UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Driving sustainable development: eco-innovation systems and public policies

Doctoral thesis

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València, March 2024

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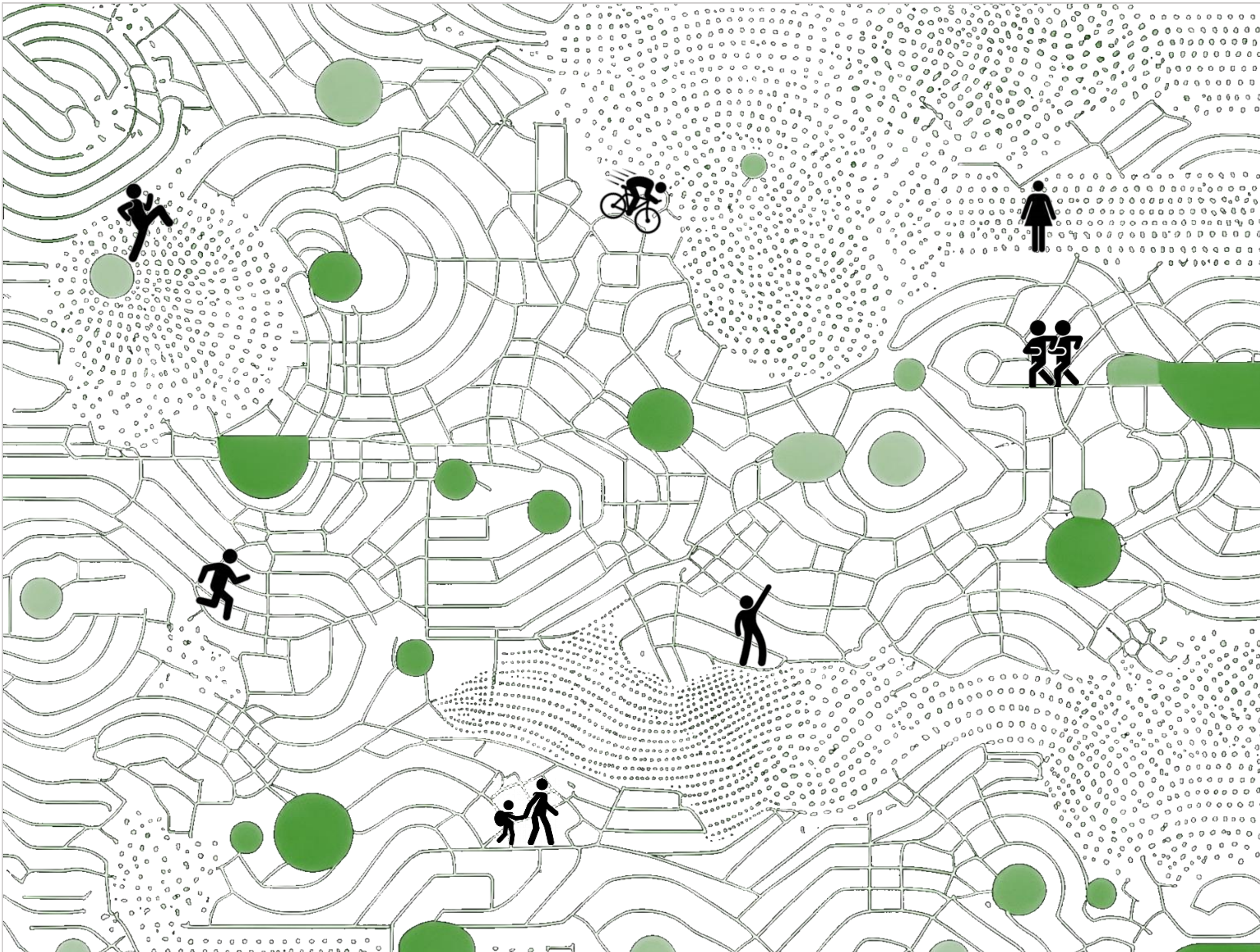

Department of Economics and Social Sciences

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presented by

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a mi familia y amigos,

a mi madre y mi yayo

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Abstract

Economic growth and competitiveness have been established at the forefront of the political agenda since the beginning of the economic development theories. Countries have tried to drive economic growth and competitiveness through the adoption of innovation policies. However, society's new demands arising from sustainable development challenges (e.g., climate change, poverty, or COVID-19 pandemic) call for a progress based on sustainability principles and the well-being of the world population. Inequalities among countries and people need to be significantly reduced and, in the best case, removed. The growing interest for sustainable development in all fields of society also demands innovation processes and activities. Innovation should be based on the economic, social, and environmental dimensions of sustainability. This is why the importance of concepts such as eco-innovation has risen during the last decades.

Achieving sustainable development through eco-innovation strategies is influenced by a multitude of factors, which also interact with each other, adding complexity to the eco-innovation process. These interactions occur within the frontiers of innovation systems defined by unique characteristics that depend on their geographical context. This variety of national or regional characteristics obliges to target eco-innovation policies. Understanding local characteristics is needed for the effective establishment of eco-innovation policies.

The thesis is based on a research agenda that considers a variety of elements associated with eco-innovation and analyzes which national characteristics trigger differences in eco-innovative performance to achieve sustainable development. The new perspectives on eco-innovation policies and strategies supply knowledge to help create new opportunities in response to climate challenges and the goals established in the 2030 Agenda.

This thesis is structured in four chapters, each one corresponding to a scientific article. Three of them have been already published in international journals. Each chapter addresses a particular aspect to meet the thesis' aims. Its main objective is to determine the connection between sustainable development, eco-innovation, and innovation systems by studying the complexity of (i) sustainability and innovation dimensions integrated into eco-innovation processes, (ii) the interaction among innovation system agents, and (iii) the socio-economic context and specific characteristics of individual countries. This three-fold connection was analyzed through four methodologies which were applied at a three-step approach. The hypothetical link between sustainable development and innovation and its facilitators was established through multiple linear regression and cluster analyses (Chapter 2). By using bibliometric methods, the current state of the literature that simultaneously studies eco-innovation and innovation systems was examined to identify the possible research avenues or possibilities on eco-innovation systems (Chapter 3). Finally, fuzzy-set qualitative comparative analysis (fsQCA) provided perspectives on how eco-innovation is explained through the interaction of factors and agents within eco-innovation systems (Chapters 4 and 5).

The conclusions of this study emphasize the need for a transition towards circular economy and sustainability models where economic growth is controlled and monitored to avoid environmental degradation. In this transition towards sustainable development, national characteristics adopt a prominent role when applying eco-innovation and sustainability strategies. In this sense, the wide variety of national contexts and the existence of limited resources for countries call for a deep understanding of eco-innovation systems. This deep understanding could reduce the complexity and uncertainty inherent to eco-innovation and the relationships emerged among the agents of innovation systems that stimulate or hamper eco-innovation activities. Therefore, the success of eco-innovation and the subsequent sustainable development achievement would be ensured by establishing tailored eco-innovation and sustainability policies adapted to the characteristics of each national eco-innovation system. Through the combination of knowledge gained from the analysis of national eco-innovation systems and participation in international collaboration, world inequalities in terms of sustainable development and well-being could be reduced.

Keywords. Eco-innovation, innovation system, eco-innovation system, sustainability, sustainable development, economic growth, environmental degradation, human capital, R&D investment, research institutions, collaboration

Resumen

El crecimiento económico y la competitividad se han establecido en la vanguardia de la agenda política desde el inicio de las teorías del desarrollo económico. Los países han tratado de impulsar el crecimiento económico y la competitividad mediante la adopción de políticas de innovación. Sin embargo, las nuevas demandas de la sociedad derivadas de los retos del desarrollo sostenible (por ejemplo, el cambio climático, la pobreza o la COVID-19 pandemia) exigen un progreso basado en los principios de sostenibilidad y en el bienestar de la población mundial. Las desigualdades entre países y personas deben reducirse significativamente y, en el mejor de los casos, eliminarse. El creciente interés por el desarrollo sostenible en todos los ámbitos de la sociedad exige también procesos y actividades de innovación. La innovación debe basarse en las dimensiones económica, social y medioambiental de la sostenibilidad. Por eso, la importancia de conceptos como la eco-innovación ha aumentado en las últimas décadas.

La consecución de un desarrollo sostenible mediante estrategias de eco-innovación se ve influida por multitud de factores, que, además, interactúan entre sí, lo que añade complejidad al proceso de eco-innovación. Estas interacciones se producen dentro de las fronteras de sistemas de innovación definidos por características únicas que dependen de su contexto geográfico. Esta variedad de características nacionales o regionales obliga a orientar las políticas de eco-innovación. En este sentido, la comprensión de las características locales es necesaria para el establecimiento eficaz de políticas de eco-innovación.

La tesis se basa en una agenda de investigación que considera una variedad de elementos asociados a la eco-innovación y analiza qué características nacionales desencadenan diferencias en el desempeño eco-innovador para alcanzar el desarrollo sostenible. Las nuevas perspectivas sobre políticas y estrategias de eco-innovación aportan conocimiento para ayudar a crear nuevas oportunidades en respuesta a los desafíos climáticos y los objetivos establecidos en la Agenda 2030.

Esta tesis se estructura en cuatro capítulos, correspondiendo cada uno de ellos a un artículo científico. Tres de ellos ya han sido publicados en revistas internacionales. Cada capítulo aborda un aspecto concreto para cumplir los objetivos de la tesis. Su objetivo principal consiste en determinar la conexión entre el desarrollo sostenible, la eco-innovación y los sistemas de innovación, estudiando la complejidad de (i) las dimensiones

de la sostenibilidad y la innovación integradas en la eco-innovación, (ii) la interacción entre los agentes del sistema de innovación y (iii) el contexto socioeconómico y las características específicas de cada país. Esta triple conexión se analizó a través de cuatro metodologías que se aplicaron en un enfoque de tres pasos. El posible vínculo entre desarrollo sostenible e innovación y sus facilitadores se estableció mediante una regresión lineal múltiple y el análisis clúster (Capítulo 2). Por medio de métodos bibliométricos, se examinó el estado actual de la bibliografía que estudia simultáneamente la eco-innovación y los sistemas de innovación para identificar posibles vías o alternativas de investigación sobre los sistemas de eco-innovación (Capítulo 3). Por último, el análisis comparativo cualitativo de conjuntos difusos (fsQCA, por sus siglas en inglés) aportó perspectivas sobre cómo se explica la eco-innovación a través de la interacción de factores y agentes dentro de los sistemas de eco-innovación (Capítulos 4 y 5).

Las conclusiones de este estudio resaltan la necesidad de una transición hacia modelos de economía circular y sostenibilidad en los que el crecimiento económico se controle y supervise para evitar la degradación del medio ambiente. En esta transición hacia el desarrollo sostenible, las características nacionales adoptan un papel primordial a la hora de implementar estrategias de eco-innovación y sostenibilidad. En este sentido, la gran variedad de contextos nacionales y la existencia de recursos limitados requiere que los países obtengan una comprensión en profundidad de los sistemas de eco-innovación. Esta comprensión podría reducir la complejidad e incertidumbre inherentes a la eco-innovación y a las relaciones surgidas entre los agentes de los sistemas de innovación que estimulan u obstaculizan las actividades de eco-innovación. Por lo tanto, el éxito de la eco-innovación y el consiguiente logro del desarrollo sostenible se garantizarían estableciendo políticas de eco-innovación y sostenibilidad adaptadas a las características de cada sistema nacional de eco-innovación. Mediante la combinación de los conocimientos adquiridos a partir del análisis de los sistemas nacionales de eco-innovación y la participación en la colaboración internacional, podrían reducirse las desigualdades entre países en términos de desarrollo sostenible y bienestar.

Palabras clave. Eco-innovación, sistema de innovación, sistema de eco-innovación, sostenibilidad, desarrollo sostenible, crecimiento económico, degradación medioambiental, capital humano, inversión en I+D, instituciones de investigación, colaboración

Resum

El creixement econòmic i la competitivitat s'han establit en l'avantguarda de l'agenda política des de l'inici de les teories de desenvolupament econòmic. Els països han tractat d'impulsar el creixement econòmic i la competitivitat mitjançant l'adopció de polítiques d'innovació. No obstant això, les noves demandes de la societat derivades dels reptes del desenvolupament sostenible (per exemple, el canvi climàtic, la pobresa o la COVID-19 pandèmia) exigeixen un progrés basat en els principis de sostenibilitat i en el benestar de la població mundial. Les desigualtats entre països i persones han de reduir-se significativament i, en el millor dels casos, eliminar-se. El creixent interés pel desenvolupament sostenible en tots els àmbits de la societat exigeix també processos i activitats d'innovació. La innovació ha de basar-se en les dimensions econòmica, social i mediambiental de la sostenibilitat. Per això, la importància de conceptes com l'eco-innovació ha augmentat en les últimes dècades.

La consecució d'un desenvolupament sostenible mitjançant estratègies d'eco-innovació es veu influïda per multitud de factors que, a més, interactuen entre si, la qual cosa afegeix complexitat al procés d'eco-innovació. Aquestes interaccions es produeixen dins de les fronteres de sistemes d'innovació definits per característiques úniques que depenen del seu context geogràfic. La varietat de característiques nacionals i regionals obliga a orientar les polítiques d'eco-innovació. En aquest sentit, la comprensió de les característiques locals és necessària per a l'establiment eficaç de polítiques d'eco-innovació.

La tesi es basa en una agenda d'investigació que considera una varietat d'elements associats a l'eco-innovació i analitza quines característiques nacionals desencadenen diferències en l'acompliment eco-innovador per a aconseguir el desenvolupament sostenible. Les noves perspectives sobre polítiques i estratègies d'eco-innovació aporten coneixement per a ajudar a crear noves oportunitats en resposta als desafiaments climàtics i els objectius establits en l'Agenda 2030.

Aquesta tesi s'estructura en quatre capítols, corresponent cadascun d'ells a un article científic. Tres d'ells ja han sigut publicats en revistes internacionals. Cada capítol aborda un aspecte concret per a complir els objectius de la tesi. El seu objectiu principal consisteix a determinar la connexió entre el desenvolupament sostenible, l'eco-innovació i els sistemes d'innovació, estudiant la complexitat de (i) les dimensions de la sostenibilitat

i la innovació integrades en l'eco-innovació, (ii) la interacció entre els agents del sistema d'innovació i (iii) el context socioeconòmic i les característiques específiques de cada país. Aquesta triple connexió es va analitzar a través de quatre metodologies que es van aplicar en un enfocament de tres passos. El possible vincle entre desenvolupament sostenible i innovació i els seus facilitadors es va establir mitjançant una regressió lineal múltiple i l'anàlisi clúster (Capítol 2). Per mitjà de mètodes bibliomètrics, es va examinar l'estat actual de la bibliografia que estudia simultàniament l'eco-innovació i els sistemes de innovació per a identificar possibles vies o alternatives d'investigació sobre els sistemes d'eco-innovació (Capítol 3). Finalment, l'anàlisi comparativa qualitativa de conjunts difusos (fsQCA per les seues sigles en anglés), va aportar perspectives sobre com s'explica l'eco-innovació a través de la interacció de factors i agents dins dels sistemes d'eco-innovació (Capítols 4 i 5).

Les conclusions d'aquest estudi ressalten la necessitat d'una transició cap a models d'economia circular i sostenibilitat en els quals el creixement econòmic es controle i supervise per a evitar la degradació del medi ambient. En aquesta transició cap al desenvolupament sostenible, les característiques nacionals adopten un paper primordial a l'hora d'implementar estratègies d'eco-innovació i sostenibilitat. En aquest sentit, la gran varietat de contextos nacionals i l'existència de recursos limitats requereix que els països obtinguen una comprensió en profunditat dels sistemes d'eco-innovació. Aquesta comprensió podria reduir la complexitat i incertesa inherents a l'eco-innovació i a les relacions sorgides entre els agents dels sistemes d'innovació que estimulen o obstaculitzen les activitats d'eco-innovació. Per tant, l'èxit de l'eco-innovació i el consegüent assoliment del desenvolupament sostenible es garantirien establint polítiques d'eco-innovació i sostenibilitat adaptades a les característiques de cada sistema nacional d'eco-innovació. Mitjançant la combinació dels coneixements adquirits a partir de l'anàlisi dels sistemes nacionals d'eco-innovació i la participació en la col·laboració internacional, podrien reduir-se les desigualtats entre països en termes de desenvolupament sostenible i benestar.

Paraules clau. Eco-innovació, sistema d'innovació, sistema d'eco-innovació, sostenibilitat, desenvolupament sostenible, creixement econòmic, degradació mediambiental, capital humà, inversió en I+D, institucions d'investigació, col·laboració

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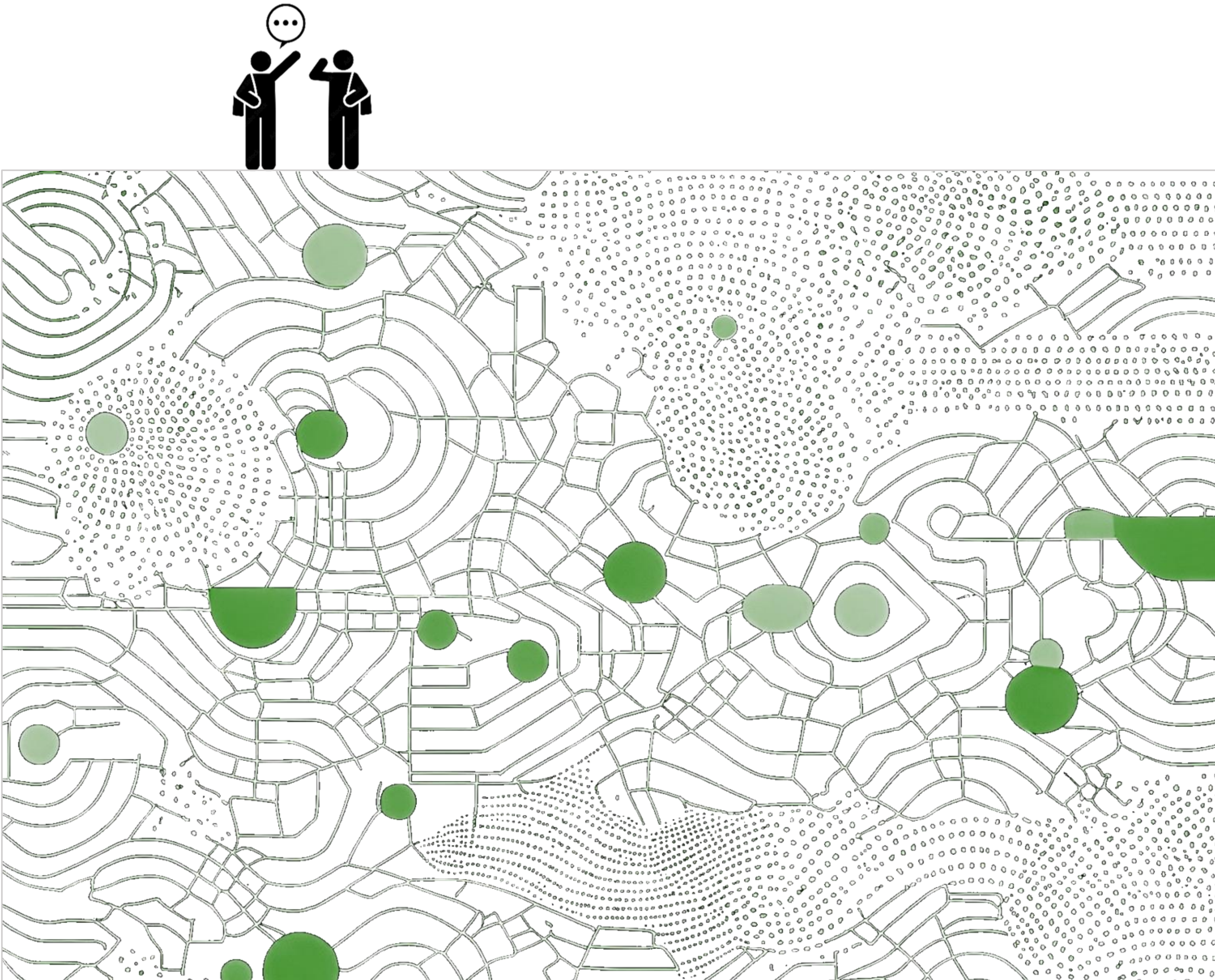
Chapter 1. Introduction



Chapter 1. Introduction

1.1. Introduction

For decades, countries and supranational organizations have been adopting innovation policies to drive economic growth, competitiveness, and business activities (López-Rubio et al., 2021; Odei & Appiah, 2023). However, country characteristics vary. Thus, comparing performance and imitating the strategies of other nations may lead to misguided policy application and thus poor regional development. Such a scenario prevents the reduction of inequalities between countries (Asheim et al. 2011). The influence of socioeconomic factors on innovation development depends on context (Tabrizian, 2019; Lu et al., 2020). The literature highlights the need for in-depth study of local innovation systems to avoid misconceptions in innovation policies and guarantee their success. Following different authors (Freeman, 1987; Mieg, 2012; Lundvall, 2016), it is important to conceptualize innovation systems as the set of unique characteristics that shape the activities, actions, and decisions that take place within the boundaries of a country or region. Within these boundaries, agents and institutions build relationships and interconnections through which they contribute to developing and introducing new technologies and knowledge.

Society constantly faces challenges that hinder its ability to meet its own current needs and may even limit the opportunities of future generations. The COVID-19 pandemic and climate change are prominent examples of how globalization and human activity lead to negative impacts worldwide, despite their economic benefits (Pan et al., 2021). These global societal challenges require innovation strategies that not only focus on the traditional solution of economic growth but also promote other dimensions of sustainability (i.e. social and environmental). The World Commission on Environment and Development introduced the concept of sustainable development to the political setting. Since then, other international organizations, such as the United Nations (UN) or the European Union (EU), have expressed their concern for sustainable development.

Sustainable development and innovation are not separate dimensions to deal with present global challenges. Innovation can make essential contributions on the path to achieving sustainable development by fostering economic growth while tackling social and environmental problems (Han et al., 2023). However, these positive contributions can only be achieved if innovation incorporates economic, social, and environmental principles. In recent decades, political and social awareness and concern on sustainable development has increased and has been progressively associated with innovation processes (Díaz-García et al., 2015; Hojnik & Ruzzier, 2016; Păcesilă & Ciocoiu, 2017). This greater awareness has led to the rise of new innovation concepts covering the three dimensions of sustainability. In this thesis, we focus on some of these concepts, such as eco-innovation.

Most of the literature highlights the role of the environmental dimension in eco-innovation due to its potential to mitigate the negative environmental effects of human activity (Horbach, 2016; Koseoglu et al., 2022). This eco-innovation idea aims to generate new processes and services that improve environmental quality, enhancing people's well-being and quality of life. Accordingly, eco-innovation has become a way of boosting prosperity on three levels: economic, social, and environmental. The holistic nature of eco-innovation means that it favors a transition from traditional growth-based development to circular and sustainable development models (Scarpellini et al., 2020). This thesis refers to eco-innovation as the type of innovation that simultaneously boosts the economic, social, and environmental dimensions of sustainability. This includes, of course, innovations that are explicitly labelled as "eco" and many other types of innovation that are more generic in their conceptualization (e.g., marketing innovation) but that also have positive effects on sustainable development.

Because eco-innovation combines sustainability and innovation, it also entails the complexity and uncertainty of both of these phenomena. This complexity and uncertainty, together with the need for a finer-grained understanding of national contexts, is a challenge for the design and implementation of eco-innovation policies. Eco-innovation is a systemic and dynamic process where different agents and actors interact and engage in relationships (Pacheco et al., 2018) that develop within innovation systems. Interaction among agents supports the success of eco-innovation by making the flow of information, knowledge, and technology easier

(Alaie, 2020). The literature identifies a myriad of factors that encourage eco-innovation. Within innovation systems, these factors interact with each other, which increases the complexity of studying and understanding eco-innovation.

While numerous studies have identified and examined the factors that influence eco-innovation (e.g. Horbach, 2008; Díaz-García et al., 2015; Hojnik & Ruzzier, 2016), few have considered the interaction between these factors as important in enabling or hindering eco-innovation development. Given the complexity involved in the interactions between factors, it is reasonable to conclude that eco-innovation cannot be studied if the relationships among the elements and agents of innovation systems are ignored. The integrated analysis of eco-innovation systems (by studying eco-innovation as well as the factors that drive it within innovation systems) can lead to the adoption of policies that effectively promote eco-innovation and thus sustainable development. Specifically, it is important to consider the complexity of (i) sustainability and innovation in eco-innovation, (ii) the interactions among innovation system agents, and (iii) the context and individual characteristics of countries.

1.2. Objective

The growing importance of sustainable development in the international context has led to an increase in literature addressing alternative models at the business, regional, and national levels. This scientific literature aims to provide insights that improve the understanding of sustainable development and related initiatives such as eco-innovation. From this understanding, policymakers and society can adopt sustainability principles on which to base their decision making. As explained earlier, eco-innovation is a multidimensional concept involving numerous actors with different aims and situations. However, to the best of our knowledge, innovation systems and sustainability (in terms of eco-innovation) have rarely been studied together. This feature of the present thesis is what makes it original and unique.

Therefore, the ***general objective*** of this thesis is to provide joint analysis of sustainable development, eco-innovation, and the elements that constitute innovation systems. The interaction among factors of eco-innovation systems is described with the aim of ensuring the effective implementation of eco-innovation policies and strategies adapted to the context of each country or region. This tailored implementation would boost eco-innovation and help achieve sustainable development.

This general objective is divided into ***five specific objectives***.

- **O1.** To assess how innovation facilitators explain national sustainable development and the extent to which they do so.
- **O2.** To examine differences between country groups based on the degree of SDG achievement and innovation facilitators.
- **O3.** To provide an overview and exploration of the literature that jointly examines eco-innovation and innovation systems.
- **O4.** To determine the national-level factors that lead to high or low levels of eco-innovation in European countries.
- **O5.** To determine the national-level factors that improve or worsen eco-innovation in European countries.

1.3. Structure

This thesis has six chapters. Chapter 1 contextualizes the research, objectives, methodologies, and structure. Chapters 2, 3, 4, and 5 describe the four studies that together form the core of the thesis. Three of these studies have been published in international journals, two of which are indexed in the Journal Citations Report (JCR) and one of which is indexed in the Scimago Journal Ranking (SJR). Each chapter addresses one or more of the specific objectives in an attempt to meet the general objective. Chapter 6 offers concluding remarks, limitations, and future research avenues to build on this thesis.

Chapter 2, "Innovation facilitators and sustainable development: a country comparative approach", was published in *Environment, Development and Sustainability* (*Springer*; JCR Q2 and SJR Q1, 2022). It focuses on determining the relationship between innovation facilitators and sustainable development in terms of national characteristics. As an initial step, it was important to identify the connection between innovation and sustainable development by analyzing how a country's innovation facilitators, which drive innovative performance, affect sustainable development achievement.

This paper had two objectives. The first was to evaluate the extent to which innovation facilitators explain sustainable development. Countries were grouped into four clusters according to their innovation and sustainability characteristics. Each country cluster was evaluated to observe whether the importance of innovation facilitators changed depending on the degree of sustainable development achievement of each country. Two multiple linear regression analyses were conducted: one for the overall sample and another for each cluster. These analyses show not only that there is a connection between innovation and sustainable development but also that the importance of innovation facilitators depends on a country's degree of sustainable development achievement. The second objective was to analyze movements of countries between clusters from 2015 to 2020 based on their degree of sustainable development achievement and innovation facilitators. Cluster analysis revealed that (i) countries moved between clusters depending on changes in national characteristics and that (ii) economic growth had limited power to explain sustainable development.

Chapter 3, "Driving research on eco-innovation systems: Crossing the boundaries of innovation systems", was published in the *International Journal of Innovation Studies* (*Elsevier*; SJR Q2, 2022). After showing that innovation facilitators influence sustainable development and that national characteristics influence the effective implementation of innovation policies, there was a need to examine the state of the art of research on eco-innovation and innovation systems. Therefore, sustainable innovations and national characteristics were simultaneously considered to determine the status of this knowledge field.

Chapter 3 explores the literature on the intersection of the topics of eco-innovation and innovation systems through bibliometric analyses. The research gaps, trends, and theoretical references (scientific publications and authors) underpinning this literature are identified. The chapter offers an overview with insights that contribute to the study of eco-innovation systems, indicating that research on both of these topics together is scarce. Policymakers are provided with essential knowledge for applying tailor-made eco-innovation policies for each national context.

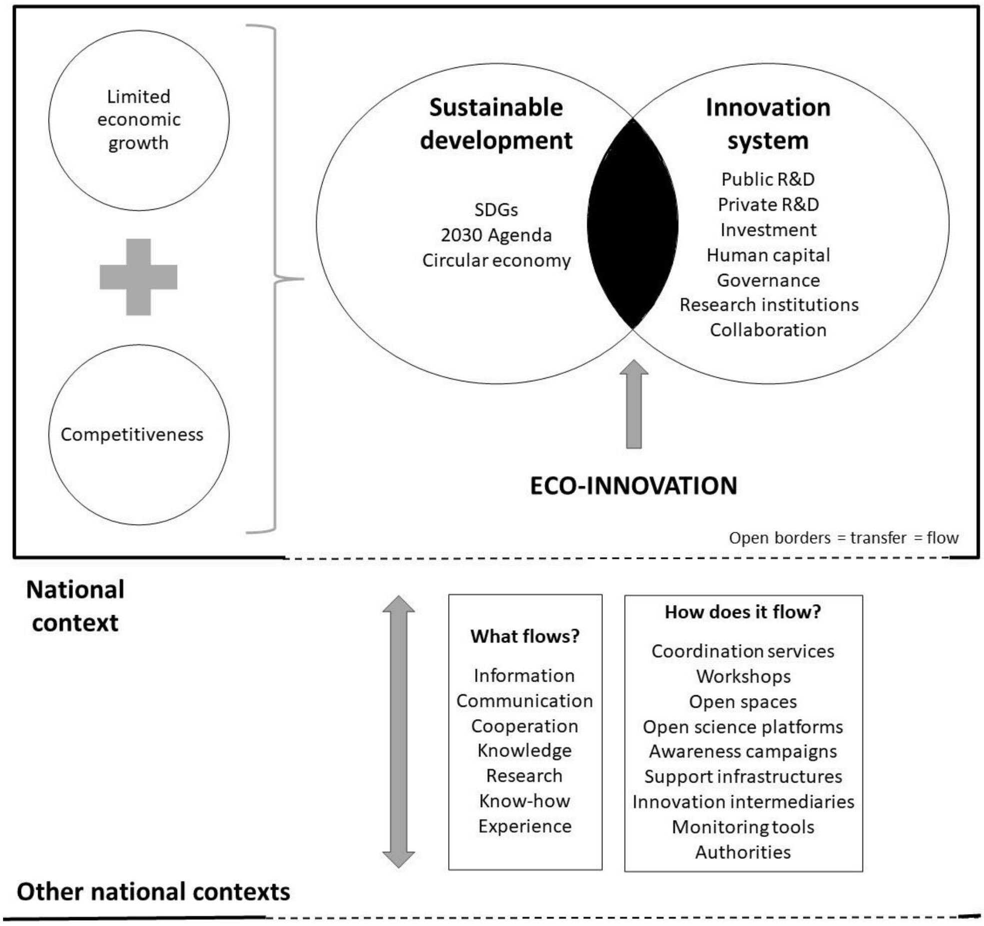
Chapter 4, "Factors driving national eco-innovation: New routes to sustainable development" was published in *Sustainable Development* (*Wiley*; JCR Q1 and SJR Q1, 2022). Research on the intersection of eco-innovation and innovation systems was lacking, so studying how factors and agents combine and interact with each other to boost national eco-innovation was expected to offer countries a finer-grained understanding of eco-innovation systems to guarantee eco-innovation success.

The objective of Chapter 4 was to detect the national factors and relationships that explain eco-innovation in European countries by applying fuzzy-set qualitative comparative analysis (fsQCA). This analysis used data collected from international indices on national levels of research and development (R&D) investment, human capital, governance, and research institutes. According to the literature, these factors play a prominent role in driving eco-innovation.

Chapter 5, "Are European countries favoring or jeopardizing their eco-innovation performance?", has been submitted for consideration for publication. It was believed to be important to analyze the evolution and trends of eco-innovation over a given period. This chapter shows the national factors and relationships that lead to better or worse eco-innovation in European countries. FsQCA showed that no single policy mix explains an improvement or worsening of national eco-innovation performance. This finding highlights the need for in-depth knowledge of the national characteristics of eco-innovation systems to guarantee the long-term achievement of sustainable development through eco-innovation.

Finally, Chapter 6 presents the general and specific conclusions of each of the previous chapters. It also discusses implications, alignment with the SDGs and the 2030 Agenda, limitations, and future lines of research. Figure 1.1 illustrates the conceptual map of the thesis research model. It highlights the need to shift from economic growth and competitiveness towards sustainable development and circular economy models. Sustainable development and the circular economy occur within the frontiers of a country or region and are influenced by the characteristics of the innovation system. Eco-innovation occurs at the intersection of sustainable development and innovation systems. The existence of open borders that allow the transfer and flow of knowledge and information between countries is important in this context. This flow is enhanced by mechanisms such as the creation of Open Science platforms, support infrastructures, innovation intermediaries, and government authorities. Under these conditions, eco-innovation can prosper, ensuring sustainable development, provided that the limits of economic growth and the importance of global collaboration are also acknowledged.

Figure 1.1. Conceptual map of the research model in this thesis



1.4. Data and methods

1.4.1. Data

Data were collected from several sources. The sources varied depending on the research objective and nature of the topic. The study described in Chapter 2 ("Innovation facilitators and sustainable development: a country comparative approach") used data from the SDG Index, Global Innovation Index (GII), and World Bank. The data were obtained for 122 countries for the years 2015 and 2020 (2020 was the latest year available as of May 2020). The SDG Index provided data on countries' sustainable development according to their degree of SDG achievement. GII offered data on innovation facilitators that enabled assessment of national innovation performance depending on different criteria. The criteria in this paper were institutional, knowledge, and environmental aspects. Finally, the World Bank database was employed to collect data on countries' economic development.

The primary data source for the study described in Chapter 3 ("Driving research on eco-innovation systems: Crossing the boundaries of innovation systems") was the Web of Science Core Collection (WoS CC). Data collection took place in January 2022, covering all documents published up to 31 December 2021. The data set included the terms "national innovation system", "regional innovation system", "eco-innovation", "green innovation", "environmental innovation", "sustainable innovation", and their variations.

The study described in Chapter 4 ("Factors driving national eco-innovation: New routes to sustainable development") used data from different sources for European countries for 2021. The Eco-Innovation Index provided the data on national eco-innovation; the European Innovation Scoreboard provided the data on human capital capacity and public and private R&D investment; the Governance Performance Index provided the data on governance; and the Scimago Institutions Rankings provided the data on research institutes. Transformations were applied to the data on research institutes prior to the analysis.

Finally, the study described in Chapter 5 ("Are European countries favoring or jeopardizing their eco-innovation performance?") used data for the same variables and from the same sources as in Chapter 4. The difference was the study period. The study described in Chapter 5 examined the evolution and trends of national eco-innovation using data for the period 2014 to 2021. It was thus possible to study whether the variable levels improved or worsened over the study period.

1.4.2. Methods

To meet the general and specific research objectives of the thesis, a range of quantitative and qualitative methods were employed for the analysis of eco-innovation. A mixed analysis approach was applied, with the following highlights:

- To analyze the power of innovation facilitators to explain sustainable development achievement, two multiple linear regression analyses were conducted: one for the overall sample and another for each country group.
- A cluster analysis was used to (i) group countries with similar national characteristics in terms of innovation facilitators and sustainable development and (ii) detect and study the changes in country groups from 2015 to 2021.
- Bibliometric techniques were applied to study the status of knowledge and provide insights into the literature that jointly addresses eco-innovation and innovation systems and to provide insights into this literature. Co-occurrence and co-citation analyses were the chosen bibliometric techniques.
- FsQCA was used to examine the effect of different factors and combinations of factors on eco-innovation. This method was employed to analyze (i) the success and failure of eco-innovation (static approach for the year 2021) and (ii) the improvement and worsening of eco-innovation (evolutionary approach for the period 2014 to 2021).

Table 1.1 summarizes the thesis structure, objectives by chapters, and methodologies.

Table 1.1. Summary of the thesis

Chapter	Paper	Objective	Methodology
2	Innovation facilitators and sustainable development: a country comparative approach	**O1.** To assess how innovation facilitators explain national sustainable development and the extent to which they do so	Multiple linear regression analysis
		O2. To examine differences between country groups based on the degree of SDG achievement and innovation facilitators	Cluster analysis
3	Driving research on eco-innovation systems: Crossing the boundaries of innovation systems	**O3.** To provide an overview and exploration of the literature that jointly examines eco-innovation and innovation systems	Bibliometric methods
4	Factors driving national eco-innovation: new routes to sustainable development	**O4.** To determine the national-level factors that lead to high or low levels of eco-innovation in European countries	fsQCA
5	Are European countries favoring or jeopardizing their eco-innovation performance?	**O5.** To determine the national-level factors that improve or worsen eco-innovation in European countries	fsQCA

1.5. Other contributions of the thesis

The thesis has led to several collaborations with scholars from the *Universitat Politècnica de València* and other international research institutes. Some contributions derive from the thesis and, although they are not included in the present text, have a direct link with innovation and sustainable development, viewed from different perspectives. These different perspectives mean that fundamental aspects of sustainable development are addressed. Although several studies have been proposed for the future, two working papers are worth mentioning and, as we expect, will lead to future publications.

The idea of sustainable development is to guarantee the quality of life and well-being of present and future generations. The thesis shows that innovation influences sustainable development, highlighting the prominent role of eco-innovation. The first working paper, entitled "Subjective and objective well-being: do innovation drivers matter?", examines the joint literature on innovation and well-being, understood as objective or subjective human development. The effect of innovation and its drivers on well-being is explored. To map the relationship between innovation, innovation drivers, and well-being, a fsQCA was conducted, considering objective and subjective well-being as separate independent outcomes. This approach showed whether innovation drivers had different effects on these types of well-being.

The second working paper, entitled "Transforming the agri-food sector through eco-innovation: a path to sustainability and technological progress", introduces a thematic area that is closely linked to sustainable development and well-being: the agri-food system. The role of the agri-food system as a provider of goods and services that meet people's basic needs is well documented. It has the potential to contribute to well-being and sustainable development by providing society not only food but also environmental and social health. However, the growing importance of technologies and innovation highlights the need to bring the agri-food system up to date through alternative models that consider economic, social, and environmental prosperity. Using Necessary Condition Analysis (NCA), this working paper identifies the extent to which eco-innovation drivers constrain eco-innovation development with a focus on agri-food firms. In other words, it shows the internal and external factors that are necessary for eco-innovation to occur in agri-food firms.

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Chapter 2. Innovation facilitators and sustainable development: a country comparative approach

Chapter 2. Innovation facilitators and sustainable development: a country comparative approach

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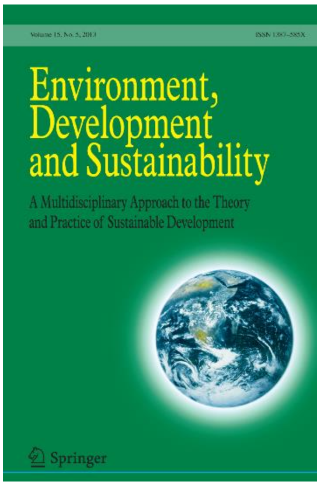


Chapter 2. Innovation facilitators and sustainable development: a country comparative approach

Abstract. National and international organizations have introduced policies aimed at sustainable development. These policies are designed to encourage sustainable forms of business to meet the Sustainable Development Goals (SDGs) of the 2030 Agenda. Regional inequalities in sustainable development may be exacerbated by disparate levels of innovation. This paper analyzes the variations between clusters of countries according to the degree to which they have achieved the SDGs and their levels of innovation facilitators. Two types of analyses were employed. First, cluster analysis was used to examine changes in groups of regions with similar innovation characteristics between 2015 and 2020. Data for 122 countries were gathered from the World Bank, the SDG Index, and the Global Innovation Index. Second, multiple linear regression analysis was used to assess the power of the variables in the model to explain the level of sustainable development. The results reveal four clusters (low, medium, high, and very high innovative facilitators and sustainable development), as well as movements between those clusters from 2015 to 2020. The multiple linear regression analysis shows that the variables have explanatory power with respect to the dependent variable of sustainable development. This analysis also reveals different degrees of importance of the variables for each cluster. The findings highlight the need to consider the limitations of economic growth in terms of innovation facilitators to promote sustainable development. If policymakers recognize the limitations of economic growth and the physical ecosystem, degradation of the environment can be avoided, even when there is innovation. Global and individual social welfare can thus be ensured. This study offers valuable insights into how to achieve sustainable development through innovation facilitators by providing in-depth knowledge of the individual characteristics of innovation systems and considering the limitations of economic growth.

Keywords. SDGs, Cluster analysis, Innovation, Economic growth, Sustainable development, Innovation facilitator

2.1. Introduction

For decades, international organizations and governments have recognized the challenges facing different regions around the world. According to the United Nations (2021c), these challenges are not only economic (e.g., driving economic growth, stimulating investment, and reducing unemployment) but also social and environmental (e.g., poverty and climate change). Failure to tackle these challenges could have negative consequences for society by limiting its ability to meet its own needs. These global problems have been exacerbated by the COVID-19 pandemic, which has highlighted the importance of employment, income, and social protection systems (United Nations, 2021a), among other issues.

Given the global situation in light of these challenges and the growing concern of governments, sustainable development policies have been introduced. The World Commission on Environment and Development brought the concept of sustainable development to the forefront of the political agenda, defining it as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987; p. 24). This definition integrates the three dimensions of sustainability (i.e., the economy, society, and the environment). However, many scholars disagree with this institutional view (e.g., Daly, 1974; Kallis et al., 2018), arguing that the economic dimension of sustainability should be kept in check because economic growth can trigger environmental degradation and destruction (Fournier, 2008). These arguments are aligned with the post-growth literature, which suggests that the contribution of economic growth to sustainable development is limited, placing emphasis on the role of the social and environmental dimensions of sustainability.

Not only has the United Nations (UN) highlighted the importance of sustainable development through its eight Millennium Development Goals (MDGs) and its subsequent 17 Sustainable Development Goals (SDGs), but many countries have also included sustainability measures in their political strategies. For example, the European Union (EU) has the next-generation EU, European Green Deal, and Horizon Europe. The participation of private companies (United Nations, 2015a), universities, and research institutions (Horbach, 2016) in sustainable development is also essential because they contribute through research and development (R&D), project financing, job creation, and trade.

The United Nations Development Program has adopted innovation, technology (Omri, 2020), and entrepreneurship (Filser et al., 2019) as fundamental pillars of the three dimensions of sustainable development. First, innovation and knowledge can contribute to improving people's living conditions in areas such as transport, production, medicine, and energy (Szopik-Depczyńska et al., 2018a). Second, all sustainability dimensions can be positively influenced by the outcomes of new technologies (de Queiroz Machado et al., 2021). In addition, entrepreneurship in all its forms has become one of the main economic and social drivers of innovation (López-Rubio et al., 2020, 2021). For these reasons, it is important to identify the interactions between economic, institutional, knowledge or human, and environmental systems (Szopik-Depczyńska et al., 2018b). This paper refers to these systems as innovation facilitators influencing both innovation activities and the achievement of sustainable development. However, innovation and technological progress could negatively affect society because innovation and technology imply an increase in pollution and material and energy use (Fournier, 2008). Moreover, innovation and technology could also foster inequalities between rich and poor countries (Rafer & Singer, 2002), including among individuals in terms of, for example, spatial and demographic distribution or abilities or infrastructures (Sovacool et al., 2022). Other adverse effects of innovation relate to digitalization, the Internet, and big data storage, all of which entail vast amounts of carbon emissions, water use, and land footprint (al Kez et al., 2022).

In recent decades, sustainability-oriented innovation has become an intensely debated topic in the literature because both concepts (i.e., sustainability and innovation) involve social and ecological aspects in organizational structures, products, and processes (Klewitz & Hansen, 2014). Different actors participate in these innovations and concerns, which are regarded as drivers of sustainable development (Mulgan, 2006). Nevertheless, there are regional differences in the ability to promote innovation systems. These differences have hindered real opportunities for sustainable development across countries (Omri, 2020).

Innovations can exacerbate the inequalities between countries, leaving many unable to achieve sustainable development. This argument is consistent with the institutional view of sustainable development, which emphasizes the role of innovation in driving the economic, social, and environmental dimensions of sustainability. Accordingly, other approaches to sustainable development (e.g., from the post-growth literature) are ignored. Therefore, the question is, are innovation facilitators (including economic growth) positively influencing sustainable development? Also, what is their real impact? In answer to these questions, this paper has two aims. First, it analyzes variations between country clusters based on the degree to which they have achieved the SDGs and their innovation facilitators (a country's economic, institutional, knowledge, and environmental facilitators) at different times. That is, the study answers the question of why countries that had similar characteristics in 2015 had shifted into other clusters by 2020. The movements between clusters over that period are captured and identified, as are the causes of different levels of sustainable development and innovation facilitators. Therefore, the differences in the sustainable development of regions are also identified. Cluster analysis was conducted to (1) group economies with similar innovation levels and characteristics and (2) study changes in these clusters of economies between 2015 and 2020. Second, this paper assesses the extent to which the variables in the model explain sustainable development, both at the overall sample level and at the individual cluster level. Two multiple regression analyses were conducted: one for the overall sample and another by clusters. The multiple regression analysis by clusters shows whether the explanatory power of the independent variables changes by cluster, with each cluster characterized by a different level of sustainable development.

Given the innovation drivers of economies, this paper presents a model based on five innovation facilitators provided by the World Bank, the SDG Index, and the Global Innovation Index (GII). These facilitators are considered important for capturing the economic, institutional, knowledge (or human), and environmental dimensions that could influence sustainable development (Rosca et al., 2018; Szopik-Depczyńska et al., 2018b; Yuan & Zhang, 2020). The five selected facilitators are GDP per capita, SDG Index, institutional framework, human capital and research, and ecological sustainability. The institutional framework, human capital and research, and ecological sustainability are considered facilitators of innovative activities within a country (Cornell University et al., 2020). The analysis in this study is based on detailed data for 122 countries. The results reveal four clusters of countries (low, medium, high, and very high innovative facilitators and sustainable development) with similarities in terms of these innovation facilitators. The results also reveal movements between clusters from 2015 to 2020. The originality and novelty of this study lie in the crucial insights that emerge from the combination of the temporal analysis of country movements and the multiple regression analyses. This dual analysis (1) shows the existence of a link between innovation and sustainable development through innovation facilitators and (2) reveals that the influence of economic growth on sustainable development is limited. Therefore, strategies that lead to unconstrained economic growth can result in environmental degradation and, ultimately, the failure to achieve sustainable development.

This paper is organized into several sections. The second section of this paper describes the framework for sustainable development, taken as a global reference, and other perspectives on sustainable development. The third section presents the factors in the model and describes the relationship with sustainable development specified in the literature. The fourth section describes the method and indices used in the analysis. The results are explained in the fifth section. Finally, the last section concludes and presents the limitations of the study and future research possibilities.

2.2. Theoretical framework

2.2.1. The SDGs as a sustainable development agenda

Sustainable development involves complexity and uncertainty for all countries and regions. Therefore, policymakers and other economic actors must identify new tools to assess the risks that may arise from decision making. Measures and actions to protect sustainability can then be introduced (Firoiu et al., 2019). In 2000, the UN created eight Millennium Development Goals (MDGs) to reduce extreme poverty, provide universal primary education, and halt the spread of HIV/AIDS. This plan was ratified by international organizations and countries around the world, which pooled their efforts and resources to satisfy the needs of the poorest and most vulnerable (United Nations, 2021d). However, in 2015, the failure to achieve these goals led to the creation and adoption of the 2030 Agenda for Sustainable Development (United Nations, 2021b).

Despite its multifaceted and complex character, the 2030 Agenda has become a reference framework for many nations by upholding human rights, humanity, and nature (Firoiu et al., 2019). This action plan introduced 17 goals separated into 169 targets covering the economic, social, and environmental dimensions of sustainable development. Initial progress in tackling the SDGs has been gradual because the idiosyncrasies of each country or region make this task difficult. For this reason, communication and information about SDGs and sustainability have become crucial to stimulate the commitment, participation, and interest of individuals worldwide (Firoiu et al., 2019).

The alarming situation in the face of global challenges (e.g., the health crisis caused by COVID-19, climate change, protection of human rights, and international law and justice) shows the need to create a global alliance to replace the current alliance, which has failed to achieve clear outcomes. Such a global alliance of both developed and developing countries would help eradicate poverty, improve education and health, boost sustainable economic growth, reduce inequality, address climate change, and conserve ecosystems (United Nations, 2021b). The 17 SDGs were created not only to tackle these challenges but also to address the implementation of actions designed to do so, as well as providing a framework for review and follow-up.

The 2030 Agenda places the focus on people, planet, and prosperity by encouraging global society to act against situations of injustice. The SDGs are interrelated, which is a crucial part of improving the quality of life and well-being of people around the world (United Nations, 2015b). Five dimensions are addressed by the SDGs. The People dimension mainly relates to health, education, gender, and poverty. Planet refers to the importance of respecting the environment at all levels. Prosperity refers to ensuring global economic, social, and environmental prosperity. Peace relates to fostering peaceful, inclusive, and just societies. Partnership refers to achieving a global alliance committed to sustainable development. However, the reality of the 2030 Agenda and the SDGs means that countries may face numerous tradeoffs to achieve sustainable development (le Blanc, 2015).

2.2.2. Sustainable development: other approaches

In the literature, there is no consensus on the definition of sustainable development, which leads to different interpretations and responses (Mebratu, 1998). Although the institutional view of the UN and other international organizations reconciles economic growth with the resolution of social and environmental problems, many authors disagree (e.g., Daly, 1974; Kallis et al., 2018). The UN's conceptualization lacks theoretical development (Purvis et al., 2019), assuming that economic growth is required to reduce poverty and environmental degradation through more accessible markets (Castro, 2004). However, this type of growth causes environmental destruction (Fournier, 2008).

Hopwood et al. (2005) argued that economic growth implies a progressive increase in the use of resources, which, in turn, generates an increase in waste production. Production negatively impacts the environment (Giljum et al., 2005). Therefore, an unsustainable situation arises, preventing sustainable development. The post-growth literature considers the limits of growth, explaining that resources are finite and that the population cannot grow indefinitely. Any economic effect on the ecosystem generates a physical transformation (Daly, 2018), which has consequences at all levels of society. Given the diversity of perspectives and approaches to sustainable development, this section presents some of the arguments from the post-growth literature, contrasting with the sustainable development institutional view and revealing arguments that illustrate the limitations of economic growth.

One of the key concepts in the post-growth literature is degrowth. Degrowth is known as "a process of political and social transformation that reduces a society's throughput while improving the quality of life" (Kallis et al., 2018, p. 292). Degrowth is based on the proposition that human development without economic growth is possible (Schneider et al., 2010). Similarly, the concept of a steady-state economy is also found in the postgrowth literature. A steady-state economy refers to the existence of a stable population and wealth, maintained at a desirable level and determined by a low level of production (Boulding, 1970; Daly, 1974). The steady-state economy approach is based on the fact that people establish goals by considering the preservation of the physical ecosystem and its limits (Daly, 2018).

Daly (1990) distinguishes between growth and development, identifying the qualitative development of non-growing countries and systems over long periods. The global ecosystem is finite. It does not grow but does develop. Since the economy is one of the areas within this global ecosystem, it is impossible to drive economic growth indefinitely or for long periods. The author claims that growth pushes the economy beyond the optimal point of physical dimensions, damaging the biosphere and increasing poverty. These arguments suggest that economic growth is an unsustainable goal that negatively affects society and the environment, undermining the opportunities of the present and future generations by exceeding nature's limitations.

Sustainable development involves moving away from the growth economy and moving toward a steady-state economy that includes both the Northern and Southern Hemispheres (Daly, 1996). Throughout history, there has been a distribution of wealth between the Northern and Southern Hemispheres. The existing Northern–Southern Hemisphere relationship is not sustainable because of their economic interdependence. Economic interdependence is the continued dependence of the Southern Hemisphere countries on the influential countries of the Northern Hemisphere in terms of resources, trade, information and knowledge flows, and other aspects. However, the economic interdependence of Northern Hemisphere countries relies on the opportunity to exploit any type of resource, such as natural or human capital resources (Sharif, 1997). Therefore, there is a need to foster a new relationship between rich and poor countries from the Northern and Southern Hemispheres in which they partner with each other (Rafer & Singer, 2002).

According to several authors in the post-growth literature (e.g., Schneider, 2003; Schneider et al., 2010), research, innovation, and technology should be oriented toward lower consumption through policy, technological, and lifestyle instruments. These instruments should impose material and energy use limits while continuing to encourage consumption. Despite the design and implementation of eco-efficient innovations, they still encourage consumption and production, leading to higher energy use, pollution, carbon emissions, and other negative effects (Fournier, 2008). This idea is aligned with the concept of rebound effects, which explain the non-decrease in energy consumption despite continuous improvement in technical energy efficiency. Lange and Berner (2022) showed that, through several rebound instruments, energy efficiency improvements trigger economic growth, thus raising energy demand. Many countries and international organizations have promoted the transition to renewable energy (Sovacool & Dworkin, 2012) because of the perceived benefits to society (Liang et al., 2019). However, energy transitions create injustices at the local, national, and global levels (Sovacool et al., 2019). These energy injustices are linked to the environment, community health, energy prices, unequal access to energy, circulation of waste, and other areas. Therefore, although eco-efficient technologies and innovations are valuable, they negatively affect the environment by triggering excessive consumption and use of natural resources that exceed biophysical limits.

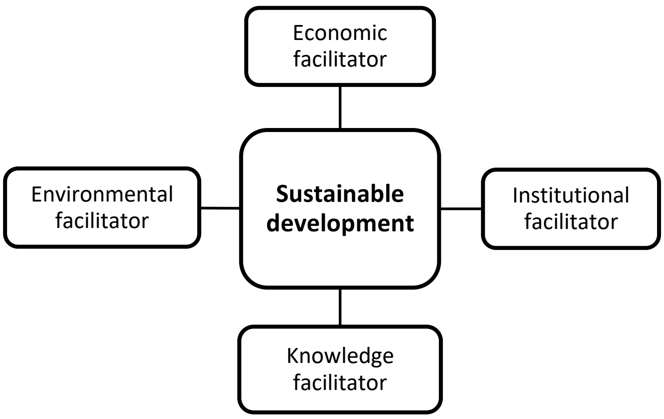
Another key concept in the post-growth literature is absolute decoupling. According to the institutional view, which reconciles economic growth with social and environmental development, promoting absolute decoupling is necessary to achieve sustainable development. Many policymakers aim to achieve absolute decoupling (Giljum et al., 2005) because they believe that it is the means to achieve sustainable development. Absolute decoupling implies an absolute reduction in environmental pressures while economic growth accelerates (Giljum et al., 2005). The result will be that the resource efficiency rate (GDP/resource use ratio) exceeds the increase in GDP. However, cases of absolute decoupling are rare. They are related to low economic growth and the increase in imports of material-intensive goods (Otero et al., 2020). They also occur over short periods.

Other theories claim that technology and knowledge are joined by a process of feedback. Countries with a higher and more complex understanding of innovation facilitators have more opportunities to improve national innovation systems. A vicious circle arises in which the poorest countries tend to continue to have high levels of poverty, high social exclusion, and low levels of growth. To reduce the gap between the Northern and Southern Hemispheres, innovation facilitators in poor countries need to be stronger and more effective (Rafer & Singer, 2002). However, innovation facilitator and innovation system characteristics of developing countries remain unexplored in the literature (Choi & Zo, 2019; Khan, 2022). Low- and medium-income countries absorb knowledge from abroad to create value for their local communities (Khan, 2022). Fernández et al. (2021) showed differences in the innovation facilitators of developed and developing countries. Developing countries rely more on collaboration, alliances, and networks. They acquire software, equipment, or machinery. They use external R&D and innovation and knowledge sources. Public support and market factors play a secondary role.

2.3. Research model: selected innovation facilitators and their link to sustainable development

The literature identifies numerous drivers of national development such as wealth, health, education (Todaro & Smith, 2020), technological development, a country's fiscal situation, and investment (Soliyev & Ganiev, 2021). In this paper, five innovation facilitators (dimensions) form the basis of the research model shown in Figure 2.1. These facilitators are sustainable development, economic, institutional, knowledge, and environmental, proxied using the SDG Index, GDP per capita, institutional framework, human capital and research, and ecological sustainability, respectively. The variables institutional framework, human capital and research, and ecological sustainability are considered facilitators of innovative activities within a country (Cornell University et al., 2020). The aim is to use these variables to create groups of countries with similar national characteristics in terms of their sustainable development.

Figure 2.1. Proposed research model



Some governments have voluntarily created indicators to review their achievement of the SDGs at the national level (Schmidt-Traub et al., 2017). However, these indicators lack international harmonization and thus comparability. The *SDG Index* is a global instrument that provides detailed information on sustainability (Kroll, 2015). This index can be used to assess and compare individual countries. The index also enables the measurement of countries' degree of achievement of the SDGs (Sachs et al., 2020), providing a set of indicators that are easily understandable and accessible, as well as comprehensive. Inclusion of this variable in the model is justified by countries' growing concern in achieving sustainable development. This variable provides information on the multifaceted characteristics of each country, reflecting the situation of each country in terms of sustainability (Kroll, 2015). However, although this paper uses the international institutional view of sustainable development (based on the three dimensions of sustainability), the post-growth literature suggests that unlimited economic growth hinders the achievement of sustainable development. In other words, economic growth stops contributing to human welfare when a certain economic level is reached due to the rising environmental degradation.

Under this institutional view, *economic facilitators* (represented by GDP per capita) would also contribute to the achievement of sustainable development. Spaiser et al. (2017) showed that wealth generally increases socioeconomic inclusion and reduces poverty. These results are in line with the findings of Hamilton and Hepburn (2014), who found a close link between wealth and sustainability, implying a decrease in future well-being when the real wealth of an economy declines. Some authors have argued that accelerating economic growth can trigger faster integration of innovation in different areas of society (e.g., Bircan & Gençler, 2015). The Kuznets curve hypothesis (Kuznets, 1955) states that economic growth leads to an increase in income inequality until a certain level of national or regional income is reached. After that income level, inequality begins to decrease. In addition to reaching this level of income, the country or region must have developed institutionally, industrially, and in terms of welfare. Therefore, according to the Kuznets curve, the relationship between economic growth and income inequality follows an inverted U-shaped curve.

Nadeem et al. (2020) found that both short- and long-term innovation is positively influenced by wealth. Innovation is based on the combination of new knowledge and existing knowledge (Awan et al., 2019), which, through a better understanding of business behaviors and processes, could promote sustainable innovation (Grabara et al., 2020). Therefore, the literature suggests that a country's level of wealth, as an innovation facilitator, also contributes indirectly to sustainable development.

Hypothesis 1: A country's wealth positively contributes to sustainable development until a certain level of economic progress.

The *institutional facilitators* (under the institutional framework) are defined as the formal (laws, rights, constitutions, etc.) and informal (customs, sanctions, traditions, codes of conduct, etc.) norms that constrain (Periac et al., 2018), stimulate, or stabilize economic, political, and social relations. Often, institutional structures encourage the achievement of welfare goals by helping establish measures related to health, gender equality, and education (Waage et al., 2015). Moreover, an improvement in the institutional framework (e.g., political stability and control of corruption) raises environmental quality levels (Khan et al., 2022). The attainment of sustainable development still largely depends on the participation of citizens (Leal Filho et al., 2018). The implication is that if the population is unaware and uninterested in sustainable activities and innovations, the country will be unable to progress in its sustainable development. In addition, companies include more SDGs in their sustainability reports when their home countries have certain institutional and organizational features such as employment protection policies or a national corporate social responsibility strategy (Tsalis et al., 2020). In some cases, institutions do not have a clear, holistic view of the determinants of sustainable development or of sustainable development itself (Sedlacek & Gaube, 2010). However, a society's lack of interest, awareness, and institutional knowledge may not be the only reason institutional facilitators fail to stimulate the design and implementation of measures to promote sustainable development. This view would be narrow and biased. The responsibility for sustainable development lies not only with citizens but also with all actors in society, including governments, private institutions, companies, universities, and research institutions. For example, Howes et al. (2017) argued that policy failure in driving sustainable development arises for several reasons, including policy conflicts of interest, inadequate administrative resources and implementation of incentives, and lack of policy objective specifications.

An institutional structure that supports sustainable practices can help achieve sustainable development by encouraging changes in technology R&D, marketing models, or financial structures (Yuan & Zhang, 2020). Moreover, institutions and other organizations also play a supporting role in the innovation process (López-Rubio et al., 2020). Therefore, the institutional facilitators are also essential to promote innovations (Cornell University et al., 2020) that encourage national and regional sustainable development. The implication is that the government and the institutional structures play a key role in encouraging the creation of sustainable development and innovation.

Hypothesis 2: A country's institutional facilitators have a positive effect on the achievement of sustainable development.

The literature shows that *knowledge facilitators* such as human capital and research influence sustainable development. Human capital is a society's set of knowledge, skills, motivations, and competencies capable of generating social well-being (Chikwe et al., 2015). Research involves studying properties and characteristics of concepts to discover information (Abali et al., 2019; Okeke, 2004). Throughout the twentieth century, economic theories about aspects that promote global economic growth, such as education, R&D, and patents, have emerged (Pelinescu, 2015). To drive sustainable development, human capital can influence environmental quality because of the link between education, environmentally friendly behavior, and environmental awareness (Ahmed et al., 2020; Chankrajang & Muttarak, 2017).

The development of human capital through higher education stimulates not only socioeconomic development but also innovation at the national, regional, and local levels (GarciaAlvarez-Coque et al., 2021). Higher education institutions are able to engage diverse stakeholders in learning activities based on sustainability (Baumber, 2021). Çakar et al. (2021) found that human capital can decrease environmental degradation while boosting economic growth. This finding indicates that human capital development leads to sustainable development by boosting the national economy while reducing pollution, which positively impacts society's welfare. Similarly, Diaconu and Popescu (2016) reported that human capital is a key element in sustainable development because it drives the three dimensions of sustainability. First, it drives economic sustainability because the greater productivity and creativity of healthier and more educated people boosts economic growth. Second, it drives social sustainability because greater development of human capital guarantees social satisfaction and therefore fosters cooperation and social well-being. Third, it drives environmental sustainability as a result of increased awareness of environmental issues.

Hypothesis 3: Knowledge facilitators encourage sustainable development.

Finally, *environmental facilitators* (represented by ecological sustainability) can also influence the achievement of sustainable development. Ecological sustainability is the long-term ability to continue living given the limitations of the biophysical world (Porritt, 2007). Ecological development based on ecological sustainability aims to minimize environmental pollution and resource exploitation by reducing the production and use of harmful substances (Littig & Grießler, 2005). From an ecological sustainability perspective, unlimited economic growth is impossible. Therefore, sustainable development has the potential to improve means and ends by recognizing the limitations of nature (Borland et al., 2016; Ekins, 2000). In contrast, other authors (e.g., Tomislav, 2018) claim that ecological sustainability is a fundamental element in driving economic and sociocultural sustainability. Nevertheless, it continues to be a topic of discussion within the framework of sustainable development. This discussion suggests that ecological sustainability may afect other dimensions. Therefore, focusing more resources or efforts on ecological sustainability could drive sustainable development more rapidly.

Hypothesis 4: Environmental facilitators foster the attainment of sustainable development.

Table 2.1 summarizes the variables in the model.

Table 2.1. Description of innovation facilitators (dimensions) included in the model

Innovation facilitator	Variable	Definition	Source
Sustainable development	SDG Index	Performance of countries in achieving the SDGs	SDG Index Report
Economy	GDP per capita	Sum of goods and services produced in a country over a given period divided by average population (OECD, 2014)	World Bank Data
Institutions	Institutional framework	Formal and informal rules or norms that structure economic, political, and social interaction	Global Innovation Index
Knowledge	Human capital and research	Set of knowledge, skills, motivations, and competencies of society that can be enhanced through research (study of the characteristics of concepts)	Global Innovation Index
Environment	Ecological sustainability	The ability to ensure the long-term survival of future generations by minimizing environmental pollution and resource exploitation, as well as considering the limitations of nature	Global Innovation Index

Source: Authors based on Okeke (2004), Littig and Grießler (2005), Porritt (2007), OECD (2014), Chikwe et al. (2015), Kroll (2015), Periac et al. (2018), Abali et al. (2019), Sachs et al. (2020), and Sautet (2020)

2.4. Data and method

2.4.1. Data

The study used data from the SDG Index, Global Innovation Index (GII), and World Bank. Data on 122 countries were gathered for the years 2015 and 2020. The year 2015 was selected because it was when the 17 SDGs were adopted, while 2020 was the latest year with available data. The World Bank offers a data analysis and visualization tool for various topics such as health, corruption, economic growth, and poverty. The tool uses time-series data. It is flexible, allowing the creation of tables and graphs that are easy to share and save (World Bank, 2021). The GDP per capita values (economic facilitator) were gathered from the World Bank database. The GDP per capita data for the year 2019 were used because those for the year 2020 were not yet available at the time of the study.

The SDG Index and Dashboards provide a set of indicators for monitoring attainment of the SDGs and for complementing the standardization and compilation by national and international organizations (SDG Index, 2021). The data on the SDG Index (sustainable development) were collected from the SDG Index and Dashboards database. In the case of this variable, data for 2016 were collected because data for 2015 were not available. This data unavailability is one of the limitations of the study.

The GII captures the characteristics and trends of the global and national innovation ecosystems through new approaches and metrics (WIPO, 2021). This index provides data that enable both the assessment of innovative performance and the introduction of new policy measures of innovation. This index provides data on the institutional framework, human capital and research, and ecological sustainability (institutional, knowledge, and environmental facilitators, respectively).

2.4.2. Method

Multiple linear regression analysis

Multiple linear regression (MLR) enables the modeling and examination of a linear relationship between explanatory variables and an explained variable (Field et al., 2012). The aim of the MLR analysis in this study was to identify how accurately the selected independent variables (economic, institutional, knowledge, and environmental facilitators) explain the dependent variable (sustainable development) for the years 2015 and 2020. Stepwise linear regression was used to select or eliminate independent variables because all of these independent variables were considered to have an equal probability of explaining sustainable development. Sustainable development was represented by an indicator (SDG Index) that determines the extent to which countries achieve the SDGs (Sachs et al., 2020).

Stepwise linear regression highlighted the variables that provided the model that best fit the data without introducing researcher bias.

Cluster analysis

Cluster analysis is the classification of similar objects (also referred to as observations or individuals) into groups where both the number of groups and their form are unknown (Kaufman & Rousseeuw, 2009). In the data mining process, clustering is a useful tool to identify groups or patterns in the underlying data (Frades & Matthiesen, 2010). The main objective of this method is to identify clusters of points in a specific space (Edwards & Cavalli-Sforza, 1965). The categorical structure that best fits the sample observations can thus be determined (Anderberg, 2014). Scholars can also fulfill several other objectives using this methodology, such as classifying objects according to an existing set of clusters or testing the existence of some natural classes of individuals or groups (Härdle & Simar, 2019).

Cluster analysis encompasses a variety of mathematical methods for determining which objects are similar or dissimilar within a group. Objects with similar descriptions are mathematically grouped together in a cluster (Romesburg, 2004). To divide the set of observations into different groups with similar properties, two elements must be selected. The first is a proximity measure (also called similarity or distance measure) by which the similarities of characteristics of each pair of individuals are tested. This proximity measure is used to determine the closeness of objects. The closer the objects are to each other, the more homogeneous they are. Hence, they are included in the same cluster. The second is a group creation algorithm through which allocations are made in such a way that the observations in a group are as close as possible, but the differences between groups are large (Härdle & Simar, 2019).

2.5. Results

2.5.1. Multiple linear regression analysis

MLR analysis was used to test whether the variables in the model explain sustainable development. Table 2.2 summarizes the results after estimating different models for the years 2015 and 2020 with sustainable development as the explained variable. In

2015, the four models consisted of several parameters. While Model 1 only included a constant, Model 2 included a constant as well as knowledge facilitators. Model 3 included a constant as well as knowledge and environmental facilitators. Finally, Model 4 included a constant as well as knowledge, environmental, and institutional facilitators. Economic facilitators were not significant and were not included in the model (see Table 2.4, Appendix 1). This finding is aligned with the literature that decouples economic growth from sustainable development. The coefficient of determination (R^2) for Models 2, 3, and 4 was high (R^2=0.765, 0.835, 0.842, respectively). These results indicate that the independent variables in each respective model explain 76.5%, 83.5%, and 84.2% of variation in the dependent variable.

For 2020, Models 1, 2, and 3 were identical to those for 2015 (Model 1 included the constant; Model 2 included the constant and knowledge facilitators; Model 3 included the constant and knowledge and environmental facilitators). The difference between the models for years 2015 and 2020 resided in Model 4, which included economic facilitators (for the year 2020) instead of institutional facilitators (for the year 2015). Institutional facilitators were not significant (see Table 2.5, Appendix 1). The values of R^2 indicate that the goodness of fit of the models was lower than in the previous analysis. Models 2, 3, and 4 had values of 0.641, 0.733, 0.743, respectively, with the independent variables in each respective model explaining 64.1%, 73.3%, and 74.3% of the variation in the dependent variable. The models were statistically significant for 2015 and 2020 because the p value was less than 0.05 (see Table 2.6, Appendix 1). Thus, the proposed models adequately explain the dependent variable of sustainable development.

Table 2.2. Summary of the model with dependent variable sustainable development for 2015 and 2020

Model	R	R^2	Adjusted R^2	RMSE
2015 sustainable development				
1	0.000	0.000	0.000	12.591
2	0.874	0.765	0.763	6.135
3	0.914	0.835	0.832	5.160
4	0.917	0.842	0.838	5.071
2020 sustainable development				
1	0.000	0.000	0.000	8.626
2	0.801	0.641	0.638	5.187
3	0.856	0.733	0.729	4.494
4	0.862	0.743	0.736	4.430

Note: RMSE = root mean square error.

All parameters in the models were significant at the 95% level because the p value was less than 0.05. Hence, they had explanatory power with respect to the dependent variable (see Table 2.4 and 2.5, Appendix 1). Finally, the variance inflation factor (VIF) indicated no collinearity problems between the variables because the values were less than 10, following the criterion of Kleinbaum et al. (1988).

Multiple linear regression analysis by clusters was also conducted to test whether the explanatory power of the independent variables varied depending on the cluster. (The naming of the clusters is described in the following section). Cluster 1 (low innovative sustainable development) reflects that a minimum level of national wealth is essential in achieving sustainable development because this type of development cannot be promoted if economic and financial resources are unavailable to meet basic needs. Cluster 2 (medium innovative sustainable development) shows that knowledge facilitators such as human capital are fundamental in promoting the achievement of SDGs. This finding indicates that it is more difficult to achieve sustainable development without an educated and well-equipped society that encourages research and activities based on sustainable development alternatives. In 2015, Cluster 3 (high innovative sustainable development) presented human capital as the variable with the highest significant value. In 2020, institutional facilitators were necessary to drive sustainable development, suggesting that national institutional structures are capable of promoting this type of development. Finally, in 2015, Cluster 4 (very high innovative sustainable development) highlighted institutional facilitators as key elements for achieving the SDGs. In 2020, environmental facilitators had gained greater importance.

This analysis shows that, to promote sustainable development, a minimum level of wealth is first necessary to satisfy basic needs. Subsequently, once the country has reached a certain level of economic development, the most relevant elements for sustainable progress are knowledge, institutional, and environmental facilitators, ordered according to their contribution to sustainable development. These findings reflect that the relevance of economic growth is limited to a certain level. Therefore, when a specific economic, knowledge, and institutional development is achieved, it is possible to invest in strategies, activities, and alternatives that preserve the environment to a greater degree.

2.5.2. Comparative analysis: a cluster analysis of similar groups

This section presents the results of cluster analysis, where countries with similar characteristics for the years 2015 and 2020 were grouped. Variation between clusters in terms of achievement of sustainable development and innovation facilitators is examined in this section. The possible causes of any movements between these clusters are identified. A k-means cluster analysis was performed using a hard partitioning algorithm. This algorithm divides the data set into different clusters, with each object belonging to a single group. Each cluster consists of data observations that show a maximum degree of similarity between one another and a minimum degree of similarity with objects in other groups (James et al., 2013).

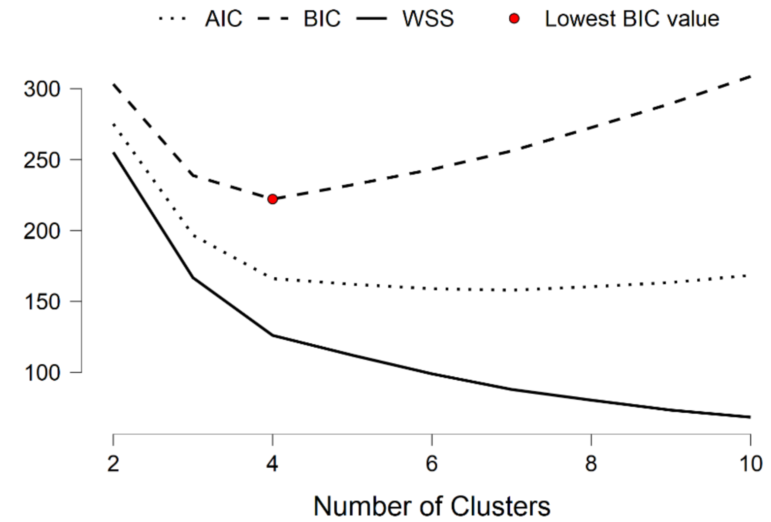
Table 2.3 presents the main data obtained from the k-means cluster analysis for 2015 and 2020. The model was optimized based on the Bayesian information criterion (BIC). The Akaike information criterion (AIC) and BIC are optimization methods to determine the quality of the resulting clusters (James et al., 2013). Both aim to avoid overfitting by penalizing for adding parameters to the model. According to the set of observations of 122 countries, the optimal number of clusters (i.e., the value that minimizes the BIC) was four (Figure 2.2). Comparing the value of the BIC for the years 2015 and 2020 shows a slight decrease in the model's goodness of fit. (Lower scores indicate a better fit of the model.) The value of R^2 was similar for both years (i.e., 79% and 78% in 2015 and 2020, respectively). Thus, the reliability of the model was relatively high.

Table 2.3. 2015 and 2020 k-means clustering

	Clusters	N	R^2	AIC	BIC	Silhouette
2015	4	122	0.79	166.07	222.15	0.37
2020	4	122	0.78	174.58	230.66	0.38

Note: The model was optimized with respect to the BIC value.

Figure 2.2. Elbow method plot



The level of similarity of the objects with other objects in the same cluster was acceptable. Hence, the resulting clusters were acceptable. Comparing the years 2015 and 2020 shows a worsening in the similarity of observations with other observations in the same cluster in most cases. However, this decrease was minimal (see Tables 2.7 and 2.8, Appendix 2).

In short, based on the selected facilitators, the cluster analysis revealed four groups of countries. The question is then, what characteristics were used to create these groups? Moreover, were there changes in the clusters from 2015 to 2020? The following section answers these questions. It also suggests possible causes of these movements.

2.5.3. Evolution of SDGs and innovation

Changes were observed in the clusters for 2015 and 2020. For 2015, Clusters 1, 2, 3, and 4 consist of 27, 47, 24, and 24 countries, respectively. Cluster 1 has 18 African countries (e.g., Ethiopia, Guinea, and Senegal), two American countries (Guatemala and Honduras), and seven Asian countries (most notably India, Nepal, and Pakistan). This cluster is mainly formed of African countries. These countries show the highest values in the GINI index, indicating that the income inequality of these countries is higher. Cluster 2 is composed of 11 countries from Europe (e.g., Armenia, Montenegro, and North Macedonia), 12 Latin American countries (most notably Argentina, Brazil, and Paraguay), 16 Asian countries (e.g., China, Lebanon, and Vietnam), and eight African countries (most notably Algeria, Egypt, and Morocco). Cluster 2 is more varied than Cluster 1 because of the greater number of countries from different continents. On average, this group of countries presents a better GINI index performance, reflecting a better income distribution compared to the countries in Cluster 1.

Cluster 3 has 18 European countries (e.g., Poland, Italy, and Spain), four Latin American countries (e.g., Chile and Colombia), one Asian country (Malaysia), and one African country (Mauritius). Finally, Cluster 4 has 14 European economies (e.g., Austria, France, and Switzerland), two American countries (Canada and the USA), six Asian countries (e.g., Israel, Japan, and United Arab Emirates), and two countries from Oceania (Australia and New Zealand). Although both clusters are predominantly European, they differ. Cluster 3 primarily consists of Eastern and Southern European countries, which tend to have lower levels of wealth than Central or Western European countries. These two clusters generally tend to have lower values in the GINI index (i.e., better performance). Income inequality levels are lower than in Clusters 1 and 2. Figure 2.3 illustrates the composition of each cluster for 2015.

Figure 2.3. Composition of clusters for 2015

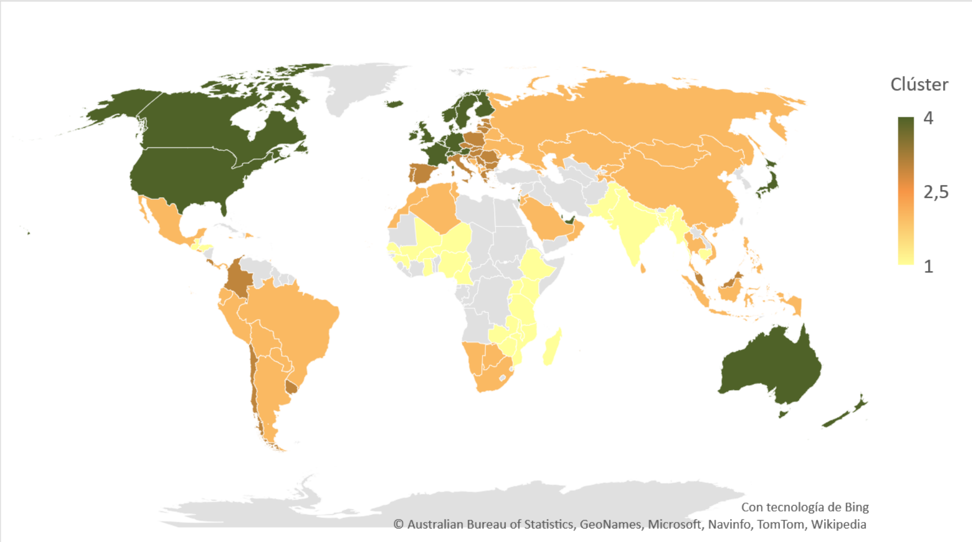


Figure 2.4 shows the cluster mean for each predictor variable. It classifies the groups based on their innovation facilitators (dimensions) and degree of sustainable development attainment. Cluster 4 has high scores for these variables, particularly sustainable development and economic, institutional, and knowledge facilitators. Despite not having the highest score for environmental facilitators, the value is still high. Given the level of innovation facilitators and high SDG achievement of the countries in this group, Cluster 4 is labeled as "Very high innovative facilitators: very high sustainable development". Cluster 3 has the second highest values in the sample, except for environmental facilitators. Therefore, this cluster is labeled as "High innovative facilitators: high sustainable development". Cluster 1 has the lowest mean values for all predictor variables, denoting lower national development. Hence, this cluster is labeled as "Low innovative facilitators: low sustainable development". Finally, Cluster 2 is defined as "Medium innovative facilitators: medium sustainable development" because its levels of sustainable development and innovation facilitators are located around zero.

Figure 2.4. Cluster mean plot for 2015

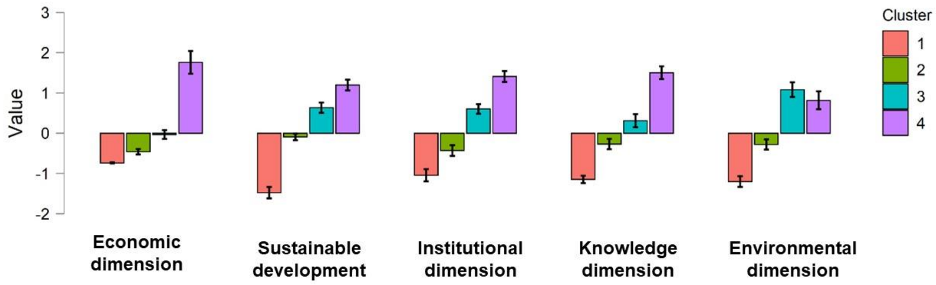
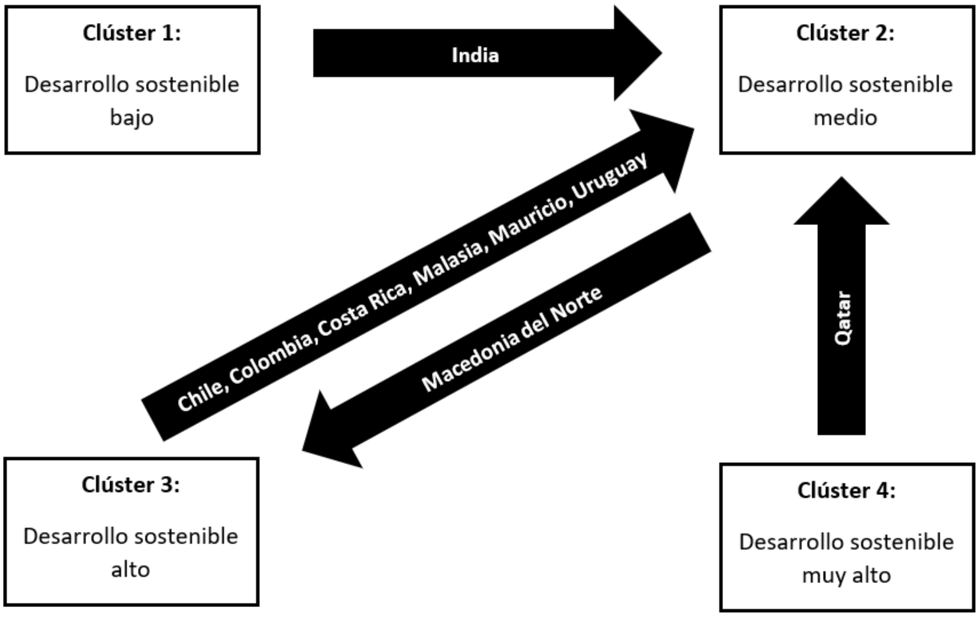


Figure 2.4 shows the lower levels of environmental facilitators in Cluster 4 than in Cluster 3. Therefore, environmental standards are lower when income is higher, suggesting that economic growth destroys the environment and its ability to conserve and regenerate itself. This finding is consistent with the approach of post-growth authors (e.g., Daly, 1974, 2018; Kallis et al., 2018). Contrary to the post-growth view, the environmental Kuznets curve implicitly suggests that absolute decoupling is possible (Otero et al., 2020).

The results of the linear regression analyses by clusters and those shown in Figure 2.4 suggest that the role of economic growth in sustainable development is limited. Economic growth is essential in the early stages of a country's sustainable development. In the later stages, countries may experience a simultaneous improvement in economic and environmental conditions. Nevertheless, once a certain level of economic growth has been achieved, its progress generates environmental destruction and degradation.

For 2020, Clusters 1, 2, 3, and 4 consist of 26, 54, 19, and 23 countries, respectively. India moved from the "Low innovative facilitators: low sustainable development" cluster (Cluster 1) to the "Medium innovative facilitators: medium sustainable development" cluster (Cluster 2). Chile, Colombia, Costa Rica, Malaysia, Mauritius, and Uruguay shifted from the "High development" cluster (Cluster 3) to Cluster 2, and Qatar moved from the "Very high innovative facilitators: very high sustainable development" cluster (Cluster 4) to Cluster 2. Finally, North Macedonia moved from the "Medium development" cluster to the "High development" cluster. Figure 2.5 illustrates these movements.

Figure 2.5. Country movements between clusters from 2015 to 2020



Given these results, the question is, what are the possible causes of the movements between clusters? The data indicate that India may have increased its sustainable development achievement because, although the level of its environmental facilitators declined, its level of wealth, institutional, and knowledge facilitators improved. Similarly, North Macedonia's shift may be explained by the large improvement in economic, institutional, and environmental facilitators to offset the decrease in knowledge facilitators. In contrast, Qatar moved to the "Medium innovative sustainable development" cluster because it had lower values for wealth and institutional, knowledge, and environmental facilitators in 2020 than in 2015.

Although Chile, Colombia, Costa Rica, Malaysia, Mauritius, and Uruguay improved their SDG Index scores, they moved to the "Medium innovative facilitators: medium sustainable development" cluster. This finding highlights one of the limitations of this paper because not all possible variables affecting sustainable development were included in the model. Additionally, the movement of these regions may be explained by the change in the innovation facilitators of the "High innovative sustainable development" countries. Consequently, by 2020, countries in these clusters had distanced themselves from these six countries. In particular, while Colombia's economic and institutional facilitators increased, its knowledge and environmental facilitators decreased. Similarly, Chile and Costa Rica increased their level of economic and knowledge facilitators, while the value of environmental and institutional facilitators decreased. Finally, Malaysia, Mauritius, and Uruguay saw only their value of environmental facilitators decrease.

2.6. Conclusions

The aim of this study was to define clusters of countries according to their sustainable development and innovation facilitators for the years 2015 and 2020 and then examine the movements of countries between these clusters. Given the clear link between sustainable development and innovation facilitators and the objective of the paper, data from 122 countries were collected from the World Bank, GII, and SDG Index databases to identify countries' innovation and sustainable development. Subsequently, cluster analysis was conducted to identify clusters according to countries' sustainable development and innovation facilitators for the years 2015 and 2020 and to examine the movements of countries between these clusters. The results reveal four clusters consisting of countries with similar sustainable development and economic, institutional, knowledge, and environmental facilitators. Linear regression analysis shows that the variables in the model have the power to explain the level of sustainable development.

Each group has unique qualities. Clusters 1, 2, 3, and 4 are labeled as "Low", "Medium", "High", and "Very high innovative facilitators and sustainable development," respectively. Countries with a higher degree of achievement of the SDGs have high values for the independent variables related to institutional, knowledge, and environmental facilitators. In addition, there is a close link between the level of wealth, institutional, knowledge facilitators. These facilitators in turn have strong relationships with each other. These strong relationships may indicate that countries with higher economic levels invest more resources in institutional, educational, and research systems based on innovation to drive national development. These results suggest that richer economies allocate greater resources to promote innovation, making it a key element in driving sustainable development.

Such a finding is in line with those of Husted (2005), who claimed that countries with stronger economies have more developed institutional and social capacities for sustainability because their strong economies provide more technology and resources for sustainable initiatives (Baughn et al., 2007; Reverte, 2022). Sustainable development means reorienting the progress of knowledge and technology, which should be neither eliminated nor interrupted (Schneider et al., 2010). Therefore, economic development, green technologies, and eco-innovations would have a positive relationship (Elgin et al., 2022).

Nevertheless, it is crucial to highlight the limited power of economic growth. This limitation is determined by the characteristics of the ecosystem and the biophysical world. The incompatibility between economic growth and biophysical limits leads to the loss of ecosystem value (Daly, 2018), reducing efficiency (Daly, 1974). Economic growth also accelerates biodiversity loss, climate change, and excessive waste and resource extraction (Kallis et al., 2012; Martínez-Alier et al., 2010). Any growth that attempts to exceed these limits generates environmental destruction and degradation (Fournier, 2008). Therefore, ecological sustainability declines, hindering the achievement of sustainable development. These conclusions indicate that the view of sustainable development adopted and promoted by international institutions is incomplete, which would fit with the perspective of Purvis et al. (2019). While sustainable development could comprise the three dimensions of sustainability (economic, social, and environmental), the economic dimension should be controlled according to environmental and social constraints. Therefore, society's ability to meet its basic needs and live in harmony with nature and the environment could be preserved. The excessive use of energy, materials, and resources encouraged by mass consumption and production could thus be avoided.

Nine countries moved between clusters, namely India, Chile, Colombia, Costa Rica, Malaysia, Mauritius, Uruguay, North Macedonia, and Qatar. These movements were due to changes in the innovation facilitators for 2020 that increased inequalities between countries and affected the clusters with respect to those for 2015. The movements were also due to possible changes in the innovation facilitators of most of the countries in the cluster for 2015, which also increased inequalities.

In short, the achievement of the SDGs seems to depend on the level of wealth of countries, with the most developed economies showing the greatest capacity for innovation. In turn, innovation is closely related to sustainable development. The results underscore the idea that implementing sustainability in countries is not a low-cost strategy. However, the poorest and neediest regions cannot be left behind. The adoption of global measures and collaboration between more developed economies to favor innovation in developing economies could reduce inequalities between countries and boost the development of poorer regions that are unable to meet basic needs. Through stronger and more effective innovation facilitators, poorer regions could narrow the lag in technology and knowledge and thus close the sustainable development gap (Rafer & Singer, 2002). Nevertheless, when implementing these new sustainable development strategies and instruments, it is essential to consider the finite nature of economic growth and the limits of the physical ecosystem. If a maximum level of economic growth is not established, it may be impossible to achieve sustainable development because unconstrained economic growth would lead to environmental degradation. This argument contradicts the environmental Kuznets curve, which suggests that the negative effects of economic growth on biodiversity increase only up to a point, after which they decrease. This decline occurs because high economic growth raises concern for the conservation and protection of biodiversity (Dietz & Adger, 2003; Otero et al., 2020).

2.6.1. Implications

This paper has crucial theoretical and practical implications for scholars and policymakers. The grouping of countries into clusters shows that national innovation facilitators lead to different levels of innovation performance. These different innovation performance levels then influence sustainable development to a varying degree. Despite this grouping and the similarities among countries in the same cluster, national characteristics still differ. The context, circumstances, and situation of each country should be considered when designing innovation policies to foster sustainable development. Policymakers or scholars can analyze the evolution of sustainable development performance or movement among groups of countries according to the level of sustainable development to modify or adopt innovation policies and initiatives that promote sustainability. In these cases, where innovation constitutes a driving force, it is important to study innovation systems because each country or region possesses unique characteristics that shape policymaking. National or regional innovation systems involve a set of connections and relationships among different agents of the innovation process within national or regional boundaries (Cooke et al., 1997; Freeman, 1987). Therefore, although collaboration could foster innovation and sustainable development (Milana & Ulrich, 2022; Ukko et al., 2019), individual national characteristics should be considered because no policy model can be applied uniformly to all countries (Tödtling & Trippl, 2005). In addition, when implementing these innovation-based sustainable development policies, a country's level of economic development must be monitored. Doing so prevents excessive economic growth from exceeding the limits of the ecosystem and, hence, environmental degradation and destruction. In short, three valuable insights can be gained from the conclusions of the paper: (1) the link between innovation and sustainable development, (2) the need to study the characteristics of each innovation system to apply sustainable development policies and initiatives tailored to each country or region and thus ensure the effectiveness and success of sustainability, and (3) the limited power of economic growth in the context of sustainable development.

2.6.2. Limitations

This research is not exempt from limitations. First, the analysis was conducted for the years 2015 and 2020. However, as mentioned earlier, data on the SDG Index for 2015 were not available. Similarly, GDP per capita data were not available for the year 2020 because it is too recent. Also, the cluster analysis only included a small number of innovation facilitators. Others, such as technological, political, and market facilitators, may also influence the achievement of sustainable development. Aspects such as political and economic stability, the investment or financing context, and competitiveness (Morkovkin et al., 2019) could also affect sustainable development.

2.6.3. Future research possibilities

Given these limitations, cluster analysis including 2020 GDP per capita data and other factors affecting countries' sustainable development capacity should be performed to examine cluster creation and subsequent movements between clusters. Possible causes and consequences could thus be identified. Similarly, given the number and variety of SDGs, similar analysis could be performed by breaking the index down to focus on a specific SDG such as poverty. This analysis would provide crucial knowledge and insights to identify the innovation facilitators that encourage the achievement of sustainable development.

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2.8. Appendices

Appendix 1: Multiple linear regression analysis

Table 2.4. Coefficients of the MLR models for 2015

Coefficients 2015

Model		Unstandardized	SE	Standardized	t	p	Collinearity Statistics Tol.	Collinearity Statistics VIF
1	(Intercept)	61.509	1.1		53.9	< .001		
2	(Intercept)	37.11	1.4		27.4	< .001		
	V2015 Human capital and research	0.752	0	0.874	19.7	< .001	1	1
3	(Intercept)	29.347	1.6		18.6	< .001		
	V2015 Human capital and research	0.546	0	0.635	12.6	< .001	0.55	1.8
	V2015 Ecological sustainability	0.366	0.1	0.358	7.1	< .001	0.55	1.8
4	(Intercept)	26.42	2		13.1	< .001		
	V2015 Human capital and research	0.469	0.1	0.545	8.7	< .001	0.34	2.9
	V2015 Ecological sustainability	0.321	0.1	0.314	5.9	< .001	0.48	2.09
	V2015 Institutional framework	0.113	0.1	0.149	2.3	0.03	0.32	3.18

Note: The following covariate was considered but not included: V2015 GDP per capita (current US$); Standard Error = SE; Tol. = Tolerance; VIF = variance inflation factor.

Table 2.5. Coefficients of the MLR models for 2020

Coefficients 2020

							Collinearity Statistics	
Model		Unstandardized	SE	Standardized	t	p	Tol.	VIF
1	(Intercept)	69.791	0.781		89.4	< .001		
2	(Intercept)	55.32	1.094		50.6	< .001		
	V2020 Human capital and research	0.446	0.03	0.801	14.6	< .001	1	1
3	(Intercept)	51.668	1.106		46.7	< .001		
	V2020 Human capital and research	0.312	0.034	0.56	9.3	< .001	0.61	1.63
	V2020 Ecological sustainability	0.245	0.038	0.387	6.4	< .001	0.61	1.63
4	(Intercept)	50.509	1.221		41.4	< .001		
	V2020 Human capital and research	0.367	0.042	0.658	8.7	< .001	0.38	2.63
	V2020 Ecological sustainability	0.259	0.038	0.408	6.7	< .001	0.59	1.68
	V2019 GDP per capita (current US$)	-5.9e -5	2.8e -5	-0.149	-2.1	.037	0.43	2.3

Note: The following covariate was considered but not included: V2020 Institutional framework; Standard Error = SE; Tol. = Tolerance; VIF = variance inflation factor.

Table 2.6. ANOVA 2015 and 2020

Model		Sum of squares	df	Mean square	F	p
2015						
2	Regression	14665.950	1	14665.950	389.642	< .001
	Residual	4516.741	120	37.640		
	Total	19182.691	121			
3	Regression	16014.796	2	8007.398	300.793	< .001
	Residual	3167.895	119	26.621		
	Total	19182.691	121			
4	Regression	16148.103	3	5382.701	209.306	< .001
	Residual	3034.588	118	25.717		
	Total	19182.691	121			
2020						
2	Regression	5775.957	1	5775.957	214.715	< .001
	Residual	3228.067	120	26.901		
	Total	9004.023	121			
3	Regression	6600.881	2	3300.440	163.433	< .001
	Residual	2403.143	119	20.194		
	Total	9004.023	121			
4	Regression	6688.122	3	2229.374	113.591	< .001
	Residual	2315.902	118	19.626		
	Total	9004.023	121			

Note: The intercept model is omitted because no meaningful information can be shown.

Appendix 2: Cluster analysis

Table 2.7. 2015 Cluster details

Cluster	1	2	3	4
Size	27	47	24	24
Explained proportion within-cluster heterogeneity	0.14	0.39	0.17	0.31
Within sum of squares	17.74	48.61	21.09	38.62
Silhouette score	0.51	0.29	0.37	0.38
Centroid V2015 GDP per capita (current US$)	-0.74	-0.46	-0.03	1.76
Centroid V2016 SDG Index score	-1.48	-0.09	0.637	1.20
Centroid V2015 Institutional framework	-1.04	-0.43	0.61	1.41
Centroid V2015 Human capital and research	-1.15	-0.27	0.31	1.50
Centroid V2015 Ecological sustainability	-1.20	-0.28	1.08	0.82

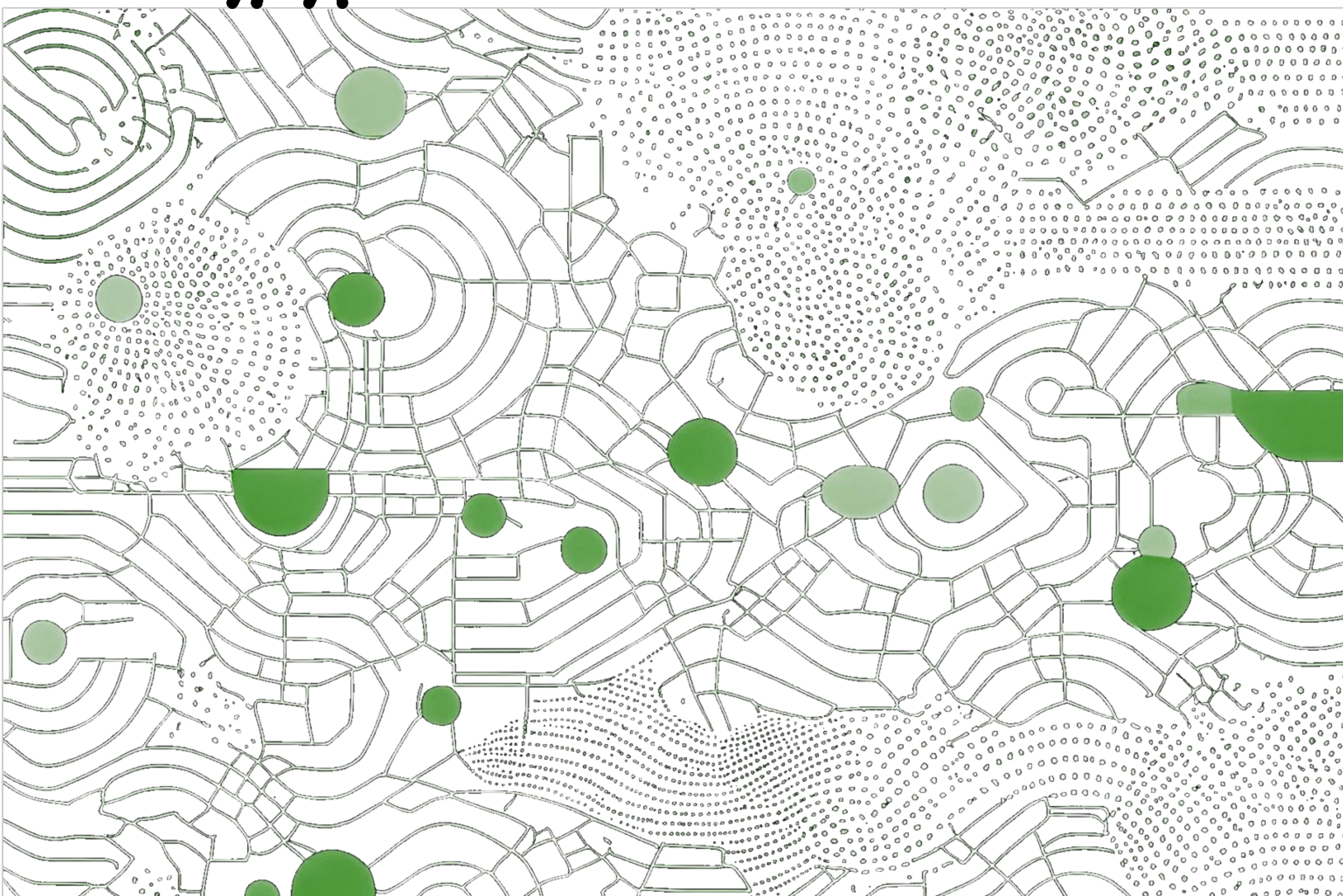
Notes: The between sum of squares of the four-cluster model is 478.93; the total sum of squares of the four-cluster model is 605.

Table 2.8. 2020 Cluster data

Cluster	1	2	3	4
Size	26	54	19	23
Explained proportion within-cluster heterogeneity	0.15	0.48	0.09	0.27
Within sum of squares	20.58	64.94	12.43	36.63
Silhouette score	0.50	0.28	0.51	0.36
Centroid V2019 GDP per capita (current US$)	-0.75	-0.41	0.09	1.74
Centroid V2020 SDG Index score	-1.49	0.001	0.81	1.01
Centroid V2020 Institutional framework	-1.04	-0.35	0.63	1.48
Centroid V2020 Human capital and research	-1.24	-0.19	0.41	1.52
Centroid V2020 Ecological sustainability	-1.04	-0.36	1.49	0.79

Notes: The between sum of squares of the four-cluster model is 470.42; the total sum of squares of the four-cluster model is 605.

Chapter 3.
Driving research on eco-innovation systems: Crossing the boundaries of innovation systems



Chapter 3.
Driving research on eco-innovation systems: Crossing the boundaries of innovation systems

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Chapter 3.
Driving research on eco-innovation systems: Crossing the boundaries of innovation systems

Abstract. Sustainability is now a part of all areas of today's society and has become a cornerstone of economic, social, and environmental prosperity. Its pivotal role means that sustainability has also influenced the innovation process. Over the last few decades, new innovation-related concepts linked to sustainable development have emerged in the form of environmental, green, sustainable, and eco-innovations; nevertheless, technological and innovation developments still occur within the boundaries of an innovation system. Innovation systems possess unique characteristics that shape activities, actions, and decisions. The separate bodies of literature on eco-innovation and innovation systems are extensive; however, the status of the literature on the intersection of these two topics is less clear. This study provides an overview of the scientific literature in the area where eco-innovation and innovation systems meet, and a bibliometric analysis shows that the joint study of eco-innovation and innovation systems is an unexplored knowledge field. Thus, the main authors and documents that provide the foundation of the literature on eco-innovation and innovation systems were identified, and theoretical knowledge was grouped into four clusters according to thematic areas: Cluster 1 related to eco-innovation; Cluster 2 related to innovation systems; and Clusters 3 and 4, which include the elements that constitute and interact within eco-innovation systems. We hope that this study will encourage scholars to conduct research on eco-innovation systems, which could have positive implications for the design and implementation of new policies and instruments to achieve sustainable development.

Keywords. Eco-innovation, Innovation system, Sustainability, Sustainable development, Eco-innovation system

3.1. Introduction

Since the 1990s, nations have implemented innovation policies as part of their political strategies (López-Rubio et al., 2021b). The reason for this political interest is that innovation has become a crucial element in boosting business and regional competitiveness (Odei & Appiah, 2022). A region's competitiveness, as well as the business that takes place within it, is shaped by the region's characteristics, which include economic activity, institutional quality, infrastructure, and clustering (Aiginger & Firgo, 2017). Therefore, the custom of comparing regions and imitating practices by policymakers has led to failures in regional development, helping maintain regional differences and inequalities (Asheim et al., 2011). The need to resolve these failures has led to the development of innovative systems that may refer to the innovation characteristics of either a country (i.e., a national innovation system [NIS]) or region (i.e., a regional innovation system [RIS]). Innovation systems, which develop continuously over time, are created through collaboration and cooperation among entities within a region or country (Doloreux & Parto, 2005).

The innovation process requires the participation and collaboration of agents in the system. Through participation and collaboration, knowledge, information, and know-how are transmitted easily and rapidly, encouraging the adoption of innovations that improve economic, social, and environmental well-being. The importance of sustainable development and innovation has increased over the last few decades, and political and social awareness is now greater (Díaz-García et al., 2015; Hojnik & Ruzzier, 2016; Păcesilă & Ciocoiu, 2017). To reflect this greater awareness, new concepts of innovation have emerged in relation to sustainability and its three dimensions (economic, social, and environmental). The authors refer to such innovations as green (Azzone & Noci, 1998; Driessen & Hillebrand, 2002), environmental (Carraro & Siniscalco, 1992; Green et al., 1994; Porter & van der Linde, 1995), sustainable (Brundtland, 1987; Schiederig et al., 2012), and eco-innovation (Fussler & James, 1996; Rennings, 2000). Eco-innovation can drive a country's economic prosperity and well-being. Economic prosperity and well-being are closely associated with the environment (European Environment Agency, EEA, 2015), and this link suggests that eco-innovation develops within the boundaries of innovation systems, influenced by a country or region's individual characteristics.

The literature on eco-innovation and innovation systems is extensive when these topics are considered separately. However, what is the literature that studies both topics jointly and what are its characteristics? This study explores the research trends that arise when eco-innovation and innovation systems are considered together to identify the theoretical references (authors and documents) underpinning the literature on both topics. Thus, it provides academics with a comprehensive overview of the literature, and bibliometric methods are used for this purpose. Specifically, this study presents co-occurrence and co-citation analyses. Co-occurrence analysis reveals links between author keywords for eco-innovation and innovation systems, while co-citation analysis reveals common literature that provides a foundation for research on both eco-innovation and innovation systems. The data on this topic were obtained from the Web of Science Core Collection (WoS CC). These findings reflect that the joint field of eco-innovation and innovation systems remains unexplored, contrary to the extensive existing research on both topics when considered separately, even though sustainability in all areas of society has become a crucial part of achieving sustainable development. In addition, we identify the main authors and documents that provide the theoretical frameworks used in the literature on this topic. The specific areas studied by these authors are then grouped into four thematic clusters: Cluster 1 is related to eco-innovation; Cluster 2 is related to innovation systems; and Clusters 3 and 4 include the elements that constitute and interact with eco-innovation systems.

The originality of this study lies in its application of bibliometric analyses to study two topics that are broadly discussed in the literature when considered independently (eco-innovation and innovation systems). Thus, research gaps and trends that could encourage scholars to further research eco-innovation systems were identified. Further research could contribute to achieving sustainable development by providing policymakers with crucial insights integrated within the national innovation system. Therefore, innovation-sustainability-related policies and instruments can be adapted to each national context to guarantee the success of sustainable development.

The remainder of this paper is structured as follows. Section 2 describes national and regional innovation systems and eco-innovation. Section 3 introduces the bibliometric analysis method and contextualizes the research on eco-innovation and innovation systems. Section 4 presents the results of the bibliometric analysis. Finally, Section 5 presents the main conclusions, limitations, and possibilities for future research.

3.2. Theoretical framework

3.2.1. National and regional innovation systems

National and regional innovation systems have emerged in light of growing international competition, the limitations of current policies and development models, and the creation of clusters of successful industries and companies (Doloreux & Parto, 2005; Enright, 2003). An innovation system is defined as a set of economic and institutional agents that, together with the implementation of policies, can influence innovation performance and behavior (Freeman, 1987; Lundvall, 1992; Nelson, 1993).

Innovation systems facilitate the flow of information and technology among institutions, firms, and individuals (Alaie, 2020). The participation of these actors is essential for the success of the innovation process because technological development and innovation arise from complex relationships among the actors in the innovation system (OECD, 1997). According to Asheim and Isaksen (2002), clusters and other agglomerations can stimulate and incentivize collective learning and innovation through communication, collaboration, and cooperation among companies, sociocultural structures, and institutional environments. In this sense, collective learning and innovation are embedded in the regions and societies in which they occur.

Innovation systems focus on the factors that can influence a region's technological capabilities (Cooke et al., 1997; Nelson & Rosenberg, 1993). The diversity found in national innovation systems results from differences in economic, institutional, and research and development (R&D) frameworks, and the institutional and cognitive structures of a given region shape what occurs within it. These structures increase regional differences, resulting in different innovation potentials (Asheim et al., 2011). Many studies have investigated the influence of innovation activities and processes on modern societies and economies (Cancino et al., 2017; López-Rubio et al., 2021d).

To improve regional competitiveness and growth, it is essential to identify patterns of innovation in each region and adapt these patterns to different regional characteristics (Lorenz & Lundvall, 2006); doing so could reduce the inequalities between regions resulting from innovation. Asheim and Isaksen (2002) show that business clusters that ultimately drive regional development employ different innovation resources. Hence, clusters use different innovation strategies, which may be successful based on their characteristics, situations, and processes. Tödtling and Trippl (2005) argue that an ideal innovation policy model does not exist, but each policy must be adapted to the economic, political, social, cultural, institutional, and environmental contexts of the region in which it is implemented. The concept of innovation policy and its subsequent implementation highlights its importance in driving and supporting innovation processes (López-Rubio et al., 2021d).

3.2.2. Eco-innovation

An innovation is "the implementation of a new or significantly improved product (good or service), process, marketing method, or organizational method in business practices, workplace organization, or external relations" (OECD, 2005, p. 46). Technological innovations affect the society and environment in which they are implemented (Omri, 2020; Weitzman, 1997). Traditional innovation is based on maximizing profits and financial results without considering the indirect effects (Silvestre & Ţîrcă, 2019). However, growing social and environmental concerns have led to other types of innovation that attempt to cover the economic, social, and environmental dimensions of sustainability (Chen et al., 2018).

Numerous terms have been used in the literature to refer to innovations related to one or more sustainability dimensions. Social innovation is a new social practice arising from intentional, collective, and goal-oriented actions, and it aims to achieve a sustainable quality of life by reconfiguring the goal-achievement system (Periac et al., 2018). This type of innovation prioritizes the social dimension of sustainability by aiming to improve social capital and contribute to society's well-being (Dawson & Daniel, 2010; Silvestre & Ţîrcă, 2019). Many scholars have not reached a consensus on the terms used to describe other sustainability-related innovations (Zubeltzu-Jaka et al., 2018). These terms include "green" (Azzone & Noci, 1998; Driessen & Hillebrand, 2002), "environmental" (Carraro & Siniscalco, 1992; Green et al., 1994;

Porter & van der Linde, 1995), "sustainable" (Brundtland, 1987; Schiederig et al., 2012), and "eco-innovative" (Fussler & James, 1996; Rennings, 2000). Although some authors use these terms interchangeably (e.g., Dias Angelo et al., 2012; Hsu et al., 2021), others make a distinction (Díaz-García et al., 2015; Schiederig et al., 2012).

Green innovation is aimed at reducing a company's environmental impact, integrating environmental objectives and innovation processes, products, and services (Triguero et al., 2013). This type of innovation combines innovation-driven development with green development by relying on the basic concepts of environmental optimization, energy conservation, and innovation (Yi & Xiao-li, 2018). According to Watson et al. (2018), environmental innovation encompasses the environmental dimensions of sustainability. For example, Tariq et al. (2022) argue that the development of green technology and energy can contribute to sustainable development, guaranteeing ecological security because implementing eco-innovations can mitigate climate change. Schiederig et al. (2012) argue that sustainable innovation is the only type of innovation that includes the economic, social, and environmental dimensions of sustainability, while the other three terms (green, environmental, and eco-friendly) cover only the economic and environmental dimensions. Nevertheless, eco-innovation promotes a green economy and technology creation and acquisition, improves social well-being, and ensures environmental protection and natural resource conservation (Demirel & Kesidou, 2019; Zubeltzu-Jaka et al., 2018). Accordingly, it can be argued that eco-innovation includes all three dimensions of sustainability.

Fussler and James (1996) introduced in the literature the term "eco-innovation." The Eco-Innovation Observatory defines eco-innovation as "the introduction of any new or significantly improved product (good or service), process, organizational change or marketing solution that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole life-cycle" (Eco-Innovation Observatory, 2010, p. 7). Hojnik and Ruzzier (2016) approve of this definition, arguing that this type of innovation enables more efficient use of resources and reduces the negative impact of resource use on the environment; thus, eco-innovation can improve the environmental performance of nations, regions, and businesses (Kanda et al., 2019). Despite the lack of consensus on the definition of eco-innovation, most definitions emphasize the role of the environmental dimension of sustainability. Reducing the negative environmental impacts and improving the use of natural resources should enhance the environment. This improvement in environmental quality should have positive effects on society by increasing social well-being and quality of life. Innovation is a crucial driver of economic growth because it increases product variety and stimulates employment (Guinet & Pilat, 1999). Hence, the concept of eco-innovation covers not only environmental aspects but also sustainable development (Rennings, 2000).

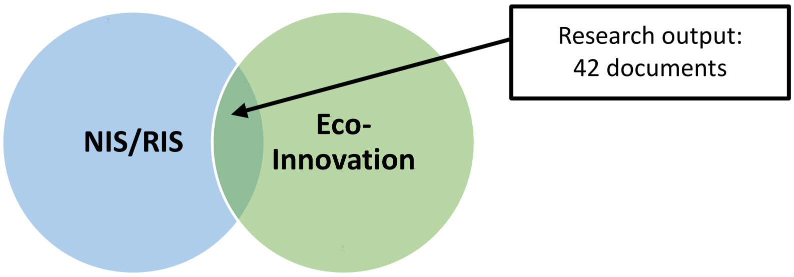
Given the wide variety of concepts and definitions related to sustainability-related innovation, this study uses the terms "green," "environmental," "sustainable," and "eco-innovation" interchangeably. The term "eco-innovation" is used the most, but it is assumed to encompass the other three types of innovation (i.e., green, environmental, and sustainable). By simultaneously analyzing the research avenues of the literature on eco-innovation and innovation systems, it is expected to identify the theoretical references (authors and documents) that support this literature.

3.3. Method and data

The literature on eco-innovation and national and regional innovation systems is extensive when these topics are considered separately. As of December 2021, the published documents on eco-innovation were 5469 and those on innovation systems 2789. According to WoS CC, the first paper on eco-innovation was published in 1978, and it was titled "The Adoption Process and Environmental Innovations: A Case Study of a Government Project" (Taylor & Miller, 1978).

Despite the extensive literature on these two topics and their importance within the current framework of sustainable development, research combining them is scarce. According to the WoS CC, the literature on both topics consists of only 42 documents, which is considerably smaller than that on either topic in isolation. Given the limited literature on the intersection of eco-innovation and national and regional innovation systems, this study aims to identify and analyze research avenues in this area while offering relevant insights (illustrated in Figure 3.1).

Figure 3.1. Intersection between innovation systems and eco-innovation



Bibliometric methods capture the nuances and evolutionary trends of existing scientific knowledge in different fields and configure and shed light on large data volumes. The development of bibliometric software (e.g., Gephi and VOSviewer) and scientific databases (WoS and Scopus) has facilitated the collection and analysis of these large data volumes. Using bibliometric methods, scholars can gain a broad literature overview while identifying knowledge and research gaps that may suggest new research possibilities (Donthu et al., 2021). Although the increasing use of bibliometrics is recent, discussions on this topic started in 1950 (Wallin, 2005). The categories of bibliometric analysis are two: first, performance analysis focuses on the scholars' research contributions, and it includes publication-, citation-, and publication-related metrics; second, science mapping allows to study the relationships between publications and academics. Techniques for this category of bibliometric analysis include citation, co-citation, bibliographic, co-word, and co-authorship analyses (Donthu et al., 2021).

Bibliometric methods are used to provide a comprehensive overview of the literature on eco-innovation and innovation systems by applying statistical measures (do Adro & Leitão, 2020). First, co-occurrence analysis was conducted to capture the co-occurrence of author keywords (van Eck & Waltman, 2010). This analysis was conducted twice—once for research on eco-innovation and once for research on national and regional innovation systems. The aim was to identify the keywords for each of the major blocks. This analysis helps explain the current state of research in this area because it shows the links between topics graphically and in such a way that they can be easily identified (Callon et al., 1983; López-Rubio et al., 2021a). Second, co-citation analysis was conducted. The purpose of co-citation analysis is to identify the common literature that provides a theoretical framework for each publication. When one or more documents cite two papers or authors, the two papers or authors are co-cited (López-Rubio et al., 2021c; Small, 1973). Both analyses were conducted using the VOSviewer software.

Figure 3.2 shows a bibliometric map of the connections among the keywords for eco-innovation. The search covered 5469 documents, including articles, proceedings, papers, book chapters and reviews, review articles, editorial materials, books, new items, letters, and meeting abstracts. This concept (together with green, environmental, and sustainable innovation) is strongly related to sustainable development, the environment, business, and regional management. These terms cover aspects related to the production and consumption models adopted by region (such as circular or green economies), corporate social responsibility (CSR), and competitiveness. This figure reflects the relevance of the environment when dealing with eco-innovation because it includes concepts such as renewable energy, climate change, and eco-design. Moreover, the literature also focuses on entrepreneurship, small and medium-sized enterprises (SMEs), and R&D, suggesting that their contribution to eco-innovation is important.

Figure 3.2. Overview of eco-innovation keywords

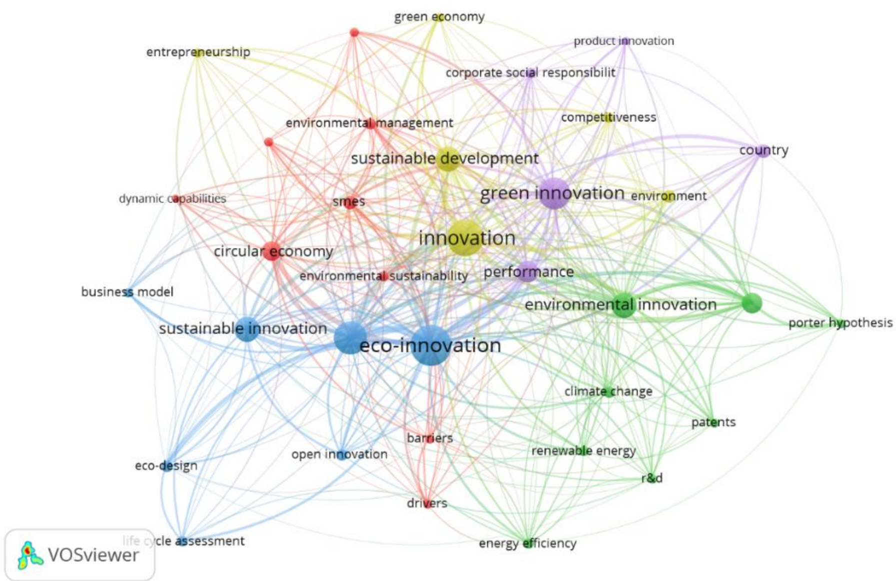
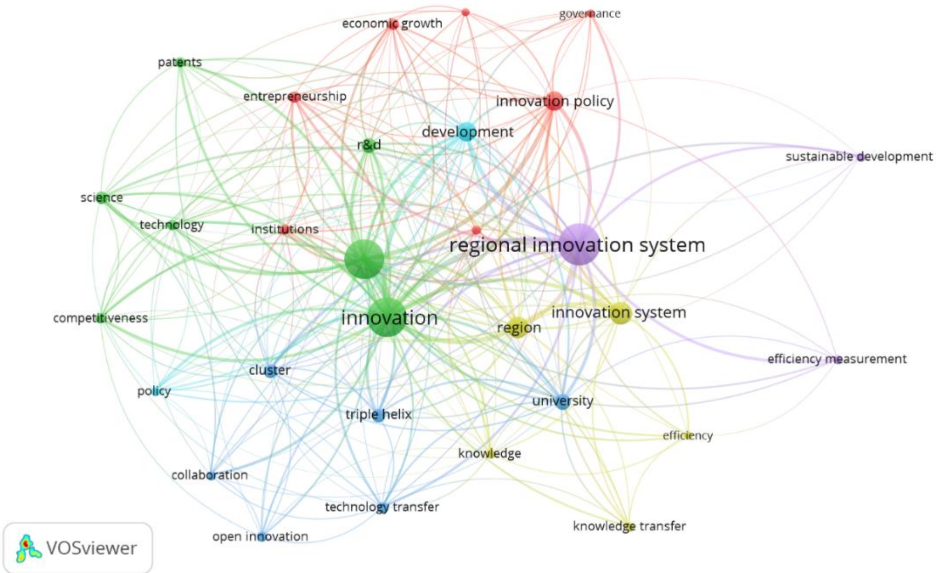


Figure 3.3 presents an overview of research on national and regional innovation systems, and it presents 2789 documents comprising articles, proceedings, papers, book chapters and reviews, review articles, editorial materials, books, new items, letters, and meeting abstracts. The figure shows that these concepts are directly related to innovation and highlights the importance of innovation system agents. Examples of such agents include institutions, universities, clusters, and governance structures. The figure also includes factors that may affect innovation systems, such as technology, science, policy, collaboration, entrepreneurship, R&D, and knowledge. These interconnected elements constitute the national or regional innovation system. Some studies have also dealt with the effects of innovation systems on the competitiveness, efficiency, development, and growth of a country or region. The implication is that when both the actions and relationships of these interconnected elements are grounded in sustainability principles, countries can achieve sustainable development and thus enhance their economic, social, and environmental growth.

Figure 3.3. Overview of innovation systems keywords

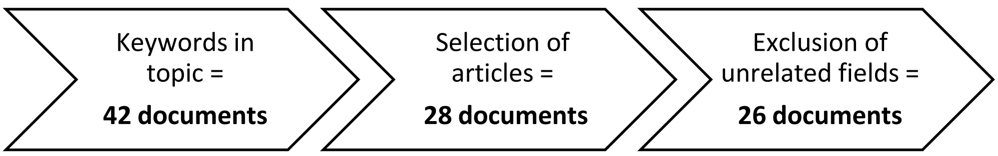


This study examined the literature on the intersection of eco-innovation and national and regional innovation systems. The literature search included 42 documents from the time of the study, which was conducted in January 2022 based on the WoS CC database. The data refer to all documents published up to December 31, 2021. The search query used to gather data was as follows:

Topic = ("national innov* system*" OR "national system* of innov*" OR "regional innov* system*" OR "regional system* of innov*") AND ("eco-innov*" OR "eco innov*" OR "ecoinnov*" OR "green-innov*" OR "green innov*" OR "greeninnov*" OR "sust* innov*" OR "sust*-innov*" OR "environ* innov*" OR "environ*-innov*").

This query returned 42 records: 28 articles, 14 proceedings papers, two book chapters, and two early access documents. The 28 articles were used for analysis, representing 67% of the documents. Two of these 28 articles, which focused on architecture and physics, were excluded because they were unrelated to knowledge. Therefore, the analysis was based on the remaining 26 articles. Figure 3.4 illustrates the article selection process used in this study.

Figure 3.4. Article selection process



3.4. Results: identifying patterns in the literature

To illustrate the focus of the research on eco-innovation and innovation systems between 1990 and 2021, 26 articles were categorized based on several variables. Table 3.1 presents the publications, number of citations, publications per year (P/Y), and citations per publication (C/P) for the 1990–1999, 2000–2009, 2010–2014, 2015–2019, and 2020–2021 sub-periods. In the 1990s and the 2000s, only one study was published per decade. The influence of publications from the 2000s appears to have been greater, as they received 114 citations. In the later sub-periods, the number of publications increased. Although the 2015–2019 sub-period had the highest number of publications (11), the 2010–2014 sub-period had the highest number of citations (363). The sub-period from 2020 to 2021 had a higher ratio of publications per year than any other sub-period. Therefore, scientific research on eco-innovation and innovation systems is expected to increase in the coming years.

Table 3.1. Distribution of publications, citations, and citations per publication over the study period

Period	TP	P/Y	TC	C/P
1990–1999	1	0.1	36	36
2000–2009	1	0.1	114	114
2010–2014	6	1.2	363	60,5
2015–2019	11	2.2	225	20,45
2020–2021	7	3.5	26	3,71

Note: TP = Total publications; P/Y = Publications per year; TC = Total citations; C/P = Citations per publication.

Table 3.1 also offers insights into the evolution of literature on eco-innovation and innovation systems. Despite some variations in scientific production, the trend has generally been increasing. Only two studies were published between 1998 and 2008, but scientific production has increased significantly over the last decade. In 2019 and 2020, the number of publications per year was four, making these the years with the highest scientific production (30.8% of the total scientific production on the topic). Three papers published in 2004, 2010, and 2013 received 114, 131, and 158 citations, respectively, highlighting their importance and influence. These findings are corroborated by Table 3.2, which presents the 10 most influential papers published from 1990 to 2021.

Table 3.2. The most influential publications on the topic of eco-innovation and innovation systems based on total citations

Authors	Title	Year	TC	C/Y
Horbach, J.; Oltra, V.; Belin, J.	Determinants and Specificities of Eco-Innovations Compared to Other Innovations-An Econometric Analysis for the French and German Industry Based on the Community Innovation Survey	2013	158	17.56
Buesa, M.; Heijs, J.; Baumert, T.	The determinants of regional innovation in Europe: A combined factorial and regression knowledge production function approach	2010	121	10.08
Doloreux, D.	Regional Innovation Systems in Canada: A comparative study	2004	114	6.33
del Rio, P.; Penasco, C.; Romero-Jordan, D.	Distinctive Features of Environmental Innovators: An Econometric Analysis	2015	65	9.29
Fabrizi, A.; Guarini, G.; Meliciani, V.	Green patents, regulatory policies and research network policies	2018	64	16
Leyden, D. P.	Public-sector entrepreneurship and the creation of a sustainable innovative economy	2016	38	6.33
Chapple, K.; Kroll, C.; Lester, T. W.; Montero, S.	Innovation in the Green Economy: An Extension of the Regional Innovation System Model?	2011	37	3.36
Roberts, R.	Managing innovation: The pursuit of competitive advantage and the design of innovation intense environments	1998	36	1.50
Chen, K. H.; Guan, J. C.	Mapping the innovation production process from accumulative advantage to economic outcomes: A path modeling approach	2011	29	2.64
Arranz, N.; Arroyabe, C. F.; Fernández de Arroyabe, J. C.	The effect of regional factors in the development of eco-innovations in the firm	2019	15	5

Note: TC = Total citations; C/Y = Citations per year.

The paper with the highest number of citations is "Determinants and Specificities of Eco-Innovations Compared to Other Innovations-An Econometric Analysis for the French and German Industry Based on the Community Innovation Survey" by J. Horbach, V. Oltra, and J. Belin, which was published in 2013 and has received 158 citations. In this study, the authors analyze the factors of eco-innovation across countries to determine whether they show national characteristics that depend on national innovation systems. "The determinants of regional innovation in Europe: A combined factorial and regression knowledge production function approach"' by Buesa, Heijs, and Baumert was published in 2010 and has received 121 citations. It explains that national and regional environments, innovative companies, universities, and public R&D are key drivers of innovation systems. Finally, "Regional Innovation Systems in Canada: A comparative study" by D. Doloreux was published in 2004 and is the third most-cited article. The authors investigated the innovation activities undertaken by SMEs to evaluate their collaborative interactions with other innovative organizations.

Table 3.3 presents the number of publications per country between 1990 and 2021. China had the most publications (four); Spain was responsible for three studies on eco-innovation and innovation systems, and Germany and the United States had two publications each. Several other countries (e.g., Australia, Finland, Lithuania, and Russia) were responsible for publishing only one paper. These findings indicate that the country with the most interest in studying the relationship between eco-innovation and innovation systems is China, followed by Spain. The conclusions and implications of publications by authors from China may help achieve sustainable national development; hence, China may have an advantage over other countries, not only in terms of economic and technological growth (as shown in recent years) but also in terms of sustainability. These four publications link the three social agents of the Triple Helix (universities, companies, and governments) to collaboration, innovation production processes, environmental impact, sustainability policies, and SMEs. Three publications by Spanish authors studied the main determinants of environmental innovators and business eco-innovations within regional innovation systems.

Table 3.3. Countries with the most citations for eco-innovation and innovation systems research

Country	TP	TC	C/P
Spain	3	201	67
Germany	2	158	79
Canada	1	114	114
USA	2	75	37.5
Italy	1	64	64
China	4	52	13

Note: TP = Total publications; TC = Total citations; C/P = Citations per publication.

Table 3.4 lists the five journals that published the highest number of articles on eco-innovation and innovation systems. The journals Business Strategy and the Environment and Research Policy published three studies on this topic. However, the three papers published in Research Policy received a higher number of citations (221 vs. 80 for papers published in Business Strategy and the Environment). The most-cited Research Policy paper is by M. Buesa, J. Heijs, and T. Baumert, and it is the second most influential in terms of the number of citations (Table 3.2). European Planning Studies, Journal of Cleaner Production, and Small Business Economics each have two publications, while Applied Economics has only one publication. These top five journals have a strong commitment to the environment, sustainability, and national, regional, and business development, in addition to focusing on development through innovative solutions.

Table 3.4. Journals with the most publications on eco-innovation and innovation systems

Journal	TP	TC	C/P
Business Strategy and the Environment	3	80	26,67
Research Policy	3	221	73,67
European Planning Studies	2	20	10
Journal of Cleaner Production	2	7	3,5
Small Business Economics	2	47	23,5
Applied Economics	1	4	4

Note: TP = Total publications; TC = Total citations; C/P = Citations per publication.

Co-citation analysis was conducted to identify the relationships between the authors and references cited in 24 of the 26 articles. Two of the 26 articles (Koblianska et al., 2020; Song et al., 2020) were excluded from analysis; therefore, they were not included in the co-citation analysis. The minimum number of citations required for an author to be included in the analysis was five, leading to the selection of 68 authors with the greatest total link strength. Figure 3.5 and Table 3.5 present the results of the co-citation analysis based on cited authors. Figure 3.5 shows the core authors cited in the 24 articles grouped into four clusters: Cluster 1 (red) consists of 22 authors focused on innovations that benefit the economy, society, and the environment (green, environmental, sustainable, and eco-innovation). Cluster 2 (green) comprises 17 authors specializing in national and regional innovation systems. Cluster 3 (blue) includes 16 authors whose research is associated with innovation, entrepreneurship, and development, as well as authors studying innovation systems. This combination of research areas can be justified by the fact that innovation, entrepreneurship, and development are studied within the context of innovation systems because of their interactions with each other within the system. Finally, Cluster 4 (yellow) consists of 11 authors who focus on other elements that interact within an innovation system, namely clusters, knowledge, policy, and industry, which may affect eco-innovation activities and decisions. Table 3.5 complements this information by displaying the authors belonging to each cluster and their main research topics.

Figure 3.5. Co-citation of authors in the eco-innovation and innovation systems literature

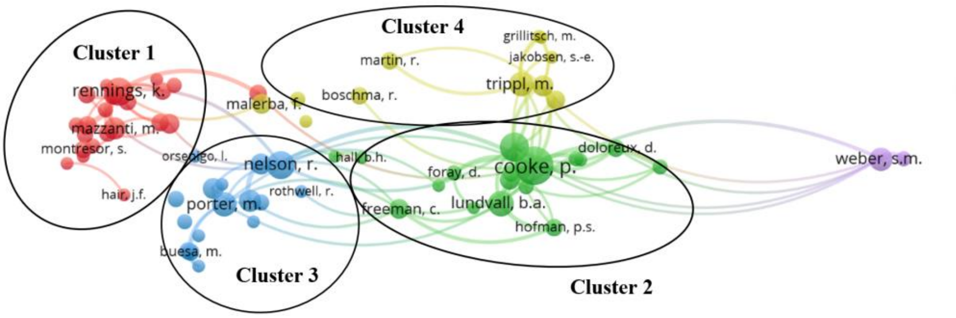


Table 3.5. Four clusters of authors according to their research areas

Cluster number and color	Authors	Topic
1 (red)	Cainelli, G.; Chesbrough, H.; de Marchi, V.; del Rio, P.; Demirel, P.; Hair, J.F.; Hascic, I.; Horbach, J.; Jaffe, A.B.; Johnstone, N.; Kemp, R.; Kesidou, E.; Marzucchi, A.; Mazzanti, M.; Montresor, S.; Oltra, V.; Popp, D.; Rammer, C.; Rennings, K.; Wagner, M.; Ziegler, A.; Zoboli, R.	Eco-innovation
2 (green)	Asheim, B.; Cooke, P.; de Laurentis, C.; Defourny, J.; Doloreux, D.; Edquist, C.; Etxebarria, G.; Etzkowitz, H.; Foray, D.; Freeman, C.; Hall, B.H.; Harmaakorpi, V.; Heidenreich, M.; Hofman, P.S.; Lundvall, B.A.; Rosenberg, N.; Todtling, F.	National and regional innovation systems
3 (blue)	Acs, Z.; Archibugi, D.; Audretsch, D.B.; Brouwer, E.; Buesa, M.; Fritsch, M.; Furman, J.L.; Griliches, Z.; Heijs, J.; Martinez Pellitero, M.; Nelson, R.; Orsenigo, L.; Pavitt, K.; Porter, M.; Rothwell, R.; Stern, S.	Innovation, entrepreneurship, and development
4 (yellow)	Boschma, R.; Coenen, L.; Frenken, K.; Grillitsch, M.; Isaksen, A.; Jakobsen, S.-E.; Malerba, F.; Martin, R.; Njøs, R.; Storper, M.; Trippl, M.	Clusters, knowledge, policy, and industry

Note: Some of the authors have also studied topics from other clusters. However, they were added to the cluster that is closest to their main area of specialization.

Table 3.6 shows the 10 most-cited authors in papers that simultaneously address eco-innovation and national and regional innovation systems. Cooke, Asheim, and Nelson are the three most cited authors, and their research is mainly related to innovation systems. Six of the 10 most-cited authors belong to Clusters 2 and 3 (three to Cluster 2 and three to Cluster 3). This distribution makes sense because research on innovation, entrepreneurship, development, and innovation systems has a decade-long history. However, the literature on eco-innovation and its drivers is more recent as sustainability concerns were first associated with innovation after

1987. In 1987, the World Commission on Environment and Development (WCED) introduced the concept of sustainable development, which is crucial in explaining eco-innovation.

Table 3.6. Authors of eco-innovation and innovation systems studies

	Author	Cluster	TC	TLS
1	Cooke, P.	2	40	3218
2	Asheim, B.	2	23	2121
3	Nelson, R.	3	22	2017
4	Rennings, K.	1	21	1907
5	Lundvall, B.A.	2	18	1725
6	Porter, M.	3	17	1631
7	Trippl, M.	4	16	1401
8	Weber, S.M.*		15	692
9	Acs, Z.	3	13	1134
10	Mazzanti, M.	1	13	1232

Note: TC = Total citations; TLS = Total link strength. *The scientific research by S. M. Weber is mainly based on organizational pedagogy. Therefore, the author does not fit into any of the clusters.

Finally, Table 3.7 presents the findings of the co-citation analysis based on the cited references in the 26 journals. The minimum number of citations for a cited reference to be included in the analysis was two, and only 16 of the 1580 references met this threshold. These 16 references were selected as the studies on which the literature on eco-innovation and innovation systems is based. The number of co-citations received by each cited reference is reflected in the total link strength (López-Rubio et al., 2021a). The study with the highest total link strength among eco-innovation and innovation systems articles is titled "On the drivers of eco-innovations: Empirical evidence from the UK" and was authored by E. Kesidou and P. Demirel. This study attempts to identify the drivers of eco-innovation using a sample of 1566 UK firms. The authors highlight the role of environmental regulations in encouraging firms to become involved in eco-innovation. Although 13 of the remaining articles had a total link strength of 200, two had a value of 100. Regarding the total number of citations in WoS, only five articles had at least 1000 citations: they were authored by Teece, Pisano, and Shuen (13,593 citations), Z. Griliches (2960 citations), K. Pavitt (2737 citations), K. Rennings (1142 citations), and F. Tödtling and M. Trippl (1098 citations). Of these five articles, only one directly dealt with eco-innovation. The remainder papers of the table cover the general concept of innovation. Therefore, given that eco-innovation is a relatively recent concept and given the high number of citations of the article by Rennings (2000), this article may be regarded as a seminal study in the field of eco-innovation.

Table 3.7. The 16 most cited eco-innovation and innovation systems papers

PY	Authors	Title	TLS	TC-WoS
1984	Pavitt, K.	Sectoral patterns of technical change: towards a taxonomy and a theory	200	2,737
1990	Griliches, Z.	Patent statistics as economic indicators: a survey	100	2,960
1992	Cooke, P.	Regional innovation systems: competitive regulation in the new Europe	200	527
1997	Teece, D. J., Pisano, G., & Shuen, A.	Dynamic capabilities and strategic management	200	13,593
2000	Rennings, K.	Redefining innovation—eco-innovation research and the contribution from ecological economics	200	1,142
2004	Smits, R., & Kuhlmann, S.	The rise of systemic instruments in innovation policy	200	359*
2005	Tödtling, F., & Trippl, M.	One size fits all?: Towards a differentiated regional innovation policy approach	200	1,098
2007	Wagner, M.	On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms	200	253

2008	Horbach, J.	Determinants of environmental innovation—New evidence from German panel data sources	200	785
2008	Wagner, M.	Empirical influence of environmental management on innovation: Evidence from Europe	200	198
2009	Oltra, V., & Saint Jean, M.	Sectoral systems of environmental innovation: an application to the French automotive industry	100	221
2011	Demirel, P., & Kesidou, E.	Stimulating different types of eco-innovation in the UK: Government policies and firm motivations	200	248
2012	Kesidou, E., & Demirel, P.	On the drivers of eco-innovations: Empirical evidence from the UK	300	372
2012	Horbach, J., Rammer, C., & Rennings, K.	Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull	200	657
2012	De Marchi, V.	Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms	200	572
2012	Cainelli, G., Mazzanti, M., & Montresor, S.	Environmental innovations, local networks and internationalization	200	142

Note: PY = Publication year; TLS = Total link strength; TC-WoS = Total citations according to the WoS. *The document was not available in the WoS. Therefore, the citation value was obtained from Scopus.

Despite the small number of studies that simultaneously address eco-innovation and innovation systems, the co-citation analysis reveals the existence of a collection of key authors and studies commonly used to build a theoretical framework for research in this area. These authors and studies seem to coincide with those that formed the basis for studies on eco-innovation or national and regional innovation systems.

3.5. Conclusions

This study provides an overview of the literature on eco-innovation and innovation systems. The aim was to identify research avenues in specialist literature by examining the authors and articles that form the basis for the theoretical framework within this field, given that the literature on the intersection of eco-innovation and innovation systems is less clear than the literature that covers both topics separately. Scientific publications on eco-innovation (5,469) or innovation systems (2,789) are numerous; however, research on both topics is scarce. According to the WoS, only 42 documents exist. A bibliometric analysis was performed on 26 of the 42 articles.

The literature on eco-innovation and innovation systems is growing. China (four articles) and Spain (three articles) have the highest scientific production in this field. Such research could provide insights for designing and implementing eco-innovation policies based on each national innovation system, as well as promoting sustainable behavior at all levels of society.

Co-citation analysis based on the most-cited authors resulted in four clusters of authors corresponding to different research focuses. Cluster 1 (red cluster) focuses on eco-innovation, while Cluster 2 (green cluster) focuses on innovation systems. These clusters include the most authors (22 and 17 authors, respectively), suggesting that they have become the basis of the eco-innovation and innovation systems literature. Clusters 3 (blue) and 4 (yellow) focus on elements that constitute and interact with the innovation system. These elements can also affect a nation, region, or company's eco-innovation ability. Co-citation analysis based on the most-cited documents identified 16 references cited at least twice by 24 articles. As mentioned previously, two of the 26 articles (Koblianska et al., 2020; Song et al., 2020) were not located and were, therefore, not included in the co-citation analysis. As these studies are most commonly found within the theoretical frameworks of eco-innovation and innovation systems, in addition to the aforementioned studies, these articles could be crucial in explaining eco-innovation systems.

The 26 articles used for the bibliometric analysis in this study were selected from the 42 documents returned by searching for research on these two topics. This low scientific production reflects a scarcity of research on eco-innovation and innovation systems. This indicates that this field of research remains unexplored. However, the growing importance of sustainability and its relevance in all areas of society, including innovation systems, reflects the need for detailed studies on the functioning and characteristics of eco-innovation systems. Eco-innovation systems can provide international organizations, nations, and policymakers with appropriate instruments and skills to achieve sustainable development by boosting eco-innovation. Eco-innovation will be successful with a collective effort to consider the individual characteristics of the individual countries that together constitute the eco-innovation system.

Altenburg and Pegels (2012) introduce the concept of sustainability-oriented innovation systems as a call to action for governments as actors capable of encouraging the use of alternative technologies to promote sustainable development. The difference between innovation systems and sustainability-oriented innovation systems lies in the importance of the government's role in driving environmentally sustainable innovation. This aligns with Sun et al. (2019), which argue that adopting eco-innovation largely depends on government support and funding; therefore, the exploitation of eco-innovation varies within eco-innovation systems. However, these systems are characterized by an open flow of knowledge between agents from other systems as well as the relevance of geographic proximity in fostering this knowledge flow (Cooke, 2011), and the concept of eco-innovation is inherent in these systems (Horbach, 2005). Innovation systems emerge from the gradual process of interaction between agents (Suurs and Hekkert, 2012). It is thus reasonable to assume that eco-innovation systems are a key topic given the links between sustainability and innovation, which have been well documented since the end of the 1990s.

For example, Yin et al. (2019) used the institutional and innovation systems theory to explain how to achieve balanced sustainable development of the rural innovation system. Similarly, Miremadi et al. (2019) provide a holistic framework for studying eco-innovation systems based on innovation processes and government involvement through support and governance policies. Ouyang and You (2021) conclude that firms should be more aware of green R&D to shift toward eco-innovation systems, and such awareness accelerates the adoption of green and sustainable business practices that drive sustainable national development. Other studies have focused on China's eco-innovation system (Li et al., 2020; Wu et al., 2021), emphasizing the prominent role of the government, institutions, R&D, knowledge, geographic proximity, and geographic characteristics in the study of eco-innovation systems. These elements were also identified in the four clusters previously described, demonstrating the relationship between eco-innovation and innovation systems. Given the need to shift toward sustainable development, the literature could contribute to countries' progress by addressing the characteristics of eco-innovation systems. Such research could provide countries with crucial insights and tools to depart from traditional growth and development models and adopt new ones based on the three dimensions of sustainability. Recent studies have offered evidence of the novelty and growing importance of eco-innovation systems.

This study has some limitations. Scientific research on eco-innovation and innovation systems not available in the WoS CC was not included in the bibliometric analysis; thus, publications that may have made crucial contributions to this field but that do not appear in the WoS CC were not considered. In addition, co-cited references and authors might not have been cited for the same purpose or might not have expressed the same idea in all 24 articles. Some citations were included for unrelated reasons; however, in this study, it was assumed that co-citations reflected a similar focus. Despite these limitations, this study successfully identifies the state-of-the-art eco-innovation and innovation systems literature by providing research opportunities and trends on this topic.

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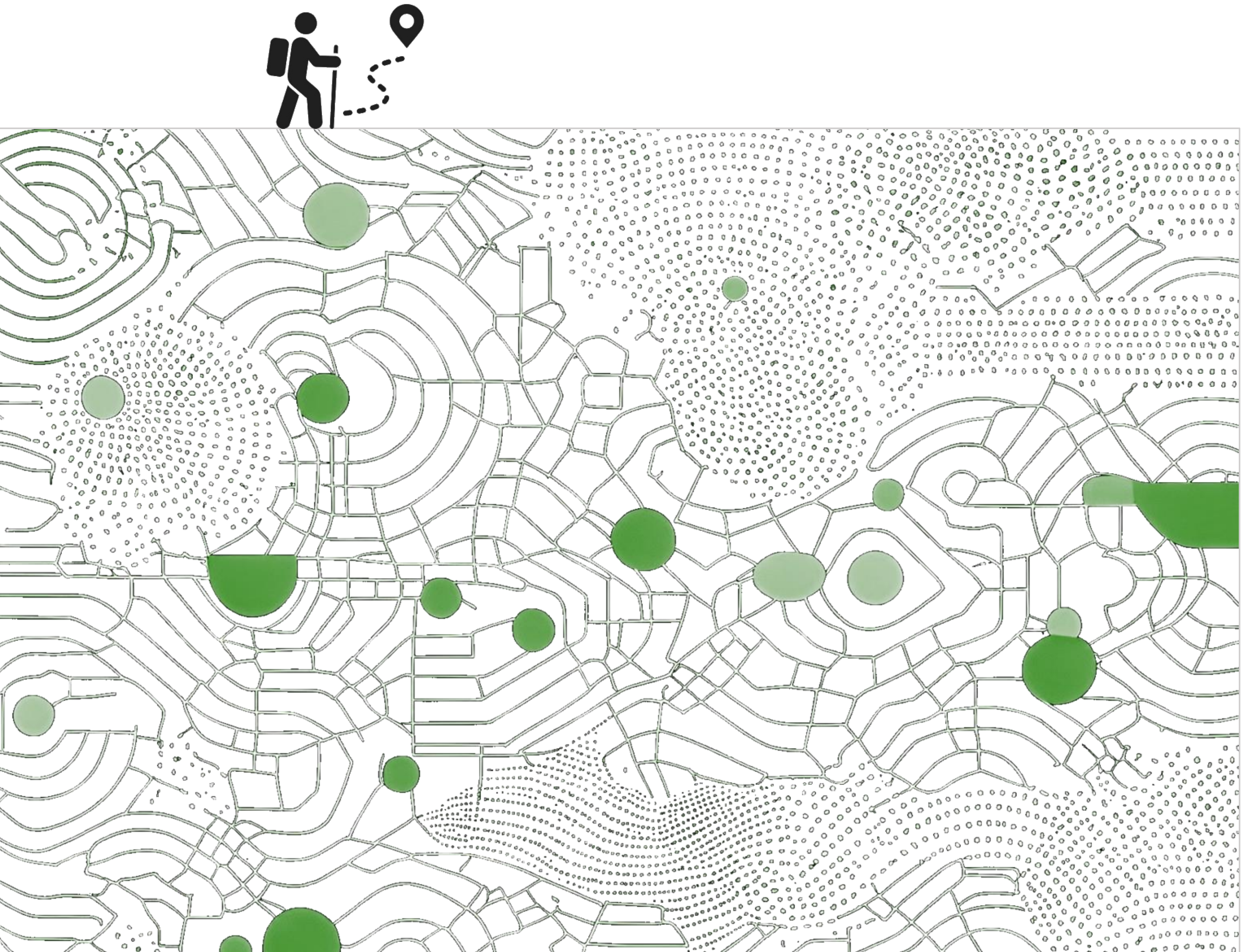
Chapter 4. Factors driving national eco-innovation: New routes to sustainable development



Chapter 4.
Factors driving national eco-innovation: New routes to sustainable development

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Chapter 4. Factors driving national eco-innovation: New routes to sustainable development

Abstract. Each country has its own set of unique elements and institutions to foster innovation within its boundaries. This combination of elements and institutions is known as an innovation system. Innovation has been used to boost countries' growth and competitiveness for decades. However, it is a much questioned strategy because it may compromise the opportunities of future generations and thus sustainable development. Hence, academics and policymakers are now turning to eco-innovation to create sustainability-based innovation systems that improve not only a country's economic efficiency but also people's well-being and quality of life. However, the uncertainty and complexity around eco-innovation hinder the creation and implementation of eco-innovation policies because of a failure to identify its drivers. The aim of this paper is to detect the national-level factors that are necessary or sufficient for eco-innovation in European countries. Fuzzy-set qualitative comparative analysis (fsQCA) is used for this purpose. The conditions in this analysis are governance, human capital capacity, research institutions, and public and private research and development (R&D) investment. The use of fsQCA to study eco-innovation systems is methodologically unique. The findings suggest that research institutions, human capital capacity, and public R&D investment are valuable for eco-innovation. Therefore, the findings of this study have implications for the design of policies aimed at creating businesses, enriching society, and boosting sustainable development through eco-innovation. Such policies should focus on education, social awareness, stakeholder engagement, support from research institutions, and public R&D investment.

Keywords. Eco-innovation, Human capital, National innovation systems, R&D investment, Research institutions, Sustainable development

4.1. Introduction

In recent decades, sustainable development has increasingly attracted the interest of society by placing eco-innovation in the spotlight (Hojnik & Ruzzier, 2016). Certain economic activities negatively affect the environment, but this type of innovation can reduce their environmental impact (Horbach, 2016; Koseoglu et al., 2022) while improving people's wellbeing and countries' economic competitiveness (Păcesilă & Ciocoiu, 2017; Porter & van der Linde, 1995). Therefore, eco-innovation has a twofold impact by reinforcing both sustainability and competitiveness. Accordingly, it has an ability to exert beneficial effects on both these areas simultaneously. This ability resolves the trade-off between either promoting environmental issues or boosting competitiveness that has troubled some authors (e.g., Andersen, 2004) in relation to aligning environmental policies with innovation to create sustainable economic value. For example, Bossle et al. (2016) argued that sustainability and economic competitiveness can be promoted through an eco-innovation-based approach. Companies can achieve competitive advantages due to their improved reputation and image from adopting new green processes and products (Chen et al., 2017).

Several authors have argued that factors other than innovation and eco-innovation stimulate competitiveness (e.g., Aiginger & Firgo, 2017; Sánchez de la Vega et al., 2019). Research by Mas-Verdu et al. (2020) has shown that, for a region to be competitive, high public and private R&D spending is necessary, as is having national-level universities ranked among the top 300 in the world. Similarly, the combination of collaboration between companies, high levels of human capital, and private R&D investment can help create competitive regions (Garcia-Alvarez-Coque, Mas-Verdú, & Roig-Tierno, 2021). These factors are also related to eco-innovation. Hence, fostering these elements could have a double impact on competitiveness by (i) exerting a direct effect and (ii) creating an indirect effect driven by eco-innovation.

Eco-innovation is characterized by a systemic and dynamic process of relationships between different factors and agents (Pacheco et al., 2018). Eco-innovation occurs within the borders of a region with national and regional innovation systems. These innovation systems encompass a set of characteristics based on culture, history, policies, and other aspects (Cooke et al., 1997). Tödtling and Trippl (2005) highlighted the importance of having an in-depth knowledge of the characteristics of the national innovation system because countries may have diverse innovation contexts.

The myriad of factors that affect eco-innovation complicates the adoption of policies that effectively promote eco-innovation (del Río et al., 2010; Díaz-García et al., 2015). This paper shows which national characteristics are necessary or sufficient to stimulate eco-innovation performance in European countries. Fuzzy-set qualitative comparative analysis (fsQCA) was used to do so. Five conditions were included in the research model. To the best of the authors' knowledge, no fsQCA studies have examined innovation systems and sustainability together, making this research unique.

The five conditions included in this study are governance, human capital capacity, research institutions, public R&D investment, and private R&D investment. These five factors are fundamental because economic agents such as governments, firms, employees, students, universities, and research institutions can influence the adoption of sustainable actions by companies and society (Horbach, 2016; Orlando et al., 2020; Păcesilă & Ciocoiu, 2017; Rosca et al., 2018). International sustainability strategies call these agents to action by participating in innovation and knowledge processes. The strongest social, human, academic, scientific, and business capital can thus join forces (Reverte, 2022). The results suggest that, despite the absence of necessary conditions, human capital capacity, research institutions, and public R&D investment play a crucial role in explaining eco-innovation. Moreover, the lack of human capital capacity and public and private R&D investment may lead to the failure of eco-innovation at the national level.

Section 2 of this paper contextualizes eco-innovation by describing its relationship with innovation systems, competitiveness, and the conditions included in the analysis. Section 3 introduces the fsQCA method and describes the data. The results are presented in Section 4. Section 5 discusses the results. Section 6 presents the conclusions of the study.

4.2. Theoretical framework

The literature cites numerous elements that may influence eco-innovation. In particular, Díaz-García et al. (2015) identified a series of drivers of eco-innovation grouped into three levels: micro-, meso-, and macro-level drivers. These factors include personnel, networking, public and private financing, R&D cooperation, norms and regulation, and subsidies. This section establishes five propositions related to the factors included in the analysis, namely governance, human capital capacity, research institutions, public R&D investment, and private R&D investment.

4.2.1. Innovation systems

Over the years, innovation has become an essential strategy for boosting economic development and competitiveness. In addition to supporting the development of innovation policies, regional innovation systems enable the identification, analysis, and understanding of the creation, development, and possible trends in regional innovation characteristics (Asheim & Isaksen, 2002; Cooke, 1998). National innovation systems, the national analog of regional innovation systems (Cooke et al., 1997), consist of a set of interconnected elements and institutions located within the borders of a nation (or region in the case of regional innovation systems), which contribute to the creation, dissemination, and use of new technologies and knowledge (Freeman, 1987; Lundvall, 2016; Mieg, 2012). Each geographical area has unique characteristics that justify the implementation of different national policies. There is no single national policy model that applies everywhere. Best practices depend on the spatial environment (Tödtling & Trippl, 2005) because socioeconomic factors shape the development of innovation differently in different contexts (Lu et al., 2020; Tabrizian, 2019). The fact that some countries succeed in innovation by applying specific measures and practices does not necessarily guarantee the success of another country with different characteristics. However, the strategies of another country could serve as a model or starting point to study the country's specific situation.

Numerous elements interact within an innovation system's frontier. The N-Helix models complement innovation system theory by considering the existence of N elements that interact within the borders of a nation or region. The latest N-Helix model is the Sextuple Helix (López-Rubio et al., 2021), based on the Triple Helix

(Etzkowitz & Leydesdorff, 2000). These N-Helix models emerged to cover the limitations of the Triple Helix model because it is crucial to understand the social implications of socio-technical transitions (Park & Stek, 2022). These models integrate innovation and sustainability by aligning the goals of the private sector, government, and universities to provide transformative solutions to economic, social, and environmental challenges (Chindasombatcharoen et al., 2022; Etzkowitz & Zhou, 2006; Lew & Park, 2021).

4.2.2. The role of governance

Over the past few decades, policymakers, academics, and other agents have focused on sustainable governance given society's desire for greater transparency and participation in public affairs (Chung & Park, 2018). Regional policy can encourage consumers and producers to ground their choices and actions in sustainability and the notion that the circular economy can have an essentially positive effect on the economy, society, and the environment (Smol et al., 2017). Given that innovation policy is not usually inclined toward sustainability (Reid & Miedzinski, 2008), the role of the government may be crucial.

Public institutions and agencies can formulate more sustainable policies that benefit the environment while contributing to economic and social development through, for example, effective innovation measures regarding pollution and resource conservation (Chen et al., 2017). For example, the European Commission has tried to increase awareness and commitment of the circular economy to encourage the sustainable behaviors of consumers and producers (Camilleri, 2020). According to Reverte (2022), public policies can drive sustainable development by improving economic freedom, governance systems, and institutional quality, while supporting the innovation and education ecosystems. Thus, policymakers should try to align environmental and innovation policy. Whereas the former internalizes the external costs arising from non-environmentally friendly but commercialized products and services, the latter seeks to reduce the cost of social, institutional, and technological innovation (Rennings, 2000). Such alignment can lead to synergies between the two policies. These synergies help integrate different aspects of sustainability in the economic process (Andersen, 2004). Various policy instruments have been introduced to encourage the adoption of eco-innovation. Examples include subsidies, funds, energy contracting, tax advantages, negotiated agreements, and other non-financial instruments (Panapanaan et al., 2014). Horbach et al. (2012) argued that government subsidies have a significant positive impact on environmental innovation because they reduce the cost of introducing eco-innovation (Tsai & Liao, 2017). Similarly, governments also play an important role in fostering innovation cooperation between different actors (Kwon, 2020), which facilitates the flow of information from knowledge generators such as universities and research centers to eco-innovation developers such as companies (del Río et al., 2015; Pereira et al., 2020). Nevertheless, the complementarities and conflicts between them have not been studied in detail (Díaz-García et al., 2015).

Proposition 1: Governance leads to high eco-innovation at the country level.

4.2.3. Human capital capacity: Education, awareness, skills, and capabilities

Given the increasing social and government concern and awareness about sustainable development, firms have used their internal drivers to identify the need to introduce innovation strategies based on environmental sustainability (Liao et al., 2020). Such strategies allow them to react proactively to sustainability challenges (Bossle et al., 2016). Human capital can determine the creation of a country's technical capacity because (i) a country's innovations rely on the talent and skills of its residents and (ii) the level of human capital is a key factor in a country's technical absorptive capacity (Benhabib & Spiegel, 1994; Zhen, 2011). Moreover, eco-innovations require more knowledge and resources than other innovations (Ukko et al., 2019). Hence, business actions related to training, dissemination, and information can stimulate eco-innovation by enhancing the absorptive capacity of human resources (Díaz-García et al., 2015). Choi et al. (2021) found that firms with links to educational institutions introduce CSR values associated with the academic sector. Hence, relationships between the private and educational sectors may have a spillover effect on society through the acceptance of sustainable innovation principles that influence human capital, namely students and employees.

The development of human capital increases environmental awareness, leading to the adoption of more efficient technologies and renewable energies (Broadstock et al., 2016; Li et al., 2020) and the reduction of environmental degradation (Khan, 2020). Hence, a country's technological and ecological capabilities could be enhanced through training and information strategies in eco-innovation at all levels of education, from undergraduate to master's or PhD levels (Chen et al., 2017). If so, education could become a pivotal way of encouraging eco-innovation. Orlando et al. (2020) reported a positive relationship between eco-innovation and the management of human capital, as well as its skills and capabilities. Therefore, adequate human capital management, through actions to raise awareness of sustainability, can increase the involvement of employees and even society in general, with people becoming more willing to engage in eco-innovation. Shou et al. (2019) argued that social and environmental principles become part of a firm's decision-making when it has a long-term internal commitment to sustainable development (Chindasombatcharoen et al., 2022).

Proposition 2: A strong human capital capacity leads to high levels of national eco-innovation.

4.2.4. Universities and research institutions

Sustainable development challenges urgently require innovation collaboration among different agents (Milana & Ulrich, 2022). Collaboration in innovation in general and specifically in eco-innovation can be fostered through universities and research institutions (Miozzo et al., 2016). These organizations possess professional expertise and knowledge through which they provide a wide range of complex and specialized services (Lessard, 2014; Szutowski, 2021). The activities they perform are primarily associated with product innovation, requiring technical expertise in consulting, engineering R&D, and software and hardware, among other areas (Cainelli et al., 2020). Firms, especially small and medium-sized enterprises (SMEs), need to collaborate with external partners to create value and develop solutions that address sustainability challenges (Ukko et al., 2019).

Sáez-Martínez et al. (2016) showed a negative relationship between research institutions and eco-innovation by analyzing the technological behavior of 212 SMEs. However, they concluded that more in-depth analysis would be needed to confirm this conclusion. Many researchers have argued that this relationship between eco-innovation and research centers or universities is positive (e.g., Cainelli et al., 2012; del Río et al., 2017). For instance, Petruzzelli et al. (2011) suggested that companies with external and internal networks tend to perform eco-innovation. Therefore, creating and employing external networks, including relationships with universities, could offer possibilities and opportunities by enhancing eco-innovation capacity (Horbach, 2016). Similarly, del Río et al. (2016) claimed that cooperation between multiple agents such as universities, competitors, governments, and other firms is necessary for eco-innovation.

Proposition 3: The contribution of research institutions is essential to stimulate a country's eco-innovation.

4.2.5. Public and private R&D investment

Countries may differ in their eco-innovation performance and activity because of differences in factors such as their level of R&D (Ghisetti et al., 2015). For example, within the European Union, Eastern European countries, except Hungary, have lower eco-innovation performance because of their lower R&D expenditure than Western European countries (Horbach, 2016). According to Cheng and Shiu (2012), the probability of success in environmental innovation increases in firms with higher R&D investment (Mercado-Caruso et al., 2020) because firms improve and update their technological capabilities based on environmental principles (Horbach, 2008). Therefore, countries or companies that allocate more resources to R&D may be more willing to introduce eco-innovation and eco-innovation strategies because of less uncertainty around eco-innovation and a lower probability of failure.

However, authors do not agree about the relationship between eco-innovation and R&D investment. Whereas some researchers have reported that R&D has a neutral effect on eco-innovation (O'Brien & Torugsa, 2011), others deny the existence of a positive relationship and argue that further research is needed to confirm the role of R&D in eco-innovation (del Río et al., 2017; Horbach et al., 2013). Some scholars (e.g., Díaz-García et al., 2015) have claimed that technological capabilities such as R&D positively affect innovation, but not green innovation. Several authors (e.g., David et al., 2000; Long & Liao, 2021; Orlando et al., 2020) have shown that, although investment in R&D has a positive impact on eco-innovation, this type of innovation is still mainly driven by the public sector, with minimal investment by companies. The reason for this finding, among other aspects, is that the public sector tends to be more long-term oriented and less risk-averse than the business sector.

In contrast, other studies have shown that the private sector is the main developer and investor in eco-innovation (Jiménez-Parra et al., 2018; OECD, 2010). Private R&D investment can also reduce firms' environmental impact without negatively affecting its economic performance (Hojnik et al., 2022). For instance, Jové-Llopis and Segarra-Blasco (2018) showed that the internal R&D spending of eco-innovation-oriented firms is higher than that of non-eco-innovation-oriented firms. This finding suggests that the R&D requirements of eco-innovation are greater and, therefore, that the development of eco-innovation may be more limited when the necessary financial resources to ensure its success are not available. Scarpellini (2022) argued that private investment is one of the main drivers of the circular economy, also contributing through the increase in eco-innovation activities (Scarpellini et al., 2020).

Proposition 4: The presence of high levels of public R&D investment contributes to eco-innovation.

Proposition 5: The presence of high levels of private R&D investment contributes to eco-innovation.

4.3. Method and data

Charles Ragin developed qualitative comparative analysis (QCA) in 1987 as a methodology for quantitative data, qualitative data, or a combination of both (Ragin, 1987). Although QCA was initially designed for use with small data sets, it is also suitable for use with larger samples (Fiss, 2011; Garcia-Alvarez-Coque, Roig-Tierno, et al., 2021; Vis, 2012). This technique uses Boolean algebra to obtain combinations of conditions, represented by simplified expressions, that lead to an outcome of interest (Fiss, 2007). QCA is directly related to the concept of equifinality, which reflects the idea that diverse and mutually non-exclusive pathways lead to the occurrence of the same phenomenon (Legewie, 2013; Schneider & Wagemann, 2012; Wagemann & Schneider, 2010). Therefore, equifinality allows for the identification of different combinations of explanatory factors, known as conditions, that lead to the same outcome. This property helps provide an understanding of the necessary conditions that explain why an outcome is present or absent (Roig-Tierno et al., 2017).

QCA cannot automatically explain the non-occurrence of an outcome purely based on the explanation of the occurrence of the outcome. A condition, or configuration of multiple conditions, indicates only one of the two qualitative states of the outcome: presence or absence (Schneider & Wagemann, 2012). These conditions are necessary or sufficient causes to explain the occurrence or non-occurrence of an outcome. A condition is necessary when it is present in all the configurations that lead to the outcome. In contrast, a condition is sufficient when it always leads to the outcome (Lucas & Szatrowski, 2014). Nevertheless, other sufficient conditions may also cause the outcome (Ragin, 2008; Roig-Tierno et al., 2017). Moreover, the outcome can also occur when this condition is absent.

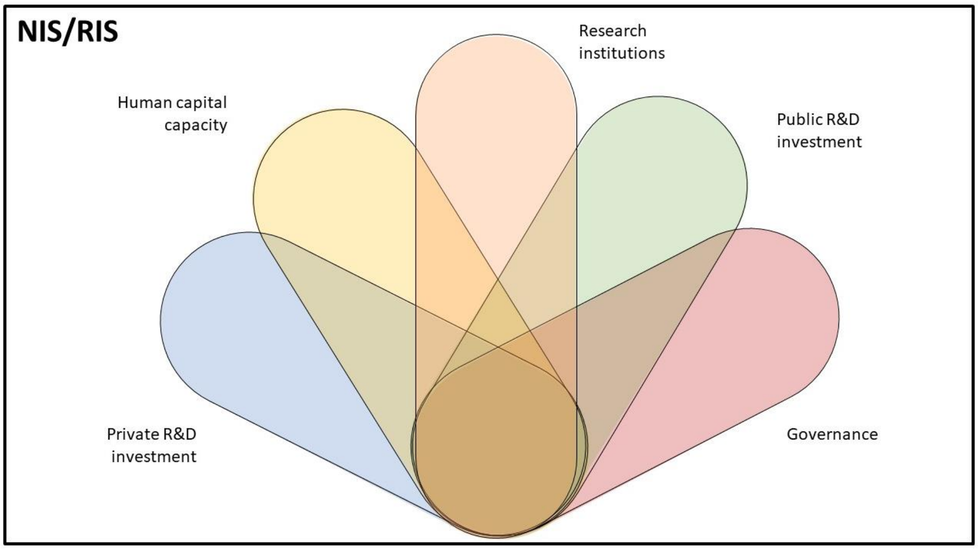
The two specific methods in QCA are crisp-set qualitative comparative analysis (csQCA) and fuzzy-set qualitative comparative analysis (fsQCA). CsQCA defines the outcome and conditions as binary structures (Wagemann & Schneider, 2010). The binary code used with each explanatory condition is 0 when the condition is absent, meaning that the condition is "fully outside" the set, and 1 when the condition is present, meaning that the condition is "fully inside" the set (Marx et al., 2013). In contrast, fsQCA cases are classified as continuous. They are assigned a value between 0 and 1, where the value represents the degree of membership in the set (Tur-Porcar et al., 2017). A condition can be fully outside the set, corresponding to a membership score of 0, fully inside the set, corresponding to a membership score of 1, or neither inside nor outside the set (point of maximum ambiguity), corresponding to a membership score of 0.5 (García-Álvarez-Coque et al., 2017; Ragin, 2000).

Using these membership scores, fsQCA can identify the necessary and sufficient conditions that explain the presence and absence of eco-innovation. Authors have cited different factors as determinants of innovation (e.g., Bossle et al., 2016; López-Rubio et al., 2021). It is reasonable to assume that eco-innovation is also influenced by many of these factors because it encompasses the uncertainty and complexity of not only innovation but also sustainability. The analysis of eco-innovation systems through fsQCA makes this research methodologically unique.

Data were collected for European countries for the year 2021 from several data sources. The data on national eco-innovation were obtained from the Eco-Innovation Index (European Commission, 2022a). The data on governance were collected from the Governance Performance Index. This index is a sub-index of the Global Sustainable Competitiveness Index (SolAbility, 2022). It is based on quantitative indicators provided by UN agencies, the World Bank, and the International Monetary Fund. The data on human capital capacity and public and private R&D investment were gathered from the European Innovation Scoreboard (European Commission, 2022b), which offers data on the innovation performance of European countries.

Data on research institutions were gathered from the Scimago Institutions Rankings (SCImago, 2022). Some transformations were applied to these data. The institutions in this ranking were classified into four quartiles. These quartiles were assigned the following scores: 100 points for Q1, 75 points for Q2, 50 points for Q3, and 25 points for Q4. The calculation of the score per quartile for each country involved taking the number of institutions of each country in a given quartile and multiplying it by the corresponding score assigned to the quartile. This process was repeated for each quartile. The sum of the quartile scores gave the country's total score in the Scimago IR. Finally, the value of the research institutions condition for each country was calculated by dividing the total score by the total population multiplied by 1000 inhabitants. Calculations were performed for European countries only. The variables integrated within the framework of national and regional innovation systems are shown in Figure 4.1. The aim was to determine the national conditions that lead to high eco-innovation performance.

Figure 4.1. Eco-innovation conditions



Source: Authors based on Horbach (2016), Păcesilă & Ciocoiu (2017), Rosca et al. (2018), and Orlando et al. (2020).

The raw data were calibrated using the direct method (Ragin, 2008). This method establishes three qualitative thresholds or anchors: full membership (1), full non-membership (0), and the crossover point (0.5). The crossover point represents the point of maximum ambiguity, where it is not possible to determine whether a case is more "inside" or "outside" a set (Ragin, 2009). Calibration is the process of assigning set membership scores to cases (Schneider & Wagemann, 2012). Typically, the anchors should be determined with theoretical and substantive knowledge (Ragin, 2000). However, in cases where researchers do not possess sufficient knowledge, they can identify the anchors using the properties of the study's sample (Greckhamer et al., 2018). In this case, all the conditions and the outcome were calibrated according to the criteria of the Regional Innovation Scoreboard (European Commission, 2021) and the study of Garcia-Alvarez-Coque, Mas-Verdú, and Roig-Tierno (2021). Table 4.1 presents the calibration thresholds and descriptive statistics of the outcome and conditions.

Table 4.1. Calibration and descriptive statistics of the outcome and conditions

Condition/ concept	FM*	Crossover point	FNM*	Max	Min	Mean (SD)
Eco-innovation	128.98	107.48	85.99	171	50	107.5 (31.5)
Public R&D investment	0.57	0.47	0.38	1	0	0.5 (0.3)
Private R&D investment	0.50	0.41	0.33	1	0.1	0.4 (0.3)
Human capital capacity	0.55	0.46	0.36	0.8	0.1	0.5 (0.2)
Governance	70.08	62.50	57.77	73.2	57.6	62.5 (4.1)
Research institutions	0.33	0.28	0.22	0.5	0.1	0.3 (0.1)

Note: *FM = Full membership; FNM = Full non-membership. Full membership: 20% above the EU average; Crossover point: average of the sample; Full non-membership: 20% below the EU average.

4.4. Results of fsQCA analysis of eco-innovation

4.4.1. Necessary and sufficient conditions for eco-innovation

For the necessity analysis, shown in Table 4.2, both the presence and absence of the conditions were considered. These conditions were the elements that drive a country's eco-innovation. The analysis reveals no necessary condition for national eco-innovation because the consistency threshold of 0.9 was not exceeded by any condition (Ragin, 2008; Schneider & Wagemann, 2012). Hence, governance, human capital capacity, research institutions, private investment in R&D, and public investment in R&D by themselves are not necessary for eco-innovation to occur.

Table 4.2. Analysis of necessary conditions for eco-innovation

Conditions tested	Consistency	Coverage
Presence of		
Public R&D investment	0.733	0.774
Private R&D investment	0.653	0.807
Human capital capacity	0.762	0.779
Governance	0.559	0.600
Research institutions	0.802	0.788
Public or private R&D investment	0.786	0.726
Absence of		
Public R&D investment	0.312	0.295
Private R&D investment	0.366	0.307
Human capital capacity	0.299	0.291
Governance	0.560	0.522
Research institutions	0.262	0.266

The implication of the results of the necessity analysis is that eco-innovation requires a combination of conditions. The conditions research institutions, human capital capacity, and public investment in R&D have consistency scores of 0.802, 0.762, and 0.733, respectively. Moreover, they cover 78.8%, 77.9%, and 77.4% of cases, respectively. Hence, although they are not necessary conditions, they appear to be relevant in explaining the presence of eco-innovation. At the national level, no specific type of R&D investment (public or private) increases eco-innovation performance. Nevertheless, the presence of at least one type of R&D investment is important in explaining national eco-innovation because it has a consistency score close to 0.8, accompanied by a case coverage of 72.6%.

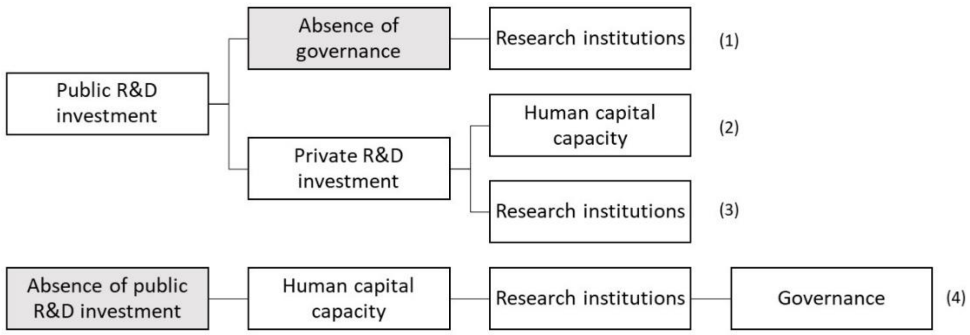
Based on the sufficiency analysis shown in Table 4.3, the research model is acceptable because it has a consistency score exceeding the limit of 0.75 (Ragin, 2008). The model has a consistency score of 0.9, accompanied by a high case coverage (81%). Table 4.3 reveals that all combinations of conditions have a consistency score of more than 0.85. Models 1, 2, 3, and 4 have a consistency score of 1, 0.93, 0.96, and 0.87, respectively. The models refer to the different pathways that explain high levels of eco-innovation in a country. The black circles ("●") represent the presence of the condition in the pathway and the white circles ("○") represent its absence (Fiss, 2011). Research institutions and public R&D investment are crucial for promoting a country's eco-innovation because both conditions appear in three of the four recipes that lead to the outcome. This result exemplifies the equifinality that characterizes the QCA methodology because four different recipes lead to national eco-innovation. Both findings are also shown in Figure 4.2, which graphically represents the four pathways that explain eco-innovation.

Table 4.3. Recipes for eco-innovation

		MODELS		
Conditions	1	2	3	4
Public R&D investment	●	●	●	○
Private R&D investment		●	●	
Human capital capacity		●		●
Governance	○			●
Research institutions	●		●	●
Raw coverage	0.380	0.500	0.517	0.195
Unique coverage	0.044	0.072	0.087	0.133
Consistency	1	0.932	0.963	0.871
Solution coverage: 0.818				
Solution consistency: 0.909				

Note: Following the notation of Fiss (2011), "●" indicates the presence of a condition, whereas "○" indicates its absence. Large and small circles represent core and peripheral conditions, respectively. However, in this case, all conditions are core conditions represented by large circles.

Figure 4.2. Graphical representation of the pathways that lead to eco-innovation

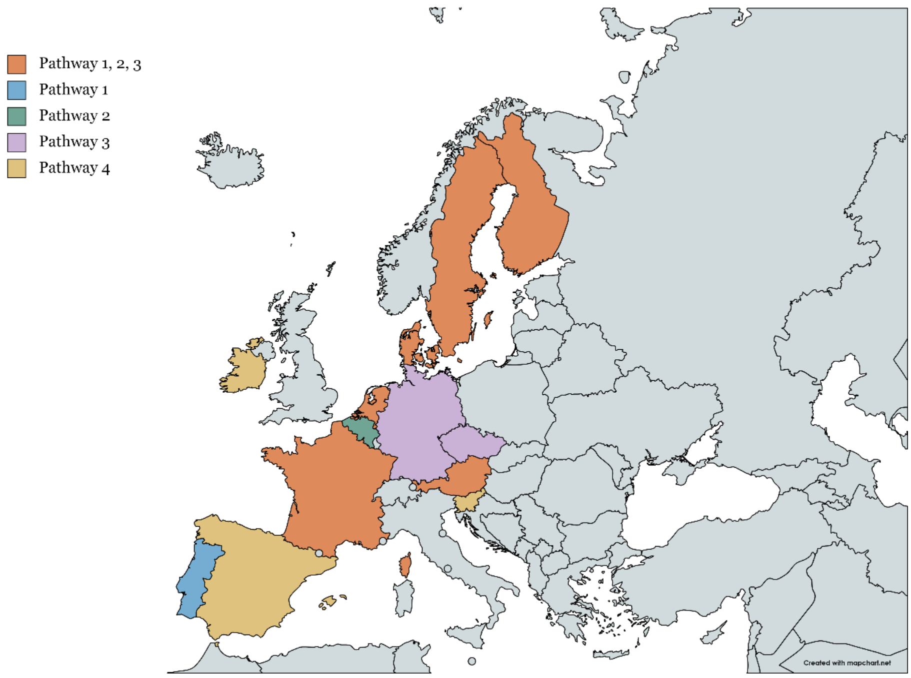


Considering the intermediate and parsimonious solutions, the core and peripheral conditions were identified. The intermediate solution shows the causal conditions with a robust causal relationships with the outcome. The parsimonious solution indicates a weaker causal relationship (Fiss, 2011). In this case, public investment in R&D, private R&D investment, governance, human capital capacity, and research institutions are considered core conditions. In addition, the absence of public investment in R&D and the absence of governance are also core conditions.

The first pathway suggests that a country that allocates public financial resources to R&D, has advanced research institutions, and has a low level of governance can succeed in implementing eco-innovation. Countries with high eco-innovation performance with this combination of conditions include Sweden, France, the Netherlands, and Portugal. The second configuration consists of public and private investment together with human capital capacity. The countries with eco-innovation under this combination of conditions include Denmark, Finland, Sweden, France, the Netherlands, Austria, and Belgium. The third combination is similar to the previous one, except with research institutions replacing human capital capacity. The countries that follow this pattern are Finland, France, Sweden, Austria, Germany, Czechia, the Netherlands, and Denmark. A final question is whether it is possible to achieve high levels of eco-innovation without public investment in R&D. Although public investment in R&D is also a key element, as mentioned above, it is not essential because it could be replaced by a high level of governance, human capital capacity, and research institutions. These conditions constitute Pathway 4. Fewer countries follow this pathway, namely Ireland, Spain, and Slovenia.

The country composition of each pathway is illustrated in Figure 4.3. The countries that achieve high levels of eco-innovation through more than one pathway are also represented in Figure 4.3. For Sweden, France, and the Netherlands, high levels of eco-innovation are explained through pathways 1, 2, and 3. These pathways highlight the role of public R&D investment, which suggests that their contribution through R&D investment is crucial to ensure eco-innovation activities among the different agents of the innovation system. In contrast, the high eco-innovation levels of Denmark, Finland, and Austria are explained through pathways 2 and 3. These two pathways illustrate the need for R&D investment collaboration between the public and private sectors. They indicate that a common commitment to sustainable development would boost R&D in technologies and innovations that positively influence the national economy, society, and environment. Therefore, these common characteristics that advanced economies require to achieve high levels of eco-innovation place the focus on different agents: (i) the public sector and institutions and (ii) the collaboration and joint involvement of the private and public sectors, which requires networks between different agents of the eco-innovation system.

Figure 4.3. Country recipes leading to eco-innovation performance



A notable case is that of Portugal, which follows pathway 1, unlike Spain, Slovenia, and Ireland, which follow pathway 4. Pathway 4 stresses the relevance of human capital and research institutions. Spain, Portugal, and Ireland generally have similar socioeconomic attributes. Czechia offers another interesting case, following pathway 3 along with the economies of Western and Central Europe.

4.4.2. Necessary and sufficient conditions for the absence of eco-innovation

In addition to helping identify the conditions that lead to eco-innovation, fsQCA also identifies the conditions leading to the non-occurrence of the outcome. The necessity analysis shows that the conditions are not necessary to explain the absence of eco-innovation because the consistency is less than 0.9 (see Table 4.4). However, high values are observed when private R&D investment is not present (consistency of 0.844). Hence, despite not being a necessary condition, the absence of private R&D investment plays an important role. The former statement could also be extended to the absence of public investment in R&D, human capital capacity, and research institutions, which have a consistency score of 0.78.

Table 4.4. Necessary conditions leading to the absence of eco-innovation

Conditions tested	Consistency	Coverage
Presence of		
Public R&D investment	0.257	0.273
Private R&D investment	0.175	0.217
Human capital capacity	0.276	0.284
Governance	0.490	0.528
Research institutions	0.279	0.275
Absence of		
Public R&D investment	0.787	0.747
Private R&D investment	0.844	0.710
Human capital capacity	0.785	0.768
Governance	0.629	0.589
Research institutions	0.785	0.800
Public or private R&D investment	0.927	0.700

In this case, the absence of public or private R&D investment impedes eco-innovation (consistency of 0.927). Hence, if a country's companies or public bodies fail to allocate financial resources to R&D, the level of eco-innovation will be low or practically zero. Notably, having either type of investment is not a necessary condition for the presence of a country's eco-innovation. However, the absence of public or private R&D investment is a necessary configuration to explain the absence of eco-innovation.

In the sufficiency analysis, the solution consistency (0.896) exceeds the limit established by Ragin (2008). Table 4.5 shows the pathways or recipes that explain the absence or low levels of eco-innovation in a country. All pathways are described by the absence of conditions from the research model (white circles, "○"). Large and small circles indicate core and peripheral conditions, respectively (Fiss, 2011). Table 4.5 shows that the absence of research institutions, governance, public R&D investment, and private R&D investment leads to the absence of eco-innovation because they appear in three of the four pathways. Nevertheless, the absence of human capital capacity plays a key role because it appears in all sufficient combinations in the model.

Table 4.5. Recipes explaining the absence of eco-innovation

	MODELS			
Conditions	1	2	3	4
Public R&D investment		○	○	○
Private R&D investment	○		○	○
Human capital capacity	○	○	○	○
Governance	○	○		○
Research institutions	○	○	○	
Raw coverage	0.391	0.387	0.552	0.393
Unique coverage	0.048	0.043	0.209	0.050
Consistency	0.863	0.893	0.912	0.871
Solution coverage: 0.693				
Solution consistency: 0.896				

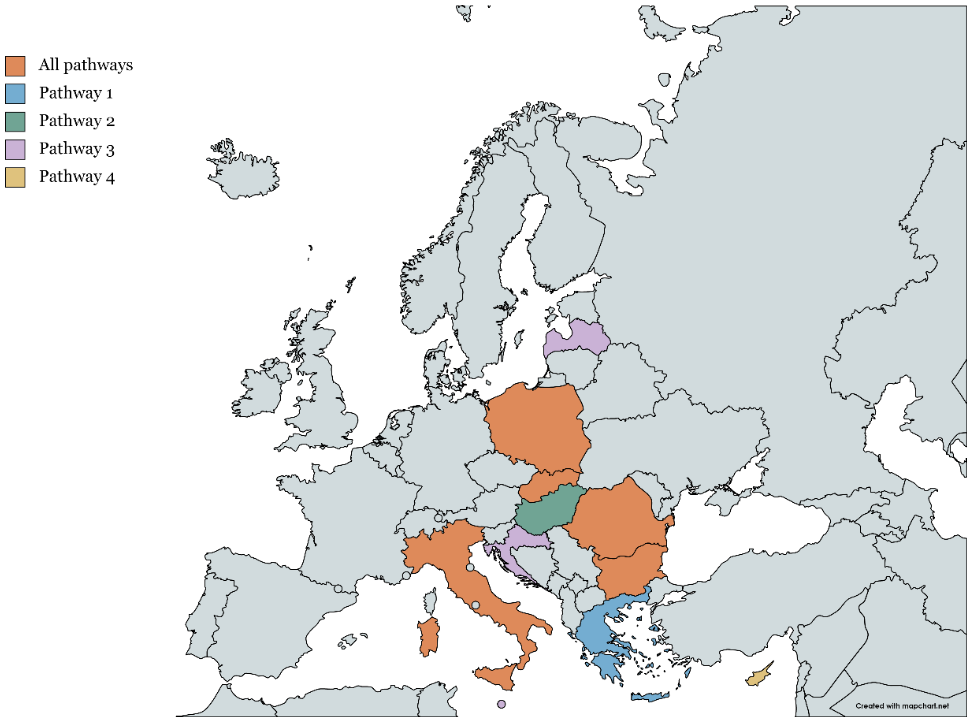
Note: Following the notation of Fiss (2011), "●" indicates the presence of a condition, whereas "○" indicates its absence. Large and small circles represent core and peripheral conditions, respectively.

Comparing the intermediate and parsimonious solutions, three of the five conditions are revealed as core conditions. The conditions that have a strong causal relationship with the absence of national eco-innovation are the absence of human capital capacity, research institutions, and public R&D investment. The peripheral conditions (i.e., those that only appear in the intermediate solution) are the absence of governance and private R&D investment. These conditions have a weaker causal relationship with the outcome.

Pathway 1 indicates that the absence of eco-innovation in a country is explained by the absence of private R&D investment, human capital capacity, governance, and research institutions. The countries with this combination of conditions are Greece, Italy, Slovakia, Romania, Bulgaria, and Poland. Pathway 2 consists of the absence of public R&D investment, human capital capacity, governance, and research institutions. Hungary, Italy, Slovakia, Romania, Bulgaria, and Poland have this combination of conditions. Pathway 3 consists of the absence of public R&D investment, private R&D investment, human capital capacity, and research institutions. The countries with this configuration are Romania, Bulgaria, Latvia, Slovakia, Malta, Poland, Croatia, and Italy. Finally, the absence of national eco-innovation is explained by the absence of public R&D investment, private R&D investment, human capital capacity, and governance (pathway 4). In this case, Italy, Slovakia, Romania, Bulgaria, Cyprus, and Poland follow this configuration.

Figure 4.4 illustrates the countries with the configuration of conditions corresponding to each pathway. Five countries (Italy, Slovakia, Romania, Bulgaria, and Poland) have low or non-existent eco-innovation performance through the four pathways identified in the analysis. This finding suggests that their country scores for the factors included in the research model to explain eco-innovation are very low. The agents of these eco-innovation systems do not trust the existing structures to boost eco-innovation: research institutions are weak and do not establish networks with the business sector; the human capital does not possess the knowledge, experience, and know-how necessary to design and implement sustainable technologies; public and/or private R&D investment is low; and government and institutional entities do not create a reliable structure to foster this type of eco-innovation.

Figure 4.4. Countries with an absence of eco-innovation



Italy, Slovakia, Romania, Bulgaria, and Poland meet all configurations with consistencies above 0.5. However, Italy has a coverage of 9.1% in all four pathways, which is a small value. Italy, Slovakia, Romania, Bulgaria, and Poland have Eco-Innovation Index values of 124, 82, 71, 50, and 63, respectively. With the exception of Italy, these countries have some of the lowest values in the whole sample. These results suggest that economies with low eco-innovation performance fail the most in introducing initiatives to promote eco-innovation. Thus, their characteristics are consistent with more configurations because they tend to have lower values in the conditions, leading to the absence of eco-innovation.

4.5. Discussion

The rapid industrialization of countries around the world has triggered not only economic growth but also environmental deterioration and degradation (Huang et al., 2021; Khan et al., 2020). Sustainable development and the circular economy have been championed by international organizations and individual countries to prevent the negative impact of human activities. Sustainable development, which is built on the three dimensions of sustainability (economic, social, and environmental), still has its limitations (Díaz-García et al., 2015). The limitations of sustainable development are linked to current technological and social systems, which are framed by the environmental resources and the biosphere's ability to absorb the impacts of human activities (Brundtland, 1987). Continued economic growth has generated enormous amounts of CO2 emissions, with negative implications for society and the environment (Li et al., 2020). Therefore, environmental responsibility has become a key issue worldwide (Fernández et al., 2021).

The transition toward sustainable development and the circular economy can be driven by eco-innovation (Scarpellini et al., 2020), which can support these two trends, despite the current economic, social, and environmental challenges (Milana & Ulrich, 2022). Eco-innovation can control pollution and mitigate its effects on the environment and society (Tao et al., 2021). This type of innovation supports not only goals addressed by traditional environmental actions and activities, such as the elimination of hazardous products, the reduction of pollution, the prevention of climate change, and the promotion of recycling, but also the creation of jobs, products, services, and competitive processes, and the raising of environmental awareness to bring about change in the behavior of individuals (Păcesilă & Ciocoiu, 2017). However, many factors influence eco-innovation. Therefore, finding a common method to improve overall eco-innovation performance is challenging (del Río et al., 2017). The literature classifies the drivers and barriers of eco-innovation using different criteria.

Díaz-García et al. (2015) showed the relevance of eco-innovation in academic research by reviewing the literature. According to their review, eco-innovation drivers can be grouped into three different levels. First, micro-level drivers are related to the value of entrepreneurs and the management, results, and performance of eco-innovation firms, as well as cost efficiency, reputation, and other such measures. Second, meso-level drivers relate to market dynamics such as market segments and new consumer needs. Finally, macro-level drivers are linked to specific policies and technological innovation systems. These micro-, meso-, and macro-level drivers correspond to drivers of eco-innovation at the national, regional, and sector/firm/individual levels, respectively (Zubeltzu-Jaka et al., 2018). Based on this classification, the drivers analyzed in this paper are macro-level drivers because the QCA was conducted at the country level to study national eco-innovation characteristics.

Other classifications separate drivers into internal and external factors that influence the decision to eco-innovate (del Río González, 2009). Internal factors (e.g., human resources, absorptive capacity, and internal financial resources) are firm characteristics or preconditions that encourage a predisposition toward or involvement in environmental technological change. External factors are stimuli or incentives that have the capacity to spark an entrepreneurial reaction. These factors include the interaction between different social, institutional, and market agents. Hojnik and Ruzzier (2016) distinguished between motivating factors, including regulatory pressure, customer demand, and expected profits of implementation, and enablers, such as technological capabilities and financial resources.

Zubeltzu-Jaka et al. (2018) grouped eco-innovation determinants into four clusters: market pull, technology push, regulatory push or pull, and firm-specific features. Market pull determinants relate to customer and supplier performance (including the demand for eco-products, customer benefits, and suppliers) and firm performance (including cost savings, economic performance, and sales forecasts). Technology push determinants involve R&D, collaboration among different economic agents, and environmental concern (e.g., organizational and resource commitment, training, and awareness). Regulatory factors cover command-and-control instruments (e.g., regulations and regulatory pressures) and economic incentives (e.g., subsidies, taxes, and public support for eco-innovation activities). Finally, firm-specific factors relate to firm size and age. This classification is similar to that of Fernández et al. (2021), who grouped the drivers of eco-innovation in developed and developing countries into market pull, regulatory push-pull, and technological push, which is in turn divided into firms' resources and capabilities (R&D related elements) and collaboration with partners, alliances, and networks.

Some of the barriers identified by scholars are high related costs, lack of funding sources, excessive perceived risks (Reid & Miedzinski, 2008), lack of environmental awareness or demand (EIO, 2011), lack of training opportunities, knowledge, and human capital (Cainelli et al., 2012), cooperation (Kiefer et al., 2019), and incentives and regulatory policies (Dias Angelo et al., 2012). These barriers are closely linked to the drivers of eco-innovation, suggesting that the presence or absence of these factors affects the development of eco-innovation activities within a country or region. Accordingly, QCA cannot automatically explain the non-occurrence of an outcome (in this case, eco-innovation) purely based on the explanation of the occurrence of the outcome. QCA results for an outcome are not symmetrical in terms of combinations of factors. A condition, or configuration of multiple conditions, indicates only one of two qualitative states of the outcome: presence or absence (Schneider & Wagemann, 2012). That is, the factors or conditions related to eco-innovation may be inversely related or unrelated to the same event (Douglas et al., 2020). Therefore, the barriers that explain the absence of national eco-innovation may not correspond to the absence of the drivers that explain the presence of eco-innovation.

When considering the configurational nature of phenomena, scholars can delve deeper and enrich their prior conclusions from regression methods (Ragin, 2006; Rihoux, 2006). Instead of detecting a single net effects model, which ignores the minority relationships between the outcome and conditions, QCA identifies and analyzes all types of relationships between independent (conditions) and dependent (outcome) variables (Douglas et al., 2020). QCA thus avoids the problems that arise when regression methods try to explain complex phenomena such as eco-innovation because such phenomena may be influenced differently depending on the case study and conditions considered in the analysis. QCA enables the analysis of asymmetric relationships between the outcome (eco-innovation) and conditions (drivers and barriers), without excluding interdependencies among them. The use of fsQCA to examine eco-innovation at the national level makes this research unique. To the best of the authors' knowledge, no fsQCA studies have explored sustainable development and innovation systems together. Methodologies employed to analyze eco-innovation at the firm, regional, or national level include bibliometric analyses, literature reviews, econometric techniques, and regression analyses.

This paper complements the existing literature by providing a finer-grained understanding of eco-innovation complexity by recognizing the interdependence of conditions and adapting to data asymmetry. Building from the factors identified by literature reviews and empirical studies, this paper analyzes the eco-innovation systems of European countries to establish different pathways to national eco-innovation. The framework of eco-innovation systems represents commitment to and concern for the sustainable development of the private and public sectors, institutional and governance structures, R&D institutions, and society.

4.6. Conclusions

In contrast to previous causally structured assertions, this research studies individual conditions that lead to a specific outcome. The analysis does not consider either independent or dependent variables. The paper's objective was to determine the necessary and sufficient conditions that result in high national eco-innovation performance. Given that eco-innovation simultaneously involves the complexity and uncertainty of innovation and sustainability, eco-innovation may be affected by many different factors, while having diverse relationships with them. In this case, public R&D investment, private R&D investment, governance, human capital capacity, and research institutions were studied as conditions that may lead to higher national eco-innovation performance.

Five main conclusions can be derived from this study. First, high levels of human capital capacity, research institutions, and public R&D investment seem to be crucial for boosting national eco-innovation. Hence, the introduction of measures that stimulate collaboration between different agents of the national and regional innovation systems could provide countries with a powerful business and social context to enhance the country's growth and competitiveness through strategies based on sustainability and eco-innovation. Prior studies, such as that of Mas Verdú (2021), suggest that intermediaries facilitate and expand firms' knowledge acquisition. However, companies cannot effectively achieve the knowledge acquisition process unless they complement their internal resources and capabilities with the external resources provided by intermediaries. This knowledge acquisition is essential for driving innovation (Miles et al., 2018).

Second, although the literature cites public and private R&D investment as relevant for innovation (García-Álvarez-Coque et al., 2017), in the case of eco-innovation, only the participation of governments and public administrations through investment in R&D is essential. Along these lines, Fabrizi et al. (2018) concluded that private actors' contribution to eco-innovation is lower than that of public actors. This finding may indicate that the involvement of non-business agents is crucial for high performance in eco-innovation because the challenges that arise when simultaneously dealing with innovation and sustainability are greater.

Third, human capital capacity is essential for eco-innovation. Hence, there is a need to promote human capital not only through education and training but also through new policies that encourage society to contribute to citizens' well-being and quality of life through sustainability and eco-innovation actions and initiatives. This finding is in line with those of Scarpellini et al. (2017), who argued that human capital involved with R&D and innovation activities drives the eco-innovation process. Moreover, the absence of this condition is one of the major barriers to eco-innovation, indicating that a society without the professional capabilities and skills necessary to drive eco-innovation leads to the absence of eco-innovation. Blättel-Mink (1998) contemplated the extent to which society recognizes sustainable development as a common global objective and is willing to embrace its three dimensions in its decision making and actions. Therefore, a lack of programs to raise awareness and train students, workers, and society could become one of the biggest threats to a region's eco-innovation.

Fourth, the absence of public or private R&D investment is necessary for the failure of national eco-innovation. This finding may imply that the level of eco-innovation in a region is low or practically non-existent when firms or public institutions do not invest in R&D. The reason is that this investment is considered fundamental to the progress of eco-innovation practices (Scarpellini et al., 2017).

Finally, most developed countries in Europe (i.e., in Western and Central Europe) appear in more than one configuration for eco-innovation. This finding could explain their high scores in the Eco-Innovation Index because they possess high levels of many of the sufficient conditions behind eco-innovation (i.e., public investment in R&D, private investment in R&D, human capital capacity, and research institutions).

These developed countries support high levels of eco-innovations through two major strategies: (i) public sector stimulation and encouragement of eco-innovation activities through R&D initiatives or (ii) the collaboration and joint participation of public and private sectors in R&D through networks of eco-innovation agents. In contrast, countries with low eco-innovation performance are found in Eastern and Southern Europe, implying that less developed economies (i.e., countries with a GDP per capita below the European average) are more likely to encounter barriers to eco-innovation.

This paper has some policy implications. Given the evidence that public R&D investment, human capital capacity, and research institutions are essential for national eco-innovation, policymakers should introduce measures and instruments that positively influence these elements. However, when designing and implementing these policies, policymakers should also consider the barriers that may hinder eco-innovation (i.e., public R&D, private R&D, and human capital capacity). Countries usually have limited resources, so they may be unable to address all aspects affecting this phenomenon. The creation of alliances based on transnational collaboration and cooperation could drive the success of eco-innovation and related initiatives because not every country has the same knowledge or experience to apply them effectively. When fostering international collaboration, studying the individual characteristics of countries may be important because the effectiveness of these policies may differ depending on the national context. Thus, eco-innovation and sustainability inequalities between countries can be reduced, allowing all economies to move together toward sustainable development.

Countries with low eco-innovation performance (i.e., Eastern and Southern European countries) or those trying to increase their eco-innovation performance should conduct in-depth analysis of their drivers and barriers. These countries could thus identify the factors that should be promoted to trigger high levels of eco-innovation. After having broad knowledge of the national characteristics of the eco-innovation system, less eco-innovative countries could seek countries with similar historical characteristics to find a reference to design and implement policies that promote eco-innovation. These policies could be based on (i) commitment from the public system to engage in eco-innovation activities by stimulating R&D or (ii) collaboration and networking among different agents within the country. This policy choice would depend on the influence and power of the public sector or the interrelationships and trust among different agents in the country.

This research is not without limitations. First, fsQCA reveals combinations of conditions related to an outcome. However, it does not explain why or how these conditions interact to lead to that outcome. Second, the set membership scores determined during the calibration process may depend on the assumptions of the research team. Hence, the research team's degrees of freedom may affect the findings of the analysis. This methodological problem of QCA is referred to as the "forking paths" problem (Gelman & Loken, 2014). Third, only five factors explaining eco-innovation were included in the analysis, despite the existence of other possible conditions. Finally, the study was static, and only countries in the European Union were examined. Consequently, future research opportunities include adding new eco-innovation determinants, as well as new cases from other non-European countries. Expanding research in this direction could help provide a broad, worldwide understanding of eco-innovation. Likewise, evolutionary analysis could identify changes in the importance of conditions or the continued presence of certain conditions over time.

4.7. References

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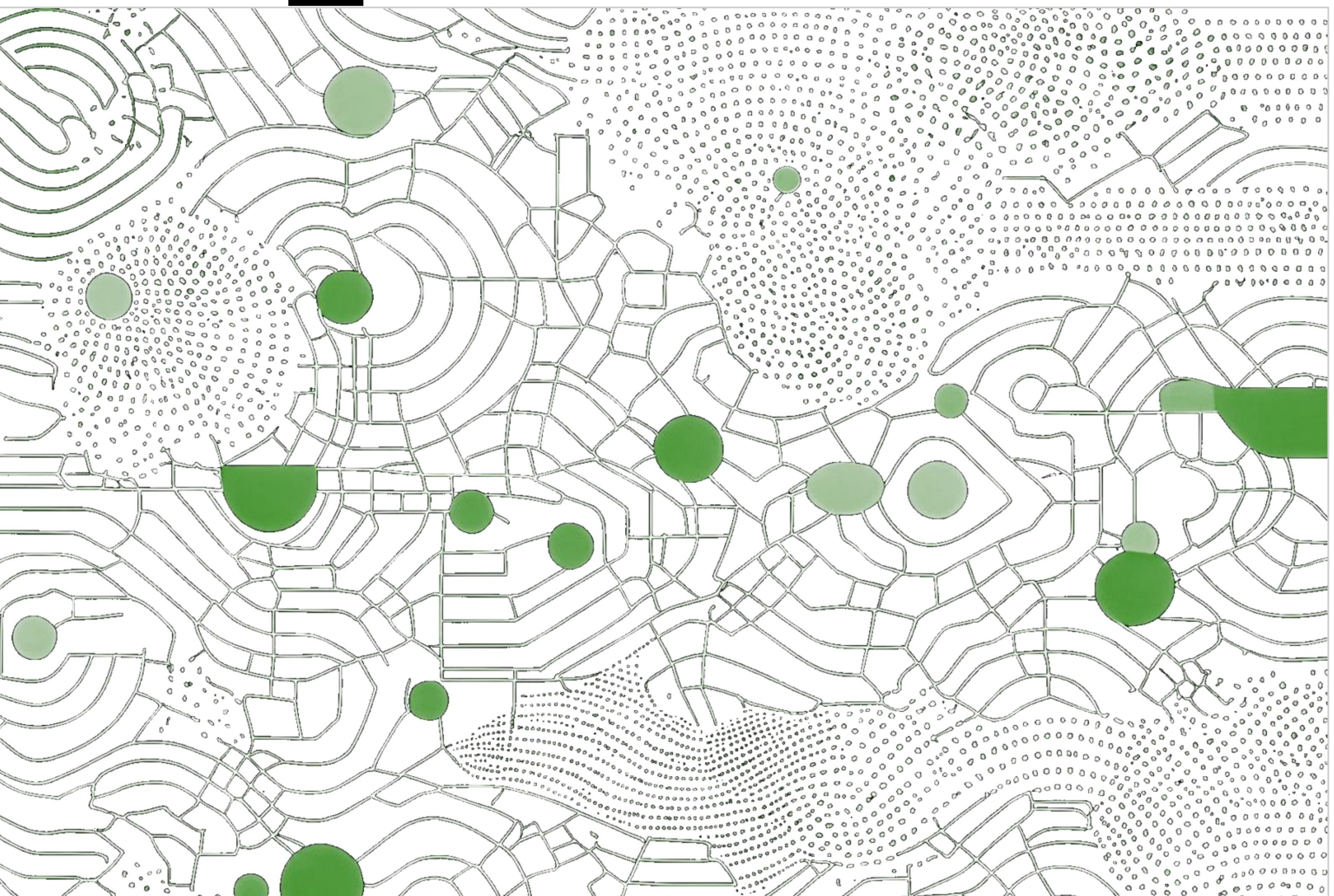
Chapter 5.
Are European countries favoring or jeopardizing their eco-innovation performance?



Chapter 5. Are European countries favoring or jeopardizing their eco-innovation performance?

Abstract. Countries have embraced eco-innovation as a strategy to transition to the circular economy and sustainable development. Eco-innovation takes place within a country's borders. Given the wide variety of country contexts and factors that influence the success of eco-innovation, understanding the knowledge drivers that favor or jeopardize eco-innovation performance is important. Within innovation systems, these factors interact, so they cannot be assessed in an isolated way. Therefore, fuzzy-set qualitative comparative analysis (fsQCA) offers a suitable approach to determine the necessary or sufficient factors or combinations of factors that explain improvements or deteriorations in eco-innovation performance. In this study, the period 2014 to 2021 is examined. The research model consists of the following factors: governance, private R&D, public R&D, research institutions, and human capital. The findings underline different combinations of factors that improve or worsen eco-innovation over time. Strong human capital and interactions between eco-innovation system agents contribute to improving national eco-innovation. A decrease in private R&D investment leads to a worsening of national eco-innovation. Policies and other measures should be based on strong knowledge of national eco-innovation characteristics to ensure eco-innovation success.

Keywords. Eco-innovation, Innovation systems, Research institutions, Human capital, R&D investment, Governance

5.1. Introduction

For many decades, sustainability has been jeopardized by globalization and human activity, despite the economic benefits of greater productivity, growth, and trade expansion (Pan et al., 2021). Given the associated environmental impacts of global warming and climate change, countries are introducing cleaner technologies that are cheaper and more eco-friendly (Horbach, 2008; Li et al., 2020). Along these lines, eco-innovation is part of a global strategy to transition from traditional growth-based models of development to models based on the circular economy and sustainable development (Scarpellini et al., 2020).

Eco-innovation is also denoted in the literature as environmental, green, or sustainable innovation (e.g., Schiederig et al., 2012; Díaz-García et al., 2015). It has received increasing attention from scholars (García-Sánchez et al., 2020). Academicians define eco-innovation as innovation that reduces environmental impact, such as through the appropriate use of natural resources, renewable energy, or waste management, while guaranteeing people's human rights (García-Sánchez et al., 2021) and increasing productivity and economic growth (Tao et al., 2021). The inclusion of economic, social, and environmental elements in the concept of eco-innovation reflects its focus on sustainable development (Aboelmaged, 2018).

Since 2009, the European Union (EU) has been a pioneer in eco-innovation. Within the EU, organizations, programs, and policy measures such as the Eco-Innovation Observatory (EIO), the Eco-Innovation Action Plan (EcoAP), and the Measuring Eco-Innovation (MEI) project have driven eco-innovation. The application of these tools emphasizes the relevance of eco-innovation in attaining sustainable development since this type of innovation enables more cooperation and efficient use of resources. Understanding and implementing eco-innovation in different European regions have become pillars of the Europe 2020 Strategy (European Commission, 2022a). The aim of the strategy is to boost competitiveness and sustainable development (Thissen et al., 2013; Aiginger & Firgo, 2017), creating employment and wealth within the EU (Arundel & Kemp, 2009). Therefore, within the EU, public administrations have adopted eco-innovation in their innovation systems (López-Rubio et al., 2021a).

A national or regional innovation system (NIS or RIS, respectively) is a set of integrated agents and institutions that encourage the introduction of government policies that foster innovation within national or regional boundaries (Metcalfe, 1995; López-Rubio et al., 2021b). Innovation systems are based on interrelationships within the borders of a region or country. A wide variety of contexts shape the relationships among the agents of innovation systems. Therefore, applying the same policy or measure in different contexts to boost innovation (or, more specifically, eco-innovation) is inefficient (Tödtling & Trippl, 2005). A deep understanding of the national and regional characteristics of an innovation system is required to stimulate eco-innovation activities in an effective manner. Choi and Zo (2019) noted that innovation systems have predominantly been studied in high-income countries instead of low- and middle-income countries. The unique economic, social, and political circumstances of low- and middle-income countries mean that each innovation system, along with its innovation drivers and barriers, should be analyzed separately (Khan, 2022b). For instance, whereas developed countries have multiple scientific, research, and technology institutions that attract talent, developing countries have fewer infrastructures and opportunities to offer those who design and implement eco-innovations (Ding, 2022).

The literature identifies myriad factors or conditions that affect eco-innovation. Examples include regulations, government incentives, public and private research and development (R&D), collaborative networks, human capital, and business strategies (Díaz-García et al., 2015). Using fsQCA, this paper aims to identify the necessary and sufficient conditions or combinations of conditions that improved or worsened national eco-innovation between 2014 and 2021. Various combinations of factors could worsen or enhance performance in eco-innovation. FsQCA has rarely been employed to explain eco-innovation, even though its use in other regional studies demonstrates its suitability for regional research (Garcia-Alvarez-Coque et al., 2021). Governance, public and private R&D, research institutions, and human capital are proposed as conditions in a research model to describe national eco-innovation performance.

The results show that no single policy mix or pathway explains an improvement or a worsening of national eco-innovation performance. The findings suggest that policymakers, member states, and international organizations should gather in-depth knowledge of the eco-innovation characteristics of each country to ensure the long-term success of eco-innovation. This success can be achieved by implementing strategies and policies that foster interaction between eco-innovation system agents. In addition, lower private R&D investment has a negative influence on national eco-innovation performance over time.

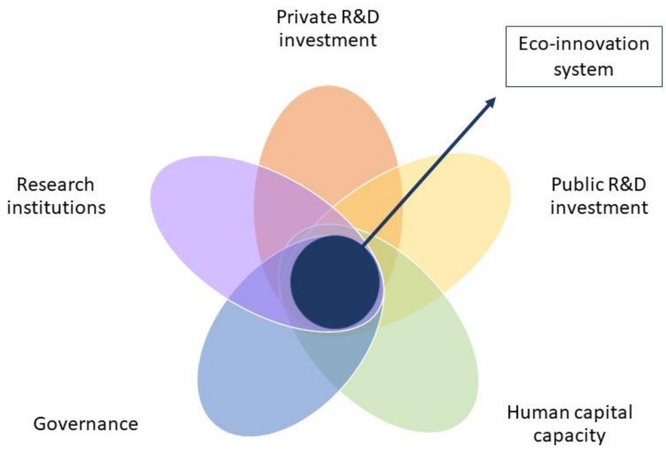
This paper has five sections. Following this introduction in Section 1, Section 2 provides an overview of the concept of the innovation system and its link to eco-innovation. It also presents the conditions and outcome considered in the research model. The methodology and data are described in Section 3. Section 4 presents the results of the fsQCA, highlighting the pathways that led to improved or worse eco-innovation performance between 2014 and 2021. Finally, Section 5 provides the conclusions, limitations, and future research avenues.

5.2. Theoretical framework

Innovation plays a prominent role in achieving sustainable development by boosting economic growth while addressing social and environmental problems (Ding, 2022). This key role of innovation highlights a need for the in-depth study of innovation systems. Innovation systems are networks of interactions among public and private institutions and other stakeholders that influence technology- and innovation-based activity (Freeman, 1987). Given each country's unique characteristics, innovation performance varies across nations. Hence, innovation strategies and policies should be adapted to the context and circumstances in each case (Tödtling & Trippl, 2005; Lorenz & Lundvall, 2006; Asheim et al., 2011). Khan (2022) identified different specifications of the concept of the innovation system at different economic levels that reflect the systemic characteristics of innovation. Besides the nation-state level, the three levels of innovation systems are (i) regional innovation systems (RIS), which represent the interaction among regional industrial districts and clusters (Cooke, 2008; López-Rubio et al., 2020), (ii) sectoral innovation systems, which represent the relationships among manufacturing firms and other organizations and institutions (Malerba, 2002), and (iii) technological innovation systems, which represent how organizations interact when new technological systems develop (Planko et al., 2016).

Innovation systems are subject to multiple factors (e.g., economic, political, environmental, and social) that affect innovation and therefore eco-innovation at different levels (Khan, 2022a). However, the complexity inherent in innovation and eco-innovation implies that these factors interact (Ding, 2022). Eco-innovation drivers and barriers have been classified in several ways. Horbach (2008) grouped them into market pull, technology push, and regulatory pull and push factors. Díaz-García et al. (2015) classified them into micro-, meso-, and macro-level factors. However, these different classifications have common eco-innovation factors. Examples include firms' sustainability strategies, human capital, R&D, financial constraints, and public support (Cuerva et al., 2014; Fernández et al., 2021). The five conditions included in the present analysis of how countries' eco-innovation performance can be improved or hindered are (i) private R&D investment, (ii) public R&D investment, (iii) human capital capacity, (iv) governance, and (v) research institutions. These five conditions and their connections with systems of eco-innovation are illustrated in Figure 5.1.

Figure 5.1. Conditions for improving eco-innovation



Many scholars have shown that R&D investment positively influences innovative behavior (Link, 2021; Ding, 2022). Investment in R&D fosters environmentally friendly innovations faster and more efficiently (Horbach, 2008; Fernández et al., 2021). R&D investment for eco-innovation requires large amounts of financial resources (Berrone et al., 2013; García-Sánchez et al., 2020). However, many barriers to financing still exist (Chistov et al., 2021). Governments and other public administrations can encourage eco-innovation through R&D investment (Ding, 2022). In an attempt to tackle sustainable development-related challenges such as global warming and climate change, policymakers are increasingly introducing R&D strategies to encourage the adoption of eco-innovations (Polzin et al., 2016). Introducing R&D policies and subsidies to stimulate eco-innovation could motivate eco-innovation system agents to develop eco-innovations and thus achieve sustainable development. Accordingly, barriers to financing would be removed, and eco-innovation participation and commitment encouraged (Johnson & Lybecker, 2012; Díaz-García et al., 2015). Orlando et al. (2020) suggested that private R&D investment in eco-innovation can improve both environmental and economic performance. These findings highlight the importance of private green R&D. However, there is insufficient evidence of the effect of public and private R&D investment on eco-innovation, despite the resources allocated to this phenomenon (Tsai & Liao, 2017; Orlando et al., 2020). In contrast, Scarpellini et al. (2012) argued that, whereas public organizations and universities are usually more focused on research due to high uncertainty levels and long-term results, the private sector tends to focus on development to achieve competitive advantages. Hence, public and private R&D investment may be complementary.

Proposition 1: An increase in public R&D investment improves national eco-innovation performance.

Proposition 2: An increase in private R&D investment improves national eco-innovation performance.

Innovation requires human capital (Kwan & Chiu, 2015; Ding, 2022). Educational infrastructures, the commitment and awareness of stakeholders, knowledge and experience within society, and absorptive capacity influence human capital capacity. First, educational infrastructures within eco-innovation systems positively influence not only innovation processes (Khan, 2022b) but also human capital, which in turn reduces barriers to eco-innovation (Fernández et al., 2021). Second, society acts according to environmentally friendly principles by introducing eco-technologies and reducing the use of resources (Broadstock et al., 2016; Li et al., 2020) when people are aware of and committed to addressing the negative impact of human activity on the environment. At the firm level, managers have high levels of decision-making power, so their concern and commitment toward eco-innovation can encourage other stakeholders such as employees, customers, or suppliers to adopt sustainable strategies (Chang, 2011). Third, human capital with suitable knowledge, skills, and experience can contribute to the development of eco-innovation. For instance, managers' lack of understanding of the eco-innovation concept and applicability and lack of qualified human capital for eco-innovation hinder the ability to adopt eco-innovation strategies (Pacheco et al., 2018). Hence, through a process of training and awareness-raising in society, managers, employees, and even their families could engage in sustainable development. The motivation of different eco-innovation system agents to work toward sustainable alternatives and eco-innovation is crucial for the achievement of sustainable development (Hojnik & Ruzzier, 2016). Finally, human capital offers organizations an opportunity to develop their absorptive capacity, which in turn drives eco-innovation (Leiponen, 2005; Antonioli et al., 2013). This absorptive capacity helps low- and middle-income countries to learn, design, and develop eco-innovations and other technologies and practices already implemented in developed countries (Dahlman & Nelson, 1995; Khan, 2022b).

Proposition 3: An increase in human capital capacity improves eco-innovation.

The influence of governance on eco-innovation has been widely documented in the literature. There are two approaches to innovation governance: (i) the regulatory framework and institutional environment and (ii) policy mechanisms and incentives. Regulations, policies, institution quality (López-Rubio et al., 2021c), political stability, and order (Tao et al., 2021) influence innovation processes. For example, the Chinese government introduced so-called carrot programs to stimulate the adoption of activities and practices related to eco-innovation through collaboration between small and medium-sized enterprises (SMEs) and big companies (Geng et al., 2021). The ISO 14001 certification offers companies competitive benefits, while improving their environmental management (Graafland & Zhang, 2014). According to Fernández et al. (2021), the importance of the regulatory framework has increased over the last few years. One reason is that international organizations such as the United Nations (UN) through the Sustainable Development Goals (SDGs) have raised the pressure on national governments to develop their economies without damaging the environment. This development could be achieved through the creation of an overall context of policies and other mechanisms that offer not only regulatory and financial support to eco-innovation agents but also training programs and environmental information. Second, environmental taxes and similar instruments encourage firms to develop eco-innovation and other eco-friendly technologies, which benefits the environment by reducing CO2 emissions and fossil fuel consumption (Tao et al., 2021). Chien et al. (2021) noted that renewable energy and innovation policies in addition to environmental taxes have had positive environmental impacts in Asian countries. Subsidies and financial aids also facilitate the development of eco-innovation strategies and processes (del Río et al., 2017; García-Sánchez et al., 2021). For instance, sound governance indicates to society the benefits of eco-innovation by reducing the ecological footprint and improving the use of natural resources (Díaz-García et al., 2015).

Proposition 4: An increase in sound governance is crucial to improve national eco-innovation performance.

When companies struggle to use and channel their resources and know-how toward eco-innovation, external collaborations among innovation system agents can provide the necessary knowledge and expertise (Kobarg et al., 2020). The complex and systemic nature of eco-innovation means that it requires more cooperation than other types of innovation (de Marchi, 2010; Chistov et al., 2021). For example, technological cooperation agreements can add value to firms' internal knowledge (Fernández et al., 2021). Innovation intermediaries boost collaboration (Miozzo et al., 2016) and support the private sector by participating in knowledge and information, technology transfer, and commercialization processes (Howells, 2006; Kivimaa et al., 2017). Examples of innovation intermediaries include universities, research institutions, science parks, public agencies, and project and business developers. Universities around the world participate in the development process as knowledge generators, users, providers, and diffusers (Mas-Verdu et al., 2020). In contrast, research institutions contribute to innovation by offering firms certain services (Muller & Zenker, 2001; Muller & Doloreux, 2009). These services provide advanced professional expertise and highly advanced technologies (Nählinder, 2005; Szutowski, 2021). Research institutions have also become a nexus between governments and other market agents (Howells, 2006; Polzin et al., 2016). Many scholars have argued that universities, research institutions, other intermediaries, and firms play a prominent role in eco-innovation because it requires high levels of research, external knowledge, and expertise (e.g., Díaz-García et al., 2015; Horbach, 2016; Pereira et al., 2020).

Proposition 5: An increase in research institutions improves eco-innovation performance at the country level.

5.3. Method and data

To identify the combinations of conditions that improve national eco-innovation performance, fuzzy-set qualitative comparative analysis (fsQCA) was conducted. Qualitative comparative analysis (QCA), which is the basis of fsQCA (Ragin, 1987), combines the strengths of variable- and case-oriented methods, also referred to as quantitative and qualitative approaches (Ragin, 1987; Marx et al., 2013). QCA examines differences and similarities between comparable cases to identify causal combinations of conditions that trigger an outcome of interest (Greckhamer et al., 2018). The idea is that more than one condition or interactions between these conditions may contribute simultaneously to the same outcome (Woodside, 2016; García-Álvarez-Coque et al., 2017). This idea follows the principle of equifinality, where mutually non-exclusive pathways trigger a particular outcome.

The relationships between conditions and an outcome are described in terms of necessity and sufficiency (Schneider & Wagemann, 2012). Necessity implies that a condition is present in every instance of the outcome. Sufficiency means that a combination of conditions causes the outcome, even though the outcome can also occur when another set of conditions is present (Legewie, 2013). In this case, the fuzzy-set variant of QCA (i.e., fsQCA) was used to conduct the analysis. In this approach, the values of each condition must be calibrated on the interval 0 to 1 (García-Álvarez-Coque et al., 2017). The two key concepts associated with QCA are consistency and coverage. Consistency expresses "how closely a perfect subset relation between a configuration and an outcome is approximated" (Ragin, 2008, p. 44). In contrast, coverage is the percentage of cases explained by a particular configuration of conditions (Roig-Tierno et al., 2017).

Given the higher complexity, risk, and cost of eco-innovation than other types of innovation (Chistov et al., 2021), numerous factors drive or hinder eco-innovation activities. FsQCA can perfectly reflect the interactions between different factors to identify different pathways through which countries have improved or worsened their eco-innovation level. The data for the period 2014 to 2021 were collected from several secondary sources. The outcome is eco-innovation, and the conditions are human capital capacity, governance, private R&D, public R&D, and research institutions. Eco-innovation data were collected from the European Union Index of Eco-Innovation. Governance data were obtained from the Governance Performance Index. Private and public R&D investment and human capital capacity data were collected from the European Innovation Scoreboard. Finally, research institutions data were obtained from the Scimago Institutions Ranking. Table 5.1 summarizes the outcome and conditions characteristics. Both are measured in terms of changes between 2014 and 2021.

Table 5.1. Outcome, conditions, and sources

		Definition	Sources
Outcome	Eco-innovation	Performance of EU member states in eco-innovation	European Commission (2022a)
Conditions	Public R&D investment	Public sector (government and higher education) spending on R&D	European Commission (2022b)
	Private R&D investment	Private sector spending on R&D	
	Human capital capacity	Number of new PhD graduates, people with tertiary education completed aged between 25 and 34, and population enrolled in lifelong learning and aged between 25 and 64	
	Sound governance	Performance of the infrastructure environment and regulatory framework of a country to encourage sustainable competitiveness	SolAbility (2022)
	Research institutions*	Total score of research institutions per 1,000 inhabitants	SCImago (2022)

Note: *The data on research institutions had to be transformed. According to the ranking of research institutions provided by SCImago (2022), the data were classified into four quartiles, which were then given different scores (100, 75, 50, and 25 points for Q1, Q2, Q3, and Q4, respectively). Each country had a score for each quartile. This score was calculated by multiplying the number of a country's research institutions in each quartile by the score for that quartile. The total score of research institutions in each country was calculated by summing the scores for the quartiles.

To assess and identify the relationships between the conditions and the outcome, the data must be calibrated. Calibration assigns membership scores to each country case (Schneider & Wagemann, 2012) by transforming the raw data. Following the direct calibration method (Ragin, 2008), three qualitative thresholds were established: fully in (1), fully out (0), and maximum ambiguity (0.5). At this point of maximum ambiguity (crossover point), the case cannot be classed as fully in or out of the set (Ragin, 2009). After clearly defining the outcome and conditions, the membership scores are set according to substantive theoretical knowledge. Nevertheless, researchers can use the properties of the sample when they do not possess sufficient knowledge (Greckhamer et al., 2018). Following the approach applied by the European Commission (2021) and Garcia-Alvarez-Coque et al. (2021), the calibration of the outcome and conditions was performed by considering the value 10% above and below the sample mean for full membership and full non-membership, respectively. The crossover point was the mean for the sample. The descriptive statistics and calibration thresholds are presented in Table 5.2.

Table 5.2. Calibration thresholds and descriptive statistics for the outcome (eco-innovation) and conditions

Condition/ outcome	Fully in	Crossover point	Fully out	Max	Min	Mean (SD)
Eco-innovation	0.18	0.16	0.14	0.52	-0.15	0.16 (0.16)
Public R&D investment	0.1	0	-0.1	0.85	-0.84	0 (0.39)
Private R&D investment	0.7	0.64	0.57	10	-0.57	0.64 (1.95)
Human capital capacity	0.09	0.08	0.07	0.62	-0.65	0.08 (0.22)
Sound governance	0.35	0.32	0.29	0.59	0.07	0.32 (0.13)
Research institutions	0.27	0.25	0.22	1.3	-0.52	0.25 (0.38)

Note: Full membership: 10% above the sample mean; Crossover point: sample mean; Full non-membership: 10% below the sample mean.

5.4. Results of the evolution of eco-innovation from 2014 to 2021

5.4.1. Necessity analysis of stronger or weaker national eco-innovation

The analysis first focused on eco-innovation improvement between 2014 and 2021 (see Table 5.3). The necessity analysis shows no necessary conditions because no condition had a consistency score higher than 0.9 (Ragin, 2008; Schneider & Wagemann, 2012). Nevertheless, the findings reveal that other factors are important when explaining an improvement in eco-innovation. An increase in sound governance and a decrease in research institutions seemed to enhance eco-innovation levels, as suggested by the consistency values of 0.748 and 0.753, respectively. These findings indicate that the countries that increased their sound governance levels may also have achieved an increase in eco-innovation performance between 2014 and 2021. Demirel et al. (2018) noted that a country's government and institutions can establish incentives and instruments that encourage the environmentally friendly behavior of firms, helping achieve sustainability objectives. The findings also suggest that a deterioration in the efficiency and quality of research institutions may lead to an improvement in eco-innovation. Therefore, high levels of eco-innovation can be achieved even if a country possesses weak research institutions. This finding contradicts those of Scarpellini et al. (2012), who reported that research institutions connect the needs of private organizations and society, thereby boosting eco-innovation because firms are usually reluctant to integrate eco-innovation in their business.

In contrast, the necessity analysis of the worsening of eco-innovation reveals that the reduction of private R&D investment is the only necessary condition (consistency = 0.91). However, the relevance of necessity (RoN) is less than 0.5 (Schneider, 2019), indicating that, despite being an important condition, a reduction of private R&D investment does not automatically worsen eco-innovation levels. In this case, a decrease in public R&D investment may also be important for explaining lower eco-innovation performance, in light of the consistency score of 0.755. This finding implies that when public administrations do not channel their financial resources toward sustainability-oriented R&D that specifically targets eco-innovation, there may be a decreasing trend in eco-innovation. In contrast, many authors have argued that financial resources are essential for eco-innovation (e.g., Hojnik & Ruzzier, 2016; García-Sánchez et al., 2020).

Table 5.3. Necessary conditions that increased or decreased eco-innovation from 2014 to 2021

	Better eco-innovation			Worse eco-innovation		
Conditions	**Cons.**	**Cov.**	**RoN**	**Cons.**	**Cov.**	**RoN**
▲ Increase in						
Public R&D investment	0.378	0.568	0.84	0.248	0.437	0.801
Private R&D investment	0.330	0.755	0.942	0.093	0.251	0.842
Human capital capacity	0.610	0.578	0.716	0.385	0.429	0.651
Sound governance	0.748	0.604	0.657	0.417	0.397	0.557
Research institutions	0.247	0.259	0.633	0.602	0.741	0.832
▽ Decrease in						
Public R&D investment	0.625	0.414	0.430	0.755	0.588	0.517
Private R&D investment	0.673	0.387	0.291	▽ 0.909	0.615	0.395
Human capital capacity	0.398	0.355	0.593	0.622	0.652	0.73
Sound governance	0.253	0.269	0.644	0.584	0.732	0.831
Research institutions	0.753	0.616	0.671	0.399	0.384	0.559

Note: Cons. = Consistency; Cov. = Coverage; RoN = Relevance of necessity. Consistency threshold = 0.9 (Ragin, 2008; Schneider & Wagemann, 2012). RoN threshold = 0.5 (Schneider, 2019).

5.4.2. Sufficient conditions for improved eco-innovation

The consistency level of the sufficiency model (0.969) exceeded the 0.75 threshold established by Ragin (2008). The sufficiency analysis shows three combinations of conditions or pathways that resulted in an increase in eco-innovation performance from 2014 to 2021. The consistency of these combinations exceeded 0.8 (see Table 5.4). Pathway 1 indicates that there was an improvement in eco-innovation performance through increased private R&D investment and sound governance. Greece, Cyprus, and Bulgaria followed this pathway. Pathway 2 shows that increasing human capital capacity and reducing sound governance and research institution quality led to higher eco-innovation performance. Germany and Italy followed this pathway showing changes in the number of trained population, coexisting with a relative decrease in governance and research scores. Finally, Pathway 3 indicates that high eco-innovation levels can be achieved through greater public R&D investment, human capital capacity, sound governance, and research institutions. Only Bulgaria followed this pathway.

Table 5.4. Configurations of conditions that explain to higher eco-innovation performances

		Pathways	
Conditions	1	2	3
Public R&D investment			▲
Private R&D investment	▲		
Human capital capacity		▲	▲
Sound governance	▲	▽	▲
Research institutions		▽	▲
Raw coverage	0.241	0.164	0.080
Unique coverage	0.232	0.162	0.072
Consistency	1	0.992	0.852
Solution coverage: 0.476			
Solution consistency: 0.969			
Pathway 1	Greece, Cyprus, Croatia		
Pathway 2	Germany, Italy		
Pathway 3	Bulgaria		

Note: "▲" represents an increase in the condition; "▽" represents a decrease in the condition (adapted from Nieto-Aleman et al., 2019).

These three pathways can improve eco-innovation performance. Pathway 1 highlights the value of collaboration between private entities and the national government. This pathway suggests that a form of governance that creates a stable, transparent, and participatory environment among eco-innovation system agents may stimulate private R&D investment in sustainability. In such a context, the private sector would trust the commitment of the government and other public administrations to the goal of sustainable development. The government would thus align its own interests with those of society and the business community. This alignment would create a joint commitment to sustainability through eco-innovation. For example, Greece, Cyprus, and Croatia saw an increase in private R&D investment of 186%, 1000%, and 69.5%, respectively. These figures show that the participation of companies and other private organizations increased substantially over the period of study.

Private R&D had a crucial impact on eco-innovation and sustainable development over the study period. Although the improvement in sound governance was smaller, it was still positive. These positive trends in private R&D investment and sound governance explain the improvement in national eco-innovation. According to Chen et al. (2017), both institutional pressure and a firm's internal resources drive eco-innovation. This idea suggests that countries cannot simply rely on institutional factors to encourage eco-innovation activities. Instead, they must also rely on forces from the private sector such as customer green demand and competitive pressure. For instance, government institutions engage businesses and other private organizations in eco-innovation through legislation (Pacheco et al., 2018). This external pressure can provide firms with competitive advantages, improving their reputation and performance due to cost reductions (Díaz-García et al., 2015). Therefore, the government-industry relationship could encourage private green R&D investment, where firms engage in eco-innovations. Such investment could ensure that their economic activity would positively impact the global economy, society, and the environment.

Pathway 2 shows the importance of human capital capacity in positively influencing eco-innovation performance over time. Under Pathway 2, countries achieved improvements in eco-innovation performance through an increase in human capital in contexts of significant numbers of people engaged in high education and training but coexisting with less active research institutions and relatively weaker governance. Human capital can be considered the basis of eco-innovation because it requires not only practical and theoretical knowledge but also an understanding of sustainable development. Countries that produce human capital with the necessary knowledge, skills, experience, and know-how can achieve greater improvements in eco-innovation. Innovation develops through technological capabilities, including knowledge on the development of eco-friendly products, services, and processes (Baumol, 2015; Chen et al., 2017). The demand for products and services with a minimal environmental impact increases with a rise in awareness and commitment toward sustainable development (Sharma et al., 2020).

Finally, Pathway 3 is an example of how collaboration between eco-innovation system actors can have positive effects on national eco-innovation. Collaboration can encourage the integration of sustainability principles in business strategies through joint R&D efforts that create more environmentally friendly societies and industries (Orlando et al., 2020). Firms participating in cluster networks can benefit from knowledge dissemination and cooperative learning among eco-innovation firms, guaranteeing eco-innovation success (Chen et al., 2017). These business networks enhance knowledge spillovers and innovation density (Díaz-García et al., 2015). Public sector interactions through R&D investment, the quality, orientation, and effectiveness of government interventions, and the involvement of human capital and research institutions could encourage the rest of society, and even the private sector, to adopt practices and principles based on sustainable development. For instance, the role of governance is crucial to guarantee society's trust in policies and actions to ensure progress toward sustainable development (Stupak et al., 2021). If the private sector does not support the development of eco-innovation through R&D, the public sector drives this type of innovation, encouraging cooperation and collaboration between research institutions, governance, and human capital. In such situations, the public system replaces the private system in encouraging the adoption of eco-innovation principles by different eco-innovation system agents, including society in general. For instance, Bulgaria had the greatest improvement in eco-innovation due to an increase in all conditions included in the model. This finding highlighting the value of private and public R&D investment and research institutions.

5.4.3. Sufficient conditions for worsened eco-innovation performance

The consistency score of the sufficiency analysis was 0.998, indicating that the sufficiency model effectively explains a worsening in eco-innovation. The results reveal three pathways to a decrease in national eco-innovation performance. The consistency scores for these pathways were all higher than 0.95 (see Table 5.5). Pathway 1 shows that a country risks having a lower eco-innovation level if there is lower private R&D investment, poorer governance, and stronger research institutions. Slovakia, Austria, Latvia, Luxembourg, Hungary, and Romania all followed this pathway. Pathway 2 indicates that the combination of lower public R&D investment, private R&D investment, human capital capacity, and governance also seems to worsen national eco-innovation performance. Latvia, Sweden, France, Hungary, and Romania followed this pathway. The combination of decreasing public and private R&D investment and increasing human capital capacity and research institutions also explains a worsening in national eco-innovation (Pathway 3). Slovakia, Spain, and Portugal followed this pathway.

Table 5.5. Configurations of conditions that explain to lower eco-innovation performances

	Pathways		
Conditions	1	2	3
Public R&D investment		▽	▽
Private R&D investment	▽	▽	▽
Human capital capacity		▽	▲
Sound governance	▽	▽	
Research institutions	▲		▲
Raw coverage	0.352	0.275	0.206
Unique coverage	0.125	0.122	0.131
Consistency	0.996	0.996	1
Solution coverage: 0.606			
Solution consistency: 0.998			
Pathway 1	Slovakia, Austria, Latvia, Luxembourg, Hungary, Romania		
Pathway 2	Latvia, Sweden, France, Hungary, Romania		
Pathway 3	Slovakia, Spain, Portugal		

Note: "▲" represents an increase in the condition; "▽" represents a decrease in the condition (adapted from Nieto-Aleman et al., 2019).

These findings provide evidence of the key role of reducing private R&D investment in the worsening of eco-innovation because this condition appears in all three sufficient pathways. This finding is aligned with the findings of the necessity analysis. Several scholars have confirmed that private R&D investment and eco-innovation have a close relationship (Díaz-García et al., 2015; Tsai & Liao, 2017), as reflected by the data. Between 2014 and 2021, countries where private R&D investment decreased experienced large declines in eco-innovation performance. In addition, the existence of research networks and structures does not guarantee an improvement in eco-innovation performance. This finding contradicts the conclusions of Horbach (2016) and Pereira et al. (2020), who found that research institutions play a key role in the development of eco-innovation. Countries need other factors that contribute to the adoption of eco-innovation. Examples include private R&D investment and sound governance. Table 5.6 summarizes the findings of the fsQCA, presenting a simplified overview of the main implications of the analysis.

Table 5.6. Summary of the results of the fsQCA

	Pathways	Countries	Highlights
▲ Improving eco-innovation	Greater levels of private R&D investment and sound governance	Greece, Cyprus, Croatia	- Collaboration between private entities and national governments - Reliable, stable, transparent, and participatory environment
	Greater levels of human capital capacity and lower levels of sound governance and research institution quality	Germany, Italy,	- Improvements in human capital capacity in contexts of weaker governance and research performance
	Greater levels of public R&D investment, human capital capacity, sound governance, and research institutions	Bulgaria	- Collaboration among eco-innovation system agents
▽ Worsening eco-innovation	Lower levels of private R&D investment and sound governance and higher levels of research institutions	Slovakia, Austria, Latvia, Luxembourg, Hungary, Romania	- Enhanced infrastructures, institutions, and networks that foster a country's eco-innovation are irrelevant if private organizations allocate little investment to R&D
	Lower levels of public and private R&D investment, human capital capacity, and sound governance	Latvia, Sweden, France, Hungary, Romania	
	Lower levels of public and private R&D investment and higher levels of human capital capacity and research institutions	Slovakia, Spain, Portugal	

5.5. Conclusions

This study tested the proposition that the improvement or deterioration of a country's eco-innovation is explained by several combinations of factors that influence this phenomenon through their interaction. This proposition is supported by evidence of the necessary and sufficient conditions or combinations of conditions that improved or worsened eco-innovation performance between 2014 and 2021. The uniqueness of this research lies in the use of fsQCA to explain eco-innovation. Although this methodology has been used in other regional studies (Garcia-Alvarez-Coque et al., 2021), it has rarely been used to explain this phenomenon. The fsQCA results reveal four main conclusions.

First, human capital plays a vital role in increasing eco-innovation, even in national contexts where research performance and governance have not significantly improved. Eco-innovation is highly complex because it involves the combination of innovation and sustainability. The current disruptive context means that countries must rapidly adapt to new and unexpected circumstances. Substantial human capital capacity enables this adaptation through a process of learning and improvement (Aleknavičiūtė et al., 2016). Countries with high human capital capacity and the necessary knowledge, skills, and experience can acquire the practical and theoretical understanding and know-how to develop eco-innovation, increase awareness, and apply sustainable development principles and values to human activity. These findings are in line with those of Ciccone and Papaioannou (2009), who found that human capital not only helps technology implementation but also boosts economic, social, and environmental value creation.

Second, collaboration and cooperation among eco-innovation system actors encourages the design, development, and implementation of eco-innovation. In open environments, free interaction among agents promotes a continuous flow of information and knowledge under conditions of trust, confidence, and reciprocity (Asheim & Isaksen, 2002). These conditions are prominent in eco-innovation (de Marchi, 2012). Eco-innovation system agents can break barriers when effectively and efficiently applying eco-innovations (de Marchi, 2012; García-Sánchez et al., 2021). They thus save money, time, and resources (Ardito et al., 2018). When eco-innovation is fostered, both the private and public sector and society are more willing to base their decisions and activities on sustainable development. In this paper, the public sector acts as an intermediary between agents, compensating for the lack of participation from the private sector.

Third, more than other types of innovation, eco-innovation depends on research and external sources of information because it combines new and disruptive fields of knowledge and technology (Horbach, 2016). For example, research institutions and universities provide companies with highly qualified human capital with a strong commitment to sustainable development (Păcesilă & Ciocoiu, 2017). These innovation intermediaries also provide companies, including SMEs, with much-needed resources, such as R&D investment, to develop eco-innovation projects (Pacheco et al., 2018). The study suggests that the existence of research institutions in a country does not necessarily imply higher eco-innovation performance, or at least, their influence depends on the national context. Where research institutions are already established, as in some European countries, their marginal contribution may be not significant, and perhaps an increased flow of trained human resources can be more effective in creating conditions for eco-innovation. This does not mean that R&D is not relevant, but research institutions and networks lose their influence on eco-innovation if a country lacks essential attributes such as private R&D investment and sound governance. Therefore, the findings contradict the idea that research institutions play a prominent role in driving and collaborating with companies in eco-innovation, as is repeatedly reported in the literature (e.g., Scarpellini et al., 2012; Triguero et al., 2013; Pereira et al., 2020).

Fourth, lower private R&D investment is the only necessary condition for lower eco-innovation performance. Although a reduction in R&D investment was observed to explain a deterioration in a country's eco-innovation performance between 2014 and 2021, some countries suffered such a decrease if this type of R&D investment was combined with other factors. Scholars have also identified factors that facilitate eco-innovation. Examples of these factors include financial resources (Hojnik & Ruzzier, 2016; García-Sánchez et al., 2020), human capital (Zhen, 2011; Scarpellini et al., 2017), and regulatory norms and pressures (del Río et al., 2015; Demirel & Kesidou, 2019). Therefore, policymakers and international organizations should consider different factors in their eco-innovation policies but should be aware that the private sector could be a crucial ally in the search for sustainable development. R&D investment may have a multiplier effect on the development of eco-innovation and, in turn, on achieving sustainable development because it positively affects technological capabilities (Horbach, 2016) and absorptive capacity (Cainelli et al., 2012; del Río et al., 2017).

The study's conclusions could provide policymakers with crucial insights into how to redirect eco-innovation policies and strategies to drive sustainable development. For example, the national scope of eco-innovation should be considered to design and implement policies that foster the effective and efficient collaboration and participation of all eco-innovation system agents. In this case, human capital capacity and networking will be key elements because they positively drove eco-innovation from 2014 to 2021. In contrast, a non-existence or reduction of private R&D investment could negatively influence eco-innovation progress.

The limitations of this study primarily relate to two areas: (i) the wide range of factors that can affect eco-innovations, given that only five conditions were included in the analysis, and (ii) the choice of countries for the analysis, given that only European countries were considered. Consequently, new eco-innovation-related factors could be added to the model, and the study context could be extended beyond European borders. Moreover, regional analysis (e.g., at the NUTS-2 or -3 level) could identify the regional drivers or barriers to eco-innovation based on each region's individual characteristics. Analysis of the regional context and situation could provide a valuable understanding of eco-innovation worldwide to ensure that all economic, social, and environmental human activity is directed toward sustainable development.

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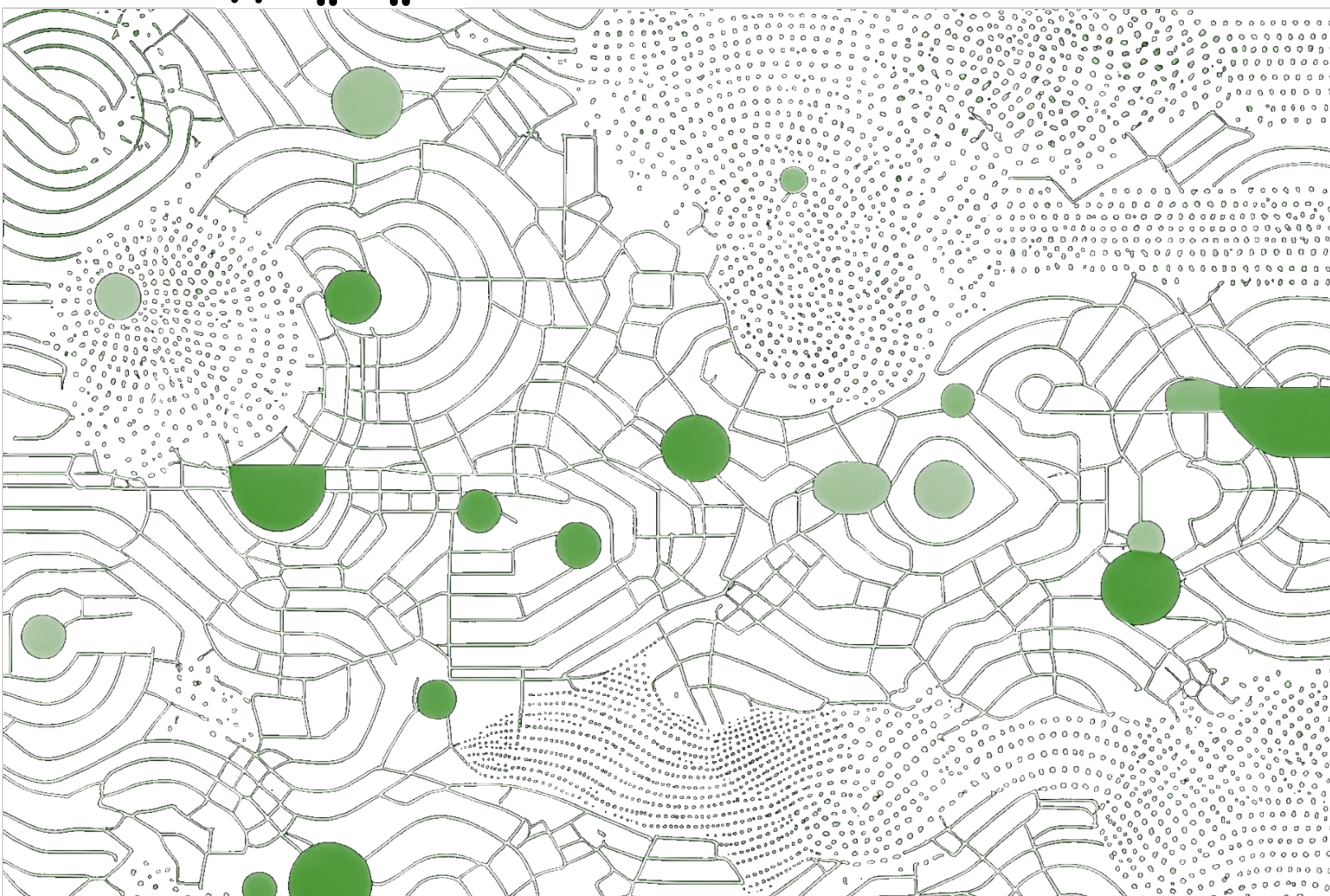
Chapter 6. Conclusions and discussion



Chapter 6. Conclusions and discussion

6.1. General conclusions

The general objective of this thesis was a joint consideration and deep study of sustainable development, eco-innovation, and elements of the innovation systems. The connection between these three aspects was considered crucial for three main reasons. First, innovation policies have been implemented for decades to enhance competitiveness, productivity, development, and economic growth. Second, the post-growth literature (Daly, 1974, 2018; Schneider et al., 2010; Kallis et al., 2018; Otero et al. 2020) has shown the limitations of economic growth given its negative effects on the environment, highlighting the need to move towards models based on sustainable development. Third, all types of innovation are found within the borders of a country or region, which have unique characteristics that help or constrain innovation development (Cooke et al., 1997). These unique characteristics that shape innovation systems arise from the relationships between factors and agents found within those borders.

Although an association between innovation (and its facilitators) and sustainable development has been recognized by innovation literature, there is still a poor understanding of eco-innovation systems and their characteristics and interactions. This suggests that the knowledge field that addresses eco-innovation and innovation systems together is largely unexplored. The complexity and uncertainty of eco-innovation systems are captured by studying how factors and agents within eco-innovation systems combine to explain eco-innovation success or failure. This complexity and uncertainty are triggered by the specific characteristics of sustainability, innovation, and agent interaction. The connection between sustainable development, eco-innovation, and the elements of innovation systems was studied using four methodologies in a three-step approach.

The thesis's conclusions evidence the need to adopt a holistic perspective where individual factors are not considered in isolation, but rather their interaction and synergies can influence and encourage the development of eco-innovations that promote sustainable development. For instance, the creation of synergies through the interaction of individual factors would be compared to the socioeconomic effect of clusters, which foster continuous innovation based on collaboration, communication, and collective learning (Asheim & Isaksen, 2002). However, this interaction may differ depending on spatial (national) characteristics, hindering the creation of global economic, social, and environmental value through technologies and innovations. Therefore, there is a need for in-depth study of the characteristics of eco-innovation systems. Such research can provide policymakers with insights to design and implement policies adapted to each geographical context with the aim of ensuring eco-innovation success and thus achieving sustainable development. This idea of adopting a differentiated innovation policy approach was also supported by Tödtling and Trippl (2005).

Table 6.1 summarizes the general and specific objectives of the thesis and links them to the chapter where they are addressed. The table also shows the findings of the analyses.

Table 6.1. Conclusions of the thesis

General objective	Paper	Specific objectives	Findings
To provide joint analysis of sustainable development, eco-innovation, and the elements that constitute innovation systems	Innovation facilitators and sustainable development: a country comparative approach (**Chapter 2**)	**O1.** To assess how innovation facilitators explain national sustainable development and the extent to which they do so	• Innovation facilitators influence sustainable development achievement • The importance of innovation facilitators depends on the level of sustainable development
		O2. To examine differences between country groups based on the degree of SDG achievement and innovation facilitators	• Countries can be grouped into four clusters according to their national characteristics • National characteristics influence the success of innovation policies and sustainable development • Economic growth has limited power over sustainable development
	Driving research on eco-innovation systems: Crossing the boundaries of innovation systems (**Chapter 3**)	**O3.** To provide an overview and exploration of the literature that jointly examines eco-innovation and innovation systems	• The joint research on eco-innovation and innovation systems is unexplored • Four clusters of authors have shaped the literature on eco-innovation and innovation systems • Insights into eco-innovation system characteristics could guarantee eco-innovation success adapted to each national context
	Factors driving national eco-innovation: new routes to sustainable development (**Chapter 4**)	**O4.** To determine the national-level factors that lead to high or low levels of eco-innovation in European countries	• High levels of human capital capacity, research institutes, and public R&D investment boost eco-innovation performance • Collaboration among eco-innovation system agents leads to eco-innovation • High levels of eco-innovation require strategies based on public R&D or public-private R&D collaboration • Barriers to eco-innovation include a lack of public or private R&D investment and a lack of human capital capacity
	Are European countries favoring or jeopardizing their eco-innovation performance? (**Chapter 5**)	**O5.** To determine the national-level factors that improve or worsen eco-innovation in European countries	• Human capital development improves eco-innovation even in contexts of weak research performance and governance • Cooperation among eco-innovation system agents increases eco-innovation • Lower private R&D investment leads to worse eco-innovation

6.2. Summary remarks per chapter

The key conclusions of the thesis are presented in the following subsections. Each subsection focuses on the conclusions of one chapter (Chapters 2, 3, 4, and 5), each of which responds to one or more of the specific objectives introduced in Chapter 1.

6.2.1. Chapter 2: Innovation facilitators and sustainable development: a country comparative approach

Chapter 2 focuses on identifying the relationship between innovation facilitators and sustainable development in terms of national characteristics. This study had two objectives (specific objectives O1 and O2). The first objective (O1) was to assess how innovation facilitators influence national development and to what extent they do so. Because countries were grouped into four clusters according to their national innovation and sustainable development characteristics, cluster analysis was also performed. This analysis detected changes in how innovation facilitators influence different degrees of sustainable development.

The findings reveal that **innovation facilitators explain sustainable development**. This finding suggests that countries that allocate resources to innovation facilitators would achieve higher sustainable development levels by boosting innovation performance. However, the potential influence of innovation facilitators changes depending on the country’s level of sustainable development. The importance of innovation facilitators for sustainable development varies. Countries must **first** reach some **minimum wealth** levels before boosting their sustainable development. When a country achieves a certain degree of **economic, knowledge, and institutional development, environmental facilitators** become more important for increasing sustainable development. Strong economies can provide more resources (financial, human, monetary, etc.) and innovations to ensure sustainable development thanks to their more developed institutional and social capabilities (Husted, 2005; Baughn, 2007; Reverte, 2022). Therefore, the need to adopting technological and knowledge progress (Schneider et al., 2010) reflects the positive implications of eco-innovation (Elgin et al., 2022) for sustainable development.

The second objective (O2) was to study clusters of countries with similar national innovation and sustainable development characteristics and to analyze the movements of countries between clusters over time. **Country movements** between clusters occurred when their innovation facilitators and sustainable development levels changed. This finding suggests that **national characteristics influence** the effective implementation of **innovation policies** and hence the achievement of **sustainable development**. The set of innovation facilitators of each country determines the achievement of sustainable development, which seems to be associated with the concept of **innovation systems**.

The findings also offer interesting reflections on the relationship between economic facilitators and sustainable development. Specifically, **economic growth has a limited influence on sustainable development**. Although countries require economic growth in the early stages of sustainable development (as previously mentioned), environmental quality decreases above a certain level of economic development. The post-growth literature is consistent with this finding (e.g. Daly, 1974, 2018; Kallis et al., 2018). Economic growth that exceeds the limits of the ecosystem and biophysical world produces environmental degradation and destruction (Fournier, 2008). This scenario leads to decreasing ecological sustainability that jeopardizes sustainable development.

6.2.2. Chapter 3: Driving research on eco-innovation systems: Crossing the boundaries of innovation systems

Chapter 3 addresses the link between sustainable development and the individual innovation characteristics of a country. This chapter explores the literature that jointly examines eco-innovation and innovation systems (O3). The chapter's primary contribution is to provide evidence that the **literature on the intersection of these two topics is scarce**, although **eco-innovation and innovation systems** have been studied separately in depth.

The persistent challenges faced by society and the increasing integration of sustainable development in all social areas are trends that highlight the need to understand the characteristics and functioning of eco-innovation systems. The global focus on new technological development (Spector & Ma, 2019) should be oriented towards sustainable principles that convert traditional innovations into eco-innovations. This chapter gives policymakers and other decision makers insights to help them implement eco-innovation policies that lead to sustainable development. A **finer-grained comprehension of the national characteristics of eco-innovation**

systems would be helpful for ensuring eco-innovation success. Eco-innovation success is supported by the government, which plays a crucial role in the eco-innovation framework (Altenburg & Pegels, 2012; Sun et al., 2019).

Other findings reported in this chapter are **the authors and topics** that provide the **theoretical frameworks** that appear in the literature dealing simultaneously with eco-innovation and innovation systems. These authors were grouped into four clusters according to their research areas. The authors in these four clusters address eco-innovation, innovation systems, and the elements that shape and interconnect within eco-innovation systems. Examples of these elements include **government, institutions, R&D investment, social knowledge and awareness, and collaboration**. The study of the characteristics of eco-innovation systems can offer essential perspectives to shift from traditional economic growth to **sustainable development and circular economy** models.

6.2.3. Chapter 4: Factors driving national eco-innovation: New routes to sustainable development

Given the difficulty policymakers face in determining the success factors in eco-innovation policy design and implementation, Chapter 4 shows the combinations of national-level factors that explain eco-innovation (O4). Several interesting findings can be observed.

Collaboration among agents of the eco-innovation system should be promoted. Such interaction creates spillovers that strengthen the business environment and society through sustainability and eco-innovation initiatives. Understanding this collaboration or interaction is what provides policymakers with the viewpoints they need for **eco-innovation policy success**. However, the **eco-innovation policy mix must adapt to the local geographical area.** Each national context has a unique set of characteristics that shape eco-innovation development (Tödtling & Trippl, 2005).

Contrary to the innovation literature, which suggests that private and public **R&D investment** is important for innovation (García-Álvarez-Coque et al., 2017), eco-innovation requires **involvement only from the public sector**. Considering the prominent role of public actors in the eco-innovative process (Fabrizi et al., 2018), these findings suggest that the commitment of public institutions to sustainable development is greater than that of companies. To **encourage companies'**

participation in sustainability, it is crucial to create eco-innovation systems where agents **trust the eco-innovation structures** introduced to boost eco-innovation activities. Most developed European countries achieve high eco-innovation levels through two major innovation system agents. Some of these countries follow a public sector strategy where **public institutions apply R&D initiatives** that encourage eco-innovation, whereas other countries rely on **public-private R&D cooperation** through eco-innovation agent networks.

Eco-innovation entails the uncertainty and complexity of sustainability and innovation, implying that major challenges must be faced by the world population. Hence, a country's **human capital capacity** plays a prominent role in achieving high levels of eco-innovation. Human capital can be developed through **education, training, awareness raising, commitment**, and policies that engage society in eco-innovation actions that contribute to global well-being and quality of life.

6.2.4. Chapter 5: Are European countries favoring or jeopardizing their eco-innovation performance?

Following Chapter 4, Chapter 5 explores the combinations of national-level factors that improve or worsen eco-innovation performance (O5). The difference between these two chapters lies in the analysis approach. Chapter 4 is based on a static approach, whereas Chapter 5 uses a dynamic approach. It was considered important to examine the trends in national eco-innovation levels over a given period. The findings show that **no single policy mix improved or worsened** levels of **eco-innovation**.

Human capital is crucial to increase eco-innovation levels, even when countries do not experience improvements in governance or research performance. Human capital capacity helps countries adapt to the disruptive changes (Aleknavičiūtė et al., 2016) that characterize the current global context. These changes may also be related to the uncertainty and complexity of eco-innovation practices. For example, human capital makes it easier to achieve **technological application and sustainable** (i.e. economic, social, and environmental) **value creation** (Ciccone & Papaioannou, 2009).

In line with the conclusions of Chapter 4, Chapter 5 also highlights the role of **collaboration among agents of eco-innovation systems**. Their interaction produces a continuous information and knowledge flow based on relationships of reciprocity, trust, and confidence (Asheim et al., 2011). The main difference is the role of the public sector. In Chapter 5, the **public sector** is shown to be an **intermediary** among agents, encouraging eco-innovation activities, despite the lack of participation of companies.

The most remarkable finding refers to the effects of innovation intermediaries on eco-innovation. In particular, improvements in eco-innovation may not necessarily be achieved through higher research performance. At the very least, national context influences its impact on eco-innovation. The marginal contribution of some countries' established research institutes may not be important. Alternatively, the conditions that enhance eco-innovation most effectively can be created through human capital development. Hence, although **research institutes** may be important in improving eco-innovation, they **are less influential if their home country lacks essential attributes** such as sound governance or private and public R&D investment.

6.3. The relevance of local and national contexts

The present thesis has provided more theoretical and practical arguments to establish the crucial relation between eco-innovation and sustainable development. Scholars, policymakers, and society have recognized the growing importance of eco-innovation because of its impact on the three dimensions of sustainability. Global initiatives have been introduced to boost and balance countries' sustainable development goals. However, inequalities remain (Bhandari, 2019). Our research has explored how countries' specificities affect eco-innovation systems and their effectiveness in addressing sustainable development. Despite immense global efforts, why do these national inequalities persist? Are these efforts and resources being effectively allocated and managed? What is the right answer to these questions when country contexts are so varied? These answers may be the key to reducing disparities between developed and developing countries.

Countries' specificities matter (Porter & Stern, 2001). Countries' situations are shaped by behavior, culture, and productive activity. Therefore, following the approach of

Tödtling and Trippl (2005), imitating the practices and policies of the most successful countries in terms of sustainable development does not necessarily imply that other countries will succeed. Given that innovation has become crucial for driving sustainable development (Omri, 2020), **national characteristics** should be considered when designing eco-innovation and sustainability policies. Policymakers should acquire detailed knowledge of eco-innovation systems, including the agents and interactions that encourage or constrain eco-innovation activities.

Relying on economic growth alone is no longer an option. Along with the lines of post-growth studies (e.g., Daly, 1974, 2018; Schneider et al., 2010), this thesis shows that meeting sustainable development challenges in a context of systemic and disruptive processes requires some kind of control of economic growth. Otherwise, social and environmental well-being becomes compromised through the deterioration and destruction of the natural environment and ecosystem, also noted by Kallis et al. (2018). When implementing strategies and measures for eco-innovation, an **economic growth threshold** and the implementation of **monitoring measures** should be established based on each country's characteristics. According to Martinico-Perez et al. (2018), sustainable development involves well-defined policies based on monitoring and evaluation capabilities.

Numerous studies (e.g., Díaz-García et al., 2015; or Hojnik & Ruzzier, 2016) have identified drivers and barriers of eco-innovation, calling for the need to promote them through national policies and incentives for certain agents in eco-innovation systems. Nevertheless, countries' institutions and society may be unable to address all eco-innovation drivers and barriers at the same time because of **limited resources**. Bretschger (2005) claims that resource scarcity problems are accentuated by fast economic development or population growth. A finer-grained **understanding of eco-innovation systems** and agents' interrelationships can help policymakers prioritize the aspects that have the strongest impact on eco-innovation in terms of national characteristics and that thus have the greatest potential to drive or hinder the achievement of eco-innovation. Some important common ingredients to drive eco-innovation are collaboration among agents of eco-innovation systems, public R&D investment, and human capital. However, private investment in R&D and human capital could eventually support but also constrain eco-innovation activities. Constraints should also be considered when creating policy instruments to encourage eco-innovation, which cannot be achieved without minimum levels of private R&D investment and human capital.

This thesis shows the need to apply **tailored sustainable development policies** and initiatives based on the characteristics of each national eco-innovation system. Similarly, Valencia et al. (2019) argue that the 2030 Agenda and others based on sustainable development require an adaptation process for their implementation because their adoption starts at the national government level. Through such tailored policies, society's actions can target practices aimed at economic, social, and environmental improvements that can be achieved together through effective eco-friendly technological development.

According to Piñeiro et al. (2021), economic and social innovation contributes to the creation of cooperative environments capable of addressing agricultural challenges (i.e., loss of production and land abandonment, among others). In this thesis framework, **international collaboration and cooperation** can provide knowledge and experience spillovers, helping less developed countries implement sustainable strategies. These countries may lack human, material, technological, and other resources. Sustainable development requires mutual efforts, and collaboration can provide a more equitable framework (Pandey et al., 2022). Less developed countries could identify the previous failures of developed economies to reduce the time required to implement the eco-innovation process. They would need to adapt existing strategies to their own national characteristics, given the dependence of policy and strategy effectiveness on national context. Inequalities between countries in terms of sustainable development and well-being could thus be reduced.

6.3.1. Policy implications and recommendations

Eco-innovation cannot succeed without a set of policies and strategies supported and encouraged by the agents of eco-innovation systems. Some policy implications and recommendations can be highlighted based on the findings and conclusions of this thesis. These policy implications and recommendations could support the process of acquiring finer-grained knowledge of the country or regional context to ensure sustainable development through eco-innovation.

Information is crucial to make well-informed, smart, and robust **decisions**. The collection and integration of this information relies on **in-depth research** into each national context, working together with the agents of eco-innovation systems. It could thus be possible to gain insights into the way these agents interact or relate with each other and their objectives, future expectations (regarding society, government, competitors, customers, business, etc.), trust of institutions, opinion of existing infrastructures, or even identification of possibilities for improving national innovation. To guarantee reliable information acquisition, **communication** with different agents of eco-innovation systems is critical. Through collaboration, policymakers and other stakeholders could gather knowledge on barriers to eco-innovation. Therefore, problems and opportunities for sustainable development could be directly tackled. These insights would simplify and accelerate the design and implementation of tailored measures that foster eco-innovation and sustainable development.

By **collaborating** within eco-innovation systems, agents can share experiences, knowledge, and know-how, stimulating the **flow of information** and eco-innovation practices. This flow could help other businesses or institutions engage in sustainable activities. It thus reflects the benefits of **sharing knowledge**, working together, cooperating, and facilitating innovative processes and tasks. This idea is related to the EU Open Science principle, which aims to spread knowledge and data in a fast and globally accessible way through digital and collaborative technology, linking research and innovation and thus encouraging partnerships among public authorities, industry, academia, and citizens (European Commission, 2023).

Collaboration among eco-innovation system agents could be promoted through **workshops** that encourage dynamic and active participation. These agents could share experiences and knowledge in an **open space** to create joint value through eco-innovation initiatives. In these spaces, agents could create an environment of trust in which they get to know each other, thus encouraging the creation of new knowledge and collaboration networks for future innovation projects. **Institutions or services for coordination** could assist with these collaboration networks.

Following the Open Science strategy, easily accessible **platforms or instruments** could be designed and made available to all citizens to share information on technological processes, cases of eco-innovation success, or entities that intend to collaborate with new partners on new projects. For instance, information on the history, background, and objectives of the companies seeking to collaborate could be provided, with easy access to meetings or contacts to gain confidence initially and establish more relationships in the future.

This **information** could be **collected** through the actions of companies themselves, which can complete and share their own data to participate in the platform. Surveys and interviews could also be conducted with companies to (i) verify the business information provided and (ii) investigate the eco-innovative experience further, thus offering data on a range of aspects that are common to all business types. The information should be arranged in a clear and uniform way. Large, medium, and small enterprises and individual entrepreneurs and other agents could access this information. Thus, numerous actors such as R&D institutions, public administrations, and financial institutions could gain access and engage in eco-innovation activities.

The difficulty of implementing eco-innovation and achieving sustainable development is widely acknowledged. In this sustainability- and technology-related process, small and medium-sized enterprises (SMEs), which account for 99% of all EU companies, may encounter even more barriers and limitations than large companies. Therefore, **support infrastructures or programs** could help companies effectively and efficiently implement environmentally friendly technologies that generate value for the economy, society, and environment. In this complex context, **innovation intermediaries** could make a key contribution. Innovation intermediaries (research institutes, science parks, technological centers, incubators, etc.) can help companies by applying for competitive R&D programs and providing knowledge-intensive services, technological consulting, and specialized training. With this assistance from innovation intermediaries, companies can explore new products or markets without committing extensive resources but with the support of well-established innovation and R&D centers. Innovation intermediaries, together with other support institutions, could offer **tools to support and monitor** the design, development, and implementation of eco-innovations, providing assessment reports. Companies could thus obtain insights into areas for improvement in future eco-innovation projects.

At the citizenship level, business objectives must be aligned with those of society so that there is consistency between business and social interests. This consistency is necessary because individuals are those who make decisions and act within the international framework, thus influencing the economy, society, and the environment. The active participation and commitment of citizens could be ensured through **awareness campaigns** on the importance of technological activities that support sustainable development progress. A paradigm shift that involves the whole society in working towards sustainability principles could contribute to ensuring global well-being and enhancing the agri-food system. It could directly link human activity not only to the sustainability agenda but also to the Farm to Fork Strategy of the European Union.

In the transition towards sustainable development and the circular economy, **international, national, and regional authorities** play a key role in promoting the green change by supporting the initiatives suggested earlier. For example, they can create environments of **trust and transparency** that foster society's commitment and participation. Moreover, they have more resources (time, monetary resources, materials, human capital, etc.) that they can allocate to **financial support for R&D and innovation projects**, as well as other types of incentives that fit within the eco-innovation framework. The public sector can also **regulate** and establish lines of action that stimulate eco-innovation behaviors based on R&D investment and cooperation.

6.3.2. Alignment with the SDGs and the 2030 Agenda

The conclusions show the relationship between sustainable development, eco-innovation, and elements within innovation systems. Given the global spread of sustainable development since the beginning of the 2000s, especially since 2015, this thesis engages with the SDGs and the 2030 Agenda by providing crucial insights and knowledge that bridge the research gap and help ensure sustainable development through eco-innovation and policy implementation adapted to each national innovation system. This section offers an overview of the extent to which the findings relate to SDGs and the 2030 Agenda.

This thesis is related to many SDGs directly or indirectly. Eco-innovation is characterized not only by its economic impact but also by its positive social and environmental effects (Bos-Brouwers, 2010; Rhaiem & Doloreux, 2022). Firms, many of which are from the agri-food sector, embrace eco-innovations in their industrial processes to improve their management of materials, water, and energy. These process eco-innovations are associated with water pollution, waste management, energy recovery, and recycling (Triguero et al., 2018). Accordingly, this thesis is linked with **SDG 6** (Clean water and sanitation) and **SDG 7** (Affordable and clean energy) because eco-innovation optimizes resource efficiency and reduces negative environmental effects (Ben Amara & Chen, 2022). Eco-innovation thus contributes to reducing water scarcity, energy consumption, the use of polluting fuels, greenhouse gas emissions, and other such environmental targets. These positive effects on the environment and society could directly influence health and well-being (**SDG 3**) and climate action (**SDG 13**), as well as water (**SDG 14**) and land (**SDG 15**) ecosystems.

One of the noteworthy conclusions of the thesis relates to **SDG 8** (Decent work and economic growth). Although economic progress is part of sustainable development and the institutional view advocates sustainable and inclusive economic growth, the findings show that economic growth has limited power over sustainable development. Exceeding a specific economic growth level implies a loss of ecosystem and biodiversity value, accelerating environmental degradation and destruction. These negative effects on the environment and society diverge from the principles of eco-innovation.

Given the existence of limited resources, countries need to understand how eco-innovation system elements interact so that they can manage these resources efficiently and implement policies to achieve sustainable development. This thesis highlights the importance of institutions, policies, human capital, and collaboration in pursuing this goal. Investments devoted to building a resilient infrastructure and innovation could empower communities by creating structures that provide benefits to society and the environment in terms of transport, information and communication technology, and energy, as outlined by **SDG 9** (Industry, innovation and infrastructure). The thesis also shows the role of institutions in creating contexts of trust and stability free of conflict, violence, insecurity, social inequality, and injustice. This finding indicates a direct link with **SDG 16** (Peace, justice and strong institutions).

To avoid the depletion of resources, society must change its consumption and production habits and patterns towards more sustainable models, as outlined in **SDG 12** (Responsible consumption and production). It is thus crucial to increase citizens' commitment and awareness regarding more environmentally friendly habits, eco-innovation, recycling, and other sustainability-based practices, as well as stopping trends such as food waste and fast fashion. These awareness campaigns and human capital training would contribute to meeting **SDG 4** (Quality education). Sustainable development cannot be achieved without collaboration between the agents of eco-innovation systems. **SDG 17** (Partnerships for the goals) calls for unity between developing and developed countries, including alliances among members of the business sector, governments, and civil society.

The thesis shows that no-one can be left behind on the route to sustainable development. This sustainable development can be achieved by making a strong commitment at the global level and by sharing knowledge and experience with other agents. Crucially, the unique characteristics of eco-innovation systems must be considered, and policies must be adapted to each national context.

6.4. Limitations and future research possibilities

This thesis has some limitations. In Chapter 2, the analysis was conducted for the years 2015 and 2020. However, it was impossible to collect all data for these two years. For example, the oldest SDG Index data were from 2016, and the most recent GDP per capita data were from 2019 (latest year available as of May 2020). Moreover, only some of the innovation facilitators that potentially affect sustainable development achievement were included in the analyses. There may be more types of innovation facilitators and other aspects that drive sustainable development (Horbach, 2008; Triguero et al., 2013; Díaz-García et al., 2015). These limitations could be addressed by analyzing the most recent data and including other factors that affect sustainable development performance. Future research could apply the same analyses focusing on a specific sustainable development goal. The findings could also be complemented with Necessary Condition Analysis (NCA) to determine the minimum levels of innovation facilitators required by each country cluster and to study how these levels change depending on the countries' degree of sustainable development achievement.

Regarding the limitations of Chapter 3, the bibliometric analysis considered only the documents available in the Web of Science (WoS), excluding all contributions that may be published but not indexed in the WoS. Moreover, co-cited authors and documents may have expressed different ideas about the same document or may have had different or unrelated reasons for being cited. Future studies could include documents from other databases such as Scopus, broadening the range of literature on the combined topic of eco-innovation and innovation systems.

The application of the same analysis and the use of similar data sets in the studies described in Chapters 4 and 5 led to practically identical limitations in both articles. Regarding the methodological limitations, fsQCA captured the conditions that trigger a particular outcome but without explaining why or how they interact. Moreover, the degrees of freedom in the analysis may have influenced the findings of the analysis because the calibration process depends on the authors' assumptions. Another limitation relates to the number of factors included in the analysis. Other conditions may have also affected eco-innovation. Similarly, only data on European countries were collected. Therefore, new eco-innovation factors and non-European countries could be added to the research model. Another study could focus on the analysis of regional factors leading to eco-innovation at the NUTS 2 or NUTS 3 level.

New approaches to development have emerged beyond traditional economic models based on financial performance, productivity, competitiveness, and economic growth. This thesis has dealt with elements related to sustainable development and eco-innovation. However, innovation environments imply dynamic and disruptive characteristics that change people's way of life. This may require adaptation periods. Therefore, the importance of aspects linked to sustainable development, such as well-being that involves healthy and clean environmental and social contexts (Maggino, 2013) or the agri-food sector as the first supplier of basic goods and food security, has increased during the last few years.

Future research aims to address the relationship between innovation and well-being, analyzing how innovation drivers influence subjective and objective well-being. In this way, other aspects that are unrelated to economic resources and may impact well-being through social and environmental progress are considered (Stiglitz et al., 2009). Furthermore, another research line would focus on studying the technological progress of the agri-food sector because this sector has traditionally been characterized by low levels of innovation and R&D. The value generated by this sector at the global level is unquestionable even though it also has adverse effects on the environment, health, and society (Food and Agriculture Organization of the United Nations, FAO, 2023). Therefore, implementing eco-innovations in this sector could accentuate its positive effects and mitigate the negative ones.

6.5. References

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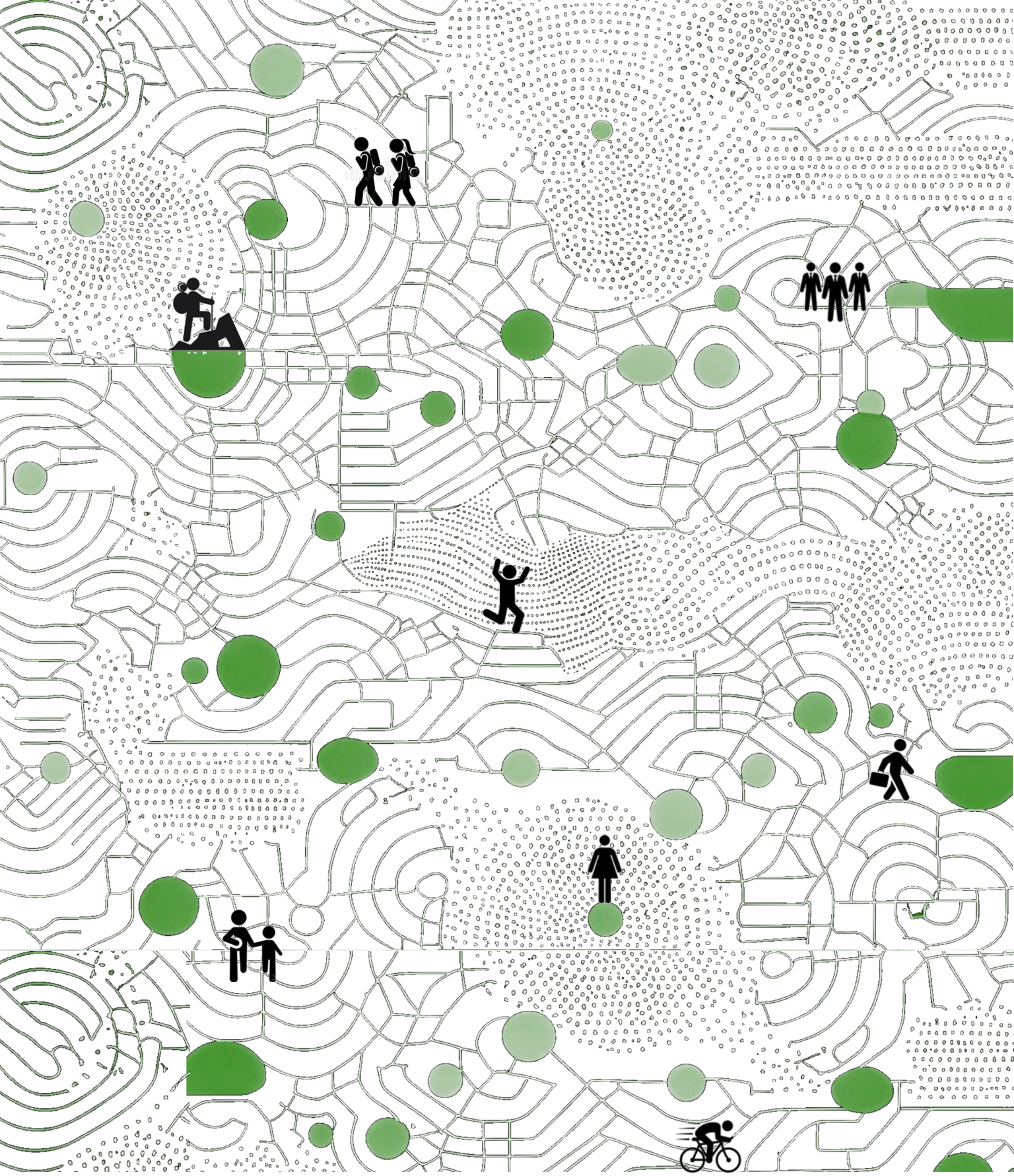

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