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Article

Understanding Eco-Innovation: A Critical Examination of Theories and Tools for Achieving Societal Sustainability

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ABSTRACT

Over the past decades, environmental issues have become a central global policy and economic development axis. In response, strategies grounded in innovation and technological change have been promoted to address these challenges while striving to preserve social well-being. However, effectively integrating these dimensions constitutes a complex challenge that requires, as a starting point, a deep theoretical understanding of how these concepts can facilitate the transition toward sustainable societies. This article presents a literature review of the theoretical foundations of the concepts of innovation, eco-innovation, and eco-design, using search engines across various scientific publishers, such as Elsevier, to address the following research questions: How is innovation defined and conceptualized from a theoretical perspective? How is eco-innovation conceptualized in academic literature? What are the main definitions of eco-design present in academic literature? Can eco-innovation be considered a case study of innovation? Through this review, the relationships between these notions are identified, the role of design in innovation processes is examined, and the concept of technology as a fundamental element of innovation is introduced. The findings of this study may help researchers, particularly those new to the field, navigate a broad and sometimes fragmented research landscape on eco-design and eco-innovation. Ultimately, the article contributes to academic literature by expanding the discussion beyond the application of these concepts in specific areas.

KEYWORDS: theoretical concepts; innovation; eco-innovation; eco-design; technology; society; environment

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INTRODUCTION

The growing threat to human well-being from climate-related issues has compelled a rethinking of economic activities. International initiatives such as the Sustainable Development Goals (SDGs), the Kyoto Protocol, the Paris Agreement, the environmental objectives of the International Maritime Organization (IMO), and criticisms of the current economic model for its contribution to inequality and pollution have positioned environmental challenges as a central pillar of contemporary international policy [1]. The pressure to address these challenges has led to numerous initiatives to profoundly transform economic and social systems towards more responsible practices aligned with sustainable development principles. However, economic transformation depends on the inclusion and participation of all social and commercial actors in consumption and production to achieve the sustainability of well-being. This approach has driven significant progress in environmental matters, such as reducing material and energy consumption, designing novel methods for recovering the value of waste [2], reducing pollutant discharge, protecting ecosystems [3], and other activities and methods for preserving natural resources and species.

The design, production, and delivery of goods and services can be integrated into eco-innovation processes by incorporating practices promoting sustainability. The concept of eco-innovation originates from the study of innovation, whose observation in human civilizations connects multiple disciplines of knowledge in developing tools and methods that improve the execution of processes and activities while protecting the environment [4]. Eco-innovations have the potential to contribute to the transition towards more sustainable models, transforming key aspects of societies and their relationship with the environment.

Implementing eco-innovation principles in developing sustainable solutions can be carried out in the early stages and in more advanced phases of product or service design [5]. This process, known as eco-design, involves integrating environmental considerations into every stage of development, fundamentally transforming the way design decisions are made [6,7]. Eco-design expands the traditional approach focused on functionality, cost, and aesthetics by incorporating sustainability criteria into the design of products, services, and systems. It considers the environmental impact throughout their life cycle, fostering a transition toward more responsible and balanced models in harmony with the environment [8]. Essentially, it translates the goals of the eco-innovation strategic framework into concrete actions by designing products or services that limit resource use, minimize waste generation, and reduce negative environmental impacts.

Numerous studies and reviews exist on the concepts of eco-innovation and eco-design. However, most research analyzes these concepts in isolation, limiting an integrated understanding of their interrelation. Díaz et al. [9] conducted a literature review using the Scopus database on eco-innovation. Based on their analysis, they developed a multi-level framework that identifies the main drivers of eco-innovation. Meanwhile, Hojnik and Ruzzier [10] focused on eco-innovation drivers, differentiating them according to development and diffusion phases and specific types of eco-innovation.

Regarding eco-design, Schäfer and Löwe [11] conducted a review, providing valuable insights into the distinctions between similar concepts, the current state of research on the topic, and other relevant aspects. Other authors addressing eco-design include Rossi et al. [12], who analyzed eco-design methods and tools to identify obstacles hindering their implementation in industrial companies. Complementarily, Bovea and Pérez [13] classified tools designed to assess environmental requirements in products and their integration into the design process.

Additionally, Cluzel et al. [14] examined the differences and similarities between eco-design and eco-innovation, exploring how they are perceived in business practice. However, their analysis focuses on an applied approach without delving deeply into the theoretical development of the concepts. This highlights the need for further research that integrates both concepts, expands their theoretical understanding, and explores their interconnections.

This article aims to contribute to a deeper understanding of innovation, eco-innovation, and eco-design concepts by analyzing their interrelation and impact on the transition toward sustainable societies. To achieve this objective, a systematic academic literature review was conducted using various scientific journal search engines, allowing for the structuring and analysis of existing knowledge in this thematic area. The documents were categorized based on their relevance to the following research questions:

- How is innovation defined and conceptualized from a theoretical perspective?
- How is eco-innovation conceptualized in academic literature?
- What are the main definitions of eco-design present in academic literature?
- Can eco-innovation be considered a case study of innovation?

This research contributes to existing literature by analyzing the relationships between these concepts from theoretical and applied perspectives and identifying areas that require further exploration. The findings of this study may benefit researchers in the field, especially those new to this topic, by helping them better understand the interconnection between these three concepts.

METHODOLOGY

This research employs a literature review methodology to rigorously identify, analyze, and synthesize existing studies on the concepts of innovation, eco-innovation, and eco-design. A systematic review follows a structured and methodical approach that minimizes researcher bias and enables a critical analysis of the literature [15]. Based on the foregoing, a research process grounded in a literature review has been designed, structured in four main phases, which are described below in Figure 1:

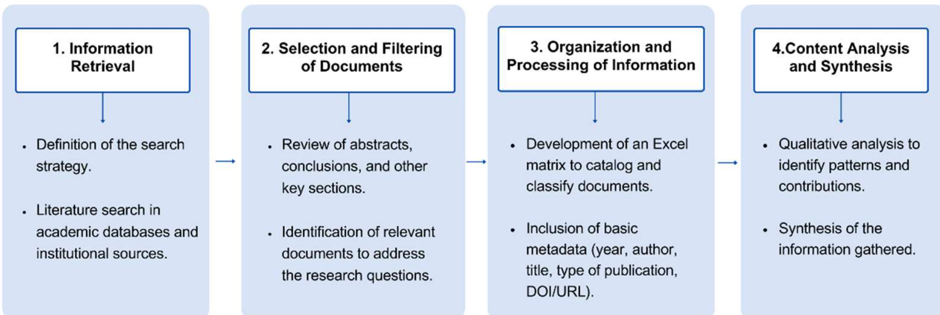

Figure 1. Stages of the systematic literature review approach defined for the methodology.

Phase 1—Information Retrieval

Initially, a comprehensive literature review was conducted utilizing multiple academic and institutional databases. Primary sources included Google Scholar, Elsevier, the Organisation for Economic Co-operation and Development (OECD), and Colombian government entities such as the National Planning Department and the Colombian Ministry of Environment. The search process was iterative, employing keywords such as Theory of Innovation, Innovation Process, Innovation Outcomes, Knowledge Management, Innovation Capacity, Eco-innovation, Environmental Innovation, Innovation in Firms, Green Innovation, Environmental Policy, Innovation Capabilities, Organizational Innovation, Innovation Strategy, Innovation Systems, and eco-design, as shown in Figure 2.

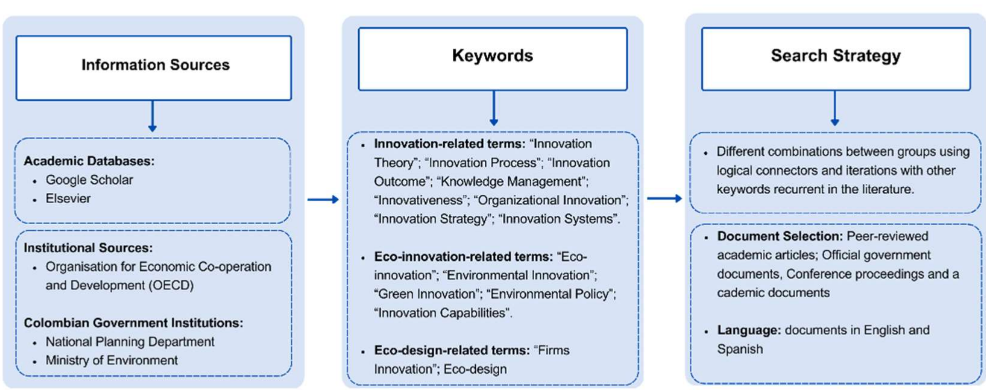

Figure 2. Overview of the methodology: Information sources, keywords, and search strategy.

Phase 2—Selection and Filtering of Documents

Second, a framework was established to select and filter relevant documents. The types of literature included peer-reviewed academic articles, case studies, official government documents, conference proceedings, and academic papers. This process resulted in identifying 143 documents to answer the research questions (see Table A1). The filtering focused on the articles' abstracts and conclusion/summary sections, with additional sections analyzed when key findings were referenced elsewhere.

Phase 3—Organization and Processing of Information

The third step involved systematically organizing the collected information. An Excel matrix was developed to catalog and classify the literature. This matrix included essential metadata such as the year of publication, author(s), title, type of publication, and publishing entity. The data organization process facilitated subsequent content analysis and identified patterns and relationships among the reviewed documents.

Phase 4—Content Analysis and Synthesis

In the final step, the content of the selected literature was analyzed. Statements mostly aligned with answering the research questions were extracted. The analysis focused on identifying theoretical foundations, conceptual frameworks, and relationships between innovation, eco-innovation, and eco-design. This step involved qualitative analysis using the Excel spreadsheet to identify patterns, trends, and key theoretical contributions. The results of this analysis are presented in the following sections of this article.

HOW IS INNOVATION DEFINED AND CONCEPTUALIZED FROM A THEORETICAL PERSPECTIVE?

A complete definition of innovation requires a comprehensive view from multiple perspectives. According to [16], innovation is the implementation of improvements on existing products or processes or the introduction of new products or processes that differ significantly from their previous versions and have been made available to potential users.

Innovation stems from the appropriate management of knowledge generated and acquired through R&D activities, technology acquisition, resources, and talent, as well as the collaboration and coordination of market actors, enabling the modernization of assets and activities performed [16]. To achieve innovation, a joint study of technical capabilities, design, manufacturing, management, and commercialization is necessary, where this introspection is carried out by public and private enterprises, non-profit organizations, households, and civil society [17,18].

The technological change achieved adds value to these actors' diverse forms of knowledge. Due to its interdisciplinarity and diversity in obtaining the aforementioned improvements and changes, the result introduces uncertainty into market dynamics and creates expectations about the future [19]. This uncertainty and its impact on human welfare establishes innovation as a broad concept that studies the relationship between technology and society [20]. Current literature studies the phenomenon of innovation from 3 analytical approaches: output, process, and mindset [21]. These approaches are presented in Figure 3.

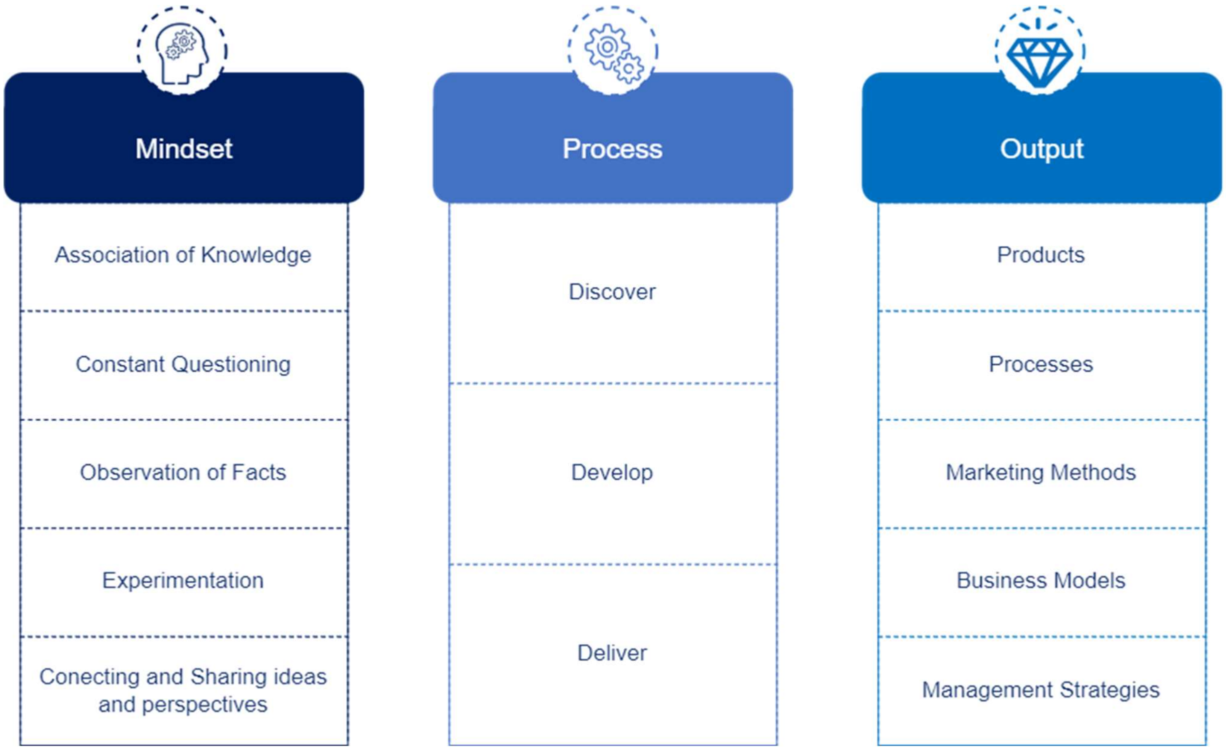

Figure 3. Approaches to the study of innovation. Own elaboration based on [21].

The approaches shown recognize artefacts, innovation systems, and the process behind the creation of technology as essential components of the evolution of civilizations. Due to the complexity of their empirical and theoretical approaches, their study involves multiple fields of knowledge.

According to Otto Scharmer [10], forms of knowledge are classified into three types: Explicit Knowledge, evidenced in concrete artefacts such as documents or physical objects; Tacit Knowledge, whose measurement complexity is more significant and is expressed in the actions, tasks, practices, and experiences of individuals; and Self-Transcendent Knowledge, related to knowledge about the origins of thought and action, which is present but has not yet been discovered or manifested. Figure 4 illustrates the relationship between the three types of knowledge.

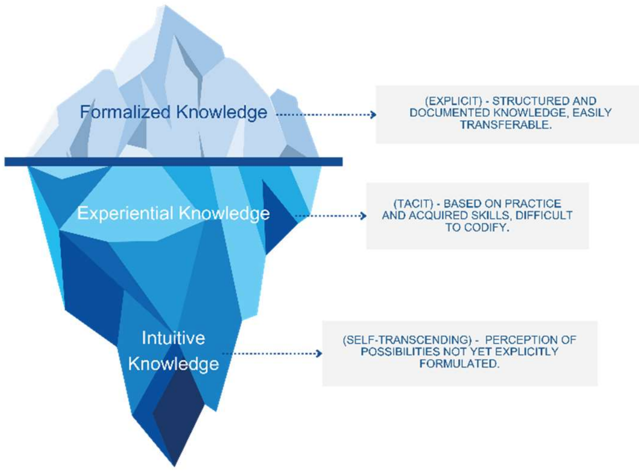

Figure 4. Classifications of knowledge. Own elaboration based on [22].

The various approaches to the study of innovation are closely linked to the analysis of different forms of knowledge. The theory associated with the different approaches to the study of innovation will be explored in more detail below:

Innovation as an Outcome

The study of innovations as outputs focuses on forms of explicit knowledge expressed in artifacts, methodologies, and models, describing the value of this knowledge to its consumers and clients [23]. Under this approach, there are theories related to the study of technological diffusion dynamics. The technology push theory considers that innovation stems from the diffusion of improvements based on discoveries in scientific fields that enhance marketed artifacts and methods [24]. The market pull and market orientation theories focus the origin of innovation on solutions demanded by customers to increase their well-being [24]. These theories are closely intertwined, as market needs and technology transformation must be compatible to achieve diffusion and success, which subsequently transforms and characterizes culture [25]. However, public institutions must manage technological improvements to ensure economic health and competitive equilibrium. The institutional and regulatory push-pull theories focus the origin of innovation on those improvements that do not detract from the health of socio-economic ecosystems Daddi et al. [26], that is, those innovations that are culturally [27], and regulatorily [28,29].

The postulates of these theories shape the diffusion of innovation theory, whose purpose is to understand from the users' perspective what allows an artifact to be accepted [30]. This theory, developed by Rogers [31] and refined by Venkatesh et al. [32], shows that innovations must meet certain expectations of performance and effort, achieved by matching technical improvements with user needs and of social influence and facilitating conditions, achieved by understanding the environment and market conditions.

Innovation as Process

Innovation is a significant topic in business management, as successful technology modification achieves competitiveness and sustainability of human systems [33]. Innovation, viewed as a process, seeks to understand how a system composed of people, artefacts, and situations can create and modify forms of explicit knowledge through knowledge management and talent [34,35]. The focus on understanding human systems and their management aims to comprehend tacit knowledge, including configuring routines, relationships, and learnings that transform human experiences into concrete or abstract objects that facilitate problem-solving [36].

There are multiple theories that seek to understand innovation as a process. The theory of trajectories and firm evolution suggests that companies, in their management, express their forms of tacit knowledge through routines that enable them to achieve objectives and create competencies [37]. These competencies establish organizational patterns that allow companies to be economically sustainable; however, the development of competencies based on work routines introduces organizational rigidity, reducing flexibility to change [38]. In response to this lack of adaptability, contingency theory highlights the need to align business resources with changes in the business environment [39].

Based on these theories, Barney [40] proclaims the resource-based view, outlining the managerial role in directing resources for work modification and successful adaptation to change. This adaptation success is termed innovation capability. Innovation capability addresses innovation as a result of efficient management, adapting ordinary capabilities of organizational knowledge forms [33]. The development of the innovation capability concept by Teece et al. [41] identifies that organizations adapt their resources through knowledge and information absorption, resource adaptation into different knowledge forms in response to changes, and learning, which enables the creation of new knowledge through the results achieved in activity development. These three activities are termed dynamic capabilities (absorption, adaptation, and learning), jointly forming the innovation capability.

On the other hand, studying the environment is fundamental to understanding the dynamics of innovation. The Quintuple Helix model suggests that innovation arises from the market dynamics among five groups of actors: Government, Academia/Knowledge Institutions, Industry, Civil Society, and the Natural Environment [42,43]. Also recognized are institutional theory, expanding its study to the effect of governmental actions on the dynamics of innovation; the multilevel perspective theory, explaining the propagation of behavior that scales from individual attitudes to the complex configuration of human systems such as regions and nations [44], and regional innovation systems, which analyze the complexity of socio-economic networks to be influenced by governmental action to incentivize development through innovation as a result of human system management [45].

Innovation as a Mindset

Innovation studied as a state of mind focuses on the innovation process within teams responsible for changing or modifying forms of knowledge [21]. This approach to innovation seeks to understand the relationship between the three types of knowledge, where individuals' experiences enable them to identify self-transcendent knowledge, express it tacitly, and subsequently make it explicit in the development and execution of ideas.

Cognitive theory contributes through the study of work, where talent and human resources enable the creation of forms of knowledge that facilitate task execution and problem-solving [46,47]. Associated with talent management, organizational knowledge theory indicates that knowledge is accumulated and shared through communication between individuals. Organizations, being systems of people who share and exchange ideas to achieve a common goal, store this knowledge through their organizational structure, task allocation, and work roles [48]. While the approach proposed in the organizational knowledge theory mentions organizational structures, the approach seeks to explain knowledge creation through the socialization, externalization, combination, and internalization of ideas carried out by individuals in the development of an activity.

In transforming knowledge into explicit form, the innovation process must create effective technological changes to enhance the artifact's value. TRIZ (Theory of Inventive Problem Solving) and design theory are relevant approaches for modifying the forms of explicit knowledge [49,50]. Design theory utilizes tools to determine optimal solutions from interrelated attributes and variables [50]. TRIZ is applied to engineering and design problems, consisting of deploying 40 inventive principles translated into parameters for the integral improvement of artifacts [51]. These theories work with mathematical tools and models that shape objects and technology, whose attributes must be dimensioned in conjunction with customer requirements and the possibilities offered by the available knowledge.

Concrete and tangible artifacts possess measurable and quantifiable ordinary capabilities, where their study shifts from the interest of innovation to the specific area of knowledge that requests such improvement (engineering, architecture, medicine, mathematics, computer science, psychology, art, chemistry, and other fields). However, the purpose of research in these disciplines is to explore principles, discover new laws, and offer new approaches whose potential has not been explored [52].

Artifact, Technology and Innovation

The concepts of innovation and technology share a close conceptual relationship, often leading to difficulties delineating the precise boundary between them. Technology is the concrete expression of knowledge regarding techniques, procedures, and artifacts [53]. However, technology cannot be conceived as a simple object due to its potential impact on human systems. Agar [54] presents the definition of technology from two perspectives: an instrumental approach, adopting the language of means and ends, where technology is seen as forms of knowledge that are strictly technical, lacking in creativity and devoid of values, and a cultural approach, defined as a configuration of human practices used for the transformation of the world, involving creativity and the use of material objects, thus evidencing a cultural expression imbued with values and endeavors.

According to the Technology Readiness Levels (TRL) model, technology becomes innovative when it reaches maturity, measured in terms of its accessibility regarding operational risk or market cost [55]. In Figure 5, we can observe the levels of technological maturity from the pre-conception of the method or artifact to the degree of innovation.

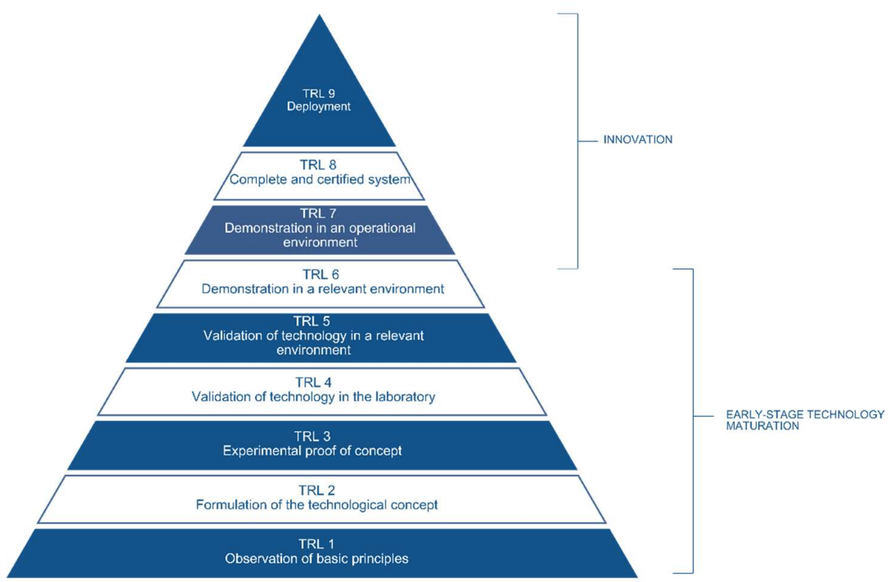

Figure 5. TRL Model. Own elaboration based on [56].

From level 1 to level 5, the developed technology comprises explicit forms of knowledge, as they are configurations of ideas derived from applying scientific principles encompassing purposes, meanings, values, and rules of engagement. Innovation occurs from level 6 onwards, where the feasibility of applying science to the specific artifact is demonstrated, and such technology is ready for use by other actors. However, it is necessary to complete the technology's maturity by reaching levels 7, 8, and 9, where its social diffusion dynamics are developed. According to [21], technology becomes innovative when successfully delivered to society and when the knowledge form is widely used and culturally appropriated. Innovation, therefore, can be considered technological novelties, and upon completing their life cycle, they may lose their innovative character as they are replaced by new improvements or technological innovations [53].

The Problem of Technology Diffusion

Revisiting the diffusion theory postulates, a technology's success depends on multiple factors classified into four key postulates [32]. Table 1 presents these postulates, and the factors associated with diffusion theory.

Table 1. Postulates and factors of diffusion theory. Own elaboration based on [32].

Axiom	Factors
Perceived Usefulness	• Extrinsic motivation for use • Ease and degree of fit • Comparative advantage • Outcome expectancies • Perceived Usefulness
Level of Effort	• Perceived ease of use • Usability • Perceived complexity
Social Influence	• Subjective norms and values • Image • Social factors
Enabling Conditions	• Perceived behavioral control • Facilitating conditions for acquisition and sustainability • User compatibility

All innovations must meet these criteria, and depending on their degree of development, innovations can be classified as incremental, disruptive, or radical.

An incremental innovation adds functions or improves the efficiency of existing technology based on minor changes in the forms of knowledge [57–59]. Disruptive innovation is broader in scope and substantially changes the architecture of the form of knowledge. The changes achieved are significant, obtained through the accumulation of incremental improvements or through the development of changes that involve the application of new knowledge without changing the technological regime or the fundamental principle on which it is based, significantly transforming existing market demand and needs [57–59]. Finally, radical innovations are obtained by having multiple disruptive innovations that allow rethinking the artifact from its fundamental principles studied by multiple actors due to the high diffusion of its problem. Radical innovations manage to change cultural and social aspects around technology, which implies not only the transformation of human systems [57–59].

Technological development must identify, discover, apply, and disseminate knowledge. Within the Technology Readiness Level (TRL) model, the purpose of research is to discover the principles of academic disciplines to understand the mechanisms of nature, thereby generating new ideas [60,61]. Development seeks the practical application of these new ideas in technological change, creating value [52]. Innovation occurs by effectively delivering knowledge forms to improve consumer well-being [21].

This process of delivering technology to the market is known as technology diffusion. Technological diffusion can occur naturally, as evidenced by discussions among multiple actors over time whose shared interest lies in applying a specific form of knowledge [62]. However, diffusion faces several multi-category barriers that hinder proper engagement and understanding between the technology and its target users. According to Gupta et al. [63], The barriers to innovation are categorized as technological, economic and financial, regulatory and institutional, social and cultural, organizational, and market and network barriers.

These barriers can be overcome depending on the engagement and enthusiasm of the stakeholders or through the planning of technology dissemination [64], which leads to establishing facilitators for dissemination and improving the delivery of the knowledge form to the customer [65].

Following Breaugh et al. [66], the development of effective dissemination plans is referred to as technological scale-up, categorized into three types: Scaling up, which aims to increase the significance of the form of knowledge; scaling out (or scaling wide), where dissemination seeks to increase its users and uses; and scaling deep, where the goal is to change about culture and its institutions. However, there must be a balance between planning the delivery of technology and the natural development of the diffusion dynamics of existing alternatives to the technology of interest not to weaken the health of innovation systems or market dynamics [67].

HOW IS ECO-INNOVATION CONCEPTUALIZED IN ACADEMIC LITERATURE?

Eco-innovation is a concept that arises from innovation and aims to integrate the reduction of environmental impacts into technological design. Eco-innovation is defined as innovations—whether products, processes, organizational changes, or marketing methods—that intend to reduce environmental risks compared to existing alternatives [4,24]. An eco-innovation reduces the use of natural resources and decreases the release of harmful substances into the environment across the various phases of a product or service's life cycle [68,69]. It is also considered a strategy applied systematically to achieve the sustainability of industrial activities in relation to environmental and social challenges [70].

Alongside the concept of eco-innovation, other related concepts include sustainable innovation, environmental innovation, and green innovation. According to Hermann & Wigger [71], sustainable innovation involves the development of innovations that enhance social and economic performance, alongside achieving objective environmental improvements.

Environmental innovation is defined as modifications or developments of new processes, systems, and products that benefit the environment [72]. This concept arises from cultural and legislative phenomena surrounding concerns about sustainability, climate change, and impacts on natural cycles caused by human activities. Awareness and dissemination of these issues create new market niches and enable the establishment of business strategies focused on sustainability [73].

Green innovation is defined as innovations in hardware and software related to products and processes that include energy-saving technologies, emission prevention, recyclable by-products, green product design, and corporate environmental management [74]. The concept of green innovation is used by the OECD [58] to guide business growth initiatives aimed at sustainability, linking the greening of business models, entrepreneurship, and emerging economies.

Eco-innovation is a concept related to the eco-efficiency of activities whose outcomes reduce environmental risks, pollutant emissions, and the negative impacts of human production activities throughout the lifecycle of goods [4]. According to Schiederig et al. [75], eco-innovation considers technical aspects to achieve cleaner production without compromising the value offered by the artifacts. Therefore, the origin of this concept lies in the study of technological development.

While these four concepts can be differentiated based on their origin and original purpose, today, they all aim for technological development to consider the principles of the triple bottom line (social, environmental, and economic development). However, the focus of eco-innovation, green innovation, and environmental innovation is to promote and enhance the value of natural assets.

Triple Bottom Line

The Triple Bottom Line (TBL) refers to the consideration of three dimensions of sustainability in human activities. According to Dyllick & Hockerts [76], corporate sustainability meets six criteria: eco-efficiency, socio-efficiency, eco-effectiveness, socio-effectiveness, sufficiency, and ecological equity. In the development of the TBL model, the aim is to shift the paradigm of neoclassical economic theory by holding market actors accountable for the externalities of resource consumption, thereby ensuring the continuity of capital for the future [77,78].

Continuing with Dyllick & Hockerts [63], the TBL examines three types of capital: Economic Capital, recognized as financial, tangible, and intangible assets, whose sustainability is based on ensuring a sufficient flow of money with a consistent return to shareholders over time. Natural Capital refers to natural resources and ecosystem services independent of human society. Its sustainability is demonstrated by aligning industrial cycles with the renewal of natural resources and avoiding activities that degrade natural services and resources. Social Capital, defined by human talent, culture, public services, motivation, and values present in civil society with which businesses interact. Sustainability in this context involves promoting communities to create and maintain this capital.

Traditionally, neoclassical economics considers the complete substitutability of capitals when expressed in monetary units, and their recovery is viewed purely as a technological issue [1,79,80]. However, natural and social capitals can become extinct (e.g., loss of species and cultures), making them characterized by non-substitutability and irreversibility in their depletion [63]. This implies that there must be a responsibility associated with the use of natural and social resources, as their disappearance not only involves the loss of a form of knowledge, energy, and matter but also a change in social and natural dynamics that can alter the environment and its relations and services permanently [81,82].

The TBL framework considers three case studies corresponding to each type of capital. The business case primarily addresses economic capital, presenting the criteria of eco-efficiency and socio-efficiency, which aim at corporate responsibility to enhance performance and business image [78]. Eco-efficiency is defined as delivering competitive products that reduce ecological impacts and resource intensity throughout their life cycle, aligning with the carrying capacity of ecosystems and measured through indicators of energy, waste, material, and pollution, while also enabling cost reduction [83,84]. Socio-efficiency seeks to increase society's added value, which implies increasing civil welfare and reducing occupational risks [85].

Regarding the promotion of natural capital, we find eco-effectiveness and sufficiency. Eco-effectiveness emphasizes the abundance of resources and the health of natural systems and structures in the creation of products, systems, and processes with positive or neutral environmental impacts throughout their life cycle [76,86]. Sufficiency is defined as the degree of satisfaction consumers derive from the resources they can extract from the environment [87].

Finally, in the promotion of social capital, two criteria are satisfied: ecological equity, which refers to the fair distribution of natural capital; and socio-effectiveness, which aims to achieve or realize objectives in terms of absolute positive impact on communities and civil society, assessed by the overall improvement in well-being [76].

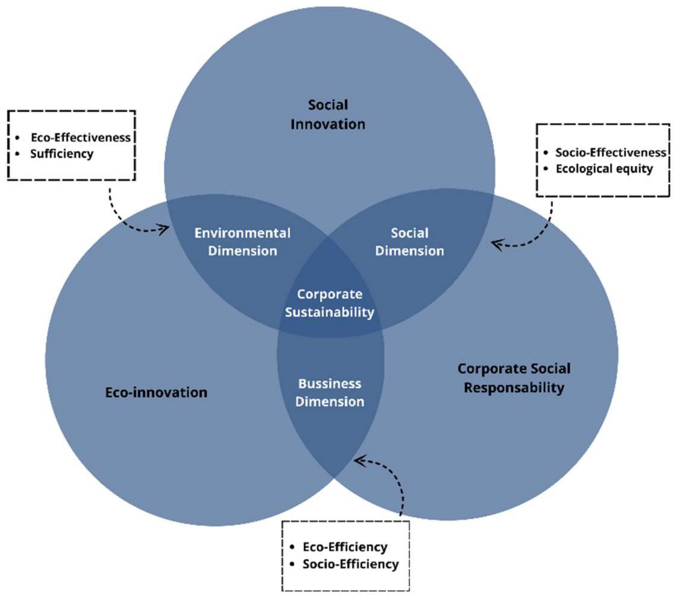

Figure 6. The three dimensions of the TBL and the 6 criteria of corporate sustainability. Own elaboration based on [76].

Figure 6 illustrates the relationship between the criteria of corporate sustainability and the dimensions of the Triple Bottom Line (TBL). Considerations regarding effective quality management in the development of incremental and disruptive eco-innovations achieve the criteria of eco-efficiency and socio-efficiency [88,89]. When eco-innovation becomes radical, it achieves eco-effectiveness by improving natural capital, and its influence can fulfill the criteria of socio-effectiveness, sufficiency, and ecological equity due to its level of social diffusion and cultural impact, transforming human systems towards a more desirable state [90].

The Mechanisms of Eco-Innovation

According to [91], eco-innovation has developed various mechanisms as technology is modified or redesigned, new alternatives emerge, and mechanisms are created to disseminate knowledge that integrates the environmental dimension as a standard indicator. These mechanisms—pollution control, cleaner production, eco-efficiency, life cycle thinking, closed-loop production, and industrial ecology—impact different eco-innovation objectives, ranging from production and organizational processes (in the case of incremental and disruptive innovations) to cultural and institutional change (in the case of radical innovations).

It is noteworthy that the initial focus on incorporating the environmental dimension into productive activities aimed at compliance with environmental policies through pollution prevention and control [71]. By conducting a deeper examination of the ways to mitigate the environmental impact of human activities and achieve the maximization of utility within governmental constraints, mechanisms such as clean production and eco-efficiency are developed, transforming compensation into a commercial and operational strategy [92,93].

Greater diffusion of clean production strategies and eco-efficiency begins to consider the impacts associated with the involvement of various actors in the supply chain. This consideration of actors identifies mechanisms such as life cycle thinking design and closed-loop production, where the diffusion of environmental issues includes the creation and development of emerging economies and industrial activities focused on circularity [94,95]. Finally, the diffusion of environmental issues associated with economic activities leads to industrial ecology, changing culture, institutions, and economic models [96]. Achieving industrial ecology involves the normalization of multiple eco-innovation mechanisms and political and regulatory support, so that the market and consumers adopt circularity dynamics as a common and everyday practice [97]. Currently, society is beginning the transition towards a circular economy, making industrial ecology still a largely theoretical concept.

WHAT ARE THE MAIN DEFINITIONS OF ECO-DESIGN PRESENT IN ACADEMIC LITERATURE?

To achieve eco-innovation mechanisms, the literature has proposed the concept of eco-design, linking impact reduction with technical changes in artifacts, methods, and operations. Zailani et al. [98] define eco-design as a business strategy to produce goods with lower environmental impacts throughout their value chain, supply chain, and life cycle. This approach integrates variables related to ecology and the environment along with quality, ergonomics, cost, or safety as design requirements.

The eco-design process consists of two key activities: life cycle assessment (LCA) and environmental improvement by designing knowledge forms belonging to different links in supply chains, aiming for eco-efficiency and eco-effectiveness [99]. Eco-design activities include reducing and eliminating hazardous materials, designing for reuse, recycling, disassembly, remanufacturing, repair, rework, material reprocessing, restoration, improving resource efficiency, and reducing material and energy consumption [98].

Eco-Design Indicators

The indicators considered in eco-design vary according to pollution prevention, eco-efficiency, and eco-effectiveness. Pollution prevention aims to reduce the impacts associated with the waste generated by an activity known as end-of-pipe impacts [100]. These indicators also allow for measuring the eco-efficiency of activities by comparing them to productivity metrics [93].

According to the OECD [101] and the Colombian Ministry of Environment [102], end-of-pipe impacts are directly associated with environmental impact indicators, which are classified into multiple categories depending on the medium, resource, issue, or situation. These values are measured and limited in order to protect natural capital. However, eco-efficiency and pollution prevention are typically assessed by measuring the level of alteration in water bodies, soil, and the atmosphere. Table 2 presents some environmental indicators considered for measuring pollution.

Table 2. Environmental impact indicators. Own elaboration based on [101,102].

Resource	Indicator
Water Bodies	• Blue Water Footprint: Consumption of water from various activities that do not return to the source. • Grey Water Footprint: Amount of water needed to dilute a specific pollutant load. • Eutrophication Potential: Calculate nutrient contribution to water by a product or service. • Pollutant Load: Mass of substances discharged into a water source. • Concentration of Fats and Oils: Concentration of fats and oils from an activity. • Total Suspended Solids: Particulate material suspended in water currents.
Soil	• Cation Exchange Capacity: Determines soil fertility by its ability to store nutrients. • Base Saturation Percentage: Indicates the degree of soil acidification. • Proportion of Area of Soils Degraded by Salinization: Degree of soil vulnerability due to salt formation. • Proportion of Area of Soils Degraded by Erosion: Proportion of soil loss due to water or wind action.
Atmospheric	• Global Warming Potential: Level of warming that could result from emissions of specific greenhouse gases (GHG). • Acidification Potential: Contribution of SO_x, NO_x, HCl, NH_3, and NF to form H+ ions in the atmosphere. • Ozone Depletion Potential: Assigned values based on the effect of CFC-11 in reactions with ozone. • Air Quality Index: Levels of air pollution based on particulate matter, SO_2, NO_2, O_3, and CO. • Levels of Offensive Odors: Perception of chemical substances present in odors. • Sound Pressure Levels: Measures of sound pressure from sound emission sources.

Environmental regulations are the governmental mechanism for controlling environmental impacts. However, they are insufficient to achieve eco-efficiency as they require time for the transition of industrial activities and economic models, and their measurement is limited to emissions within a specific geographic area [103]. Due to this, the market has developed new mechanisms for the economy and industrial systems.

The most well-known economic mechanism is carbon credits, which aim to offset environmental impacts by financing and developing activities that seek to improve natural capital [104]. Industrial mechanisms have greater complexity and aim for a complete economic transition. The circular economy (CE) is a response that shifts human systems by designing technology that recovers value from waste obtained at different stages of transformation in the life cycle and supply chains [105]. Kristensen & Mosgaard [106] show some micro-level indicators that measure the degree of CE development, classified into indicators of recycling potential, remanufacturing, reuse, reduction, disassembly, extended lifespan, waste management, life cycle management, and multidimensional indicators.

Biotic indicators also monitor the status of ecosystems, flora, and fauna. Among these indicators are the ecological quality index, the index of remaining natural vegetation, the human appropriation of net primary production index, the abundance of relative species, changes in the area covered by natural forests, the number of endemic species, the percentage of infestation by invasive species, and measures of ecotoxicity, among others [102]. However, their conversion into economic terms is complex, as their monitoring falls under the responsibility of the government and reflects the complete dynamics of the managed human system. For sustainability, monitoring socioeconomic indicators is also important; however, these indicators fall outside the scope of the eco-design objective.

The Practice of Eco-Design

As eco-innovation mechanisms evolve, including the presented indicators complicates the task of eco-design. A wide range of conceptual and philosophical approaches have been proposed to simplify this complex activity. Biomimicry, which draws direct inspiration from the actions and characteristics of various life forms and climatic and landscape configurations, offers a solution to specific problems [107]. This approach is known as Nature-Inspired Design (NID). It considers six principles: closed-loop systems (using waste as raw material), local responsiveness, fitting into the immediate environment (adjusting activities based on perceived environmental cues) and evolving with change, use of renewable energy inputs, integrating growth with development, and achieving resource efficiency [108].

Another approach is sustainable design, integrating social issues and facts (DfS) [109]. This approach involves observing civil activities, understanding consumption patterns, and developing support systems influencing people's activities to achieve environmental objectives and social innovation [110]. This design ideology considers concepts associated with CE. Finally, designs for X (DfX) designs aim to rethink incremental designs about forms of knowledge with a specific purpose [111], being a more general approach.

The application of various design ideologies aligns with specific technical requirements to achieve established goals related to quality, ergonomics, safety, and other critical factors. To ensure compliance with these requirements, different tools and methodologies are employed, such as TRIZ, LCA [112], computer-aided design tools, diagrams, guidelines, and checklists that classify and profile products and processes; customer specification sizing methods like Quality Function Deployment (QFD) and Six Sigma [51]; and the recognition of feasible solutions through Case Based Reasoning (CBR) [12,113].

Relationship between Innovation, Eco-Innovation, and Eco-Design

When examining the various definitions presented, eco-innovation can be understood as a particular case study of innovation that addresses a specific societal and market problem and whose evolution follows the theoretical principles of innovation. However, the problem related to the environmental dimension has modified the consideration of actors and rethought the fundamentals of innovation theorists.

The Study of Eco-Innovation from the Perspective of Innovation Theories

Hazarika and Zhang [114] demonstrate that multiple theories from various knowledge areas allow for observing and understanding eco-innovation diffusion. These theories are classified into three levels of analysis: macro, meso, and micro.

At the macro level, this research addresses the governance of the innovation process and the impacts of innovation as an output, with states being responsible for configuring socioeconomic systems. The study links approaches such as the theory of moral legitimacy, evolutionary economics, and regional innovation systems. Literature has identified three key approaches in eco-innovation evolution from a macro-level perspective: neoclassical economic theory, the multi-level perspective, and institutional theory [114].

Neoclassical economic theory was the first to acknowledge the possibility of achieving economic and sustainable benefits through mitigating environmental impacts via technological solutions [115,116], despite being criticized by the TBL [76,117]. This economic shift towards creating sustainable value is linked to institutional theory, from which Porter's hypothesis emerged, emphasizing the role of policy as a mechanism for sustainable growth to drive the industry towards sustainability [118]. However, it has been accused of being responsible for the origin of environmental risks affecting civil society [119,120].

Simultaneously, establishing these policies must consider the multi-level perspective's tenets to assess legislation's impacts on networks and market actors' individual decisions. Here, the theory of innovation helices is recognized, linking civil society and the environment as key actors in the diffusion of innovation [42,121,122].

The multi-level perspective and helix theory examine innovation through the lens of inter-actor relationships, which is situated at the meso level of analysis. This level investigates socioeconomic networks and market dynamics where innovation emerges from consensus and agreements for creating, managing, and delivering technology. At this analytical level, the postulates of organizational integration and innovation process theories, ambidexterity, game theory, the innovation paradox, and group consciousness, among others, become evident [114].

To understand the diffusion of eco-innovation in social networks, the ecological modernization theory [123] and the resource alignment theory [124] posit that the development of green technology should be cross-cutting, involving all actors that make up human society. Achieving the criteria of the TBL must also consider the actions of actors within the supply chain, segmenting the responsibility for eco-innovation into three groups: government, business, and civil society.

Companies must configure networks that enable them to achieve sustainability without neglecting the market, developing the concept of Corporate Social Responsibility (CSR) [125]. Civil society expresses itself through pressure on actors, who, in the struggle to fulfill their duties, develop a collective moral and ethical consciousness evidenced in the postulates of actor-network theory (ANT), social network theory, practice theory, and stakeholder theory [28,114,126,127]. However, civil society actors are characterized by the development of free and informal relationships, so technology adoption complies with the postulates of the diffusion of innovations theory.

Individual decision-making is studied at the micro level and collectively significantly influences market dynamics. This level of analysis exposes patterns of behavior and decision-making among actors as individuals in the creation and adoption of technology (innovation as a mindset and output), acknowledging the application of theories such as cognitive theory, the concept of complementary assets, resource renewal cycles, systems theory, higher-order escalators, among others [114].

Considering organizations as commercial entities, the resource-based view (RBV) through the Natural Resource-Based View (NRBV) proposed by Hart [128] states the need for proper resource management to be coupled with the pursuit and monitoring of environmental objectives, consolidating sustainable competitive advantages over time that are aligned with the new environmental paradigm. Additionally, the capacities for technical change in corporate structures evidence the application of TRIZ methodology, design theory, eco-efficiency, and organizational creativity in technical transformation processes considering environmental indicators through eco-design.

While preserving the liberties and informal relationships of civil society, efforts to disseminate eco-innovation incorporate the tenets of stakeholder theory, social innovation, norm activation [129], value-belief-norm (VBN) theory [130], theory of planned behavior (TPB) [131], trait activation theory (TAT) [132] and theory of consumption values (TCV) [133]. These theories offer psychological and sociological approaches to studying innovation adoption, examining the individual reasons for acquisition through internal and external motivations, and finding common ground with the postulates of diffusion of innovations theory.

Barriers to Eco-Innovation

As demonstrated, the relationship between eco-innovation and innovation is close; however, not all theories include the environmental variable. Theories focused on studying individual behavior do not explore the relationship between the environmental dimension and individuals' reasoning in technology acquisition. This fact presents a series of barriers to developing and adopting eco-innovation.

When exploring eco-innovation from the perspective of innovation as an outcome of consumer and client interactions, gaps emerge where the role of the consumer in the transition towards sustainability is not investigated [134].

From a business perspective, customers are key to the development of eco-innovation, where the procurement of technology and services at different stages of the supply and value chain are strategic decisions that articulate and strengthen ties, improving the production of goods or services and their associated impacts [135].

In practice, the acquisition operation is hindered by customer and supplier resistance to change, the scarce traceability and inclusion of environmental indicators on the products or services acquired, and market preparedness [136]. The literature has explored the first two barriers through the development of eco-innovation and eco-design, but coordination difficulties persist in developing more eco-effective mechanisms [91]. This fact limits eco-design, as it fails to explore disruptive and radical innovation alternatives due to the risk in technological creation expressed in the innovation paradox theory [114,137,138]. The exploration of the third barrier is studied in the field of social innovation, which focuses on educating the population and developing infrastructures that allow sustainability to be achieved by linking civil actions and initiatives [139].

TRIZ methodology and design theory consider eco-design from the perspective of eco-efficiency, aiming to enhance technology through resource-saving and optimization. Beltrami et al. [140] established a clear example of this, linking the adoption of Industry 4.0 technologies to improved environmental performance. However, as environmental impact measurement indicators become more complex and eco-innovation mechanisms advance, selecting design parameters, tools, and objectives becomes more challenging [12].

The literature presents several cases of alternative selection applying and developing multi-criteria decision-making tools for the selection of green suppliers, the study of consumer preferences, and the development of eco-designs about new eco-innovation mechanisms [141–148], While the application of the models in other contexts has been suggested, multicriteria selection models in environmental issues remain a nascent research area. There is a pressing need for the comprehensive inclusion and evaluation of the aforementioned indicators, the genuine consideration of the company's environmental strategy, and the practical application of the designed tools [141,149].

A further problem identified is the insufficient data concerning the launch environment of the development, tied to market dynamics, regulatory frameworks, and customer adoption patterns of the technology, which involves civil society engagement [12,32,63,66]. In the case of eco-innovation and eco-design, customers do not perceive that the improvements justify the increased price and activities associated with eco-products, despite quality certifications and goodwill [150]. Regarding the business environment and industrial networks, there may be a lack of technical expertise to troubleshoot issues, information asymmetries, high adoption costs, deficiencies in industrial and government networks, and cultural rigidity [151,152]. These barriers manifest similarly to the general case of innovation, and, by diffusion theory, impact technology adoption associated primarily with the postulates of enabling conditions and social influence, where the phenomenon of norm activation and the theory of planned behavior are insufficient.

In relation to the foregoing, market preparation involves the normalization of eco-product acquisition and requires addressing purchasing decisions based on customer motivations and interests. States are responsible for creating mechanisms and policies that facilitate the development of activities associated with eco-innovation and its mechanisms by civil society, assisting the business transition in creating experiences, accompaniment, and involvement [134,136,153,154], and enabling shared responsibility between the state, business, and civil society.

CAN ECO-INNOVATION BE CONSIDERED A CASE STUDY OF INNOVATION?

Eco-innovation theories focus on achieving the greening of industries and culture, which is viewed as a problem that can be solved through the market [155]. This has enabled the evolution of certain innovation theories to consider the environmental variable, categorized at the macro and meso levels of analysis. Figure 7 illustrates the theoretical contributions of eco-innovation to the theories of innovation, organized by study approach.

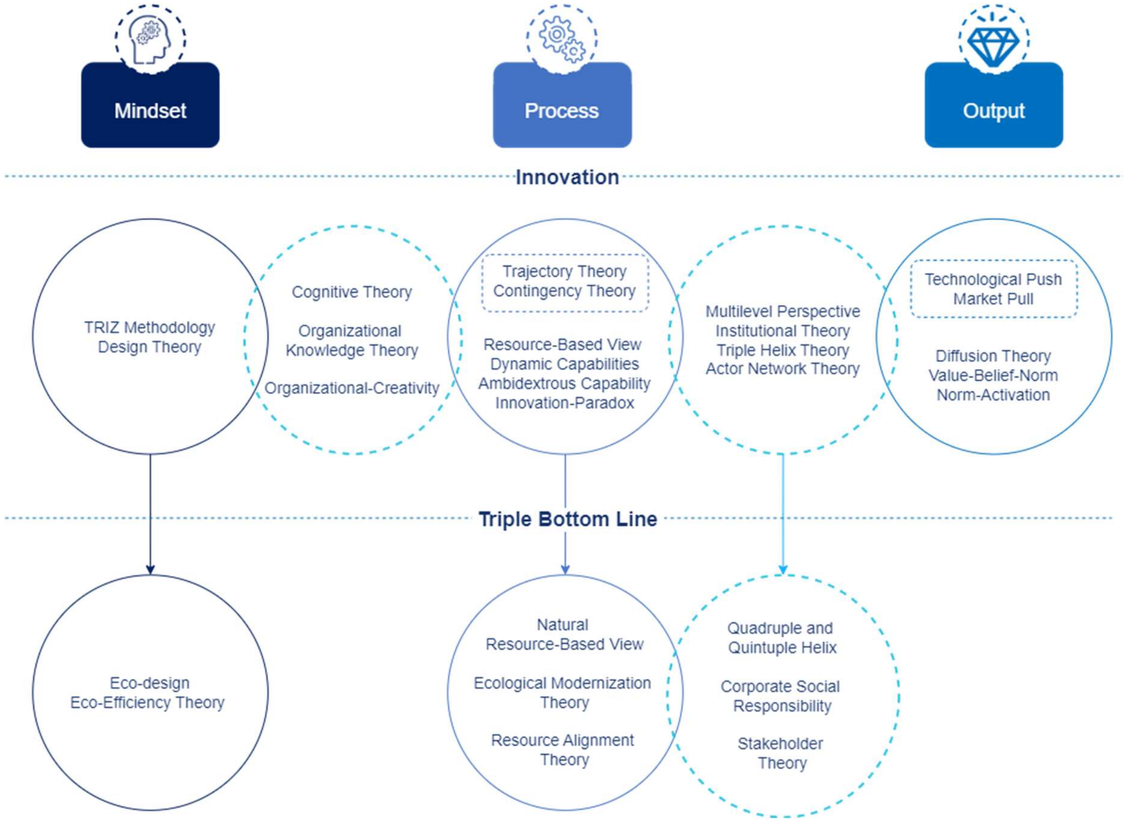

Figure 7. Theoretical development of eco-innovation. Own elaboration based on [21] and [63].

Nevertheless, no contributions or a direct connection of eco-innovation to innovation theories at the micro level of analysis are appreciated. This may be because the environmental problem is an effect of the development of human systems, where the evaluation of individual actions in the creation and adoption of technology may have a minor effect on the overall problem.

However, the development of mechanisms focused on addressing the coordination of micro-level barriers has the potential to significantly impact meso and macro-level effects, theoretically enabling the development of disruptive and radical innovations. Enabling the adoption of new eco-innovation mechanisms requires the engagement of individuals as drivers of eco-innovation, where micro-level innovation theories can be explored with a clear connection to the environmental dimension.

Thus, the emergence of eco-innovation posits that sustainability is not solely focused on the effects of the human system on the environment; it also involves the consideration of responsibility in the use of technology, acknowledging the potential threat of its misuse at micro, meso, and macro levels of analysis [156,157]. In this sense, eco-innovation is not a particular case study of innovation, as it establishes a new field of exploration in change management and technological development: shared responsibility, purpose, and the appropriate use of technology.

LIMITATIONS

The present study presents several limitations that should be considered when interpreting the results obtained. First, the nature of this literature review, although developed systematically, is limited to the knowledge available in the consulted databases. While diverse sources such as Google Scholar and Elsevier were included, it is possible that relevant studies hosted in other databases or written in languages other than English and Spanish were excluded, which could have provided valuable information or even altered the results of this study. Furthermore, no specific time frame was established for the selection of documents, which may have led to the inclusion of concepts or theories that have significantly changed in recent years, particularly in dynamic fields such as innovation and eco-design, where ideas and studies evolve rapidly.

Another aspect to consider is the methodology used to filter the documents, initially based on reviewing abstracts and conclusions. Although this method proved efficient for managing the large volume of documents collected, there is a possibility that important details contained in the main body of some works were omitted, especially those that did not pass this initial filter. The qualitative content analysis allowed for an in-depth exploration of the concepts and their interrelationships, but as it is an interpretive approach, it is subject to the perspective of the researchers, introducing a degree of subjectivity into the research. Additionally, as no complementary quantitative methodologies were employed, validating the findings through methodological triangulation was impossible.

Lastly, the keywords selected to guide the search may have excluded relevant literature that uses different terminology or employs other conceptual frameworks related to the study topics but not directly aligned with the selected terms. For this reason, it is essential that future research address these limitations, either by expanding the consulted databases, employing mixed-methods approaches, or considering different temporal and linguistic perspectives to build a more comprehensive and dynamic understanding.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Throughout the theoretical review, it has been possible to refine the definitions of innovation, eco-innovation, and eco-design concepts. Furthermore, the existing relationships between these three concepts have been observed, as well as how the different theories developed in literature are linked to examine their expression in everyday practice.

The study highlights both advancements and limitations in innovation theory concerning sustainability. It emphasizes the significant focus on studying systems at macro and meso levels yet points out the lack of connection between environmental facts from a micro perspective.

The research has demonstrated the utilization of eco-design tools and highlighted the interconnectedness of economic, social, and environmental factors in technological development and its subsequent applications. By presenting these analytical frameworks, the study aims to stimulate investigation into governmental, societal, and corporate strategies that can promote the broader adoption of eco-innovation to support sustainable human endeavors.

DATA AVAILABILITY

The dataset of the study is available from the authors upon reasonable request.

AUTHOR CONTRIBUTIONS

Conceptualization, EPS; Methodology, EPS; Software, EPS; Validation, EPS, DGM and JCH; Formal Analysis, EPS; Investigation, EPS; Resources, EPS; Data Curation, EPS; Writing—Original Draft Preparation, EPS; Writing—Review & Editing, EPS, DGM and JCH; Visualization, EPS; Supervision, DGM and JCH; Project Administration, EPS; Funding Acquisition, EPS.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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APPENDIX

Table A1. Compendium of reviewed articles.

Author(s)	Year	Title	Ref. No.
Scoones, Ian	2016	The Politics of Sustainability and Development	[1]
Kemp, Réne; Pearson, Peter	2007	Final report MEI project about measuring eco-innovation	[4]
Rossi, Marta; Germani, Michele; Zamagni, Alessandra	2016	Review of ecodesign methods and tools. Barriers and strategies for an effective implementation in industrial companies	[12]
OECD/Eurostat	2006	Manual de Oslo: Guía para la recogida e interpretación de datos sobre innovación	[16]
DNP	2021	Política Nacional De Ciencia, Tecnología e Innovación 2022–2031	[17]
OECD/Eurostat	2018	Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation	[18]
Parayil, Govindan	1991	Technological knowledge and technological change	[20]
Kahn, Kenneth B.	2018	Understanding innovation	[21]
Otto Scharmer, Claus	2001	Self-transcending knowledge: sensing and organizing around emerging opportunities	[22]
Park, Chansoo; Ghauri, Pervez N.; Lee, Jeoung Yul; Golmohammadi, Ismael	2022	Unveiling the black box of IJV innovativeness: The role of explicit and tacit knowledge transfer	[23]
Horbach, Jens; Rammer, Christian; Rennings, Klaus	2011	Determinants of eco-innovations by type of environmental impact. The role of regulatory push/pull, technology push and market pull	[24]
Kammerer, Daniel	2009	The effects of customer benefit and regulation on environmental product innovation.	[25]
Daddi, Tiberio; Testa, Francesco; Frey, Marco; Iraldo, Fabio	2016	Exploring the link between institutional pressures and environmental management systems effectiveness: An empirical study	[26]
Cui, Anna Shaojie; Griffith, David A.; Cavusgil, S. Tamer; Dabic, Marina	2006	The influence of market and cultural environmental factors on technology transfer between foreign MNCs and local subsidiaries: A Croatian illustration	[27]
Cheng, Wenjuan; Appolloni, Andrea; D’Amato, Alessio; Zhu, Qinghua	2018	Green Public Procurement, missing concepts and future trends – A critical review	[28]

Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Chen, Xiaohong; Yi, Na; Zhang, Lu; Li, Dayuan	2018	Does institutional pressure foster corporate green innovation? Evidence from China's top 100 companies	[29]
Kapoor, Kawaljeet Kaur; Dwivedi, Yogesh K.; Williams, Michael D.	2014	Examining consumer acceptance of green innovations using innovation characteristics: A conceptual approach	[30]
Rogers, Everett M.	1995	Diffusion of innovations	[31]
Venkatesh, Viswanath; Morris, Michael G; Davis, Gordon B; Davis, Fred D	2003	User Acceptance of Information Technology: Toward a Unified View	[32]
Paipa, Edwin; Escalante Torres, Felipe; Adarme Jaimes, Wilson; Coronado Hernandez, Jairo	2024	Exploring Innovation Capabilities in Organizations through a Scientometric Approach in the Context of Manufacturing Industry	[33]
Mardani, Amirhosein; Nikoosokhan, Saghi; Moradi, Mahmoud; Doustar, Mohammad	2018	The Relationship Between Knowledge Management and Innovation Performance	[34]
du Plessis, Marina	2007	The role of knowledge management in innovation	[35]
Venkitachalam, Krishna; Busch, Peter	2012	Tacit knowledge: review and possible research directions	[36]
Nelson, Richard R.; Winter, Sidney G.	1982	An Evolutionary Theory of Economic Change	[37]
Lam, Alice	2004	Organizational Innovation	[38]
Van de Ven, Andrew H.; Ganco, Martin; Hinings, C. R. (BOB)	2013	Returning to the Frontier of Contingency Theory of Organizational and Institutional Designs	[39]
Barney, Jay	1991	Firm Resources and Sustained Competitive Advantage	[40]
Teece, David J.; Pisano, Gary; Shuen, Amy	1997	Dynamic capabilities and strategic management	[41]
Carayannis, Elias G.; Campbell, David F.J.	2022	Towards an Emerging Unified Theory of Helix Architectures (EUTOHA): Focus on the Quintuple Innovation Helix Framework as the Integrative Device	[42]
Leydesdorff, Loet; Etzkowitz, Henry	1996	Emergence of a Triple Helix of university—industry—government relations	[43]
Milfont, Taciano L; Markowitz, Ezra	2016	Sustainable consumer behavior: a multilevel perspective	[44]

Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Delvenne, Pierre; Thoreau, François	2012	Beyond the “Charmed Circle” of OECD: New Directions for Studies of National Innovation Systems	[45]
Fiol, C. Marlene	2017	Intraorganizational Cognition and Interpretation	[46]
Brown, John Seely; Duguid, Paul	1991	Organizational Learning and Communities-of-Practice: Toward a Unified View of Working, Learning, and Innovation	[47]
Nonaka, Ikujiro; Takeuchi, Hirotaka; Umemoto, Katsuhiro	1996	A theory of organizational knowledge creation	[48]
Ilevbare, Imoh M.; Probert, David; Phaal, Robert	2013	A review of TRIZ, and its benefits and challenges in practice	[49]
Baskerville, Richard; Pries-Heje, Jan	2010	Explanatory Design Theory	[50]
Ekmekci, Ismail; Nebati, Emine Elif	2019	Triz Methodology and Applications	[51]
Mankins, John C	1995	Technology Readiness Levels	[52]
Berry, M. M. J.; Taggart, J. H.	1994	Managing technology and innovation: a review	[53]
Agar, Jon	2020	What is technology?	[54]
Sauser, Brian; Verma, Dinesh; Ramirez-Marquez, Jose; Gove, Ryan	2006	From TRL to SRL: The Concept of Systems Readiness Levels	[55]
Lindgren, Peter	2018	Disruptive, Radical and Incremental Multi Business Model Innovation	[57]
OECD	2011	Fostering Innovation for Green Growth	[58]
Shestakov, D; Poliarush, O	2019	The Degree of Innovation: Through Incremental to Radical	[59]
Chalmers, A. F.	1999	Cap. 1. Science as knowledge derived from the facts of experience	[60]
Manterola, Carlos; Otzen H, Tamara	2013	Porqué Investigar y Cómo Conducir una Investigación	[61]
Kongsvik, Trond; Haavik, Torgeir; Bye, Rolf; Almklov, Petter	2020	Re-boxing seamanship: From individual to systemic capabilities	[62]
Gupta, Himanshu; Kusi-Sarpong, Simonov; Rezaei, Jafar	2020	Barriers and overcoming strategies to supply chain sustainability innovation	[63]

Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Turner, James A.; Klerkx, Laurens; White, Toni; Nelson, Tracy; Everett-Hincks, Julie; Mackay, Alec; Botha, Neels	2017	Unpacking systemic innovation capacity as strategic ambidexterity: How projects dynamically configure capabilities for agricultural innovation	[64]
Willis, Cameron D.; Riley, Barbara L.; Stockton, Lisa; et al.	2016	Scaling up complex interventions: insights from a realist synthesis	[65]
Breaugh, Jessica; McBride, Keegan; Kleinaltenkamp, Moritz; Hammerschmid, Gerhard	2021	Beyond Diffusion: A Systematic Literature Review of Innovation Scaling	[66]
Mankiw, N. Gregory	2012	Los diez principios de la economía	[67]
Cheng, Colin C; Shiu, Eric C.	2012	Validation of a proposed instrument for measuring eco-innovation: An implementation perspective	[68]
Doranova, Asel; Roman, Laura; Bahn-Walkowiak, Bettina; Wilts, Henning; O'Brien, Meghan; Giljum, Stefan; Ann Kong, Mary; Hestin, Mathieu	2016	Policies and Practices for Eco-Innovation Up-take and Circular Economy Transition	[69]
Cainelli, Giulio; Mazzanti, Massimiliano; Montresor, Sandro	2012	Environmental Innovations, Local Networks and Internationalization	[70]
Hermann, Roberto; Wigger, Karin	2017	Eco-Innovation Drivers in Value-Creating Networks: A Case Study of Ship Retrofitting Services	[71]
Oltra, Vanessa; Saint Jean, Maïder	2009	Sectoral systems of environmental innovation: An application to the French automotive industry	[72]
Menon, Ajay; Menon, Anil	1997	Enviropreneurial Marketing Strategy: The Emergence of Corporate Environmentalism as Market Strategy	[73]
Chen, Yu-Shan; Lai, Shyh-Bao; Wen, Chao-Tung	2006	The Influence of Green Innovation Performance on Corporate Advantage in Taiwan	[74]
Schiederig, Tim; Tietze, Frank; Herstatt, Cornelius	2012	Green innovation in technology and innovation management – an exploratory literature review	[75]
Dyllick, Thomas; Hockerts, Kai	2002	Beyond the business case for corporate sustainability	[76]

Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Muñoz-Pascual, Lucía; Curado, Carla; Galende, Jesús	2019	The Triple Bottom Line on Sustainable Product Innovation Performance in SMEs: A Mixed Methods Approach	[77]
Żak, Agnieszka	2015	Triple bottom line concept in theory and practice	[78]
Hormio, Säde	2017	Climate change mitigation, sustainability and non-substitutability	[79]
Pansera, Mario	2011	The Origins and purpose of Eco-Innovation	[80]
Sodhi, Navjot S.; Brook, Barry W.; Bradshaw, Corey J. A.	2009	Causes and Consequences of Species Extinctions	[81]
Valiente-Banuet, Alfonso; Aizen, Marcelo A.; Alcántara, Julio M., et al.	2015	Beyond species loss: the extinction of ecological interactions in a changing world	[82]
Caiado, Rodrigo Goyannes Gusmão; de Freitas Dias, Raquel; Mattos, Lisiane Veiga; Quelhas, Osvaldo Luiz Gonçalves; Leal Filho, Waler	2017	Towards sustainable development through the perspective of eco-efficiency—A systematic literature review	[83]
Ehrenfeld, John R	2005	Eco-efficiency: Philosophy, Theory, and Tools	[84]
Fedorova, Elena; Caló, Antonio; Pongrácz, Eva	2019	Balancing Socio-Efficiency and Resilience of Energy Provisioning on a Regional Level, Case Oulun Energia in Finland	[85]
Barbiroli, Giancarlo	2006	Eco-efficiency or/and eco-effectiveness? Shifting to innovative paradigms for resource productivity	[86]
Zavestoski, Stephen	2001	Environmental Concern and Anti-consumerism in the Self-Concept	[87]
Abbas, Jawad	2020	Impact of total quality management on corporate sustainability through the mediating effect of knowledge management	[88]
Green, Kenneth W.; Inman, R. Anthony; Sower, Victor E.; Zelbst, Pamela J.	2019	Impact of JIT, TQM and green supply chain practices on environmental sustainability	[89]
Folke, Carl; Hahn, Thomas; Olsson, Per; Norberg, Jon	2005	Adaptive Governance of Social-Ecological Systems	[90]
Machiba, Tomoo	2011	Eco-Innovation for Enabling Resource Efficiency and Green Growth: Development of an Analytical Framework and Preliminary Analysis of Industry and Policy Practices	[91]

Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Giannetti, B.F.; Agostinho, F.; Eras, J.J. Cabello; Yang, Zhifeng; Almeida, C.M.V.B.	2020	Cleaner production for achieving the sustainable development goals	[92]
Müller, Kaspar; Sturm, Andreas	2001	Standardized Eco-Efficiency Indicators. Report 1: Concept Paper	[93]
Low, Jonathan Sze Choong; Lu, Wen Feng; Song, Bin	2014	Product Structure-Based Integrated Life Cycle Analysis (PSILA): a technique for cost modelling and analysis of closed-loop production systems	[94]
Govindan, Kannan; Soleimani, Hamed	2017	A review of reverse logistics and closed-loop supply chains: a Journal of Cleaner Production focus	[95]
Graedel, T E	1996	On The Concept of Industrial Ecology	[96]
Huber, Joseph	2000	Towards industrial ecology: sustainable development as a concept of ecological modernization	[97]
Hanim Mohamad Zailani, Suhaiza; Eltayeb, Tarig K.; Hsu, Chin-Chun; Choon Tan, Keah	2012	The impact of external institutional drivers and internal strategy on environmental performance	[98]
Vallet, Flore; Eynard, Benoît; Millet, Dominique; Mahut, Stéphanie; Tyl, Benjamin; Bertoluci, Gwenola	2013	Using eco-design tools: An overview of experts' practices	[99]
Fernando, Yudi; Wah, Wen Xin; Shaharudin, Muhammad Shabir	2016	Does a firm's innovation category matter in practising eco-innovation? Evidence from the lens of Malaysia companies practicing green technology	[100]
OECD	1998	Towards Sustainable Development	[101]
Ministry of Science, Technology and Innovation of Colombia	2021	Banco de indicadores para el proceso de licenciamiento ambiental	[102]
Van Bueren, Ellen; De Jong, Jitske	2007	Establishing sustainability: policy successes and failures	[103]
Ramesh, Varsha; Toffel, Michael W.	2023	What Every Leader Needs to Know About Carbon Credits	[104]
Cerdá, Emilio; Khalilova, Aygun	2016	Economía Circular	[105]
Kristensen, Heidi Simone; Mosgaard, Mette Alberg	2020	A review of micro level indicators for a circular economy—moving away from the three dimensions of sustainability?	[106]

Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Baumeister, Dayna; Tocke, Rose; Dwyer, Jamie; Ritter, Sherry; Benyus, Janine	2014	Biomimicry Resource Handbook: A Seed Bank of Best Practices	[107]
Mendoza, Joan Manuel F; Sharmina, Maria; Gallego-Schmid, Alejandro; Heyes, Graeme; Azapagic, Adisa	2017	Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework	[108]
UNEP	2009	Design for sustainability: a step-by-step approach	[109]
Rocha, Cristina Sousa; Antunes, Paula; Partidário, Paulo	2019	Design for sustainability models: A multiperspective review	[110]
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Hazarika, Natasha; Zhang, Xiaoling	2019	Evolving theories of eco-innovation: A systematic review	[114]
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Porter, Michael E; Van Der Linde, Claas	1995	Toward a New Conception of the Environment-Competitiveness Relationship	[118]
Bakshi, Bhavik R.	2019	Business and the Environment	[119]
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Author(s)	Year	Title	Ref. No.
Colapinto, Cinzia; Porlezza, Colin	2012	Innovation in Creative Industries: from the Quadruple Helix Model to the Systems Theory	[122]
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Huang, Jing-Wen; Li, Yong-Hui	2018	How resource alignment moderates the relationship between environmental innovation strategy and green innovation performance	[124]
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Hart, Stuart L	1995	A Natural Resource-Based View of the Firm	[128]
Schwartz, Shalom H.	1977	Normative Influences on Altruism	[129]
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Ajzen, Icek	2012	The Theory of Planned Behavior	[131]
Tett, Robert P.; Toich, Margaret J.; Ozkum, S. Burak	2021	Trait Activation Theory: A Review of the Literature and Applications to Five Lines of Personality Dynamics Research	[132]
Sheth, Jagdish N; Newman, Bruce I; Gross, Barbara L	1991	Why We Buy What We Buy: A Theory of Consumption Values	[133]
Bag, Surajit; Wood, Lincoln C; Xu, Lei; Dhamija, Pavitra; Kayikci, Yaşanur	2020	Big data analytics as an operational excellence approach to enhance sustainable supply chain performance	[134]
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Viale, Laurence; Vacher, Stéphano; Bessouat, Jeanne	2022	Eco-innovation in the upstream supply chain: re-thinking the involvement of purchasing managers	[136]
Oughton, Christine; Landabaso, Mikel; Morgan, Kevin	2002	The Regional Innovation Paradox: Innovation Policy and Industrial Policy	[137]

Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Zeng, Delin; Hu, Jingbo; Ouyang, Taohua	2017	Managing Innovation Paradox in the Sustainable Innovation Ecosystem: A Case Study of Ambidextrous Capability in a Focal Firm	[138]
Frantzeskaki, Niki; Dumitru, Adina; Anguelovski, Isabelle; et al.	2016	Elucidating the changing roles of civil society in urban sustainability transitions	[139]
Beltrami, Mirjam; Orzes, Guido; Sarkis, Joseph; Sartor, Marco	2021	Industry 4.0 and sustainability: Towards conceptualization and theory	[140]
Abdulla Alajami Alshamry, Maha Taha	2021	Modeling and Evaluation of Supplier Selection for Green Supply Chain using MCDA	[141]
Chica, Manuel; Hermann, Roberto Rivas; Lin, Ning	2023	Adopting different wind-assisted ship propulsion technologies as fleet retrofit: An agent-based modeling approach	[142]
Ziemba, Paweł	2021	Selection of Electric Vehicles for the Needs of Sustainable Transport under Conditions of Uncertainty—A Comparative Study on Fuzzy MCDA Methods	[143]
Oliveira, Gabriela D.; Dias, Luis C.	2020	The potential learning effect of a MCDA approach on consumer preferences for alternative fuel vehicles	[144]
Ren, Jingzheng; Lützen, Marie	2015	Fuzzy multi-criteria decision-making method for technology selection for emissions reduction from shipping under uncertainties	[145]
Solesvik, Marina Z.	2018	Partner Selection in Green Innovation Projects	[146]
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Wątróbski, Jarosław	2016	Outline of Multicriteria Decision-making in Green Logistics	[148]
Barrak, Erika; Rodrigues, Carla; Antunes, Carlos Henggeler; Freire, Fausto; Dias, Luis C.	2024	Applying multi-criteria decision analysis to combine life cycle assessment with circularity indicators	[149]
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Table A1. *Cont.*

Author(s)	Year	Title	Ref. No.
Mercado Caruso, Nohora	2021	Determinantes de eco-innovación en clústers industriales. Una aplicación empírica en el departamento del Atlántico	[151]
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