace actions or strategies based on their experience as they explore (Arthur, 2013). Thus, individual choices are made between alternatives, which are subjective representations of alternative future outcomes, and not between future results themselves (Basili & Zappia, 2010).

At the micro level, actors are understood as bounded rationales. Their rationality is limited by the manageability of the decision problem, the actor's cognitive limitations, and the time available to make the decision. Hence, individuals, in general, do not optimize (for example, utility) but instead engage in cognitive processes, such as social comparison, imitation, and repetitive behavior (habits) to use their limited cognitive resources efficiently (Arthur, 2013).

In this sense, behavioral economics, according to Arthur (2013), suggests that contexts determine how people decide, and cognitive science suggests that if a decision is important, people can take a step back and try to make sense of it from guesswork, guessing, or based on past knowledge or experience. Therefore, one way to model this is to assume that economic agents form and continually update individual beliefs about their situation. That is, they adapt or reject it and replace the actions or strategies based on what they explored by deploying rationality through induction.

The central idea of inductive reasoning, described by Arthur (2015), is that it is made up of multiple elements in the form of belief models or hypotheses that adapt to the aggregate environment that they jointly create. Therefore, economy qualifies as a complex adaptive system. After some initial learning, the hypotheses or mental models in use adapt to each other. Agents compete for survival against the ideas or mental models of other agents. It is a world both evolutionary and complex.

3.2.3 Economy, sustainability, and cooperative behaviors

The system's sustainability arises from the interrelation of links that are not in their individual elements. According to Acquier et al., (2017) products, services, technologies, and organizations cannot be considered sustainable by themselves but elements of a sustainable socio-technical system.

On the other hand, Gomez and Gubareva (2021) suggest that traditional economic models are inadequate to address sustainability issues such as climate change, specifically for four reasons: 1) These models do not adequately address uncertainty. The economy is constantly moving as agents explore, learn and adapt. Therefore, it involves something that will occur in the future, bringing a certain degree of ignorance (Arthur, 2013). This lack of knowledge translates into uncertainty contributed by the agents and the system as a whole. 2) Inability to address aggregation and heterogeneity. 3) The preceding implies that traditional models offer insufficient explanations of innovation and technological change. 4) There is a difficulty in designing functions that realistically assess the economic impact of the consequences on the environment or climate change.

By considering the interactions of agents who can learn, adapt and evolve, the complexity approach can identify more sustainable patterns used by firms and consumers (Gomez & Gubareva, 2021). In this context, this paper proposes intergroup selection mechanisms that induce cooperative behaviors that favor peace and thus contribute to sustainability and peace. Sustainability in social terms requires cooperation since, at times, individual and short-term interests must yield to give way to general and long-term interests, that is, that future generations have the same opportunities as the present ones but also between members of this generation (Vera, 2013).

3.2.4 Selection mechanisms that favor cooperative behaviors

Once the inductive rationality of the agents in the complex adaptive system has been described, selection mechanisms that favor cooperative behaviors are presented. When complexity theory is intertwined with evolutionary theory, the concept of fitness stands out, an idea that represents how well an individual, group, species or strategy is performing compared to competition and, therefore, how likely to prosper (Newman, 2009). Holland (1996) explains this process within the system as an allocation of credits that provides the system with hypotheses that anticipate future consequences by strengthening the rules that lay the foundation for later activities that are openly rewarding. In this sense, the author points out that, in mathematical studies of genetics, economics, and psychology, these rewards are assigned by decree when assigning numerical values to objects of interest. Fitness is assigned to chromosomes, utility to goods, and rewards to behaviors. Through competition with local payments, the evolutionary dynamic is developing.

However, evolution occurs not only from selection processes but also from interbreeding. Therefore, as Paravantis (2016) suggests, a fundamental pattern in the evolution of CAS is the combination of old and new building blocks (groups of components), in which those with the highest fitness remain to generate unexpected properties and, therefore, alternative futures, which can become innovations. Added to this process is mutation, which, according to Holland (1996), is the process in which each of the alternative forms is modified randomly to finally close the evolutionary cycle with the substitution in which the new agents replace the previous ones.

This coexistence between the theory of complexity science and evolutionary theory is justified by authors such as Axtell et al. (2016), who point out that a CAS is not necessarily evolutionary, although it can be. These systems are conceived as information that is remembered in the form of rules, which define the system (environment), and strategies, which determine the system's agents (or nodes). When complex adaptive systems are evolutionary, selection can occur on at least two levels: at the level of the individual agent or the level of the system as a whole when interacting with other systems. Even if the information defining the interaction of the agents resides entirely in them, the level at which the selection occurs can lead to very different results. In this way, Bowles (2004) states that the population can be hierarchically structured, individuals interacting with individuals. However, they also constitute groups (such as families and companies) and other superior entities (such as nations) with which they also interact and in which that selection occurs at more than one level.

In this same line, Wilson et al. (2016) consider that, based on complexity theory, the fact that systems are composed of elements governed by simple rules of behavior and, from there, selection can be explained as an emergence without considering natural selection, is an error since, in the absence of selection, properties that arise from complex systems are nothing more than adaptations to the environment with mutations. From this perspective, he argues that there are two types of CAS:

1. CAS 1: Complex adaptive system as a system.

2. CAS 2: Complex system composed of agents that use adaptive strategies.

The radical difference is that CAS 2 is not adaptive as a whole. According to evolutionary theory, the functional organization exists at the level of individual organisms due to processes of natural selection among individuals. For CAS 1, the system must have a selection unit; otherwise, the system would qualify as CAS 2. The central idea is that an effective self-organizing process must be selected from many less effective self-organizing regulatory processes. Thus, at the group level, the functional organization requires individuals who perform services for each other or for their group as a whole. Members who cooperate are less good at surviving or reproducing than those who are free riders or who actively exploit cooperators. When this happens, the functional organization stops at the level of the individual organism and does not extend to the social group or to a higher level.

Cooperation can be a disadvantageous selection compared to non-cooperatives (free riders) or exploiters in the same group, but groups composed mainly of cooperators have an advantageous selection over groups of exploiters and non-cooperators. Hence natural selection occurs between members of the same group and between groups. An adaptation that benefits the group can evolve if the selection between groups is more potent than disruptive opposition within the group. In this sense, groups of prosocial individuals have a competitive advantage over groups governed by egoists. Prosocial behaviors can win from the Darwinian perspective as long as the selection between groups in a multigroup population is strong enough to prevail in selecting individuals in the groups. Then, evolution is determined by coopetition, that is, simultaneous agents' cooperation and competition (Paravantis, 2016). In intergroup selection, Bowels and Gintis (2002) found that this selection mechanism favors individual traits beneficial to the group as a whole, which has pushed altruistic forms of human sociality toward non-family or group-level institutional structures., such as resource sharing, which have emerged and spread, repeatedly, and in a wide variety.

Next, we present how these cooperative behaviors favor the emergence of patterns that contribute to peace.

3.3 Peace

This section addresses peace from the theoretical approach of complex systems, from which operating mechanisms are identified, and later examples of self-organization are presented.

Based on complexity, Coleman (2016, p. 150) has defined sustainable peace as "the state where the probability of using destructive conflicts and violence to solve problems is so low that it does not enter into any party's strategy, while the probability of using cooperation and dialogue to promote social justice and well-being is so high that it governs social organization and life". On the other hand, Eoyang (2015) argues that peace is a pattern that emerges from systemic interactions based on simple rules that are repeated in different types of relationships, and it is relevant to know the link between each individual and the systemic pattern to have an impact on problems affecting it.

In this field of complexity, the work of Coleman (2020) identified that, in the context of stable peaceful societies, although peace is complex and idiosyncratic, it can be operationalized based on the relationship of positive intergroup reciprocity (PIR) and negative intergroup reciprocity (NIR). The central dynamics responsible for the emergence and maintenance of sustainable peaceful relationships in societies are the thousands or millions of reciprocal intergroup interactions that occur daily between members of different groups in those communities. Peace depends on the degree to which positive interactions outweigh negative ones. The higher the PIR:NIR ratio, the higher the probability of stable peace.

In the same line Fry et al. (2021), in their ethnographic research, found that, over time, reciprocal prosocial relationships are developed and linked to non-war societies within a broader common social system, where cooperation and unity prevail, while war between members is no longer considered an option. Thus, the direct link between cooperation and peace is evident. According to studies by Bowels and Gintis (2002), cooperation is based, in part, on the distinctive abilities of humans to build institutional environments that limit competition inside the group by increasing the relative importance of inter-group competition, which carries high individual costs and implies deciding, better, for beneficial behaviors in groups to coevolve. For this reason, in the history of humanity, cooperation has favored evolution by improving individuals' opportunities for mating and coalition formation. In their analysis of dynamic models, the authors find that cooperative behaviors that bring benefits to group members allow groups with high cooperative ties to dominate in intergroup conflicts, which results in an evolutionary mechanism of internalizing norms since it leads to improving individual fitness in a world where social behavior has become too complex for individual rational evaluation. Thus, conflicts can decrease when agents carry out cooperative actions that give value to all agents (win-win) (BenDor & Scheffran, 2019). For this reason, as Cottey (2018) states, cooperation can prevent conflict since the latter thrives in environments of individualism, competition, and accumulation by showing a severe attitude towards losers.

Continuing with the dynamics displayed by a CAS, Mesjasz (1988) states that, for social studies, in order to prevent violence, the hope of centralized control must be abandoned. Peace studies must take into account the role of self-organization in sociotechnical systems. That is crucial for sustainability transition. From this perspective, de Coning (2020) states that peacebuilding is based on stimulating and facilitating the ability of societies to self-organize. It means managing their tensions, pressures, disputes, crises, and shocks without relapsing into violent conflict. The strength and resilience to generate this self-organization determine how much society can resist pressures and shocks that lead to violent conflict. This self-organizing process must stem from a context-specific, bottom-up local process.

Once cooperative interactions have been identified as individual mechanisms that can promote peace and give way to self-organized and evolutionary behaviors, some examples are presented below.

3.3.1 Emerging collective action (ECA)

According to Maldonado (2019), classical collective action theory is based on the rational selection theory, which: 1) Focuses on solving problems relevant to collective action through the design of incentives (such as the stick or the carrot); 2) Seeks to solve problems of lack of cooperation through psychological solutions and voluntary changes; 3) Guides people to cooperate in collective actions guided by meta-preferences (values or morality); 4) Is based on the power of coordination. Conversely, swarm collective action with strategies without central control emerges from complexity science. This phenomenon has been identified in systems such as nature, subatomic particles, culture, economics, and even politics. This practice emerges as a rationality of collective emergent behavior without a plan or strategy from the outset, but affords each individual possibilities, obstacles, and problems with greater benefits as part of the swarm rather than individually. Therefore, common objectives, goals, and evaluations become more important, which eliminates the free-rider problem.

According to Axelrod (1984), this type of cooperative behavior, when the probability of two individuals meeting each other again is high enough, promotes cooperation based on reciprocity and can be evolutionarily stable in a population without much kinship. Hence, this type of behavior is characterized by permanent communications, continuous networking, and active personal participation in assemblies and meetings, with spontaneous learning arising as an important condition of adaptation (Maldonado, 2019).

3.3.2 Adaptive governance

According to Folke et al. (2006), adaptive governance is a form of social arrangement in which actions are voluntarily coordinated by individuals and multi-individual groups with self-organization and the ability to enforce, with nested polycentric institutional arrangements and quasi-autonomous decision makers at different levels, relying on networks that connect individuals, organizations, agencies, and institutions at multiple levels of organization and provide collaboration, flexibility and learning-based ecosystem management approaches. In other words, an evolutionary structure of multiple interactions is observed at different levels for the coordination of actions without a great central power.

Dietz, Ostrom, and Stern (2003) propose that the requirements for adaptive governance in a complex system are: 1) Providing reliable information on stocks, flows, and processes with the resources of the governed system; 2) The ability to handle conflicts: As large differences in power and values among different parties inherently lead to conflict, it is convenient to promote analytical deliberation through a well-structured dialogue represented by the different actors; 3) Providing infrastructure and being prepared for change: Institutions must be designed to support change without very fixed rules and be prepared to give great importance to the current state of knowledge; 4) Nesting: institutional arrangements nested in several layers.

3.3.3 Social learning

Foster (2005) proposes four levels of order in complex systems: 1) Imposed energy: no adaptive structures such as fractals observed in physico-chemical fields; 2) Knowledge imposition and energy acquisition: energy received is transformed into a knowledge structure that allows it to acquire energy, as in biological systems in which information is genetically provided; 3) Knowledge acquisition: a biological system interacts with the environment and a possible world, knowledge is cumulative and can be in a mental model; it is a complex and adaptive system in which adaptation is not only selection but also creativity; 4) Interactive knowledge: interaction between mental models, a type of system that prevails when people create aspirations and commitments in the future and enter into installment contracts and other agreements with end dates in the future, gathering the aspirations of individuals in "understandings" allowing the creation of organized complexity. It is in this fourth order context that the aspirations of individuals lead to "understandings" that allow the creation of organized complexity (Foster, 2005). Folk et al. (2005) suggest that the processes that generate learning, meaning, and experience of the ecosystem dynamics in terms of management practices are part of the social capacity to respond to environmental changes. They thus propose that a clear vision, complete stories and meanings, good social connections, and trust with other interested parties can mobilize interest groups at various levels and initiate a process of self-organization of learning and generation of social capital for the management of CASs.

Cumming (2013) emphasizes social learning "by doing" through experiences in successful group processes, which should change the understanding of the individuals allowing the change to go beyond individuals and incorporate not only a large number of them, but also community practices through social interactions and processes between actors with social networks (Cumming et al., 2013). Therefore, in social learning persists the idea that mutual understandings between individuals lead to practices in the community at different levels of self-organization that generate changes beyond each individual.

However, the theoretical elements discussed throughout this article can provide a clearer idea of their contribution to peace when presented in a comprehensive manner, as outlined in the following section.

4. Peace contributions

This study aimed to identify theoretical elements from a complex system approach that offers a mechanism to favor peace as an emergence due to economic, social, and environmental interactions. The following figure summarizes the ideas proposed.

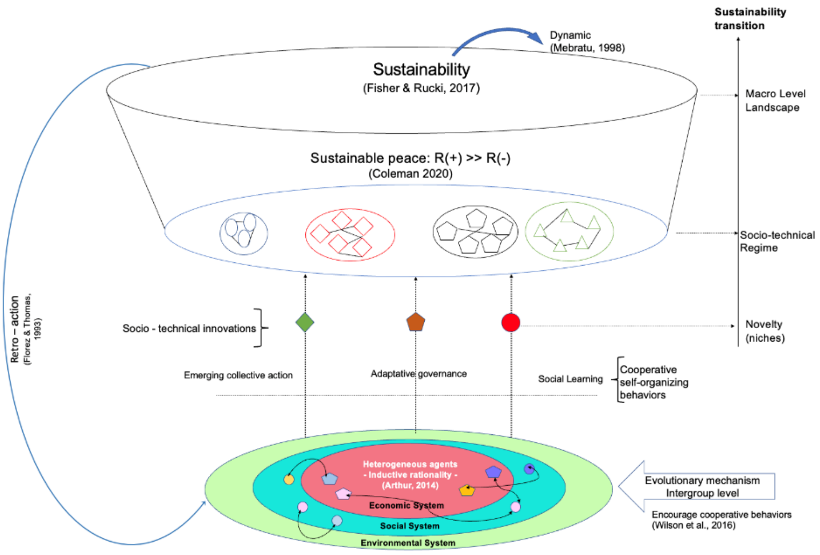

Figure 2: Peace emergence. Source: Own elaboration, based on the multilevel structure of Grin et al (2010, p. 19)

At the figure's base, the relationships between open systems are schematized based on interactions between economic, social, and environmental systems. They are made up of heterogeneous agents with cognitive capacities and limited information that, through inductive rationality, adapt or evolve about them and with the environment. Complexity Economy provides this theoretical framework.

The processes of evolution occur through selection mechanisms among various alternatives executed systematically at different scales. Mechanisms of intergroup selection are suggested, which, as Wilson et al. (2016) and Coleman (2020) describe, can favor cooperative behaviors that, in turn, radiate to the upper level of the metasystem, promoting positive reciprocity.

To the extent that the cooperative strategy dominates, it can give way to self-organized behaviors, such as emergent collective action, adaptive governance, social learning, or another of similar nature. These behaviors can promote technical and social innovations that affect the socioeconomic system and are aligned with the idea of sustainability that is dynamic, and thus change over time. For this theoretical proposal, the Fisher and Rucki (2017) sustainability concept is considered, as the process of maintaining the gains made in desirable system dynamics while actively changing, modifying, or improving other dynamics to move the system closer to the goal of social justice and human well-being. Economic development, ecosystem functioning, peace, and conflict management are necessary components.

Sustainability requires cooperation to promote the common interest. In that sense, to the extent that these cooperative behaviors are strengthened, behaviors that favor peace also begin to emerge. It would be an additional or collateral benefit that the search for sustainability brings through stimulating cooperative behaviors through intergroup selection. Studies by Coleman (2020) indicate that, in a society characterized by stable peace, the difference between positive intergroup reciprocities far exceeds negative intergroup reciprocities. Given that, to the extent that the difference between cooperative and non-cooperative actions is greater, peace, as an emergence, can be established as a stable behavior.

Since sustainability is the epistemological resource of how the future is desired (Mebratu, 1998), which is subject to the relationships within the system, its nature is dynamic. This same idea of sustainability, created by all agents of the system, once again permeates the decisions of individuals, generating feedback to give way to individual decision processes. These decisions go through evolutionary processes to generate innovations or niches as are called by sustainability transition studies. Later, these niches permeate the socio-technical system and then impact the landscape, restarting the loop systematically.

This theoretical proposal, framed in a complex systems approach, has the advantage, as Gomez and Gubareva (2021) suggested, of allowing a dynamic representation of a network of relationships on which public authorities must act. Complexity economics does not advocate that state policies are solutions to the market, but rather recognizes their interdependence and co-evolutionary character. In this sense, the state can intervene through policies to favor processes of differentiation, selection, and amplification of business plans (Beinhocker, 2006). This type of interference is not through specific policies, but by stimulating the co-evolutionary context between the state and the market, which can be useful for stimulating CAS1 by promoting selection among more effective groups in terms of cooperation in self-organization processes.

One of the benefits of the implementation of inter-group selection to promote cooperative behaviors is the emergence of peace and sustainability as an endogenous result of the system. Therefore, according to the characteristics of each system, of its past that constitutes it, from a cooperative but self-organized (not imposed) perspective, the niches and structures for each system are formed. That is different from a solution used for several systems and implemented exogenously.

In this way, as observed in the first section where the problem was introduced, the economic, environmental, and social systems are interconnected. Recognizing dynamics that create intertwining between them is relevant to direct the systems to display desired patterns.

5. Conclusions

To understand how peace in a context of sustainability can emerge as a pattern in a complex adaptive system, the holistic and systemic view of the complexity science provides epistemological elements to understand better the dynamics between the economic, social, and environmental systems. From a bottom-up analysis, it can be located at a privileged point of high aggregation, not of the agents, but of the system as a whole, to spot emergences that are not found in individual agents, nor the aggregation of the same type of agent without participating in the system. In this way, it is possible to understand the behaviors in the forest, that cannot be explained by the trees. Typical in social systems that, as Coning (2020) states, are highly dynamic, non-linear, and emergent.

Intergroup selection is identified as a trigger for peace in the sustainability transition context from complexity and evolutionary frameworks. Bowels and Gintis (2002) found that this selection mechanism favors individual traits that are beneficial to the group as a whole. In this sense, Wilson (2016) argues that an adaptation that benefits the group as a unit can evolve if the selection between groups is strong enough in the face of disruptive opposition within the group. For this to happen, groups composed primarily of cooperators are in advantageous selection compared to exploitative and non-cooperative groups. Therefore, intergroup selection favors prosocial behaviors (Wilson, 2016). It is connected with Coleman's finding that peace emerges as a stable behavior when the difference between positive intergroup reciprocities is much greater than negative ones (Coleman et al., 2020). Hence, implementing intergroup selection mechanisms can favor the emergence of lasting peace. From niche innovations, new behaviors, in this case, more prosocial ones, are disseminated on the social-technical level where strong rules and structures are established. Then, those affect the highest level of aggregation. Consequently, an intergroup selection that promotes cooperation should affect the state of the environment and society's relationship with it through self-organized structure and endogenous feedback. This intergroup selection mechanism can become a tool to fulfill the sustainable development objective of peace, justice, and strong institutions by promoting peaceful societies in a context of sustainability.

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Original Paper

Biophilic design of building façades from an evolutionary psychology framework:

Visual Attention Software compared to Perceived Restorativeness

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Keywords: Biophilic Design; building façades; Perceived Restorativeness Scale; Visual Attention Software.

Abstract. *Built environments that integrate representations of the natural world into façades and interiors benefit occupant psycho-physiological well-being and behavior. However, the biophilic quality of buildings does not depend exclusively on "green", but also upon "organized complexity" in their structure. In this exploratory study we compare quantitative (Visual Attention Software) and qualitative approaches (self-rating scales) in the perception of biophilic design of building façades. Eight façades varying in their degree of biophilic design (High, Medium, Low, No biophilic qualities) were assessed on the Perceived Restorativeness Scale-11, on preference, and on a series of physical aesthetic attributes. The eight façades were scanned with Visual Attention Software (VAS). These measures show many overlapping points. VAS can be considered a way to operationalize the engagement of attention in the first 3-5 seconds of gaze in exploring building design, and self-ratings assessments a measure of to what extent the building is perceived as restorative. Higher perceived restorativeness and preference match a higher degree of biophilic design, which corresponds to a building where vegetation is integrated in an organic structure. Vegetation is not the only biophilic characteristic to be considered in biophilic design and this emerges clearly from self-ratings and VAS. Exploring organized complexity is fundamental for understanding human responses to architecture.*

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1. Towards an Evolutionary Psychology framework for biophilic design

The idea that humans are drawn to Nature-inspired architectural forms dates back several centuries. For example, in *The Stones of Venice* (1851-1853) John Ruskin pointed out three virtues of a built environment, in that: (1) it acts well, (2) it looks well, and (3) it speaks well. In the first place, a built environment "acts well" when it fulfills the human need to find a refuge. Secondly, it "looks well" when it meets traditional human aesthetic requirements. For Ruskin Nature is the model for beauty and he relied so heavily on the design seen in Nature that to him lines and shapes in architecture should stem from the natural environment. Finally, according to Berto (2019) a built-artificial environment "speaks well" when it fosters emotional attachment to it; emotional attachment appears to be an emergent property of individuals interacting with environments that are pleasing both aesthetically and functionally, because they present some properties of the environment in which humans evolved. This attachment facilitates the vision of an interaction between "form" and "function" that stimulates progressively stronger positive emotions towards the environment itself (Petrich, 2015).

Individuals seek places that support the biological needs of *making sense* and *exploring* (Kaplan and Kaplan, 1989) which, in turn, sustain environmental preference and perceived restoration (Barbiero and Berto, 2018). Since our ancestors lived in a Nature-filled environment, we feel more comfortable, more relaxed, more "like home" when we are exposed to natural environments (Barbiero and Berto, 2021). Biophilic design contends exactly that humans have developed affinities for naturalistic forms in their surroundings over the course of evolutionary history; therefore, naturalistic patterns in architecture are preferred over synthetic forms never seen in our ancestral world (Barbiero, 2009; Coburn et al., 2019). Moreover, there is accumulating evidence that Nature-inspired architectural features foster important psychological benefits (Berto, Barbiero and Nasar, 2022; Joye, 2007; Salingaros, 1998).

Biophilic design is closely related to restorative design, an approach that focuses on the promotion of restoration from stress and/or mental fatigue as a key component of the individual's relation with the environment (Hartig et al., 2008). Restoration may stem from the presence of plants and other natural elements, but it can also occur in places that do not have obvious natural elements (Berto, 2019). Restorative design may be considered a more general form of biophilic design that aims to promote restful experiences characteristic of natural environments but is not necessarily restricted to natural elements (Gifford and McCunn, 2019). Biophilic design has two separate contributions: (i) the presence of plants, animals, sunlight, and water; and (ii) very special geometrical characteristics such as fractals and nested symmetries. The best biophilic designs are buildings that embody appropriate geometrical characteristics in their tectonics and ornamentation (if there is any), and which try to add as many natural elements and plants as is practically possible (Salingaros, 2019).

Starting from the premise that the biophilic quality of buildings does not depend exclusively on green, but also upon the "Geometry of Nature" in their structure, the experiment presented here wants to verify the role of "organized complexity" and "green" in preference and perceived restorativeness of building façades, using a mixed methodology made up of quantitative and qualitative instruments. From our point of view, the exploration of organized complexity is fundamental in understanding human responses to architecture from the evolutionary perspective. To address this issue properly, first a brief hint of evolutionary aesthetics introduces the role of natural selection in recognizing the aesthetic qualities of an environment. Then how the Geometry of Nature is responsible for aesthetics and fascination in Nature will be explained. The introductory section closes with an overview on environmental perception and the difficulty in managing the perception of real-world scenes.

1.1. Evolutionary aesthetics

Humans are able to experience a broad array of phenomena in terms of "beauty" and "ugliness" (e.g., tastes, smells, humans, artifacts, places, etc.) and it is safe to assume that the pleasure response is "immediate" and "functionless" (Voland, 2003). However, this does not imply that aesthetic judgment has no function as a biological trait. Sexual selection favors fitness indicators that help select the best possible partner for reproduction (Miller, 2001). For example, whenever we see other human beings, we instantly judge their attractiveness; this automatic evaluation of attractiveness uses all the information available about the other person: their body shape and size, their facial symmetry, their movement, their odor, their voice, etc. (Grammer at al., 2003). These visual cues might indicate "good genes", i.e., a genetic endowment which is able to cope well with the current environment, indicating "functional optimality" (Rhodes, 2006). The aesthetic terms of "beauty" and "ugliness" therefore refer to a first level of selection linked to reproduction.

Natural selection can also play a role in aesthetic evaluation. The ability to search for resources and shelters is a behavioral trait that has arguably long been favored by natural selection in the fight against the hostile forces of Nature (Buss, 2016, pp. 68-99), and which promoted the evolution of a cognitive system that arranges the phenomena of our world using aesthetic judgments (Voland and Grammer, 2003). This mechanism explains why the kind of places we find intriguing, and which we gravitate towards, are rooted in our evolutionary history (Berto, 2019; Kaplan and Kaplan, 1982). Humans' predisposition to recognize the aesthetic qualities of a certain habitat reflects the adaptations designed by natural selection aimed to help us to choose a place to inhabit (Kaplan, 1992; Orians and Heerwagen, 1992) and it could be an adaptation that is the result of several cycles of ex-adaptations (Barbiero and Berto, 2021).

1.2. Nature's restorativeness, fractals, and biophilic design

Abundant evidence favors the proposition that Nature is restorative. Nature improves cognitive functioning, productivity, mood, vitality, speed of recovery in hospital: it reduces stress and anger, and these benefits hold for being in Nature, for merely having some Nature in a room (e.g., plants), for seeing a poster image of Nature, or even for seeing Nature through one's window (for a review see Berto, 2014). The pioneering experiments by Roger Ulrich (1981, 1984) showed that exposure to natural scenery induced positive physiological changes in people, including significant stress reduction, thus laying the foundation of Stress Recovery Theory (SRT; Ulrich et al., 1991). In the meantime, Rachel and Stephen Kaplan (1989) explored humans' innate preference and fascination for Nature. Later, Stephen Kaplan introduced Attention Restoration Theory (ART; 1995) and proposed that "fascination", i.e., involuntary effortless attention induced by Nature stimuli, differs from "directed attention", i.e., voluntary effortful use of directed attention usually required for demanding tasks, and that Nature's fascination restores depleted mental resources exhausted by the effort use of directed attention.

Fractals (forms that are subdivided in a regular manner going all the way down in scales; for more details see Mandelbrot, 1982) are responsible for the aesthetics and fascination of Nature. The prevalence of fractal objects in Nature (e.g., clouds, trees, mountains, cauliflowers, fern leaves, etc.) led to the formulation of the "fractal fluency model" (Taylor and Spehar, 2016; Stadlober et al., 2021; Salingaros, 2012). Whether natural or created, fractals represent a profound ingredient of our visual experiences in which human vision has become fluent and can process efficiently. The fractal fluency model predicts that increased performance of basic visual tasks during "effortless looking" will create an aesthetic experience accompanied by significant reductions in stress and mental fatigue (Taylor, 2021). Automatic fractal processing triggers initial attraction/avoidance evaluations of an environment's salubriousness, and its potentially positive or negative impacts upon an individual (Brielmann et al., 2022). Unfortunately, people are surrounded by urban landscapes and risk becoming disconnected from the relaxing qualities of Nature's fractals. To this end, designers and architects should address the individual's need to be exposed to the restorative qualities of Nature by creating fractal designs and architecture, in particular mid-*D* fractals (Abboushi et al., 2019): the visual information of mid-*D* fractals is easy to process, and fractal fluency is accompanied by a powerful aesthetic experience. In fact, the fractal qualities of the visual environment either encourage or discourage movement and navigation in urban spaces; this effect is responsible for feeling "at ease" in an urban environment. Going beyond aesthetic attraction, fractal patterns of the right dimension are shown to exert a measurable healing effect on humans (Brielmann et al., 2022), and the healing properties of environments correlate with definite characteristics: specifically, with particular geometrical qualities.

Biophilic design "is the deliberate attempt to translate an understanding of the inherent human affinity to affiliate with natural systems and processes — known as biophilia — into the design of the built environment" (Kellert, 2008, p. 3). Biophilic design takes advantage of our biological attraction to natural forms, and the special geometric patterns that mimic them. Salingaros (2019) argues that the *complex geometry* of the environment is in part responsible for the effect of design on an individual's wellbeing. Modern architecture inflicts shapes, color, spaces, texture, surfaces, etc. etc. that disconnect people emotionally from Nature (Aresta and Salingaros, 2021); much of architecture continues to be based on design that is neutral in its biophilic impact, or worse, explicitly *antibiophilic* (Salingaros, 2015).

Most buildings built by industry since the Second World War suffer from "Nature deficit *design* disorder" (Berto and Barbiero, 2017). Biophilic design can bridge the gap between human beings and Nature, by taking evolutionary biology, ecology, and environmental psychology as the basis for design. However, biophilic design is not just an exotic garden outside the building, or a piece of vertical landscape situated on a wall purely for aesthetic reasons, but rather a holistic "restorative" design that does not alienate people, as environment-friendly technological buildings very often do. Biophilic design is "cognitively sustainable" design (Berto, 2011) and can be applied at all levels of scale, creating interior and exterior revolutionary forms, private and public buildings, landscapes, and whole cities.

A radical change in design intentionality would discard architectural formalisms to adopt a completely new method of healthy design (Buchanan, 2012). Human beings require intimate contact with Nature and also a special "biophilic" geometry in the artificial built environment, i.e., patterns that trigger the same reactions as natural forms. People have clear preferences for combinations of building shape, color, and arrangement, etc. (Smith, Health and Lim, 1995; Zacharias, 1999), and a building that achieves intimate contact with Nature triggers positive emotions. More and more contemporary buildings pay attention to green, but plants satisfy only one part of biophilia — the part that depends upon proximity to Nature — and could neglect the need for biophilic geometries in the building itself. The biophilic quality of buildings does not depend primarily upon green, but upon a special type of "organized complexity" (i.e., symmetry, alignment of elements, scaling symmetries, scaled-up elements) in their structure, which contributes to an unconscious connection with Nature; together with the actual presence of Nature and/or representations of Nature's components (Salingaros, 2017).

1.3. Environmental perception

The study of human perception and aesthetic response to built environments might be central to progress in many areas of pure and applied research, in particular to architecture and design. It is the key to planning environments that sustain the individual's need of recovery from psycho-physiological stress.

In the classic perception literature, perception and cognition can be considered two distinct processes, while in Environmental Psychology the debate is still open. According to Ittelson (1976) perception and cognition cannot be considered separately, for a series of reasons: (1) environmental perception is made up of information conveyed from all the senses and not only from a specific one; (2) the environment surrounds us, therefore it has to be explored more than simply seen; (3) environmental information is more than what can be processed, therefore an intentional or automatic selection must be implemented; (4) environments have physical, social, and affective aspects; (5) environmental perception is aimed towards deciding for action. However, Gestalt psychology and in particular Lewin (1936) anticipated the modern Environmental Psychology highlighting: the active role of the subject in perceiving the distinction between physical and phenomenological environments; the need to consider the perceived object as part of its context (an object is more than the sum of its parts); human behavior (B) as a function of the environment (E) and of the person (P): $B = f(E, P)$; events must be studied in interrelation, which is a dynamic approach; the environment also has social aspects.

Gibson's approach (1966; 1979) to the environmental perception issue is completely different. Things have bad or good values (i.e., response valences evoked in the individual) that can be easily taken by the perceiver. Environmental invariants can be directly perceived without cognitive mediation - i.e., the light glazes, the spatial layout, the in/animated objects, the fixed or mobile objects, etc. All these affordances or utilities are meaningful and useful aspects of the environment that attract our attention and aim our action. Actually, it is not easy to distinguish among perception *per se*, the environment, and the individual's cognitive processes because bottom-up and top-down processes interact and overlap in environmental perception (Berto, 2011). Hochstein and Ahissar (2002) state that explicit vision advances in reverse hierarchical direction; conscious perception begins at the hierarchy's top, gradually returning downward as needed. Thus, our initial conscious percept - e.g., vision at a glance - matches a high-level generalized, categorical scene interpretation, identifying "forest before trees" - i.e., the gist of a scene is captured together with our blindness to the details (Hochstein and Ahissar, 2002).

Basically, research in human perception can be divided into three areas of investigation. *Low-level or early vision*, i.e., extraction of physical properties such as depth, color, and texture from an image as well as the generation of representation of surfaces and edges (Marr, 1982); *intermediate level*, i.e., extraction of shape and spatial relations that can be determined without regard to meaning, although this typically requires a selective or serial process (Ulman, 1996); *high level vision*, i.e., the mapping from visual representations to meaning, which includes the study of processes and representations related to the interaction of cognition and perception, including attention, the active acquisition of information, short-term memory for visual information, and the identification of objects and scenes (Henderson and Hollingworth, 1999).

To manage real-world complexity, visual attention is guided to important scene regions in real time. According to "image guidance theories", attention is directed to scene regions on the basis of semantically uninterpreted image features, i.e., attention is a reaction to the image properties of the stimulus confronting the viewer, with attention "pulled" to visually salient scene regions (Henderson, 2017). The most comprehensive theory of this type is based on visual salience, in which basic image features such as luminance contrast, color, and edge orientation are used to form a saliency map that provides the basis for attentional guidance (Itti and Koch, 1998; 2001; Harel, Koch and Perona, 2006).

An alternative theoretical perspective is represented by "cognitive guidance theories", in which attention is directed to scene regions that are semantically informative. This position is consistent with strong evidence suggesting that humans are highly sensitive to the distribution of meaning in visual scenes from the earliest moments of viewing (Biederman, 1972; Wolfe and Horowitz, 2017). According to this interpretation, attention is primarily controlled by knowledge structures stored in memory (see Schema Theory; Neisser, 1976). Those knowledge structures contain information about semantic content and the spatial distribution of that content, which is based on experience with general scene concepts and the specific scene instance currently in view (Henderson and Hollingworth, 1999). Recent literature reveals that both *meaning* and *salience* predict the distribution of attention (Henderson and Hayes, 2017), yet when the relationship between meaning and salience was examined, only *meaning* accounted for unique variance in attention. This pattern of results was apparent from the very earliest time-point in scene viewing, concluding that *meaning* is the driving force guiding attention through real world scenes.

1.4. Epistemological approaches to biophilic quality of buildings

This study is based on knowing that visual perception is a complex process and is greatly influenced by bottom-up and top-down processes. We mix quantitative (Visual Attention Software) and qualitative approaches (self-rating scales) to encompass the relation between perceived restorativeness and the engagement of attention in perceiving biophilic design of building façades. The study starts from the premise that the biophilic quality of buildings does not depend exclusively on "green", but also upon organized complexity in their structure. According to this model, exploring organized complexity is fundamental in understanding human responses to architecture.

2. Materials and Methods

2.1 Stimulus Material

Eight photographs depicting building façades were chosen from many different types of buildings. The purpose was to sample façades (two photographs per category) belonging to three approximate levels of Biophilic Design: Low, Medium and High Biophilic Design, and to compare those to "No Biophilic Design" as the control group (see Figure 1).

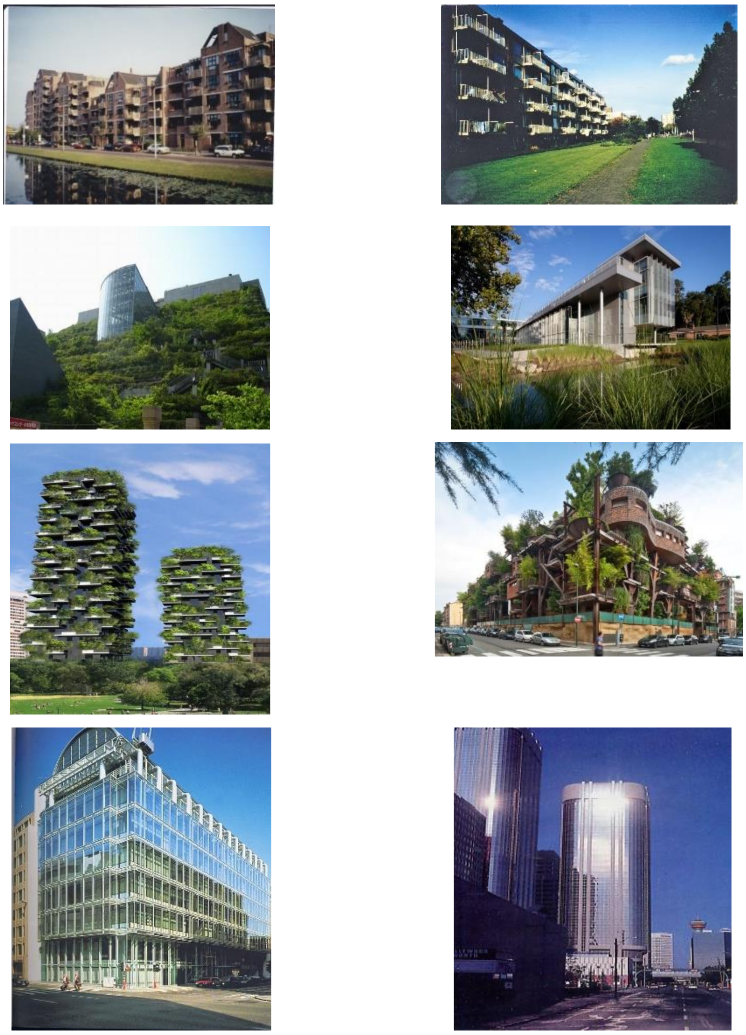


Figure 1. The stimulus material. From the top to the bottom: the Low Biophilic Design (Low-BD) buildings (photograph 1 on the left, photograph 2 on the right); the Medium Biophilic Design (Medium-BD) buildings (photograph 3 on the left, photograph 4 on the right); the High Biophilic Design (High-BD) buildings (photograph 5 on the left, photograph 6 on the right); the no Biophilic Design (No-BD) buildings (photograph 7 on the left, photograph 8 on the right).

Photographs do not differ in their environmental information ($p > .05$); this is a central issue in the engagement of involuntary attention-fascination (Berto 2011; Berto et al., 2015). The amount of information contained in photographs was analyzed at a basic level using the Lempel-Ziv-Welch lossless compression algorithm (LZW). The LZW algorithm has practically become the standard compression procedure (commonly referred to as "zip") and constitutes a simple but reliable method of comparing image information content. By removing *redundancy*, compression leaves the compressed file with only the actual or salient information content; images often contain quite redundant information or have multiple sections containing identical information. The LZW algorithm determines the amount of unique information in the information source (for more details see Unema et al., 2005; Itti, 2006). The compression *ratio* (defined as the fraction of the size of the uncompressed file divided by that of the compressed file) is expressed as a percentage: the higher the ratio, the more visual *redundancy* the image contains. The compression ratio was calculated for the eight photographs and since the LZW algorithm does not consider any pre-existing knowledge about the world, it can be safely assumed that the procedure of compression affected all the images similarly.

2.2 Self-rating scales

2.2.1 Participants

Twenty-five students (mean age = 28 years, SD = 6.06; 96% female, 4% male) at the University of Valle d'Aosta, Italy, volunteered to participate.

2.2.2 Instruments

A questionnaire was administered that required subjects to assess the eight buildings/façades using the Perceived Restorativeness Scale-11 (PRS-11) with two additional items included to assess familiarity and preference, and a list of physical and aesthetic attributes.

The PRS-11 (Pasini et al., 2014), based on the original version by Hartig et al. (1997), measures an individual's perception of four restorative factors:

I. *being-away* (BA; 3 items): a setting that allows physical and/or psychological distance from demands on directed attention;

II. *fascination* (FA; 3 items): the type of attention stimulated by interesting objects, namely a setting that provokes curiosity in the individual and fascination about things, and is assumed to be effortless and without capacity limitations;

III. *coherence* (COH; 3 items)*:* a setting where activities and items are ordered and organized; and

IV. *scope* (SCO; 2 items)*:* a setting that is large enough such that it does not restrict movement, thereby offering a sort of "world of its own".

Additional items were included in the PRS-11 in order to assess familiarity (FAM; 1 item) and preference (PREF; 1 item). Items are rated on a 0 to 10-point scale, where 0 = not at all, 6 = rather much, and 10 = completely.

In addition to the above PRS-11, it is useful to estimate to what extent the building/façade possesses the following 10 quite separate physical aesthetic attributes (Nasar, 1994): novelty, building for leisure activities, maintenance, cleanliness, representativeness, luminosity, openness, harmony, visual diversity, and vegetation. All of these attributes are rated on a 1 to 5-point scale, where 0 = not at all, and 5 = a lot.

2.2.3 Procedure

Subjects were tested individually in a distraction-free laboratory at the GREEN LEAF Groupe de Recherche en Education à l'Environnement et à la Nature, Laboratory of Affective Ecology, University of Valle d'Aosta. Subjects were seated in front of the computer and instructed to look freely at the photographs and to fill in items for the PRS-11 and rate the physical aesthetic attributes for all the photographs. The presentation order as shown on the computer screen was randomized between subjects.

2.3 Visual Attention Scans (VAS) and biophilic design

Most research on attentional guidance in scenes has focused on image salience. This exploratory research study on biophilic design of building façades also utilizes visual attention scans, performed using 3M Company's Visual Attention Software (VAS; 3M, 2020). The software produces heat maps of where the subject's unconscious attention is supposed to be distributed during the first 3-5 seconds of gaze. This result is obtained through visual rule-based simulation, not direct eye-tracking, yet is claimed by the manufacturer to be 96% accurate when compared to direct eye-tracking experiments. The software does not recognize plants or natural scenery *per se* but works strictly on the geometrical characteristics of the image. Natural scenery, and plants in particular, are characterized by a mid-range fractality (Abboushi et al., 2019). Altogether, the brain's recognition mechanism for biophilic design relies upon very similar mathematical cues as those programmed into the VAS software (Salingaros and Sussmann, 2020). For this reason, these scans can be helpful for analyzing the biophilic design content of images. The reason that VAS works so well to measure biophilic design is that it ignores the difference between living components, such as plants or animals, and human made components. Therefore, one obtains a general measure of the interest the design arouses that is independent from the category/meaning the various elements present in the scene belong to.

VAS provides five different results of visualizations of an image as follows:

1. *Areas of Interest.* These can be specified by the user, and each one of them has a numeric score which is the probability that a person will look somewhere within that area during the pre-attentive period. We did not use this feature.

2. *Heat map.* This is a color-coded probability map that a certain part of the image will attract the gaze during the pre-attentive period. We used this feature in all the scans, adopting it as the most direct and useful diagnostic tool for our analysis.

3. *Hotspots.* A simplified version of the heatmap results shows only the areas that are most likely to be seen during the pre-attentive scan, with a numeric score indicating the probability that a person will look somewhere in that region during the pre-attentive period.

4. *Gaze Sequence.* This indicates the four most likely gaze locations, in their most probable viewing order.

5. *Visual Features.* This visualization gives an insight to how the algorithm works, by extracting those same features that drive pre-attentive processing in our visual system (Itti and Koch, 2001); namely edges, intensity, red/green color contrast, blue/yellow color contrast, and faces. We used this feature only in the first scan, for demonstration purposes.

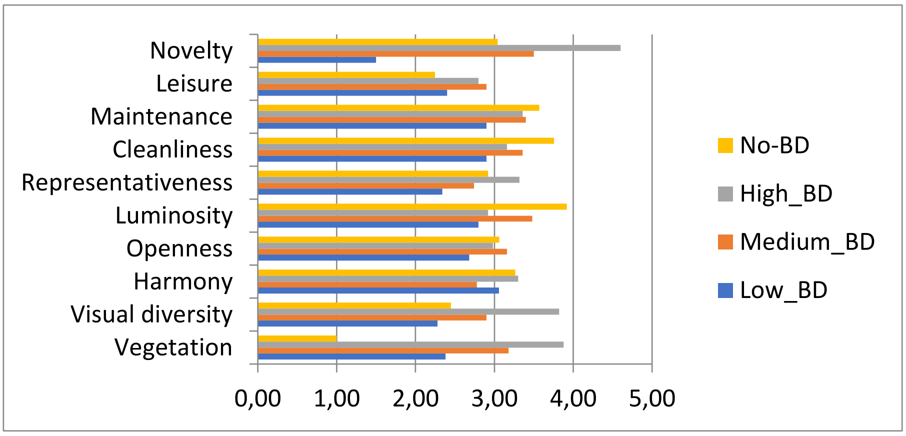
The heat maps for the eight photographs shown in Figure 1 were generated using the VAS software, and will be discussed in sequence in the rest of this paper.

3. Results and discussion

3.1 Self-rating assessments

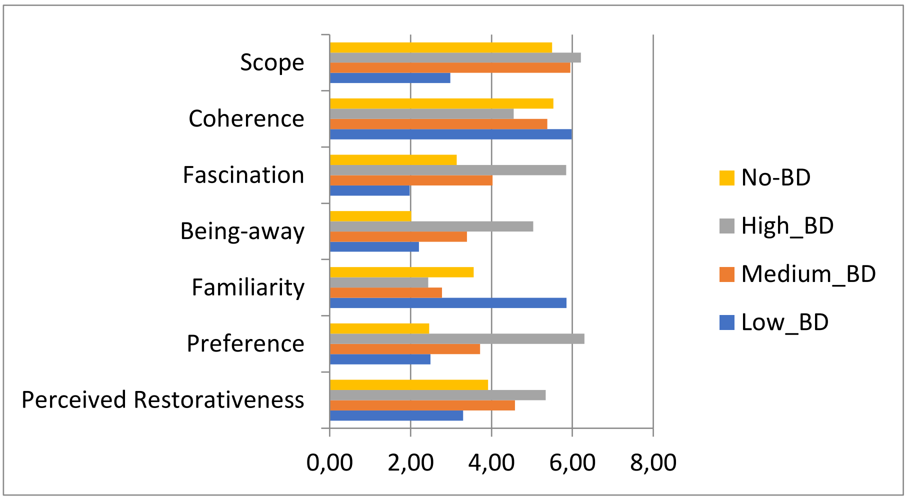
3.1.1 Results

A MANOVA (multivariate analysis of variance) was run to investigate the effect of each category (fixed factor, 4 levels: H-BD, Medium-BD, Low-BD, No-BD) on the physical-aesthetic attributes, the PRS-11, PREF and FAM. A significant effect of category emerged for: vegetation, $F(3,199) = 143.74$; visual diversity, $F(3,199) = 24.89$; luminosity, $F(3,199) = 15.29$, representativeness, $F(3,199) = 6.12$; cleanliness, $F(3,199) = 9.51$, maintenance, $F(3,199) = 5.54$; leisure, $F(3,199) = 5.48$; novelty, $F(3,199) = 106.78$; FAM, $F(3,198) = 15.98$; PREF, $F(3,198) = 21.31$; PRS-11, $F(3,198) = 12.44$; BA, $F(3,198) = 14.32$; FA, $F(3,198) = 23.82$; COH, $F(3,198) = 5.76$; SCO, $F(3,198) = 21.42$; all $p < .05$.



Graph 1. Mean scores of the physical aesthetic attributes for each category: No-Biophilic Design (No-BD), High-Biophilic Design (H-BD), Medium Biophilic Design (M-BD), Low-Biophilic Design (L-BD).

In brief, the categories differ significantly on all physical-aesthetic attributes (see Graph 1), but harmony and openness, with High-BD images, score higher on vegetation, novelty, and representativeness. The categories also differ significantly on perceived restorativeness, preference, familiarity, and the four restorative factors (see Graph 2), with the High-BD score higher on perceived restorativeness, preference, scope, fascination, and being-away, but the lowest on familiarity. The Low-BD images resulted the most familiar and coherent.



Graph 2. Mean scores of the perceived restorativeness scale, preference, familiarity, and the four restorative factors: being-away, fascination, coherence, and scope, for each category: No-Biophilic Design (No-BD), High-Biophilic Design (H-BD), Medium Biophilic Design (M-BD), Low-Biophilic Design (L-BD).

To verify further differences between photographs within each category (Low-BD, Medium-BD, High-BD and No-BD) independent sample t-tests were performed on the physical aesthetic attributes, PRS-11, PREF, FAM, BA, FA, COH and SCO. In the Low-BD category (photograph 1 vs 2) significant differences emerged for: vegetation, $t(48) = 4.10$; novelty, $t(48) = -2.45$; PREF, $t(48) = -2.18$; all $p < .05$ (see Table 1). In the Medium-BD category (photograph 3 vs 4) a significant difference emerged for: vegetation, $t(48) = 3.13$, diversity, $t(48) = 2.21$, novelty, $t(48) = 2.82$, FAM, $t(48) = 2.31$, COH, $t(48) = 2.44$; all $p < .05$ (see Table 1). In the High-BD category (photograph 5 vs 6) a significant difference emerged for: vegetation, $t(48) = 2.52$; PREF, $t(48) = 2.67$; BA, $t(48) = 2.16$; FA, $t(48) = 3.31$; COH, $t(48) = 3.05$; SCO, $t(48) = 3.05$; PRS-11, $t(48) = 2.02$ ($p = .049$); all $p < .05$ (see Table 1). In the No-BD category (photograph 7 vs 8) a significant difference emerged only for novelty, $t(48) = 4.22$, $p < 0.05$ (see Table 1).

	Low-BD		Medium BD		High BD		No BD	
	Photo 1	Photo 2	Photo 3	Photo 4	Photo 5	Photo 6	Photo 7	Photo 8
Vegetation	**2.00 *** (0.64)	2.76 (0.66)	**2.76 *** (0.92)	3.60 (0.86)	**3.84 *** (0.62)	3.92 (0.81)	1.04 (0.20)	0.96 (0.20)
Visual diversity	2.40 (0.76)	2.16 (0.86)	**2.60 *** (1.04)	3.20 (0.86)	4.16 (0.74)	3.48 (1.12)	2.32 (1.18)	2.64 (0.95)
Harmony	3.20 (0.91)	2.92 (0.95)	3.00 (1.08)	2.56 (1.15)	3.28 (1.06)	3.32 (1.10)	3.44 (1.00)	3.12 (1.05)
Openness	2.76 (1.01)	2.60 (0.81)	3.32 (0.94)	3.00 (0.86)	2.96 (0.93)	3.00 (1.04)	3.00 (1.11)	3.13 (0.94)
Luminosity	2.80 (0.81)	2.80 (0.86)	3.56 (0.91)	3.40 (0.86)	2.88 (1.01)	2.96 (1.17)	3.80 (0.91)	4.08 (0.90)
Representativeness	2.60 (0.95)	2.08 (1.22)	2.64 (1.07)	2.84 (1.10)	3.48 (1.32)	3.16 (1.34)	3.12 (0.97)	2.72 (1.17)
Cleanliness	2.84 (0.74)	2.96 (0.67)	3.48 (0.77)	3.24 (0.92)	3.08 (0.75)	3.24 (0.92)	3.56 (0.91)	3.96 (0.78)
Maintenance	2.96 (0.67)	2.40 (0.62)	3.52 (0.91)	3.28 (0.97)	3.20 (0.92)	3.52 (0.91)	3.64 (0.75)	3.52 (1.00)
Leisure activities	2.20 (0.70)	2.60 (0.95)	3.00 (0.91)	2.80 (0.95)	3.12 (1.01)	2.48 (0.96)	2.16 (1.02)	2.32 (0.82)
Novelty	**1.68 *** (0.55)	1.32 (0.47)	**3.16 *** (0.98)	3.84 (0.68)	4.68 (0.55)	4.52 (0.87)	**2.44 *** (0.96)	3.68 (1.10)
Familiarity	5.72 (2.79)	6.08 (3.54)	**3.56 *** (2.14)	2.12 (2.26)	2.60 (2.54)	2.28 (2.50)	4.24 (2.68)	2.88 (2.71)
Preference	**3.28 *** (2.59)	1.84 (2.03)	3.16 (2.79)	4.12 (3.46)	**7.36 *** (2.27)	5.24 (3.24)	2.20 (2.00)	2.72 (2.85)
Being-away	2.71 (2.68)	1.75 (1.54)	2.88 (2.80)	3.77 (2.78)	**5.95 *** (2.89)	4.12 (3.07)	2.01 (2.15)	2.03 (2.08)
Fascination	2.47 (1.97)	1.63 (1.61)	3.43 (2.51)	4.55 (2.75)	**6.99 *** (1.99)	4.72 (2.77)	2.76 (2.01)	3.52 (2.29)
Coherence	5.83 (1.46)	5.99 (1.51)	**5.88 *** (1.41)	4.91 (1.35)	**3.81 *** (1.57)	5.29 (1.83)	5.64 (1.90)	5.43 (1.76)
Scope	3.38 (2.17)	2.72 (1.72)	5.50 (2.35)	6.36 (2.30)	**7.42 *** (1.94)	5.00 (2.36)	4.92 (2.32)	6.08 (1.84)
Perceived Restorativeness	3.56 (1.76)	3.05 (1.17)	4.38 (1.91)	4.76 (1.89)	**5.92 *** (1.74)	4.76 (2.25)	3.73 (1.50)	4.10 (1.38)

Table 1. Mean scores (and standard deviation in parenthesis) of the physical aesthetic attributes, the perceived restorativeness scale, preference, familiarity, and the four restorative factors: being-away, fascination, coherence, and scope for the two photographs of each category. * = significant statistical difference: $p < .01$

To assess the direction and strength of the relationship between PRS, PREF, and FAM, a Pearson's correlation was run between these variables considering first all subjects and all categories together, and then each category separately. The following correlation turned out significant: for all categories together: PRS*PREF, $r = .84$ ($p < .01$); for L-BD, PRS*PREF: $r = .68$ ($p < .01$); PREF*FAM: $r = .36$ ($p < .01$); for M-BD, PRS*PREF: $r = .87$ ($p < .01$); for H-BD: PRS*PREF: $r = .89$ ($p < .01$); PRS*FAM: $r = .37$ ($p < .01$); PREF*FAM: $r = .38$ ($p < .01$); for No-BD: PRS*PREF: $r = .76$ ($p < .01$); PREF*FAM: $r = .31$ ($p < .01$).

The strength of the correlation between PRS and PREF for each category appears to follow the strength/level of the biophilic quality value assigned to that category. Considering the correlation results, FAM may affect both PRS and PREF for the H-BD and the No-BD categories. The significant correlations revealed between PRS and PREF and between PREF and FAM for all the categories were not unexpected; on the other hand, this study keeps showing a significant correlation between PRS and FAM that recently appeared in literature (see Berto et al., 2018).

Pearson's correlations were also run between the PRS score for each category and the physical aesthetic attributes. Table 2 shows the significant correlations between the variables addressed.

	L-BD	M-BD	H-BD	No-BD
Vegetation	.216	.656**	.313*	.172
Visual diversity	.327*	.580**	.518**	.316*
Harmony	.477**	.680**	.661**	.562**
Openness	.445**	.555**	.449**	.650**
Luminosity	.400**	.503**	.578**	.688**
Representativeness	-.039	.726**	.407**	.324*
Cleanliness	.334*	.531**	.544**	.534**
Maintenance	.396**	.530**	.398**	.391**
Leisure activities	.387**	.684**	.625**	.226
Novelty	.414**	.649**	.357*	.255

Table 2: Pearson's correlations between the Perceived Restorativeness Scale score (PRS), and the physical-aesthetic attributes scores for each category: High-Biophilic design (H-BD), Medium-Biophilic Design (M-BD), Low-Biophilic Design (L-BD), No-Biophilic Design (No-BD).
* = significant statistical difference: $p < .05$ **= significant statistical difference: $p < .01$

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Results that catch the eye include the non-significant correlations for the Low-BD category between PRS and vegetation, and between PRS and representativeness; for the High-BD category the low correlation value, though significant, between PRS and vegetation; and for the No-BD the non-significant correlation between PRS and vegetation, between PRS and leisure activities, and between PRS and novelty (see Table 2).

3.1.2. Discussion

Results show that High-BD buildings are not characterized by all physical aesthetic attributes, in particular these buildings scored low on luminosity, cleanliness, and maintenance; these characteristics distinguish the No-BD buildings the most from the other buildings. The presence of dense and widespread vegetation, typical of High-BD buildings, which makes them representative, novel, and different from usual buildings, does not go hand-in-hand with luminosity and cleanliness; vegetation is perceived as a potential problem for the building maintenance. Nevertheless, High-BD buildings are perceived as the most restorative among all the buildings: they offer a temporary escape from "urban visual routine" (being-away), they allow the engagement of involuntary attention (fascination), which is attracted in the first place by vegetation (Kaplan, 1995), and secondly, by shapes with the right amount of complexity that attract visual interest (scope). High-BD buildings score the least coherent and familiar, thus accordingly high preference for these buildings might be sustained by their novelty (see The Schema Discrepancy Model; Purcell, 1986).

Results show that Medium-BD buildings are the most suitable for leisure activities; their articulated shape together with the opportunity they allow to see through the stained-glass windows make these buildings comprehensible enough to plan activities.

The results also show that Low-BD buildings scored the lowest in perceived restorativeness, even lower than No-BD buildings. Low-BD buildings are low in fascination and scope, and the presence of a lawn and water do not necessarily correspond to a biophilic and/or restorative visual experience. Nevertheless, the Low-BD buildings are the most coherent and not surprisingly the most familiar, and in fact they are rated as the least novel.

3.2 Visual Attention Software outputs

3.2.1. Heat maps of the Low Biophilic Design buildings

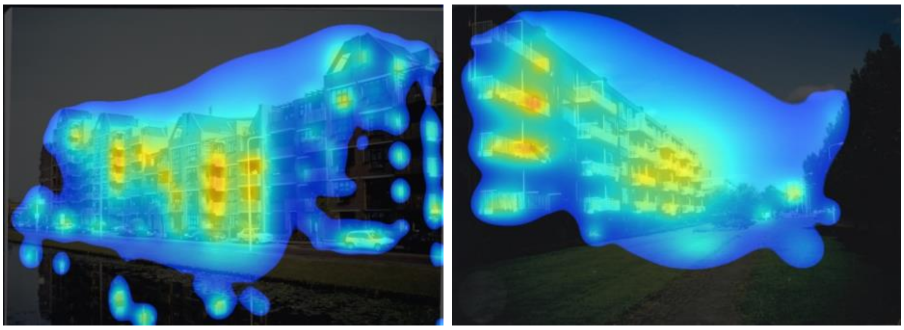

Figure 2. Heat maps of photograph 1 (on the left) and 2 (on the right).

Photograph 1. In these apartments, the attention is drawn to the contrast of the balconies against the rest of the building. The visual interest is not triggered by the trees and plants on the building, as one might expect if there was indeed a biophilic effect, this response is simply due to visual contrast. Furthermore, visual interest fails to identify the building's entrances. As an aside, the strip of lawn in front reveals itself as an extremely weak biophilic element, thus disproving universal efforts to raise the biophilic qualities just by adding some flat lawn. A common misconception is that biophilic design requires some lawn because that is an organic element, but its visual complexity is far too low to have any significant effect. One has to incorporate more complex elements for a setting to become an effective biophilic design.

Photograph 2. These apartment buildings show hotspots on their balconies. While visual interest is drawn throughout the façade, there is no significant design or functional reason for the hard focus on the balconies except for the vertical structure in the middle of each balcony. The overall impression is comfortable without in any way being notable. The lawn in front fails to draw any visual attention, hence is a very weak biophilic element in the overall composition.

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3.2.2. Heat maps of Medium Biophilic Design buildings

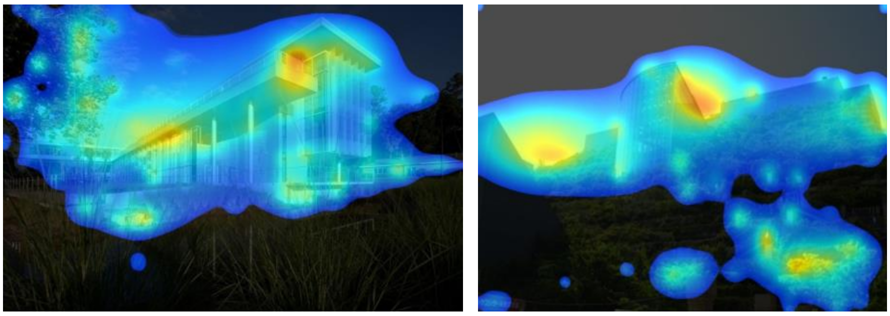

Figure 3: Heat maps of photograph 3 (on the left) and 4 (on the right).

Photograph 3. The trees, bushes, and tall grass in front are wholly biophilic, but the building's structure is not, and it therefore contrasts with its setting. There is visual interest throughout the building because the structural subdivisions offer some degree of organized complexity. Nevertheless, design flaws become evident since the attention is drawn to two hot spots: the edge of the canopy supported by the columns, and the join of the same canopy to its support. Those regions are irrelevant. They do not visually anchor the building's design or function, nor do they enhance its entrance or circulation realms. What would at first appear to be a building with a biophilic design (because of the preponderance of vegetation) reveals problems on closer examination of the scan.

Photograph 4. Here we see the failure of a glass façade to engage with the viewer's interest. This building is entirely devoid of organized complexity. The attention is drawn only to irrelevant edges on the skyline and not to the actual building. Furthermore, this attention occurs because of the light contrast, not the design; this might support the lack of spread interest. Of course, the vegetation below provides an attractant, but the overall visual interest does not extend to the material structures, which remain separated, apparently out of interest. This example appears as a non-biophilic building that is situated in a richly biophilic setting.

3.2.3. Heat maps of the High Biophilic Design buildings

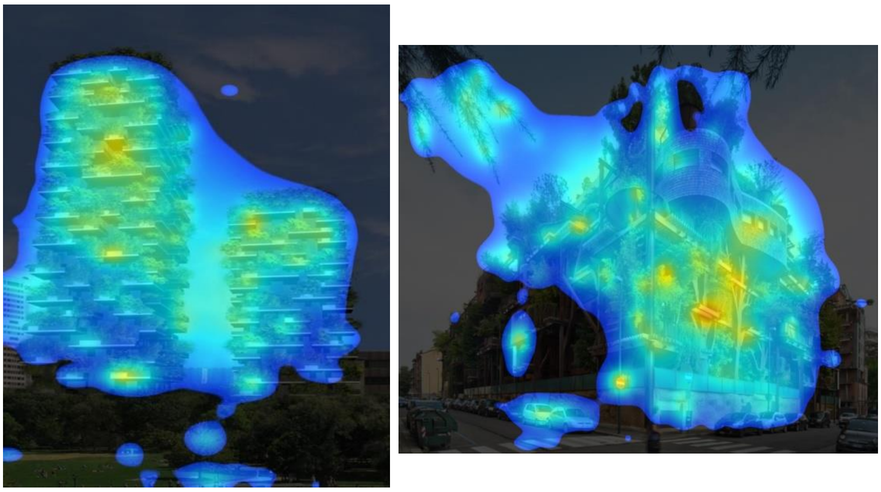

Figure 4. Heat maps of photograph 5 (on the left) and 6 (on the right).

Photograph 5. As expected from skyscrapers where trees grow on every balcony, these high-rise buildings appear to be highly biophilic. The visible material structure blends with and does not detract from the biophilic design offered by the multiple trees. There is a void in the VAS scan where the building meets the ground, whereby the ground floor and entrance are invisible to a potential viewer. This is a design flaw common with many high-rises that neglect the importance of a visual ground connection. Since these buildings are skyscrapers, attention is drawn higher, and on the asymmetrical balconies where vegetation abounds.

Photograph 6. This building draws considerable attention, which is fairly well distributed over the better lit façade to the right. The uniform blue glow indicates that the design and structural details engage attention in a wholistic manner throughout the visual field (Salingaros and Sussman, 2020). Note two artifacts of the scan that reveal some interesting background about attention: (a) The interest is drawn to a branch that enters the picture on the top left; (b) Two parked cars draw attention away from the building itself, despite the building's considerable organized complexity.

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3.2.4. Heat maps of the No Biophilic Design buildings

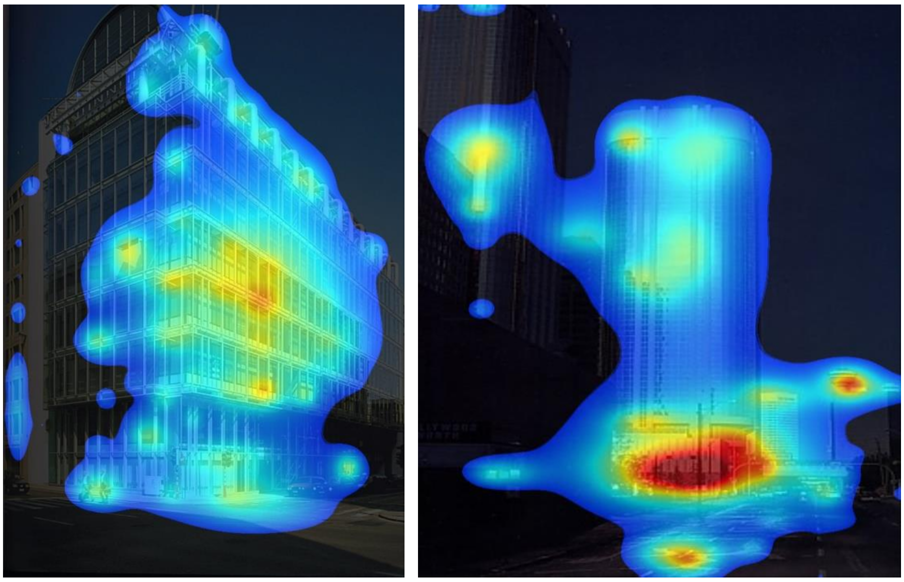

Figure 5. Heat maps of photograph 7 (on the left) and 8 (on the right).

Photograph 7. The repeating subdivisions of this glass building are enough to attract interest to its middle. It has a certain degree of organized complexity, although not high enough to distinguish its design. But the actual point of interest that is the hot spot in the scan (the windows somewhere in the middle of the façade) is not particularly relevant from an architectural and urban point of view. Also, the entrance is ignored because it fails to stand out through its articulation.

Photograph 8. There is a considerable hot spot of attention at the base of this building, but this is where the skyscraper contrasts with another building in front that appears to be built of "solid" materials. The VAS scan is empty, which reveals that there is no interest for a potential viewer. This glass skyscraper has no biophilic design qualities, since its design does not follow any organic complexity, and the building does not contain or support any vegetation.

3.3. Comparison between self-ratings assessments and VAS heatmaps

VAS analysis shows that vegetation *per se* does not always draw interest. Vegetation engages attention when it is integrated within an articulated structure. VAS doesn't disclose, as self-ratings do, that vegetation might act to the detriment of the building when it removes luminosity, compromises maintenance, and make it appear less clean. Indeed, dense and widespread vegetation might work against "cognitive sustainability" (Berto, 2011) and VAS clearly reveals that disarticulated and chaotic vegetation is not that attractive. Self-ratings assessments and VAS show that people are not used to vegetation "on" the buildings, and on the contrary, they are familiar with lawns, which VAS shows are mostly neglected. VAS highlights that the base/entrance of the building rarely catches the focus of attention, as if the building is an object on its own, independent from the context (the problem here is that 20C design philosophy does promote buildings as detached objects). This result makes sense if one considers that the photographs depict buildings detached from their context. VAS shows that attention follows the building structure horizontally or vertically and holds when a visual discontinuity occurs, e.g., in material, color, shape, direction, symmetry, etc. VAS shows that buildings articulated in a more organic manner draw the most interest, while in a parallel demonstration the self-ratings assessments show that these buildings are the most restorative hence preferred. VAS doesn't show that transparent buildings are associated with leisure activities, which is what emerges from self-ratings assessments.

If VAS can be considered a way to operationalize the engagement of attention in biophilic design, and self-ratings assessments a measure of to what extent the building is perceived as restorative, then it can be concluded that these measures show many overlapping points. Higher ratings for biophilic design match higher perceived restorativeness and preference, corresponding to a building where vegetation is integrated into an organic structure. Vegetation is not the only biophilic characteristic to be considered in biophilic design and this conclusion emerges clearly from self-ratings and VAS.

3.4. Content, process, and structure

The experience of Nature through human evolution has left its mark on our minds, our behavioral patterns, our physiological functioning, in what we pay attention to in the environment, how we respond to stimuli, and what that experience means to us (Barbiero, 2014). The Biophilia Hypothesis tells us that, as a species, we still respond strongly to Nature's forms, processes, and patterns (Kellert and Wilson, 1993; Kellert, Heerwagen and Mador, 2008). The dynamic qualities of Nature scenes, e.g., the curvilinear forms, the continuous gradation of color and shapes, the blending of textures, changes associated with seasons, etc., are highly effective in holding our interest/attention effortlessly, and this is reflected in eye movement patterns (for a review see Berto, 2014). The involuntary process can be engaged when environmental information is fascinating, i.e., if it doesn't overload the attentional system (Kaplan and Kaplan, 1981). Therefore, fascination with Nature derives not only from natural elements, but also from the qualities and attributes of Nature that people find aesthetically pleasing when reproduced in the built environment as well.

Fascination is not only a matter of *content* (natural vs. built), but also of *process* (top down vs. bottom-up process). Fascination is derived and tied to particular stimulus patterns, whereas the directed attention component is generic and content free (Kaplan and Kaplan, 1981). While fascination is elicited bottom-up, directed attention is top-down; researchers refer to directed attention as endogenous attention, and to fascination as exogenous attention (Corbetta and Shulman, 2002). Attention works best when something in the environment can fascinate, and the highest fascination occurs when content (the stimulus pattern) and process (the involuntary mode) operate together (Kaplan, 1978).

Currently research is directed towards finding out what is common to environments that engage fascination from a perceptual point of view. It may be that variations in both preference and fascination of scenes depend on their underlying geometry, with a high preference and fascination being associated with Fractal Geometry. It is important to recall that the perceived visual complexity of a fractal is determined by the contribution of fine-scale structure, with more ordered fine structure generating higher complexity. This complexity is determined by the D value (the fractal dimension), which controls the ratio between fine and coarse structure, and by the range of scales over which the fractal is observed; increasing this range increases one measure of the visual complexity (for more details see Abboushi et al., 2019; Salingaros, 2018). VAS is an attempt to verify the inherent structure of environmental stimuli which are supposed to engage pre-attentive process, i.e., the "scene structure" (see also Lavdas, Salingaros and Sussman, 2021), going beyond the debate between process and content. VAS provides the opportunity to determine visual patterns that produce optimal perceptual responses.

To better explain this point, VAS heat maps were generated for two images of natural environments, i.e., sunrise beaches with no green vegetation (see photographs 9 and 10). It is reasonable to say that here content and process might overlap, but VAS works on the structural features that attract attention the most at first glance, regardless of meaning.

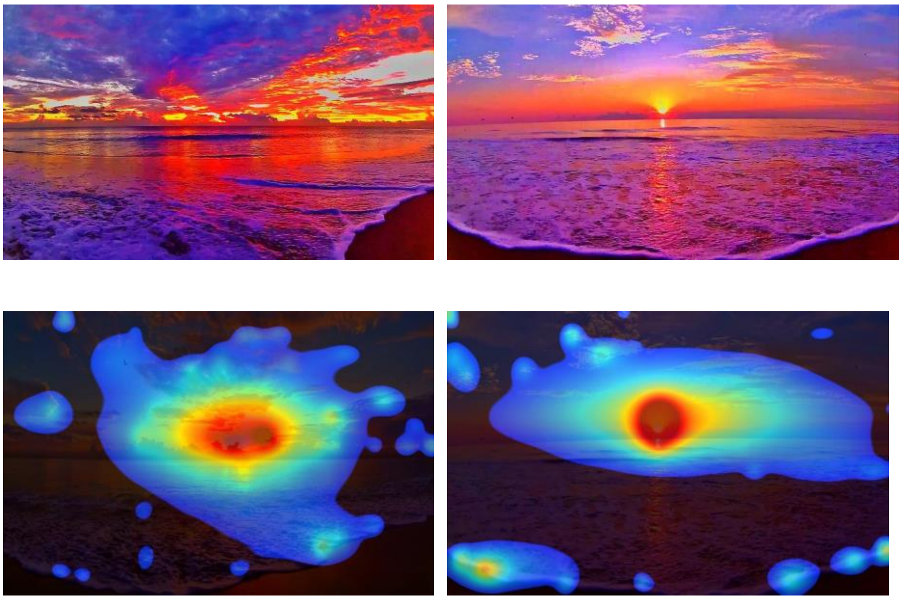

Figure 6. Photograph 9 (on the left) and 10 (on the right) and the corresponding heat maps below. Photographs credit: Rip Read.

A visual attention scan of a natural landscape, in this case two views out to sea, reveals unexpected features of our attention. These are very different from highly organized complex scenery like the building façades, which draws the eye's attention more or less uniformly (as would be revealed in a uniform blue glow in the VAS heatmap). The scans of Figure 6 confirm that in watching Nature scenery the eye moves effortlessly from one feature to another (Berto, Massaccesi and Pasini, 2008). Attention focuses on the sun on the horizon, and on the other visually interesting elements seen on the sea's surface, on the beach, in the clouds, in the curvilinear forms, in the continuous gradation of color and shapes, in the blending of textures, and in shadow features associated with light. It is not by chance that these surrounding visual elements are fractals to some extent. Clouds and waves are characterized by fractal dimensions that receive greatest preference (see Table 1 in Taylor et al., 2021), i.e., they are much smoother than natural scenery composed of trees, bushes, and other landforms such as weathered rocks.

The hotspots in heat maps coincide with functional/evolutionary points of interest, which can facilitate the exploration and understanding of the environment and, consequently, the search for adaptation solutions to obtain psychological benefits (Barbiero and Berto, 2021). In fact, from an evolutionary point of view, it makes sense that the sun attracts our attention the most, and attention falls on certain characteristics, e.g., where the water meets the sand, or where cloud shapes let you see what is behind. The beach is the meeting point of the three matrices of Gaia, which allow the biosphere to flourish: the lithosphere (beach), the hydrosphere (sea), and the atmosphere. The fascination that a natural beach arouses could drive the correct interpretation of the quality and quantity of environmental resources (Barbiero, 2021). The perception of "beauty" would be an adaptation to recognize places rich in resources at "first glance". These outputs suggest that these images might engage fascination because they are characterized by structural features that are supposed to engage the involuntary process, at least at "first glance", as VAS shows.

Identifying features of natural environments capable of arousing fascination makes it possible to mimic or replicate these features even in artificial environments. In this way, the search for topics that have a plausible evolutionary matrix (Bolten and Barbiero, 2020), and that engage the involuntary process at "first glance", could be the goal of biophilic design. For example, an essential topic for building human places is that an analysis of the geometry tells us if we are heading in the right direction. We need to see fractal scaling, organized complexity, and repeating symmetries in natural settings first, to build restorative biophilic places. Here we see that the predicted pre-attentive visual scan behaves exactly as expected, confirming an innate reaction to this geometry, which drives our pre-attentive response to necessary features. Biophilic design aims to utilize the beneficial effects of natural geometry, and to transform those patterns into the built environment.

4. Conclusions

Human evolution is central to understanding the modern human relationship with the environment (Berto and Barbiero, 2017; Berto, 2019). From an evolutionary point of view, competence in appreciating beauty appears to be a universal trait in late species of the genus *Homo*. Both *H. neanderthalensis* (Abadía and González Morales, 2010) and *H. sapiens* possessed the ability for appreciating aesthetic qualities in objects, movements, sounds, in natural objects and events, such as sunsets on a beach, whales' songs, or flights of birds (Cela-Conte and Ayala, 2018). Humans' predisposition to recognize the aesthetic qualities of a given habitat reflects the adaptations "designed" by natural selection aimed to help us choose a place where to live (Kaplan, 1992; Orians and Heerwagen, 1992). Humans are programmed by natural selection to handle a wide range of challenging environments, but this has its limitations in terms of the psychophysiological resources. After a stressful event, resources need to be recovered, and the best way to recover them is through exposure to an environment perceived as safe. Since our ancestors lived in natural environments only, the ability to recognize and prefer a safe natural environment conferred an adaptive advantage (Kaplan, 1987). Focusing on the positive valence of aesthetic appraisal, Brown et al. (2011) hold that "such a system evolved first for the appraisal of objects of survival advantage, such as food sources, and was later coopted in humans for the experience of artworks for the satisfaction of social needs". According to Barbiero and Berto (2021) aesthetic appraisal evolved also to support our informational needs (making sense, exploring solutions for adaptation), and steered us towards psychological benefits (e.g., stress recovery and attentional restoration). The present study suggests that the perception of "beauty" should be an adaptation to recognize environments rich in resources, at "first glance". Such an adaptation engages the process of involuntary attention and can be a useful guideline for both explaining and implementing biophilic design.

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Competing Interests

The authors declare no conflict of interest.

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Original Paper

Sustainable development through aesthetic expertise?

Results and reflection on an experimental case study on arts-science policy intervention

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Abstract. *This article presents an innovative prospect for arts-social science collaboration in the context of sustainable development. Based on the conceptual and methodological perspectives of sensory, arts-based* *sustainability science on the one hand and on artistic inquiry and intervention on the other hand, a new approach for collaboration between arts, social science and policymaking is explored. Beyond traditional scientific expertise in social science-policy interfaces, the suggested model of arts-social science-policy intervention aims at providing aesthetic expertise by co-creating scientific and artistic insights and developing creative options for sustainable development at the local level. First the novel approach is introduced, then an experimental case study in a German rural municipality, its course of action and the results are presented and discussed. The article ends with an outlook on the potential and challenges for* aesthetic expertise *through policy-oriented arts-social science collaboration.*

1. Introduction

In 2015, when 193 nation states agreed upon the Transformation Agenda 2030 including the global sustainability goals, there was hope that the expressed common interest and inter- and transnational cooperation would lead to multilateral and multi-level policy-making and joint engagement by state and non-state actors for collectively shaping sustainable development. By now, more than one third of the 15-year agenda has passed, and the balance sheet is meagre (Biermann, 2022, Sachs et al., 2020; UN, 2019). Reasons for the slow or even non-existent progress are manifold. As well as deeply rooted structural conditions such as unsustainable forms of resource-exploiting economic growth in global capitalism, a wave of right- and left-wing populism and nationalism across the world and – closely related – renewed geopolitical and social tensions and conflicts have made joint efforts on global sustainable development much more difficult (Marschall & Klingebiel, 2019; Rosa & Henning, 2018). More recent call for inclusive growth and fair and just transitions show that lessons have been learned but are yet to be implemented (Stevis & Felli 2020). In this regard, it can be concluded that transformative policymaking should strive for well-being-oriented sustainable development in order to ensure social acceptance (Rogers, 2012).

This could be considered especially relevant at the local level, where people live their daily lives. The perspective of arts-based and sensory sustainability science in general and, more specifically, sensory-informed policymaking both aim at contributing to confronting this challenge (Heinrichs, 2019 & 2020; Heinrichs & Kagan, 2019; Kagan, 2011). Based on approaches to sensory studies and arts-based research the multisensorial reality of human beings must be explicitly addressed, and creative options stimulated in collaborative processes between social science, arts and public policy. In the context of sustainability science, this perspective has much in common with the discourse and practice of artistic inquiry and intervention (Kagan, 2015; Balkema & Slager, 2004). While arts-based and sensory sustainability science aims at employing arts-based methods and strategies in research and teaching on sustainable development, research-oriented arts strive to develop epistemologies, methodologies, and institutional approaches in order to enhance the ability of arts to conduct artistic inquiry and produce creative insights in and through its aesthetic practices. Thus, arts-based sustainability science and artistic inquiry and intervention on issues of sustainable development represent a reciprocal border crossing, both aiming at seizing the best out of the scientific-rational and artistic-aesthetic ways of accessing the world in order to open up new insights and grasp creative ideas.

Within this perspective this article brings together the work of an artist and a social scientist, who jointly developed and conducted the study presented, to discuss the potential and challenges for arts-science policy intervention. The guiding research question is: how can science-arts collaboration contribute to local sustainable development by co-creative research and intervention? First, the conceptual and methodological foundations are introduced. It is argued that systematic collaboration between arts and social science can co-produce *aesthetic expertise* for transformative policymaking, which goes beyond traditional scientific policy advice on the one hand and forms of artistic interventions on the other hand. Then the conceptual approach is explored within a case study in the rural municipality "Samtgemeinde Wathlingen" in Lower-Saxony, Germany. Finally, the results of the case study are presented, followed by a conceptual discussion and consideration of practical implications and identification of the need for further research.

2. Aesthetic expertise for sustainable development – conceptual and methodological foundations

Given that people in private, professional, or civic contexts are embedded in multilayered and intertwined socio-material practices, science-based information or moral prompts seem to be insufficient to transform individual and collective behavior (Reckwitz, 2012). Humans are not only cognitive information processing machines, but also constituted and driven by implicit embodied imagination and world sensing. Therefore, cognitively based approaches, as in the international sustainable development goals, national sustainability strategies, sustainability reporting or solution-oriented deliberative contexts fall short (Heinrichs, 2020). To ensure civic support and stimulate engagement and commitment for change and unlock creativity for co-creating sustainable development, more attention should be paid to the multisensoriality of human existence and well-being-oriented transitions.

Beyond cognitive-rational insights regarding the need for long-term oriented sustainability transformations, the well-being discourse sensitizes to the need to pay more attention in policymaking to concrete multidimensional human needs beyond materialistic economic values, such as meaningful social relations or healthy and stimulating physical environments (Kubiszewski et al., 2013; Sachs, Layard, Helliwell, 2018; Rauschmayer et al., 2012). If this perspective is taken seriously, a different approach regarding sustainable development seems advisable. Based on theoretical and empirical insights from interdisciplinary sensory studies (Howes, 2013) and arts-based research (Leavy, 2015; Baron & Eisner, 2011), it can be argued that actions for sustainable development should become more sensory and aesthetic in order to better reflect the multisensorial experienced reality of people and grasp the (embodied) imagination and creativity for shaping sustainable development not technocratically but humanely. Looking at (un)sustainable developments and transformative policy-making through this lens, a wide range of topics arise, including: corporeal-sensorial manifestations in varying mobility options; atmospheres in nature-, land- and city-scapes; resonance in human/non-human interactions; multisensorial dimensions in varying sustainability-relevant occupational and consumption practices; sensory-scapes of places (smell, taste, touch, sight, hearing and kinesthetics); the relationship between virtual (mediated) and real (immediate) multisensorial phenomena; socio-cultural diversity of corporeal-sensorial experience, embodied cognition and imagination; multisensoriality in social and environmental inequality and the quest for just and sustainable sensory well-being. Arts-based and sensory sustainability science and artistic research appear to be well-equipped to analyze and reflect on sensed realities, stimulate associations and feelings and open up new perspectives. The sensory-aesthetic competence of artists and artistic strategies can enrich in a complementary way established scientific data- and text-based approaches.

Despite a long and multifaceted history of collaboration between social science and arts on the one hand, and social science or arts and policymaking on the other hand, there is hardly any routinized interface connecting systematically social science, arts, and policymaking. From the viewpoint of sociological systems theory (Luhmann, 1995), a transsystemic social science-arts-policy collaboration can be seen as fruitful, but also presuppositional. All three spheres have their own logics and rationalities, which appear as strengths and weaknesses of functional differentiation. Policymaking is focused on collectively binding decision-making and is dependent on legitimation, while social science strives for proven knowledge based on review procedures of the scientific community, and arts, claiming autonomy and creative freedom, is oriented towards aesthetic insight and originality. Despite the very different institutional conditions and role expectations of the involved actors, we believe that a carefully designed approach, which does justice to the legitimate rationalities and equally takes advantage of the respective strengths is conceptually feasible. Thereby mutual blind spots can be overcome and release the potential for new perspectives and pathways. The ideal-typical model for artistic-social scientific policy intervention, which is based on theoretical and methodological considerations of sensory sustainability science and artistic inquiry and intervention, sketches how the interface could be organized to deliver aesthetic expertise, combining social scientific inquiry with artistic practice and policymaking.

This ideal-typical procedure combines the specific rationalities and competencies of arts and social science with organized settings for collaboration, information exchange and joint reflection between actors in these fields and that of policymaking. The procedure builds on different phases, from problem definition through social scientific inquiry and artistic intervention up to reflection on findings and creation of (integrative) products of aesthetic expertise. In order to allow for a collaborative process at face level between all the actors the process may start within the logic of transdisciplinary practice with a joint gathering in order to define the scope and goal of the project and clarify tasks and role expectations (Nicolescu, 2002). In the next phase social science and arts start working with their respective epistemologies and methodologies, for example, quantitative and qualitative social research and artistic inquiry and preparation of participatory interventions. Of key importance are regular exchanges between science and arts for cross-fertilization as well as deliberation of interim insights and results with involved policy actors for safeguarding practice relevance and social learning. Through this procedure, policy-oriented aesthetic expertise can be produced, which is qualitatively different from merely scientific expertise or artistic artifacts. It can provide new insights and impulses for sustainable development by drawing together the rational-analytical strength of social science with the creative-aesthetic strength of arts.

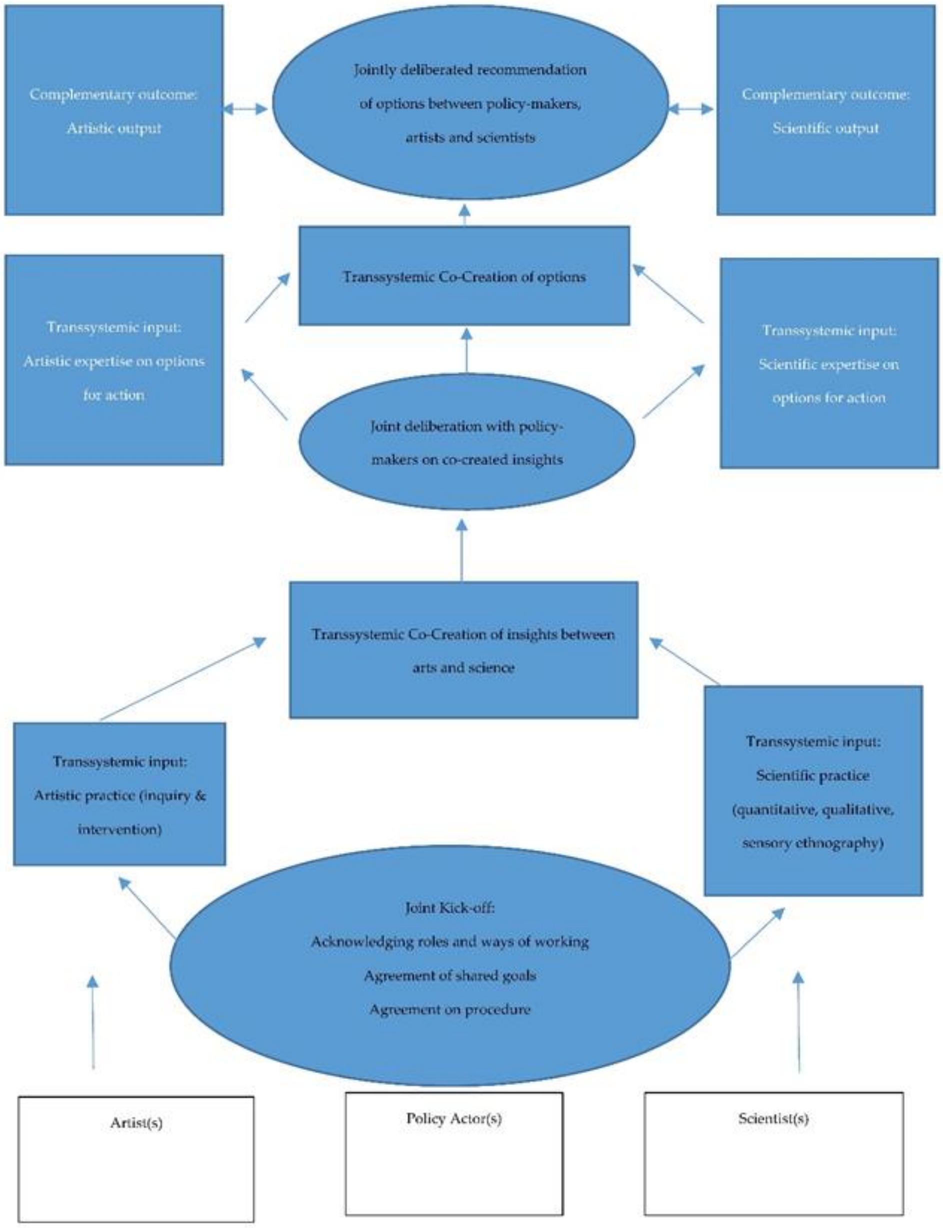

Figure 1. Artistic-Social Scientific Policy Intervention

3. The "Samtgemeinde Wathlingen" case study

The approach to aesthetic expertise through arts-social science inquiry and intervention was explored within an experimental case study. The project was realized in cooperation with the leadership of the local administration of the municipality "Samtgemeinde Wathlingen" in the state of Lower Saxony, Germany. This municipality is located in a pre-urban, rural area, approximately 30km from the city of Hannover, the capital of Lower Saxony. Based on previous contacts with the mayor and the municipal council in the context of a project in cooperation with the Environmental Ministry of Lower Saxony in 2018, the municipality expressed their willingness to participate in the experimental undertaking. Samtgemeinde Wathlingen consists of three relatively dispersed parts, - Wathlingen, Nienhagen and Adelheidsdorf - on an area of 68,47 km², with slightly more than 15.000 habitants. The surrounding area is marked by agriculture and forests. The population includes slightly more woman (56%) than men (44%), it has an average adult age of 50.74, and an overall stable population dynamic. The political landscape is characterized by two dominant parties, the Christian Democrats (CDU) and Social Democrats (SPD) followed by Greens, Liberal Democrats and by the Independent Voters Association. As a model community within the Ministry project, Samtgemeinde Wathlingen started in 2018 a process of information gathering and systematization of sustainability-related activities and measures. Amongst others, a sustainability officer was appointed in the year 2019. Against the background of this administration-centered activities the experimental project on artistic-scientific policy intervention was agreed upon. The municipal leadership was interested in opening its sustainability perspective beyond the administration to include society and to get new insights and impulses, which go beyond general sustainability management approaches, for shaping and stimulating local sustainable development process and measures. These shared interests of the participating municipal representatives, the artist and the scientist provided a fertile common ground for the undertaking.

3.1 The design and implementation of the experimental study

The generation and provision of aesthetic expertise for sustainable development requires an adequately designed collaborative process. A procedure was defined in which co-creative collaboration between science and arts as well as continuous cooperation with the political-administrative personnel involved throughout the project could be realized. The workflow was characterized by three key features: 1) periods in which arts and social science focused on their respective work; 2) collaborative formats in which science and arts jointly reflected on their parallel activities and co-created joint insights and ideas; 3) cooperative formats in which the cooperation was organized throughout the process.

The first workshop took place in February 2019. In this meeting the procedure, including a general time schedule and content of the project was jointly elaborated by the artist, the social scientist and the mayor and deputy mayor. In March, however, the Covid-19 pandemic and the general lockdown in Germany interrupted this plan. Given the difficult situation, the plan was adapted in three ways: 1) the formal start of the project was shifted towards the summer; 2) the meetings with the representatives from the municipality to initiate collaborative work between social science and arts were changed to virtual meetings; 3) the social scientific studies – including personal interviews – were switched to digital formats; 4) the artistic interventions were realized under the required hygiene measures in an aligned form. With these changes, the project was conducted between June 2020 and July 2021.

The artistic-social scientific research and intervention is described in three steps: the social scientific contribution, the artistic contribution, and finally the provision of aesthetic expertise. It is noteworthy that the scientific and artistic activities took place in parallel with regular exchange between the artist and the scientist. It was explicitly not organized as a linear process, in which social science produces knowledge, which then forms the basis for arts production. The artist and the social scientist worked simultaneously and co-creative by employing their respective methods and strategies, such as quantitative and qualitative studies for science and artistic exploration and participatory interventions for the arts. The respective procedural steps, for example, designing the questionnaire or recruiting participants for the interventions, as well as interim findings, were discussed in an ongoing process of exchange.

3.2 The social scientific contribution

The particular contribution of social science in the co-creation of aesthetic expertise was aimed at gaining a more differentiated understanding of the perceptions, opinions and future expectations of functional elites as well as citizens regarding sustainable development in Wathlingen. Three empirical studies were conducted: 1) guided interviews (online) with representatives from political parties, municipal administration, civil society and private sector in order to get an overview of the sustainability perceptions and assessments of local elites; 2) an analysis of sustainability-related policy documents and communications of the municipal administration, in order to get an insight into concrete policy measures and activities of the local government; 3) a citizen survey, focused on opinions and attitudes towards the local quality of life, sustainable development and willingness to change. This mixed-methods approach was employed with the aim to obtain a comprehensive understanding of the perceived sustainability and future perspectives in the municipality. The topics addressed in the empirical studies were discussed and elaborated between the participating scientist and artist, in order to incorporate the artistic perception of the local situation, and finally agreed upon by the cooperation partners from the municipality, in order to secure policy-practical relevance. In the following essential results of the analyses are briefly summarized.[1]

3.2.1 Video interviews

The guided interviews took place in September and October 2020 (online). Twelve representatives from civil society and municipal policymaking were asked to participate and ten interviews were finally conducted. The interviews lasted between 30 and 60 minutes. For the data analysis the software MAXQDA was employed. The key topics addressed in the interviews were understanding of sustainable development, perception of challenges, potential and willingness for change of institutions and citizens, significance of the local sustainability initiative and future visions. The results show, apart from minor differences and priority settings, quite similar perceptions of the interviewees regarding three salient areas.

First, despite some media reports, the public has so far only been reached in a limited way with information on sustainable development and citizens have not been included broadly in the process. Thus, a more decentral approach is considered as desirable since sustainability activities necessarily need to be concretized on the ground in the three member communities. Second, a more systematic activation of citizens associations and volunteers are considered as particularly relevant for a deeper anchoring and creative shaping of local sustainable development. In particular, associations can provide opportunities to experience concrete sustainable practices. Third, a very important, but challenging field of action for sustainable development is considered to be mobility and infrastructure. Room for improvement is seen for public transport, alternative mobility models, such as car sharing, as well as bicycle traffic, even though with respect to the geographic situation – dispersed member communities – and deeply anchored car routines no easy solutions are in sight.

[1] Further information is provided at the project's website: https://hoernemann-walbrodt.de/aexpertirience/

Beyond these major topics, shared widely by the interviewees, other points were mentioned, for example, the crucial relevance of national and regional policies as a prerequisite for municipal sustainability activities, the adequate financing of sustainability initiatives and programs or the role of education and local knowledge networks. It can be concluded that the interviewees showed a clear interest in engaging further with sustainable development and that the already existing social relationships between people and institutions in the municipality provide a good basis for further steps towards a more sustainable future.

3.2.2 Document review

To get a better understanding of the extent to which the perspectives of the interviewed representatives reflect actual sustainability activities of the municipal administration, key documents considered by the municipal leadership as sustainability-related were looked at. Even though the municipality started with specific sustainability activities only in 2018 within the model project "Municipal sustainability in small and medium-sized municipalities in Lower-Saxony", altogether 61 thematically relevant documents could be identified for the period 2018-2020. This includes resolutions of the municipal council, (internal) municipal briefings and information as well as press releases by the municipal administration. These materials were evaluated according to two dimensions: 1) regarding the type of document (resolution, briefing, press release); 2) content wise concerning the areas of activity on sustainable development. For this the categories employed in the content analysis of the online interviews were applied. The distribution of the types of documents shows that press releases constitute one third of all documents. This would seem to contradict the findings of the interviews with representatives that the citizenry has not been sufficiently reached with sustainability information. However, from a closer study it emerges that relatively few individual topics are dominant, e.g., international partnerships or reports on the municipal leadership, but a strategic sustainability communication, addressing systematically sustainability challenges and diverse target groups is not present.

The second largest group of documents are council resolutions. Resolutions, such as related to "climate crisis" can be viewed as particularly relevant, because they show an essential political majority will for approaching sustainable development. Internal municipal briefings and information are a third important group of documents. Here efforts to start introducing sustainability in the municipal administration through targeted information for administrative staff on measures and options to contribute at the workplace become evident. As regards the content of the material, the category of "sustainability in politics and administration" is dominant, reflecting a strong focus on addressing particularly the political-administrative system and not the wider community. A second focal point is the topical area of energy transition and electric mobility. Finally, a relevant number of documents deal with the topics "public communication and sustainable development", "sustainable infrastructure" and "availability and sustainability of water", with a specific focus on wastewater and wastewater treatment. The overview of the sustainability-related press releases, council resolutions and municipal briefings and information suggests that the municipal administration supported through the municipal council in the past two years is on its way towards sustainable development with mostly small-scale steps and some that larger.

3.2.3 Citizen Survey

A citizen survey was conducted in November 2020 (questionnaire in annex). The survey aimed at gathering opinions and attitudes regarding (local) sustainable development and transformation. Due to limited resources a sample-based survey with personal or telephone interviews conducted by a professional survey institute was not feasible. Instead, a postal questionnaire was distributed via the local weekly journal "Wathlinger Bote", which is distributed to all households by the municipal administration. A total of 204 questionnaires were returned to publicly accessible collections points such as the town hall. In relation to the structure of the population the participants of the survey turned out to be a little older (55,7 to 50,74 years) and slightly more men (51% to 44% in basic population) than woman (49% to 56% in basic population). Regarding education, the distribution shows 66% with higher education, 27% with secondary education and 7% with low/no educational attainment. Concerning social status, two groups are dominant: 53% are in employment and 42% are retired persons, self-employed or temporarily without employment. Students, apprentices, or unemployed people have low representation. The key results of the study are:

1. A ranking of relevance of current topic shows, that sustainability issues, such as climate change, environmental protection or social cohesion are considered, after the Covid-19 pandemic as most important.

2. The quality of life in the municipality is perceived as quite positive, with most respondents choosing the category "good" or "gratifying".

3. A core question of the questionnaire was focused on the assessment of areas of sustainable development already addressed by the municipal administration.

The findings show that no field is considered very bad nor very good. However, there is a clear picture of which fields are perceived as more problematic. While peaceful cohabitation, health promotion, and sports are indicated as positive, the challenges of sustainable consumption, (un)employment projects, sustainable infrastructure and agriculture are seen as more critical (grade 3 and lower).

4. Regarding the future relevance of these municipal sustainability fields, it emerges that sustainable water management, sustainable agriculture, sustainable energy, education, and climate change are perceived as particularly important. International town twinning, gender equality or nature – given the rural context – are noticeably less often mentioned as important topics.

5. The basic orientation towards sustainable development was also surveyed. The interviewees were asked to decide between several opposing options. The data shows a substantial general sustainability orientation, especially regarding responsibility towards future generations or solidarity and nature protection, but not at any cost. A significant number of respondents believes that economic growth and sustainable progress are possible and that more income is desirable.

6. A similar picture appears regarding attitudes to change. Here the data reveals that a basic openness and willingness to change can be assumed, but for many respondents it is important to safeguard achievements and preserve what is considered as good.

7. Asked which actors are particularly willing to change, the interviewed citizens rank the business sector first, closely followed by associations and the municipal administration. The participants are more skeptical about their fellow citizens.

8. Regarding the citizens' opinion of the potential of artistic interventions for contributing to sustainable development, one third believes the arts could play an important role, but a majority does not know about such approaches and a minority think it is of less importance.

Based on the empirical results of the citizen survey – considering that the sample is slightly older and more male than the overall municipality – it can be concluded that the residents of Samtgemeinde Wathlingen evaluate the current quality of life relatively positively, but they have a differentiated view of current and future sustainability challenges. Considering a mostly distinct sustainability orientation and an observable willingness to change, especially of important actors such as businesses and associations, it appears that many citizens are ready for further steps toward sustainable development.

3.3 The artistic inquiry and intervention contribution

As an artist I'm interested in the aesthetic nature of what I focus on. And I do it in an objective-subjective way, which means that I'm personally responsible for what I sense and do, but not just as a private experience. For years I have been reflecting on the way I do my work as an artist in a non-artistic environment. If you have a blocked sink, a plumber is the right person, but if a municipality is looking for sustainability strategies, an artist doesn't seem to be the right person. However, if you consider that nothing at this time is needed more than creativity to find ways of facing and solutions for wicked problems, then it makes sense to call an artist. Artists are skilled at holding the space of not-knowing, at being consciously playful and at taking responsibility for the impossible. The inquiry of an artist is an improvisation in doing and reflecting, alternating both in a short distance of time. Improvisation in the arts doesn't mean to "just do something". It rather draws on practice to use all available skills and experiences and decide at the moment, sensing what can be expressed here and now.

3.3.1 Meta-tools: triangles

For some time, I have been using a certain type of meta-tools: triangles. The first triangle is well known: I perceive, I think, and I do. With the second triangle, art has a chance to emerge. The way I do it is unique, irrational, and responsible. The quality of the atmosphere which I create is presence, warmth, and inspiration. And the last triangle describes what I work with as an artist: space, material and interaction.

Over a period of one year, I spent fifteen days on site in Samtgemeinde Wathlingen. When I went there for the first time, the mayor showed me the municipality and the steps already achieved towards sustainability. After that, I wandered around by myself to get a feeling for the environment. And I got lost. My impressions can be described as

1. The streets are straight.
2. The potassium dump is visible.
3. Everyone has enough space for themselves.
4. The administration initiates and implements.
5. Need is not noticeable, continuous overload is very much so.
6. Three villages were forced to come together.

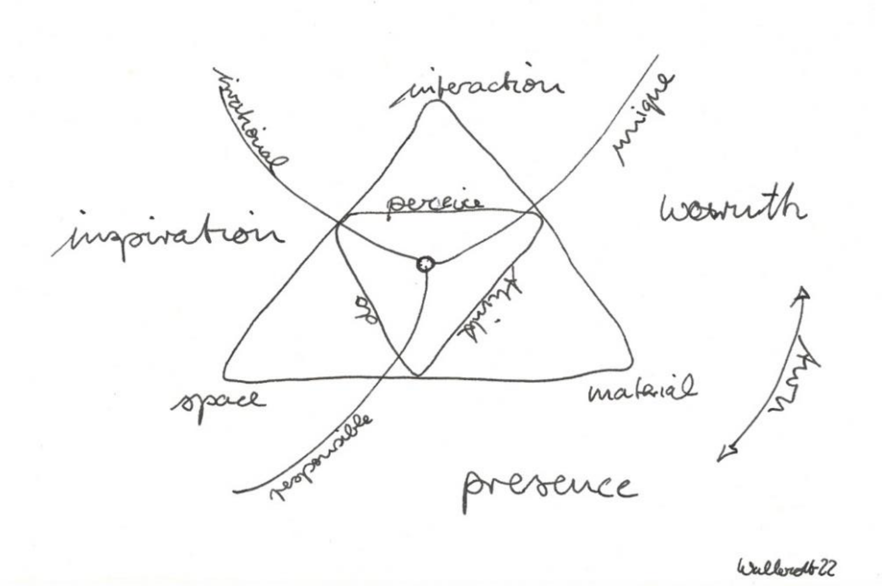

Figure 2. Triangle – unique, irrational, responsible

Figure 3. Potassium Dump **Figure 4.** Arranged Map

Starting out from the perspective that art does not reflect what is seen, but rather makes the hidden visible, the intention of my artistic interventions is to build atmospheres in which creativity becomes visible.

3.3.2 Social Sculptures

To do so I created four social sculptures.

1. In the first one I initiated the PRINCIPAL OFFICE FOR THE IM-POSSIBLE (Grundsatzamt für Un-Mögliches) and became the honorary head of department. The focus was set on the administration internally. As part of a performative approach a desk with office equipment was installed at a well-visible corner in the entrance area of the town hall. Apart from sitting like any administrative staff at my desk, I took a mechanical typewriter and visited the administrative staff to ask them what they considered to be im-possible.

Figure 5. Principal Office for the Im-Possible

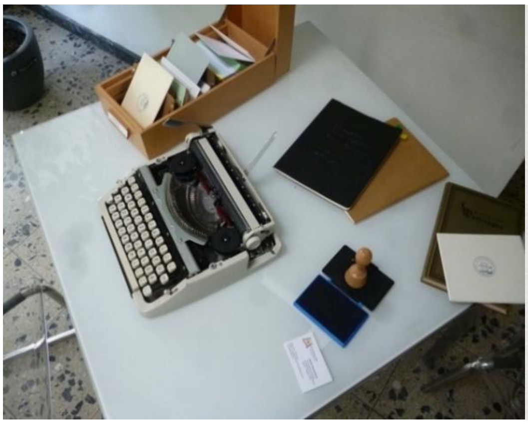

Figure 6. Mechanical Typewriter

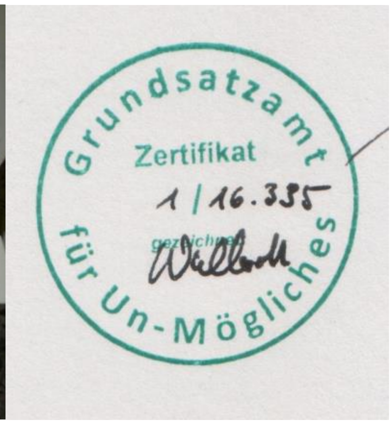

Figure 7. Stamp "Principal Office for the Im-Possible"

The PRINCIPAL OFFICE FOR THE IM-POSSIBLE collects and moves everything impossible in the Samtgemeinde. The collection is done by mail and the email address: un-moegliches(at)wathlingen.de. On every first Tuesday of the month, all those who feel involved meet. The meeting lasts exactly 60 minutes (a clock is provided) and takes place in the office. The following general conditions are set and read out at the beginning of each meeting:

1. No one leads the meeting, everyone leads together.

2. The meeting begins with each person individually confirming that it is impossible.

3. All impossible topics are noted and ordered on the analog typewriter of the office.

4. the following rules are to be observed when dealing with the topics:

a. there is an obligation to listen carefully;

b. no solutions may be sought;

c. the essence of the topic must be understood;

d. everyone gets a turn.

From the 50th minute (the clock gives a signal) of the meeting, each person present confirms that the PRINCIPAL OFFICE FOR THE IM-POSSIBLE has done a good job in allowing failure. This is the end of the monthly meeting. The resulting document is stamped with the office stamp and displayed in a picture frame.

2. Secondly, I installed the ATELIER FOR ALL. An atelier can be seen as a space where one works on a base of not-knowing, open-mindfulness, and curiosity. Citizens were invited through the local gazette "Der Wathlinger Bote" to work co-creatively in the field of sustainability.

Figure 8: Public "Atelier for All"

Figure 9. Impression from "Atelier for All"

The ATELIER FOR ALL is a space in which work is done with an attitude of not knowing, openness to results and the joy of trying things out. In it, the impossible is taken apart, enriched, and put together anew. Connections are created that have not yet been thought of and responsibility is taken for the qualities of the irrational in Wathlingen. The studio takes place simultaneously in different places in the joint municipality:

1. At home in the basement, in the kitchen and in the living room.
2. In temporary open spaces of the joint municipality.
3. Under the open sky.

 http://dx.doi.org/10.13135/2384-8677/7311

4. Mobile e.g., as a cargo bike, construction trailer or public bus.

Every citizen can open a studio and invite others to work together. Every citizen is an artist. As such, they bring three qualities to the balance created:

- uniqueness;
- irrationality;
- responsibility.

The ATELIER FOR ALL takes place at any time in any place. It lasts as long as it takes and is not repeated twice in the same way.

3. Thirdly, I created a format called SUSTAIN-ABILITY TALKS (Nachha l l tigkeitsgespräche). I invited citizens from different backgrounds, who normally don't meet, to talk about sustainability under the premise of being creative.

Figure 10. Impression from "Sustainability Talks"

Figure 11. Impression from "Sustainability Talks"

Four times a year, the municipality opens the registry office to everyone and invites them to talk about sustainability. They always take place from 7 to 8:30 p.m. and are led by a citizen who is authorized or empowered to make connections. Two leaders are also possible. The conversations take place in the following framework, which is read out at the beginning of the conversation:

1. Everyone sits in a large circle or in small circles.
2. No solutions are sought.
3. Everyone strives to make connections.
4. Everyone is given a period of time in which to speak.
5. The issues are made visible/tangible.
6. The dimensions of sustainability (social, ecological, economic) are given equal attention.

From 7:50 p.m. the leaders begin to make connections. Topics, competencies, resources, ideas, and possibilities are related to each other in the large circle or in small circles. Around 8:20 p.m., the connections made are documented. The conversation ends in the large circle with a silent minute. Reverberation.

4. As the fourth social sculpture I initiated a taskforce to plan and prepare the COMMUNITY WORLD CELEBRATIONS (Samtgemeindefest für die Welt). For the first time all three parts of the municipality create a joint day in the context of sustainability.

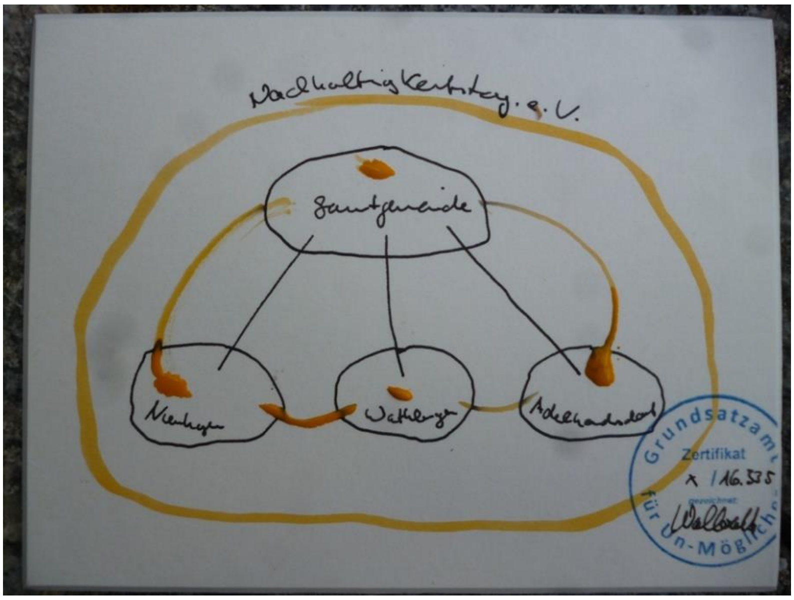

Figure 12. Artifact "Community World Celebration"

Every year the municipality organizes a festival with all citizens. The venue changes. The framework for the festival is provided by the UN Sustainable Development Goals (SDGs). At this festival all the citizens of the joint municipality come together to show the following in actions, at booths, on stages and in games:

1. Individual skills, resources, or offerings.
2. Collectively created skills, resources, or offerings.
3. Missing skills, resources, or offerings.
4. Future skills, resources, or offerings.
5. Everything shown can be tried out and experienced with all senses.

As a highlight of the festival, "the sustainability jester" is elected. All citizens of the joint municipality can apply for this award. For one year, jesters have the task of pointing out, as irrationally as possible, the issues that are important to everyone. They are noticed for this and are listened to in any case. In addition, they are invited to dinner once a week or can invite themselves to citizens' homes. The jester is chosen by the artist of this sculpture.

Finally, I asked the citizens to give me their old picture frames. I took all the pieces of work I created during my stay in the Samtgemeinde Wathlingen and all the social scientific results and put them into the frames. All the pictures became a Salon Hanging – a so-called "Petersburg Hanging" – in the town hall of Wathlingen, as illustrated in Figure 13.

Figure 13: Aesthetic Expertise – Salon Hanging

3.4 Provision of aesthetic expertise

The artistic-social scientific explorations, findings and interventions were finally merged into three forms: 1) artifacts & permanent installation; 2) text; 3) power-point presentation.

1. Several artifacts, employed throughout the artistic activities, were handed over to the municipality. These are on the one hand artifacts used during the interventions, such as a mechanical typewriter, a slip box, stamps, banner. On

the other hand, the artistic and scientific results were merged into a permanent installation of pictures and collage. Employing the approach of "Petersburg Hanging" the social scientific and artistic insights of the experimental project are now aesthetically processed and permanently exhibited in the town hall.

2. A text of 10 pages was compiled describing the collaborative artistic-social scientific process and integrating their findings as well as key information for further reading. The report was text-based information and did not include graphics or photos. The writing style and layout was sober, mimicking usual policy documents.

3. Finally, a power point presentation was provided as a pdf document with 34 slides containing an overview of the project and the findings, including the final recommendations for further action. Key information on procedure and results of the artistic-social scientific project is presented with crisp text, diagrams for the citizen survey and photos documenting the artistic interventions. The power point presentation aims at providing an overview for decision-makers as well as for interested (lay) audiences.

These products represent the co-creative outcome of the experimental project on artistic-social scientific policy intervention. Given the combination of terminological information combined with artifacts in the final products as well as the artistic-aesthetic practice of the social sculptures during the project, we can say that *aesthetic expertise* has been generated and provided to the political-administrative decision-makers as well as to the interested public in Samtgemeinde Wathlingen. Finally, the project and the project results are documented at a website, in order to make it accessible to interested audiences[2].

4. Discussion and Conclusions

Reflecting on the experimental implementation of the conceptual model for co-creating aesthetic expertise through collaboration between arts and social science for policymaking on sustainable development, several insights can be inferred. Content wise it can be stated that the approach managed to deliver scientific empirical information, released a perturbating and productive impulse in the municipal administration and across the spheres of administration and civil society by the artistic interventions, keeping the co-produced knowledge and insights permanently alive through the aesthetic manifestation in the permanent installation in the town hall. Regarding the collaborative process, it can be said

[2] https://hoernemann-walbrodt.de/aexpertirience/

that, despite the challenges of the Covid-19 pandemic, which led to greater online-exchange, the fundamentally open-minded attitude, especially on the side of the project partners from the municipality, allowed for a productive and cooperative atmosphere.

The procedural structure of the conceptual model proved to be well-functioning. The mix of parallel work streams for the social scientific and artistic activities, together with the close exchange between the social scientist and the artist and the regular exchange between them and representatives of the municipality, can be seen as key for cross-fertilization between the different perspectives and perceptions. For instance, the foci in the survey and the guided interviews on attitudes to transformation, perceptions and responsibilities of actors were informed and guided by the insights of the artistic observation and sensing on site, and the data were co-interpreted by the social scientist and the artist and finally jointly reflected with their partner in the overall venture. Moreover, the scientific insights, for example, through the interviews with representatives or the municipal documents, were instructive for shaping the participatory artistic intervention.

Finally, the concluding Petersburg Hanging installation integrated aesthetically the multilayered insights co-created between social science, arts, and the municipality. Against the background of the conceptual and methodological considerations on arts-based and sensory sustainability science and artistic inquiry and intervention, it can be concluded that it is principally viable to combine the strengths of social science and arts for practical policy contexts. The production and communication of empirical knowledge, with the ability the of arts to stimulate (new) thinking, sensing and creativity for practical purposes and the final aesthetic preparation, together lead to a different kind of experienced insight compared to expertise produced at conventionally social science-policy interfaces or political artistic intervention alone. Alongside scientific facts and figures the participatory artistic interventions enabled sensory-aesthetic dimensions to become part of the overall generated insight. Finally, given that the overall enterprise is not dominated by the perspective of social science, the arts or the municipality, it purposefully represents an in-between phenomenon for which we have created a neologism to grasp its specificity: AExpertierience, merging Aesthetics (Arts), Expertise (Science) and Experience (Practice).

We believe that our experimental case study has shown that the production and provision of aesthetic expertise is both possible and promising in its significance. Based on this outcome and the project experience, some considerations for further research and practice can be inferred. First, more experiments and research will be needed to analyse more systematically under which conditions and for which topics the proposed approach can be most effective. This is particularly relevant with regard to the finding that a majority of the surveyed citizens said that they are not familiar with the role of the arts in this context.

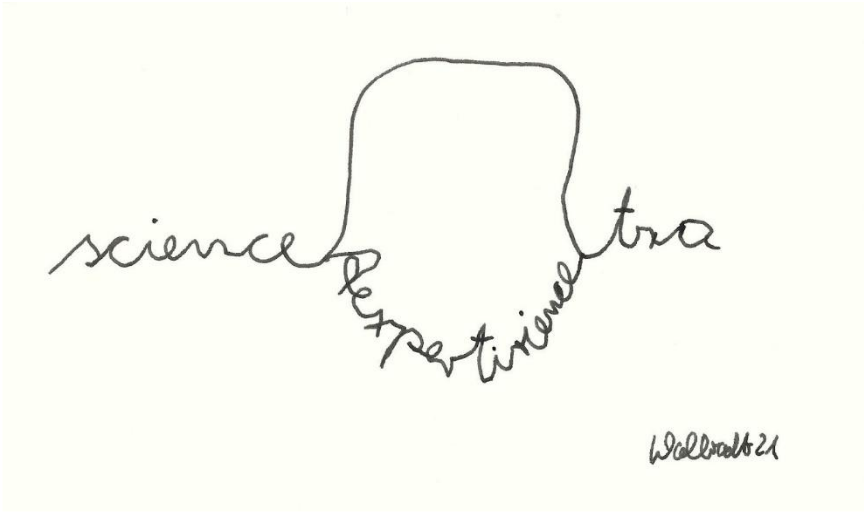

Figure 14. Art and Science by Walbrodt

Second, the material impact of aesthetic expertise could be evaluated through the contribution given by lens of sustainability assessment. Third, concerning the social science-arts collaboration and the social science-arts-policy interface, reflective studies could generate a more nuanced understanding of requirements and success factors for such transsystemic interaction. Despite the need for more experiments and research to develop the approach of aesthetic expertise further, the project delivered results, which were considered by the participating practitioners as valuable. The co-created aesthetic expertise was evaluated as an informative, lively and effective approach to drive forward local sustainable development. Based on the positive evaluation, the mayor invited the artist and social scientist for a follow-up project. In this respect, some general recommendations for further practice can already be formulated. The joint problem and goal definition as well as the transparency of the procedure of the co-creative process are as important as nurturing the willingness of the participating partners to engage with each other and the heterogenous perspectives and the openness for potentially surprising results. Given that there is no routine in political-administrative systems for this kind of project, as opposed to social scientific consultancy on the one hand or commissioned artistic work on the other, institutional creativity is clearly a prerequisite before the project may start in order to provide the space for enabling an experience which can produce aesthetic expertise for sustainable development.

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Original Paper

Citizen's willingness to pay for private forest certification in Kenya

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Keywords: Awareness; deforestation; responsible forest management; standards; sustainability.

Abstract. *The desire for responsibly managed private forests through certification is steadily growing around the globe. However, there is limited information on citizens' willingness to accept or pay for private forest management certification in the process of sustainable development. This study used literature review and online survey questionnaires administered in a workshop set up targeting those with and without private forests to address this question. Results from Kenya substantiate that private forestry can contribute to sustainable socio-economic development and as such the sector is steadily growing. To augment this growth, the country has developed supportive policies and legislation for forest certification which provide opportunities for the participation of a wide range of stakeholders. Already, some Private Sector Enterprises have received Forest Stewardship Council (FSC) Chain of Custody (CoC) certification mostly in the packaging industry. In addition, an interim FSC standard was launched by the government of Kenya in the year 2022. Various state agencies are already conducting piloting and field testing of certification. Kenya Forest Service (KFS) is conducting field testing of the FSC Interim Standard within public forests. Kenya Plant Health Inspectorate Service (KEPHIS) has certified over 250 nurseries across the country. Kenya Forestry Research Institute has developed the Tree Nursery Certification Protocol, 2021 as a practical guide for tree nursery certifiers. This unwavering government support for forest certification may have contributed to the high level of willingness to pay or accept private forest certification among the study respondents who were already consuming certified products. However, certification faces a number of challenges, including; lack of regulations for operationalizing the private forest development incentives outlined in the Forest Conservation and Management Act, 2016 and lack of county forestry programmes. Thus, this study recommends the need for increased education and awareness on private forest management certification and conducting more* *studies on the type and market share of certified products from private forest that are consumed in the country and the speedy formulation of regulations for operationalizing incentives for private forestry development.*

1. Introduction

The proper management of environmental resources is important for maintaining a balance between the ecological, social and economic aspects of sustainable development. Environmental resources such as forests and allied natural resources provide many benefits which are important for promoting sustainable socio-economic development and human well-being (Sun et. al. 2022). One of the most important assessments that illustrate the contribution of forested ecosystems to societal well-being is highlighted by the framework of ecosystem services as documented in the Millennium Ecosystem Assessment Report of 2005, which provides a detailed account on the benefits provided to the society by environmental resources such as forests. Ecosystem services provided by forests are diverse and may include tangible products or goods such as timber, spices and fruits, also called provisioning services, and intangible products categorized as regulating services, for instance, soil and water conservation or carbon sequestration. Forst ecosystem services are also classified as supporting services and cultural services in view of their educational use or during tourism. Even though the ecosystem services approach is widely used to inform natural resource management policy and to link ecosystem functions and human well-being, the concept has also been criticisized for being overly simplistic, inaccurate and negating the human contribution to enhancements of ecosystems (Comberti et al. 2015). In this paper we assert that these classifications help the society to identify, describe and evaluate these benefits for the purpose of sound policy and management actions (MEA, 2005; de Groot et al. 2002).

However, agricultural intensification, urbanization and illegal logging are hastening forest loss and degradation at an alarming rate that threatens the sustainability of ecosystem services (FAO 2020). Hence, there has been a rising need for responsible forest management which balances the social, economic and environmental aspects of the forest sector. Sustainable forest management integrates these aspects and provides a widely accepted policy option for enhancing research on the sustainable furnishing of ecosystem services. Studies conducted within this framework indicate that most ecosystem services research appears more focussed on the ecological and economic aspects. However, socio-cultural evaluations of ecosystem services are also becoming more important as a strategy for promoting sustainable development and promoting effective forest conservation (Chan et al. 2012). As a result of such research, many forest management approaches and policies have been implemented to slow down deforestation and degradation. At national level in most countries, forest laws have been enacted and their increased enforcement strengthened on illegally imported timber, protected areas have been created, and programmes for payment of ecosystem services have been introduced. At the global level, commitments have been ratified to slow deforestation, including payment of carbon credits under the United Nations Framework Convention on Climate Change (UNFCCC) with private supply chain actors introducing eco-labelling and certification as a part of their wider corporate social responsibility strategy aimed at promoting responsible forest management.

Despite the growing research interest in forest certification, longitudinal studies in private forest governance and certification are still comparatively few on a national level (Johansson, 2012). This paper addresses this question by attempting to provide a new understanding on citizens' willingness to pay for private forest certification for the purpose of shaping discourses on sustainable management of private forests. Using literature review and data collection from 20 workshop participants with and without private forests from Kenya, this study asked if private forest certification can be an important tool for promoting the sustainable management of private forests in Kenya. In order to comprehensively address this research question the study will first review the link between private forest governance and certification, explore the impacts and challenges of private forest certification, and the willingness to pay for forest certification. The environment for the development of private forests and certification in Kenya will be reviewed in order to provide context to the study. Furthermore, the results from 20 online survey questionnaire administered to workshop participants will be explored in order to draw key conclusions from the study.

1.1. *Private forest governance and certification*

A private forest is defined as a forest owned by individuals, families, communities, private co-operatives, corporations and other business entities, religious and private educational institutions, pension or investment funds, NGOs, nature conservation associations and other private institutions (FAO 2020). Private forest governance and management activities include tree nursery establishment, tree planting, tending and maintenance, harvesting and replanting as the cycle continues. In recent times, following the adoption of sustainable forest management, private forest management plans are drawn up and highlight all the management activities to be undertaken in a given private forest. Forest certification is emerging as one of the approaches for promoting sustainable private forest governance and refers to a voluntary, market-based approach for enhancing forest management, assuring society that the provision of private forest ecosystem goods and services will be maintained and enhanced in the course of responsible forest management (Perera et. al. 2022). Certification or voluntary sustainability standards refers to an independent, third-party evaluation of forest management against an agreed standard. Forest certification is innovative and ensures that the social, economic and environmental aspects of responsible forest management do not create problems for local communities or reduce the value of the forest estate (George et. al 2022; Cashore et al. 2004; Rubino et. al. 2022).

Historically, forest certification started in the 1990s, following the failure of the Earth Summit to produce a legally binding agreement on forest management, but then opted for Agenda 21 and the non-legally binding Forest Principles (Tikina et. al. 2008). As a result, many non-governmental organizations coalesced and agreed on the establishment of a non-governmental, independent and international forest certification scheme as a means to prevent deforestation and degradation in the tropics, by assuring buyers of products that the wood used had been sourced from a sustainably managed forest. The initial efforts and consultations led to establishment of the Forest Stewardship Council (FSC) in 1993 (Barklund and Teketay, 2004). Over time, it was realized that other important players such as private forest owners were not involved in establishing FSC. In addition, despite the existence of national certification schemes, certification still faced the problem of broader acceptance in export markets (Nussbaum and Simula, 2013). This led to the proliferation of other certification schemes in different regions of the world.

The Programme for Endorsement of Forest Certification (PEFC) emerged in Europe by 1997 as a scheme for mutual recognition of national certification schemes. Other regional certification schemes have subsequently been developed, including the North American Sustainable Forestry Initiative (SFI) and the African Ecolabelling Mechanism (AEM) (Teketay, 2016). National certification schemes in existence include the National Certification Scheme in Chile, the Canadian Standards Association, Lembaga Ekolabel Indonesia, Malaysian Timber Certification Council, the Gabon and Cameroonian Associations of Pan African Forestry scheme (Teketay et al. 2016). However, existing literature suggests that the Forest Stewardship Council (FSC) seems to have won the "war of certificates", to emerge as a leader in sustainable forest management in tropical countries (Humphreys 2006). In addition, the Programme for the Endorsement of Forest Certification (PEFC), Forest Stewardship Council (FSC) and Sustainable Forestry Initiative (SFI) affect the majority of forest land globally. To date, forest certification has been implemented in virtually all wood producing regions of the world. It is estimated that 11% or approximately 1 billion acres of the world's forests are certified (Alvarez 2017).

Existing literature also indicates that the infusion of voluntary sustainability standards into public policy has been the key driver in promoting their adoption, with the FSC emerging as the leading voluntary sustainability standard with greater institutionalization. Certification and other voluntary sustainability schemes are increasingly being recognized by many governments as transnational governance tools (Depoorter and Marx 2021). However, other studies indicate that the adoption of certification which characterizes public-private interactions may be antagonistic where public and private practice conflict, substitutive where public policy adopts voluntary sustainability standards from the private sector, or complementary interaction where voluntary sustainability standards fill public policy gaps or reinforce public policy (Marques and Eberlein 2020; Marx, 2018). There are many examples on how institutionalization of voluntary standards is fast emerging (UNFSS, 2020). In the Republic of Korea, the Sustainable Use of Timbers Act of 2017 explicitly recognizes voluntary sustainability certificates as an approach for controlling illegal timber imports. Certificates act as credible proof of compliance with requirements such as risk assessment procedures or due diligence and legality requirements. The Government of Gabon has pegged the issuing of all forestry concession permits on FSC certification by the year 2022 in order to promote its timber exports (FSC, 2020a). Governments are also adopting certification and voluntary sustainability standards in state-owned operations. For example, in Croatia, a considerable area of state-owned forests is certified by the FSC (FAO and UNECE, 2020). Exploring the Kenyan context for private forest management certification can offer insights into the role of the government in forest certification and be of interest to the global community.

1.2. Private forest governance and certification

Forest certification is based on standards, accreditation authorities and independent certification bodies (Cashore et. al., 2006; Gallison 2003; van der Ven and Cashore 2018; Schulze et al. 2008). Certification has many influences on the state of forestland ownership, forest protection and marketing of forest products. In general, certification has been associated with improved forest health, improved price premiums for buyers, reduced waste production, and enhanced and better environmental management practices (Lemes et. al. 2022; Mexia et al. 2022; Gutierrez Garzon et. al. 2022; Panico et. al. 2022).

The current forest certification process involves attaching an emblem onto a wood product which is meant to alert the buyer that the wood used to assemble the product is from a certified forest. There are four types of certification: forest management certification which evaluates the management of a particular tract of forestland against some agreed management standards; chain of custody certification which tracks wood from the forest to the finished wood product; group certification which has been designed to reduce the certification costs on individual land owners; and fiber sourcing standard which caters for wood companies that do not produce or manage forest lands themselves (Gullison 2003; Newsom et. al. 2006; Schlyter et. al. 2009).

1.3. Challenges of forest certification

Certification of forests is also increasingly being discredited as a result of certain controversies over the criteria employed: possible conflicts concerning definition of the stakeholders; problems regarding the 'neutrality' of the institutions involved; problems concerning how to effect controls and combat illegality. Certification has been accused of being costly and having direct and indirect costs for landowners, including small scale private forest owners across the globe. Certification assessment as a direct cost varies depending on the scheme of certification, the size of the forest land being certified, and other factors. In addition, a willing landowner may be required to join the certification scheme upon payment of some fees. There may also be changes in record management practices and the procedures for forest monitoring and evaluation. As such, the antagonists of certification claim that certification is costly and time consuming and there is limited knowledge of perceived benefits. Certification is also regarded as an abstract idea with too much science involving cumbersome paperwork.

In addition, certification systems, even the most widespread and complete ones such as the FSC, always deal with forest management starting from productivistic assumptions, assuming that all forests are able to or "must" produce goods. Further, there is still no certification system that assesses the compatibility of forest conservation with its utilization, while this topic is of great importance in fragile countries and ecosystems such as those of equatorial Africa. Therefore, in order to fully understand the best way of delivering certification systems, including a country like Kenya which is part of equatorial Africa, there is a need to understand the willingness to pay for private forest certification as a way of acknowledging, balancing and distinguishing the market demands for various products, the environmental sustainability of forestry businesses, and the rights of local communities.

1.4. Willingness to pay for private forest management certification

Nevertheless, protagonists and antagonists both agree that perceptions of the cost of private forests certification are driven by limited resources, low-capacity building and lack of clear stringent policies. Moreover, the supporters of certification have called for the generation of more data on certified forest products in the market by type and market share, improved collaboration between the major certification schemes in order to avoid cases of double certification, and reduction of the costs for small forest holders (Wobowo 2002; Taylor 2005). As such, researchers are increasingly leveraging on qualitative and quantitative perception studies that use socio-economic attributes of the individual landowners to understand the willingness to pay for certification costs and the policy and management options for forest certification.

Through these studies, links have been established between the increased desire to pay for certification and certain socio-economic attributes of the landowners and stakeholders (Tian 2022). Socio-cultural and socio-economic data is important for revealing the differences in perceptions amongst stakeholders because the willingness to accept certain certification costs may be at the expense of others. Hence, divergent stakeholder opinions may be used to devise robust certification strategies since stakeholders' values are different due to differences in social background and personal characteristics such as income, age, gender, education, and location of residence (Scholte et al. 2015; Tian 2022). For individuals, families, communities, private co-operatives, corporations and other business entities, religious and private educational institutions, pension or investment funds, NGOs, nature conservation associations and other private institutions, there are both external and internal motivations that drive the need for certification.

Studies show that access to market motivation is the main external driver identified in most literature since certification is a tool for providing competitive advantage to most businesses. In addition, the quest for trust and legitimacy from promoters of sustainability motivates actors towards certification alongside legal motivations where regulation by governments help to prevent illegal logging by imposing strict controls (Faggie et al. 2014; Zubizarreta et al. 2021). Internal motivations include personal moral motivations based on individual ethical values and learning motivations where a company could transfer knowledge and skills through adoption of certification (Zubizarreta et al. 2021). In China, a study conducted on marketing of certified wood floorings of perceived benefits to manufacturers and developers established that for manufacturers the important benefits for certification were to meet the purchasing requirements of foreign consumers, to support sustainable forestry and environmental protection and to meet corporate social responsibility goals, while for housing developers the benefits included product differentitation, the need to acquire 'green consumers' and branding with high end image (Wang et al. 2011).

Studies also show that many landowners are unfamiliar with certification and that younger and well-educated land owners with relatively high incomes and having a high desire for conservation of nature are highly likely to pay for private forest certification upon receipt of professional advice on forest management (Tian 2022). In the United States a study conducted to determine the willingness of consumers to buy environmentally certified forest products established that there was a strong relationship between willingness to pay and income (Aguilar & Vlosky 2007). Based on these relationships, studies recommend that in order to promote responsible forest management through certification, there is need to address policy, market and institutional failures, inadequate tenure, rising populations and their demands, fragmentation of the forest estate as well as inappropriate infrastructure, technology and skills (Upton and Bass, 1995). In this paper, we observe that in order to address such challenges, there is the need for policy decisions to be made at national, regional and international levels, based on data on the willingness to pay for private forest certification. At the international level, global agreements such as the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the United Nations Convention to Combat Desertification (UNCCD) provide the overall policy framework for private forest certification. However, existing literature has identified that, in general, many policies on forest management were meant to have a narrow scope, are static with limited goals and are largely government controlled instead of being more dynamic and focused on groups such as the private sector and communities.

In Kenya, there are limited national level studies on the willingness to pay for certification by private forest owners and how this affects the sustainability of private forest management. This study uses literature review and semi-structured online questionnaire survey to establish the willingness to pay for private forest certification for the first time. The key question that guided the study was: what is the citizens' willingness to pay for forest management certification as an approach for promoting sustainable private forestry development in Kenya? Kenya has been chosen for this study because the country recently launched an interim FSC standard, thus it is interesting to evaluate the willingness to accept certification costs by private forest owners. This information is critical for foresters, environmentalists and policy makers in order to make informed policy decisions in a manner that stimulates a sustainable private forest sector in the country.

1.5. The environment for private forest management certification in Kenya

Kenya has a forest coverage of 7.2% of the land surface, representing 4.18 million hectares which can be classified into four (4) major forest types and eight (8) sub-types. Table 1 depicts information on the forest types, sub-types, and the approximate area for each category as of 2010. Dryland forests represent the majority of the state's forest cover (45.4%) out of the total forest area, followed by montane forests at 32.9%. Public and private forest plantations comprise a mere 5% of the total forest area in Kenya.

Forest type	Forest sub-types	Approximate area (Ha)	% of total forest area
Western rainforest	Natural forest (mixed indigenous) [*Kakamega, Nandi forests*]	144,615	3.5
Montane forests	Natural forest (mixed indigenous) which include Mt. Kenya, Aberdares, Mau, Cherangany, Mt. Elgon, Matthews Ranges and Chyulu Hills	1,359,860	32.9
	Bamboo	85,693	2.1
Coastal forest	Natural forest (mixed indigenous trees) [*Arabuko sokoke, Dakatcha, Boni, Shimba Hills, Kayas*]	295,871	7.2
	Mangroves	48,522	1.2
Dryland forests	Natural forest (mixed indigenous trees) [*Hilltops in Eastern and Northern Kenya and Lake Victoria regions*]	1,875,316	45.4
	Riverine forest	135,231	3.3
Forest plantations	*Public and private forests*	186,716	4.5

Table 1: Forest Types in Kenya (Source: National Strategy for Achieving and Maintaining 10% Tree Cover, 2019).

Forests rank highly as one of the most important national assets, providing environmental, ecological, economic, social and cultural benefits (Kagombe et. al. 2020). While the intangible benefits have not been adequately quantified, the sector contributes more than Kshs 20 billion shillings worth of goods to the economy annually and employs over 50 thousand people directly and another 300 thousand indirectly (Odwori et al. 2013). In addition, over one million households living within a radius of five kilometres from the forest reserves depend on forests for cultivation, grazing, fishing, food, fuel wood, honey, herbal medicine, water and other benefits (Odwori et al. 2013).

The private forest sector is dominated by tea estates owned by multinationals and local companies that planted mostly eucalyptus tree species for tea curing as a substitute for expensive furnace oil. The growth of private forests can be attributed to many factors. However, the inability of the public forest plantations to meet the local timber demand has attracted several investors, including wood-based companies, syndicated private investors and large-scale farmers that are motivated by commercial interests. In addition, the expanded electricity power distribution in the country has created high demand for transmission poles, mostly sourced from *Eucalyptus grandis* trees, making it one of the leading short rotation crops grown by private forest investors. Most private forest investors deploy integrated wood utilization processing and value addition to minimize wastage and improve their operating profit margins. The business model is largely a diversification strategy from a predominantly core agricultural based business into a profitable forest business that takes both vertical and horizontal integration dimensions depending on the core business of the investor (Cheboiwo et. al. 2018).

Even though existing literature shows that the private plantations expanded marginally by 1.1% from 68,000 to 90,000 hectares in the period 1990-2010 and lately have been dominated by large companies that purchase huge tracts of land for tree growing, the sector has limited room for expansion due to shortage of land and competition from agricultural enterprises and settlements (Cheboiwo et al. 2018). However, there are indications that private forests are likely to expand as they leverage on efficiency in land use, efficient technologies and high demand for forest products to compete in local and regional timber markets.

Private forestry actors are involved in both primary and secondary value chain production activities. However, studies show that the key activities include sawmilling, wood-based manufacturing complexes, furniture making and collection, processing and value addition of non-timber products (Cheboiwo 2014; Kagombe et al. 2020; Choge, 2002). The diverse private forestry activities create employment opportunities for many people, generating taxes for governments, interest for financial institutions, and significant profits for forestry investors.

Recent national-level legal and policy reforms, coupled with deliberate government efforts to increase tree cover, are providing impetus for the development of the private forest sector. For instance, the constitution of 2010 is very explicit on Kenya's intentions towards increasing tree cover. It calls for the need to achieve and maintain 10% tree cover in the country on public, community and private lands. Other policy documents such as the blueprint Vision 2030, the Draft Forest Policy of 2020, Forest Conservation and Management Act of 2016, the Agriculture (Farm Forestry) Rules of 2009, are in keeping with the constitution 2010 and promote tree growing activities by private forest owners. Part IV, section 30 (i) (a-d) and Article 72 (1) of the Forest Conservation and Management Act, 2016 are clear concerning the need to develop a robust private forest sector in the country. However, the Ministry of Environment and Forestry has yet to develop regulations for operationalizing private forest development incentives. In addition, the Forest Conservation and Management Act, 2016 lacks provisions for forest certification.

The County Government Act of 2013 provides for the establishment of institutions within devolved units for implementing many development functions, including tree planting on community and private lands for sustainable development. In order to fully implement development initiatives, including development of tree resources, counties have developed many tools such as the County Integrated Development Plans (CIDPs). However, most counties are still at nascent stages in the process of establishing forestry programmes. Interestingly, even with these forestry challenges, in general, a review of the performance of devolved units show that devolution has enhanced equitable resource distribution, improved economic and social development, increasing citizen inclusion and participation in decision making, and promoted accountability, transparency, and national unity (KIPPRA 2016, UNDP 2017, Ngigi and Busolo 2019). With improving democratization and good governance, it is hoped that private forests and tree resources in counties will become critical county infrastructure supporting socio-economic growth.

In attempts to overcome the policy and regulatory gaps for private forest development, in 2021 Kenya launched the FSC Interim National Forest Management Certification Standard, whose main objective is to promote conservation of forests for ecosystem services. Through engagement with the Kenya Forest Service (KFS), the state corporation responsible for forest management in the country, the Forest Stewardship Council (FSC) has identified pilot sites for field testing the FSC certification. KFS has identified Eburru Forest and other forest blocks in the Aberdares range as pilot sites for field testing of the FSC Interim Standard. Currently, a team from KFS is working closely with FSC to describe the chosen sites in biophysical and social dimensions, which will be followed by gap analysis to identify and describe areas or issues for improvement. This will be a major first application of the newly approved Interim National Standard in Kenya. Hence, it is critical to examine the citizen's perception towards implementation of the FSC standard and draw lessons for Kenya and beyond.

However, existing literature also shows that forest certification is not new in Kenya. Some years ago, wood carvers from coastal forestry initiatives were certified with support of the WWF Office. Already, 11 Private Sector Enterprises have received FSC Chain of Custody (CoC) certification, mostly in the packaging industry. Private sector uptake in CoC certification is crucial in that it provides an internal market for certified goods and services and reduces or mitigates illegality in the timber trade in the country. Besides this progress, Kenya Plant Health Inspectorate Service (KEPHIS) has introduced a plant nursery certification scheme where all kinds of plants that are grown are inspected and audited at the production premises to ensure they are free from pests and are of high quality. A certificate is issued as evidence of compliance with the set laws and regulations. Plant nurseries are classified as either fruit tree nursery, vegetable nurseries, flower nursery, forest tree nurseries, or miscellaneous nurseries where seedlings with greater economic value are propagated (KEPHIS Newsletter 2021).

Kenya Forestry Research Institute (KEFRI) has also developed the 'Tree Nursery Certification Protocol, 2021' for voluntary tree nursery certification process. The protocol is based on the fact that forests and trees on farms play a critical role in the provision of goods and services and are a major source of livelihoods for many communities. Successful forest conservation and regeneration efforts require the use of reproductive materials that meet appropriate genetic, morphological and physiological quality standards. However, research and field experiences invariably show that most of the seedlings planted out are of low quality leading high mortality rates when out planted. Hence, certification of tree nurseries will address problems of low quality, low vigor and poor health that is associated with high field mortality at out-planting.

The main purpose of tree nursery certification is to ensure production of quality and healthy planting materials for quality products and maintain environmental health. The accreditation process recognizes two types of tree nurseries: (i) commercial tree nurseries whose sole purpose is to produce certified tree seedlings of any of the commercial tree species and (ii) general purpose tree nursery which may combine production of commercial tree species and other species for conservation purposes. Applications for certification are invited from tree nurseries owned and managed by Government Ministries, Departments and Agencies/Institutions; learning institutions, both public and private; Non-Governmental Organizations (NGOs), Private Companies; Faith Based Organizations (FBOs) and Community Based Organizations (CBOs); Community Forest Associations (CFAs); Timber Manufacturers Associations (TMAs) and Tree Growers Associations (TGAs); groups (youth, men/women groups); individuals; any other organized groups. A nursery seeking certification under the 2021 protocol must be in the KFS register of tree nurseries.

2. Materials and Methods

This study seeks to provide information on the willingness to pay for forest management certification by private forest owners in Kenya. As such, both primary and secondary qualitative data were collected from 20 participants using an online survey questionnaire during the proceedings of a workshop which aimed at sensitizing various stakeholders, including five government officials, three private sector development actors, five community groups and seven individual private forest owners on the importance of tree growing. The 20 participants originated from all seven agro-climatic regions of the country and were all adults of sound mind. Kenya had seven agro-climatic zones, namely, Zone I-VII (Somroek et al 1982). There were three participants from agro-climatic zone I-VI and two participants from zone VII. Thus, although their number was relatively low, the participants constituted a fairly representative sample that could be evaluated to provide evidence for the study.

2.1 Primary data collection

The survey questionnaire generated both qualitative and quantitative. The qualitative aspects evaluated included the demographic attributes of respondents, their perception towards private forest certification which was interpreted as the willingness to pay or accept private forest certification, and the ways of improving private forest certification as shown in annex 1 of this study. Examples of key questions asked on willingness to pay for certification in the questionnaire were: Are you interested in knowing the origin of wood products and how they have been produced? How many certification schemes do you know? Which certification scheme do you prefer? Which examples of forest products (e.g., indoor furniture, food, clothes etc.) would you wish to have a wider choice of certification? Do you wish to see an increase of certified private forest area in the country? Whom do you think is most responsible for ensuring the certification of private forests in the country? In which actor do you have the highest trust that they will ensure private forest certification in the country? Which wood-based products do you often/frequently buy? What do you think are positive impacts of private forest certification in Kenya?

In order to enhance comprehensibility of the study variables, the definition of key terms was provided in the questionnaire. A key term such as 'forest' was defined as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. A private forest was defined in accordance with the provisions of the Forest Conservation and Management Act, 2016, part IV section 30 (4) which states that private forests include (a) forests on registered land held by any person under any freehold tenure; (b) forests on land held by any person under leasehold tenure; (c) any forest owned privately by an individual, institution or corporate body for commercial or non-commercial purposes; and (d) forests on any other land declared private land under an Act of Parliament. P.20.

Where clarification was required, the principal investigator was present to interpret various research aspects. No major problems were reported during data collection. Two hours were required to gather the required primary data.

2.2 Secondary data collection

Secondary qualitative data collection involved an in-depth document review targeting the country's key development policies and documents as summarized in Table 2. The review was designed to determine whether these policy documents were providing adequate anchorage for private forest development and certification in Kenya.

No.	Document	Information sought	Source
1.	Blueprint Vision 2030 for Kenya	Whether forests, including private forests are important for Kenya's socio-economic development	Vision 2030 Website. Accessed at https://vision2030.go.ke/
2.	The Constitution of 2010	Land tenure system and how it affects private forest management certification	Kenya Law Reporting portal accessed at http://kenyalaw.org/kl/index.php?id=400
3.	The Draft Forest Policy of 2020	The policy statements on development of sustainable private forestry in Kenya	Kenya Law Reporting portal accessed at http://kenyalaw.org/kl/index.php?id=400
4.	Forest Conservation and Management Act of 2016	The institutions established to promote private forestry development and the legal provisions that support certification such as chain of custody	Kenya Law Reporting portal accessed at http://kenyalaw.org/kl/index.php?id=400
5.	FSC Interim National Standard for Kenya 2021	If the standard complements, substitutes, or contradicts the existing framework for private forest management certification in Kenya	Forest Stewardship Council website. Accessed at https://fsc.org/en/document-centre/documents/resource/472

Table 2: Key Documents Consulted

The workshop research methodology was used in this study because it aims to fulfil participants' expectations to achieve something related to their own interests (Ørngreen and Levinsen, 2017). This was part of the intentions of this study with regard to willingness to pay for private forest certification. Moreover, workshops generate reliable and valid data about the domain in question (Ørngreen and Levinsen, 2017). Workshops are carried out by people with practical experience within the given field, and they encourage honest involvement. The participant groups are kept small to allow maximum personal attention and to enhance the chance for everyone to be heard. Moreover, the key members of the workshop are expected to actively participate and influence the direction of decisions taken. Additionally, workshop participants and organizers expect an outcome. These characteristics informed the choice of the workshop approach adopted in this study.

2.3 Data analysis

The quantitative results obtained from the primary data sources were later exported to an excel spreadsheet and classified in two broad groups: those with a private forest and those without a private forest. Based on these groupings, quantitative data was analyzed using Microsoft Excel software to generate the descriptive statistics and visualizations used in this study. Later, the results were evaluated by comparison with secondary data and findings from reviewed literature in order to draw the policy implications that emerge from this study.

3. Results

In total, 20 survey questionnaires were distributed to participants and a 100% response was obtained. 30% of all respondents were female. 60% of respondents belonged to the 36-45 Years age bracket while the remaining 40% belonged to the 18-35 years age bracket. Up to 95% of the respondents had a tertiary level of education, indicating a relatively high level of literacy. With regard to income distribution, 55% of the respondents had a weekly income of Kshs. 7,500 and above, while 45% earned an income of Kshs. 1-7,500 per week.

The overall household size of respondents ranged from one to more than four people. 60% of respondents indicated that their households comprised four or more people, 25% of respondents indicated they had a household size of two people, while 15% reported that they had three people in a household (Figure 1).

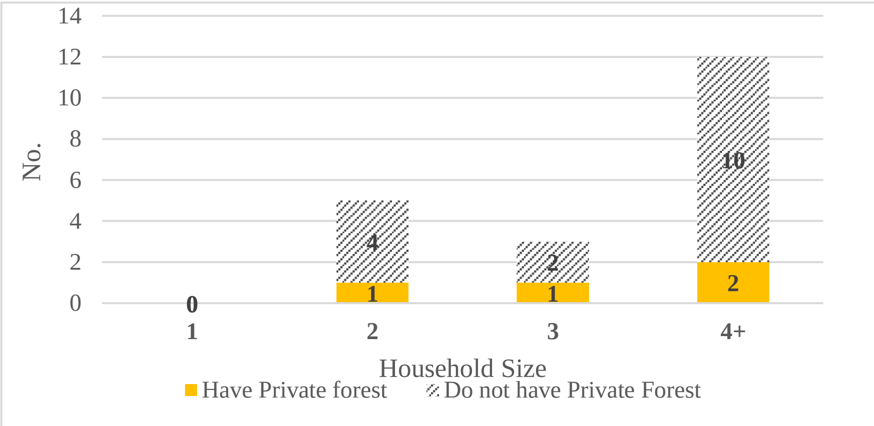

Figure 1: Household size and private forest ownership

Up to 60% of the respondents were government employees, 20% belonged to the private sector, 15% were not employed, and 5% were self-employed (Figure 2).

Figure2: Employment Status and private forest ownership

Overall, the results show that 80% of the consulted respondents do not own a private forest, while only 20% own a private forest. Among those who own a private forest, 15.8% own a private forest less than 1 ha in size, while another 15.8% own between 1-10 ha of private forests.

3.1 Perception of willingness to pay for private forest certification

The perception of stakeholders towards private forest certification is critical for understanding how the sector can be stimulated toward responsible forest management. Overall, the study results show that private forest certification appears to have a positive perception among the surveyed respondents who frequently consume wood-based paper products. Paper is a frequently purchased wood-based product, as shown in Figure 3.

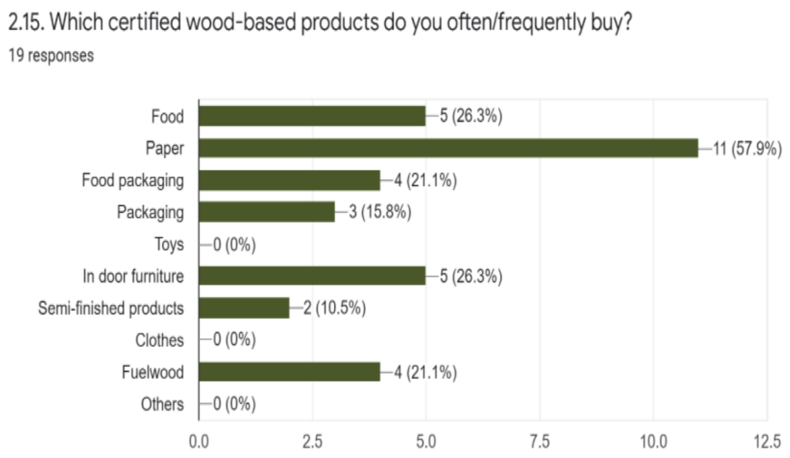

Figure 3: Certified wood products mostly bought

In addition, all respondents appeared to be interested in knowing the origin of the wood products they consumed and how they were produced, as well as having the desire to receive more information on the origin of wood products.

Up to 45% of all respondents indicated that they did not know of the existence of private forest certification schemes. While 30% knew about the existence of one scheme, 25% knew about the existence of more than one. Overall, 47% of all respondents knew about the existence of SFI, followed by FSC (36%) and others (31%). When asked about the certification scheme, respondents preferred certification of Kenya's private forests, 42% preferred SFI, 36% preferred FSC, and 10% preferred PEFC. Regarding the willingness to buy certified products from Kenya's private forests, 85% indicated a willingness to buy, 10% were unwilling, and 5% were unsure. 68% of respondents wished to have a wider choice of certification schemes for indoor furniture, paper (42%), food packaging (31%), and food, fuelwood, and general packaging (21%).

Up to 80% of respondents believed that timber production or forest management is the greatest cause of illegal logging, which also extends to private forests. 50% believe that agriculture is the main cause of illegal logging in the country. 25% of respondents had heard about deforestation last year, 25% last week, 20% did not know, and 20% had heard about deforestation last month. 100% of the respondents wished to see an increase in certified private forest areas in the country.

3.2 Perception on improving private forest certification

The study showed that 80% of the respondents believed that timber production and forest management contributed the most to deforestation and illegal logging (Figure 4). Overall, 85% of respondents believed that forest certification was the best tool to enhance sustainable forest management in the country. 70% of respondents believed private forest certification would better manage private forests. However, 40% of the respondents think private forest certification is costly, bureaucratic, complex, and time-consuming. 45% of respondents attributed a negative perception of certification to limited knowledge of perceived benefits. Hence, 80% of respondents indicate the importance of raising education and awareness to improve private forest certification in the country.

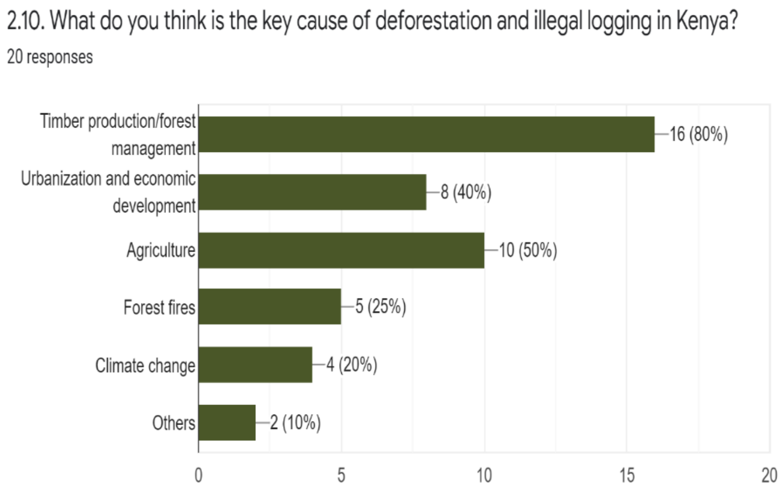

Figure 4: Causes of illegal logging in private forests

In addition, there is a strong indication of the desire to hasten and improve private forest management certification in the country. Respondents believed that existing institutions are adequately resourced to promote certification. The results show that all respondents had an equal proportion of trust in the government and certification schemes for properly implementing private forest certification in the country (Figure 5).

Moreover, respondents appeared to be apportioning different levels of responsibility for institutions and organizations involved in private forest management certification. Up to 55% of the respondents believed that the government was the most responsible actor or agent for ensuring the proper implementation of private forest management certification in Kenya (Figure 6).

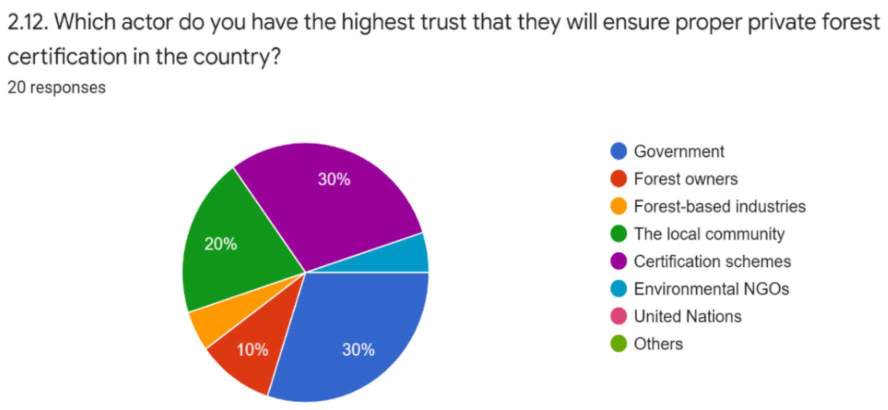

Figure 5: Trust levels amongst actors

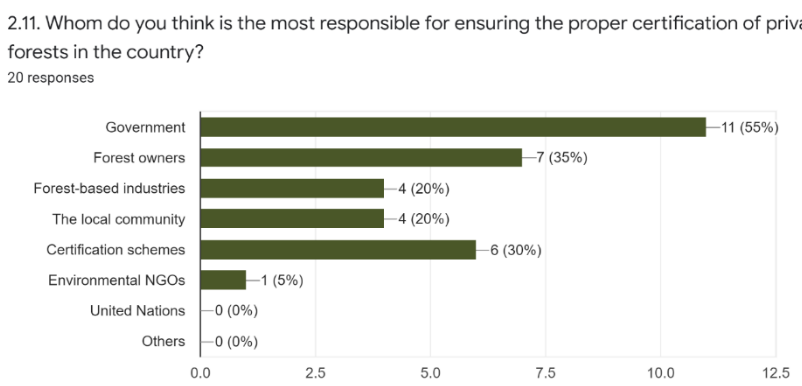

Figure 6: Responsibility for certification

4. Discussion

Private forests are important national assets for promoting socio-economic development (FAO 2020; MEA 2005; Sun et al., 2022; Perera et al., 2022; Cashore et al., 2004; Rubino et al., 2022; Cashore et al., 2006; Gallison 2003; van der Ven and Cashore, 2018; Schulze et al., 2008). In order to promote the sustainable management of these forests and to assure society that these forests are being managed for posterity in the light of the growing threats of deforestation and degradation, private forest management certification is fast emerging as a mechanism for promoting sustainability (George et al., 2022). A range of literature reports that forest certification has emerged as a multi-stakeholder process sustained by coalitions of many like-minded public and private organizations whose aim is to prevent deforestation and degradation by promoting responsible consumption and production of forest products (Barklund and Teketay, 2004; UNEP, 2008; Teketay, 2012). To date, many countries around the world are actively participating in implementation of different forest certification schemes targeting all types forests, including private forests. Studies show that over 11% of the world's forests have been certified under various schemes (Alvarez, 2018).

The literature also shows that certification schemes do not wield equal influence and that the FSC scheme appears to have won the 'war of certificates' across the globe. FSC's forest management certification system appears to be anchored to collaborative alliances aimed at delivering better forest management certification. The scheme provides a system for voluntary accreditation and independent third-party certification and allows certificate holders to market their products and services as having been produced in an environmentally appropriate, socially beneficial and economically viable manner.

The key lesson learnt from FSC certification is the value of objectivity in auditing management organizations. In this study, while we concur that FSC's forest management certification is quite robust, we do not view forest certification in the context of 'winners' and 'losers'. We see FSC's domination of certification schemes as a demonstration that the world now cares about the sustainability of forests, including private forests. Forest certification is affected by the dynamics of forest products supply chains, technological innovations, and government policies. We believe that growing interest and innovation in forest management certification also present the opportunity to revisit forest certification and recommit to identifying collaborative ways of securing the future of forests and forest products as well as improving impacts and measurable outcomes. Our study also notes that whereas competition between certification programs and programmes can be useful, this should work towards addressing the drivers of deforestation and degradation, creating opportunities for socio-economic development.

Moreover, given the existing competition where FSC appears to be a front runner in forest certification, there is a risk of double certification and other inefficiencies. Therefore governments need to stop this trend with supply chain influencers by embracing a neutral stance to certification schemes or at least adopting a ranked choice approach that allows for alternative schemes to thrive rather than complete exclusion of some schemes.

In Kenya, private forests are critical national assets contributing to national development a (Table 1; Choge, 2002; National Strategy for Achieving and Maintaining 10% Tree Cover, 2019; Odwori et al. 2013; Figure 3). As such, the area under private forests has grown by 1.1% from 68,000 to 90,000 hectares between 1990 and 2010 (Cheboiwo et al. 2018; Cheboiwo et. al. 2020). Studies indicate that the current expansion of private forests could be attributed to many political, economic, social and policy or legislative reasons. However, reviewed literature shows that the private forest sector continues to grow due to supply shortfalls from public forest plantation as a result of the current moratorium on logging in community and public forests and the growing demand for key forest products such as transmission poles (Cheboiwo et. al. 2018). This demand is bound to rise with the growing human population (Kagombe et al. 2020). Kenya has 47 million people, and the population is projected to reach 60 million people by 2030 (Kenya's NDC 2021).

Fortunately, Kenya is already making significant policy and legal strides aimed at promoting the sustainable management of private forests. The constitution of 2010, the blueprint Vision 2030, the Draft Forest Policy of 2020, Forest Conservation and Management Act of 2016, the Agriculture (Farm Forestry) Rules of 2009 and the FSC Interim National Standard for forest management certification recognize the importance of forests, including private forests in Kenya's development ambitions. These private forestry development tools recognize and confer private property rights to individuals willing to establish private forests in the country. For instance, the Forest Conservation and Management Act of 2016 is highly explicit in requiring registration of all private forests in the country and spelling out the incentives for such registration, including free technical advice, access to loan opportunities and exemption from payment of land rates. These policy initiatives show the importance of the government in shaping policy discourse on certification and are in agreement with findings from our survey, where respondents applauded the centrality of the government in promoting certification by expressing their trust (Figures 5 & 6).

However, the development of private forestry and certification have been slow because to date the Ministry of Environment and Forestry has yet to develop regulations to operationalize these incentives. Moreover, at the county level, most devolved units are yet to establish county forest programmes which would provide the necessary anchorage for private forest development and certification. In addition, there is the need to review the Draft Forest Policy of 2020 and the Forest Conservation and Management Act of 2016 in order to incorporate explicit provisions on forest management certification. In the meantime, the FSC interim National Standard could complement public policy by filling this clear policy gap. Reviewed literature shows that voluntary sustainability standards also fill gaps in public policy (Marques and Eberlein 2020; Marx, 2018; UNFSS, 2020; FSC, 2020a; FAO and UNECE, 2020). It is hoped that with sustained capacity building of counties by the national government agencies forestry programmes will transform counties for greater socio-economic development. Already, there are signs of positive change in counties with regards to equitable resource distribution, citizen inclusion and participation in decision making, accountability, and transparency (KIPPRA 2016, UNDP 2017, Ngigi and Busolo 2019). In this conducive environment, forest certification will help promote the productivity, vitality and sustainability of all types of forests in the country. Reviewed literature shows that in the year 2021 the country launched the FSC Interim National Forest Management Certification Standard whose main objective is to promote conservation of forests for ecosystem services. The FSC standard appears quite robust and deliberately defines the irreducible minimums for forest management certification. These standards complement the existing efforts to promote forest management in the country through objective-led management plans. It is hoped that these standards will promote responsible forest management as proposed by Lemes et. al. (2022), Mexia et al. (2022), Gutierrez Garzon et. al. (2022) and Panico et. al. (2022).

Tree nursery management is also an important ingredient for sustainable private forestry. In order to promote certification in this segment, KEPHIS is already conducting certification of forest tree nurseries in order to provide pest free high-quality seedlings to the public. To date, over 250 nurseries largely vegetable and fruit trees have been certified (KEPHIS Newsletter 2021). KEFRI has also developed the Tree Nursery Certification Protocol, 2021 as a practical guide for certifiers. Study results from Kenya attest to the effect of these positive conditions and present many opportunities for advancing private forest certification. Results indicate that there is significant concurrence between respondents with and without private forests on the willingness to pay or accept the cost of private forest certification. Already, respondents from the two study groups frequently consume certified wood-based products, especially paper (Figure 3). All respondents have also expressed willingness to know the origin of consumed wood products and other pertinent information. This positive desire for private forest certification may be attributed to the favorable environment provided by the existing forest policy framework and the relatively high levels of literacy amongst the study participants. However, there is need for further studies to investigate the impact of demographic variables on willingness to pay for forest certification. Reviewed literature shows that age, income and education appear to be significant variables (Scholte et al. 2015; Tian 2022).

Reviewed literature also indicates challenges with private forest certification schemes are already emerging. Competition between schemes, unpredictable changes in government policy and technological changes have been refered to in reviewed literature. These challenges have also been identified by Upton and Bass (1995). However, in this study, given the greatest role played by the government as the formulator of policies for forest management, Kenya should embrace a certification program/scheme neutral stance or at least a ranked choice approach allowing for alternatives rather than program/scheme exclusion. Moreover, there is a need for supporters of certification to generate more data on certified forest products in the market by type and market share. Even though this study did not evaluate smallholder certification, reviewed literature also shows that certification should be tailored to target smallholders as a potential area of collaboration where tree growers can be engaged to enhance the market of forest products and services from farmland. Supporting the group certification scheme has the potential of adding value to the ongoing initiatives on farmlands, including enhancing the bamboo value chain. Supporting the already existing 11 Private Sector Enterprises who have received FSC Chain of custody (CoC) certification mostly in the packaging industry should also be pursued. Private sector uptake in CoC certification is crucial in that it provides an internal market for certified goods and services and can reduce or mitigate illegality in the timber trade in the country. It is hoped that with the introduction of Kenya's Interim National Standard, several companies will be in a better position to track their products from the certified forests to shelf and trigger further investments in the forestry sector. However, there is also aa need for the government to support several officers who have already been trained on FSC certification processes in order to deepen their understanding of certification process as a whole.

5. Conclusion and Recommendations

Forest certification can be a good tool to promote responsible private forest management. The transparency that accrues from certification demonstrates the management performance of private forest management and can bring clear financial and market opportunities while ensuring the conservation of biodiversity and continuity of sustainability of forest management. As a result, awareness concerning the ecological, social and economic benefits and impacts of scientifically driven sustainable private forest management is growing, with many governments across the world reviewing and developing appropriate policy and legal frameworks for improving certification.

In Kenya, private forestry is steadily growing and so is private forest management certification. The country has developed supportive policies and legislation which provide opportunities for stakeholders to fully participate in private forestry activities. Consequently, study respondents have demonstrated that there is a high level of willingness to pay or accept private forest certification in Kenya. In fact, a significant proportion of respondents have asked for an increase in the area under certification in the country, besides being frequent consumers of certified wood-based products. This presents many opportunities for private forest certification in Kenya.

However, there are still a number of challenges affecting certification, including lack of regulations for operationalizing the private forest development incentives outlined in the Forest Conservation and Management Act of 2016 and lack of county forestry programmes. Thus, there is a need for developing regulations, establishing county forest programmes to promote certification, increased education and awareness about private forest management certification, and conducting more studies on the type and market share of certified products from private forests that are consumed in the country. Moreover, this study shows the need for more research, especially quantitative studies on the motivations and impacts of certification on different stakeholder groups in specific niches of private forest management, such as tree nursery management, which appears to have taken off in Kenya. While the major limitation of this study was the relatively small number of participants involved, this was balanced by a qualitative study approach based on in-depth literature review and secondary data and can contribute to signalling future developments for research and policy initiatives.

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Annex 1: Survey Questionnaire

1. : Questions regarding demographic characteristics

1.1. What is your gender?

1.2. What is your age?

1.3. What is your highest education level?

1.4. What is your average weekly income?

1.5. What is your family size?

1.6. What is your employment status?

1.7. Do you have a private forest?

1.8. Size of private forest ______ Hectares

(NB: A forest is land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ)

2. Perception of willingness to pay for private forest certification

2.1. Are you interested in knowing the origin of wood products and how they have been produced?

2.2. Would you like to receive more information about the origin of wood products and their production method?

2.3. How many certification schemes do you know?

2.4. Which certification scheme do you know?

2.5. Which certification scheme do you prefer?

2.6. Are you willing to buy certified forest products?

2.7. Which examples of forest products (e.g. in door furniture, food, clothes etc.) would you wish to have a wider choice of certification?

2.8. Do you wish to see an increase of certified private forest area in the country?

2.9. When did you hear or read a story about illegal logging?

2.10. What do you think is the key cause of deforestation?

2.11. Whom do you think is the most responsible for ensuring the certification of private forests in the country?

2.12. Which actor do you have the highest trust that they will ensure private forest certification in the country?

2.13. Is certification the best tool for ensuring the sustainable management of private forests in the country?

2.14. Which wood-based products do you often/frequently buy?

2.15. Which certified forest products do you buy?

2.16. What do you think are positive impacts of private forest certification in Kenya?

2.17. What do you think are negative impacts of private forest certification in Kenya?

2.18. What are the main causes of negative perception of private forest certification?

3. Improving Private Forest Certification

3.1. How can certification of private forests be promoted in Kenya?

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Competing Interests

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Original Paper

When a Good Policy Goes Bad.

An analysis of framings and silences in Uganda's 1995 National Environment Management Policy and effects on forest conservation

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Keywords: sustainability, biodiversity, conservation, institutions, participation, marketization.

Abstract. *I critically analyze the Uganda National Environment Management Policy (NEMP) from 1995. The big question is why Uganda continues to experience tremendous loss of forest resources while the NEMP, which set strong objectives towards forest conservation and management, has been in effect for nearly three decades. I apply Carol Bacchi's "What's the Problem Represented to be?" approach to unpack how the problem of forest and biodiversity loss is represented in the NEMP, the underlying presuppositions that enliven it, and the processes and practices that led to the pervasiveness of these problem representations. In addition, I identify the silences and effects of the problem representations and ways in which the policy has been disseminated, defended, or contested. I have found that the language in NEMP around defining sustainability, biodiversity conservation, institutional collaboration, public participation, and marketization largely aligns with language promulgated in international treaties and institutions like the Convention on Biological Diversity and the FAO. The NEMP is therefore subject to the discursive critiques of these themes that scholars in various fields have developed in the past decades. While my analysis engages briefly with these critiques, my central argument centers on the active silences such as corruption and ignorance that underlie environmental injustices and that are worsening forest degradation. In conclusion, without addressing these silences, the NEMP has little chance of slowing or reversing biodiversity loss.*

1. Introduction

Environmental management has for decades been on Ugandan political agenda. Uganda's forests suffered from especially 1972 to 1985. With a new focus on "good governance" in 1986, Uganda aligned national with international policies and agreements, thereby establishing the Ministry of Environment in 1987, under which the National Environment Action Plan (NEAP) was developed in 1991. The NEAP led to the enactment of the National Environment Management Policy (NEMP) in 1995 with the goal:

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> Sustainable social and economic development which maintains or enhances environmental quality and resources productivity on a long-term basis that meets the needs of the present generations without compromising the ability of future generations to meet their own needs (NEMP, 1995).

Under the broad objective of sustainability, the NEMP includes six specific sectoral policy goals and objectives: agriculture and farming systems, forest conservation and management, wildlife conservation and management, livestock and Rangelands management, fisheries and other aquatic resources conservation and management, as well as energy (Republic of Uganda, 1995). The present study focuses on the second objective; conserving and managing forests (NEMP, 1995-chapter IV).

Despite the focus on sustainability in the NEMP, two decades ago, NEMP instead increased biodiversity loss in Uganda's forests, with 25% forest cover in 1990 to 9% in 2017 (NFA, 2018), which situation was aggravated by increase of oil palm plantations from 3% in 2010 to 8% in 2017 (NEMA, 2019) especially in Kalangala District, the focus of this study. Here residents have been dispossessed of their farms to make way for commercial oil palm plantations. Furthermore, carbon trading/commodification of forest resources has become the dominant approach to conservation.

2. Methodology

To better understand the pre and post 1995 situation and the question of the NEMP not to have slowed forest biodiversity loss in Uganda, I analyzed the original NEMP document using Carol Bacchi's *What's the Problem Represented to be?* (WPR) approach. The WPR policy analysis is supplemented with insights from fieldwork carried out in Kalangala District from 2015 to 2020.

The WPR (Bacchi, 1999; 2012a;2012b; Bletsas and Beasley,2012) derives from Foucault's famous poststructuralist approach to policy analysis (Fischer, et al., 2015; Yanow, 2015). The solutions in policy proposals are the problem representations because they reflect the problem. Policy analysis is based on the notion that "what one proposes to do about something reveals what one thinks is problematic and needs to change" Bacchi (2012, p. 21). Problem representations exhibit "two interrelated levels of analysis and judgement", including the concern and causes of a problem (Bacchi, 1999, p.4). In their engagement with Carol Bacchi, Bletsas and Beasley (2012 p. 38) also indicate that the solution to a policy proposal is "what the problem is *understood- represented* to be" (Bacchi, 2009;2019).

This logical understanding enables policy analysts and other professionals to reflect upon policy problems.

The first reason I used the WPR approach to analyze the NEMP (1995) was because it is applicable to any policy proposal (Bacchi, 1999). Secondly, problem representations are the problem implied solutions in the policy document (Bastian and Coveney (2013). Thirdly, the approach is open to studying beyond single issues, and identifying a range of issues that would go unnoticed, because it follows a step-by-step analysis of six questions which include (Q1-Q6):

1. What is the problem of forest conservation and management represented to be in the NEMP (1995)?
2. What assumptions underpin these problem representations?
3. How did these representations of the problem come about?
4. What is left unproblematic in these problem representations, and thus is silent?
5. What effects are produced by these representations of the problem?
6. How/where have these representations of the problem been produced, disseminated, questioned, replaced and or defended?

The specific focus was forest conservation and management. I critically interrogated how the NEMP issue of forest conservation and management was problematized, the premises that problem representations rest upon, and its effects, as well as problems that could be nested in the policy problem itself.

In question 1, synthesized problem representations identified in the policy proposal itself were categorized into themes based on created paradigms. In question 2, I reflected on the underlying premises or "knowledges" in identified problem representations. To examine these "knowledges", I adopted a Foucauldian archaeology (Bastian and Coveney, 2013) where I questioned the commonly accepted authoritative "knowledges" or discourses that determined the truth in our society, thus ontology and epistemology (Tubey etal., 2015; Guba and Linccoln, 1994; Rehman and Alharthi, 2016). To deepen my understanding of the presuppositions that underpin the NEMP problem representations, I further borrowed ideas from Bastian and Coveney (2013, p.164) to examine the "language used and meanings attached to key concepts" that revealed the NEMP underlying assumptions and values (Bastian and Coveney, 2013). Therefore, to identify assumptions underpinning problem representations in the NEMP, I compared NEMP discourse to ongoing debates around sustainability, biodiversity conservation, institutional collaboration, public participation, and marketization of nature. In other words: what notions of these terms are suggested and advanced in the NEMP? The goal was to summarize debates and distill what approach to each "concept" underlies NEMP. To answer question 3, I applied a 'Foucauldian genealogy', to analyze the NEMP "in both temporal and spatial context" (Bacchi, 2016: p.9). As regards question 4, I scrutinized the "possible gaps or limitations in the representations of the problem, accompanied by inventive imagining of potential alternatives (Bacchi, 2012a: p.22) or that there exist other ways of thinking about this particular problematization, but which were left silent in the policy. For question 5, I identified possible effects of the problem representations/solutions, and in question 6, I extracted from the relevant literature ways and where problem representations were shared locally in Kalangala district, nationally, continent wide and globally.

Therefore, I adopted a qualitative interpretive approach, acknowledging interpretivism as the nature of knowledge, purposely to understand the studied phenomenon (Guba andLincoln, 1994; Tubey, et al, 2015; Yanow, 2015), and so related the NEMP framing of forest conservation and management to other authors' beliefs as paradigms for what I studied. Such literature included paradigms like (1) Sustainability (Brudtland, 1986; Caldwell,1998; Fischer et al., 2015; Francis et al., 2003; Namanji, et al., 2019; OECD, 2011; Schneider and Francis, 2006; Siamanta 2017; Wu, 2013;); (2) Biodiversity Conservation (Adams, 2017; Blaikie, 2006; Boyle and Boontawee, 1995; Barrow and Murphree, 2001; Büscher, et al., 2012; Brundtland, 1985; CBD, 1993; Clark and Munn, 1986; Dasgupta, 2021; Eckersley, 1992; Elliot, 1996; Griggs et al., 2013; Kashwan, 2020; Kiwango, et al.,2015; Moreno et al., 2017; Muir, 1898; NEMA, 2010;2016 and 2019; Sachs, 2012; Silva and Mosimane,2013; Thakholi,2021; Towns, et al., 1990; UNSDG,2015; West and Brockington, 2006); (3) Institutional collaboration (Bastian and Coveney, 2013; Bazaara, 2003; Namanji, et al., 2017; North, 1990; Ostrom, 2008; Ribot, et al.,2010); (4) Public participation (Brundtland, 1986; Chambers, 1992;1997;2010; Clark and Munn, 1986; Claridge, 2004; Collins, et al., 2021; Eckersley, 1992; Griggs et al., 2013; IUCN, 1980; Saschs, 2012; SDGs 4and6; Ribot et al., 2010;) and (5) Marketization paradigms (Asiyanbi and Massarella, 2020; Collins et al., 2021; Fairhead,et al., 2012; Green and Adams, 2015; Ian and Qin, 2019; UNCED,1992; UNFCCC, 1992).

(1) Sustainability is a difficult concept to define. It can either be (overly) simplified and self-evident, as in the Bruntland (1986) report definition, or it can be a highly contested term, the simplification of which tends to conceal complex social relations and inequalities on the ground. In the Brudtland (1986) report,

sustainability relates to an aspect that "meets the needs of the present without compromising the ability of future generations to meet their own needs'.

(2) Biodiversity is a resource component of a strongly sustainable ecosystem, which must be conserved (CBD,1993). Thus, biodiversity is the variety and variability among living organisms and the ecological complexes in which they occur (Boyle and Boontawee, 1995). Biodiversity conservation is a World community's commitment to sustainable development through conserving, through sustainable use, and fair sharing of genetic resources (UNCBD, 1992).

(3) The definition of institutions varies. North, (1990 p. 1) and Ostrom (2008) define institutions as "rules of the game in society…or devised constraints that shape human interaction", or organizations in general (Ribot et al., 2010). North (1990) distinguishes between institutions and organizations by showing that while institutions are the rules of the game, organizations are the players, bearing the responsibility of enforcing rules or taking actions to achieve the desired goal. In this study I defined institutions as organizations responsible for implementing rules or actions towards sustainable conservation and management of biodiversity. While performing their duties, these organizations do not work in isolation, whereby institutional collaboration. Collaboration involves two or more organizations working together for a common goal, also called joint management. This is the dominant approach which involves cross-sectoral collaboration, including ministries, local government, and communities.

(4) There is a substantial amount of work on participation, a concept that has evolved and defined widely (Chambers,1997; 2010, Ribot et al.,2010). Chambers' work presents two distinct ways of understanding participation, first as a method and second as a methodology. Participatory method is "a discrete type of activity, usually facilitated, usually carried out interactively by a group of people" (Chambers, 2010 p.8). It involves activities such as social mapping in which the local people are actively involved in all activities that determine their social status (ibid). Participatory methodology is a "A combination of approach and methods through which people do things themselves interactively" (Chambers, 2010 p. 8). For example, people do participatory planning by involving in processes to identify their needs and means of solving them thus empowering communities to contribute towards their wellbeing. Ribot et al. (2010) focus on popular participation through democratic decentralization, the meaningful transfer of power to community representatives, to exercise their authority. Popular participation, termed as "inclusive of the whole population" (ibid, p.2) is what I refer to as public participation in this article, thereby involving the representatives of the public in decisions towards the management of forest resources.

(5) Marketization of forest resources takes its roots from "the establishment of the framework of forest carbon sequestration" Ian and Qin (2019 p. 7), leading to global initiatives towards the management and mitigation of global warming. The global initiatives commenced with the June 1992 United Nations Conference on Environment and Development in Rio de Janeiro. The Rio conference adopted the United Nations Framework Convention on Climate Change (UNFCCC, 1992) which aimed at stabilizing greenhouse gas concentrations. To finance climate adaptation projects, the UNFCCC had to establish an adaptation fund, the Clean Development Mechanism (CDM) and Emission Trade (ET). These initiatives asked countries to increase greening activities and reforestation to offset carbon dioxide emissions. In relation to the current debates about marketization, the United Nations Conference on Climate Change (UNCCC) in Copenhagen in 2009 emphasized Reducing Emissions from Deforestation and forest Degradation (REDD+). To meet the REDD+ objective of removing greenhouse gasses by forests, the Paris Agreement developed the carbon market, to incentivize carbon emissions. The global market-based initiatives to solve natural resources depletion have emerged with a new appropriation of nature termed as green grabbing (Fairhead et al., 2012). Although green grabbing seems to be new, it has become a dominant approach. Green grabbing is the appropriation of land and resources for environmental ends. Appropriation is the transferring of resource rights from certain groups to others who may be more powerful (ibid), for capital gain. Among the main processes that lead to the appropriation of nature is financialization, where financial systems facilitate redistributive activity. Another process is through "crisis narratives" (Schneider, 2014) such as "resources scarcity…to justify large-scale land investment" (p. 8).

These paradigms were subjected to the content analytical method (Lal Das, 2008) to arrive at themes. I utilized the steps followed in content analysis, first by deciding the level of analysis, which in my case led to themes. Secondly, by flexibly deciding how many concepts to include in the analysis. Thus, I identified key words or statements to mean themes under each research question, where applicable.

3. Findings and discussions

This section presents results of the analysis of the NEMP based on WPR, with the 6 research questions, under which results of identified themes are presented and discussed. Problem representations flow through the six research questions.

Themes are not exclusive, and theme content is complementary especially in the case of problem representations.

3.1 Problem Representations

Synthesized problem representations were in the policy proposal itself and were categorized into themes based on existing paradigms. Themes included sustainability, biodiversity conservation, institutional collaboration, public participation, and marketization of nature. Every theme consists of the most appropriate problem representations (PRs) indicated in the policy document. Thus, sustainability has 3 PRs, biodiversity conservation 4 PRs, institutional collaboration 5 PRs, public participation 4 PRs and marketization has 5 PRs. There were three cross-cutting PRs (Table 1).

3.2 Presuppositions underpinning the problem representations

Assumptions underpinning problem representations in the NEMP were identified. NEMP discourse to ongoing debates around sustainability, Biodiversity conservation, institutional collaboration, public participation, and marketization of nature paradigms were compared to determine notions of these terms as suggested and advanced in the NEMP. Debates were summarized and distilled to ascertain the “concept” that underlies NEMP as presented in Table 1.

NEMP 1995: Forest Conservation and Management		
Themes	**Problem representations (S/N)**	**Whose responsibility?**
Sustainability	1. The Forestry Department to supervise and regulate sustainable use of forests resources 2. Encourage production of timber products in line with the principles of sustainable use 3. Necessitate multi-sectoral collaboration in both the classification and management of all levels of protection in the PA system	-National Forestry Authority (NFA)
Biodiversity conservation	4. Revise and strengthen the Forest Act with particular regard to gazetting and degazetting 5. Establish a common agency with a mandate to coordinate institutions concerned with biodiversity conservation and management 6. Provide total protection and classification of identified key biodiversity rich ecosystems 7. Subject the introduction of non-invasive and invasive exotic species to the environmental impact assessment process, as well as monitor and control the spread of invasive species	-NFA -National Environment Management Authority (NEMA) -Uganda Wildlife Authority (UWA)

Institutional collaboration	Problem representations 3,5 and 7 crosscut here 8. Develop and disseminate scientific and technical information conducive to more efficient utilization of forest resources. 9. Revise the forestry training curriculum to enhance the environmental and socio-economic aspects of forest management	-NFA -Office of the Prime Minister (OPM) -Ministry of Water and Environment (MWE) -NEMA -UWA; -Ministry of Agriculture(MAAIF) Ministry of Education (MoE) -District Environment Committees (DECs)
Public participation	10. Plan and implement Protected Area system according to particular local needs 11. Improve local capacity to manage protected and gazetted forest reserves by encouraging people's participation in the planning, management and in the sharing of benefits from forests and PAs 12. Encourage communities to participate in non-destructive use of forests such as eco-tourism and agro-forestry 13. Enhance participatory adaptive research, monitoring capacity and information dissemination in all areas of forest management and PA systems for sustainable utilization of forest resources	-NEMA -NFA -UWA -DECs
Marketization	14. Quantify Uganda's forest environmental services and values in terms of short-term market economics 15. Review financial management systems in relation to revenue and forest management costs and explore innovative methods of collecting forest user fees 16. Provide economic incentives and the necessary legal framework and technology to encourage and facilitate stakeholders to be self-sufficient in forest product requirements 17. Promote export of value-added timber products 18. Set prices that reflect the true value of forest products	-OPM, -Ministry of Finance, -Ministry of Gender, -Uganda Bureau of Statistics -NEMA, -NFA, -UWA -DECs

Table 1: Dominant Problem Representations of. Forest conservation and Management in the NEMP 1995

Sustainability

Here, the question is whether current environmental activities have the capacity to meet future human needs. Thus, sustainability is understood as perpetual replenishment of resources. A dominant approach to sustainability, for example shows that to sustainably address human needs, then sustainable approaches ought to include three pillars: environment, economy, and society (Wu, 2013). Sustainability perceived as the ability for an environment to provide economic and social development, termed as the triple bottom line definition of sustainability; "People, Planet and Profit". This sustainability definition requires balancing economic activities with social and environmental consequences such that none of these dimensions is compromised. Thus, other than defining sustainability as the mere need for environmental conservation, Wu (2013) affirms that sustainability ought to be approached with a triple bottom line notion in mind. In the contemporary world, sustainability is understood as a global governance issue, employing "expert indicators as a means of packaging and presenting knowledge in objective and universally valid ways for transparent and democratic policy analysis" (Fischer et al., 2015 p. 19). Fischer's insights highlight Laureen Elgert's focus "on the construction and use of sustainability indicators in contemporary global governance". Elsewhere, researchers do offer critical thoughts about sustainability which focus on applying ethics to growth, development, and environment (Caldwell, 1998). Thus, in the study on 'building a green economy of low carbon', Siamanta (2017) shows a new paradigm of sustainable development called the 'green growth' proposed by the Organization for Economic Co-operation and Development (OECD). According to OECD (2011) green growth supports the Brundtland (1986) definition of sustainable development, where economic growth and development should ensure the continued provision of natural resources towards human wellbeing (OECD, 2011).

Both dominance considerations and critical arguments are valid when empirically verified. As such, we consider sustainability measurements to include weak, strong, or absurdly strong sustainability, as by Wu (2013), though these are relative measures. Weak sustainability promotes economic development at the expense of environmental quality, for instance, in situations of huge infrastructure development, industrialization and plantation agriculture without regard to the environment substituting natural resources with man-made resources. Alternatively, strong sustainability calls for a complementarity rather than the substitutability of natural with man-made capital. The implication is that, for sustainable development, natural and man-made capital support each other and must therefore be balanced. Absurdly strong sustainability leaves nature intact without any substitution (Wu, 2013). This is the extreme of strong sustainability. Nature alone does not fully serve humanity, hence the need for strong sustainability, such as community practices that promote agro-ecology (Francis et al.,2003; Schneider and Francis, 2006). The NEMP broad objective assumes sustainability to be strong because it aims at social and economic development, and it is in support of the triple bottom line definition of sustainability, assumed to be achieved through the sustainable management and conservation of biodiversity.

Biodiversity Conservation

Biodiversity conservation is important due to the need for complex forest ecosystems which maintain stable functioning relations between living and non-living parts of the environment. This maintenance is achieved through preserving biodiversity and respecting principles of optimum sustainable yield in the use of natural resources, as well as effective forest conservation and management. Therefore, the complex forest diversity includes the diversity in forests, among species and ecosystems (Towns et al.,1990), which must be conserved.

There are dominant approaches to conservation including Protected Area systems (PAs) (Adams, 2017; West and Brockington, 2006; Muir, 1898), Community Based Conservation (CBM) (Adams and Hulme, 2001; Burrow and Murphree, 2001) and Market-based conservation (Dusgupta, 2021; Buscher et al, 2012). First, PAs is a dominant approach to conservation that dates back from 1700s in India/Mongolia. Adams (2017) also refers to PAs conservation as strict conservation or as 'top-down conservation". Other scholars like John Muir have referred to PAs conservation as "Preservationism" (Muir, 1898). Muir's interests were in the total conservation of forests from development by arguing that other species should be given the absolute right to live. In line with this preservationism, several PAs around the world have been established and initiatives to encourage nations to take on conservation initiatives have been implemented (Elliot, 1996). Since then, the PA sort of conservation has been a global agenda as articulated in SDG 4,5 and 6 (UN-SDG, 2015; Brundtland, 1986; Clark and Munn 1986; Griggs et al., 2013; Sachs, 2012).

PAs have persisted as a way of protecting biodiversity; conservation of nature imposed from top to bottom; planning done by nature experts and imposed on local communities (Adams, 2017). The need for PAs arose from those who loved nature, so they perceived the idea of wilderness. North America is one of those countries that adopted this conservation model. The proponents of PAs argued that biodiversity was being destroyed by unnatural human beings who could not co-exist so it needed protection (West and Brockington, 2006). In addition, the International Union for Conservation of Nature (IUCN) argued for PAs on the premises that morally animals needed to thrive, endangered species and ecosystem services needed protection for carbon sequestration and for economic benefits such as ecotourism, yet also PAs have the potential to benefit some of the World's poor people.

However, the PAs system has some drawbacks such as not aligning with the franchised indigenous way of life (Kashwan, 2020), as well as the spatialized and racialized division of labour (Thakholi, 2021). Furthermore, PAs would improve nature, but they do not favor economic growth and have high potential to deprive local communities of their livelihoods because they promote 'Green grabbing' (Fairhead et al., 2012). Accordingly, PAs conservation differs from the social science aspect of conservation as "things people do to maintain good relations with nature" (Sandbrook, 2014). Thus, people can informally respond to nature as they are part of it, hence the bottom-up conservation. Although top-down is the dominant paradigm of conservation, it is important to exercise a mixture of both top-down and bottom-up conservation approaches, because the 'future of conservation depends on equilibrium between these conservation visions" (Adams, 2017; p. 121).

Community Based Natural Resource Management (CBNRM) is also another main biodiversity conservation paradigm. According to Dressler et al. (2010), CBNRM emerged in the 1970s arising from the many critiques of PAs. Consequently, it was realized that effective conservation is achieved if local people are involved and benefit from such conservation. Approaches to CBNRM common in East and Southern Africa include protected area outreach, collaborative management and community-based conservation (Barrow and Murphree, 2001). Accordingly, protected area outreach aimed at species biodiversity and ecosystem conservation, with the state as the final decision maker and owner of land resources like national parks and forests, with beneficiary rural communities' collaboration. The objective of Community-based conservation is sustainable rural livelihoods, emphasizing developing the rural economy where land and resources are owned by local users although the state may have final control. Other than addressing the challenges of protected area conservation, Silva and Mosimane (2013) have presented other advantages of CBNRM including its ability to combine environment and development strategies, providing economic benefits, and giving responsibility to local communities. In addition, a bottom-up rights-based conservation supports justice when done meaningfully[1]. However, Kiwango et al. (2015) have shown that although CBNRM is fostered, its invisibly successful because of the state's upper hand, biased towards development industry other than local communities (Blaikie, 2006).

Third Market-based conservation forms include payments for ecosystem services such as REDD+, conservation marketing, ecotourism etc. (Dasgupta, 2021). Market-based conservation arose from the need to adequately align conservation with economic issues such that all conservation problems can be addressed through the market. The argument is that, if people are incentivized, they can change their behavior. Thus, the advantage of market-based conservation is that nature is prioritized in all business decision-making (Dasgupta, 2021). However, market-based conservation is contradictory by encouraging activities such as ecotourism which increase flights and safari jeeps leading to mass tourism. In

[1] https://www.youtube.com/watch?v=agQDKkueT-c

addition, market-based conservation has disembodied humans from nature through tourism, nature documentaries, and thus nature is consumed at a distance (Buscher et al., 2012).

Critical approaches to conservation include the resource conservation Paradigm, where biodiversity should be conserved for its continued provision and wellbeing of society (Elliot, 1996). This paradigm supports strong sustainability. At the United Nations conference on environment and development in 1992 and the Helsinki resolutions of 1993, it was noted that humanity is central to conservation (Eckersley, 1992). Thus, issues of democratic rights, equal access to natural resources, environmental quality, psychological and recreational needs are a must consideration when conserving natural resources. Accordingly, Adams (2017 p. 114) indicates that the new paradigm of PAs would be that of "equitably integrating them with the interests of all affected people". Furthermore, this inclusiveness and care about humanity creates an enabling environment for effective forest conservation and management.

To gauge whether there is effective forest biodiversity conservation and management, it is important to understand ways of measuring or defining biodiversity. To determine levels of Biodiversity, we consider its common measure to be the alpha, beta, and functional diversity (Moreno, et al.,2017). While alpha diversity measures biodiversity on a small scale within an ecosystem, beta diversity considers the diversity between two ecosystems. Functional diversity measures the variability in the functional characteristics of species. Biodiversity affects how an ecosystem functions so the range of species in an ecosystem have different functions which form a complex environment with a wide range of services (ibid). Each of these functions support each other so are equally important.

Therefore, when the NEMP included PAs, the aim was to have biodiversity conserved within different forest ecosystems. The understanding of conservation was first in gazetting of PAs, although there was need for some community access and earning income from forest resources. This later proved a mixture of PAs, CBNRM and market-based conservation (Table 1). This means that for the NEMP proponents, conservation aimed at having communities access some forest resources concurrently with areas designated as protected and completely sealed off from the community, though earning revenue. In implementing biodiversity conservation activities, the NEMP proposal provides institutions that had to collaborate in the process.

Institutional collaboration

The NEMP assumed institutional collaboration through decentralization. To solve natural resources conservation and management problems, the government of Uganda embraced decentralized governance (Bazaara, 2003), aiming at creating related institutions and involving local communities in conserving and managing forest resources. To achieve the NEMP objectives, sectoral and cross-sectoral objectives had to be operationalized by multi-sectoral engagements and institutional collaboration. Relevant ministries and institutions such as the National Forestry Authority (NFA), the National Environment Management Authority (NEMA), the Uganda Wildlife Authority (UWA), the district forest services which later comprised the district and local environment committees, had to work simultaneously to manage and control the use of forest resources. Therefore, according to the NEMP, institutional collaboration would help in enforcing environmental laws through a participatory approach.

Public participation

In the 1960's development decisions were top-down and concentrated in the hands of foreign experts, or governments and scientific knowledge were dominant (Claridge, 2004). From the 1980s local poor peoples' needs and aspirations were recognized, hence their participation through Participatory Rural Appraisal (Chambers, 1992). There is an increase in the spread of the bottom-up development approach involving communities in natural resource management towards sustainable development (Claridge, 2004).

Sustainable development goals 4 and 6 deal with inclusive governance, linking agencies, institutions, structures, and networks on environment programmes (Griggs et al., 2013; Sachs, 2012). Inclusive social and economic development is one of the drivers of improved resource productivity as these calls for fairness, ethical, accountable sustainable use of environment and resources (Brundtland 1985; Clark and Munn 1986; IUCN 1980; Sachs, 2012). Additionally, in a study on "plotting the coloniality of conservation", Collins et al. (2021), emphasized conservation as an outcome of social organization, that empowers citizens' participation in decision making. These authors argue for the spirit of '*Buen vivir",* which "recognizes the importance of diverse ontologies and epistemologies in valuing how and why nature matters"*, Ubuntu* which highlights "communal and mutual responsibility for humans and the environment" and *Eco-swaraj* which highlights "the need to empower every citizen to be part of decision-making in the spirit of ensuring a right to and responsibility of meaningful participation (p. 17)". Their argument for *buen vivir, Ubuntu* and *Eco-swaraj* was based on the background from the colonial legacies of "Eurocentric, abyssal thinking of monopolizing judgement on what counts as true knowledge" (p. 17). Thus, inclusive governance which promotes the human welfare conservation paradigm (Eckersley, 1992).

Measuring participation requires understanding its different meanings because some approaches are regarded as participatory, yet they do not provide meaningful sharing of power. Thus, just informing people is passive participation, but if participants are actively involved in answering questions, they participate even though may not make major contributions to changing their circumstances. Also, if participation is through people's provision of services, such as payable labor, participation would be without their control. Lastly, where people/agencies take active part in joint activities, in a multidisciplinary approach, to tackle multiple objectives, this is interactive participation and with full control of their destiny (Claridge, 2004).

The NEMP 1995 understood public participation to be involving a mixture of bottom-up, top-down, and multidisciplinary approach, where different agencies and ministries were supposed to interactively participate in the management of natural resources. The NEMP documents wide participation, consultation, and focused thought. Recommendations in the NEMP also provide for public interactive participation to be part of conservation (Table 1). So, the NEMP plan encouraged public interactive participation even in the sharing of forest benefits and incentivizing forest resources through marketization.

Marketization

All marketization initiatives aimed at combating environmental damage through deforestation. However, studies have shown gaps in the ability of initiatives like REDD+ to generate substantial results (Collins et al., 2021; Asiyanbi and-Massarella, 2020). In this discussion, I'm aware that the NEMP came into being before some global initiatives towards marketizing environmental resources, but I had to comprehend the various discourses regarding this concept and how it relates to the NEMP.

According to Green and Adams (2015), it is neoliberal conservation being market driven, with regulation of nature through commodification. Neoliberal conservation gives an upper hand to non-state actors and capitalists who commodify and trade natural resources in markets. Commodification of natural resources is supported by privatization of forests and reducing the opportunity for local people to enjoy ecosystem services from the once public forests. Privatization of forest resources has intensified forest loss because it laid the ground for green grabbing, the appropriation of land and natural resources for green credentials.

In the NEMP, one of the solutions to improve biodiversity conservation and management was to accord forests their true value, thus creating "a market for different elements of valued ecosystems" (Fairhead et al., 2012, p.244). Thus, the NEMP perceived the need to market nature as a way of improving it. Other problem representations on marketization articulate this (table 1). However, marketizing forest resources poses the danger of NEMP's opening the way for "contemporary market-based policies, which build on and revitalize preceding colonial modes of governing nature-society relation" (Collins et al., 2021, p.3). In common terms, marketization was perceived in the NEMP as those market-based solutions to the problem of biodiversity conservation and management, but which could be leading to further degradation of resources because of profit incentives.

In a nutshell, the presuppositions that underpin the problem representations in the NEMP objective of forest conservation and management showed the NEMP's understanding of sustainability, biodiversity conservation, institutional collaboration, public participation, and marketization as summarized in table 2.

3.3 How did this come to be?

Here, I discuss NEMP's reflection of both international and national understandings, approaches, and historical trajectories to conservation. So how did these problem representations come to be as important aspects, and what process did they take (Q3)? Subsequently, I identified the various Global and national initiatives and processes through which I could understand how problem representations of forest conservation and management were framed in the NEMP.

In the late 1980s, there was a global threat of the Sahara Desert gradually extending southwards. This change in climatic and vegetation conditions prompted African countries, including Uganda, to act immediately. Elsewhere, there were similar observations and so action was eminent as evident from the global response scale. Global initiatives started with the June 1992 United Nations Conference on Environment and Development held in Rio de Janeiro and Uganda got committed to this global environmental agreement. Other initiatives followed, that is the Convention for Biodiversity (CBD) of 1992, Secretariat of the Convention on Biological Diversity (2005), the UNFCCC (1992), and United Nations Convention to Combat Desertification (UNCCD) (1994). Uganda, among several countries, ratified the CBD and related treaties such as the

UNFCCC (1994), and UNCCD (1994), prompting the enactment of the NEMP (1995).

At the national level, in 1986, Uganda gained political stability after the war of liberation. This stability promoted population growth, economic reforms, increased urbanization, increased demand for food products and for export marketing, which put pressure on forests and other natural resources (NEMP, 1995). It is noted that by the time of writing the NEMP 1995, over 90% of Uganda's population depended directly on natural resources for their survival. Besides, the investment policy favored Indian and Chinese investors by allocating free land to such investments. This also paved way for industrial development. All these occurrences required a legislation to guide natural resources use to attain sustainable socio-economic development. So, Uganda enacted a National Environment Action Plan (NEAP) (1992) which paved way for emphasizing the country's natural resources. The NEAP process culminated in the NEMP (1995) strategy to combat environmental degradation. The Uganda Constitution was also enacted in 1995 providing the context for the NEMP. The constitution provided institutional arrangements towards the conservation and management of biodiversity. Consequently, the NEMP was formulated by a policy committee in the Office of the Prime Minister. The committee comprised of all line ministries including the Prime Minister as Chairman, and Ministers responsible for Natural Resources, Agriculture, Finance and Economic Planning, Education, Health, Lands, Housing and Urban Development, Local Government, Gender and Community Development, Tourism, Wildlife and Antiquities, and Trade and Industry. This committee provided guidelines, then formulated, and coordinated the environment policy development in liaison with the National Cabinet. The policy committee had technical committees such as soils conservation, pollution, biodiversity conservation, and environment impact assessment. The Policy Committee also put in place a statute to bring into force the National Environment Management Authority, NEMA (2006) with mandate to identify funding, and initiate policy research, legislative proposals, standards, guidelines, and ensures observance of proper safeguards during planning and implementation of all development projects. Other institutions and organizations in collaboration included the Uganda Wildlife Authority (UWA) and the National Forestry Authority (NFA).

Later in 1997, Uganda enacted a decentralization policy under the Uganda constitution (1995) and other Acts such as the Local Government Act, cap. 243 and the Environment Act, cap. 153. Decentralization involves devolving a significant amount of power to local authorities to manage natural resources (Ribot et al., 2010). In Uganda, natural resource management was devolved to the district and village levels, culminating into establishment of district and local/village environment committees. Decentralization also extended natural resource management to include civil society organizations/NGOs, the private sector, and private landowners.

Subsequently, it was necessary for the NEMP to come into force, to bring back Uganda's glory once the "Pearl of Africa" as described by Sir Churchill Winston in recognition of the fact that before Uganda's independence in 1962, its environment was the best in the whole of Africa (Rwakakamba, 2009). Besides the conventions, policies and local events that took place, there are various conceptualizations on respective problem representations in the NEMP. For instance, an IFRI pilot study in Uganda showed forest degradation as a global environmental problem which required reference to international treaties and national policies (Becker et al., 1995). Relatedly, Gasparatos and Wallis' (2015) green economy study showed the crucial roles of nature services such as clean air, fertile soils, and food, thus requiring the "realization that biodiversity and human well-being are inextricably linked", leading to adopting numerous environmental policies (p. 2). Although this genealogy describes a robust process and existence of practices leading to the pervasiveness of the problem representation, the policy document and later research (Namanji et al., 2019) unveiled some silences that were not problematized in the policy.

3.4 Silences

Having identified the NEMP (1995) forest conservation and management problem representations (Q1), the underpinning presuppositions (Q2) and the process through which problem representations came to be (Q3), I posed the question of what was left unproblematic in those problem representations (Q4)? Having an environment policy together with continuous loss of biodiversity, has serious implications that the policy could have inadequate solutions, or the problem may have unaddressed underlying ontological and epistemological premises. The WPR approach by Bacchi guides that problem representations are "nested one within the other (Figure 1), necessitating repetition of the question what's the problem represented to be?" (Bacchi,1999: p.5). Even though elsewhere policy statutes and acts bring out more in-depth problems, there are core underlying concerns that may remain silent in all categories of the NEMP framework. So, at this level I step back and identify silences for problem representations under each theme as presented below.

Sustainability

Although the NEMP has solutions towards acceptable levels of exploitation, this is not realized in practice according to observations and the various state of environment reports for Uganda (NEMA,2010; 2016;2019). Elsewhere, there was concern about putting too much emphasis on development activities without regard for environmental health (Namanji et al., 2019). This notion of weak sustainability is evidenced in situations where oil palms replace natural forests. Thus, although the NEMP theoretically emphasizes strong sustainability, it is silent on mechanisms to ensure definitive implementation.

Biodiversity conservation

One strategy for improving forest conservation and management is through both private and public forests having and implementing forest management plans, although this is not emphasized in the NEMP problem representations. According to Namanji et al. (2019) the government gazette forest reserve Towa had a forest management plan but not implemented. Hence, its trees had a diameter at breast height (dbh) of less than 50cm (meaning that all trees were young and the mature ones had been cut), and had limited ecosystem goods for communities. Effective policy implementation towards forest conservation and management requires implementing forest management plans. However, “there is political pressure on forest managers to ignore forest management plan prescriptions” (Ruhombe, 2014 p. 8). Consequently, the policy is silent on strict implementation and enforcement mechanisms as well as government funding of conservation activities.

Institutional collaboration

First, in its problem representations, the policy mentions collaborative developing and disseminating scientific technical information for efficient utilization of forest resources, through conservation organizations. However, sophisticated information mostly ends up on shelves and is not utilized by local groups. The policy would emphasize integration of Community-Based Research (CBR) through incorporating indigenous knowledge into scientific information, omitting the mode of dissemination. Furthermore, local environment committees were unaware of the environment policy and programmes to ensure its implementation (Namanji et al., 2016), thus creating ignorance in the part of environment committees.

Secondly, problem representations show multi-sectoral collaboration as a necessary aspect in both the classification and management of all levels of protection in the Protected Area (PA) system but leave out other related aspects such as systemic participation, representation, teamwork, and facilitation that move hand in hand with collaboration. Thus, a systemic perspective is missing. Systems thinking means environment components being synergistic (Kim, 1999). Even if the NEMP mentions multi-sectoral forest conservation and management, this is not enough without systemic participation and representation, adequate funding, and teamwork. These aspects are not clearly streamlined in the NEMP 1995.

Thirdly, the NEMP does not mention how to deal with institutional failure caused by bribery and corruption in the PA system. As long as institutions set up to enforce environmental laws have corrupt officers at all levels, there cannot be progress in conservation. As in cases like Environmental Impact Assessments (EIA), the legal framework to incentivize local communities to be self-sufficient in forest product requirements and collection of forest user fees and revenue from PAs cannot work if corrupted.

Fourth, to operationalize institutional collaboration, the government of Uganda enacted a decentralization policy. Even if decentralization had good intentions, it showed some gaps, including the limited collaboration within these institutions, the overlapping roles/activities and the inadequate delegation of decision-making powers over forest management (Turyahabwe, et al., 2007; Smith, 2012). For instance, the policy is not clear on which institutions should support agroforestry as well as strategies for its proper implementation (Kiyingi, et al., 2020). In addition, local and district environment committees were in place to support NEMA in NEMP implementation, but these committees were not trained in their jobs and had a very limited mandate to perform, a sign of institutional failure (Namanji et al., (2017). As Ruhombe (2014), notes Uganda has good policies and laws but there is limited institutional and human capacity in management of forests. These gaps are silent in the policy and certainly lead to inadequate policy implementation.

Public participation

Although the policy mentions enhancing local community participation in the management of PAs, it leaves out the important aspect of meaningful participation, where participants are selected according to sectors and disciplines and are thus able to contribute meaningfully to environmental issues and policy discourse. If participation is not clearly streamlined, there are tendencies to cause some stakeholders' ineffective contribution to forest conservation programmes. In addition, if through decentralization the government of Uganda were to devolve power of forest management to local governments, then that local power should come with representation. Otherwise, it ceases to be democratic decentralization (Ribot, et al., 2010). The reverse is also true if representatives are powerless amidst powerful autocrats. In addition, there are still questions on inclusive governance being the government's motive, due to the inconsistencies in the policy leading to practice dilemma due to poor enforcement, limited/or no public participation. The policy needs to put more emphasis on enforcement/implementation mechanisms.

Marketization

One of the problem representations was to encourage communities to participate in non-destructive use of forests such as eco-tourism and agro-forestry. However, the PAs system is under government control and management with limited community participation and awareness on ecotourism resources. In addition, ecotourism has some negative impacts. In Kalangala district in Uganda, experience shows that there are increased land and commodity prices due to increased influx of tourists. This has a negative effect to local communities whose cost-of-living increases. The NEMP has no mechanisms to deal with such negative impacts of ecotourism.

Exporting timber implies having faster growing species to keep constant supply but this is not compatible with biodiversity conservation. There is a danger of over extraction of forest resources due to profit incentives. In the NEMP, we do not see how this overexploitation should be dealt with. Besides, the policy is silent on mechanisms for replanting indigenous trees after harvesting, and silent on how to access quality germplasm to support agroforestry (Kiyingi et al., 2020). Namanji et al, (2017) also showed that communities could not access seedlings for planting indigenous trees and what was available were only fruit trees but in inadequate quantities.

The policy mentions reviewing financial management systems in relation to revenue and forest management costs and explore innovative methods of collecting forest user fees. However, the policy is silent on ensuring strict financial audits on how the collected money is used. This has intensified corruption, bribery, nepotism, and favoritism. In addition, increase in timber export has intensified illegal harvest due to corruption. If the policy encourages agroforestry, it should also mention the inclusion of farm trees in the National Forestry Inventory and other environmental accounting systems in Uganda. But this is silent in the NEMP 1995.

All identified silences/nested problems in the NEMP 1995 have been summarized under respective themes and presented in Figure 1.

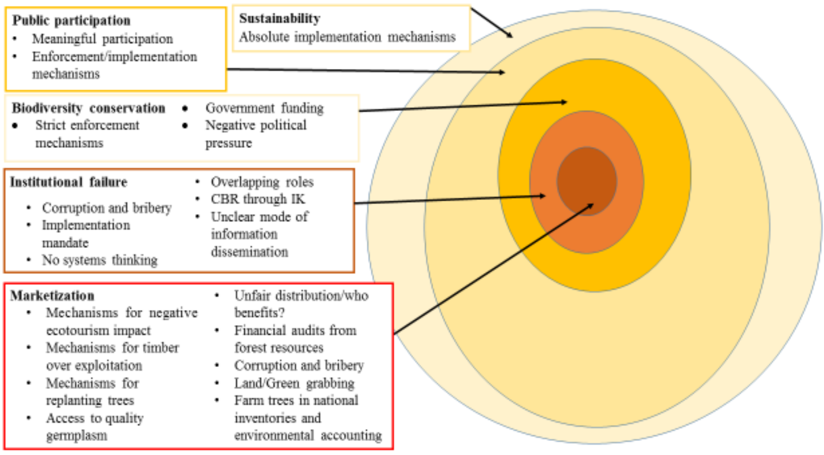

Figure 1 Nested problems not addressed in the NEMP and so remain silent to the failure of the policy. The deeper the color the more silent, critical, and causative the problem.

The stated silences in the problem representations had three kinds of effects: "Discursive, Subjectification and Lived effects" Bacchi (2009, p.48; 2019). Discursive effects link back to question 4. These are effects that follow from the limits imposed on what can be said and thought, how other things are said while others are left out. Subjectification effects show how power shapes our subjectivity; the ways in which subjects and subjectivities are constituted in a discourse. Lived effects indicate how problem representations have an effect on how people live their lives. Bacchi (2019) shows the need to detect implications in particular problem representations that the researcher decides are negative or hurtful to particular groups of people[2]. Therefore, I further analyzed the NEMP 1995 in relation to question five which creates the opportunity to identify the discursive, subjective, and lived effects produced by the respective problem representations.

3.5 Effects

This analysis generated multiple possible discursive, subjectification and lived effects of NEMP-provided solutions to forest conservation and management. Effects could be enablers or deterrents for implementing forest conservation and

[2] https://youtu.be/2WesB_p2Vc8.)

management. As such, they are not taken for granted, and so they are presented here for the purpose of integrating them into mitigation strategies for future revision of the NEMP. The effects are presented within respective themes and problem representations.

Sustainability

Namanji et al. (2019) reports massive forest degradation and so communities may wonder whether the NFA or NEMA do not promote degradation instead of being custodians. Besides, if forests that belonged to the community are now termed "gazette", there is transfer to those who apparently hold them in custody and are the key timber value adding and exporters, not the local community.

If forest gazetting is a problem representation for ***biodiversity conservation***, then what is the importance of gazetting when there is encroachment on gazetted forests? Moreover, does NEMA as an umbrella organization create a coordinated system when forest degradation continues in spite of NEMP? The effect trickles down to community conservation becoming a myth when responsible institutions are not well coordinated and collaborative.

Institutional collaboration

The effects of problem representations 3, 8 and 9 (in Table 1) under institutional collaboration vary. First, if each sector focuses on benefiting from forest resources, lead sectors may not effectively engage others who in turn become more aggressive in harvesting forest resources as an opportunity arises or simply keep aloof. Secondly, the process of developing scientific and technical information related to utilization of forest resources does not involve communities hence generated technologies are left on the shelf. Thirdly, as long as corruption is still at large, even when the forest curriculum is revised, forests degradation will continue because graduates will have nowhere to implement conservation programmes.

Public participation

The effects of problem representations under institutional collaboration relate to those under public participation. This is so because, without institutional collaboration, there is minimal public participation. Thus, communities lose interest in participating in forest conservation vs those who exploit forests. Besides, since most forest communities are not educated, they get left behind, yet they should be the major beneficiaries of forest resources. Encouraging communities to plant trees comes together with discursive effects of communities questioning between food and trees. Thus, the need to strike a balance between the two.

Marketization

One of the discursive effects of problem representations under marketization is that, due to the ongoing degradation, forests have lost their original potential. Thus, inaccurate data may be generated from quantifying Uganda's forests. The lived effect is of poor planning for forest resources. Without combating corruption, even if forest management systems are reviewed, there shall be misuse of forest user fees. Besides, commodification may not improve biodiversity conservation when forest resources are subjected to over exploitation due to profit incentives. This has a lived effect for communities who cannot access privatized forests.

3.6 Dissemination

Lastly, I addressed question six. The effects of the solutions towards forest conservation and management are the basis for the solution being either reproduced, disseminated, and defended or being questioned, disrupted and replaced. All these scenarios are discussed in view of the global, continental, national and case perspectives.

Globally

The global initiatives mentioned in the methodology section are in line with biodiversity management and emphasize sustainable development. In addition, the recent United Nations Food Systems Summit in 2021 emphasized inclusive sustainable food systems, animal welfare, optimizing land productivity, and reducing land under cultivation, conservation and restoration of natural ecosystems to mitigate climate changes in respect of United Nations 2030 Agenda and Sustainable Development Goals (2015), in particular goal 15 to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss". Other initiatives like the Conservation International identified hotspots for international conservation as a way of prioritizing conservation (Adams, 2017). Conservation International worked hand in hand with those concerned with the protection of nature and sustainable development similar to the NEMP's forest conservation and management problem representation of developing a coordinated PA system. Coordinated global players included the World Conservation Strategy (1980) by the World Wildlife Fund, International Union for the Conservation of Nature (IUCN), and United Nations Environment Programme (UNEP). These are powerful conservation organizations with expertise in conservation planning and would therefore handle conservation as a top-down agenda (Adams, 2017).

The top-down notion of conservation is in line with what the NEMP aimed at by proposing that institutions concerned with biological diversity be coordinated to manage and conserve nature. The NEMP also embraced a mixed conservation approach in which community and conservation experts (in this case institutions) are involved. It is noteworthy that community conservation has been difficult to implement (Adams, 2017) globally, and Uganda is not exclusive because as noted from the lived effects of the respective problem representation, forest communities are mostly not educated, and so arises the question as to whether community conservation could solve the problem of biodiversity loss. In this line of thought, we also ask whether policy coordinators and implementers would involve uneducated local communities at the expense of conservation experts like those in international NGOs and partners? Adams (2017) reported that the dominant idea of conservation is something that comes from those who are trained to understand the problem of biodiversity loss. This implies an urgent need to fight ignorance in the forest communities.

Africa-wide

The Malabo declaration elaborated in the Comprehensive Africa Agriculture Development Programme (CAADP) of the African Union AU (2014) stresses the significance of enhancing conservation and sustainable use of all natural resources such as land and forests. It also stresses the importance of multi-sectoral engagements and inclusive growth. The NEMP stresses multi-sectoral collaboration in both the classification and management of all levels of protection in the PA system. Furthermore, the FAO (2014) report on Africa shows that 85% countries support putting emphasis on the Conservation for Biological Diversity. In their report, Keeley and Scoones (2003: p.3) indicated that in sub-Saharan Africa, issues of soil fertility decline, deforestation and desertification are deeply entrenched policy problems. New challenges such as oil palm, soil fertility decline, oil and gas prompted the ongoing revision of the NEMP, as of 2017.

Perspectives on the national scene

Uganda still has a challenge of balancing conservation and forest exploitation (Banana, 2005). Research in Uganda by Buyinza and Teera (2008), Egeru, et al., (2014), Namaalwa (2006), Namaalwa, et al., (2007), Petursson, et al., (2006), Slette, et al., (2008) Vedeld, et al., (2004) established, that deforestation varied with the forest ecosystems behavior. Ruhombe (2014) and Rwakakamba (2009) questioned the high rates of natural forest tree biodiversity loss in a country where forest protection is adequately articulated in the National Constitution, with a National Environment Management Policy, and questioned the effectiveness of Uganda's environmental policies. Furthermore, Banana, et al., (2012) reported that Uganda's deforestation rate, which was already the highest in Eastern Africa, had accelerated from the year 2000. By 2010, the NEMA (2010) state of environment report for Uganda indicated that the area of forested land in Uganda continued to decline from 3.6 million ha to 3.3 million ha at an annual rate of 1.86%. On 20th September 2018, in a press statement on corporate social responsibility on tree planting, the NFA indicated that by 2017 Uganda's forest cover had declined to about 9% of the total land area (NFA, 2018), while NEMA (2019), indicated further decline in forest resources. All these results pose questions about the effectiveness of solutions to forest conservation and management. This implies that the forest conservation and management problem is still at large and therefore needs to be handled with utmost importance. Since 2017, there has been contestation of the current NEMP 1995 (NEMA,2017) because there are new and emerging environmental issues and challenges like climate change, oil and gas, electronic waste, and SDGs (2015) that the current NEMP does not address.

The case of Buggala Island, Kalangala District

Buggala Island in Kalangala District-Uganda had massive deforestation to plant oil palms and other infrastructure, whereby various instances exhibited the ineffectiveness of the current problem representations in the NEMP. For example, in 2009, the Kalangala District NGO Forum reported that in Buggala Island, over 6000ha of natural forest cover had been cleared and planted with oil palms with support of the World Bank/IFAD, yet FAO (2014) identified small islands such as Ssesse Islands ecosystems that were at high risk of biodiversity loss, as was also reaffirmed by Kalangala District state of environment report (2005). Ssemanda and Opige (2018) indicated that on Buggala island, the tropical high forest fully stocked was reduced from 57% of the area in 1990 to 20% in 2015, with an increase in uniform monoculture oil palm farmland from 0 in 1990 to 31% in 2015. It has been noted that Oil Palm plantation agriculture came with unfair acquisition of land in Uganda. Land grabbing has been much debated and contested by various NGOS such as Friends of the Earth International (FoEI) in a Newsletter on 17th Nov 2014; "Take action, stop land grabs in Uganda"[3]. Others are the media such as in the New Vision 17 April, 2013 Uganda: "Unfair Government Policies Fanning Land Grabbing" by Uganda Land Alliance. Therefore, there is need for moral behavior within agroecosystems due to the environmental effects associated with agricultural systems (Schneider and Francis, 2006).

[3] http://www.foei.org/news/take-action-stop-land-grabs-in-uganda

For instance, although the problem representation about reviewing financial management systems in relation to revenue and forest management costs may enable earning from the Carbon fund under the REDD+ initiative, isn't this a mechanism of this neoliberal approach to provide an opportunity for the large corporations to invest in and profit from the marketization of nature? (Adams, 2017). Large corporations have access to carbon funds and are engaged in monocultures, but monocultures do not improve biodiversity.

4. Conclusions and recommendations

4.1 Conclusions

The NEMP presents a multiplicity of forest conservation and management problem representations, with presuppositions and processes in line with global beliefs. However, this WPR based research shows that there remain serious silences which affect attempts at solving the forest conservation and management problem. Among the many silences presented in the NEMP, I emphasize two fundamental issues/silences including *corruption* and *ignorance* which ought to be tackled if nations like Uganda are to achieve sustainable forest conservation and management of biodiversity through progress in conservation. It is noted that the NEMP does not mention how to deal with institutional failure caused by bribery and corruption in the Protected Area system and there is concern about local environment committees being unaware of the environment policy and programmes to ensure effective policy implementation (Namanji et al., 2016) and inadequate institutional collaboration. Yet institutional failure and inadequate institutional collaboration have a negative effect on the uneducated forest communities who are left out of environment management programmes because they are left ignorant. Within the context of the conflicting relationship between ecology and economics, in particular a capitalist economics based on the growth imperative, the NEMP and other related policies cannot lead to sustainability, fairness in distribution, and efficiency in resource allocation-aspects in Ecological Economics (Costanza, 2008; Leefers and Castillo, 1998), if issues like institutional failure characterized by corruption and ignorance of the forest communities are left unproblematized or silent in the policy. Therefore, the success of recommendations in this article shall be based on tackling the key silences of corruption and ignorance and related representations, as well as those with positive effects. Recognizing this as an essential prerequisite, I make some recommendations for a more sustainable management of forest resources.

4.2 Recommendations

1. Adopt a zero-tolerance policy towards corruption and effectively facilitate and motivate coordinating actors, who should restore and safely guard community rights to forests, by entrusting forests to communities living around them as well as their cultural leadership, because gazetting them and putting them in hands of local authorities has not worked.
2. Embrace inclusiveness in enforcing and awareness of the policy but with specific consideration of women and youth involvement. It is the women and youth that collect forest ecosystem provisions and appreciate them most. As such, they would be much more interested in ensuring conservation of forest resources than men who tend to only wish to exploit forest resources for especially commercial timber woodlots.
3. Enforce adherence to environment ethical values among those working with forest related public organizations such as NEMA, NFA, and UWA.
4. Establish and understand the economic value of invasive species to interest stakeholders in protecting them and harvesting them appropriately.
5. Enforce regulations on harvesting, movement, and commercialization of forest resources.
6. Let technocrats, local leaders and communities come together to develop and enforce forest management plans in English and local languages.
7. Mitigate the negative mindset and "To Whom It May Concern attitude" in communities by ensuring their participation at all stages of NEMP implementation.
8. Provide affordable alternative green technologies to substitute forest ecosystem services for indigenous communities so that they spare and conserve forests.
9. Guide and monitor cost effective and efficient land use to ensure sustainable productivity instead of increased production which expands into conserved forest areas.
10. Ensure employee recruitment systems that are ethical in all aspects, and a civil service which recruits, develops, disciplines, and creates room for succession.

11. Monitor generation of data on forest resources such that it is representative of what is on the ground.
12. Develop adequate institutional and human capacity to patrol forests and markets to prevent illegal timber harvest and export.
13. Deliberately sanction politicians who pressurize forest managers to ignore forest management plans.
14. Prioritize the conservation and management of forests resources budgets.
15. Ensure that trees on farms are included in the National Forestry Inventory and other environmental accounting systems in Uganda.

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Position Paper

Decentralization to decarbonize the Indian economy

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Keywords: net zero; decarbonization; decentralization; economy; renewable energy.

Abstract. *Renewable Energy (RE) plays an important role in India's energy security and reducing greenhouse gas emissions. Energy generated at the* *centralized level has significant shortcomings, and environmental concerns drive a shift to decentralized energy. India is a developing country. Renewable energy power generation promotion is very important to create awareness among consumers and retailers. India's energy transition and decarbonization agenda aim to build a new clean energy system that is reliable, affordable, sustainable, and energy independent. The Indian government has taken several initiatives to increase domestic manufacturing capacity, particularly solar Photovoltaic (PV), Electric Vehicles (EV), and batteries. This paper aims to present significant achievements through different RE schemes, consider projections, and analyse India's ambition of net zero through the current policy concerning the decentralized use of renewable technologies prospects.*

1. Introduction

The electricity demand of a nation reflects its social conditions, the pace of economic growth, geographical variations, and the demography of the population at large. Electrical energy consumption rises year after year as people become wealthier and populations grow. Electrical energy generation and distribution are of vital importance. Currently, the majority of power generation, transmission, and distribution in India is through a centralised system. Centralized power means few power plants produce most of the power we use. Most of this power is generated in centralised locations and then sent via the power grid to homes and businesses. When transmission and distribution are centralized, the losses are high, so to reduce the losses and maximise the utilisation of renewable energy, a decentralised system is required. Decentralized energy is electricity that is generated not on the main grid but near where it will be utilized, instead of at a large plant elsewhere and sent through the national grid. The rapidly rising levels of global energy consumption are prompting increasing concern about the depletion of natural resources and the growing effects of environmental pollution, such as ozone depletion, climate change, and global warming. As economic stability and population growth increase, nations contribute to greater global energy consumption (Hassanein et al., 2019, Saleh et al., 2021, Momete, 2018, UNNATEE, 2019, CEA India, 2020).

Decarbonization is key to combatting global warming. It is the process of reducing or eliminating greenhouse gas (GHG) emissions by phasing out fossil fuels and moving to renewable energy sources such as the sun, wind, and geothermal heat. Developing decentralized renewable energy systems is critical for the global decarbonization of energy generation. Figure 1 lists the major challenges for decarbonizing.

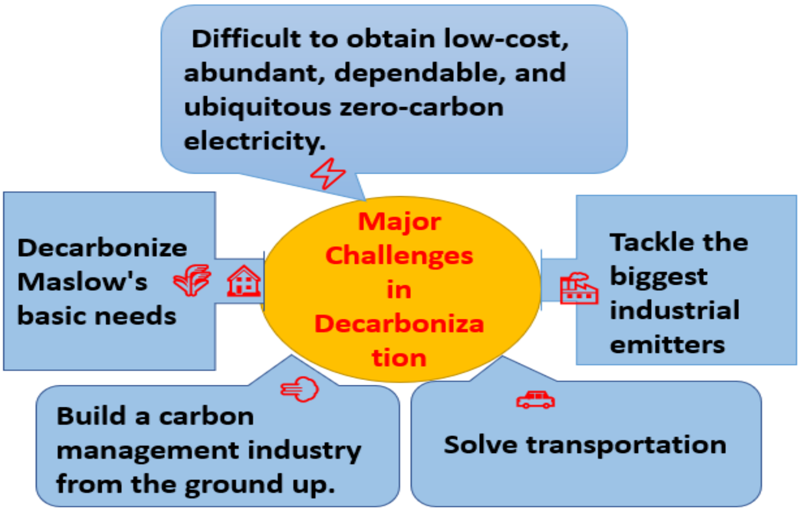

Figure 1. Major challenges in decarbonization

India's long-term vision of decarbonizing its economy and reaching net zero by 2070 requires a holistic approach to integrating sustainable solutions at various levels (Shankar et al., 2022, Sheoran et al., 2022a). These changes also challenge traditional electricity demands and, thereby, the tariffs that must be revised to architect an effective policy in developing nations like India. The nation must significantly reduce emissions to accomplish its net-zero targets. This is because 2070 is less than 50 years away, and there are numerous uncertainties regarding developing new technologies and financing schemes for sustainable development (Sheoran et al., 2022b, Chopda et al., 2021). The government must take several crucial initiatives to solve the net zero equation. Companies too must enter the net zero space quickly. Five industries, including power (which accounts for more than 40%), iron and steel, cement, transportation, and agricultural, are responsible for most of our emissions. Other sectors, including those in refining and chemicals, come after these. These sectors will require significant expenditure to meet our net zero targets over the coming years. India's energy sector is evolving quickly, supported by decarbonization, with 50% RE capacity by 2030, decentralization by moving from centralized to distributed generation, democratization giving customers economic choice, digitization through use of technology to optimize grid power consumption and captive power consumption and its role in future demand requirements.

The role of on-grid and captive power consumption is in helping to advance the Nation's Energy System (NES). The most common type of solar PV system is on-grid, also known as utility-interactive. Grid-tied systems are linked to the electrical grid and allow building residents to use solar energy and grid electricity. Grid-connected systems do not have to meet a home's or business's electricity demand. When there is no demand for energy, the solar panels discharge excess energy into the grid for use elsewhere. A captive power plant is a facility that provides an energy user with a localized source of power. These are usually industrial plants, large offices, or data centres. The plants can operate in grid parallel mode and export excess power to the local power distribution network. They may also be able to operate in island mode, that is, outside of the local electricity network.

Figure 2 shows sector demand for electricity consumption. Renewable energy sources are most important for any country's development, and the advantages of renewable energy are numerous and affect the economy, environment, national security, and human health. This paper analyses discussions around the current policy concerning the decentralised use of renewable technologies, their prospects, and the policy push.

2. Policies in place and their progress

Conventional energy sources, such as oil, coal, and natural gas, are highly effective in driving economic growth, but they are harmful to both the environment and human health. Alternative energy sources have the potential to mitigate these risks. The potential of renewable energy sources is enormous, since they have the potential to meet many times the world's energy demands. Renewable energy sources such as biomass, wind, solar, hydropower, and geothermal can provide sustainable energy services using routinely available indigenous resources. A transition to a renewables-intensive energy future is con-

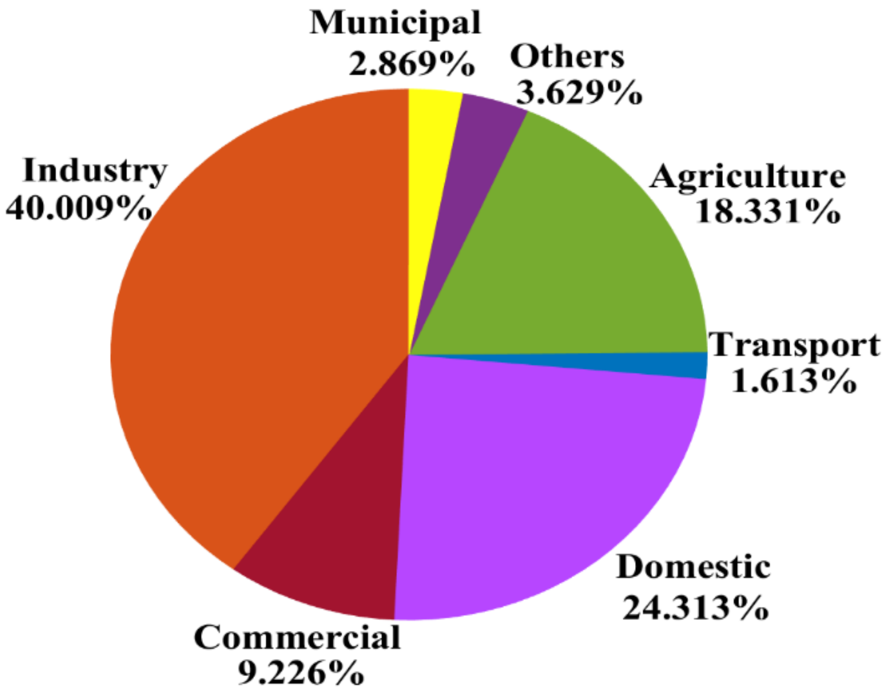

Figure 2. Sectoral demand for electricity consumption (UNNATEE, 2019).

sidered as increasingly likely (Shankar et al., 2022, Sheoran et al., 2022a, Sheoran et al., 2022b, Chopda et al., 2021).

The Indian government has set out an ambitious target of achieving a RE capacity of 175 Gigawatts (GW) by 2022 and 500 GW by 2030 to boost the Indian energy infrastructure and decarbonize the environment. Furthermore, the country is committed to fulfilling 50% of its energy requirement through Renewable Energy System (RES) by 2030. Several RE-based grid-connected and off-grid projects have been enabled by a range of union and state-level policies to facilitate energy transition goals and combat global climate change in a decentralized fashion. Figure 3 shows the progress in the grid-connected solar rooftop program. This section examines the existing policies of RE addition in various sections of the economy and their progress.

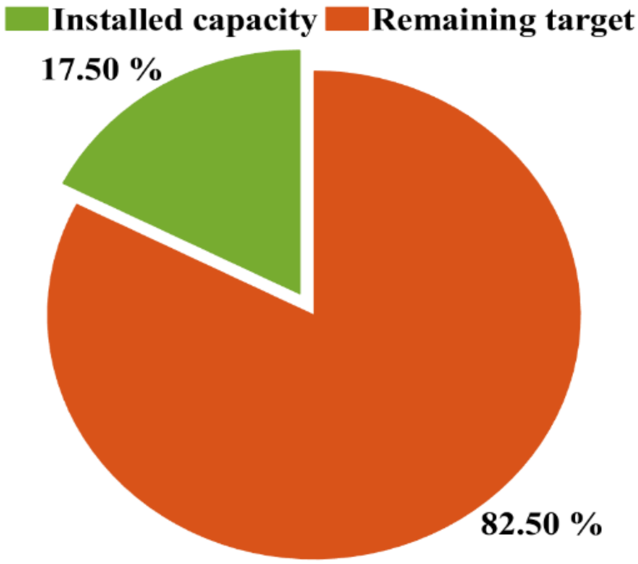

Figure 3. Progress on grid-connected solar rooftop program (Murthy, 2022, pv-roof, 2021).

2.1 Residential Sector

A grid-connected rooftop PV program has been launched to decarbonize the building sector and achieve a cumulative capacity of 40 GW by 2022 through a project conducted with with the Central Financial Assistantship (CFA) (Solar Rooftop, n.d., Adithya, 2016). The regulation of net metering has also been approved for this scheme by the government so that customers can earn extra credits when they generate more surplus energy than they need. As of December 2021, 7 GW of rooftop solar PV modules have been installed under the umbrella of this program (Murthy, 2022, pv-roof, 2021). The government had planned to invest 756 billion rupees through Deen Dayal Upadhya Gram Jyoti Yojana (DDUGJY) to enable the much-awaited reforms of electrifying rural India. With this scheme, the government has approved the electrification of an additional 11.83 lakhs connections, including 1.35 lakhs connections through solar PV-based standalone systems. A Central Public Sector Undertaking (CPSU) scheme Phase-II has been designed to set up a 12000 MW grid-connected solar PV project by the government producers with Viability Gap Funding (VGF) support for self-use or use by the government entities through Distribution Companies (DISCOMS) or directly. The government has extended a VGF of up to 70 lakhs/MW on the CPSU scheme to the eligible organization for this project. To electrify every household in this country, the suubhagya yojna project was launched in September 2017. As of 31 March 2021, as many as 2.817 crore houses had been electrified through saubhagya yojana including 4.16 lakh households through solar PV-based standalone systems.

2.2 Agriculture/Farming Sector

To decarbonize the farming sector, the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM KUSUM) scheme was launched with a target of adding RE capacity of 25750 MW by 2022 with a CFA of 34,422 crores. Pan India tender capacity under the PM KUSUM scheme shown in Figure 4 reflects that 3473 Megawatts (MW) of solar capacity is distributed among the states. As of December 2021, the solar PV modules with a total capacity of 4909 MW have been approved through component A of this scheme. A total of 3.59 lakh standalone solar pumps are provided for under component B, out of which more than 75000 pumps have been installed. In addition to components A and B, more than 9 lakh existing water irrigation pumps are planned to be solarized through component C of this scheme. The progress of the PM-KUSUM scheme shown in Figure 5 indicates that its execution needs to be increased to decarbonize the agriculture sector.

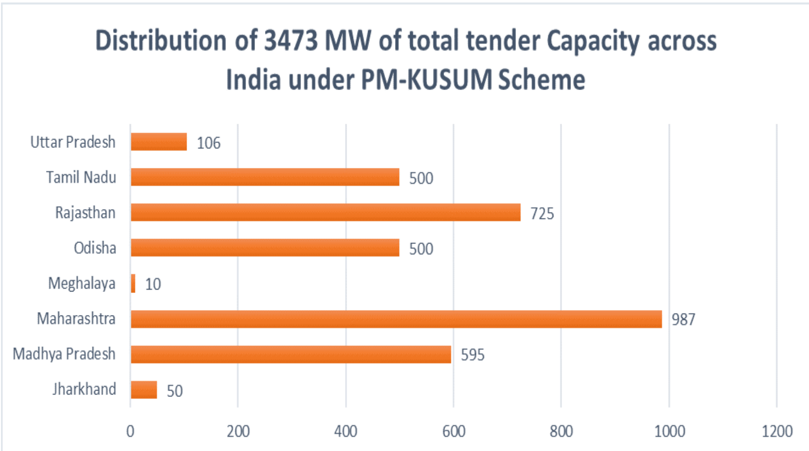

Figure 4. Progress on PM-KUSUM scheme (Vasudha_power, 2022)

The "Development of Solar Parks and Ultra-Mega Solar Power Projects" initiative was launched in December 2014 to make it easier for solar project developers to set up projects using a plug-and-play paradigm. Through this scheme, the Ministry of New & Renewable Energy (MNRE) has approved setting up 25 solar parks targeting over 40000 MW. The MNRE provides a CFA of 25 lakh per solar park for the composition of a Detailed Project Report (DPR) and an additional CFA of 20 lakh/MW, including grid connectivity cost. Off-grid and decentralized solar PV applications program Phase III was launched by the MNRE to set up an additional off-grid solar capacity of 118 Megawatts plant (MWp) by 2021 through 2.500.000 solar study lamps, 300.000 solar street lights, and 100 MWp of off-grid solar power plants. Furthermore, the electrification of several public institutions in rural regions, including health centres, anganwadis, offices, schools, panchayats, railways, and bus stations, is also planned through this scheme. As of 31 Dec 2021, 216.88 MW of RE installation has been completed through this scheme in various applications. In addition to the above-mentioned schemes, several other schemes such as "AICTE Training And Learning (ATAL) Jyoti yojana," "scale up of access of clean energy for rural productive uses," and "seven million solar study lamp scheme for school-attending children," and others, have been launched by central and state governments in a decentralized fashion to decarbonize the environment.

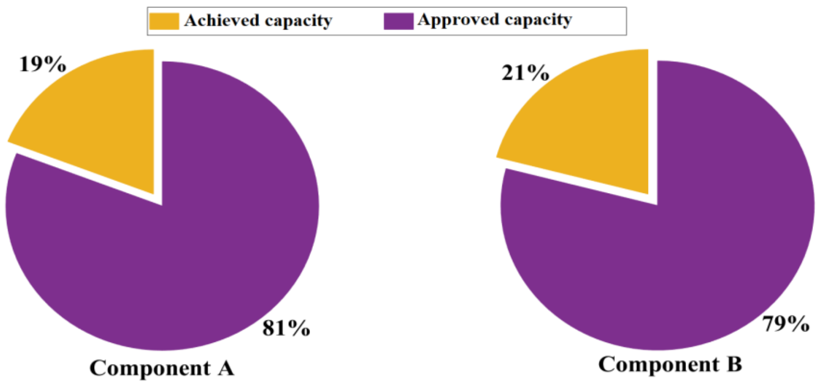

Figure 5. Progress on PM-KUSUM scheme (Vasudha_power, 2022).

2.3. Future key areas enabling decentralized RE addition: progress and future scope

2.3.1. Agriculture

Being one of the most important sectors of the Indian economy, agriculture consumes 20-22% of the entire electricity demand, which accounts for 240 terawatt hours (TWh) annually. Furthermore, this sector is expected to demand 300-330 TWh of electrical energy by 2030 (IEA, 2021). Managing the agricultural load is increasingly becoming a challenge for electrical utilities. In the light of this, the government has launched the PM-KUSUM scheme to decarbonize the agriculture sector and supply clean energy using decentralized RES. With a growing scattered electricity demand, this sector provides a greater potential to enable decentralized RE addition and is expected to need 172-188 GW of solar PV deployment to fulfil its electricity demand. Solarizing the irrigation sector by enabling decentralized RE addition also holds great potential for reducing the Transmission and Distribution (T&D) losses to a considerable extent.

2.3.2. Commercial/Residential

In 2018, the urban population comprised 55% of the world population and is likely to cross 65% by 2050 (Hassanein et al., 2019, Saleh et al., 2021, Momete, 2018), resulting in an expected rise in the global energy demand by 52% from 2018 to 2040 (IEA_US, 2018). India is expected to add a built area of 35 billion m^2 by 2050(Shankar et al., 2021b), which would demand extra energy to cater for its needs. Currently, buildings account for 30-40% of the total energy demand of the globe and are expected to grow by an average of 8% per year for developing nations like India (Shankar et al., 2020). Supplying electricity to widely scattered buildings from remotely located energy centres adds T&D losses, which have been recorded as 20.66% at the national level (R_CEA). Therefore, satisfying the required energy demand of the buildings by employing on-site environmentally friendly RES is key to turning an energy-hungry building into a Zero-Energy Building (ZEB). Moreover, decentralized RES is the most likely factor that can contribute to reducing T&D losses significantly.

India has a remarkable potential of 1.7petawatt hours per annum through rooftop solar PV installation against India's existing electricity demand of 1.3petawatt hour per year (R_IEA, USAID, Shrestha et al., 2019, Bukya, et. al., 2019). In 2015 the Indian government set an ambitious target of achieving 175 GW of grid-connected RE capacity by March 2022. The national target for rooftop PV installation was fixed at 40 GW (IEA, 2022, Bhanja, & Roychowdhury, 2021). However, the installed rooftop capacity up to Q3 of 2021 was recorded as 6.7 GW (R_rooftop, 2021, Anupama Khare Saxena et., al 2020). Therefore, the deployment of rooftop PV needs to be increased to realize the concept of ZEBs and to reach the mark of 40 GW of decentralized RE for decarbonizing the environment.

Rooftop PV modules often fall short of catering for the electricity demand of high-rise buildings in an urban environment, which is growing at a rate of 2.7% annually. Therefore, deploying PV on the vertical surface of the buildings becomes imperative for decentralized clean energy generation. Semi-transparent building integrated-photovoltaic (BIPV) modules placed at the facade of the high-rise buildings also allow daylight harvesting in the buildings that further reduce the electricity demand across artificial lighting systems and strengthens the energy efficiency (Shankar et al., 2021a). BIPV modules are less efficient than rooftop PV due to their sub-optimal placement and semi-transparent nature. However, they do not require any functional space in the building for their deployment in an urban environment. Therefore, the deployment of BIPV modules must be increased in urban environments to enable decentralized RE addition and enhanced energy efficiency.

2.3.3. Industry

The industrial sector in India consumes the largest share of electricity, which accounts for 40-42% of total electricity demand. As of 31 March 2021, the installed capacity of industry-owned captive power generation (above 1 MW) was recorded as 70000 MW, generating energy of 200000 GWh in the fiscal year 2020-21(IEA_US, 2018). Coal-based power plants account for 64% of total installed capacity, followed by 20.27% for oil, 11.46% for natural gas, and 5% for RES. In addition to the 70000 MW of captive power generation capacity, diesel generators of 75000 MW (excluding sets of size below 100 kVA and above 1 MW) have also been installed in the country (Deisel_gen, 2014). Furthermore, catering for emergency energy needs during power outages, many diesel generators with a capacity of less than 100 kVA have also been installed, giving rise to a large amount of carbon emissions. Therefore, deploying decentralized RES is the most suitable option to cater to the industrial energy demand and decarbonize the environment.

2.3.4. Green Hydrogen

Low-carbon hydrogen has the potential to be a valuable source of clean energy in the fight against poor air quality and climate change. Generating green hydrogen on a large scale by utilizing electricity from the utility grid is unconstructive, expensive, and economically non-viable. However, utilizing captive power generation using RES in a decentralized fashion for generating green hydrogen is a viable solution that decarbonizes the environment and reduces the growing burden from transmission and distribution systems. The National Hydrogen Mission launched by the Indian government aims to generate 5 million tonnes of green hydrogen by 2030. The policy promotes the utilization of RE as the basic ingredient in producing green hydrogen that will help meet the international commitments of clean energy and climate change.

2.3.5. Mini-grid

Decentralized RE sources such as mini-grids/microgrids offer a considerable opportunity for energy access in remote and unprivileged areas. The primary goal of rural electrification was to extend the central grid across the nation. However, the plan lacked serious efforts to promote productive uses and deliver an uninterrupted power supply. While the central grid remains the favoured source of electricity among the rural population, rural enterprises are taking up mini-grid as an additional source of electricity in the absence of electricity from the central grid. Mini-grids are successfully implemented in parts of India, Afghanistan, Nepal, and Tanzania as pilot projects (Shrestha et al., 2019, Bukya, et. al., 2019). Different RE technologies, such as solar, hydropower, biomass, wind, and energy storage systems are used by mini-grids in different ownership models varying from government, private, to non-profit organizations. Mini-grids have been popular in meeting basic needs such as lighting and irrigation due to affordability issues in the rural environment. However, with advancements in technology and decreasing battery prices, mini-grids could be a potential candidate for delivering uninterrupted electricity to less privileged areas and decarbonizing the environment.

An example of mini-grids as an alternative way to electrify rural India is provided by the state of Bihar. Although India achieved 100% household electrification in 2019, 37% of rural households in Bihar still do not have access to dependable electricity. Mini-grids are viewed as stable alternate sources of power in the state, which has about 8% of the country's mini-grids. The state's program plans to build on this momentum by installing another 100MW of renewable-based mini-grids with a capacity of less than 500 kilowatts(KW). Husk Power and other private energy service companies (ESCOs) have led the way in the state. Tariffs of Husk Power are cost-reflective and do not include subsidies, allowing the developer and consumers to determine their tariffs. Despite the higher prices relative to centralized grids (now available where mini-grids operate), most customers are willing to pay the extra price for a reliable energy supply.

3. Discussion and required policy push

Achieving India's 2070 net zero goal while supporting strong economic growth is highly challenging. There are multiple paths to choose from renewable sources such as wind and solar, while these need to be complemented with other sources like gas and supported by storage systems. Therefore, policy measures on decarbonization must adhere to the parameters of reliability, affordability, and energy independence.

Thus far, we have presented the existing schemes and policies pertaining to the decentralized usage of RE technologies to meet international commitments on climate change and clean energy. However, implementing these schemes does not seem to meet the commitments to decarbonize the environment. Therefore, we add some recommendations for consideration in terms of the necessary action to achieve India's ambition of net zero. Figure 6 shows India's foreseen net zero achievements by 2070.

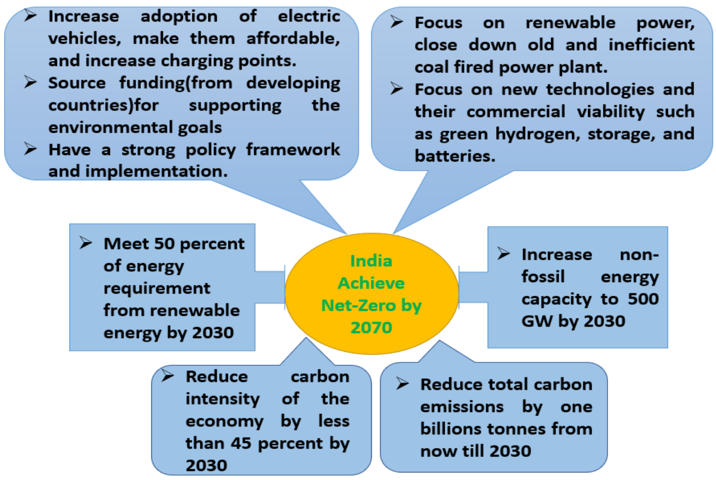

Figure 6. Net-Zero Plan Implementation (IEA_2021).

3.1 Accounting – registration

If it can be said that knowledge equals power, knowledge about power is immensely valuable for utilities. The registration of connections through smart meters provides a deep understanding of the consumer's energy profile, i.e., when, how, and where energy is consumed across the network. Utilities can utilize the historical data of energy consumption in power procurement cost, future energy planning, power quality monitoring, thereby avoiding revenue losses due to power quality events, and avoiding blackouts. Further, Discoms can use historical energy consumption data to implement the time of the day (ToD) tariff to incentivize changes in demand patterns. In addition to registering customers, utilities should improve their billing and collection efficiency through enhanced metering. They should fully use the restructured central government reform strategy to accomplish 100% metering with prepaid/smart meters while also being wary of cybersecurity dangers.

3.2 Subsidies/Tariff relief/financial schemes (CFA)

The central and state governments provide subsidies for schemes like solar rooftops, PM-KUSUM, etc., for decentralized RE addition. However, the higher initial investment in such projects discourages a huge portion of the population from opting for such schemes. Therefore, the agencies must extend incentives to the customers through subsidies/tariff relief/financial assistantship to tempt them.

3.3. Open access

The schemes on decentralized RE must be free from red tape and customer friendly. In addition, the schemes should be open access in the market with the help of private players with straightforward processes.

3.3. Target based governance

Poor implementation of projects often results in falling short of reaching the stipulated targets. The number of approved and installed capacities in projects like PM-KUSUM indicates a lethargic implementation process that detrimentally affects the fight against climate change. Therefore, target-based governance is recommended for completing the projects within the designed time interval.

4. Conclusion

India has been actively promoting renewable energy in a decentralised fashion, electrifying transportation systems, and improving energy efficiency in the wake of attaining the ambitious net zero emissions target by 2070. This paper considers an overview of the most innovative developments in relation to power system developments and trends. In particular, decarbonization and decentralisation are the main drivers of big transformations, and we have discussed the Indian government's schemes, policies in place, and their progress in detail. According to our study's findings, for India to achieve net zero emissions by 2070, it must maximise renewable energy output and storage solutions, including carbon capture technologies for coal, the country's primary energy source. There is a need to promote and frame new policies for green energy through demand-side incentives and policies to reduce costs, notably through production-linked incentives for renewable energy generation at the domestic and industrial levels. Further research will have a significant role to play in facilitating these developments.

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Original Paper

Demystifying the economic and energy potential of Building-Integrated Photovoltaics in achieving India's intended Nationally Determined Contribution

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Keywords: renewable energy, Building-Integrated Photovoltaics (BIPV), energy transition, decentralization, Levelized Cost of Energy (LCOE).

Abstract. *The focus of this paper is on a techno-economic analysis concerning Building-Integrated Photovoltaics (BIPV) in the Indian context. Globalization and swift urbanisation have led to increased energy demand across buildings. India's contributions to environmental improvement are the most ambitious in current global development. The nationally determined contributions (NDCs) look at the country's policies and programmes promoting clean energy, enhancing energy efficiency, and developing resilient urban centres. It also captures citizens' and private sector contributions to* *combating climate change and abating pollution. Buildings account for 35–45% of global energy consumption, and their use is increasing at an 8% annual rate. To overcome the environmental problems caused by fossil fuels, there is a need to use renewable energy sources optimally to meet the energy requirements of buildings in smart cities. Building-Integrated Photovoltaics (BIPV) is suitable for India's highly populated cities because solar rooftops alone can't meet building energy needs. BIPV adaptation in congested structures requires economic analysis and discussion of NDC to determine optimal use. In this paper, the BIPV module is considered a source of clean energy for the building's facade (vertical portion), and a techno-economic analysis of BIPV modules has been performed and compared with the optimally placed rooftop PV module to explore the potential of BIPV in achieving India's NDCs.*

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1. Introduction

Rapid urbanization and infrastructural development across the globe has resulted in escalated energy consumption and carbonizing environment in emerging countries like India. Buildings are responsible for 35–45% of global energy consumption and increasing at an annual pace of 8% (Shankar et al., 2022; Shankar & Bukya, 2022). To overcome the environmental problems caused by fossil fuels, there exists a need to use renewable energy sources to meet the energy requirements of buildings in smart cities (BEE (2021), Mungai et al., 2022)). As a result, both the preservation and protection of our resources for future generations and environmental values are not jeopardized. Semi-transparent PV kinds are getting prominence for deployment in building walls, roofs, and windows due to their versatile properties, such as supplementing structural materials, offering great insulation, enabling daylight, and generating power (Gholami, & Rostvik, 2020; Banerjee, 2022). In this viewpoint, Building-integrated photovoltaics (BIPV) can be deployed where the building facade or rooftop of the building is made with Photovoltaic panels. It is an emerging technology that serves buildings' space constraints in urban environments.

NDC(s) stand for 'Nationally Determined Contributions, ' indicating each country's commitment to reducing greenhouse gas emissions. Every five years, countries are expected to review and improve their NDCs and propose more ambitious greenhouse gas reduction actions. India has said that at least 40% of its installed capacity for power generation will be derived from non-fossil fuel-based energy sources and is trying to achieve a projected capacity of 525 GW by 2030, as shown in Figure 1. The principal activity is to execute the energy transition from fossil fuel to renewable energy. Figure 2 manifests that the current status is 106 GW, and by 2022, the target output capacity will be 175 GW.

Between April 2000 and March 2021, India's renewable energy sector attracted 10.02 billion dollars in foreign direct investment. According to the analytics firm British Business Energy, India ranks third in the world in terms of renewable energy investments and intentions in 2020 (Shankar et al., 2021a).

Also, the PM of India has announced some key points at COP 26 summit held in Glasgow. Some of them are:

- To attain a non-fossil energy capacity of 500 GW by 2030, shown in Figure 1.
- To provide 40 percent energy requirements through renewable sources.
- Reduce approximately 1 billion carbon emissions by 2030.
- Reduce carbon intensity.
- India aims to achieve the target of Net-Zero by around 2070.

One of the PV's major challenges is an area with solar panels deployed in broad open spaces to extract the maximum power. Transmission losses arise due to transmission lines used to deliver power to the load. PV panels can be employed to generate required energy at the load centre but often, buildings in urban areas have limited rooftop areas and other constraints described in Figure 3, which in turn limits the energy generated from using PV panels alone. The usage of BIPV mitigates these drawbacks. The proximity of energy-generating facilities to the location of energy consumption distinguishes the BIPV system. (Ghosh, 2020)) conducted an economic analysis of BIPV systems as the building envelope in European structures. BIPV is one of the most important characteristics of zero-energy buildings that also improves the built environment's aesthetic appeal. However, it now only accounts for around 1% of the worldwide photovoltaic industry. This necessitates a greater focus on this topic (Osseweijer et al., 2018)). BIPV modules can switch an energy-hungry building into an on-site sustainable energy generator, minimizing transportation losses and, resulting in the cost of power. The amount of energy produced by BIPV modules is largely measured by the amount of solar irradiation received from the sun. The energy generated by BIPV modules is affected by the facing of the BIPV module on the building site, and the local topographical variables (Shankar et al., 2021a; Chopda et al., 2021).

The primary findings of this paper are encapsulated as follows:

- BIPV module is proposed as an envelope material in the North, East, South, and West directions of the building facade.
- The solar irradiation falling at the surface of the BIPV module erected vertically at different azimuth angles (North, East, South, and West directions) are estimated using the solar transposition model (Shankar et al., 2021).
- The energy performance of the BIPV module mounted in each direction of the building facade is presented and compared with the optimally placed PV module.
- Economic analysis of BIPV mounted vertically at different azimuth angles (North, East, South, and West directions) is presented and compared with the optimally placed PV module.
- Analysis of the environmental sustainability of BIPV modules mounted vertically as an envelope of the building facade in each direction is presented.

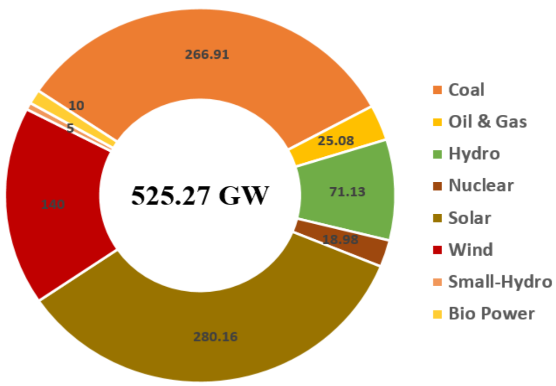

Figure 1. Projected capacity of total energy generated by 2030

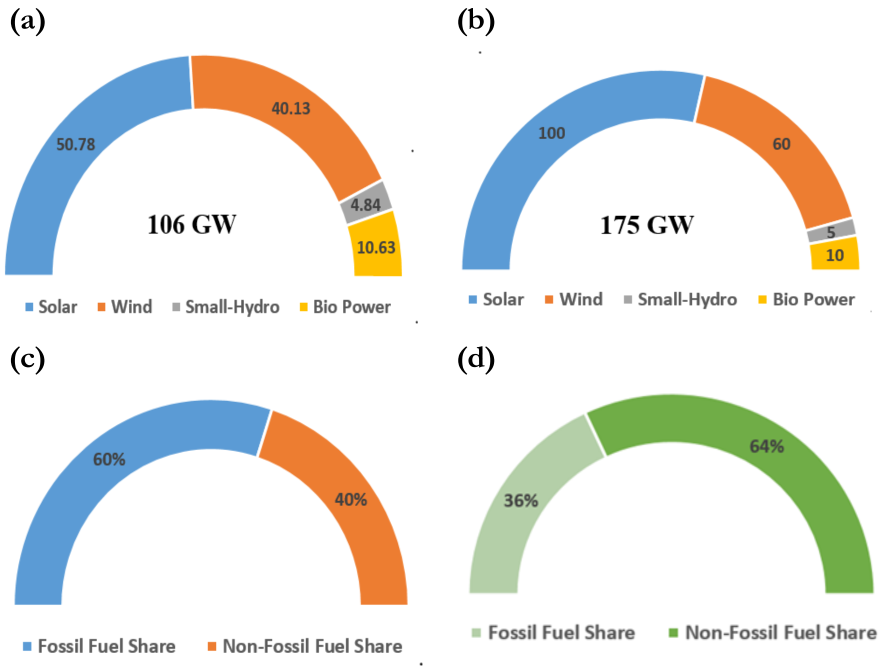

Figure 2. India's NDC tracking. (a) Currently installed capacity of renewable energy; (b) Target by 2022; (c) NDC target by 2030; (d) Projected capacity by 2030.

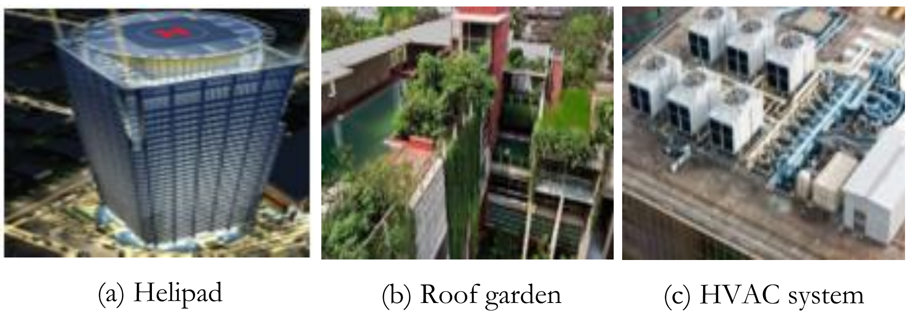

Figure 3. Challenges of rooftop PV

2. Methods

Building-integrated photovoltaics are a viable method for incorporating renewable energies into the built environment. This integrates solar PV panels into building roofs, windows, facades, and shading systems. BIPV maximises renewable energy generation, making a building more sustainable and environmentally beneficial. After optimising the design, the next step to be considered is technical evaluation. Here the assessment of BIPV layouts integrated within the building architecture from a technical standpoint is necessary. This includes the performance of the PV and BIPV system and Energy cost calculations.

The rooftop PV is considered to be optimally placed, whereas the BIPV modules are mounted vertically across the building facade in all directions of the building. The yearly solar irradiation at the geographical location of New Delhi, India, was acquired from the European Commission's Photovoltaic Geographical Information System (PVGIS), and the output power was produced from optimally placed rooftop PV and BIPV modules mounted in each direction (North, East, South, and West) is calculated by Equ.1 and Equ.2 respectively (Pvgis, 2021), A. Shankar et al. 2021b).

The power performance of PV and BIPV modules is formulated as follows:

$$P_{PV,t} = \eta_{PV}\, A_{PV}\, \frac{H_{PV,t}}{H_{stc}} \left[1 + \alpha_p (T_c - T_{stc})\right] \eta_{dr_{PV}} \tag{1}$$

$$P_{BIPV_N,t} = \eta_{BIPV}\, A_{BIPV}\, \frac{H_{BIPV_N,t}}{H_{stc}} \left[1 + \alpha_p (T_c - T_{stc})\right] \eta_{dr_{BIPV}} \tag{2a}$$

$$P_{BIPV_E,t} = \eta_{BIPV}\, A_{BIPV}\, \frac{H_{BIPV_E,t}}{H_{stc}} \left[1 + \alpha_p (T_c - T_{stc})\right] \eta_{dr_{BIPV}} \tag{2b}$$

$$P_{BIPV_S,t} = \eta_{BIPV}\, A_{BIPV}\, \frac{H_{BIPV_S,t}}{H_{stc}} \left[1 + \alpha_p (T_c - T_{stc})\right] \eta_{dr_{BIPV}} \tag{2c}$$

$$P_{BIPV_W,t} = \eta_{BIPV}\, A_{BIPV}\, \frac{H_{BIPV_W,t}}{H_{stc}} \left[1 + \alpha_p (T_c - T_{stc})\right] \eta_{dr_{BIPV}} \tag{2d}$$

Where:

η_{BIPV}, η_{BIPV} : Efficiency of the PV and BIPV module, %

A_{PV}, A_{BIPV} : Intrinsic area of the PV and BIPV module, m²

$H_{PV,t}$: Solar irradiation falling at the surface of optimally placed rooftop PV, kW/m²

$H_{BIPV_N,t}\ H_{BIPV_E,t}\ H_{BIPV_S,t}\ H_{BIPV_W,t}$: Solar irradiation falling at the surface of BIPV module mounted vertically at north, east, south, and west facade of the building, kW/m²

H_{stc} : Solar irradiation under standard test conditions (STC)

α_p : Temperature coefficient of power, %/^{0}C

T_c : Historical data of temperature, ^{0}C

T_{stc} : Temperature of the PV module under STC, ^{0}C

$\eta_{dr_{PV}}$ $\eta_{dr_{BIPV}}$: De-rating factor of PV and BIPV module, %

The cost of the 100 m^2 BIPV module and the cost of the power converter are included in the proposed PV-BIPV system's economic analysis. Equ.3 is used to compute the present worth (PW) of each factor's cost, which encompasses investment, operation, and maintenance. The total of all the components of PW is the life cycle cost (LCC). Annualized LCC (ALCC) from Equ.5 utilizing the cost of cumulative present worth PW yields the levelled cost of energy (LCOE).

Energy cost calculations are as below:

$$PW = \left(\frac{1+r_f}{1+r_i}\right)\left(1-\left(\frac{1+r_f}{1+r_i}\right)^n\right) \quad (3)$$

$$R = C_0\left(\frac{1+r_f}{1+r_i}\right)^n, \; M = C_0\,PW \quad (4)$$

$$ALCC = \frac{K+R+M}{PW}, \; LCOE = \frac{ALCC}{E_T} \quad (5)$$

Where:

r_i , r_f : Rate of interest and inflation, %

C_0, n : Present worth (PW), INR and life of the project, Yr

K : Initial investment on project, INR

R, M: PW of replacement and O& M cost, INR

ALCC: Annualized life cycle cost, INR

LCOE: Levelized cost of energy, INR/kWh

E_T: Annual energy generation

3. Results and Discussion

The results of the analysis of this study were as follows: (i) Power generated by optimally placed PV module; (ii) Output power from 100 m^2 of BIPV module mounted as an envelope of the building façade; (iii) Energy profile for PV and BIPV modules; (iv) GHG reduction, Comparison of PV; (v) BIPV modules on LCOE.

The output power provided by the BIPV module positioned vertically in all four directions (various azimuth angles for the North, East, West, and South facades) is computed and displayed in Figure 5. Similarly, the intrinsic area of an ideally located PV module is considered, and the PV module's output power is depicted in Figure 4. Because of their ideal positioning, rooftop PV modules generate more electricity than BIPV modules. Furthermore, as shown in Figure 6, the BIPV module put on the North façade produces less electricity than the BIPV modules mounted on the building's other sides.

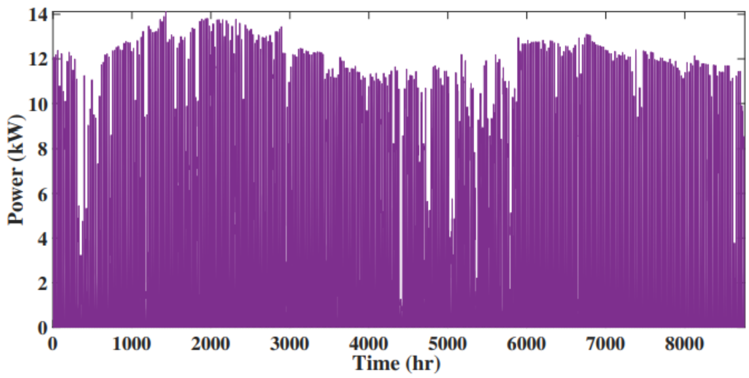

Figure 4. Power generated by optimally placed PV module

Energy profiles for PV and BIPV modules have been plotted for all months of the year ranging from January to December. It has been noticed that the PV module generates a relatively higher amount of energy compared with the BIPV module. Energy generated by BIPV modules facing North, East, West, and South directions have been simulated and it's evident out of all directions energy generated by the BIPV module facing North direction is least and energy generated by BIPV module facing South is maximum.

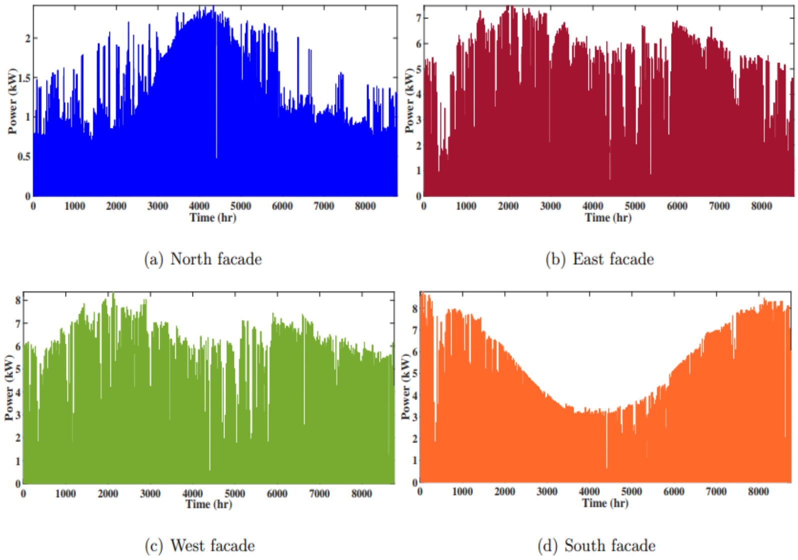

Figure 5. Output power from 100 m² of BIPV module mounted as an envelope of the building façade.

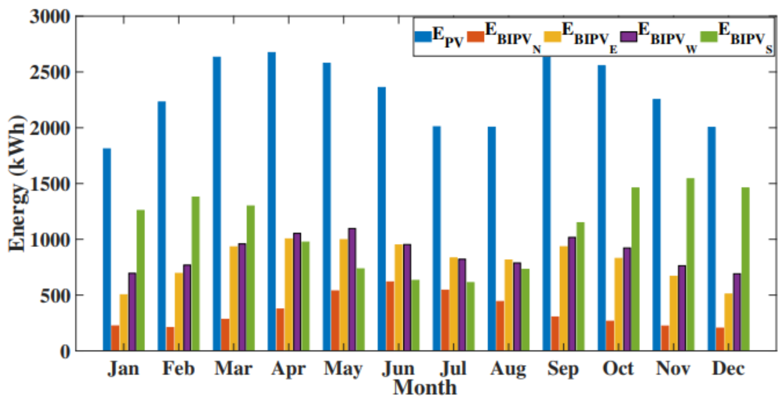

Figure 6. Energy profile for PV and BIPV modules

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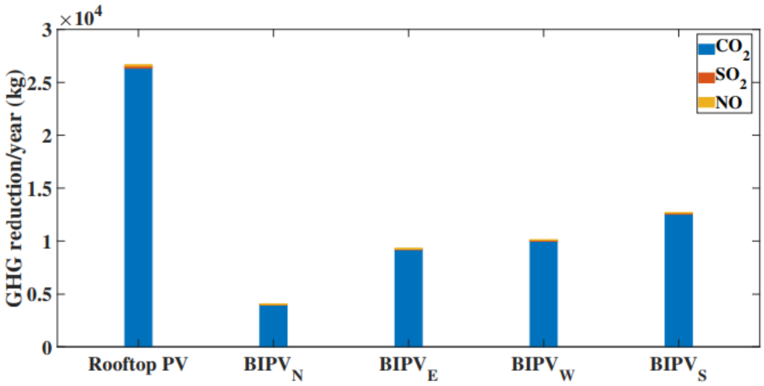

Figure 7. GHG reduction

In India, CO_2 emissions per unit of energy are projected to be 0.91 to 0.95 kg/kWh, SO_2 emissions are 6.94 to 7.20 g/kWh, and NO emissions are 4.22 to 4.38 g/kWh (Mittal et al., 2012). The environmental sustainability study of the PV and BIPV modules presented in Figure 7 shows that the BIPV module, as an envelope of the building facade, serves to eliminate a significant quantity of GHG from the environment without taking up any functional space.

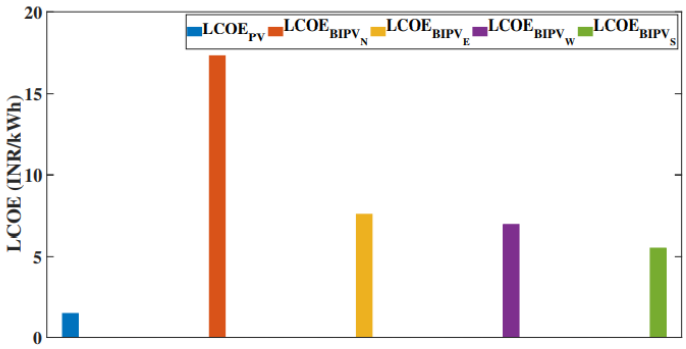

Figure 8. Comparison of PV and BIPV modules on LCOE

Figure 8 shows the LCOE of a 100 m² PV and BIPV module. The BIPV module positioned as an envelope of the building facade delivers energy at a lower rate than an appropriately placed PV module. Furthermore, the BIPV module positioned on the North facade produces the least yearly energy, resulting in energy supply at a higher rate. Similarly, because BIPV on the southern façade creates more energy than BIPV on the other sides of the building, it supplies energy at a reduced amount than other facades.

S.No	Parameters	Value
1	Capital cost of rooftop PV and BIPV module, INR/kW	45000, 135000
2	Capital cost of power converter, INR/kW	8400
3	Maintenance cost on PV and BIPV module, INR/Yr	2%
4	Inflation and real interest rate, p.a.	6.5%, 6 %
5	Lifespan of rooftop PV, BIPV and converter, Yr	25, 25, 10
6	Efficiency of PV and BIPV module, %	17.32%, 12.7%
7	αp, Hstc	-0.4%/ ^{0}C, 1 kW/m^2
8	Tstc	25^{0}C
9	$\eta_{dr_{PV}}$ $\eta_{dr_{BIPV}}$	80%, 85%

Table 1. Input parameters for power performance and economic analysis of PV and BIPV module (Shankar et al., 2022).

Table 1 shows a comparison of the performance of an appropriately positioned PV and a vertically installed BIPV module. PV modules with a 100 m^2 intrinsic area achieve a peak rating of 17.32 kW, whereas BIPV modules with a comparable intrinsic area achieve 12.7 kW. Table 1 further indicates that 100 m^2 of appropriately positioned PV modules produce more energy yearly than BIPV modules.

4. Conclusion

In urban environments, the available space for photovoltaic (PV) modules on rooftops are frequently insufficient to meet the total energy consumption of the buildings. The demand for the BIPV module on the building facade's vertical portion to generate on-site clean energy is the solution to mitigate the energy demand for the building. Discussed India's NDC and the techno-economic study of the BIPV module suggested a building envelope installed on the North, East, South, and West facades are presented in this research. A 100 m² BIPV module is used for the energy performance analysis compared to a similar area of the ideally positioned PV module. The BIPV on the building's south façade is the most energy-efficient, followed by the West, East, and North sides. Although a well-placed PV module delivers more energy than BIPV modules put on the building's façade, PV installation necessitates horizontal space, which is restricted in the urban setting. As a result, BIPV may be used as a secondary source of sustainable energy generation in metropolitan areas. At INR 5.52, 6.94, and 7.56 per kWh, the LCOE from the South, West, and East facades is shown to be cost-effective. BIPV can eliminate a significant amount of GHG emissions from the environment as a building facade envelope, according to an environmental sustainability analysis.

India's renewable energy capacity, excluding big hydro, has surpassed 100 GW, and the country is aiming for a 500 GW target by 2030. The infrastructure of high-rise buildings is rising in tandem with urbanization. As a result, BIPV modules can potentially be a major player in India's ambitious goal of 500 GW of renewable energy installation and carbon neutrality.

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Original Paper

An experimental approach towards cost benefit analysis of 850 kW solar PV plant

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Keywords: solar photovoltaic; energy; economic; power plant; electricity cost.

Abstract. *Solar photovoltaic (PV) cell technology is the simplest way to generate renewable power and reduce our reliance on non-renewable energy sources. Because India is located on the earth's equatorial sunbed, it receives a lot of radiant energy from the sun. Most Indian states have approximately 250–300 d of clear, bright weather per year. Among all the states, Rajasthan* *is one of India's sunniest states, and it is a solar energy hotspot. Manipal University Jaipur (MUJ) is situated in Jaipur, Rajasthan, with 26.8^0 latitudes and 75.56^0 longitudes and a surface area of 122 acres. It receives high levels of solar radiation. All the hostel's block rooms have air conditioners (ACs), so the energy demand in the summer is high. The performance assessment of 850 kW installed capacity on hostel building-mounted solar photovoltaic power plant has been carried out, in view of obtaining better designing, operation/maintenance characteristics of the system. MUJ installed an 850-kW solar power plant for on-site generation and utilization to overcome this enormous electricity bill problem. The paper aims to collect the solar power generation of the plant from April 2019 to March 2020 and shows an investigation of the variation of energy consumption from the Electricity Board (EB), Jaipur Vidyut Vitaran Nigam Ltd (JVNL) of the university hostel block while using solar power and maintains the conventional system. The paper also explores the cost-benefit analysis of 850 kW solar power plants. The impacts of various economic parameters are also taken into consideration.*

1. Introduction

In the present era, solar photovoltaic technology for energy generation is expanding faster. The photovoltaic (PV) effect generates direct electricity from sunlight, with the names photo and voltaic representing light and energy, respectively. The purpose of a solar cell, a light-sensitive semiconductor device, is to generate direct electricity from the sun. Edmund Becquerel (Becquerel, 1839), a French scientist, was the first to identify the photovoltaic phenomenon in 1839. Even so, it was only in discovering quantum theory and solid-state physics that it developed its distinct personality. The first crystalline silicon solar cell with a 6% efficiency was found in by (Chapin et al., 1954) at Bell Laboratories. Following that, scientists worked tirelessly to produce highly efficient solar PV materials. As fossil fuels become scarcer and more expensive, renewable energy sources, such as solar energy, become more popular. Build solar PV systems in regions where solar radiation is available all year to create the highest electricity possible (Green, 1993, Sheoran et al., 2023, IRENA, 2012).

In India, most areas receive a solar irradiance of about 4 to 7 kWh/m^2/day, and its terrestrial mass is expected to receive about 5000 trillion kWh of solar energy per annum. With the advancement of the Jawaharlal Nehru National Solar Mission beginning in 2010, solar photovoltaic system installations in India have been growing exponentially (Green et al., 2018), Bukya et al., 2023, Shankar et al., 2023).

Today's breakthrough for renewable energy sources in electricity generation is PV power systems. PV power systems offer the benefits of more effective use of the highest renewable energy source output and a long-term growth tendency. The output performance of grid-connected PV power systems is significantly influenced by the solar module's cell temperature, ambient temperature, and solar irradiation.

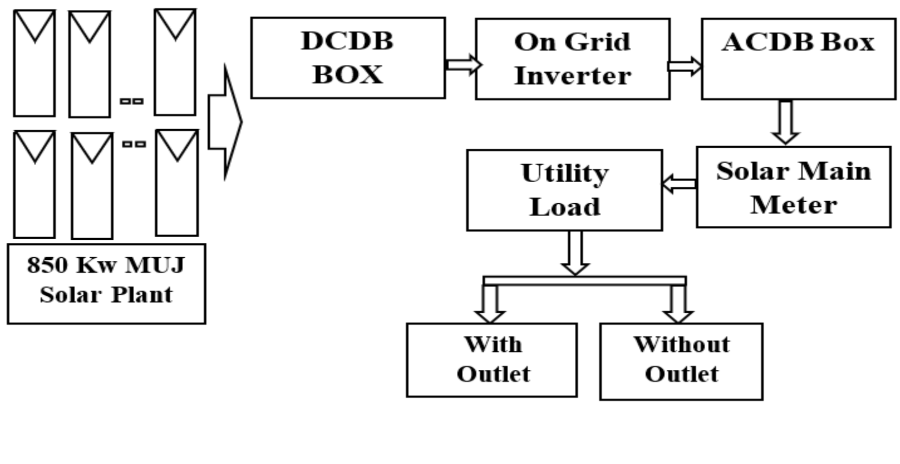

Figure 1. MUJ 850 kW solar Power Plant Schematic Diagram

In this research paper, an experimental analysis has been done on an 850-kW solar power plant installed in the MUJ Jaipur youth hostel. MUJ Jaipur is a world-renowned university established in 2011 to achieve academic excellence. It is located off the Ajmer-Jaipur-Rajasthan Highway. Although India provides electricity to every niche of the country, variations in the electricity bill are still reported in the regions of Rajasthan. We can solve this problem with the wide use and installation of the solar photovoltaic system. This document addresses and resolves the same issue by modelling the cost-benefits of 850 kW solar power plants.

2. Materials and Methods

For an efficient utilization of a solar power plants, a cost benefit and techno economic analysis is very important for determining the optimum conditions for efficient operation. The analysis of all of the economic aspects relating to a photovoltaic system is complex, considering that each installation must be evaluated in its particular context (local conditions, regulations, solar radiation, available areas, etc.)

S.No	Recycled & Recovered Materials	% Material Composition
1	Al	17.5
2	Glass	65.8
3	Silicon	2.9
4	Copper	1
5	Plastic	12.8

Table 1. Composition after Recycling

The software is widely used by researchers and academics to perform energy and cost benefit analysis for renewable energy systems, furthermore it is a freeware and easy to use. In our study, five criterions are selected for analyzing the financial viability for QASP (Payback Period, NPV, internal rate of return (IRR), benefit-cost ratio (BCR), and reduction in GHG Emissions). To state our aims briefly, this analysis will ascertain the time it would require recuperating the initial investment and determine what the yearly cash inflows will be throughout the life of the project. This analysis helps commercial and future investors evaluate the economic and financial benefits of investing in solar PV technology in similar areas to that of QASP, India.

Once the solar panel has completed their end life the following materials come in picture by using thermal, mechanical, or chemical technique, or by removing the panels as shown in Table 1 (Domínguez and Geyer, 2017). Tables 2 and 3 indicates the technical specifications of solar modules and inverters used in an 850-kW installed solar power plant.

Parameter	Rating
Solar Cell	Polycrystalline silicon 156 x 156 mm (6 inches)
Number of Cells	72
Dimensions	1956 x 992 x 40 mm (77.0 x 39.1 x 1.6 inches)
Weight	25.8 kg
Front Glass	4 mm (0.16 inches) tempered glass
Frame	Anodised aluminium alloy
Junction Box	IP67 rated (3 bypass diodes)
Connectors	MC4 compatible
Back Sheet	High resistant polyester
Encapsulating Material	Ethylene Vinyl Acetate (EVA)

Table 2. Technical Data of 320-Watt Anchor Panasonic Solar Panel (Panasonic, 2017).

Parameter	Rating
Absolute maximum DC input voltage (Vmax)	1000 V
Start – up DC I/P voltage (Vstart)	300-500 V (Default 360)
Rated DC I/P voltage V_{dcr}	715 Rated DC input V_{dc}
Rated DC I/P power P_{dcr}	51250 W
Number of independent MPPT	1
MPPT input DC voltage range	520-800 V_{dc}
Max DC I/P current (I_{dcmax})	100 A
Max I/P short circuit current	144 A
Number of DC input strings / pairs	12 or 16 string combiner version available
AC Grid connection type	3-Phase, 440 V
Rated AC power	50000 W
Max AC output power	50000 W
AC voltage range	422-528 V
Max AC output current (I ac max)	61 A
Rated o/p frequency (f_r)	50 Hz

Table 3. Technical Data of the Inverter (Solar Inverter, 2011).

3. Results

In this article we have experimentally investigate the cost benefit analysis of 850 kW solar power plant as situated in Manipal University Jaipur. Here we monthly note down the onside energy generation and their unit reading. Present experimental analysis has done under standard test conditions (STC), including 1000 W/m² of solar irradiation and a temperature of 25°C.

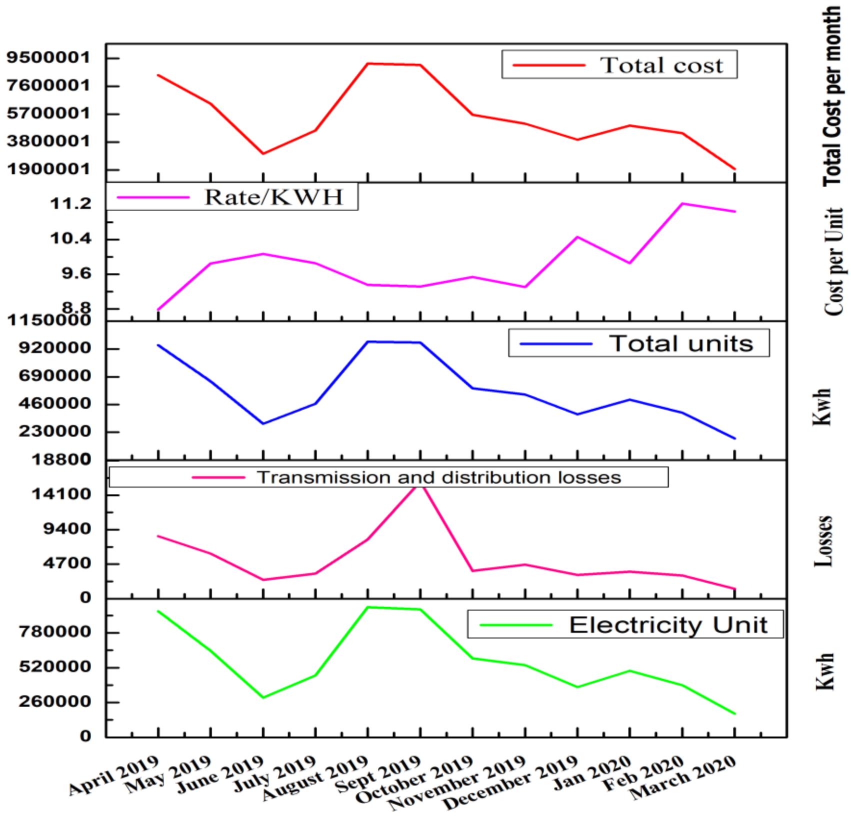

Figure 2. Annual Electricity Consumption and their Costing

All the solar side generated data has been taken and summed up. Figure-1. Indicates the schematic layout of 850 kW installed solar Power Plant in MUJ Jaipur hostel block.

Figure 2 gives the in-depth details of monthly energy consumption, transmission and distribution losses included in the total unit calculation; the losses considered from JVNL transformer to MUJ power distribution board. Figure 3 shows the energy consumption without outlets. The outlets energy consumption will be borne by private vendors.

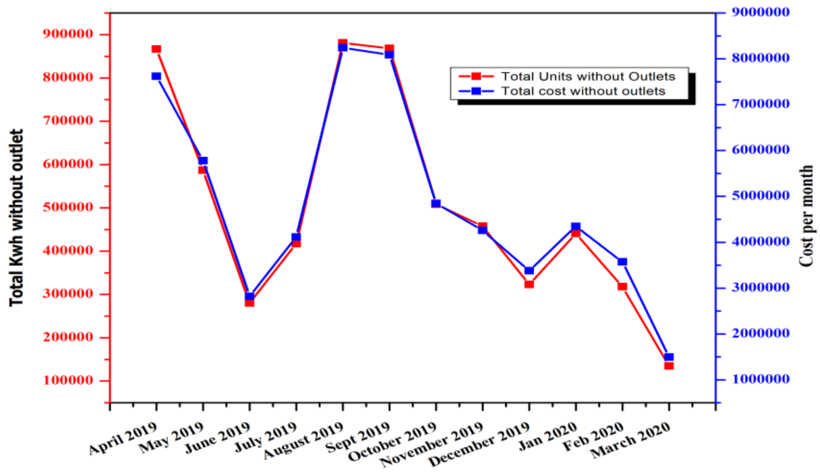

Figure 3. Total Electricity unit consumption without outlet

Figure 4 shows the electricity unit generation by solar plant and their costing for energy consumption calculation compensation of conventional energy and the solar power generation cost considered per unit is INR. 5. Figure 5 shows the total energy consumption patterns, the energy consumption from Electricity Board (EB) and solar with outlets and without outlets and their costing shown clearly.

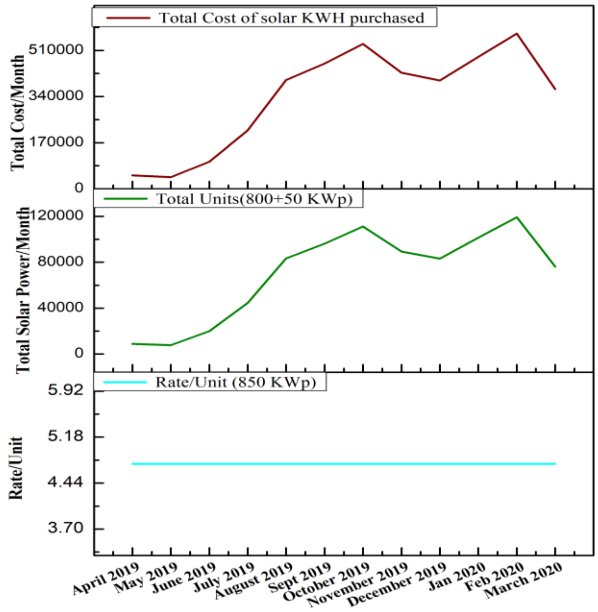

Figure 4. Electricity Unit generation by solar plant and their costing

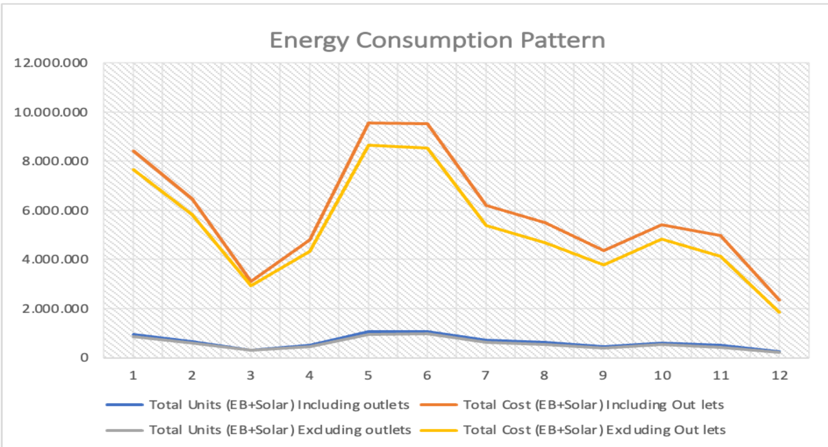

Figure-5. Energy consumption pattern

4. Discussion

The yearly electricity bill paid by MUJ to Jaipur Vidyut Vitaran Nigam ltd (JVNL) for the hostel block is about 6.909.850 INR. The installation cost was around 34.000.000 INR. The annual unit generated by the installed solar power plant is 840.663 and the yearly saving (April 19 to March 20) from this plant is 40,57780 INR. The energy recovery period at the plant is approximately seven years. After the energy recovery period, the plant will continue to produce electrical energy for the next 18 years. The cost benefits that occur during this period from the plant are around 85.192.776 INR. This economic advantage indicates the savings in electricity costs per solar plant in terms of clean energy and limited conventional energy reservoir savings.

From April 19 to March 20, the total unit generation by 850 kW solar power plant in the MUJ hostel campus is 840.663 and the per-unit cost is 5,63 INR.

Total saving from plant (April 19 to March 20) = 840.663 x 5,63 = 4.732.932,69 INR

Energy payback time = Total cost of solar power plant/yearly unit cost generation by the solar plant = 34.000.000/4.732.932,69= 7,18 yr

Assumed life cycle of plant = 25 year

After seven-year for the next 18 years, electricity generated by solar plants is almost free.

Total saving and free electricity produced by solar plant = 18 x 4.732.932,6 = 85.192.776 INR.

PV has expedited its growth in the power generating business as alternative energy to meet existing conventional energy constraints like fossil fuel extinction, environmental issues like the greenhouse effect, and growing electricity costs. PV electricity generation changes throughout the year as a result of solar irradiation. The test site is selected in Jaipur, India, at the 26.8^{0} latitude and 75.56^{0} longitude with a surface area of 122 acres. The monthly electricity bill paid by MUJ to JVNL for the hostel block is approximately 6.909.850 INR, and an 850-kW solar power plant has been installed on the MUJ campus to reduce this vast electricity expense. The MUJ PV facility has an investment cost of 34.000.000 INR. The installed solar power plant generates 840.663 units per year and saves 4.057.780 INR per year (from April 19 to March 20). As a result, with a total implementation cost of 34.000.000 INR, a 7-year payback period may be calculated.

5. Conclusion

In order to address current conventional energy constraints, such as the depletion of fossil fuels, environmental problems like the greenhouse effect, and rising electricity bills, PV has intensified its growth as an alternative energy source in the power-generating industry. The amount of solar radiation that enters the system varies throughout the year, which affects how much power is produced by solar PV. In an effort to lower this high cost of electricity, an 850-kW solar power plant has been installed on the MUJ campus, which covers 122 acres of land area and is situated at 26.8^0 longitude and 75.56^0 latitude. The investment cost for the MUJ PV facility is 34.000.000 INR. The installed solar power plant produces around 840.663 units of electricity annually. For the power used by the hostel block, MUJ pays JVNL about 6.909.850 INR every month. The present study states that between April 2019 and March 2020, savings from solar plant generating totaled 4.057.780 INR. With a 25-year lifespan and an estimated 7-year energy payback period, the proposed solar power plant can expect to generate nearly free electricity for up to 18 years, resulting in massive savings of around 73.040.040 INR. In light of the rapid rate of global climate change, the economic and technical studies we have considered showed that the solar PV system benefits MUJ hoteliers, lowers environmental pollution, and strengthens India's green economy.

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Original Paper

The role of place attachment in defining a relationship between green awareness, conservation commitment and environmental responsible behavior of university students in India

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Abstract. *This study focuses particularly on Indian university students and tries to explore the role of place attachment in defining the relationship between Green Awareness, Conservation Commitment, and Environmental Responsible Behavior. The data was collected from the top ten awarded universities in the field of following green and sustainable practices by the government of India. A total of 352 valid questionnaires were obtained and further analyzed. The results offer an insight into how green awareness among students can positively influence their conservation commitment, leading to adopting environmental responsible behaviour, while place attachment moderates the overall relationship.*

1. Introduction

This paper explores the role of place attachment in defining the relationship between Green Awareness, Conservation Commitment (CC), and Environmental Responsible Behavior (ERB). Green Awareness (GA) is "knowledge among the people about the environment, key relationships and issues foremost to environmental impacts, an appreciation of the 'whole systems', and joint responsibilities necessary for sustainable development" (Chelliah, Atteyat and Huoy, 2017, p.44). Conservation Commitment (CC) "refers to perceived feelings of obligation toward the environment, so those people who personally have lot more commitment towards the environment are more likely to engage in environmental responsible behavior in comparison to the people with no such commitment" (Stern, 2000; Davis et al., 2011, p.261). Environmentally Responsible Behavior (ERB) refers to "any action, individual or group, directed toward remediation of environmental issues/problems" (Sivek and Hungerford, 1990, p.38). Place attachment is a psychological attachment with the natural world which can lead to the long-term orientation toward ERB (Sun et al., 2022: Davis and Green, 2009).

Our study starts from the recognition that there is an increasingly urgent need to define sustainable development goals and green initiatives (Mohideen et al., 2021) and education has an unquestionably essential role to play in this (Vladimirova and Le Blanc, 2016). Universities are a source of knowledge and innovation for society and increasingly work towards educating global citizens in terms of sustainable practices (Purcell et al., 2019). UNWTO (2022) is providing partnership opportunities to the educational institutions to strengthen their commitment to the 2030 Agenda for Sustainable Development Goals and promote awareness of green practices among students.

At one level, in the context of campus sustainability, government and policymakers are, for example, guiding institutions in the direction of adopting environment-friendly energy systems, especially after the outbreak of COVID-19 (Tian et al., 2022). At the same time, since there is a strong correlation between notions of sustainable development and human behaviors (Ari and Yilmaz, 2017; Blok et al., 2015), universities can be seen as dynamic places to encourage and research student's environment responsible behavior through the linking of motivation, involvement, beliefs, personal norms, and values. Therefore, several researchers have applied different theories to study of these factors amongst students (Akhtar et al., 2021), and focus on sets of behaviors practiced by individuals that are undertaken by taking calculated actions directed to promoting positive changes in the environment (Carmi et al., 2015).

In promoting environmental responsible behavior, colleges, universities, and training centers play a vital role where young generations can be more easily led towards individual behavioral change (Massaro et al., 2018; Ting and Cheng, 2017). Universities play an important role in the promotion of environmental sustainability and university activities impact on the environment in both direct and indirect ways, for example, as regards matters concerned with usage of electricity, waste generation, material consumption, enormous movement of people, and transport on campus (Akhtar et al., 2021). Campus sustainability can only be possible and achieved effectively with the active involvement of students (Zamora-Polo et al., 2019). According to El-Jardali (2018), "universities are responsible for training and shaping the future leaders of sustainable development" (p. 4).

In the context of education, pro-environmental shifts are taken into consideration by many organizations because of their sustainability goals and the implications of these for student enrolment (Žalėnienė and Pereira, 2021). Students may wish to develop sustainable environmental behavior by engaging in environmental education (Blok et al., 2015). GA is a significant part of learning because it creates commitment among individuals to save the planet and making it healthy and a good place to live for future generations (Kousar et al., 2022). ERB consists of such aspects as energy conservation, waste avoidance, recycling, green mobility and transportation, green consumerism, and environmentally friendly social behaviors (Kaiser and Wilson, 2004). According to Ling-Yee (1997), CC leads to environmental responsible behavior). Smith-Sebasto and D'Costa (1995) suggested dividing ERB into civic, educational, financial, legal, physical, and persuasion actions.

To motivate educational institutions in India, the All-India Council for Technical Education launched an "award for clean and smart campus" for all institutions including polytechnics, approved colleges, and universities (AICTE, 2020). However, the success of such an initiative cannot be achieved by the efforts of the management authorities of universities only, but also requires the support of students as well (Ribeiro et al., 2019). In this respect, the current research is conducted to analyze the factors that promote behaviors of students that contribute to conserving the environment and maintaining the university's natural ecosystem.

Students' food-related environmental views and behaviors (Arvai, 2015), electronic environmental knowledge (Zareie and Navimipour, 2016), intention and loyalty toward green products (Yu et al., 2017), and the interplay between gender differences and ERB (Vicente-Molina et al., 2018) have been explored in many studies (Meng and Trudel, 2017). However, there is no research available that could explain the factors that determine students' ERB. To promote sustainable development, it is important to ensure that everybody is aware, conscious, educated, and compliant (Mensah, 2019). To understand this behavioral pattern, we targeted the top ten universities that in 2019 successfully achieved the "Swachhata Ranking Awards by the Ministry of Human Resource Development (MHRD) (Ministry of Education, 2019), as this may help us understand the universities' role in achieving sustainable development in campuses.

2. Defining the research focuses

Even while recognizing the importance of ERB, as Ertz et al. (2016) demonstrate, there are some factors including time, cost, and effort which may impede individuals practicing it. Sometimes individual beliefs, motives, and commitment to the environment are influenced by their desire to be ecologically friendly (Khare, 2015). This responsible behavior is more likely to be adopted by highly educated individuals with thoughtful environmental knowledge and motivation (Chakraborty et al., 2017). Factors like environmental commitment (Han and Hyun 2017), pro-environmental lifestyle (Suki, 2016), self-efficacy

(Kim et al., 2016), and GA (Ari and Yilmaz, 2017; Mishal et al., 2017; Nazir and Pedretti, 2015) also determine the ERB of people (Chakraborty et al., 2017).

2.1 The relationship between green awareness and conservation commitment

Many studies look at community engagement for the environment, particularly focusing on students in educational institutions. The relationship between knowledge, attitudes, and green awareness among students pursuing higher education are studied for how these factors shape their behavior towards environmental protection (Mei et al., 2016). Particularly in developing nations like Malaysia young people are found to be aware of the environmental problems in their country (Abd Rahim et al., 2012). Young adults are found to be the age group that is more aware, concerned, and educated about the problems of the environment and even capable of addressing environmental-related issues and environmental sustainability challenges of the future (Ojala, 2012).

GA stimulates assuming responsible citizenship behavior to face and attempt to solve various environmental issues and problems through attitudes, values, and the necessary skills (Sadati, 2014; Sengupta et al., 2010). Those people who act in a more environmentally friendly way are those who always try to relate environmental problems to their behavior, taking responsibility on their shoulders (Van Der Werff et al., 2013). It means that when individuals are aware of the consequences of their behavior, they feel responsible for their actions (Sogin and Pallak, 1976) and are more likely to become committed to environmental conservation ((Juvan and Dolnicar, 2014).

Awareness helps individuals weigh the costs and benefits of their actions toward the environment, making them adopt and remain committed to such conservation practice (Steg, 2009). In this respect, our first research focus is on the extent to which GA has a positive impact on the CC of university students.

2.2 The relationship between conservation commitment and environmental responsible behavior

Universities are indeed playing an important role by introducing programs to encourage and increase the students' knowledge and attention to recycling (Dicle, Iil and Safiye, 2010). Some scholars have found a correlation between CC and ERB. Hojnik et al. (2020) have demonstrated that consumers' environmental commitment has a positive impact on green purchase intentions, thus leading to green consumerism (an actual purchase or environmentally friendly behavior). CC has also been shown to have an influence in promoting household recycling (Katzev and Pardini, 1987). It is argued that ERB needs to be encouraged by political action and education to promote recycling practices, green consumption, and community activism (Chiu et al. 2014; Thapa, 2010). An educational and promotional program highlighting the benefits and importance of environmental conservation and practice adoption encourages students to participate in the initiatives (Barata, Castro and Martins-Loução, 2017). However, the effectiveness of programs can only be measured in terms of the student's practice in implementing recycling practices. Rahman and Reynolds (2016) and Han and Hyun (2016) have argued that individuals' readiness to do what is necessary for the sake of the environment depends on their development of environmental commitment.

A commitment to the environment includes practices that demonstrate ecologically conscious behavior (Goldman et al., 2006) and Cialdini (2003) has described the role of persuasive communication in this respect. These practices include all the activities which have minimum impact on the environment like recycling, conserving water, saving electricity, and using public transportations or riding bikes or even walking, properly handling and disposing of non-recyclable waste, or using less paper when printing (Bissing-Olson et al., 2016; Vaske and Kobrin, 2001; Vaidyanathan and Aggarwal, 2005). Moreover, "commitment is considered to emerge from structural interdependence with the environment" (Davis, Le and Coy, 2011, p.263). An individual's pursuit of environmental sustainability, readiness to forgo personal satisfaction, reduction of resource waste, use of environmentally friendly new products, and support of governmental adaption policies are all examples of ways in which CC becomes ERB (Yu et al., 2019; Iwata, 2001). In this respect, our second research focusis on the extent to which CC is positively related to ERB in Indian university students.

2.3 *The moderating role of Place Attachment*

The most common connotation of PA involves a sense of bonding and linking with a specific place and shows a sensation of feeling and identification a person has with a particular place (Zhang et al., 2014). It is basically concerned with the ties that form between humans and physical places and can be characterized by ambiguity (Hernandez et al., 2014; Williams and Stewart, 1998). Some terms like sense of place, topophilia, insideness, and community sentiment have been associated with the concept of PA (Halliwell et al., 2021). PA involves a cluster of emotional bonds between individuals, communities, and their daily life settings (Brown, Smith and Assaker 2016) and is sometimes associated with terms such as "belonging" or "sense of belonging" to a place (Baskin et al., 2010; Freeman et al., 2007), including attachment students have with a university or school (France et al., 2010).

The degree of attachment that individuals have to a place will increase with their active participation in, tie with, and feeling of belongingness to that place. Environmental factors and personal conceptual models combine to make up attachment to academic settings (Moghisi, Mokhtari and Heidari, 2015). Moreover, the quality of a place stems from the amount and level of the activities, and the ratio of activity costs to benefits (Lin, Chen and Filieri 2017). PA can be seen as a chain based on links between individuals and a meaningful environment (Giuliani, 2003). It is argued that creating an emotional connection to a location through a series of activities there will strengthen relationships and commitments between students and nature (Cownie, 2019) and influence their behavior towards the environment (Vorkinn and Riese, 2001).

Cheng and Wu (2015) found that strong attachment of an individual to a place led to positive ERB. Kyle et al. (2014) argued that individuals' different ways of connecting with different places creates a particular environmental identity. Devine-Wright (2009 suggests that the cognitive connection of the individual with nature impacts on PA. Studies by Anton and Lawrence (2016) and Kyle et al. (2005) demonstrate that individuals' way of connecting to a place affect their willingness to protect that place. A feeling of belonging for a particular place creates and develops a deeper sense of emotional commitment to the environment (Lee, 2011).

For the purposes of our study, PA is seen as related to both the place (the universities studied) and the community (the university students in our study), which it hosts and with which an individual may identify to a greater or lesser extent (Atta-Owusu and Fitjar, 2022; Fitjar, 2010). Some studies have shown that when individuals feel a robust bond to a socio-physical environment, the chances they will enact pro-environmental behaviors increase (Brown, Smith and Assaker, 2016; Zhang et al., 2014). In this respect, our third research focus is on the extent to which PA moderates the relationship between CC and ERB in Indian university students.

3. The research methodology

3.1 Sample area and sample size

Out of 48 universities, we selected the top 10 (UGC approved) awarded with Swachhata Ranking Awards by the Ministry of Human Resource Development (MHRD) in 2019 (Ministry of Education, 2019) as sample areas.

These include Koneru Lakshmaiah Education Foundation (Guntur); OP Jindal Global University (Sonipat); Symbiosis International University (Pune); Manipal University (Jaipur); Siksha 'O' Anusandhan (Odisha); OP Jindal University (Chhattisgarh); Chitkara University (Solan); Jyoti Vidyapeeth Women's University (Jaipur); Dr. D.Y. Patil Vidyapeeth (Pune) and Reva University, (Bangalore). To ensure an adequate representation of the student population, data from various areas of India were collected online (Chaturvedi, 2021).

A preliminary survey was conducted with 20 doctoral candidates and two professors from selected institutes, before the collection of the final data, and small changes were made to the questionnaire based on their feedback. Since the final survey was aimed at exploring the role of university attachment in determining the overall ERB of students, final year students, especially those pursuing master's degree courses, were chosen as more likely to possess more knowledge and skills than undergraduates (O'Donnell et al., 2009). Another reason for selecting these students was that they could be supposed to be highly attached, since according to Anton and Lawrence (2014), attachment to any area or place increases with prolonged living in and visiting a place. The purposive sampling technique for research was adopted (Richardson, 2010).

Kline (2015) and Harrell (2015) state that 10–15 responses can be collected for each variable, while Osborne (2015) recommends using larger sample sizes for more accurate results. So, we distributed about 500 questionnaires, and 382 of them were returned. Only 352 responses were deemed reliable for further analysis.

Since the respondents selected were students, questions on professional education were not considered as suitable items for analysis. The 352 respondents were equally divided between male and female. Most of the students were within the age group of 21-30 (149 in nos.) whereas 133 were within the age group of 31-40 and only 70 were only above 41. The data was collected from January to May 2022.

3.2 *Measurement scale*

A survey questionnaire was created to obtain data on sample characteristics, including age, gender, and household income of students from the targeted areas. It included various scales that were adapted from earlier studies (Table 1). A five-point Likert scale technique was applied (considering 1 as highly disagree and 5 as highly agree). Accordingly, GA was measured using 6 items (Chen and Tsai; 2016; Dutcher et al., 2007; Liu et al., 2009); CC was measured using 3 items (Lee et al., 2011); ERB was measured using 5 items (Chiu et al., 2014; Thapa, 1999; Su et al., 2018); and PA (Universities) was measured using 4 items (Confente and Scarpi, 2021; Kaplanidou et al., 2012).

The psychometric properties of the research scale were examined using SPSS 22.0. Utilizing Exploratory Factor Analysis and the reliability check, the data structure was established. Following the desired value of more than 0.70, a satisfactory Cronbach alpha or reliability coefficient value verified the internal consistency of the scale items (Hair et al., 2014). Further construct validity was ensured by determining the convergent and discriminant validity.

3.3 *Data analysis and interpretation*

A satisfactory Cronbach alpha (α) or reliability coefficient value (ranging between 0.798 and 0.920) confirmed the internal consistency of the scale items by meeting the recommended value of more than 0.70 (Considine, Botti and Thomas, 2005). The convergent validity and discriminant validity were ascertained to ensure construct validity. Convergent validity was determined using the factor loadings, the average variance extracted (AVE), and composite reliability (CR). The observed variables with factor loadings less than 0.60 were omitted from the data analysis (Table 1).

	Loading	**Mean**	**SD**
Green Awareness (Cronbach α = 0.79; AVE = 2.0; CR = 0.930)			
I am used to telling my friend about environmental protection	0.79	4.57	0.63
I am aware of activities ad products that are environmental friendly and less polluting	0.70	4.52	0.50
I report to authorities about any mishandling of the environmental regulation	0.81	4.24	0.71
I try my best to follow the 3R' reduce, reuse, and recycle in daily life	0.69	4.55	0.64

Conservation Commitment (Cronbach α = 0.83; AVE = 1.82; CR = 0.923)			
I am willing to volunteer for groups that help the environment (clean surrounding, water usage and waste reduction etc.)	0.74	4.75	0.50
I actively participate in environmental assessment workshops and initiatives in the university to report green practices	0.73	4.71	0.48
I donate money to initiatives specially carry out for the conservation of the environment like planting trees	0.67	4.50	0.61
I vote for the candidate whose views support environmental protection	0.77	4.65	0.52
Place Attachment (University attachment) (Cronbach α = 0.80; AVE = 1.68; CR = 0.912)			
I feel this university means a lot for me	0.62	4.42	0.51
I feel this university is a part of me	0.73	4.61	0.54
I feel very attached to this university	0.62	4.53	0.55
I enjoy being in this university more than any other place	0.87	4.46	0.55
Environmental Responsible Behavior (Cronbach α = 0.78; AVE = 2.33; CR = 0.926)			
I carpool or utilize the mass transit system to commute within and outside the institute	0.72	4.56	0.59
I insist students have a pro-environmental policy	0.80	4.35	0.81
I purchase a product packed in a recycle or reusable containers only	0.77	4.41	0.53

Table 1. Constructs loading and statistical measures

Comparative estimates of the square root of the AVE for each construct (Table 2) were used to demonstrate the discriminant validity of the constructs, which outperformed correlation for selected constructs for research (Hilkenmeier et al., 2020). Additionally, none of the correlation estimates between the components were higher than 0.70, which can display the possibility of multicollinearity in the present study (Hair et al., 2019; Hair et al., 2015). Also, results for discriminant validity confirm the validity of the constructs for further hypotheses testing.

	GA	CC	PA	ERB
GA	**1.41**			
GPA	.542	**1.34**		
PA	.631	.619	**1.29**	
ERB	.506	.467	.515	**1.52**

Table 2. Discriminant validity of constructs

As far as the descriptive analysis of the constructs is concerned, in terms of GA it was observed that participants not only strongly agreed to tell their friends about environmental protection (Mean= 4.57; S.D=0.63), but also follows 3R' reduce, reuse, and recycle practice in their daily life (Mean=4.55; S.D=0.64). In terms of CC, students' were found highly willing to volunteer for groups that help the environment (Mean=4.75; S.D=0.50) followed by the agreement on participation in workshops and initiatives in the university/institute to report green practices (Mean=4.71; S.D=0.48) (table1). As regards students' PA to their university/institute, it was observed that they strongly feel their university/institute as a significant part of their life (Mean=4.61; S.D=0.54) and they are highly attached to their institute/university (Mean=4.53; S.D=0.55). Similarly while analyzing the their ERB, it emerges that students carpool or utilize the mass transit system to commute within and outside the institute (Mean=4.56; S.D=0.59), and purchase a product packed in a recycle or reusable containers only (Mean=4.41; S.D=0.53) (Table 1).

3.4 Evaluating the research focuses

The structural model was evaluated to see if the relationships considered by the three research focuses were confirmed. The structural model revealed a good fit in accordance with the given threshold criteria given by Hair et al. (2015) where $\chi 2$ = 1.501; GFI = 0.99; AGFI = 0.96; CFI = 0.99; IFI = 0.96; TLI = 0.99; Relative Normed Fit Index (RNFI) = 0.97; RMSEA = 0.051 and SRMR = 0.076 (Hair et al., 2019). At first, we tested and applied the SEM technique without using any moderator. It was found that GA has a significant and positive influence on CC (β = 0.711; t = 5.411; p = 0.000). These results confirm the research conducted by Ofori and Kien (2004) explaining that awareness acts as a determinant for commitment (Goldman, Yavetz and Pe'er, 2006).

Moreover, the CC amongst students was identified as having a significant and positive impact on their ERB ($\beta = 0.528$; $t = 2.563$; $p = 0.000$). These results are in line with the results of the research conducted by Lee (2011); Cheng and Wu (2015).

Finally, we tested the moderating influence of PA as a moderator between CC and ERB. The SEM analysis depicted a significant model fit summary (χ 2 = 1.062; IFI = 0.98; TLI = 0.99; CFI = 0.99; SRMR= 0.06 and RMSEA = 0.035), thereby confirming the moderating influence of PA in the tested model. CC has a significant relationship with ERB amongst students who are attached to their university of school ($\beta = 0.681$; $t = 2.136$; $p < 0.00$). These results are again in line with the threshold criteria given by Hair et al. (2015), thereby confirming that university/institute PA moderates the relationship between CC and ERB in Indian students (Lee, 2011; Chiu, Lee and Chen, 2014).

4. Conclusions

Several aspects are correlated with ERB, such as knowledge of action strategies, knowledge of issues, sense of responsibility, locus of control, and verbal commitment (Hines, Hungerford, and Tomera, 1987), and some actions are there to measure the level of ERB, such as civil action, educational awareness, institutional support, and policy initiatives (Smith-Sebasto and D'Costa, 1995). This research suggests that students today are aware and are more inclined to conserve the environment and underlines the importance of institutes and authorities acting to increase awareness about environmental needs and requirements.

Our results show that GA exerts a significant influence on students' CC, specifically in the context of how the university environment leads them to adopt ERB (Monroe, 2003). According to Cottrell and Graefe (1997), it is the individual's environmental concern, commitment, and ecological knowledge that demonstrate ERB (Chiu et al., 2014). The moderation effect of university/institute's attachment amongst the students emphasizes its importance amongst the various constructs undertaken for determining ERB (Lee, 2011; Chiu et al., 2014). The targeted institutes and universities can serve as an example, encouraging ERB amongst the students and promote green practices implications at ground level. If PA significantly predicts ERB (Halpenny, 2010), then institutes and universities should base all forms of environmental education on encouraging PA as an essential prerequisite for promoting successful outcomes.

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Original Paper

What drives consumers' sustainable mobility behaviour? An empirical investigation of Delhi consumers

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Keywords: Attitude; Behavioural intention; Consumer; Norms; Sustainable mobility behaviour; Theory of Planned Behaviour; Structural Equation Modelling.

Abstract. *The current mobility behaviour of consumers has threatened the life of people and ecosystems. Thus, it becomes imperative to explore the motives and hurdles blocking the way towards a cleaner, safer and affordable mobility system. This study investigates the determinants of consumers' sustainable mobility behaviour using the extended Theory of Planned Behaviour (TPB). For this, the study incorporates four additional variables (environmental knowledge, government actions, personal norms, and product attributes) into the original TPB model. Using a self-administered questionnaire, data is collected from a sample of 440 Indian consumers, and hypotheses are tested using structural equation modelling (SEM). The result reveals a significant positive impact of the product attributes, perceived behavioural control, attitude, environmental knowledge, and personal norms on the behavioural intentions of consumers to adopt sustainable mobility behaviour, while social norms and government actions are not found to affect the consumer's sustainable mobility intentions. Moreover, the study finds that the respondents do not prefer to pool or share their private vehicles very much and are also reluctant to use public transport for daily commuting to their workplace. They pay greater importance to the quality, trust and user-friendliness of the products while making a consumption decision. The study thus suggests a mix of strategies that can be taken into consideration by producers, marketers, and policymakers to encourage consumers' sustainable mobility behaviour.*

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1. Introduction

Current mobility behaviour poses a serious challenge to the economic, environmental, and social sustainability of nations around the globe (Lanzini & Khan, 2017; Nijhuis, 2013). The increasing preferences of people to own an automobile have relentlessly put pressure on the existing infrastructure and fossil fuel-based economy (WRI, 2019). Road transport accounts for the largest consumption of oil-based fuels and generates around three-quarters of total transport carbon emissions. Over 1 billion passenger cars travel on the streets and roads of the world today, and this is expected to double in the next twenty years (IEA, 2018). The rapid increase in personal and commercial road transportation has driven up the demand for oil, gas, and petroleum products, leading to a surge in fuel prices. The financial burden of fossil fuels, along with their negative impacts on health and the environment, are major concerns of present time. Urban communities are struggling with escalating issues, including traffic jams, road anger, respiratory ailments, and early mortality. (UN, 2022). The issue of mobility has intensified in emerging economies, which now face the double challenge of ensuring accessible and safe transportation for everyone while also reducing their carbon footprint (WEF, 2020). The transportation sector, which accounts for 23% of CO2 emissions related to energy, is scaling up global warming, thereby exacerbating climate change (UNFCCC, 2019). The efficiency improvement claims by the producers seem to be insufficient in the light of the continued demand for mobility by the people. The reality is that transport emissions are climbing, and the present mobility system has moved beyond sustainable boundaries, leading to an urban sprawl (Holden et al., 2020).

The need for a safer, cleaner, and accessible mobility system first appeared in the EC's Green Paper on the Impact of Transport on the Environment which widely acknowledged the detrimental effect of the transport sector on the environment and underscored the need to reduce urban car traffic. The paper further called for the "fundamental changes in the way societies commute and consume" (EC, 1992; Holden et al., 2020). More recently, the UN's Second Global Sustainable Transport Conference 2021 has also pointed out the key role of consumers' sustainable mobility behaviour in combating climate change and achieving the goal of a 1.5 degrees Celsius increase in temperature for a greener, inclusive and equitable future. Recognizing this, efforts have been placed to develop the necessary infrastructure, strategies, systems, and policies to deal with the multifaceted and tenacious mobility issue. However, the desire to do so is not reflected in consumers' actions (Holden et al., 2020).

The available literature has largely discussed the role of various socio-psychological factors in influencing consumer's sustainable behaviour (Carrus et al., 2021; Dutschke et al., 2022; Pronello and Gaborieau, 2018; Si et al., 2020). However, the role of contextual factors in swaying consumer's sustainable mobility behaviour is less researched. Furthermore, the majority of these studies have been conducted in the westernized world, having different level of education, awareness, norms, and policies. Thus, there is a need for a comprehensive exploration of all the factors determining consumers' mobility behaviour in the emerging economies accounting for majority of the world's population. With this aim in mind, the present study investigates: a) The current mobility behaviour of consumers in terms of sustainability; b) Factors influencing the behavioural intention of consumers for sustainable mobility behaviour; c) The relationship between the selected factors, behavioural intention and sustainable mobility behaviour of consumers so that appropriate strategies could be formulated to promote sustainable mobility behaviour in India - a country with rapid economic development and home to one-fifth of the total world population.

The failure of the public transportation system to keep up with demand, together with increasing purchasing power and personal convenience, has driven the demand for two and four wheelers among young consumers in India (MORTH, 2019). According to World Road Statistics (2018), the country ranks first in terms of two-wheeler ownership and eighth in terms of total vehicles in use, with 42.5 million vehicles. The country boasts one of the largest road networks in the world, yet every year, an estimated 150.000 people die in road accidents, averaging 422 deaths per day or 18 per hour. Road traffic fatalities are the leading cause of death for people aged 15 to 49. In 2020, India ranked first in the number of deaths from road accidents among 207 countries, with an average of 151,417 fatalities. (MORTH, 2021). Automobile exhaust is a major source of air contamination in cities and metropolitan areas throughout the country. The Centre for Science and Environment reports that they make up the largest portion of PM 2.5 levels in Delhi. The 2021 World Air Quality Report lists Delhi as the most polluted capital city in the world, a rank confirmed for the fourth year in a row (CSE, 2021). However, recognizing the disastrous consequences of this global problem, the country has initiated a series of fledgling sustainability initiatives. This study examines understanding of the global concept of sustainable mobility behaviour SMB at the local level in an effort to understand how to raise awareness and encourage adoption among consumers.

2. Context and previous research

2.1 Conceptual framework

SMB refers to individuals' use of means of transport that does not compromise public health or ecosystems while meeting their own mobility needs (Nijhuis, 2013). It requires linkages among the three pillars of sustainability i.e., economic, environmental, and social. Sustainable mobility thus aims at providing a cost-effective means of transportation to people without putting strain on the country's resources, promoting mobility practices that do not endanger the lives of people, animals, or any other species, and a safer and healthier mobility way that is accessible to all for a better and improved quality of life (Rodrigue, 2020). In this respect, Banister (2008) emphasized the need to reduce car use through the promotion of walking, cycling, and public transportation. Similarly, Hamidi & Zhao (2020) argued for improving the quality and accessibility of the public transport system coupled with cycling-related perceptions, attitudes and skills for substituting car use and shaping individuals' sustainable travel behaviour. The introduction of electric vehicles also allows consumers to adopt a cleaner and sustainable mobility behaviour by reducing their reliance on fossil fuels and combating climate change (Jansson et al., 2017; Sang & Bekhet, 2015). The negative impact of private mobility on society and the environment can also be reduced by encouraging more people to carpool. Carpooling could play an important role in the transition to a more sustainable way of living (Bachmann et al., 2018; Baptista et al., 2014). Adoption of SMB offers an extensive advantage to commuters which are crucial to the well-being of people as well as the planet. From reducing the levels of energy-consumption, pollution and greenhouse gas emissions to solving the problems of traffic congestion, road accidents, public health, and accessibility, it is often regarded as vital for an improved and sustained life (Rodrigue, 2020; Tight et al., 2011).

The role of private mobility behaviour in driving economic, social and environmental impacts has been long recognized. Around 72% of global GHG emissions are a result of private individual consumption (Hertwich & Peters, 2009; UNEP, 2020), which is difficult to control solely through regulatory policy measures (Hori et al., 2013). Individual consumption decisions incorporate and respond to a variety of psychological, contextual and demographic factors, motivations and preferences, which challenges understanding of their consumption behaviour (Olsson et al., 2019; Spangenberg & Lorek, 2002; UNEP, 2005).

2.2 Model of study and hypothesis development

One of the most promising and widely used cognitive models is the Theory of Planned Behaviour (TPB) developed by Ajzen (1985), which incorporates attitude towards behaviour, subjective norms (SN) and perceived behavioural control (PBC) to predict behavioural intention (BI) of people to perform a given behaviour. The theory further establishes a direct link between BI and behaviour, and PBC and behaviour. Various scholars have tested TPB in different areas of sustainable behaviour, including mobility (Bachmann et al., 2018; Bamberg & Schmidt, 2003; Chen & Chao, 2011; Lane & Potter, 2007), food (Ajzen, 2015;

Vermeir & Verbeke, 2008), housing (Liao et al., 2020; Xu et al., 2017) and other areas (Armitage & Conner, 2001; Chekima et al., 2016; Kaiser & Gutscher, 2003; Wang et al., 2014) of sustainable behaviour. Despite the widespread usage of TPB, the model is criticized for ignoring many other psychological and contextual factors significant in determining the behaviour of people (Peattie, 2010; Steg & Vlek, 2009; Zhou et al., 2013). At the same time, the model itself welcomes the inclusion of additional factors if found to have an impact on the given behaviour (Ajzen, 1991; Alam et al., 2020). In this direction, Heath & Gifford (2002) incorporated factors such as personal norms, environmental values, and perceived responsibility for and awareness of the problems into the original TPB to study public transportation use by university students. It was concluded that the travel behaviour was well predicted by the original TPB, and the addition of all included factors significantly improved the prediction of the study. Similarly, Bachmann et al. (2018) identified that adding personal norms as a direct predictor of carpooling intention to the framework of the TPB enhanced the explained variance in carpooling intention from 68.1 percent to 81.1 percent among carpooling passengers and from 69.5 percent to 84 percent among carpooling drivers. Sang & Bekhet (2015) also found performance attributes, financial benefits, environmental concerns, demographics, infrastructure readiness and government interventions as the key predictors for electric vehicle usage intention. Thus, the extended TPB has gained popularity and acceptability in sustainability studies (Alam et al., 2020; Kritikou et al., 2021; Paul et al., 2016; Santos et al., 2021; Xu et al., 2017; Yadav & Pathak, 2016). To better understand the sustainable mobility behaviour of consumers, it is important to investigate all the external and internal factors influencing the behaviour (Sang & Bekhet, 2015). Based on this premise, the present study has incorporated four additional variables namely, "environmental knowledge", "government actions", "personal norms" and "product attributes" as the direct predictor of behavioural intention for SMB.

2.2.1 Attitude

According to the TPB, a person's attitude has a significant positive influence on his behavioural intention, which in turn affects his actual behaviour. Attitude refers to people's perception of the environment and society and belief that their behaviour will not have significant negative consequences (Ajzen, 1985). A meta-analysis carried out by Lanzini & Khan (2017) identified attitude as a significant predictor of intentions to choose an eco-friendly travel alternative. Similarly, to examine the factors shaping an individual's sustainable travel behaviour, Hamidi & Zhao (2020) found a significant effect of attitude in choosing a sustainable mode choice such as cycling over personal car use. Paul et al., (2016) established that attitude is the strongest predictor of intention to purchase green products. Therefore, we propose the following hypothesis:

H1: "Attitude towards sustainable mobility positively influences the behavioural intention of consumers for sustainable mobility behaviour."

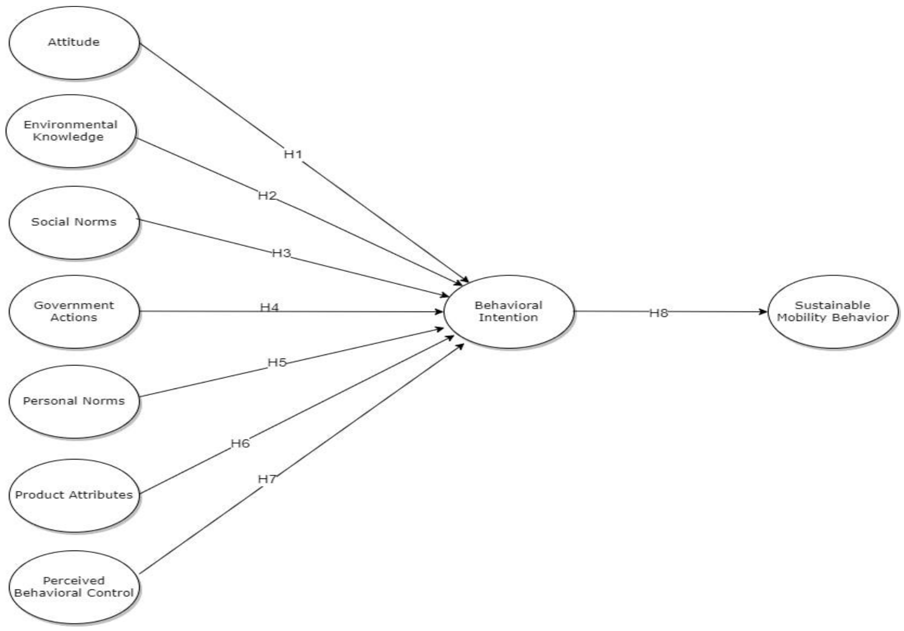

Figure 1. Outlines the conceptual model and the hypothesized relationship, discussed in detail below.

2.2.2 Environmental Knowledge (EK)

In addition to the antecedents of BI as discussed in the "TPB", the literature highlights a number of factors that can significantly affect one's behaviour. EK, which refers to an individual's knowledge of surrounding environmental and social issues and the possible course of action to deal with them, facilitates their decision-making process in a more logical way (Kumar et al., 2017). Zsoka et al., (2012) found EK to be central in shaping the attitude towards sustainable consumption behaviour among school and university students. Similarly, Kanchanapibul et al., (2014) concluded that young generation consumers with more knowledge about green issues had a stronger intention to buy green products. Maniatis (2016) believed the presence of EK to have a significant positive impact on the consumer's intention to buy sustainable products and that lack of such knowledge often acts as a barrier and prevents consumers to translate their concerns into actual sustainable consumption behaviour (Haron et al., 2005; Lane & Potter, 2007; Tanner & Kast, 2003; Vermeir & Verbeke, 2006). To understand consumers' intention toward green product purchase in India, Yadav & Pathak (2016) found a significant influence of EK on consumers' intention and reported an improvement in the explanatory power of the TPB model with the addition of EK. Available literature thus highlights increased use of EK as one of the significant variables affecting BI for SCB of consumers (Biswas & Roy, 2015; Gatersleben et al., 2002; Hines et al., 1987; Kritikou et al., 2021; Young et al., 2010). Hence, we propose the hypothesis:

H2: "Environment knowledge positively influences the behavioural intention of consumers for sustainable mobility behaviour."

2.2.3 Social Norms (SN)

The TPB defined social norms as the "perceived social pressure to perform or not perform the behaviour" (Ajzen, 1985, 1991). This takes into account the influence of families, relatives, neighbours, co-workers and other reference groups in the decision-making process (Joshi & Rahman, 2015, 2017). It is believed that individuals with strong social or external pressure are more likely to follow group behaviour and can be easily motivated toward performing sustainable behaviour (Kumar et al., 2017; Yadav & Pathak, 2016). Following this, Jansson et al., (2017) concluded that electric vehicle adopters in Sweden exhibited strong levels of social motivation. Similarly, Sang & Bekhet (2015) affirmed a statistically significant positive relationship between social influences and electric vehicle usage intentions among Malaysian consumers. Exploring sustainable mobility behaviour, Donald et al., (2014) revealed that social beliefs have a strong impact on the commuter's intention to use a sustainable travel mode. Similarly, a vast number of studies have observed a positive relationship between SN and the BI of consumers for SCB (Alam et al., 2020; Figueroa-Garcia et al., 2018; Xu et al., 2017). Therefore, we propose the following hypothesis:

H3: "Social Norms positively influence the behavioural intention of consumers for sustainable mobility behaviour."

2.2.4 Government Actions (GA)

This refers to an appropriate form of government that ensures the dissemination of adequate information to consumers, development of necessary infrastructure and facilities, policy measures and other socio-political and legal regulations aiming at influencing the consumption behaviour of consumers more sustainably (Haron et al., 2005; Jackson, 2005). The available literature has highlighted a significant role of economic instruments, pricing policies, rewards and government subsidies in encouraging consumer's pro-environmental behaviour (Hori, 2012; Lorek, 2014; Steg, 2009; Stern, 2000). Government plays a formative role in building infrastructure, availability of sustainable alternatives, and awareness and promotional campaigns that influence the BI of consumers to adopt SCB (Biswas & Roy, 2015; Hori, 2012; Lorek, 2014; Peattie, 2010; Spangenberg & Lorek, 2002; Steg, 2009; Stern, 2000). Chen & Chai (2010) found a significant role for government in preserving the environment and influencing consumers' attitudes towards green products. Similarly, Sang & Bekhet (2015) believed that there exists a significant positive relationship between government interventions and the usage intentions for electric vehicles among Malaysians. Banister (2008) argued that GA in the form of parking controls and road pricing can help in reducing car use and urban traffic. Also, reallocating space to public transport will encourage its wide use, thereby achieving a sustainable mobility system. Lorek and Spangenberg (2014) emphasized strong governmental leadership and the importance of economic and regulatory instruments in enabling SCB among people. Lack of government measures has been reported as one of the factors responsible for the current unsustainable consumption behaviour of people (Jain & Kaur, 2004). Thus, the present study seeks to explore the role of GA in promoting SMB and propose the hypothesis:

H4: "Government Actions positively influence the behavioural intention of consumers for sustainable mobility behaviour."

2.2.5 Personal Norms (PN)

Personal Norms have been defined as "self-expectations that are based on internalized values" (Schwartz, 1977). It reflects an individuals' obligation and responsibility to carry out a particular behaviour (Stern et al., 1999). Thogersen (2006) believes that PN guides human behaviour through the conception of right and wrong behaviour. It helps to develop an individual's sense of moral responsibility and values towards others (Bai & Bai 2020). A large pool of studies concerning pro-social and pro-environmental behaviour have found a significant influence of PN on an individual's BI for SCB (Chan et al., 2012; Chen & Chai, 2010; Gleim et al., 2013; Joshi & Rahman, 2015; Schwartz, 1977; Wang et al., 2014; Young et al., 2010). Jansson et al., (2018) found electronic vehicle adopters exhibited high levels of personal norms which are more effective in explaining the behaviour as compared to external social norms, due to their lesser level of internalization. Harland et al. (1999) found that PN had an independent contribution to the explanation of BI and its inclusion increased the explanatory power of the TPB model by 10%. Bachmann et al., (2018) also added PN as a direct predictor of carpooling intention to the TPB and found that the intentions of passengers to carpool increased from 68.1 percent to 81.1 percent and from 69.5 percent to 84 percent among carpooling drivers. Recently, Santos et al., (2021) extended the TPB to measure the impact of PN on the purchase intention of organic food in sustainable packaging among Portuguese and found a significant contribution of PN in explaining the intentions towards behaviour. Thus, the available literature underlines the importance of internal values in explaining BI for SCB especially using TPB (Bamberg & Schmidt, 2003). In the light of this, we propose the following hypothesis:

H5: "Personal Norms positively influence the behavioural intention of consumers for sustainable mobility behaviour."

2.2.6 Product Attributes (PA)

This refers to the presence of certain desirable features and the absence of some traits which influence the consumer's purchase and consumption decisions. Product quality in terms of safety, durability, credibility and health benefits is an essential attribute influencing consumers' intention to buy sustainable goods and strongly affects their engagement in pro-environmental and pro-social behaviour (Ahmad & Juhdi, 2008; Joshi & Rahman, 2015; Steg & Vlek, 2009). The presence of clear and user-friendly eco-labels and certifications on the product helps in informing consumers about the sustainable characteristics of the product and often builds their trust which results in more sustainable purchases (Kaufmann, 2012; Liu et al., 2012; Young et al., 2010). Furthermore, ease of using products is an essential criterion that increases their usability by the consumers (Xie et al., 2022). PA are often discussed as contextual factors affecting individual consumption behaviour in several studies (Kaufmann, 2012; Lorek, 2014; Olander & Thogersen, 1995; Peattie, 2010; Steg & Vlek, 2009; Vermeir & Verbeke, 2006; Wang, 2014) and also included as a significant independent factor in Stern's (2000) Attitude-behaviour-context model. The available literature highlights the presence of such factors such as user-friendly, quality products with clear and informative labelling that fuels consumer's choice and facilitates their demand and consumption of sustainable goods (Alam, 2020; Jain & Kaur, 2004; Joshi & Rahman, 2015; Moser, 2015; Ritter, 2015; Tanner & Kast, 2003). Chen & Chao (2011) found perceived ease of use and perceived usefulness crucial in determining the switching intentions of private vehicle users towards the public transport system. Similarly, Sang & Bekhet (2015) concluded that performance attributes of vehicles such as comfort, and ease of driving act as a key predictor of usage intentions of Malaysian consumers for the adoption of an electric vehicle. Similarly, Biswas & Roy (2015) observed PA as the primary driver of consumer choice behaviour in the consumption of sustainable goods. Maniatis (2016) also found that sustainable product quality and labelling are very effective in increasing sales and are essential for making sustainable consumption decisions. Therefore, the following hypothesis is proposed:

H6: "Product Attributes positively influence the behavioural intention of consumers for sustainable mobility behaviour."

2.2.7 Perceived behavioural control (PBC)

This refers to one's perception of the inner self-efficacy and ease or difficulty in performing a behaviour (Ajzen, 2002; Zhou et al., 2013). Individuals with a strong belief that adopting SMB will help in reducing their burden on the environment and society are more likely to perform various sustainable actions (Straughan & Roberts, 1999). Donald et al., (2014) identified PBC to be one of the strongest predictors of intentions to use public transport. Similarly, Paul et al. (2016) emphasized that PBC is the leading predictor of the intention to consume green products. In a meta-analysis of determinants of travel mode choice, Lanzini & Khan (2017) found PBC to be one of the main predictors of BI to choose a sustainable alternative.

However, the direct impact of PBC on behaviour has not been fully established (Armitage & Conner, 2001; Bamberg & Schmidt, 2003; Gleim et al., 2013; Joshi & Rahman, 2015; Kaiser & Gutscher, 2003) and is also not considered in current work. Therefore, the following hypothesis is framed:

H7: "Perceived behavioural control positively influences the behavioural intention of consumers for sustainable mobility behaviour."

2.2.8 Behavioural Intention (BI)

The available literature has discussed a large number of psychological and contextual factors influencing the BI of consumers for SCB. Thus, BI, which refers to "an individual's readiness to execute a given behaviour", plays a mediating role between these factors and the actual behaviour and is often discussed as the immediate antecedent of the behaviour in the TPB (Ajzen, 1985, 1991; Bamberg & Moser, 2007). Studies based on TPB have found a significant positive relationship between consumers' green purchase intention and their green purchase behaviour (Jaiswal & Singh, 2017; Kumar et al., 2017). Wang et al., (2014) found BI plays the most dominant role in explaining the SCB of rural residents in China. Xu et al., (2017) have found waste separation intentions of households positively influence their waste separation behaviour. Intentions do have a significant positive impact on consumers' choice to purchase energy-saving appliances (Liao et al., 2019). Similarly, Donald et al. (2014) concluded that the use of public transport and personal car by commuters was greatly influenced by their intentions to use them. In a meta-analysis on psychological and behavioural determinants of travel mode choice, Lanzini & Khan (2017) established that intentions play a key role in the determination of travel mode choice. Therefore, the following hypothesis is developed:

H8: "The behavioural intention of the consumers positively influences their sustainable mobility behaviour."

3. Methodology

3.1 Research Instrument

Data for the study was collected using a questionnaire, designed referring to the existing literature with necessary modifications (Table 2). The study uses eight constructs: "attitude" containing 4 items, "environmental knowledge" having 5 items, "social norms" and "personal norms" and "product attributes" with 3 items each, "perceived behavioural control" with 6 items, "government actions" with 4 items and "behavioural intention" using 9 items. The responses for each statement in the constructs were recorded using a seven-point Likert scale validated in earlier studies of a similar domain where (1) represents "strongly disagree" and (7) represents "strongly agree". The actual mobility behaviour of consumers was measured using 4 statements and the responses were recorded again on a seven-point Likert scale where (1) represents 'Never' and (7) represents 'Every time'.

3.2 Sampling and data collection

To gather the responses from a large audience in a cost-effective and time-saving manner, an online survey method was adopted using a structured questionnaire.

The questionnaire was mailed to consumers, above 18 years of age, educated and residing in Delhi, a large metropolis and the capital of India, representative of the entire nation. Data were collected between April and June 2022 using the judgmental sampling technique. Out of the 510 received responses, 440 were found to be usable, meeting the criteria of applying SEM (Hair et al., 2014). Initially, a pilot study was conducted with thirty-six experts to test the drafted questionnaire and a total of six items were deleted on account of duplicate statements and difficult to be understood by the respondents.

Socio-demographic characteristics of the respondents revealed that both males and females participated almost equally in numbers. Out of the 440 respondents, the majority of them (n=294) belong to the young (18-34) age group. 45% (n=198) of the total respondents have graduate degrees, 40% (n=178) are post-graduates and n=8 with a doctorate. Most of the respondents belong to the area of management (n=172) and engineering (n=102), followed by commerce (n=88), science and law. Around 40% of the total respondents (n=178) are working with the corporate sector whereas (n=74) are associated with their own business, (n=74) are homemakers while (n=52) are students and (n=40) are teachers. A large number of respondents i.e., 82% (n=364) live in their family bungalow or flat followed by a shared apartment and rented house. 44% (n=194) of the respondents have a monthly family income of more than Rs 2 lakh while others have lesser family income. Single and married respondents are approximately equal in numbers.

3.3 Data analysis

The study used SPSS and AMOS, version 22 software to analyse the conceptual framework. A two-stage structural equation modelling (SEM) was applied to test the hypothesis of the study (Anderson and Gerbing, 1988). To begin with, a confirmatory factor analysis (CFA) was carried out to assess the reliability and validity of the measurement model and then the complete model fit, and hypothesized relationships were estimated with the help of standardized regression coefficients (β) and p-values.

4. Results

4.1 Sustainable mobility behaviour: Descriptive analysis

The study measured the SMB of respondents using four statements (Table 1) on a seven-point frequency scale. The mean score of SMB was found to range from 3.73 to 4.06, which shows the present mobility behaviour of households is not very sustainable. The study found not much variation in different mobility behaviour items. It was found that the respondents do not prefer to pool or share their private vehicle or car with others while going to their destination (SMB 3, mean score= 3.69). The frequency of using public transport by the respondents to travel to their workplace or desired destination is also low (SMB 2, mean score= 3.73). While buying a new vehicle, the respondents do not consider much the environmental friendliness of the fuel type (SMB1, mean score= 3.88). However, the respondents consider a little more walking to their nearby destination or even use a bicycle (SMB 4, means score= 4.06). The standard deviation of the responses indicates the variation in the responses. The Skewness and kurtosis of the responses are found to be less than one, indicating that the distribution of the responses is normal. Since the value of Cronbach alpha is 0.803, the mobility scale represented is quite reliable.

Consumption behaviour: Mobility	Mean (SD)	Skewness	Kurtosis	Cronbach Alpha
SMB 1. I consider buying a vehicle which uses clean fuel (such as CNG, electric or hybrid).	3.88 (1.723)	.217	-.962	.803
SMB 2. I use public transport for going to place of work/college.	3.73 (1.726)	.208	-.867	
SMB 3. I pool or share car /private vehicle.	3.69 (1.440)	.391	-.469	
SMB 4. I prefer to walk or use cycle to go nearby.	4.06 (1.738)	.031	-.951	

Table 1: Descriptive analysis: Sustainable mobility behaviour. Note: Construct items source- Donald et al., 2014; Heath & Gifford, 2002; Potoglou & Kanaroglou, 2007

4.2 Measurement Model: Reliability and validity of the constructs

The CFA method has been applied to test the construct validity and reliability of the measurement scale used to measure the different factors affecting the BI of consumers for SMB. Initially, an assessment of model fitness was made using the following indicators: $\chi 2$ (chi-square), $\chi 2/df$ (chi-square to the degree of freedom ratio), GFI (goodness-of-fit index), AGFI (Adjusted goodness-of-fit index), CFI (comparative fit index), TLI (Tucker–Lewis index), and RMSEA (root mean square error of approximation). In the present study, CFA results depict

CMIN/df estimate to be 2.060, which lies in the required range (value to be between 2 and 5), the GFI and AGFI are found to be 0.859 and 0.835 (these should be greater than 0.8). The CFI, TLI and NFI are found to be 0.952, 0.947 and 0.911 (the required value for each should be more than 0.9). Further, the RMSEA is found to be 0.049 (the required value should be less than 0.08). Hence, all indices are more than in line with the recommended criteria and the model is found to be a good fit (Bagozzi & Yi, 1988).

Next, the construct validity comprising convergent as well as discriminant validity was examined through construct loadings, composite reliability (CR), average variance extracted (AVE), and comparing the AVE of each construct with its maximum shared variance (MSV) using Fornell Larcker criteria. It was found that all constructs in the measurement model have CR above the acceptable value of 0.70, which reveals the model has good reliability. The higher construct loadings (more than the acceptable value of 0.50) signify that the item adequately represents the construct. Results achieved of the factor loadings are shown in Table 2 ranging from 0.71 to 0.91. This indicates that observed items are adequate and correspond to their constructs. Thus, the construct's convergent validity can be confirmed. To assess discriminant validity, the MSV of constructs were compared with their AVE estimates and it is expected that MSV should be less than its AVE estimate. Since the results found MSV to be less than the AVE of the respective constructs, this shows that discriminant validity of constructs has been achieved (Hair et al., 2010).

Constructs	**Source**	**Items**	**Factor loading**	**CR**	**AVE**	**MSV**	**Cronbach Alpha**
Attitude	Joshi & Rahman, 2017; Paul et al., 2016	AT1: It is important to me that my consumption behaviour does not endanger the lives and survival of humans, animals and other species.	0.9	0.927	0.762	0.487	0.924
		AT2: I believe the consumption of sustainable goods will help me in improving my health.	0.804				
		AT3: I believe the consumption of sustainable goods will help in reducing the problems of resource shortage and environmental degradation.	0.87				
		AT4: I am positive about consuming sustainable goods.	0.914				

Environmental Knowledge	Maniatis, 2016; Wang et al., 2014	EK1: Consumption of sustainable products promotes the environment, health and well-being of society.	0.876	0.911	0.671	0.503	0.91
		EK2: Use of too many petroleum products is harmful to the health of people.	0.864				
		EK3: Labelling, trademarks and certifications provide adequate information about sustainable goods.	0.78				
		EK4: Having not received an environmental education, I am not able to understand the benefits of using sustainable goods.	0.763				
		EK5: There is a lack of information and communication about sustainable products in our country.	0.808				
Social Norms	Biswas & Roy, 2014; Jansson et al., 2017	SN1: When choosing a product or service, other people's opinions are important to me.	0.815	0.889	0.728	0.423	0.887
		SN2: Purchase of sustainable products/environment-friendly cars will help me gain respect in society.	0.881				
		SN3: Purchase of sustainable products/environment-friendly cars will make a positive impression on peer groups/neighbours and family.	0.862				
Government Actions	Chen & Chai, 2010; Figueroa-Garcia et al., 2018	GA1: In my city, the government does enough to motivate more sustainable behaviour through subsidies, awareness programs, etc.	0.82	0.926	0.757	0.46	0.925
		GA2: People will not adapt to sustainable practices unless they are penalised under government laws through fines etc.	0.886				
		GA3: If there is a government subsidy, I am willing to purchase sustainable/environment-friendly products such as solar panels, electric cars, etc.	0.86				
		GA4: I can change my consumption to more sustainable products due to government rules and regulations (such as pollution	0.911				

		checks of vehicles, waste segregation, etc.)					
Personal Norms	Prakash & Pathak, 2017; Jansson et al., 2017	PN1: I consider the "well-being of others" while making a purchase decision.	0.916	0.93	0.815	0.438	0.929
		PN2: I feel morally obliged to decrease the negative impact of my consumption/car driving.	0.883				
		PN3: I feel bad to see humans are damaging the environment and society.	0.909				
Product Attributes	Chen & Chao, 2011; Maniatis, 2016; Ritter et al., 2015	PA1. Sustainable products have better quality standards.	0.886	0.904	0.759	0.507	0.904
		PA2. Sustainable products are user-friendly.	0.941				
		PA3. I often doubt the genuineness of labelling on eco-labelled products. (R)	0.779				
Perceived Behavioural Control	Paul et al., 2016; Wang et al., 2014	PBC1: I can protect the environment and help society by buying sustainable products.	0.798	0.932	0.696	0.497	0.932
		PBC2: An individual can have a positive impact on the environment and society by using resources judiciously.	0.798				
		PBC3: I don't have sufficient resources, time and opportunities to buy sustainable products. (R)	0.86				
		PBC4: There are few sustainable product brands available in the market, so it is difficult to choose them as an alternative. (R)	0.831				
		PBC5: Most of the sustainable products I want to purchase are too expensive. (R)	0.842				
		PBC6: My city lacks infrastructure for garbage disposal, public transportation system, etc. (R)	0.874				
Behavioural Intention	Jaiswal & Singh, 2018; Wang et al. 2014	BI1: I will recommend sustainable products to my family/friends or peer groups. family acquiantances family/ friends or peer groups.	0.762	0.915	0.545	0.507	0.914
		BI2: I am willing to spend more money to buy sustainable products.	0.658				
		BI3: I would like to stop buying products from companies that	0.711				

		pollute the environment even though it might be inconvenient.					
		BI4: I would like to participate in community-based programs such as environmental education campaigns etc.	0.747				
		BI5: I would buy sustainable products when they are easily acquirable in proximity.	0.761				
		BI6: If my neighbours or families prefer purchasing sustainable products, I will also want to purchase the same.	0.707				
		BI7: When I have to choose between two similar products, I choose the one that is less harmful to the environment and society.	0.782				
		BI8: I would be willing to buy products from companies that are supporting a social cause (such as any NGO).	0.714				
		BI9: I do not care about environmental or social issues while making a purchase. (R)	0.79				

Table 2: Reliability and Validity Analysis

The results of the Fornell Larcker criteria are reported in Table 3. The table shows that the square root of the AVE of different factors influencing BI for SMB was found to be more than the correlation among the constructs, thereby ensuring the presence of discriminant validity in the measurement scale.

4.3 Analysis of Structural Model and Hypothesis Testing

The structural model is developed indicating the impact of different factors on SMB among consumers. The factors supposed to influence SMB are “Attitude”, “Environmental Knowledge”, “Social Norms”, “Government Actions”, “Personal Norms”, “Product Attributes”, “Perceived Behavioural Control” and “Behavioural Intention”. These factors are measured using "selected statements" built into the questionnaire. All the factors are hypothetical to be "reflective" and "zero-order" in nature. First-order SEM analysis is used to examine the hypotheses outlined above.

	Product Attributes	Attitude	Environmental Knowledge	Social Norms	Government Actions	Personal Norms	Perceived Behavioural Control	Behavioural Intention
Product Attributes	**0.871**							
Attitude	0.553	**0.873**						
Environmental Knowledge	0.561	0.615	**0.819**					
Social Norms	0.392	0.377	0.438	**0.853**				
Government Actions	0.451	0.583	0.55	0.65	**0.87**			
Personal Norms	0.485	0.529	0.504	0.546	0.615	**0.903**		
Perceived Behavioural Control	0.581	0.513	0.541	0.439	0.588	0.522	**0.834**	
Behavioural Intention	0.712	0.698	0.709	0.564	0.678	0.662	0.705	**0.738**

Table 3. Correlation among constructs. Note: The diagonal bold values represent square root of the average variance extracted for each construct and the rest of the values are the squared correlation between constructs.

4.3.1 Statistical fitness of the structural model

Table 4 describes the result of SEM carried out for extended TPB. It shows the estimated value of all indicators and the values required. The results show an adequate fit to the data (CMIN/df = 1.911, GFI=0.855, AGFI =0.834, CFI=0.951, TLI= 0.947, NFI=0.903 and RMSEA= 0.046). Hence, the structural model used for the hypothesis testing using SEM analysis is statistically fit (Bagozzi & Yi, 1988).

Statistical Fitness Index	**CMIN/df**	**GFI**	**AGFI**	**CFI**	**TLI**	**NFI**	**RMSEA**
Estimated value of the index	1.911	0.855	0.834	0.951	0.947	0.903	0.046
Required value of the index#	Less than 3	Greater than 0.8	Greater than 0.8	Greater than 0.9	Greater than 0.9	Greater than 0.8	Less than 0.08

Table 4. Model fit indices. Note: N=440, # source: Bagozzi & Yi, 1988

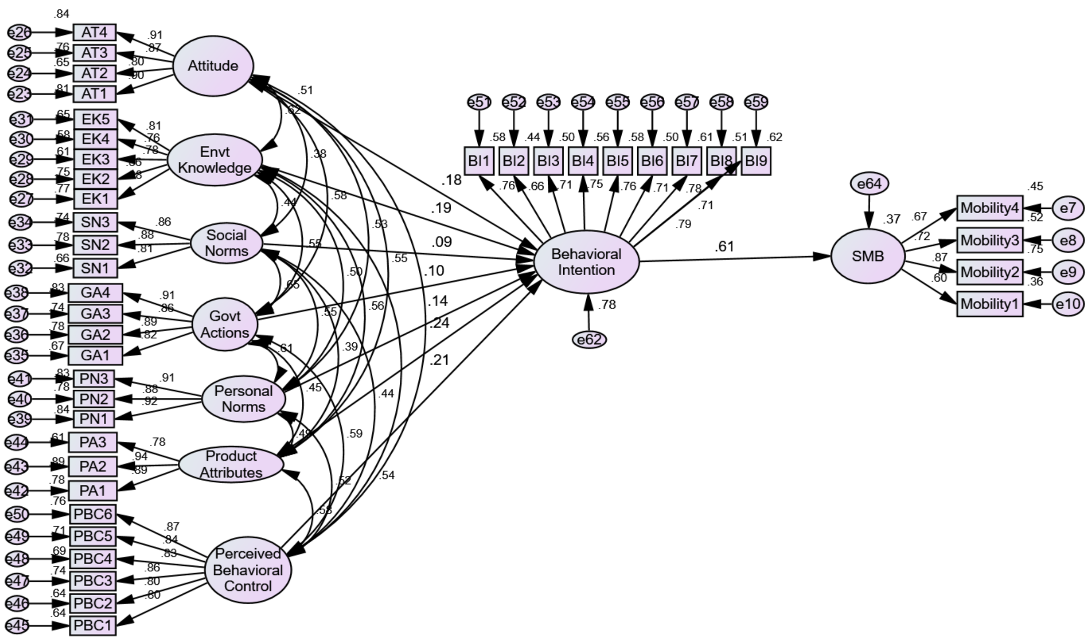

Figure 2. Causal relationship among factors affecting sustainable mobility behaviour using structural equation modelling.

Dependent Variable	Independent Variable	Estimate	S.E.	C.R.	P	Results	R Square
Behavioural Intention	Attitude	.179	.036	4.146	***	Accepted	
Behavioural Intention	Environmental Knowledge	.188	.036	4.392	***	Accepted	
Behavioural Intention	Social Norms	.091	.042	2.157	.031	Rejected	
Behavioural Intention	Government Actions	.096	.048	1.932	.053	Rejected	37 %
Behavioural Intention	Personal Norms	.140	.030	3.391	***	Accepted	
Behavioural Intention	Product Attributes	.237	.036	5.691	***	Accepted	
Behavioural Intention	Perceived Behavioural Control	.208	.043	4.890	***	Accepted	
SMB	Behavioural Intention	.606	.056	9.846	***	Accepted	

Table 5: Regression Weights. Note: *** significant at 0.001 levels

5. Discussion

The objective of identifying the determinants of SMB of consumers was achieved by incorporating the variables "environmental knowledge", "government actions", "personal norms" and "product attributes" into the well-established TPB model. The responses collected from 440 respondents were analysed using SEM and the results are shown in Table 5. These results reveal that except for SN and GA, all other factors have a significant positive impact on the behavioural intentions of the consumers for adopting sustainable mobility behaviour.

Product attributes emerge as the strongest predictor of BI for SMB of consumers in India, which shows the primacy of product characteristics while making a mobility decision. The outcome is in line with the existing literature which indicates that consumers give due consideration to the quality, labelling and ease of use of the proposed mode of transport (Hamidi & Zhao, 2020; Maniatis, 2016; Moons, 2015; Sang & Bekhet, 2015).

The second most important determinant that emerges is the PBC. Consistent with the findings of the available literature (Donald et al., 2014; Lanzini & Khan, 2017; Sulikova & Brand, 2021), the study confirms that consumers' belief about the effectiveness of their efforts and probable ease or difficulty in obtaining sustainable products strongly influences their intention to engage in SMB. The limited availability of sustainable products in the market makes it difficult for them to translate their sustainable motivation into actual consumption behaviour (Wang et al., 2014). Respondents also affirmed that in most cases sustainable products are expensive as compared to other available substitutes, which negatively influences their BI to engage in SMB (Gleim et al., 2013; Joshi & Rahman, 2015). This contradicts the findings of Prakash & Pathak (2017) who argued that Indian consumers are no longer price-sensitive to buying sustainable products. The low level of available infrastructure is also a great challenge before them.

EK has also turned out to be an important factor positively impacting intentions for SMB. This result confirms the findings of the existing literature (Dangi et al., 2020; Figueroa-Garcia et al., 2018; Yadav & Pathak, 2016), stating that consumers have adequate and relevant information and knowledge about various environmental and social issues and the impact of their consumption on environment and society plays an important role in promoting their intentions towards SMB.

The next factor that emerges is the attitude of consumers toward sustainable consumption. Consumers having a positive attitude, care and concern towards the environment and society are more willing to adopt SMB. This finding is in line with previous studies (Bachmann et al., 2018; Hamidi & Zhao, 2020; Sulikova & Brand, 2021), which concluded that an individual's attitude is one of the most consistent and significant predictors for explaining their BI for SMB.

The study shows that an individuals' value systems, ethics, moral obligations and personal responsibilities are essential in influencing their BI for SMB. This complies with the work of various scholars (Bachman et al., 2018; Bai & Bai, 2020; Jansson et al., 2017) who found a strong effect of PN in fostering environment and socially responsible behaviour.

The results show that SN do not exert any influence on the BI of consumers for SMB, which contradicts the findings of (Chen & Chao, 2011; Donald et al., 2014; Sang & Bekhet, 2015; Sulikova & Brand, 2021) that SN are one of the important determinants of commuters' mobility decisions. However, studies examining sustainable food behaviour (Chekima et al., 2019; Kritikou et al., 2021) support the findings of the current work stating that most individuals do not feel much external pressure to engage in sustainable behaviour.

The results also reveal that GA do not influence the BI of consumers to adopt SMB. This finding complies with the work of various scholars (Gracia et al., 2018; Wang et al., 2014) who argued that government policies lack the sensitivity, appeal and proper enforcement needed to address the everyday mobility issues of the commuters.

Finally, the outcome of the study is in line with the existing literature (Chen & Chao, 2011; Heath & Gifford, 2002; Lanzini & Khan, 2017; Si et al., 2020) in stating that the intention to use sustainable mobility modes is the key predictor of actual sustainable mode choice. The positive intentions of the people towards the sustainable purchase and use of mobility styles positively influence their actual behaviour.

6. Conclusions

The current study extends previous research concerning SMB of consumers' by incorporating the variables "environmental knowledge", "government actions", "personal norms" and "product attributes" to the well-established "TPB model". The empirical analysis discloses that the respondents do not prefer to pool or share their private vehicles much and are also reluctant to use public transport for daily commuting to their workplace. Therefore, it is essential to recognize the key factors which can significantly influence the intentions of consumers towards SMB.

Consistent with the existing literature, the study establishes a significant positive impact of PA, PBC, EK, Attitude and PN on the intentions of consumers to adopt SMB while the influence of SN and GA are not found to affect them. The study also confirms the major role of BI in stimulating SMB. The result signifies that the inclusion of additional factors to the "TPB model" enhanced the understanding of the current mobility behaviour of consumers and their BI for SMB. This emphasizes the need to extend the current "TPB model" which can be applied to study other environmentally relevant clusters such as food, housing and clothing (Alam et al., 2020; Bachmann et al., 2018; Santos et al., 2021; Si et al., 2020). As time has progressed, there have been shifts in the needs, preferences, and environment of individuals, making it imperative to more fully investigate the significant factors that influence behaviour.

The results also suggest that consumers pay greater importance to quality, trust and user-friendliness of products. Therefore, producers and marketers should focus on the "product attributes" while formulating the 4Ps of marketing. It is also important to trigger the self-worth of people and reduce impeding factors, thereby paving the way for the successful adoption of SMB. Manufacturers and government agencies should use the information available and education-based interventions to make commuters aware of the available sustainable products and the urgent issues threatening life on the planet. Understanding consumers' attitudes towards SMB would assist producers in forecasting the demand for their products, and the government in formulating policies, rules and regulations for a better and sustainable mobility system.

The findings reveal that, despite a high level of education, awareness, concern and general attitude towards environmental and social issues, consumers have not made the same shifts in their SMB. Therefore, it is imperative that consumers share equal responsibilities with producers, marketers and government agencies with a committed adoption of SMB (Holden et al., 2020; Olson et al., 2021). The study thus contributes to promoting the SDG goal twelve of "Responsible Consumption and Production".

The results of the study have provided insights into the SMB of the consumers. However, it may not portray a fully accurate picture, as the respondents tend to overestimate their self-reported behaviour (Armitage and Conner, 2001). Future studies should employ additional methods such as interviews, case studies and group discussions.

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Original Paper

Bibliometric analysis of the transformation in air logistics operations in terms of digitalization and sustainability

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Abstract. *Digitalization and sustainability are essential in today's globalized business environment. Within the logistics sector, aviation plays a critical role in this dynamic environment by enabling rapid, safe transportation worldwide. While applying new approaches, air logistics processes should incorporate the technologies and applications enabled by digitalization, and* *consider environmental, social, and economic sustainability impacts. These can be mutually beneficial in that new digital technologies can reduce environmental impacts, make a social contribution, and increase economic gains. While there is rapidly expanding literature about integrating these concepts for various purposes in different sectors, applications in air logistics are particularly promising. Accordingly, this study contributes to digital and sustainable air logistics research by identifying current trends, revealing gaps in knowledge, and proposing future research directions. To do so, a literature review and a bibliometric analysis were conducted using VosViewer software. As a result, five potential research areas were proposed.*

1. Introduction

Two major trends shaping the current globalized business environment are digitalization and sustainability. With the Fourth Industrial Revolution, digitalization provides a significant competitive advantage for organizations. However, while focusing on economic gains, organizations also need to consider social and environmental issues. Therefore, sustainability and digitalization can be seen as two inseparable elements for organizations. As de Sousa Jabbour et al. (2018) put it, "these cannot individually be considered new industrial revolutions; through their overlap and synergy they may together comprise a distinct industrial wave that will change worldwide production systems forever" (p. 18).

The enormous changes introduced by digitalization and the search for sustainability affect supply chains at every stage. Being a core element, logistics operations need to meet the sustainability goals while staying up to date through digitalization. Within the current industrial revolution, logistics operations have evolved new characteristics, such as using big data analytics for route optimization, decreased storage requirements thanks to new techniques, optimized inventory control with autonomous robots, reduced bullwhip effects due to real-time information exchange, and minimal information disruption through smart items (Winkelhaus and Grosse, 2019).

With the increase in the level of digitalization in the logistics sector, the philosophy of doing business in warehouses is starting to change. With automated warehouses, new business models where heavy work is done by machines/robots and people exist in the system with the role of supervisor will provide more efficient operations for many users (Bolatan, 2021). Digitization in warehouses is a very effective element that comes to the forefront in the transformation of logistics processes with the key factors of "Improve Accuracy, Increase Transparency, Boost Efficiency, Reduce Costs, and Strengthen Customer Service" (Marak, 2021). On the other hand, in parallel with the transformation experienced in the technological domain throughout the world, there are also various transformations in the social and economic sphere. In this sense, the benefits of the sharing economy to many different sectors and businesses will provide important opportunities for logistics and therefore storage. Warehouses located in almost every region of the world sometimes serve below their capacity and infrastructure facilities at various levels remain idle. With the cooperation of digitalization and sharing economy, stakeholders will be able to gain significant advantages in terms of sustainability with the shared warehouse philosophy, with the advantages of low cost, short delivery time, and easy cheap storage by using a warehouse near the region they want to export to through a digital platform (StoringCargo, 2021). This will undoubtedly create an important advantage for the stakeholders in the air cargo supply chain processes. Since airports are one of the logistics platforms/hubs like other warehouses and terminals, they can become a center of attraction for both their own processes and intermodal processes (El Ouadi et al., 2021).

This study focuses specifically on air logistics, a field which has been significantly impacted by the digital transformation because connectivity, mobility, and personalized services are prioritized. Indeed, recent technological developments and innovations have resulted in immense changes (Büyüközkan et al., 2019). Furthermore, digitalized air logistics, also known as Aviation 4.0, makes use of cyber-physical systems that support human decision making or even autonomous task completion (Kahraman and Aydın, 2021).

On the other hand, a critical issue for air logistics is applying sustainability principles to minimize negative environmental and social impacts while maintaining profitability. The air logistics industry has generally started to place more importance on sustainability in recent years. Mészáros et al. (2020), for example, offer the following suggestions to all stakeholders to increase sustainability and environmental awareness:

- designing sustainable operations
- observing sustainability criteria in new aircraft orders

- applying technological and environmental solutions for aircraft fuel, energy, and power systems
- digitalizing the documents and equipment used in passenger and cargo operations, such as paper and packaging

Each of these areas involves considerable investment in research and development. For example, as regards technological and environmental solutions, the use of abundant fossil fuels for air transportation has a significant impact detrimental to the environment (Johnson et al., 2018) and. From this perspective, hydrogen powered air transportation can be seen as a strong alternative to fossil fuels, and thereby an important step for sustainable aviation (Yussaf et al., 2022). Proponents of this perspective believe that zero emissions could be achieved in air transportation and would be beneficial for especially environmental sustainability by hydrogen powered systems (Khandelwal et al., 2013).

The present study focuses on the integration of digitalization and sustainability practices in air logistics. Although digitalization has a great potential to support sustainable processes, there is a gap in air logistics regarding the integration of digitalization and sustainability.

Accordingly, our aim is to identify current trends and future research directions for sustainable air logistics in the digital era by conducting a bibliometric analysis. To do so, we first analyse recent studies under different classifications. Secondly, we use Vosviewer to conduct a co-occurrence analysis to investigate future research directions in more detail.

The main contribution of this study is that it identifies ways to integrate digitalization and sustainability practices in air logistics, thereby expanding both theoretical and practical knowledge. Furthermore, the revealed gap in knowledge can encourage future researchers to focus on this field. This area also offers promising practical applications for air logistics to use digital approaches not only for economic gains but also to reduce harmful environmental impacts and increase social wellbeing.

This paper is structured as follows. First, a literature review is presented. Then the research methodology is explained. The fourth section presents the findings regarding current trends and the bibliometric analysis. The fifth section future discusses possible research directions based on the findings while the final section suggests some conclusions.

2. Literature review

Various academic studies have investigated digitalization and sustainability, although only a few have focused on air logistics specifically, mostly regarding technology-based transformations and applications. More research is needed, especially given the ever-increasing impact of digitalization on the logistics industry. While operations currently rely mainly on human brain power, the system will become too difficult to manage in this way as transportation services become more complex and modular, and consumer needs more variable and demanding (Bavrin et al., 2021). At this point, digital tools will become essential.

The importance of integrating digitalization elements into supply chain processes, especially for transportation and distribution stages is increasingly recognized. In China, for example, during the Covid-19 pandemic, businesses used smart/digital logistics technology to conduct important operations by estimating the availability of medical supplies (Li, 2020). Based on this experience, Li (2020) recommended the complete digital integration of air logistics operations. As an essential branch of logistics, humanitarian logistics operations are particularly significant examples here as it is critical to consider all micro and macro factors to ensure sustainability. Given recent experience, in the event of any future pandemic or other disaster, integrated digital tools will contribute significantly to the sustainability of operations by creating value and building trust in the supply chain (Baffoe and Luo, 2021). Air logistics operations, whose importance and popularity have increased with the pandemic, stand out as an example of the sustainability-digitalization relationship.

According to the International Civil Aviation Organization (ICAO), the main sustainability areas to prioritize in air transport are technology development, operational processes, and energy use. The ICAO highlights the importance of stakeholders in technological investments and argues that this situation may be affected by the current damage caused by the Covid-19 pandemic (Bartle et al., 2021). On the other hand, while the sector's future will be based on passenger-oriented operations, businesses should not ignore the opportunity for digitalization investments in air logistics operations in the pause due to the pandemic.

Regarding the sustainability of aviation operations, several large projects have been implemented, such as SESAR[1] in Europe and NextGen[2] in the USA, while the development of new technologies, standards, and procedures by all stakeholders is also very important (Guimarans et al., 2019). Indeed, many elements

[1] https://www.sesarju.eu/ (14.01.2022)
[2] https://www.faa.gov/nextgen/ (14.01.2022)

need to be transformed using digitalization to ensure sustainability, from airline passenger transportation to logistics processes, and from aircraft technology to airport operations. For example, Choi et al. (2019) identified various risks in air logistics supply chain operations and highlighted the application of blockchain. Similarly, di Vaio et al. (2020) showed that blockchain technology increased sustainability in airport operations. In another study of airports, Kelemen et al. (2020) proposed training content for an information system to improve sustainable risk assessment.

Ordieres-Mere et al. 2020) examined how the digital transformation in the manufacturing and aviation sectors can promote sustainability, particularly through knowledge creation and new strategies. Portapas et al. (2021) focused on Vertical Take-off and Landing (VTOL) aircraft as a symbolic example of digitalization and technological sustainability in aviation. Despite their limited use due to high cost and lack of supply, VTOL aircraft offer economic advantages by saving time and money, flexible planning possibilities, and environmental sensitivity.

As in the air transport sector generally, sustainability in air logistics operations depends crucially on fuel consumption or transforming energy resources. Thus, matching the basic structure of aircraft and energy consumption with the concept of digital twins is one of the key strategies for sustainability (Portapas et al., 2021). This aircraft technology will enable the expansion of the "green logistics" approach, currently one of the prominent business models for sustainability in the logistics industry (Barykin et al., 2021). According to Wu and Yang (2021), the main success factors for environmental sustainability in air logistics are aircraft weight, energy conversation, and fuel efficiency. One of the key drivers of this transformation will be technology and digitalization, especially of aircraft and their components.

According to a 2021 report from the International Air Cargo Association (TIACA), trust, safety, and digitalization are important in sustainable air cargo while the industry's vision should commit to and develop lean and efficient business processes. According to the 2020 Air Cargo Sustainability survey, respondents are said to care more about digital transformation than before, and about 60% now have a digital transformation plan (TIACA, 2021).

Regarding the sector's regulatory authorities, given the likelihood of future emergencies like pandemics, both the United Nations Economic Commission for Europe (UNECE) and the International Civil Aviation Organization (ICAO) aim to facilitate contactless global air movements by preparing digital air cargo technical specifications for safer and sustainable supply chains (UNECE, 2022). For example, one of the air cargo industry's important actors, Lufthansa Cargo, considers digitalization and sustainability to be the key elements deciding its future. More specifically, using digitalization, a series of physical transformation tools, such as container tracking and management of customer/stakeholder relations, especially to reduce the time needed for document circulation, will enable innovation, efficiency, and sustainability (John and Ayaj, 2021). Polar Air Cargo, which has the vision of becoming the world's most sustainable cargo airline, also uses digital tools to achieve one its sustainability goals, namely its "paperless promise" (Polar Air Cargo, 2021). The digital air cargo reservation platform CargoAi has also developed an innovative digital tool. This helps users analyse the impact of their business's emissions by calculating and reporting the CO2 emissions of every shipment by each route and airline (Brett, 2021).

Paprocki (2021) highlights the importance of digital technologies and innovative solutions for the transportation sector in general, especially regarding climate policy. Chung et al. (2020) offer a radical proposal of using the sharing economy to provide added value through the optimum use of idle aircraft and aircraft loading areas while the integration of Internet of things (IoT) and blockchain applications can improve data security. A summary of the literature review is presented in Table 1.

Author(s), year	**Aim of study**	**Key concepts**
Baffoe and Luo, 2021	Sustainability of humanitarian logistics	Digital business ecosystem
Bartle et al., 2021	Sustainability of air freight/logistics	Sustainable development
Barykin et al., 2021	Integration of digital logistics and marketing approach	Digital platforms
Bavrin et al., 2021	Impact of digitalization on logistics	Digitalization and automated systems
Choi et al., 2019	Global supply chain risk with air logistics	Blockchain
Chung et al., 2020	Data science and analytics in aviation studies	Data science and advanced technologies
Di Vaio et al., 2020	Supply chain management for sustainable performance	Blockchain
Guimarans et al., 2019	Sustainability in aviation	Efficient management
Kelemen et al., 2020	Educational information model for sustainable air transport	Airports
Li, 2020	SWOT analysis of China's air cargo sector	e-commerce and digital logistics
Ordieres-Mere et al., 2020	Sustainability with integration of digital transformation	Digital transformation and Industry 4.0
Paprocki, 2021	Business model proposal to reduce the emission	Virtual airport and digital technologies
Portapas et al., 2021	Proposed system for flexible, environmentally friendly transport	e-VTOL and autonomous zero-emission vehicles
Wu and Yang, 2021	Drivers and strategies of sustainable aviation logistics	Data-driven analytics

Table 1. Summary of Literature Review

Although the number of studies investigating the link between sustainability and digitalization in air logistics is limited, the findings clearly indicate that the field has considerable potential. Thus, it is useful as a reference for future research to identify the common points in these studies. Accordingly, we conducted a bibliographic analysis. The following sections present the method and the findings.

3. Research methodology

In this study, we focused on academic research studies on the integration of sustainability and digitalization in air logistics operations to address the gap of knowledge in the field and propose future research directions. To do so, we followed the five-stage research methodology shown in Figure 1.

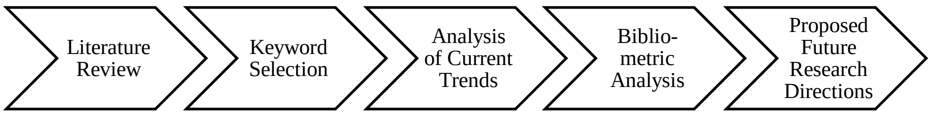

Figure 1. Research flow

The first stage involves conducting a literature review of studies of sustainable and digital air logistics. In this study, recent studies directly related to the selected field were reviewed to reveal any gaps in knowledge. The second stage involves selection of keywords to represents the area. In this study, the selected key words were "sustainable", "digital", "logistics, and "air OR aviation". The keyword search was conducted in the commonly used, multidisciplinary SCOPUS database. The third stage involves analysis of the search results to identify current research trends in terms of publication years, subject area, paper type, etc. and guide the future research. The fourth stage is bibliometric analysis, conducted in this study using the VOSViewer program. VOSViewer creates maps for visualizing and exploring network data. Although it is mainly designed for bibliometric network analysis, the software can be used for any type of network data (Eck and Waltman, 2013). The final stage involves identifying future research directions based on the results of the bibliometric analysis, in this case for sustainable and digitalized air logistics.

4. Findings

The findings are presented in two sections. The first part gives the results of the database search to show current research trends in the field while the second part, gives the bibliometric analysis results.

4.1 Current research trends

As mentioned in the previous section, current research trends were identified from a keyword search of the SCOPUS database. Studies were filtered using the following search string: ((TITLE-ABS-KEY (sustainable) AND TITLE-ABS-KEY (digital) AND TITLE-ABS-KEY (logistics))) AND (air OR aviation). To gain a deeper understanding, studies were not filtered by year of publication or research subject. The search identified 41 potential studies to use for identifying current research trends and for the bibliometric analysis.

Regarding publication year (see Figure 2), over half were conducted after 2020, and it is expected that the number of studies will increase in 2022.

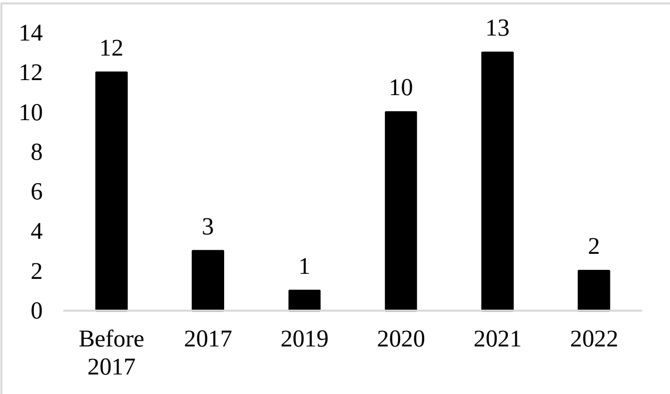

Figure 2. Year of Publication

Regarding the type of studies (see Figure 3), 34% were articles while 32% were conference papers. There were also review papers and conference reviews but few books or book chapters. This may indicate a more detailed theoretical knowledge gap in the field.

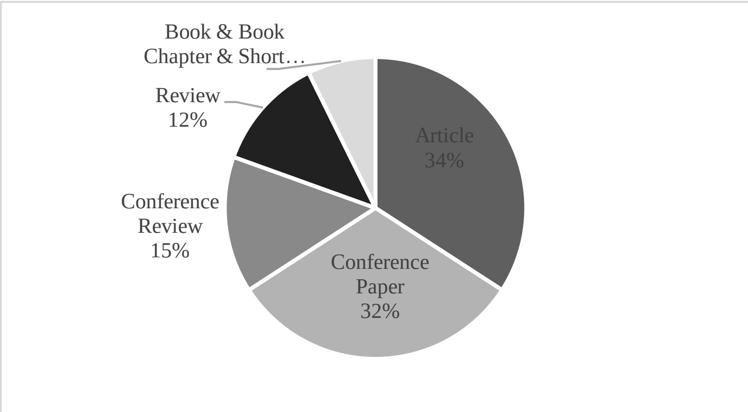

Figure 3. Type of Study

The 41 studies covered various academic disciplines (see Figure 4). The most common field was engineering (30% of studies), followed by energy (18%) and environmental science (16%). For this study, business management and accounting were categorized separately from other social sciences. The results indicate that more studies are essential, especially by social science and managerial researchers.

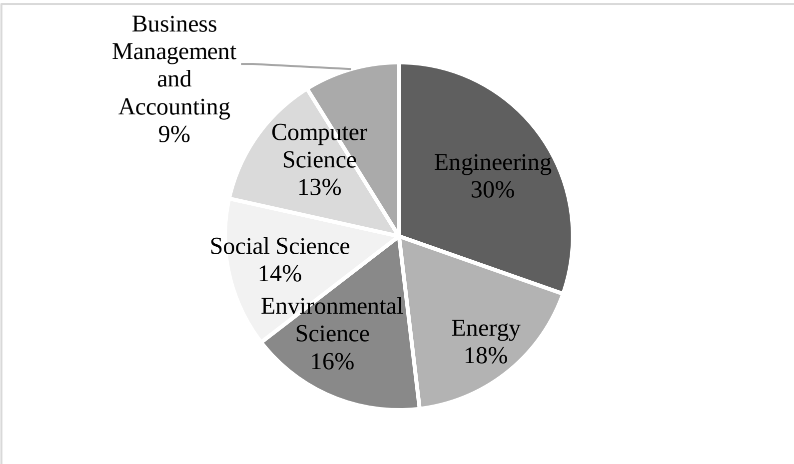

Figure 4. Academic Discipline

The sources in which the studies were published provided further indication of current research trends. Figure 5 identifies the sources that published at least three studies while the remaining sources are grouped in the "others" category. The results show that 10% of the studies were published in Sustainability Switzerland Journal, which is indexed in Web of Science, followed by Advanced Materials Research, International Journal of Production Research, and Applied Mechanics and Materials. The studies in the "other" category were mostly conference papers.

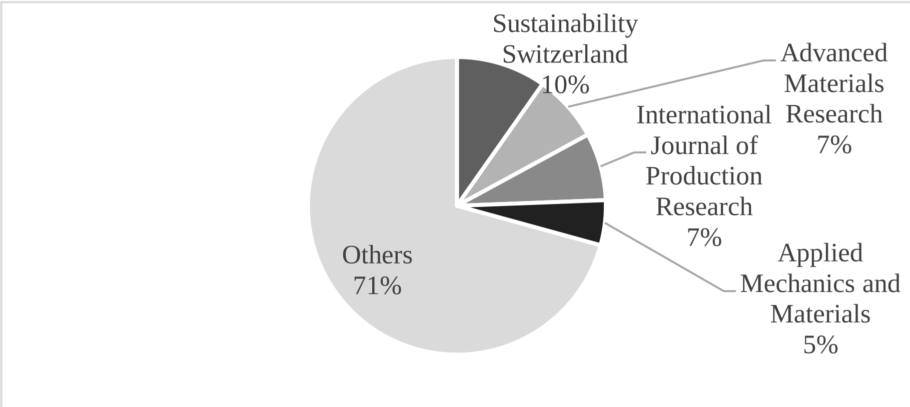

Figure 5. Source Titles

Regarding the geographical distributions of authors, the countries coloured in Figure 6 indicate that a wide range of countries are represented in these studies.

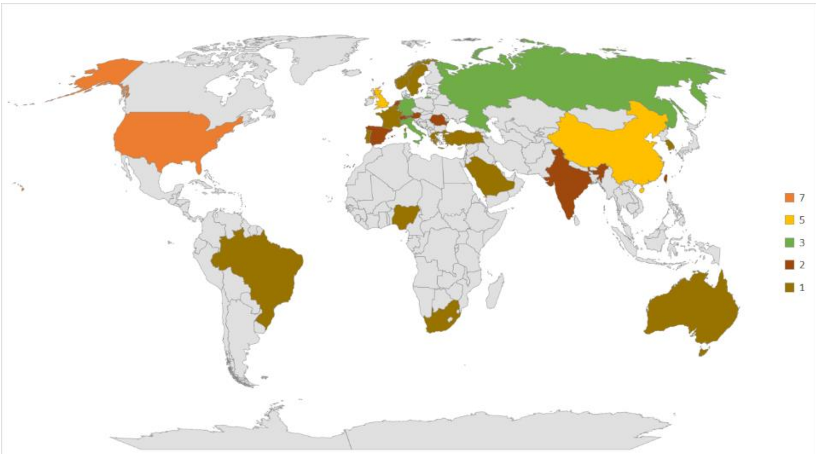

Figure 6. Geographical Distribution of Authors

However, the largest number of authors came from the United States, followed by China and the United Kingdom.

Regarding the methodologies of the current studies in the field (see Figure 7), the majority were theoretical, with desk research, such as proposing frameworks or presenting theoretical models, being the most common. These were followed by studies conducting systematic reviews or secondary data analysis while there were also a few surveys and case studies. Other qualitative techniques used included SWOT analysis and semi-structured interviews while other quantitative techniques included discrete event simulation, multi-criteria-decision making methods, and structured equation modelling.

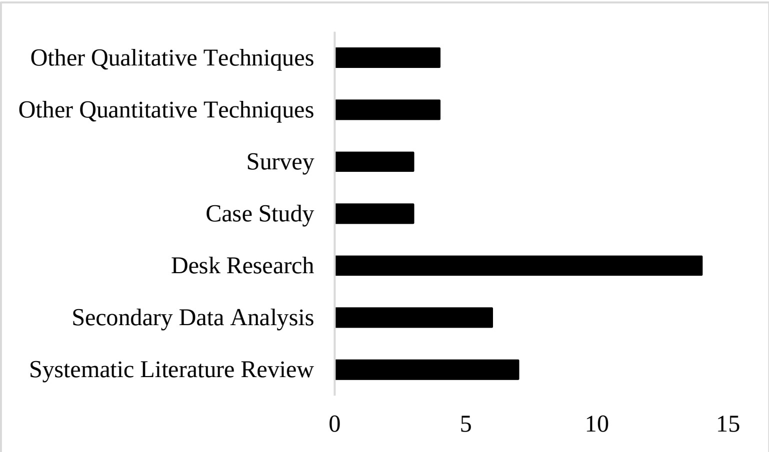

Figure 7. Methodological Approaches

The following section presents the bibliometric analysis of the 41 studies.

4.2 Bibliometric analysis

Bibliometric analysis, also called science mapping, is a method to visualize bibliometric research outputs and a powerful tool for analysing bibliographic networks (Van Eck & Waltman, 2014). Of the various approaches available for conducting bibliographic analysis, co-occurrence analysis and co-authorship networks were applied in the present study using Vosviewer.

The Vosviewer map shown in Figure 8 was created with 51 of the most meaningful co-occurrences from the 601 keywords identified from the 41 studies. In this map, keywords (items) are represented by circles while closely related items are colour coded to represent a cluster (Van Eck & Waltman, 2014). The size of the items represents the weight of the keywords while the lines between items represent their inter-relationships, with the proximity of items or sets indicating the strength of their relationship (Van Eck & Waltman, 2013). Table 2 presents the 19 items (keywords) with the highest weightings and strongest relations.

Items (Keywords)	**Occurrences**	**Total Link Strength**
Sustainable Development	20	82
Digital Storage	7	33
Sustainability	6	16
Carbon Footprint	4	28
Environmental Sustainability	4	28
Supply Chains	4	26
Automation	4	21
Decision Making	4	20
Blockchain	4	18
Digital Twin	4	17
Environmental Technology	3	19
Life Cycle	3	19
Information Management	3	18
Freight Transportation	3	16
Digital Transformation	3	14
Industry 4.0	3	12
Planning	3	10
Smart City	3	8
Logistics	3	6

Table 2. Frequencies and Values of Selected Items (Keywords)

As Figure 8 shows, the keywords fell into five clusters, coloured purple, red, yellow, green, and blue. The purple cluster was the weakest with only five items whereas the red cluster, with fourteen items, was the most crowded cluster. Regarding the weight of the items, yellow was the strongest cluster with thirteen items.

Regarding each cluster, the purple cluster revealed several interesting features. First, the only item related to aviation identified in the analysis was “air transportation”. This was included in the purple cluster and directly related to “sustainable development”. Second, the inclusion of “China and Covid-19” as an item indicates the world’s focus during the previous two years. Third, it is notable that “marketing” is closely related to “digital logistics”, “sustainable development” and “Industry 4.0”. This indicates that, apart from technical and operational processes, marketing is an important key to sustainability.

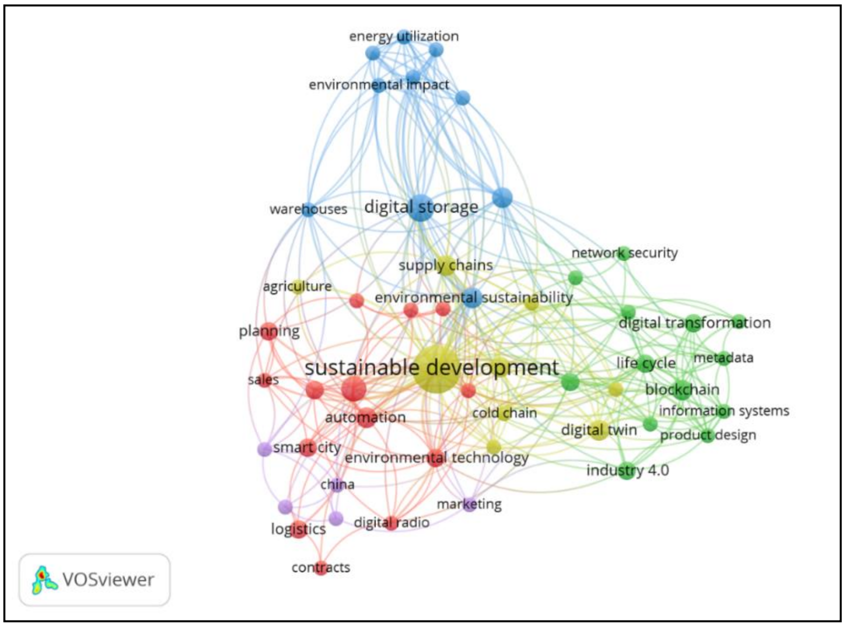

Figure 8. Co-occurrence Analysis of 41 Selected Studies

The red cluster includes items related to transformation processes, such as “digitalization”, “automation”, and “smart city”. Reflecting the elements that most concern the transportation and logistics sector, “energy” and “fuel consumption” were also included.

The blue colour contained items revealing the environmental importance of sustainability, with keywords such as “carbon footprint”, “greenhouse gases”, “energy utilization”, and “environmental impact”, which were also related to digitalization through the item “digital storage”.

The yellow cluster, which included the item with the highest interaction and weight, "sustainable development", synthesized a wide range of items, such as "quality processes" to "supply chain", from "decision-making processes" to "economic and social effects". It also included "digital twin", showing its relationship to digitalization.

The green cluster included the elements that were the basis of each study, notably "technological evolution", "digital transformation", "blockchain", "metadata", and "Industry 4.0".

To summarize, this bibliometric analysis of the keywords from the 41 studies aimed to reveal which keywords were most prominent regarding sustainability and digitalization in air logistics operations. It identified the following in order of occurrence: "digital logistics" in the purple cluster, "automation" in the red cluster, "digital twin" in the yellow cluster, "digital storage" in the blue cluster, and "digital transformation", "artificial intelligence", "metadata", "blockchain", and "information systems" in the green cluster.

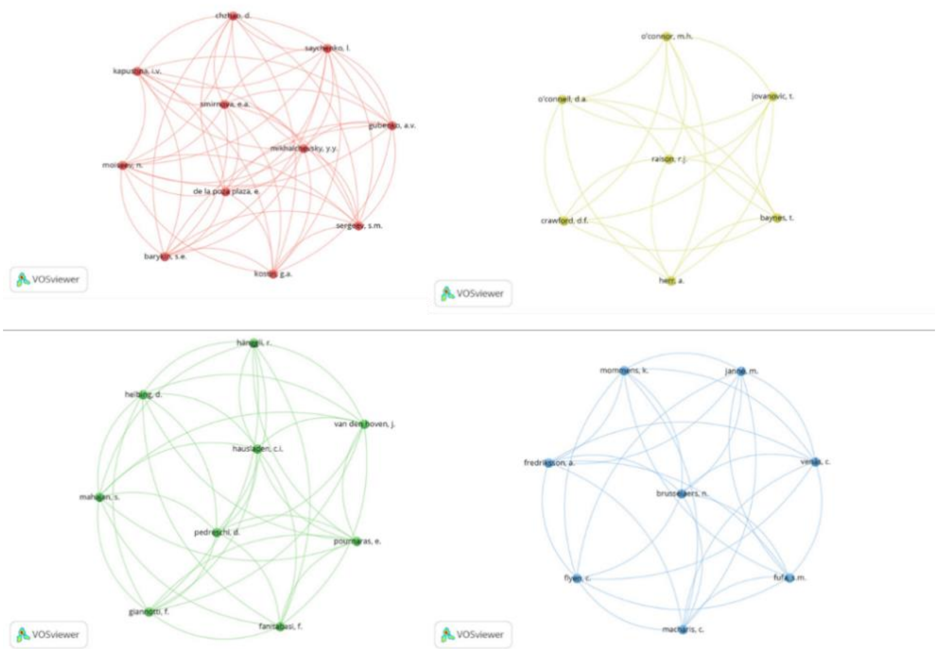

Figure 9. Bibliometric Analysis of Co-Authorships

A bibliometric analysis of co-authorship was also conducted to map which authors have been collaborating in sustainable and digital air logistics research. However, only a few co-authorships were identified due to the limited number of studies.

Figure 9 presents separate co-authorship maps for the four clusters shown in Figure 8. Only links with over seven items were considered in the analysis. The findings show that collaboration between authors across different studies is currently weak in this field. The following section discusses possible future research directions based on these results.

5. Discussion

As explained in the previous section, the bibliometric analysis results showed that current research can be grouped in five clusters. Based on these clusters, the following five research directions can be proposed: sustainable air logistics elements, technical elements, operational elements, environmental elements, and contemporary elements.

Regarding the sustainability element, sustainability is traditionally considered along three dimensions as the environmental, social, and economic triple bottom line (TBL). This could also be useful for analysing air logistics field more holistically. While a few studies have already tried to integrate TBL and digitalization (Braccini and Margherita, 2019; Jayashree et al., 2021), applying these ideas to air logistics could be a promising research area. Other possible research directions could include focusing on resilience and improving the sustainability of air logistics activities.

Regarding operations, future studies can extend in risk management approaches to air logistics activities using data analytics and smart techniques, given that air logistics includes many different risk areas that organizations must deal with.

Regarding technology, blockchain can be used for risk assessment or managing demand-related risks. Research can also focus on producing operational excellence using smart scheduling techniques, which would especially support economic sustainability. Another research direction could be improving technical elements through interdisciplinary research. For instance, digital marketing practices can support social sustainability, thereby increasing both internal and customer satisfaction.

Air logistics activities currently account for around 2% of global CO2 emissions (Gössling et al., 2021), thereby greatly impacting the environment. It is therefore critical to ensure environmental sustainability in this sector. Digital technologies and smart information systems can minimize these negative environmental impacts by balancing energy utilization, minimizing carbon emissions, and eliminating waste. Furthermore, circular approaches can also be integrated with digitalization to create mutual benefits. Thus, future research can focus on digital applications in air logistics to advance environmental sustainability.

Future studies should also consider contemporary issues. In particular, as the bibliometric analysis indicated, the Covid-19 pandemic significantly impacted air logistics operations. New rules, regulations, and standards in the global trade have been implemented. Digital solutions offer a way to meet the challenges caused by the pandemic. For instance, tracking and traceability have become even more important, so improved RFID IoT technologies can be applied to air logistics processes. Thus, in addition to technical implementations, future studies can suggest new frameworks and roadmaps to guide policymakers.

To sum up, besides technical studies, new studies in other directions, especially in business and management science, are essential to ensure a sustainable and digitalized air logistics field. Future studies can also integrate theories and adapt traditional practices to the new environment.

6. Conclusion

Sustainability and digitalization are highly significant topics, especially in operational fields, with the number of studies increasing rapidly. The integration of sustainability and digitalization is also a promising research area in that research into the use of digital technologies to increase sustainability is valuable both theoretically and practically. While Industry 4.0 or digitalization concepts, such as automation, artificial intelligence, and big data, are important for all industries, they were previously somewhat overlooked in the air cargo sector. However, due to global changes, especially during the Covid-19 pandemic, air cargo stakeholders increasingly realize that digitalization is essential for ensuring the sustainability of air cargo supply chains (Kuehne Nagel, 2022). Accordingly, the present study focused on the air logistics industry, which is a significant sector that affects other sectors because of its critical role in a globalized world.

Although sustainable aviation, or sustainable air logistics is a relatively popular research area and digital applications in the air logistics industry are increasing rapidly, few studies have integrated these concepts. Therefore, by conducting a bibliometric analysis, this study represented an initial attempt to demonstrate the potential of integrating sustainability and digitalization in air logistics. Its main contribution is to reveal a gap in knowledge and indicate future research directions to extend theoretical and practical knowledge in the field. The study also aimed to encourage future research into practical implementations and improve digitalization and sustainability in air logistics.

The lack of studies of air logistics and sustainability limited the available keywords for this study. Nevertheless, the analysis revealed a number of key concepts in sustainable aviation and sustainable logistics. To ensure that air logistics are sustainable, it is critical to consider Industry 4.0 elements from a technical, operational, and environmental perspective. That is, it is meaningless to consider this sustainability from a single perspective because improvements in any individual process will have a knock effect across the supply chain.

In addition to academic studies that produce theoretical knowledge, existing applications in the sector should also be analysed to reveal the air logistics' overall situation. One of the most logical short-term steps to increase sustainability in air logistics would be to reinterpret and transform current problems, such as bottlenecks, and solution proposals in terms of Industry 4.0.

This study revealed that there are many open research areas in sustainable air logistics in the digital era, particularly integrating sustainable development principles with digitalized air logistics operations. Moreover, technology-based applications in air logistics for sustainable practices can be implemented, and new ways of minimizing environmental impacts using digital technologies can be investigated. Finally, new business models for the post-Covid-19 era in air logistics can be developed by integrating sustainability principles and digital technologies.

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The contribution of the authors to the study is equal in each section.

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Original Paper

Evaluation of the physical properties of banana pseudostem for textile application

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Abstract. *Handling waste resulting from food production in an environmentally sustainable manner is a highly important issue. Residues from banana cultivation generate waste that often lacks proper management. The objective of this research was to evaluate the physical properties of banana* *pseudostem for textile application, with specific reference to the species* Musa paradisiaca, Musa sapientum *and* Musa acuminata*. A completely randomized design was applied with three treatments, corresponding to the species under study, carrying out five repetitions for each treatment. The fiber extraction was artisan and followed the following steps: cutting, cleaning and transport (pseudostem), extraction, combing, drying and storage (fiber). The results of the statistical analysis showed that* Musa sapientum *fibre has the most length (123.34 cm}, greater elongation (7.93%), and the highest resistance (30.52 MPa) and linear density (0.070 dtex), when compared with the results of the species* M. paradisiaca *and* M. acuminata*. All the species under analysis had a circular cross section.* Musa acuminata *presented the greatest uniformity in the arrangement of filaments. In addition, the three evaluated species are similar to abaca, ramie and sisal in length and thickness. Finally, it was found that the cost of production of the artisanal extraction of banana fibre requires an approximate investment of $3.60. In conclusion, the fiber obtained from the three of the species studied has appropriate physical properties for textile application.*

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1. Introduction

An estimated 33% of the 2.01 billion tons of municipal solid waste produced annually around the world is not handled in an environmentally sustainable manner. Since more than half of garbage is being deposited in an open area, the trajectory of waste increase will have significant effects on the environment, human health, and economic growth (World Bank, 2022). Consequently, waste management becomes a priority for every nation. In the United States of America, for example, the environmental impacts of food waste are equal to the quantity of water and energy required to power more than 50 million households, the amount of fertilizer necessary to cultivate all of the country's plant-based foods for human consumption, an area of agricultural land equivalent to California and New York or greenhouse gas emissions of more than 42 coal-fired power plants (Environmental Protection Agency, 2021).

The food supply chain makes use of a wide range of resources, such as land, water, energy, and chemical inputs. Among the phases of the food supply chain, primary production is the one that uses the most different types of environmental inputs. While greenhouse gas emissions, water and energy usage, and the use of pesticides and fertilizers are mostly associated with primary production, they are also present across the whole food supply chain (Jaglo *et al.,* 2021)

As consumer requirements evolve and consumption patterns alter, the sustainability of food production and consumption as a whole is seriously threatened. As a result, the supply chains for food and energy are linked to complex and interrelated environmental and socioeconomic effects (Sala *et al.,* 2017). In order to address a range of sustainability questions, a number of methodologies are required due to the diversity of issues and viewpoints associated with food systems. This calls for a shift to systemic thinking, whereby the effects of planetary carrying capacities, or the sustainability thresholds known as planetary limits, are maintained through patterns of global production and consumption (Malley *et al.,* 2021). Food systems include the whole supply chain, from agriculture through production, trading, distribution, consumption, and waste generation. Food systems that are "resource-smart" are essential given the growing global population (Filho *et al.,* 2022).

Banana production generates 0.86 kg of greenhouse gas emissions per kilogram (Ritchie, & Roser, 2020). In addition. banana is a highly commercialized product, and, with the gradual growth of its production, there is a directly proportional increase in the generation of waste (Diniz *et al.,* 2014; Chávez & Rodríguez, 2016). According to crop management practices, the pseudostem is eliminated immediately after harvest, generating approximately three tons of residue for each ton of bunches harvested, resulting in a waste ratio of approximately 3: 1 (Balda *et al.,* 2021; Universidad Politecnica de Madrid, 2016; Diniz *et al.,* 2014).

The abundance of banana by-products makes them a renewable resource, which can be converted into raw material and with potential to be easily biodegradable, which has a positive environmental acceptance and greater commercial viability (Padam *et al.,* 2014). In addition, it has been determined that banana fibre has high strength, good brightness, light weight and great moisture absorption, properties that make it an ideal candidate in textile applications (Abad *et al.,* 2012). Moreover, obtaining and extracting natural fibres is easier and presents reduced costs compared to artificially obtained fibres (Armas et al., 2016).

According to production statistics from the Ministry of Agriculture and Livestock of Ecuador (MAGAP, 2017), bananas represent 16% of the total planted area, being the third most produced plantation. According to MAGAP (2017), with a production of 307 143 t of bananas in Manabí, more than 900 t of residues would have been generated (including only the pseudostem). Therefore, without proper management practice of these by-products, a large amount of valuable untapped products will be lost (Haro et al., 2017; Kumar et al., 2018). However, there are no studies that describe the physical properties of the banana fibre produced in Ecuador. Therefore, the purpose of this research was to evaluate the physical properties of banana pseudostem for textile application.

2. Literature review

Worldwide, the development of the agricultural industry generates a large amount of waste, due to the implementation of new techniques and technologies to produce and satisfy the demand that is generated on a large scale. But many times, due to ignorance of the different technological alternatives that exist for the treatment of agricultural residues, it is not used effectively since it is estimated that these include a great cost (Nadeem *et al.,* 2022).

Due to the use of cutting-edge methods and technology to create and satiate the massive demand, the industry's expansion globally produces a significant quantity of waste. However, it is frequently not used efficiently because there is a lack of understanding of the many possibilities for treating agricultural waste. In this respect, Sustainable Development Goal (SDG) 12 of the Agenda 2030 for Sustainable Development is defined as "Ensure sustainable modes of consumption and production," and target 12.5 affirms the need "by 2030, [to] significantly reduce the generation of waste through prevention, reduction, recycling, and reuse." In order to promote sustainable consumption and production, it is stated that infrastructure must be built that is sustainable, essential services must be more readily available, and good, green employment must be created. All of this should result in a higher quality of life for everyone and contributes to the realization of SDG, the reduction of future economic, environmental, and social costs and the improvement of economic competitiveness (Economic and social overview of Latin America and the Caribbean, 2019).

According to the approach proposed by the United States Environmental Protection Agency (EPA, 2015), the use of by-products generates opportunities to: i) address climate change; ii) increase food security, productivity, and economic efficiency; and iii) conserve energy and other resources. In addition, the implementation of these measures has the potential to increase employment, decrease methane emissions from landfills, and conserve resources. Moreover, the EPA's proposed hierarchical pyramid for the recovery of organic waste has six levels, with the reduction in the source representing the preferred scope (Figure 1).

As was said in the preceding section, losses or waste along the food chain or manufacturing are a source of banana waste or byproducts. The pseudostem, a name given to the banana plant's trunk, is composed of leaf sheaths that are encircled by a soft inner core (Figure 2). In addition, the majority of the biomass wastes of banana plants are the pseudostems, which only bear fruit once in their lifetime before being replaced. It is estimated that each hectare of banana plantations produces roughly 220 tons of biomass trash (Balda *et al.,* 2021).

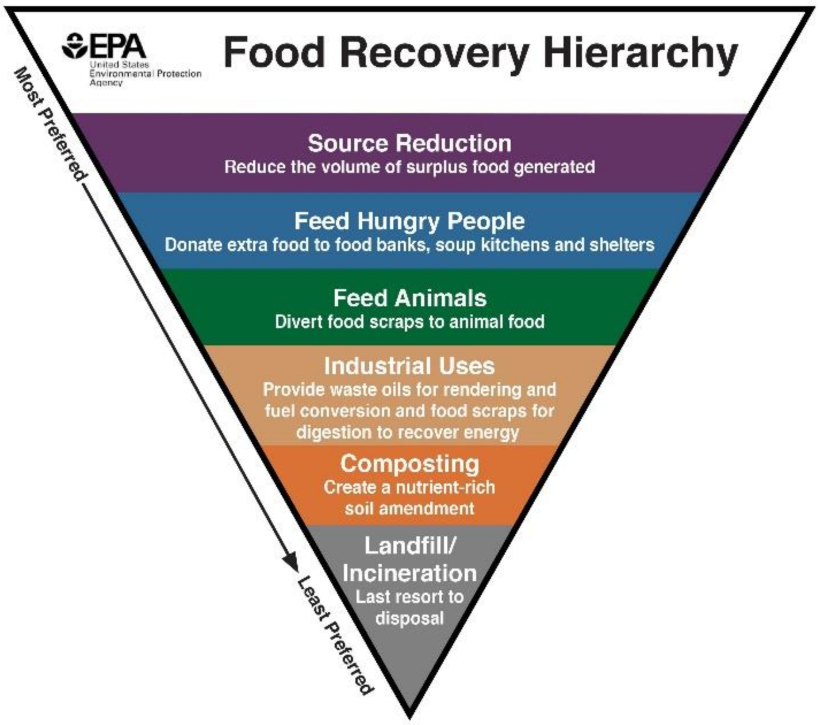

Figure 1. Food Recovery Hierarchy. Source: https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy

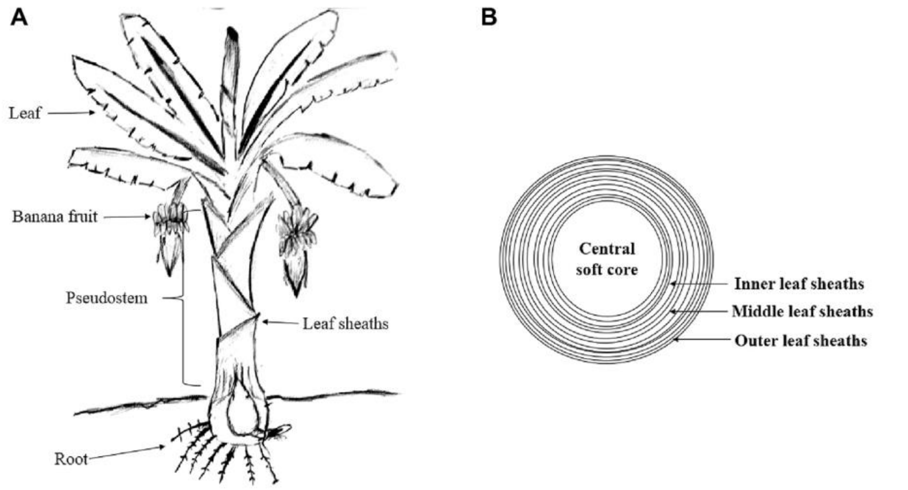

Figure 2. Representation of A: Banana Plant and B: Cross-sectional view of banana pseudostem Source: (Balda *et al.,* 2021).

Various banana plant components, including the leaves, pseudostem, pith, and fruit peels, can be utilized in both food- and non-food-based applications, including the creation of tea bags, biofertilizers, wastewater treatment, paper (Tripathi *et al.,* 2019), textiles, and composite materials (Padam *et al.*, 2014). (Akinyemi & Dai 2020). Research is being done on using banana pseudostem to obtain high-quality fibre. Banana pseudostem fibres have similar mechanical characteristics to conventional reinforcements, much as other natural fibres. This offers business extra advantages as an environmentally friendly option because it is a fibre of vegetable origin (Yan *et al.,* 2016).

This research contributes to the subject of study by providing information on the physical characteristics of banana fibre from three different species that were gathered in Ecuador's coastal area, for which the literature contains no prior references for the type of data mentioned above. Moreover, a manual extraction method that can be used by any producer is described, and a cost analysis that enables proving the financial advantage of banana fibre extraction is outlined.

3. Materials and methods

As well as bibliographic, our research is experimental and deductive, and statistical methods were applied for its execution. A completely randomized design to the three treatments (corresponding to the species under study) with five repetitions per treatment was applied.

3.1. Place of extraction of banana pseudostems

The banana pseudostems were extracted in the Mocoral community of the Canuto parish, Chone – Manabí, at coordinates 597187; 9909044 (Zone 17S) and 62 meters above sea level. In this area, the climate is tropical with an average rainfall of 121.9 mm, an average temperature of 26ºC and 83.5% relative humidity (National Institute of Meteorology and of Ecuador - INAMHI, 2019).

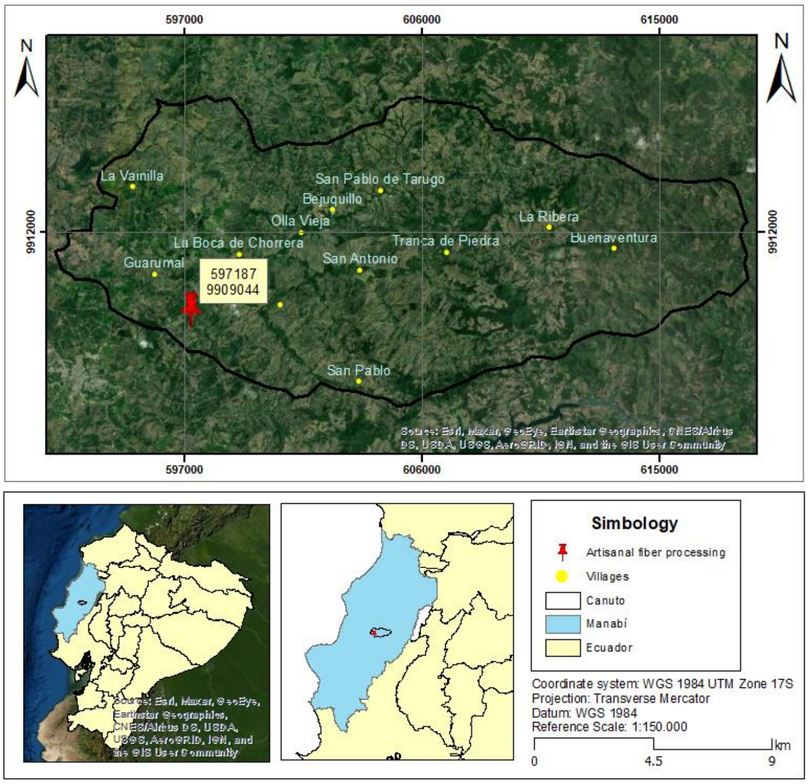

Figure 3. Geographical location of the place of extraction of the banana pseudostems.

3.2. Determination of the physical properties of the fibre of the pseudostem of the species Musa sapientum*,* Musa paradisiaca *and* Musa acuminata

The collection of pseudostems was carried out at age nine months of the banana plants, the time when the fruit is harvested. A cut was made ten cm from the soil, cleaning the pseudostems of leaves in the field adapting the procedure proposed by (Motaleb *et al.,*2021; Libertejidos SanAgustin, 2019). The processing of the fibre was manual and, in Figure 4 the steps carried out until the fibre was obtained are graphically detailed. To calculate the efficiency of the process, the number of sheaths and length of each pseudostem was considered.

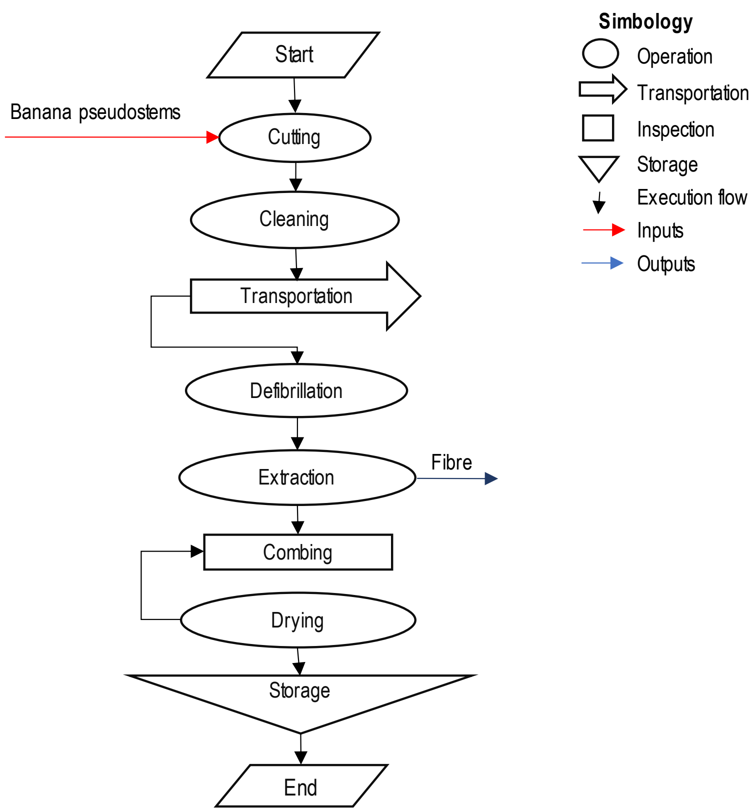

Figure 4. Process diagram for the artisanal extraction of banana pseudostem fibre.

Once the fibre was obtained, the physical properties described in Table 1 were analysed.

Property	**Equipment / instrument**	**Unit**	**Reference**
Length	Flexometer	Centimeter (cm)	Carrera (2017)
Thickness	Microscope OPTIKA B-150, images were processed in ImageJ software	Microns (µm)	Carrera (2017)
Cross section shape	Microscope OPTIKA B-150	-	Carrera (2017)
Linear density	$\rho_l = \frac{m_b}{n_f x l_f}$ ρ_l: Linear density m_b: Fibre bundle mass (mg) n_f: Number of fibres in the bundle l_f: Length of bundle fibres (mm)	Decitex (dtex)	Ecuadorian Technical Standard NTE INEN-ISO 1973 First edition 2014-01
Resistance	Texturometer SHIMADZU EZ-LX.	Megapascal (MPa)	Carrera (2017)
Elongation	Texturometer SHIMADZU EZ-LX.	Percentage (%)	Carrera (2017)

Table 1. Description of the analysed physical properties of the banana pseudostem fibre.

The analysis of variance (ANOVA) and the Tukey test (95%) were applied in the JASP software to determine statistically significant differences between the treatments (for the species under study). Likewise, a comparison was made with the thickness and length properties of other plant species used for textile purposes (Table 2).

Type of fibre	**Thickness (µm)**	**Length (mm)**	**Reference**
Abaca (*Musa textiles*)	250-300	2000-4000	(Freire, 2019)
Cotton (*Gossypium*)	5-20	20-40	(Alonso, 2015; Carrera, 2017)
Hemp (*Cannabis sativa*)	16-50	35-40	(Alonso, 2015; Carrera, 2017)
Jute (*Hibiscus cannabinus, H. sabdariffa, Abutilon avicennae, Urena lobata, U. sinuata*)	12-30	2	(Alonso, 2015; Carrera, 2017)
Linen (*Linun usitatissimum*)	20-25	13-55	(Alonso, 2015; Carrera, 2017)
Ramie (*Boehmeria nivea* and *Boehmeria tenacissima*)	25-75	50-150	(Alonso, 2015; Carrera, 2017)
Sisal (*Agave sisalana*)	200-400	500-2000	(Alonso, 2015; Carrera, 2017)

Table 2. Thickness and length of other vegetable fibres used in textile industry.

3.3. Estimation of the cost of the artisanal extraction process of banana pseudostem fibre

Based on 125 g of fibre (equivalent to 500 meters), an economic estimate ($) was made considering the costs described in Figure 5 and the items listed on Table 3. For the cost of labour, the hourly wages set by the Comptroller General of the State of Ecuador (2021) were used. The salary of a labourer per hour is $ 3.62, while that of a supervisor reaches $ 4.07 (Office of the Comptroller General of Ecuador, 2021). Since the supervisor does not fulfil a role that requires his presence throughout the extraction process, 0.2 was considered in quantity. The cost of a spatula and a comb that are used in practically the entire process was taken into account. Finally, applying formula 1 (Valenzuela, 2014), the unit cost of the artisanal extraction process was obtained.

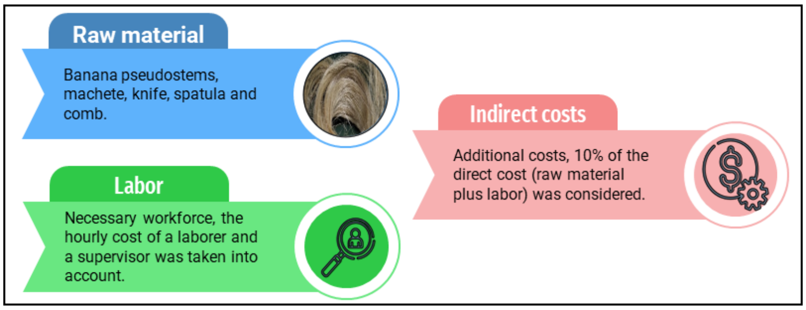

Figure 5. Description of the elements considered for the economic estimation.

Unit cost = (Cost of production) / (Total of units) (1)

Artisanal extraction of banana pseudostem fibre (500 m; 125 g)					
LABOUR					
Description	Quantity A	Pay/ hour B	Cost/hour C = A*B	Efficiency R	Cost D = C*R
Labourer	1	3.62	3.62	0.50	1.81
Supervisor	0.2	4.07	0.81	0.50	0.41
Subtotal N					2.22
MATERIALS					
Description		Unit	Quantity A	Unit cost B	Cost C = A*B
Banana pseudostems		-	5	0	0.00
Spatula		-	1.00	0.70	0.70
Comb		-	1.00	0.30	0.30
Subtotal O					1.00

Table 3. Quantity, cost and efficiency considered for the economic estimation.

Results and Discussion

It was found that *Musa sapientum* pseudostem had an average length of 170 cm and 8 sheaths, producing about 308.30 g of fiber. The efficiency of the process for *Musa paradisiaca* rated second with 150 cm of length, 7 sheaths and 277.50 g of fiber. Finally, with *Musa acuminata* 113.70 g of fibre was produced with pseudostems of 6 sheaths and 140 cm length.

As regards the fibre itself, it was determined that the species with the longest average length was *Musa sapientum* with 123.34 cm, followed by *Musa paradisiaca* with 113.04 cm, while *Musa acuminata* presented 98.75 cm in length. Furthermore, *Musa paradisiaca* presented a narrow data distribution, in contrast to *Musa acuminata* (Figure 6).

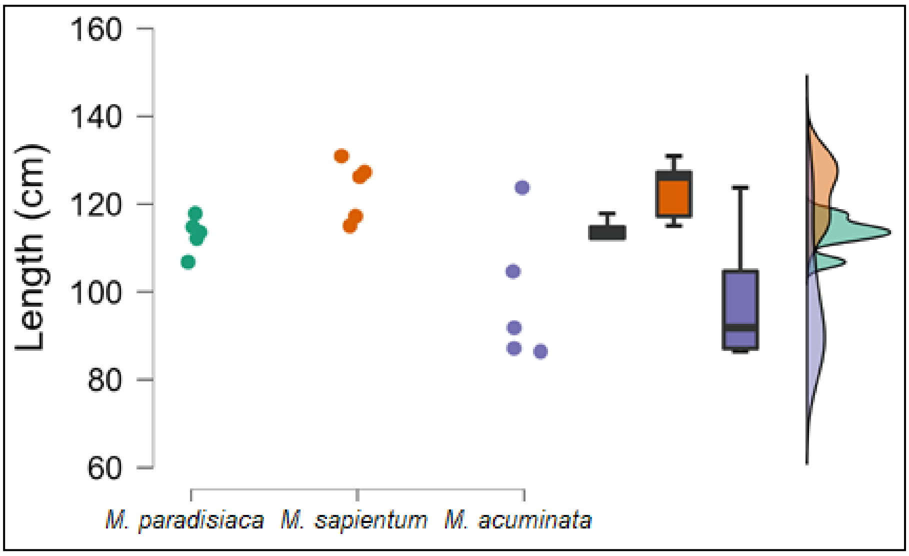

Figure 6. Length of the species under study.

After applying the ANOVA, it was determined that there is a significant statistical difference between factors (species), as observed in Table 4 with a significance equal to 0.008. Regarding the multiple comparison, *Musa paradisiaca* and *Musa sapientum* are similar, forming one group. *Musa paradisiaca* and *Musa acuminata* are two groups with a statistically significant difference (Table 5).

 http://dx.doi.org/10.13135/2384-8677/7061

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	1526.100	2	763.050	7.330	0.008
Residuals	1249.229	12	104.102		

Note. Type III Sum of Squares

Table 4. ANOVA - Length (cm).

		Mean Difference	SE	t	p_{tukey}
1	2	-10.310	6.453	-1.598	0.284
	3	14.290	6.453	2.214	0.109
2	3	24.600	6.453	3.812	0.006

Note. P-value adjusted for comparing a family of 3

Table 5. Length Post Hoc Comparisons - Treatment

For a fibre to be useful in textile industry, it must have a very small diameter/thickness in relation to its length, be relatively flexible and present homogeneity to obtain yarns with the same characteristics (Arsène *et al.,* 2017; Alonso, 2015; Nguyen & Nguyen, 2022). The fibres obtained by hand show a greater elongation to the pseudostem layers due to the tension exerted in the extraction. Nevertheless, the length of the three species exceeds the thickness considerably. Therefore, their length is appropriate for textile purposes.

The average thickness of *Musa acuminata* is the smallest, with an average of 30.45 µm, *Musa paradisiaca* is 56.96 µm in thickness, while *Musa sapientum* is the thickest species with 64.62 µm (Figure 7), reflecting a minimal distribution in the thickness data for *Musa sapientum*, given that the values range from 63.04 to 64.76 µm.

The results of the ANOVA applied to the data of this parameter showed that there is a statistically significant difference (Table 6). Similarly, the multiple thickness comparison revealed that the three species under study are different in terms of this characteristic (Table 7), presenting three subsets for alpha = 0.05.

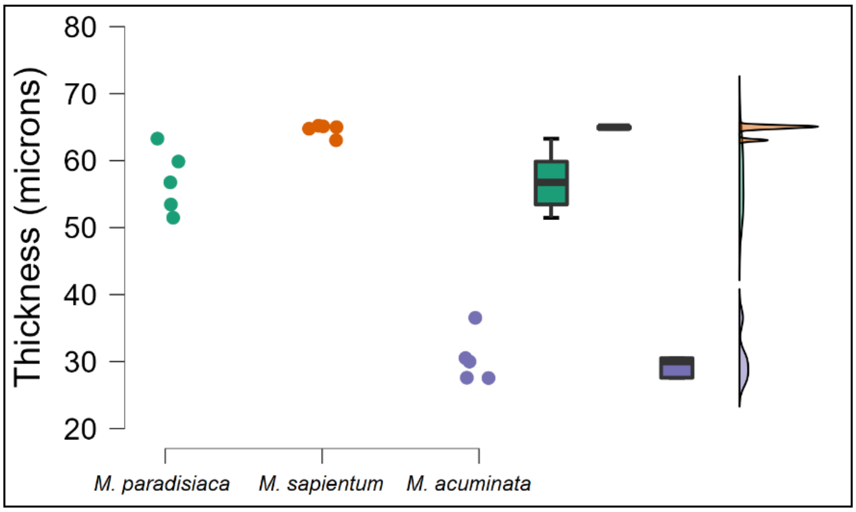

Figure 7. Data of the thickness of the species under study.

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	3216.009	2	1608.005	130.599	< .001
Residuals	147.751	12	12.313		

Note. Type III Sum of Squares

Table 6. ANOVA - Thickness (microns)

		Mean Difference	SE	t	p_{tukey}
1	2	-7.658	2.219	-3.451	0.012
	3	26.516	2.219	11.948	< .001
2	3	34.174	2.219	15.399	< .001

Note. P-value adjusted for comparing a family of 3

Table 7. Thickness Post Hoc Comparisons - Treatment

In India *Musa sapientum* fibre has been found to have a diameter ranging from 80 to 100 µm (Kulkarni *et al.,* 2010), whereas in Ecuador the fibre of the same species has a smaller diameter, which can reach up to 75 µm. Thinner fibres are better valued in the textile industry (Carrera, 2017; Chand, & Fahim, 2021; Priyadarshana *et al.,* 2020). However, in the case of *Musa acuminata* the extraction process is difficult since the fibre is much more susceptible to ruptures, indicating that in the studied species the thickness is directly proportional to the resistance of the fibre. On the other hand, between the length and thickness of the fibre of the studied species exists a ratio of 1: 10 000.

As regards the shape of the cross section, *Musa paradisiaca* has a circular shape (Carrera, 2017; Debnath, 2017; Ramesh, 2018) as shown in Figure 8, the fibre of this species is composed of continuous filaments with circular ends.

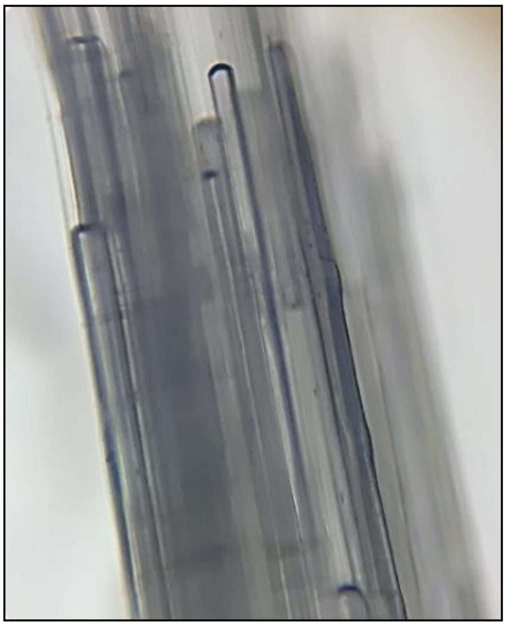

Figure 8. *Musa paradisiaca* cross section.

Musa sapientum showed a circular cross section with a peculiar configuration that can vary from circular to oval (Carrera, 2017; Motaleb *et al.,* 2021). Thus, this species presents shorter and less uniform filaments as shown in Figure 9.

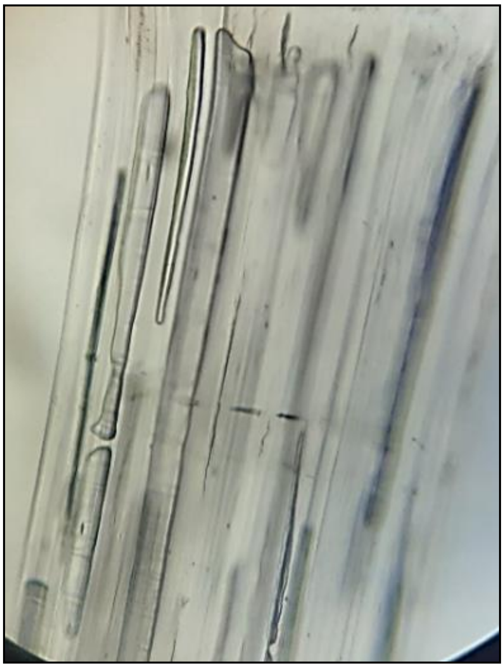

Figure 9. *Musa sapientum* cross section.

Musa acuminata has a circular cross section with filaments similar to those of *Musa paradisiaca*, although less uniformity is observed in their distribution (Figure 10). The circular shape imparts a strong shine to the fibre or filament because incident light is reflected unevenly, and this tends to result in a rather harsh brightness. When the fibre or filament is transformed into thread or cloth, its circular shape allows it to reflect the same amount of incident light despite the irregularity of its reflection. Furthermore, this shape results in a high bending stiffness, rigid fibre and less flexible due to its regular diameter (Kusić *et al.,* 2020; National Program for Technological Enhanced Learning [NPTEL], 2012; Subagyo & Chafidz, 2018).

Musa paradisiaca has an average of 0.062 dtex of linear density, presenting an atypical value of 0.064 that is far from the narrow distribution of the data for this species. Meanwhile, *Musa sapientum* is the species with the highest value in this parameter (0.070 dtex) and *Musa acuminata* the species with the lowest linear density (0.055 dtex), results that are graphically expressed in Figure 11.

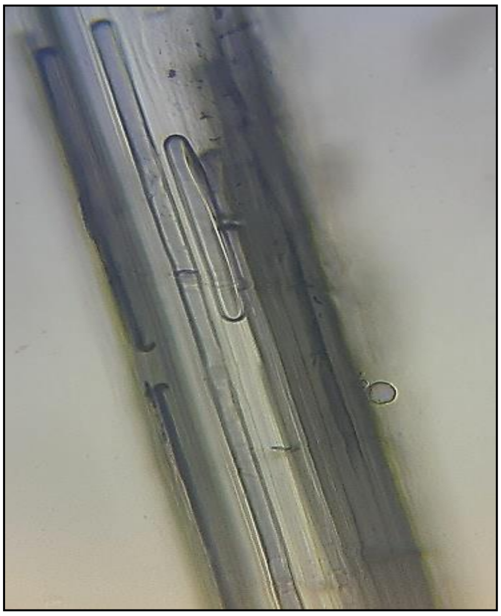

Figure 10. *Musa acuminata* cross section.

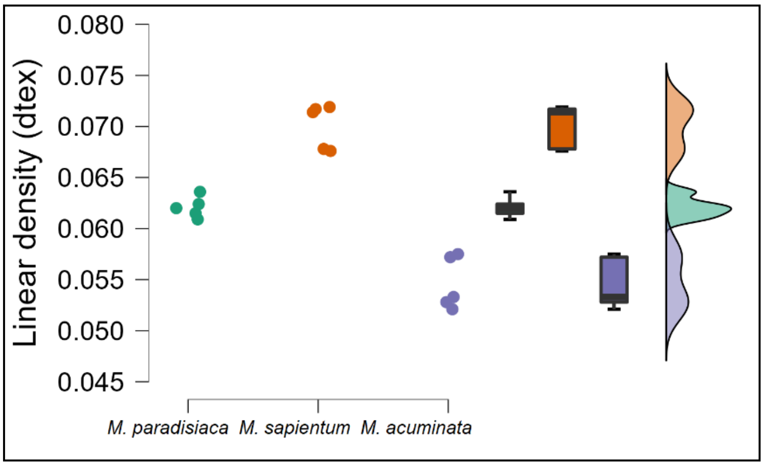

Figure 11. Linear density of the species under study.

According to the ANOVA performed, the linear density of the species under study shows a statistically significant difference (Table 8). Likewise, the Tukey HSD test revealed that there are differences between treatments, forming three subsets for alpha = 0.05 (Table 9).

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	6.008e-4	2	3.004e-4	72.793	< .001
Residuals	4.952e-5	12	4.127e-6		

Note. Type III Sum of Squares

Table 8. ANOVA - Linear density (dtex).

		Mean Difference	SE	t	p_{tukey}
1	2	-0.008	0.001	-6.226	< .001
	3	0.007	0.001	5.837	< .001
2	3	0.015	0.001	12.064	< .001

Note. P-value adjusted for comparing a family of 3

Table 9. Linear density Post Hoc Comparisons – Treatment.

Figure 12 synthesizes the distribution of the resistance data of the three species under study, indicating that the species with the most resistant fibre is *Musa sapientum* with 30.52 MPa. *Musa paradisiaca* obtained an average of 27.58 MPa and *Musa acuminata* is the least resistant species with 22.65 MPa.

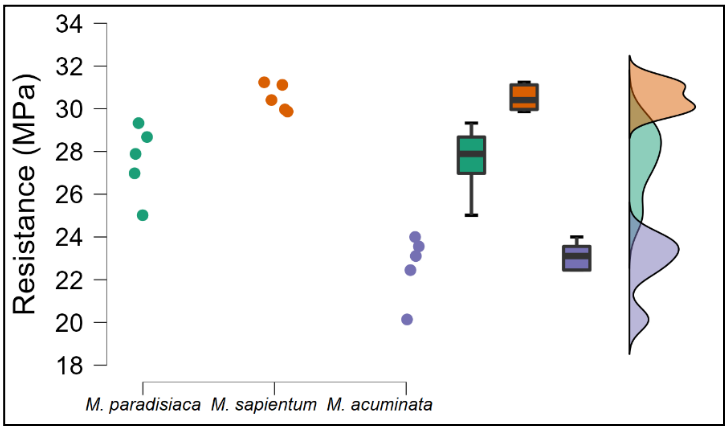

Figure 12. Resistance of the species under study.

The result of the ANOVA applied indicates a statistically significant difference ($p < .001$) between the three species (Table 10). In agreement with the results of the ANOVA, the Tukey HSD test shows that the three species are different in terms of resistance, with three subsets for alpha = 0.05 (Table 11).

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	158.129	2	79.065	42.931	< .001
Residuals	22.100	12	1.842		

Note. Type III Sum of Squares

Table 10. ANOVA - Resistance (MPa).

		Mean Difference	SE	t	p_{tukey}
1	2	-2.942	0.858	-3.428	0.013
	3	4.928	0.858	5.742	< .001
2	3	7.870	0.858	9.169	< .001

Note. P-value adjusted for comparing a family of 3

Table 11. Resistance Post Hoc Comparisons – Treatment.

The resistance of banana fibre in India ranges between 24-32 MPa, and this resistance can be increased up to 90 MPa through reinforcement treatments. Logically, there are many factors that influence the resistance of the fibre, such as nature resin and fibre chemistry, fibre orientation, aspect ratio, fibre length, uniform fibre distribution, and surface area, as well as others (Kavitha & Aparna, 2021; Senthilkumar et al., 2018). These values coincide with the findings of this investigation, especially with *Musa sapientum* and *Musa paradisiaca*, since *Musa acuminata* presented values below 24 MPa.

Since elongation is equivalent to resistance, it was obtained that *Musa sapientum* has greater elongation (7.93%), while *Musa paradisiaca* has 5.86% and *Musa acuminata* showed 4.83% elongation (Figure 13). In the textile field, it is known that mercerization (treatment with sodium hydroxide) gives cotton an exceptional elongation of between 10 and 30% (Alonso, 2015; Zheng et al., 2021). Therefore, considering that no treatment has been carried out on the fibres of the species under study, it is inferred that the elongation could be considerably increased when applying a textile treatment to the fibre.

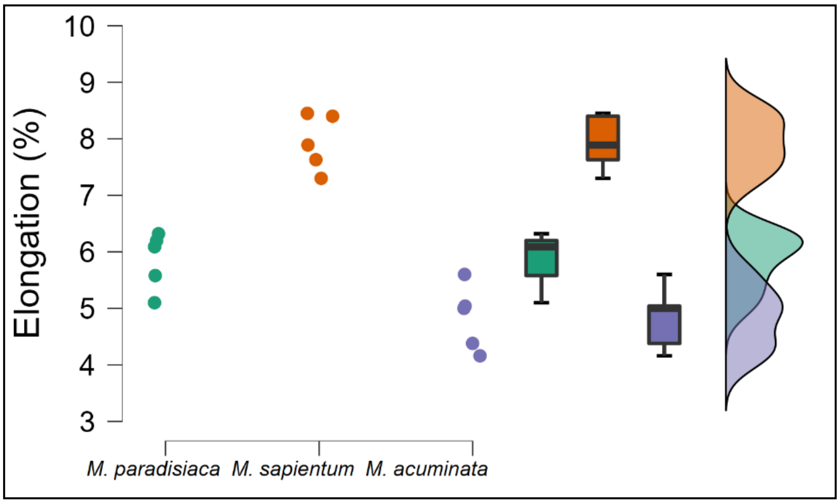

Figure 13. Elongation of the species under study.

In this case, the ANOVA also reflects a statistically significant difference (Sig. = 0.000) as shown in Table 12. While, the results of the Tukey HSD test (Table 13), reflect that the difference is significant between all three species in terms of elongation, forming three subsets.

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	24.920	2	12.460	44.861	< .001
Residuals	3.333	12	0.278		

Note. Type III Sum of Squares

Table 12. ANOVA - Elongation (%).

		Mean Difference	SE	t	ptukey
1	2	-2.076	0.333	-6.228	< .001
	3	1.022	0.333	3.066	0.025
2	3	3.098	0.333	9.295	< .001

Note. P-value adjusted for comparing a family of 3

Table 13. Elongation Post Hoc Comparisons - Treatment

Figure 14 shows the fibre extracted from the three species under study, where it is evident that all species are similar in colour, while in volume *Musa sapientum* and *Musa paradisiaca* have greater corpulence. In the case of length, M*usa sapientum* is the one with the greatest uniformity to the naked eye.

Figure 14. View of the extracted fibre. From left to right: *M. sapientum, M. acuminata, M. paradisiaca*

In the economic estimation made, for the equipment item, 5% of the cost of labour was considered to include the cost of tools such as machetes and knives. Regarding transportation, no item was considered because in this case the pseudostems were manually moved to the place of fibre extraction. Likewise, the value of banana pseudostems was not considered since in the area where the project was carried out they are considered by-products.

Table 14 shows the economic estimate made, demonstrating that the artisanal extraction of 500 m (125 g) banana fibre requires an investment of approximately $ 3.60. Given the lack of estimates of this type, it was not possible to make a comparison of items with other findings. However, 1 g of Musa textiles fibre is $ 0.002. Although this value is lower than that estimated for banana fibre, it should be emphasized that improvements in the efficiency of the extraction process can reduce production costs (Pera, 2019).

THESE PRICES DO NOT INCLUDE TAXES	Direct cost (N+O)	**3.27**
	Indirect cost (10% Direct cost)	**0.33**
	Total	**$3.60**
	Unit cost by meter	**$0.01**
	Unit cost by gram	**$0.03**

Table 14. Results of the cost of production analysis.

5. Conclusions

Transforming agricultural waste into textile fibre has great potential for rendering human trajectories more sustainable and recycling banana pseudostems can play an important role in this process. The fibre of the three species studied (*Musa paradisiaca, Musa sapientum* and *Musa acuminata*) presents favourable conditions for its use in the textile industry, and, taking into account its characteristics, could be used in the elaboration of various products, depending on the specific requirements. The species with the best physical properties is M. *sapientum*, whose fibre showed better values in the evaluated physical characteristics (length, thickness, cross-section shape, linear density, resistance, and elongation). However*, M. paradisiaca* and *M. acuminata* also present appropriate characteristics for their use for textile purposes, those products that require less fineness would have a better finish with *M. acuminata* fibre. Likewise, local producers of *M. paradisiaca* could give added value to the by-product of this species, which is quite similar to *M. sapientum.* The artisanal extraction of 500 m (125 g) of banana pseudostem fibre requires an approximate investment of $ 3.60, resulting in a unit cost per meter equal to $ 0.01 and a unit cost per gram of $ 0.03. These values could be used as a basis to set a sale price of the fibre of the species studied. The practical contribution of the above, lies in the fact that a baseline is presented on the mechanical properties of the pseudostem fibre of three banana species from Ecuador.

Therefore, in future research it is suggested that studies of other properties of the fibre are necessary in order to fully ascertain its application in the textile field.

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