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Do ESG Ratings Promote Green Innovation Inside the European Union?

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Abstract

The research provides a detailed analysis of environmental, social and governance (ESG) factors in the context of EU Member States. The impact of ESG metrics is explored, ranging up from their roots conceptualized with Nobel laureate Elinor Ostrom through to their formal introduction in the United Nations Global Compact Initiative report. The study, establishes the role of ESG ratings in driving long-term economic prosperity and societal well-being, highlighting their influence on investor decisions and risk management strategies.

Afterwards, the paper investigates the growing importance of green innovation (GI), delineating its diverse nature and its central role in enhancing market competitiveness and environmental sustainability. While exploring diverse facets of GI, from eco-innovation to sustainable innovation, it addresses barriers to adoption and outlines a complete cycle for promoting green innovation. Besides, the intersection of agency theory, stakeholder theory and institutional theory in promoting sustainability and green innovation is examined, highlighting the roles of governments, institutions and stakeholders in shaping policy and organisational responses.

A significant contribution of the thesis lies in the empirical analysis of the relationship between ESG ratings and green patenting in EU Member States. Through regression analysis and robustness tests, the thesis establishes a positive correlation between higher ESG ratings and increased green patenting activity, particularly driven by social factors. These results underline the importance of addressing countries disparities and promoting sustainable practices to foster innovation and improve the EU's overall ESG performance.

Contents

1. Introduction

1.1 Background

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 and has been trying to manage the threat of climate change ever since, as the latter is generating the need to develop a coordinated international response.

The European Union has one of the highest environmental standards in the world, both because it formulates investment plans to green the economy, as well as playing a leading role in international climate negotiations (Cifuentes-Faura, 2022). The author goes on to explain that conferences such as the 26th United Nations Conference of the Parties on Climate Change (COP26), demonstrate involvement and commitment to take action to combat climate change and provide assistance to vulnerable nations. The EU is dedicated to the proper implementation of the Paris Agreement (an international treaty on climate change established at COP21) by seeking to promote low-carbon technologies and to protect and improve the quality of the environment. As a result of these plans and strategies adopted by the European Union, the latter can be recognized as a global example in the fight against global warming.

A Corporate Transparency Directive (CSRD) was established within the European Union, which came into force on January 5, 2023, (European Commission, 2023). This directive is worth highlighting since it extends the environmental, social and governance (ESG) reporting requirements established by the Non-Financial Reporting Directive (NFRD). Indeed, according to the European Commission, the aim of the directive is to:

> *'Enable investors to redirect investments towards more sustainable technologies and companies, helping to make Europe climate neutral by 2050' (European Commission, 2023).*

The majority of European research on ESG concerns financial issues. Therefore, it is the changes in ESG ratings on financial and equity performance that are the main focus of the European literature (Giese, et al., 2019).

Alongside climate change, there are other environmental challenges, such as resource depletion, that urgently require the global community to change to more sustainable practices. As both companies and countries nowadays attempt to balance economic growth with sustainability, environmental, social and governance (ESG) considerations have grown in importance (McGowan, 2023). ESG issues were first mentioned in the 2006 United Nations Principles for Responsible Investment (PRI) report where environmental impact, social responsibility and governance practices became the key areas in which ESG evaluates the performance of both companies and nations (Atkins, 2020). The European Union established high targets in order to accomplish climate neutrality and sustainable development, however, these several initiatives provide an opportunity to examine the role of ESG ratings in promoting green innovation in EU member states. Knowledge of the dynamics between ESG and green innovation is crucial in the EU due to its ongoing commitment to sustainability.

1.2 Research Questions

While the connection between ESG and sustainability is commonly recognized, at the same time a gap exists in the understanding of how ESG ratings contribute to green innovations. To fill this gap, this study employs a quantitative approach, using regression analysis to examine the correlation between ESG scores and green patenting activities in EU Member States over a fifteen-year period from 2005 to 2020. Data sources include ESG scores from the World Bank and green innovation indicators from OECD.Stat, with a focus on green tech patents. The analysis incorporates country-specific fixed effects to control for unobserved heterogeneity. Although the existing literature recognizes the general importance of ESG in promoting sustainability, a more nuanced investigation of the mechanisms involved in the EU context is needed. A key question this study aims at answering is:

Do ESG ratings promote green innovation in EU Member States and how do these relationships differ at national level?

This research is needed to identify the specific patterns involved regarding the interplay of environmental, social and governance elements, including the EU's country-specific context. However, the methodology used to develop this article has some limitations. First need to specify that the cause of both a limited number of data sources, and due to the exclusive use of green tech patents as an indicator of green innovation, the full extent of ESG activity and innovation may not be captured. In addition, correlations rather than causal relationships are primarily analyzed.

Understanding the intricate relationships between ESG assessments and green innovation is critical for several stakeholders as not only do policy makers need evidence-based insights to refine sustainability policies, but also companies need guidance to align their practices with ESG standards. The empirical analysis developed in this research shows that the higher the ESG ratings, the greener patenting occurs. However, the study reveals significant disparities between EU countries in both ESG ratings and green patenting activities, underscoring the need for customized policies to address these differences and promote sustainable practices uniformly across the EU.

1.3 Significance of the Study

The importance of this study lies in the commitment and efforts that UE shows to become a leader in sustainable practices. The role of ESG assessments in driving green business innovation is crucial as the region encourages companies to take green and socially responsible measures (Salihi, 2024). The goal of the research is to understand the details of these relationships and offer ideas that can be used for the broader EU sustainability plan.

By focusing on the specific context of the European Union, the research aims to add depth to the existing literature and improve our understanding of the dynamics between ESG considerations and corporate sustainability practices. The results of this research have practical implications for policymakers at the national and EU levels, as policymakers can use the study's findings to refine regulations that encourage companies to adopt green practices.

The author Salihi (2024) highlights how companies operating in the European Union are facing a changing landscape in which sustainability is increasingly integral to long-term success. Therefore, understanding the incentives from high ESG ratings can enable companies to make informed decisions that contribute not only to their financial success, but also to their environmental and social impacts. As confirmed by author Martini (2021) investors, both institutional and individual, are placing greater emphasis on sustainable investments because doing so allows them to go beyond financial gains and include social welfare, environmental conservation, and the promotion of a responsible corporate culture.

This study is intended to be a catalyst for positive changes in different sectors, laying the foundation for future research efforts where researchers can investigate specific aspects not covered in this study and explore causal relationships between ESG assessments and various dimensions of corporate sustainability.

1.4 Structure of the Thesis

The structure of this thesis would begin with a comprehensive review of the existing literature on environmental, social and governance (ESG) ratings, green innovation, and related theories. This will lay the theoretical foundation necessary to conduct the research, identifying key concepts, trends, and gaps in current knowledge.

This will be followed by the data section where the rationale will be described for then delving deeper on the chosen variables that will characterize the results of this research.

Chapter 4 delves into the components and indicators of ESG ratings and green innovation. It will be explored the environmental, social and governance dimensions first, for then focusing on the metrics chosen to measure green innovation. Specifically, the unique context of the European Union is examined, and trends and variations observed in ESG ratings and green patents across member states are discussed.

Chapter 5 describes the methodology of the study. Here how the panel data regression is running will be discussed, followed by the explanation of the estimation strategy selected to best interpret the analysis.

Moreover, it will be tackling the empirical analysis, namely the stating of the hypothesis and the scrutiny of robustness analysis. In this chapter, the results will be interpreted, and it will be possible to explore the relationships between ESG ratings and the number of patents for environmentally friendly technologies.

It will then be time to discuss the research results in depth. The chapter explores the implications of the findings, considers the variations between environmental, social and governance dimensions and discusses the broader context of the study. The results of the empirical analysis are used to answer research questions and contribute to existing knowledge.

Afterwards, the limitations with which this research was developed are discussed, thus providing the necessary recommendations for the development of further studies on correlated topics.

The concluding chapter summarizes the main findings, contributions to academic knowledge and practical implications.

2. Literature Review

2.1 ESG Ratings and their Importance

2.1.1 Definition and Components of ESG

Environmental, social and governance (ESG) factors are a framework that assesses the sustainability and ethical practices of a company or, in the context of this study, a country. ESG factors include a wide range of criteria that assess a nation's impact on the environment, its social responsibility, and the effectiveness of its governance practices. To best understand why the criteria is able to properly assess a nation's sustainable impact we use the research conducted by Nobel Prize winner Elinor Ostrom. This theory gained notoriety because it succeeded in demonstrating how a theory of resource management was not very inclusive (Ostrom, 2012). The theory, commonly referred as the "tragedy of the commons," argued that the lack of private property led to the ruin of common resources. Ostrom’s (2012) results suggested that the management of shared resources also strongly depends on social and technological circumstances external to a specific common. For this reason, understanding three-dimensionality, and thus ESG factors, is critical to understanding how countries integrate sustainability into their activities.

The term ESG emerged officially in 2004 through the publication of the report "Who Cares Wins" by the UN Global Compact Initiative (United Nations, 2004). It aimed to consolidate three key ethical pillars: environmental, social, and governance. Each of these pillars encompasses distinct issues and evaluation criteria. The environmental aspect concentrates on topics like climate change, deforestation, air and water pollution, assessing efforts in energy efficiency, greenhouse gas emissions, and resource management (Billio, et al., 2021). On the other hand, the same article specify that the social pillar encompasses issues like human rights protection, workplace safety, public health, and income distribution, all of which impact employee satisfaction. Finally, the governance pillar is defined by the article to pertains to aspects such as shareholders' rights, control mechanisms, legal compliance, and anti-corruption practices.

Paying attention to ESG ratings is valuable since they enable the generation of long-term value. Indeed, this is most simply confirmed by Kaplan and Norton (1992) who developed what we know today as the balanced scorecard, and which demonstrates the how a company's value depends on more than just financial factors. ESG has contributed to the advancement of the balanced scorecard as it gave each company the opportunity to question themselves about which Key Performance Indicators ("KPIs") would have helped to determine if they were meeting the established sustainable expectations (Edmans, 2023). Most importantly, these ESG metrics capture "harm", namely the amount of damage the country does to society. Although this is certainly important, the long-term benefit concerns far more about whether the country is "actively doing good". Edmans (2020) illustrates this concept by implying that any sustainable development applied to increase a country's ESG rating must then be followed by a country-specific strategy so that value creation can be tracked.

Through the research conducted by authors Wang, et al. (2023), and their use of both the Cobb-Douglas growth function and cross-country panel regression, it was found that improvement in ESG scores is positively associated with GDP growth. The authors continue the article by explaining that the economic benefit is particularly driven by efforts to protect the environment and institutional governance. Authors Crossland & Hambrick (2011) further elaborate those channels such as energy efficiency, increasing female labor force participation, and attracting foreign investment, contribute to its positive impact.

Wang et al.'s study (2023) further explores moderating factors, indicating stronger effects in high-income countries, with limitations in resource-dependent economies. Therefore, the article highlights how effective government regulation and financial system characteristics play a crucial role, while cultural factors, such as individualism and low power distance, influence the economic benefits of sustainability. Agreeing with this viewpoint are the authors Porter and Kramer (2006) whom explain how the implementation of ESG policies is well established in low power distance societies that maintain social harmony among different stakeholders. In fact, the authors specify that in individualist societies, private economic actors enjoy more discretion, and therefore companies in these societies are more likely to respond to countries' sustainable development plans as a deliberate and strategic business decision.

2.1.2 Global Trends in ESG Adoption

Already as early as 1995, Porter outlined how world demand was already moving rapidly in the direction of valuing low-pollution, energy-efficient products, not to mention products that were more resource efficient and had a higher resale or scrap value (Porter & Van der Linde, 1995). The authors Skordoulis, et al., (2020) endorse what was previously reported and go on to elaborate that many companies are using innovation to gain competitive advantage over price rewards for "green" products and open up new market segments. The article goes on to pose as an example Germany, which adopted recycling standards earlier than most other countries, which has given German companies an advantage in developing less packaging-intensive products that have been welcomed by the market. Similarly, Scandinavian pulp and paper manufacturers have been leaders in introducing new environmentally friendly production processes, and as a result, Scandinavian pulp and paper equipment suppliers, such as Kamyr and Sunds, have made significant international gains in selling innovative bleaching equipment (Edmans, 2023). In the United States, a parallel example is Cummins Engine's development of low-emission diesel engines for trucks, buses, and other applications in response to U.S. environmental regulations (Skordoulis, et al., 2020). This new expertise is enabling the company to gain market share internationally.

Clearly, this argument works only to the extent that national environmental standards anticipate and are consistent with international environmental protection trends, rather than breaking them (Porter & Van der Linde, 1995). Bearing this in mind, the authors Skordoulis et al. (2020) are pointing out the example of the U.S. Superfund law that deals with creating expertise in the cleanup of abandoned waste sites. This hardly benefits U.S. suppliers if no other country adopts similar requirements for toxic waste remediation. However, when a competitive advantage is achieved, especially because a company's home market is demanding enough to push the company to innovate further, the economic gains can be long-lasting.

For what concerns the United States, the Securities and Exchange Commission (SEC) has not yet promulgated a regulatory definition of ESG (U.S. Securities and Exchange Commission, 2022). On the other hand, EU regulatory schemes prove to be much more technically developed, thus presenting the opportunities and challenges of leadership, including the need for coordination and harmonization (Bradford, 2020). Just one example is the proposal regarding the introduction of a European label for ESG benchmarks, an addition to the benchmark regime initiated in 2018, to be able to thereby enhance the quality of ESG benchmarks and reduce greenwashing[1] (European Securities and Markets Authority, 2022). While it is true that this proposal represents another opportunity for the EU to be called a

[1] Enhancing the quality of ESG benchmarks promotes integrity, accuracy, and credibility in sustainability reporting, making it more challenging for companies to engage in greenwashing practices. By fostering transparency, standardization, and accountability, high-quality ESG benchmarks contribute to building a more sustainable and responsible business environment.

frontrunner, it is important to keep in mind that its regulations must also recognize the need to take into account third countries, as they were previously granted a grace period for compliance that expired in 2023 (European Commission, 2023).

ESG regulation in the Asia-Pacific region is also developing rapidly, however with greater variability among its constituent countries (Trahan & Jantz, 2023). Wang, et al. (2023) have developed the broadest cross-country spectrum in the sustainability literature, obtaining 730 unique country-year observations across 109 countries. This is illustrated in Figure 1, where we can see an upward trend in average country ESG scores during the sampling period, except for a sharp decline in 2013[2].

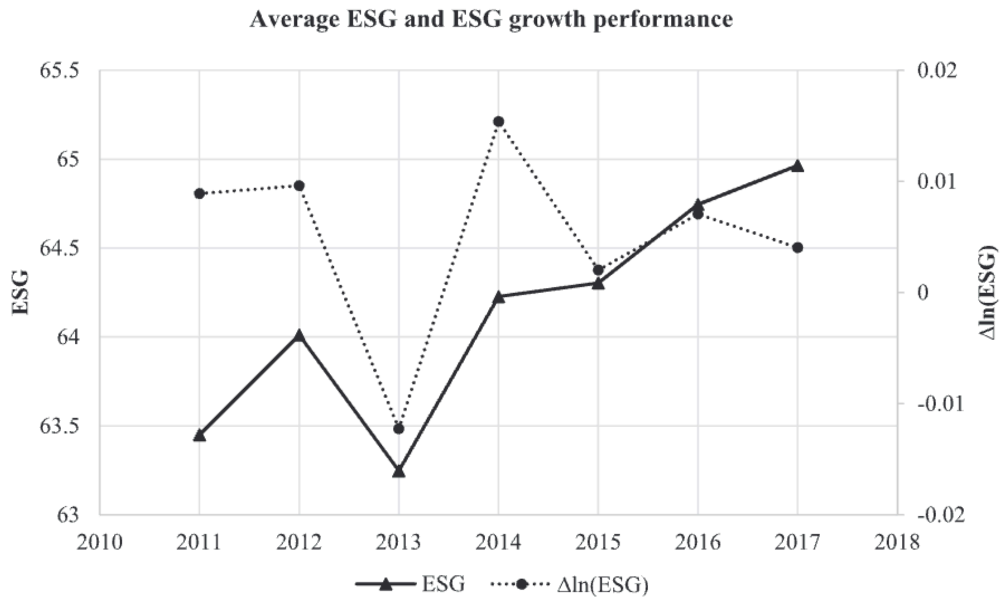

Figure 1. Cross-country average environmental, social and governance performance over time. Source: Wang et al. (2023)

While Europe continues to make progress toward adoption of the proposed Corporate Sustainability Directive, in the United States 19 states attorneys issued a letter to BlackRock[3], denouncing its ESG-influenced energy investment planning (Fink, 2022). The article states

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[2] The decline in ESG scores in 2013 reflects a mix of reasons: economic struggles, policy shifts, environmental disasters, political unrest, methodological changes, more scrutiny, and altered data practices. These show how ESG ratings is complex and reacts to different external pressures and contexts.

[3] BlackRock is an American multinational investment company. It is included in the Big Three asset manager. Therefore, together with State Street Global Advisors and Vanguard, they are the three world's largest ones. The content of the letter discusses BlackRock's analysis and its investments in the energy transition that are not by nature agnostic but, on the contrary, politically motivated.

that BlackRock's position is pushing companies toward energy paths motivated by values other than investor returns. The uncertainty behind the underlying principles and definitions of ESG can fuel such politicized claims and criticisms. Indeed, it extends to service providers as well, which is why some U.S. senators wrote to 51 large law firms to suggest that ESG activities could be a threatening restriction on carbon-producing industries, as they might result in challenges over the U.S. antitrust law. (Latham & Watkins, 2023).

2.1.3 Incentives for ESG Ratings

A higher ESG scores increase a country's attractiveness to those investors seeking sustainable opportunities, leading to a potential increase in foreign direct investment (FDI) and capital inflows. This phenomenon is supported by research conducted by Narula (2012) which recommends the application of sustainable investment (SI) to inbound FDI, while emphasizing the integration of ESG factors. This can enable countries to attract investors who prioritize sustainable and responsible investment practices. Such an approach is in line with the growing trend of investing through the SI, which emphasizes the importance of ESG factors in investment decision making (Narula, 2012). Moreover, SI generates higher returns and reduces portfolio risk in the long run. Therefore, integrating SI principles into FDI will not only attract sustainable investments, but also contribute to the long-term economic and social development of the recipient country. ESG scores are vital indicators that influence long-term performance and resilience, guiding investors in identifying environmentally and socially responsible opportunities (Moliterni, 2018).

ESG scores play a crucial role for identifying and managing potential risks. According to the authors Eccles et al. (2014) such a positive rating suggests that the country is proactively addressing key sustainability challenges, which in turn contributes to greater resilience and effective risk mitigation strategies. Countries with higher ESG scores are more likely to adopt and enforce stringent environmental regulations and policies (Moliterni, 2018). Furthermore, the author Edmans (2011) highlights how countries with higher ESG ratings tend to prioritize social issues, such as human rights, labor practices, and community engagement. The author goes on to explain that this focus contributes to the creation of a more equitable and inclusive society, reducing social risks associated with inequality and social unrest. Robust governance practices in countries with higher ESG scores help create transparent and accountable institutions (Martini, 2021). By doing so, it will be possible to reduce governance-related risks and fosters a stable political and economic environment. For this reason, higher ESG scores contribute to a country's overall resilience, creating the foundation for sustainable economic development (Eccles, et al., 2014).

In addition to financial incentives, ESG ratings can act as a catalyst for innovation (Dechezleprêtre, et al., 2019). The same article explains the fundamental role of climate change regulations in driving low-carbon innovation, emphasizing the need for a shift in the use of technologies to meet global carbon emission reduction targets. The Intergovernmental Panel on Climate Change (IPCC) recommends a 60% reduction in the carbon intensity of global GDP by 2050, requiring a radical change in energy technologies and substantial investment in research, development and demonstration (RD&D) (Dechezleprêtre, et al., 2019). The article goes on to explain that climate change policies act as key drivers for the adoption of clean technologies, stimulating what is called "induced innovation[4]". Moreover, the passage emphasizes that the impact of climate change regulations on innovation is significant and occurs rapidly.

As we see in Figure 2, which is only a part of a research carried out by the International Energy Agency's (2021), a support is needed to incentivize R&D investment, and to increase overall deployment levels to help reduce costs. The development and deployment of these technologies would create new industries and employment opportunities. The research goes on to explain that in order to reach the level we want for 2050, portrayed in Figure 2, it is necessary to mobilize $90 billion in public funds globally.

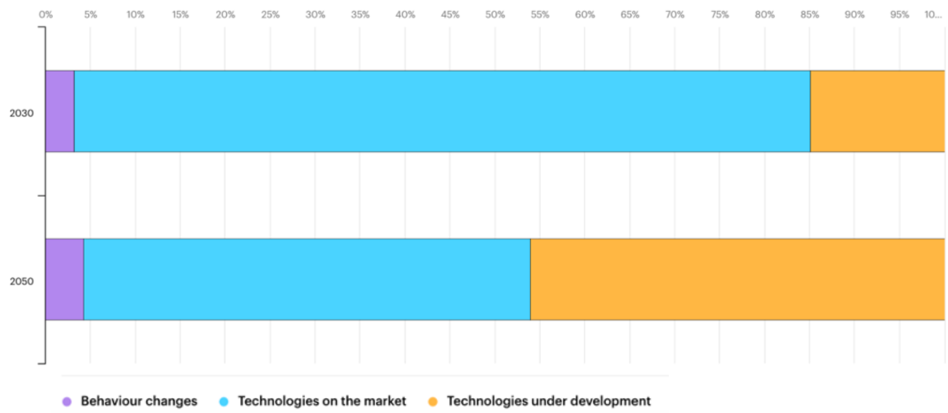

Figure 2. Annual CO2 emissions savings in the net zero pathway, 2030 and 2050, relative to 2020. Source: International Energy Agency's (2021)

[4] Induced innovation refers to the process where changes in economic conditions, or policies, stimulate innovation and technological advancements in response to new demands or opportunities.

2.2 Green Innovation and Patents

2.2.1 Conceptualizing Green Innovation

The amount of research involving green innovation (GI) has been developing and growing in recent years as a result of its many applications, as well as the growth of environmental awareness (Takalo, et al., 2021). Nowadays, GI is a crucial tool used to improve one's market position, attract more customers, offer green services, and gain a competitive advantage over competitors. Considering the multiple challenges that the global community has been facing over a long period of time, new management models represent an opportunity to overcome the current set of difficulties. Molina-Azorín, et al. (2009) do specify as an example that environmentally focused management, is gaining momentum in today's social and business environments, and therefore organizations are showing more inclination to engage in more sustainable practices.

In the article wrote by Chavira, et al. (2023) is reported the definition of green innovation which was defined by researchers Kemp and Pontoglio (2007) such as:

> *"a product, production process, service, or management or business method that is new (to the company implementing it) and that results, throughout its life cycle, in a reduction in environmental risk, pollution, and other negative impacts of resource use (including energy) compared to relevant alternatives".*

On the other hand, there is another way of describing those types of innovation characterized by the creation of something new (processes, business models, operational practices) that possess a positive impact on the three dimensions of sustainable development: social, economic and environmental. We are indeed referring to the sustainable innovation (Szekely & Strebel, 2013). Thereafter, one may also have to refer to eco-innovation. The latter is defined by the European Commission (2013) as any form of innovation, both technological and non-technological, that can create new business opportunities, but at the same time, generate a benefit to the environment through preventing, reducing their impact, or even through optimizing resource use. Although there are small differences between the three notions, they are often used interchangeably as synonyms in current literature (Chavira, et al., 2023). On account of the previous argument and practical issues, this research will refer to the concept of green innovation (GI), since they all ultimately imply the need and willingness of organizations to start working with different approaches and get rid of "old" operational practices.

In order to offset environmental expenditures, countries can promote the use of green innovation by demonstrating to all its companies how it makes them increase resource productivity. In addition, companies advancing in emerging markets will benefit from "first mover advantages," which will enable them to command higher prices for environmentally friendly products, improve their brand image, market their environmentally friendly products and services. In fact, according to Kneipp, et al. (2019) the benefits will be seen in the long run and only if organizations possess the necessary conditions to implement them properly. Likewise, it is important to remember that the process of achieving the above benefits is not linear as it involves failures, but also a return to the initial stages, and hypothetical recycling and discarding of ideas. This is why it is important for the country to sponsor a sequence of many innovations over time and not just the implementation of one in particular.

Through our research we can confirm that green innovation is increasingly becoming an imperative, by making us question: Why do countries are finding themselves fostering it? Several barriers exist to hinder this widespread adoption. One of those existing obstacles that countries face in promoting green innovation is described by authors Chien et al. (2021). Indeed, they deal with the presence of what they refer to as a lack of urgency. Going into more detail, the researchers explain that many companies focus solely on short-term gain, and since such an innovation is structured with a long-term project, this would cause a barrier for what would be immediate revenue. In addition, some companies tend to focus on improving their ecological footprint but only on 1% of it, thus neglecting the remaining 99% (Kneipp, et al., 2019). The article goes on to explain that by doing so the reputation of the organization it will be damage as it involves the phenomenon of greenwashing. Greenwashing in the European Union refers to those deceptive practices of companies that exaggerate, or falsely state, their commitment to environmental sustainability (European Commission, 2019). The article also specify that EU recognizes greenwashing as a significant problem, which is why it has issued a new law that aims to limit a range of unfair corporate tactics that could mislead consumers.

Another barrier that might prevent countries from promoting green innovation would be a company's fear of losing control (Huang et al., 2022). Partnership is essential when it comes to innovation, as it not only provides access to diverse expertise and resources, thus accelerating innovation, but also allows for offsetting research and development costs (Cecchi-Dimeglio, et al., 2022). For a partnership to be successful, both parties have to make an effort to be able to find win-win terms for both entities. Therefore, the company must overcome the fear of sacrificing authority over its business. That said, a further impediment for companies relates to their insufficient revenue as some companies may not generate sufficient funds to switch to green innovation (Chien, et al., 2021).

2.2.2 Indicators of Green Innovation

In light of not only increasingly stringent environmental constraints, but also consumer demands and stricter regulations, a change in both operational and attitudinal mindsets is required, and green innovations are needed to succeed. This chapter seeks to provide a comprehensive understanding of green innovation indicators, focusing on how these indicators reflect the innovative capabilities of countries in adopting environmentally friendly technologies. For this reason, Chavira et al. (2023), contextualize in the form of a cycle green innovations, Figure 3.

The cycle starts from "Driving Forces," which include external pressures such as regulatory requirements, market demand for sustainable products, and social expectations, which motivate organizations to pursue green innovation. It then continues clockwise, thereby reaching the "Means." This stage involves the methods and resources required for innovation, including workforce engagement through retraining programs, collaboration with partners, and leveraging digital tools (Chavira, et al., 2023). The subsequent phase is the one where, as a result of the development of the driving forces, and the exploitation of the means necessary, the culmination of the cycle is reached by producing 'green innovations'. At this stage, all efforts made by both countries and companies reach their peak. However, one should remember that the development of green innovations per se is not enough, rather, it is essential to initiate and implement them properly.

Figure 3. Green Innovation Cycle Source: Chavira et al. (2023)

It is also important to consider other indicators that contribute to a holistic view of green innovation. These include research and development (R&D) investments, which are critical precursors to innovation. Higher R&D spending in green technologies often correlates with increased green patenting activity (Jamwal, et al., 2021). The same article proceeds to specify how effective green innovation frequently results from collaboration between the public sector, private enterprises, and research institutions. These partnerships can accelerate the development and diffusion of green technologies. Moreover, the integration of Industry 4.0[5]. technologies, such as the Internet of Things (IoT) and artificial intelligence (AI), can enhance green innovation by optimizing resource efficiency and reducing waste (Kamble, et al., 2018).

Seeing the benefits generated by innovation takes time. While these benefits have an impact mainly on the environmental dimension, they also have an impact on the economic and social dimension of organizations, such as pollution and carbon footprint reduction, inter and intra recycling policies or even energy saving and uses of greener energy sources. The most important part of this cycle, Figure 3, is that the process continues even after the "Benefits" phase, by restarting (Chavira, et al., 2023). This happens since the benefits gained from the GI should improve the country's current environmental, social, economic, and operational conditions. Over some time, the needs, state and limitations of the world will be different and therefore, the internal and external pressures, which ultimately shape the driving forces, will also be diverse (Gast, et al., 2017). This also applies to the means since trends, technologies and co-creation methods update in short periods, and therefore the GIs to be obtained when the cycle is being iterated will not be the same, nor will the benefits.

2.2.3 Patents as Metrics for Green Innovation

According to the World Intellectual Property Organization (2023) a patent is an exclusive right to manufacture, use, sell or import an invention for a limited period of time, 20 years from filing, within the country in which the application is made. The same article explains that patents are granted for new inventions with an industrial application. Although there are also copyrights, design protection and trademarks, patents are not the only type of exclusive right on intangible goods but they are the only ones that provide broader protection that goes beyond the specific expression of an invention and extends to the invention itself (Oltra, et al., 2008).

[5] Industry 4.0 is also known as the "fourth industrial revolution," which was coined at the 2011 Hannover Fair in Germany.

The article also points out that since a patent is only valid within the country where it was granted, it is subject to national laws and disputes resolved in national courts. There are, however, international agreements such as the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), signed in 1994 and overseen by the World Trade Organization (WTO), which introduced intellectual property rules into the multilateral trading system for the first time, in an attempt to ensure the same minimum standards of protection in all countries (World Trade Organization, 2023). Patents are used as specific indicators to compare innovation levels between countries, providing valuable insights into global innovation performance (Kemp & Pontoglio, 2007). Kleinknecht & Henk (2012) explain with microanalysis that patents are portrayed as useful indicators of innovation because they provide insights into technological advances and industry-specific innovation practices. Therefore, patents provide a good measure of technologically new knowledge, and the article goes on to illustrate that several studies have recently used patents as a measure of innovation performance, all coming to the same conclusion, namely that patents measure something "beyond R&D inputs, namely the creation of an underlying stock of knowledge".

Patents recognize and reward inventors for their innovative contributions, promoting a culture of innovation and protecting intellectual property rights (Castaldi, 2021). Authors Dechezleprêtre, et al. (2019) agree with the statement expressed before but delve deeper by explaining how in most cases, new inventions must be made public in order for the inventor to reap the benefits of the invention. However, by doing so, some (if not all) of the knowledge contained in the invention becomes public knowledge. This is why patents are designed to protect inventors from such copying. However, the authors go on to clarify how their effectiveness varies depending on how easily inventors can 'circumvent' the patent by making small changes to the invention. That said, the authors illustrate how these knowledge spillovers provide benefits to the public as a whole, but not to the innovator. Indeed, economists consistently find that knowledge spillovers determine a widespread between private and social rates of return on R&D (Dechezleprêtre, et al., 2019). This is supported by da Hall et al. (2010) which demonstrate that typical results include marginal social rates of return of between 30 and 50 percent, whereas estimates of marginal private rates of return on investment vary only between 7 and 15 percent. With this evidence, the authors conclude that since firms make investment decisions based on their private returns, the wedge between private and social rates of return suggests that socially beneficial research opportunities are ignored by firms because they are unable to reap the full benefits of such innovations. Consequently, innovation in low-carbon technologies induced by climate change policies can increase welfare. However, this depends crucially on whether new R&D investments in low-carbon technologies come at the expense of innovation in other technologies.

Some companies are also in a position to give patents away for free through donations to public entities such as universities or through participation in patent commons [6] (Castaldi, 2021). The author explains that these initiatives are relevant for sustainable innovation, especially for those cases related to green technology patents, as this promotes technological advances even more. Green innovation can be defined as the process of creating new technologies to reduce environmental impacts, such as pollution and the negative consequences of resource extraction (Castellacci & Lie, 2017). The OECD divides green innovation into two primary measures, R&D that addresses environmental problems, and patents that provide an environmental benefit (Kemp & Pearson, 2007). The article explains that patents are the most widely used measure of green innovation as they are advantageous compared to R&D, since high R&D expenditure does not guarantee successful innovation. If we keep in mind the green innovation cycle depicted in Figure 3, we see that R&D is the input for then generating green patents. Therefore, the success of green innovation efforts should be measured by results rather than inputs.

2.3 Theoretical Framework

2.3.1 The Agency Theory

Agency theory is an economic principle that conceptualizes organizations as networks of contracts between interested individuals, distinguishing between principals and agents. Linder & Foss (2015) define agency theory as the one that analyses problems and solutions related to the delegation of tasks by principals to agents in the context of conflicting interests between the parties. Starting from clear assumptions about rationality, bargaining and information conditions, the theory addresses the problems of ex ante information asymmetry, namely what we can call hidden characteristics, and ex post, hidden action, respectively, along with the examination of the conditions under which various types of incentive and monitoring

[6] Patent commons involve collaborative efforts where patents are shared without royalties or restrictive terms, fostering innovation and technology access among stakeholders.

instruments can be employed to minimize welfare loss (see Figure4) (Linder & Foss, 2015). The objective of the theory is to determine the most efficient contract governing the principal-agent relationship, given assumptions about persons (for example, self-interest, bounded rationality, risk aversion), organizations (such as conflict of objectives between members) and information (in the sense that information is a commodity that can be purchased) (Eisenhardt, 1989). In other words, the question becomes: is a behavioral-oriented contract (for instance, salaries, hierarchical governance) more efficient than a result-oriented contract (in the form of commissions, stock options, transfer of ownership rights, market governance)?

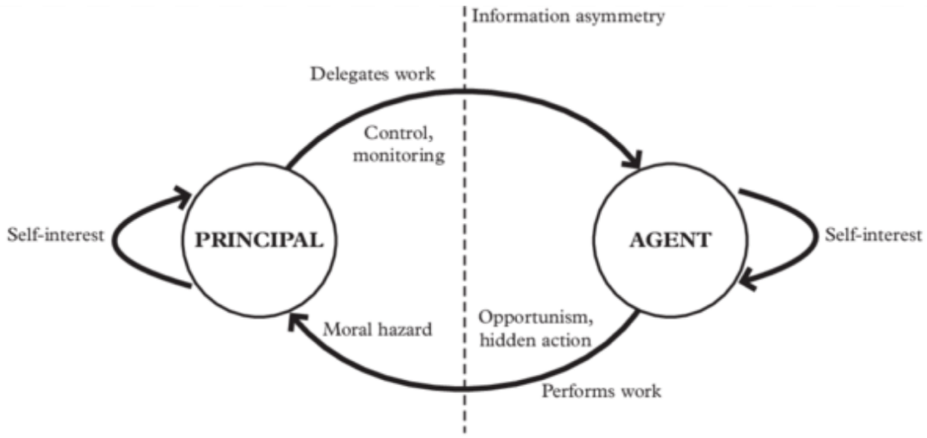

Figure 4. The agency theory with the assignment of work from the principal to the agent. Source: Slyke (2006)

Conforming the agency theory to our research involves defining the principal as the collective interest of the citizens, and the agent as the government, policy makers and public institutions of the country. The application of Agency Theory allows for an analysis of the extent to which the government aligns its actions and policies with the interests of the country, particularly with regard to ESG considerations and green innovation. ESG ratings, in this context, can be seen as a mechanism for the principal (citizens) to monitor and evaluate the performance of the agent (government) in promoting sustainable practices and green innovation.

In the corporate governance contest, we have that the agent (government) possesses more information than the principal (citizens) (Cui, et al., 2018). The article proceeds to explain how this is referred by the term information asymmetry as government can access a large amount of information, including economic data and policy decisions, while citizen do not, resulting in a non-transparent government action. Furthermore, agency theory recognizes the risk of moral hazard. In this case, we see the agent acting in its own interest rather than in the interest of the principal. In the governance of a country, this can manifest itself when government officials pursue policies that serve short-term political interests, thereby generating conflicts with the long-term interests of citizens (San-Jose, et al., 2022). As highlighted previously; to successfully develop green innovation, it is essential to focus on long-term interests instead of short-term ones. For this reason, the article wrote by San-Jose et al. (2022) specifies that it is necessary to align incentives to mitigate conflicts. Furthermore, the authors point out how a monitoring system can help identify and assess existing moral hazard, and in the case, it would be the be ESG ratings. The latter can serve as mechanisms to monitor and control government actions, revealing conflicts when policies are not aligned with sustainability goals and thus increasing the level of transparency.

The agency theory presents what can be defined as several constraints. One of them is that it assumes rational behavior from both principals and agents, overlooking the complexities of human decision-making and by not reflecting on the evolving dynamics of principal-agent relationships over time (Linder & Foss, 2015). In practice, the article also states that drafting comprehensive contracts to address all potential conflicts is difficult, leaving room for uncertainties and opportunistic behaviors. Furthermore, conflicts of interest may emerge due to divergent goals and incentives between the parties involved. The author San-Jose et al. (2022) also specify that the theory tends to overlook non-financial objectives and fails to accommodate cultural and contextual differences.

2.3.2 Stakeholder Theory

Stakeholder theory holds that all persons, or groups, with legitimate interests who participate in an enterprise do so to obtain benefits, and that there are no interests, and benefits, that have priority over others (Donaldson & Preston, 1995). This is demonstrated in Figure 5, where indeed the arrows between the enterprise and its stakeholders run in both directions. All the relationships with stakeholders are represented with the same size and shape and are equidistant from the "black box" [7] of the firm in the center.

[7] Adam Smith's characterization of the firm as a black box highlights the challenges in understanding and analyzing the internal dynamics of firms, particularly their decision-making processes and organizational structures, which play a crucial role in determining their behavior and performance in the marketplace.

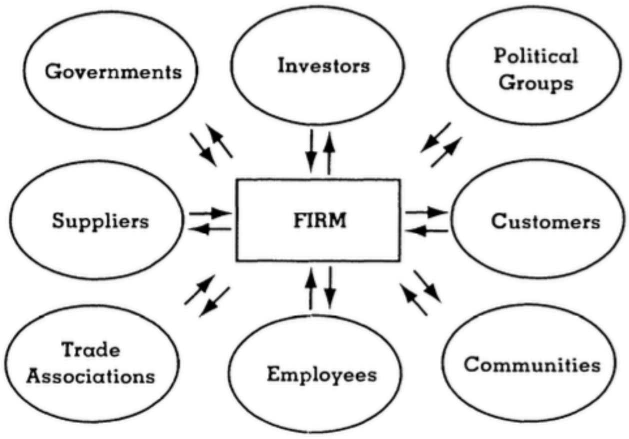

Figure 5. The Stakeholders Theory Source: Donaldson & Preston (1995)

Deeply rooted in the descriptive and normative dimensions, stakeholder theory offers a compelling framework for understanding the intricate relationship between a country's ESG assessments and its commitment to green innovation. This perspective not only presents a descriptive model of the corporate landscape, but also establishes normative principles that emphasize the intrinsic value of stakeholder interests. Indeed, Friedman (1970) states that the concept of corporate social responsibility has been expressed in normative terms.

Stakeholder theory possesses three aspects (Figures 6) namely: descriptive, instrumental, and normative. Descriptive explanations serve to make the theory based on a demonstration that the embedded concepts correspond to the observed reality (Donaldson & Preston, 1995). Instead, the authors explain that instrumental justifications aim to demonstrate the connection between stakeholder management and corporate performance. As for normative explanations, they appeal to underlying concepts such as individual or group "rights," the "social contract," or utilitarianism.

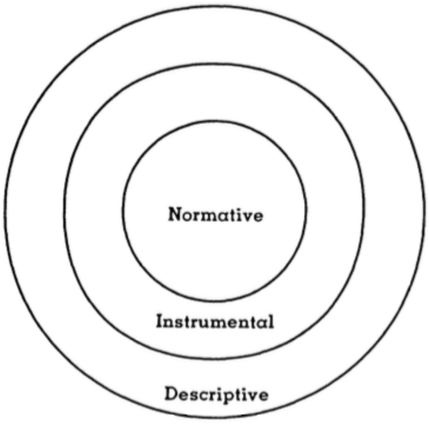

Figure 6. Three Aspects of Stakeholder Theory Source: Donaldson & Preston (1995)

In the most outward aspect of the theory, we deal with what is descriptive in nature by explaining that companies, or in the case of this research countries, are intricate constellations of cooperative and competitive interests with intrinsic value (Donaldson & Preston, 1995). Stakeholders, defined by their legitimate interests in the formal and substantive aspects of corporate activity, become instrumental in shaping the overall governance landscape. Subsequently, the instrumental aspect of Stakeholder Theory is addressed, and in the context of a country, this translates into exploring how simultaneous attention to stakeholder interests, as indicated by ESG scores, can influence the country's overall performance in terms of stability, economic growth, and other indicators. Stakeholders, identified by their legitimate interests in the country's activities, form the basis for normative considerations. In accordance with the theory, and thus what is explained by Donaldson and Preston (1995), the interests of all stakeholders possess intrinsic value, emphasizing that each group deserves consideration for itself.

Applying stakeholder theory to the relationship between a country's ESG ratings and green innovation involves recognizing that the interests and concerns of stakeholders, including environmentalists, communities, investors, and the public, have intrinsic value. A country with a high ESG rating demonstrates a commitment to responsible governance and, in doing so, would succeed in enhancing its legitimacy from a stakeholder perspective. This, in turn, can become an instrumental incentive for the country to engage in green innovation practices. Therefore, it summarizes by explaining that as countries strive for higher ESG ratings, influenced by societal expectations and regulatory standards, the normative underpinning of the theory guides governance structures and policies toward environmentally sustainable practices.

There are certain limitations to stakeholder theory. The main issue concerns the lack of clear guidelines for the identification of stakeholders (Donaldson & Preston, 1995). The authors themselves explain that such complexity, both theoretically and practically, raises problems of accessibility, limiting its direct application in organizational settings. In accordance with this is also Brummer (1991) emphasizing the need for clearer guidelines for stakeholder identification, to address inherent trade-offs, and to refine the theory to improve its practicality.

2.3.3 Institutional Theory

Institutional theory is based on the premise that organizations are not autonomous entities but are instead shaped by external social norms, constraints, and expectations (Zucker, 1987). According to institutional theory, organizations seek legitimacy by aligning their strategies and behaviors with the expectations of relevant institutions. This process of alignment is defined by Scott (2005) as institutional isomorphism, according to which organizations become more similar when they respond to shared institutional pressures. Therefore, its ca be said that this theory emphasizes the role of institutions—formal rules, norms, and cultural beliefs—in shaping organizational behavior and outcomes. By applying Institutional Theory, it can explore how ESG ratings, as institutionalized measures of corporate performance, drive firms to adopt innovative practices that align with broader societal values and regulatory expectations.

The EU, recognizing the imperative to create a sustainable and competitive society, uses institutional pressures to shape the behavior of organizations (Arranz & Arroyabe, 2023). This is reflected in environmental regulations and policies designed to mitigate environmental pollution, such as the Circular Economy Action Plan (CEAP), [8] which includes 54 measures that set the framework for implementing sustainable economy at the institutional level (European Commission, 2019). The same authors Arranz and Arroyabe (2023) provide evidence that in response to these pressures given by the European Union, but also in order to succeed in gaining institutional legitimacy, organizations are incentivized to improve their ESG ratings to comply with these regulations, avoid penalties, and gain access to subsidies and other financial incentives for green innovation. Therefore, the authors argue that EU consumption policies, which include regulations and information dissemination, play a crucial role in promoting green innovation, but also that consumption regulations have a particularly positive impact. This is perfectly in line with the statement of theory expressed by DiMaggio and Powell's (1983) according to which institutional pressures positively influence organizations seeking legitimacy.

[8] The Circular Economy Action Plan (CEAP) is an initiative of the EU to tackle environmental issues and foster economic sustainability.

In addition, the emphasis on information dissemination aligns with cognitive pressures as it fosters consumers' environmental awareness (Arranz & Arroyabe, 2023). The same article highlights how this increased awareness acts as a driver for demand for sustainable products and, as a result, encourages organizations to engage in green innovation to meet this demand. Authors Demirel and Kesidou (2019) further add that consumer-focused regulations; thus, those that reflect regulatory and normative pressures, prove instrumental in overcoming the internal and external risks associated with green innovation. However, the article proceeds to elaborate that internally, the costs and technical risks of innovation projects are mitigated, while externally, the risks of market acceptance are addressed. This falls neatly under the institutional theory according to which organizations under institutional pressures tend to adopt practices that enhance their legitimacy while navigating potential risks (Arranz & Arroyabe, 2023).

There are several criticisms regarding institutional theory, as it identifies institutions as stable entities and fails to capture their dynamic nature, especially when dealing with rapidly changing environments (Berrone, et al., 2013). Moreover, the same article points out how theory tends to homogenize organizations within the same institutional environment, oversimplifying the different responses they may exhibit. Furthermore, there is a limited ability to predict organizational responses to specific institutional changes and it is crucial to recognize the importance of innovation, the dynamic nature of institutions and the interplay between formal and informal influences (Willmott, 2015).

3. Data

3.1 Data Collection

3.1.1 Sources of ESG Scores and Ratings

Environmental, social and governance (ESG) ratings are essential parameters for assessing a nation's sustainability, although they are not without limitations. One challenge lies in the lack of standardization and harmonization of ESG methodologies. In addition, limited regulatory oversight can compromise the accuracy and reliability of ESG information. To be able to bypass these limitations, and thus promote transparency and encourage sustainable practices, it is essential to be able to understand the sources and methodologies behind ESG scores. Only by doing so, one will be able to perform in-depth analyses and draw conclusions on the correlation between ESG performance and green innovation.

Hence, The World Bank's database for this research is called the Environmental Social and Governance (ESG) Data (2024). This ESG dataset provides a collection of indicators for sustainable investment analysis, based on a draft framework of 17 key sustainability criteria. The indicators come from various World Bank databases and external data providers. The data represented within the database has been updated the 17 January 2024. With this Dataset, we have narrowed down to the 27 countries [9] of the European Union covered in this study.

Upon the dataset download of the countries we were interested in, we had to select only those series where all 27 countries possessed completeness of data over a time period spanning from 2005 to 2020. These series amount to 46 for each country and these, in turn, are subdivided into 18 series related to the Environment, 14 for Governance and 14 for Social.

3.1.2 Green Innovation Indicators

A country's green innovation indicators have obstacles and factors that it is crucial to bear in mind when interpreting and analyzing them. It is often complicated to establish uniform criteria and techniques for evaluating green innovation and, furthermore, the accurate

[9] The EU countries are Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden

assessment of green innovation indicators can be constrained by limitations in the quantity and quality of available data.

Patents come from various entities, including individuals, universities, research institutes and companies, and these all together contribute to the total number of patents in a country. To conduct this research, we will use the dataset generated by The Organization for Economic Co-operation and Development Statistics (OECD.Stat, 2024) which is known as the number of patents on technological development. The data in this dataset has been last updated the 14 January 2024 and has a time frame from 2005 to 2020. The size of the patent family [10] selected for this research includes multiple patent applications or patents granting protection to a single invention by a common inventor, which is why they are referred to as two and larger.

Afterwards, it will only be taken into considerations data pertaining to the 27 countries within the European Union and related to the domain of environmental related technologies, so that it is confirmed that it holds data regarding green innovation, measured by patents related only to sustainable technological development, within the EU. The expression "number of patents, with fractional OECD country value" that we find as a variable in the dataset refers to a method used by the OECD to calculate the number of patents, as the OECD uses fractional counts to account for inventors or assignees from multiple countries. With this method, patent counts can be adjusted to reflect the contributions of multiple countries involved in the patenting process.

3.2 Variables and Operationalization

3.2.1 ESG Ratings Variables

Variables can be classified into two main categories, namely, categorical, and numerical. In the case of this research, numerical variables are used. The process of determining ESG ratings

[10] A family of patents is a group of related patent applications that protect a single invention in several different jurisdictions. It includes the original priority filing and any equivalents filed with other patent offices throughout the world. Patent families, which are frequently represented by patent family trees, provide wide protection for inventions or related characteristics. Understanding patent families aids in devising strategies for global patent protection, irrespective of the multitude of jurisdictions involved.

involves a comprehensive examination of various factors including the environmental, social and governance domains.

Environmental Variables:

Variables	*N*	*Min*	*Max*	*Mean*	*Std. Deviation*	*Skewness*
Agricultural land (% of land area)	432	7,37	67,75	41,59	16,11	-0,59
Agriculture, forestry, and fishing, value added (% of GDP)	432	0,21	8,49	2,26	1,27	1,07
Annual freshwater withdrawals (% of internal resources)	432	0,99	105,70	21,88	24,60	1,84
CO2 emissions (metric tons per capita)	432	2,97	25,61	7,26	3,38	2,13
Cooling Degree Days	432	0,00	2795,58	519,61	571,1	1,89
Energy intensity level of primary energy (MJ/$2017 PPP GDP)	432	1,22	7,36	3,72	1,13	0,60
Food production index	432	65,69	126,36	97,09	9,00	-0,38
Forest area (% of land area)	432	1,09	73,74	34,50	16,990	0,47
Heating Degree Days	432	743,70	11282,81	5509,57	2078,63	-0,12
Land Surface Temperature	432	0,69	30,44	15,66	5,97	0,01
Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	432	0,99	91,29	21,55	19,66	1,33
Methane emissions (metric tons of CO2 equivalent per capita)	432	0,44	3,88	1,01	0,52	3,55
Nitrous oxide emissions (metric tons of CO2 equivalent per capita)	432	0,09	2,35	0,67	0,44	1,78
PM2.5 air pollution (micrograms per cubic meter)	432	5,26	27,36	14,76	4,96	0,13
Population density (people per sq. km of land area)	432	17,22	1610,41	173,93	257,08	3,90

Renewable energy consumption (% of total final energy consumption)	432	0,14	58,40	18,61	11,80	0,83
Standardized Precipitation-Evapotranspiration Index	432	-2,47	2,41	-0,34	1,02	0,36
Tree Cover Loss: replacement of vegetation greater than 5 meters	432	0,00	339968,00	37861,86	63347,21	2,81

Table 1. Descriptive Statistics Environmental Variables of the 27 European countries, from 2005 to 2020, World Bank (2024)

From Table 1, it can be seen that Agricultural land (% of land area) have a significant negative skewness (-0,59), indicating a distribution strongly skewed to the left. This negative skewness suggests that most observations are concentrated towards the lower end of the distribution, with a long tail extending towards higher values. This implies that there are cases of high percentages of land area compared to lower ones.

On the other hand, the population density variable has the highest skewness, which is 3,90, indicating a distribution strongly skewed to the right. Therefore, most are grouped toward the upper end of the variable, and there are some outliers that extend away from the main cluster.

Social Variables

Variables	*N*	*Min*	*Max*	*Mean*	*Std. Deviation*	*Skewness*
Fertility rate, total (births per woman)	432	1,13	2,06	1,54	0,20	0,61
Gini index	432	21,20	42,00	31,34	3,75	0,04
Government expenditure on education, total (% of government expenditure)	432	7,16	18,90	11,46	2,23	0,66
Income share held by lowest 20%	432	4,67	10,30	7,80	1,22	-0,20
Individuals using the Internet (% of population)	432	19,97	98,46	71,24	16,98	-0,69
Labor force participation rate, total (% of total population ages 15-64) (modeled ILO estimate)	432	57,55	82,93	71,64	5,13	-0,22
Life expectancy at birth, total (years)	432	70,87	83,83	78,97	3,11	-0,68

Mortality rate, under-5 (per 1,000 live births)	432	2,10	18,30	4,83	2,22	2,33
People using safely managed drinking water services (% of population)	432	69,57	100,00	95,89	5,23	-2,04
People using safely managed sanitation services (% of population)	432	49,24	99,69	84,65	10,91	-0,86
Population ages 65 and above (% of total population)	432	10,30	23,37	17,51	2,70	-0,51
School enrollment, primary (% gross)	432	84,13	128,64	101,60	5,02	1,29
Unemployment, total (% of total labor force) (modeled ILO estimate)	432	2,01	27,47	8,55	4,29	1,71

Table 2. Descriptive Statistics Social Variables of the 27 European countries, from 2005 to 2020, World Bank (2024)

The variable government expenditure on education is important to consider as it indicates that on average 11,46 percent of the government budget is allocated to education. However, the skewness value of 0,66 indicates that there may be some countries with higher public spending on education than others.

In addition, the total unemployment variable shows up with a standard deviation of 4,29. This allow to highlight the variability of unemployment rates across countries. In fact, its distribution is 1,71, thus strongly skewed in the positive direction, implying that most observations are focused on the lowest unemployment rates.

Governance Variables

Variables	*N*	*Min*	*Max*	*Mean*	*Std. Deviation*	*Skewness*
Control of Corruption: Estimate	432	-0,38	2,46	0,97	0,79	0,18
Economic and Social Rights Performance Score	432	1,90	2,63	2,42	0,10	-1,16
GDP growth (annual %)	432	-14,84	24,37	1,76	4,03	-0,44
Government Effectiveness: Estimate	432	-0,36	2,35	1,08	0,59	-0,18

*Net migration (*the *number of immigrants - the number of emigrants).*	432	-254292,00	774489,00	33990,17	102883,74	3,41
Political Stability and Absence of Violence/Terrorism: Estimates (perceptions of the likelihood of political instability and/or politically motivated violence)	432	-0,47	1,59	0,75	0,38	-0,45
Proportion of seats held by women in national parliaments (% parliamentary seat)	432	8,70	47,28	25,75	10,23	0,26
Ratio of female to male labor force participation rate (%) (modeled ILO estimate)	432	43,58	90,49	78,68	7,10	-1,53
Regulatory Quality: Estimate	432	0,14	2,04	1,16	0,44	-0,05
Research and development expenditure (% of GDP)	432	0,37	3,73	1,54	0,89	0,68
Rule of Law: Estimate	432	-0,16	2,12	1,08	0,61	-0,20
School enrollment, primary and secondary (gross), gender parity index (GPI)	432	0,94	1,10	1,00	0,03	1,12
Scientific and technical journal articles	432	78,90	109378,75	18105,42	24525,78	2,04
Strength of legal rights index (higher scores = laws are better designed to expand access to credit)	432	1,00	9,00	5,07	2,19	-0,13

Table 3. Descriptive Statistics Governance Variables of the 27 European countries, from 2005 to 2020, World Bank (2024)

The net migration variable suggests a positive trend. The latter is the difference between the number of immigrants and emigrants and has an average value of 33990,17. In addition, it also possesses a high skewness value (3,41), indicating that most countries tend to have relatively low rates of net migration, with a minority experiencing substantial immigration.

Another variable worth highlighting is the ratio of female to male labor force participation rates. As a result of the skewness value (-1,531) we see that countries exhibit higher male labor force participation rates than female ones. This disparity underscores broader issues related to gender equality, highlighting the need for targeted policies and initiatives to address barriers to women's participation in economic activities.

3.2.2 Green Innovation Indicator Variables

The variable "Green patents" refers to all those patents granted for inventions related to the environment and sustainability. According to the OECD.Stat dataset, the total number of patents for environment-related technologies consists mainly of those with innovations in environmental management, climate change mitigation and adaptation, waste management, renewable energy, sustainable transportation and other similar [11]areas. It is important to note that patented green technologies are distinguished from gray technologies [12]and that the listed technologies are in fact considered green because of their goal of addressing environmental challenges and promoting sustainability.

The descriptive statistics, Table 4, offer insights into the distribution of environment-related technological innovations in the countries and years observed.

Variables	*N*	*Min*	*Max*	*Mean*	*Std. Deviation*	*Skewness*
Green Patents	432	0,20	7141,98	475,98	1177,60	4,10

Table 4. Descriptive Statistics Green Patents Variable, of the 27 European countries, from 2005 to 2020, OECD.Stat (2024)

As it is indicated by the average value of 475,98, the dataset reached a significant degree of innovation in environmental technologies. Considering that the minimum value is 0,20, it can be deduced that some countries issue fewer green patents in a given year, possibly due to factors such as low R&D capacity or lack of emphasis on environmental innovation. However, the maximum value of 7141,98 demonstrate a strong commitment to environmental management and sustainability.

The standard deviation of 1177,60, which underlines the variation in the number of green patents between nations and years, confirms this finding. In addition, the skewness value of 4,10 indicates a distribution of green patents strongly skewed to the right, suggesting that most

[11] Environment-related technologies is the sum of: Environmental management, Climate change energy, Waste management, ICT, Greenhouse gases, Climate change transportation, Climate change buildings, Climate change production of goods, Climate change adaptation technologies, Sustainable Ocean economy.

[12] Gray technologies are existing technologies that may not be inherently prioritized for environmental sustainability but can be adapted or optimized to reduce their environmental impact. Green technologies, on the other hand, are specifically developed or designed with environmental sustainability as a primary goal

countries have a relatively low number of patents, with a few countries having an exceptionally high number of green patents. This skewness accentuates the unequal distribution of environmental innovation among countries, there being some leaders in the development of green technologies and others lagging behind.

3.3 Calculation of the ESG score

Having established the elements to be used, the calculation of ESG ratings will then be carried out in this research. For the purpose of starting the calculation, it is necessary to normalize all indicators before calculating the average of the components, as for now, indicators are measured on very different scales and if one would proceed without normalization, more weight would implicitly be given to indicators with a larger scale. Consequently, the first step is to normalize on the minimum and maximum scales. This normalization using Equation 1 described below, is ideal as the values will range between 0 and 1, and negative numbers will be avoided.

Equation 1. Normalization minimum and maximum scale

$$X_{normalized} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

Where in the equation X is the original value of the indicator for a specific country. Then, X_{min} represent the minimum value of that indicator across all countries and, in the same manner X_{max} is the maximum value of that indicator across all countries. Therefore, $X_{normalized}$ will be the normalized value of the indicator for that specific country. In this manner, each indicator is given equal weight in the calculation of the average component.

Following normalization, it is necessary to identify those indicators whose high value represents a negative factor [13] for the development of the country's ESG score and thus have these indicators set as negative. By doing so, one can proceed with the averaging of the

[13] In this research we are namely referring to: CO2 emissions (metric tons per capita), Energy intensity level of primary energy (MJ/$2017 PPP GDP), Gini index, PM2.5 air pollution, mean annual exposure (micrograms per cubic meter), Methane emissions (metric tons of CO2 equivalent per capita), Mortality rate, under-5 (per 1,000 live births), Nitrous oxide emissions (metric tons of CO2 equivalent per capita), Population ages 65 and above (% of total population), Cooling Degree Days, Population density (people per sq. km of land area), Level of water stress: freshwater withdrawal as a proportion of available freshwater resources, Food production index (2014-2016 = 100), Unemployment, total (% of total labor force) (modeled ILO estimate).

components to obtain the final ESG rating certain that the negative factors do not add any value to the ESG score, but rather the opposite.

For the calculation of the countries' ESG rating, we will follow the formula explained below:

Equation 2. Calculating ESG rating

$$ESG_{\text{Rating}} = \frac{1}{3}(\text{Environment Score} + \text{Social Score} + \text{Governance Score})$$

For each of the three categories, an average score will be calculated based on the relevant set of metrics. This means that for the environment the score will be averaged across the 18 sets, for social the average score will be across the 14 sets and for governance across the 14 sets. This calculation will be performed for each of the 27 countries in order to then be able to compare the results between each country and, therefore, assess their environmental, social and governance performance against each other.

4. Trends and Variations between Countries over Time

4.1 Environmental Rating

4.1.1 Trends and Variations

Thanks to the graph developed with the dataset provided from the World Bank, the study is able to filter the type of information that we need. This part of the research will focus on the Environmental Rating calculated of the 27 country analysed. In the Figure 7 it is possible to have an overview of how the countries are doing regarding their environmental evaluation.

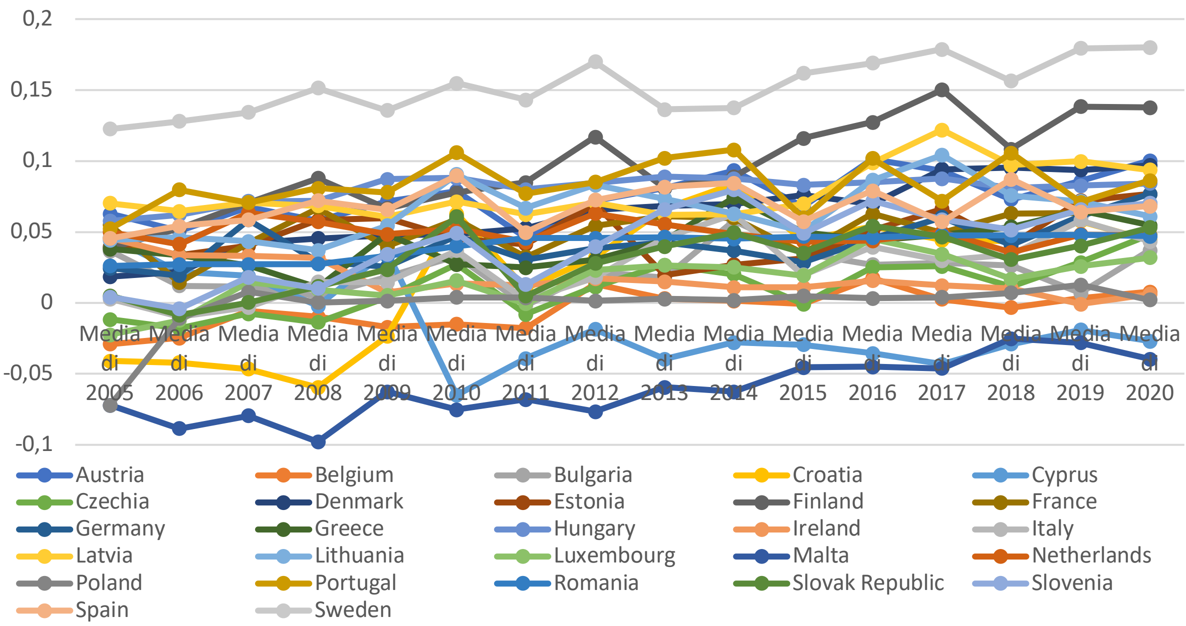

Figure 7. Environmental Rating, calculated by using Equation 2

The countries that mainly stands out are Sweden and Finland. Indeed, by analysing the dataset, we can notice that these two countries are well above average for the 15 years took into consideration. Going into more detail, in Figure 8, we are able to notice also how Denmark was able to constantly increase year by year till reaching a close environmental rating compared to Finland in 2013 and 2018.

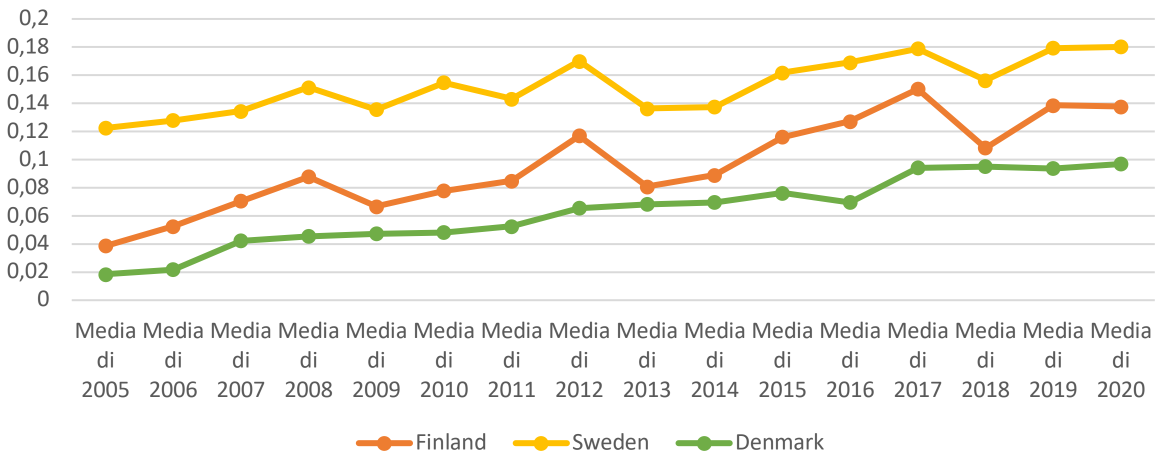

Figure 8. Environmental Ratings, comparison between the highest scores

On the other hand, the lowest 20 rating were registered mainly from Malta, Cyprus and Poland. Cyprus had a huge decline in 2009 where it reached negative values. On the other hand, the Environmental score of Poland started as negative for then increasing and remaining constant for the rest of the period analysed, as we can easily notice by the graph in Figure 9.

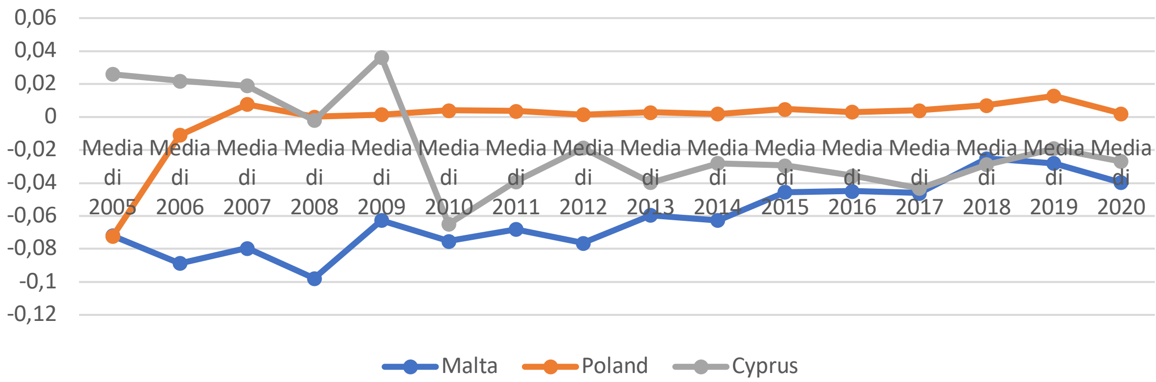

Figure 9. Environmental Ratings, comparison between the lowest scores

4.1.2 Insights into National Sustainability Practices

The EU's member states have demonstrated different levels of environmental stewardship over this time, which reflects the specific difficulties, laws, and socioeconomic environments of each nation. As an example, countries such as Finland, Sweden, and Denmark are the one that have a constant high environmental rating. These nations have favorable environmental standing in part because of their strong environmental policies and sustainability practices. Indeed, they frequently prioritize the adoption of renewable energy, sustainable land management, and emissions reduction strategies.

On the other hand, Bulgaria, Poland, Romania, Malta, and Croatia are among the EU nations that continuously have lower environmental ratings. These countries face difficulties mainly related to land surface temperatures, food production indices, and the highest number of cooling degree days. Based on freshwater withdrawal rates relative to available freshwater resources, Malta is particularly affected by high levels of water stress. With the highest levels of PM2.5 air pollution exposure per cubic meter, Cyprus and Bulgaria have major air quality challenges.

As demonstrated, these nations' relatively poorer environmental performance can be attributed to their heavy reliance on fossil fuels, intensive agricultural practices, and industrial pollution. On the other hand, higher environmental ratings are typically attained by nations with larger shares of renewable energy consumption, lower CO_2 emissions (metric tons per capita), and efficient land management techniques.

Countries variations in environmental scores highlight the disparities in environmental priorities and challenges among EU member states. While some nations are endowed with a favorable geographic location and an abundance of natural resources that support sustainable practices, others struggle with issues of urbanization, industrialization, and resource depletion. Member states of the EU must work together, share knowledge, and develop strategies specifically designed to address these regional disparities.

4.2 Social Rating

4.2.1 Trends and Variations

To evaluate the trends and variations of the social evaluation of each country member of the EU we will follow the same strategy used previously, namely we will take a deep look into the dataset developed by the World Bank. A big overview of the situation is given by the Figure 10.

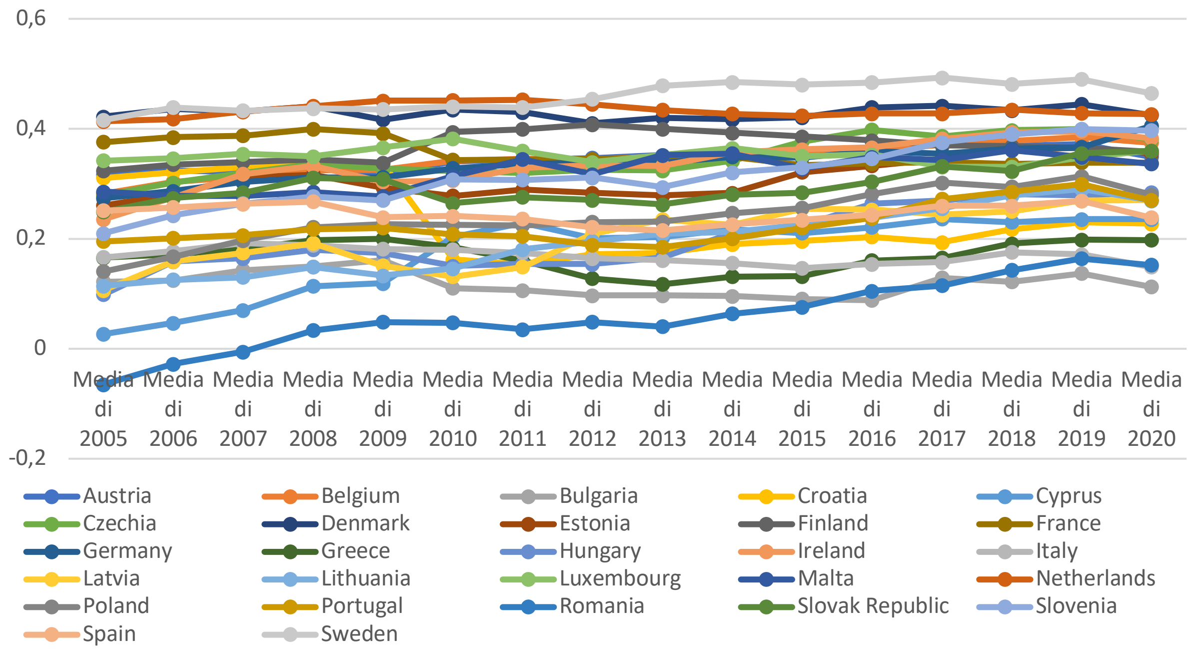

Figure 10. Social Ratings, calculated by using Equation 2

From Figure 10 it is shown that Sweden, Netherlands, and Denmark are those countries with the highest 10% of values.

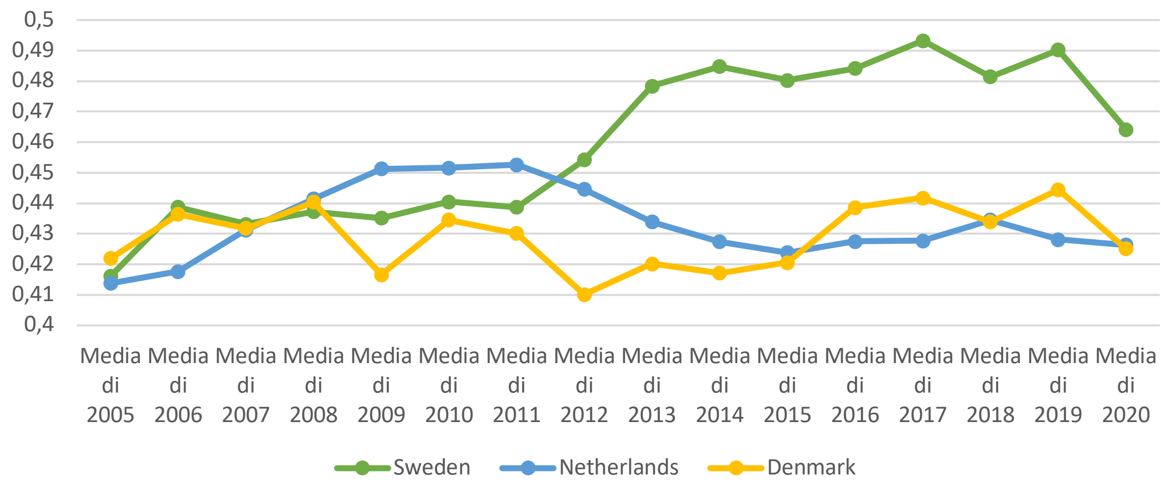

Figure 11. Social ratings, comparison between the highest scores

By looking into more detail, and therefore by focusing into the highest rating represented in Figure 11, it shows that Denmark started in 2005 as the highest for then, in 2008, decreasing and having its social rating always below the other two countries. On the other hand, both Sweden and Netherlands continued constantly increasing from 2005 to 2011. Here we can see that Netherlands decreased, while Sweden increased even more for then reaching its peak in 2017.

Conversely, the lowest ratings were recorded from Romania, Bulgaria, Italy and Cyprus. Highlighted in Figure 12 is the social score of each country that increased in these fifteen years, apart from Bulgaria and Italy that, one from 2009 and the other from 2007, started declining. Romania started as the country with the lowest social rating inside the European Union, even if, in 2016, managed to reach a level higher than Bulgaria and meet Italy in 2020. Romania, together with Cyprus, are the ones that had a major increase in the European Union during this period.

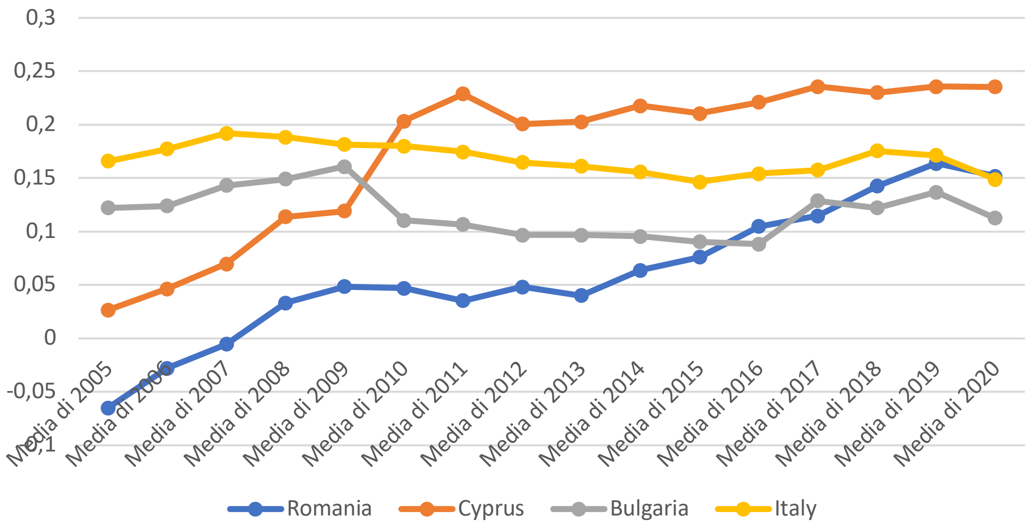

Figure 12. Social ratings, comparison between the lowest scores

4.2.2 Implications for Social Sustainability

The social ratings of European Union member states have shown significant fluctuations over time, which can be attributed to the unique social environments and policy preferences found in each country. Strong social welfare systems, inclusive policies, and high standards of living are characteristics of nations like Sweden, Denmark, and the Netherlands, which continuously maintain high social ratings. To promote social cohesion and population well-being, these countries place a high priority on investments in healthcare, education, and social protection. Sweden stands out with the highest value in terms of fertility rate (also Finland), government spending on education, by highlighting its dedication to family support and education.

On the other hand, countries with lower social ratings, such as Greece, Cyprus, Bulgaria, and Romania, are characterized by enduring social inequality, difficult economic conditions, and obstacles to social mobility. Romania, Italy, and Greece have very low levels of public spending on education, suggesting areas where funding and quality could be improved.

Furthermore, according to the modelled ILO estimate, Italy and Romania have the lowest rates of labor force participation (percentage of the total population ages 15 to 64), indicating possible difficulties in accessing the labor market and finding work.

Targeted interventions are needed to improve social inclusion, economic opportunities, and vulnerable populations' access to basic services in order to address these disparities. Indeed, the COVID-19 pandemic has highlighted the value of social cohesion and resilience in handling emergencies and preserving public health.

Indeed, the social ratings of EU countries provide information about the intricate interactions between social policies, economic variables, and cultural dynamics that influence social sustainability in the area. To achieve the common objectives of the European Union and advance the social dimension of sustainability, cooperation, policy innovation, and investments in social infrastructure are crucial.

4.3 Governance Rating

4.3.1 Trends and Variations

By analysing the governance ratings, it is possible to highlight, one more time, the difference between countries and the reason behind their score. As seen in Figure 13, the governance measures seem to be constant for the majority of the countries above the huge decline of France in 2009 and the increase of Cyprus and Finland recorded in the same year.

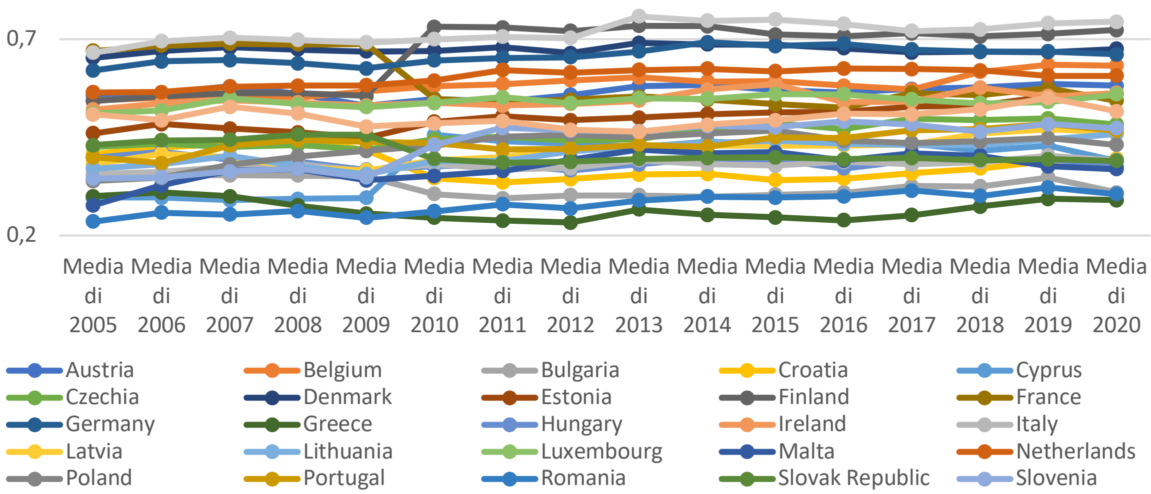

Figure 13. Governance score, calculated by using Equation 2

By taking a deeper look into the highest scores, Figure 14, we notice a constant increase of Germany and Netherlands till 2016 followed by a slight decline. Otherwise, Denmark had an accentuated decline starting from 2013 till then increasing again in 2017. Finland started as the lowest country between the ones highlighted but had a huge increase in 2009 that made its score being always close to Sweden's one.

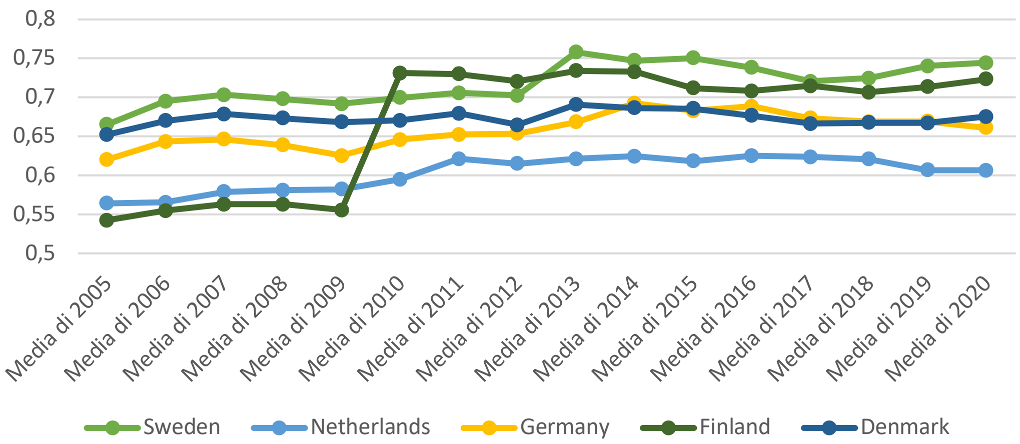

Figure 14. Governance score, comparison between the highest scores

On the other hand, the lowest scores were measured by Romania, Greece, Malta, Bulgaria and Hungary. As highlighted in Figure 15, Romania started as the country with the lowest governance rating for then constantly increasing and reaching Bulgaria in 2020 and surpassing Greece. Following on, the country Romania and Malta follow a similar path by more or less constantly increasing their governance score in this 15 years frame. It is worth highlighting that both Greece and Hungary started in 2005 by increasing their governance score but straight in 2006 both countries started a constant decline.

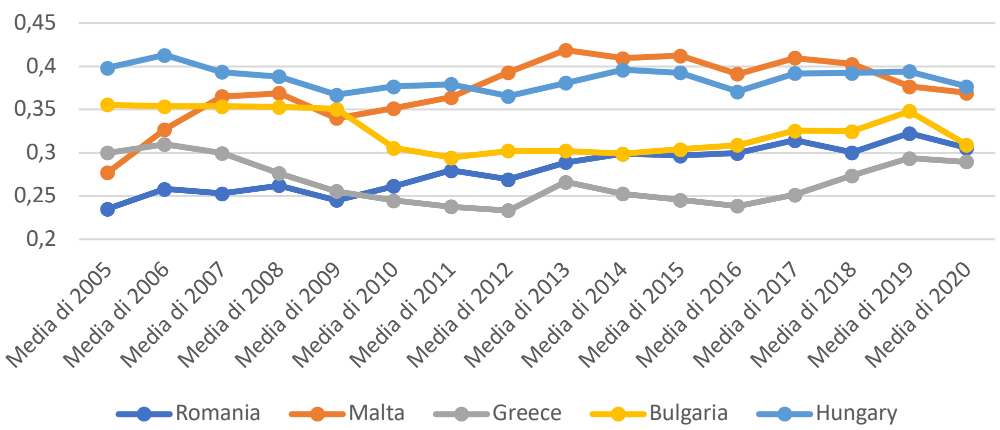

Figure 15. Governance score, comparison between the lowest scores

4.3.2 Linkages to Governance Practice

To assess the effectiveness of public institutions and encourage inclusive growth, accountability and transparency, governance performance is a crucial criterion. Finland, Denmark, and Sweden stand out among European countries as models of effective governance. Several indicators, like a strong institutional framework, efficient governance systems and a dedication to social justice and equality, place these Nordic countries at the top.

Further, Belgium is noteworthy for its excellent performance in a few governance-related areas. The country's overall success in governance can largely be attributed to its emphasis on inclusive growth policies and investment in innovation. While encountering obstacles in some areas, Croatia achieves remarkable results in terms of economic and social rights and gender equality in education. The nation's commitment to promoting opportunity and equality has enabled it to receive comparatively better ratings in these areas.

On the other hand, Romania and Bulgaria continue to struggle with lower scores in terms of economic and social rights, rule of law, government effectiveness and control of corruption. Their lower rankings are the result of continued difficulties in fighting corruption, poor institutional frameworks, and differences in access to basic services. Greece, Malta, and Cyprus face challenges due to difficulties in maintaining political stability, promoting gender equality in politics, and encouraging women's participation in the workforce. Their susceptibility to external shocks and economic vulnerabilities also affects governance performance.

As such, it is proven that a complex interplay between institutional capacities, political priorities and socioeconomic dynamics is reflected in the governance performance of European nations. To improve the well-being of European citizens and beyond, legislators, civil society and international partners must work together to develop a culture of good governance.

4.4 Eco-friendly technologies: Green Patents

4.4.1 Trends and Variations

Patents pertaining to eco-friendly technologies are what we define the total number of green patents that the 27 member states of the European Union filed between 2005 and 2020. The graph in Figure 16 shows that the number of green patent applications filed varies amongst the member states of the European Union. Over time, some nations have steadily increased their number of green patent applications, while other nations' patent filing patterns have been irregular.

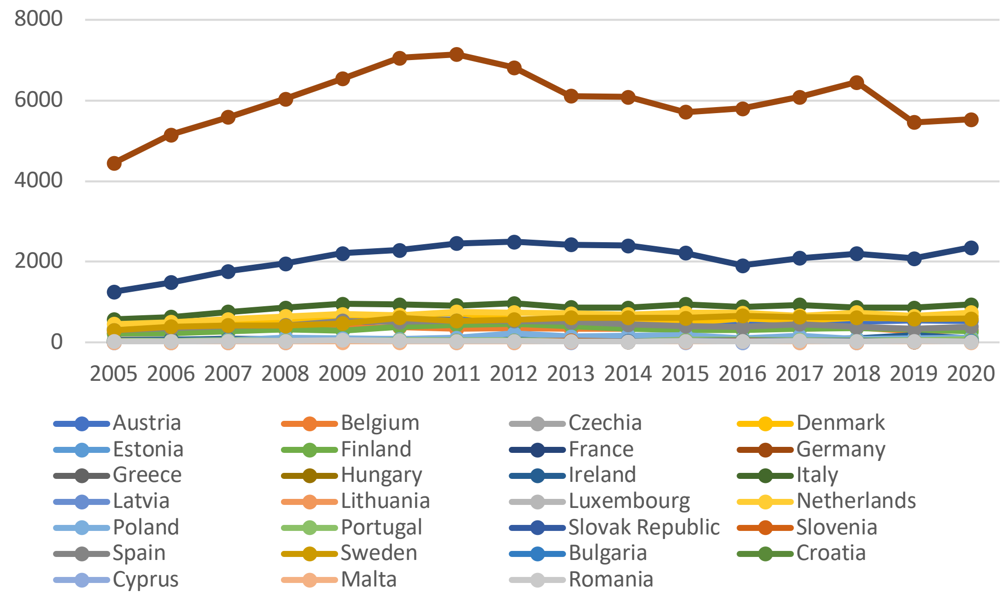

Figure 16. Green Patents. Source: OECD.Stat (2024)

From Figure 16 we see that Germany has a leading position in green patent filing, with a generally increasing trend over time and countries like France, Italy, and the Netherlands also display significant numbers of green patent applications filed annually, even though with some differences highlighted in Figure 17. Furthermore, a large portion of their total patent activity in the green technology sector is also derived from their high concentration of patents covering climate change mitigation technologies connected to energy generation, transmission, or distribution, as well as climate change mitigation technologies related to transportation.

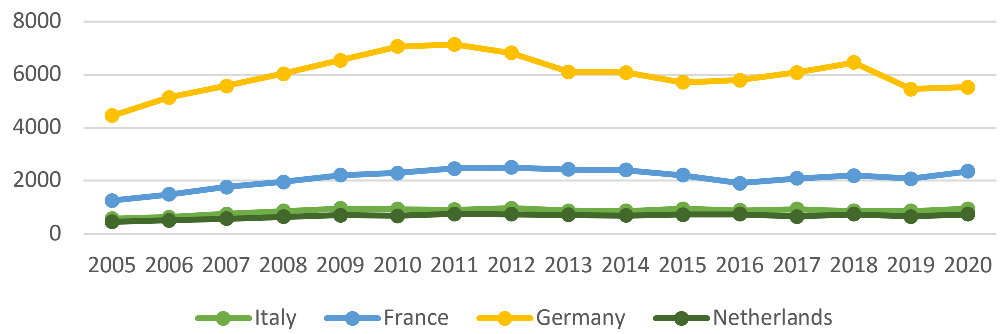

Figure 17. Comparison between highest number of Green Patents

As Figure 18 shows, countries like Malta, Cyprus, Estonia, Lithuania, and Croatia generally file fewer green patents during a year, with irregular fluctuations in their patent activity. The primary cause of these nations' lowest rankings in the issuance of green patents is a shortage of patents covering enabling technologies that could directly or indirectly reduce greenhouse gas emissions. Moreover, they hold the fewest patents granted for transportation-related climate change mitigation technologies.

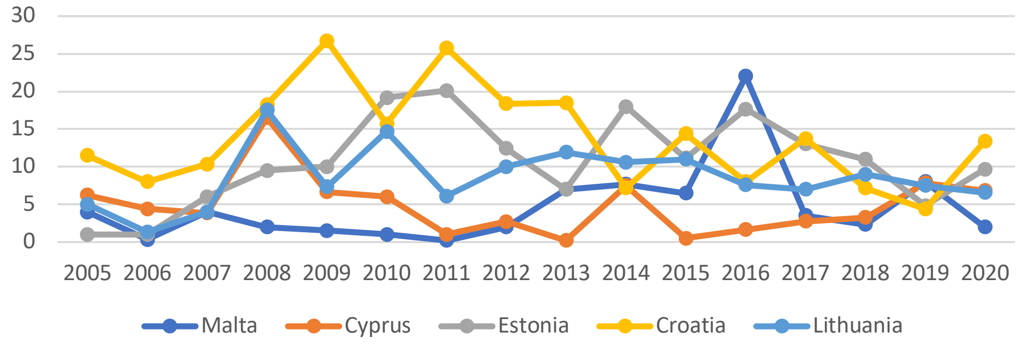

Figure 18. Comparison between lowest number of Green Patents

However, let's analyze the share of green patents in a country's total patents as represented in Figure 19.

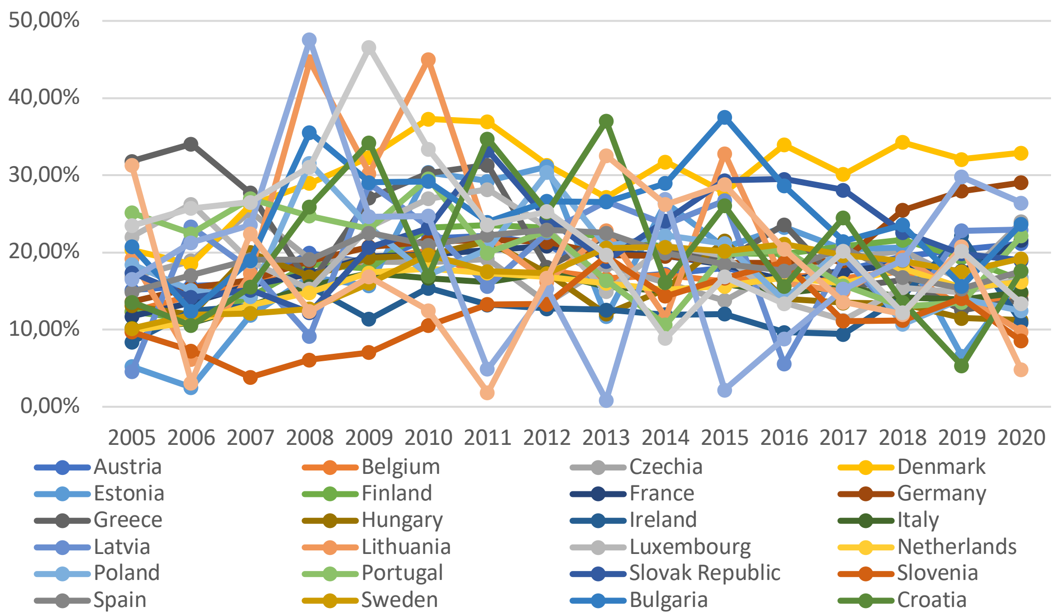

Figure 19. Share of green patents to total patents. Source: OECD.Stat (2024)

Among the highlighted nations, Malta, Romania, Lithuania and Cyprus have some irregular and high peak of the proportion of green patents compared to the total number of patents, leading to speculation about their environmental innovation capacity compared to larger economies such as Germany, Italy, France, the Netherlands and Denmark. One reason behind this is due to the international collaboration that emerges between smaller countries and larger economies. Indeed, Malta's emphasis on maritime industries, due to its geographical location (Xerri, 2023), and Cyprus' focus on solar renewable energy could inherently predispose them towards environmentally friendly technologies (European Commission, 2017). This will also explain the reason why we see them only as peaks, as the one of Cyprus in 2008.

Meanwhile, Denmark stands out as consistently demonstrating an upward trajectory in green patents over the years. With the highest shares of green patents registered, Denmark's ongoing commitment to environmental innovation underlines its proactive approach to sustainability. Factors such as strong government support, investment in renewable energy research and a favorable regulatory environment contribute to Denmark's remarkable performance in this area. Furthermore, Germany continues demonstrating its commitments in green patents by constantly increasing its shares of green patents from 2005 to 2020 and reaching a level close to Denmark.

4.4.2 Key Metrics for Green Innovation and the EU benefits

States such as Germany, France, Italy and the Netherlands are emerging as leaders in green patenting. The prominent nations have given priority to environmental management patents, which cover, waste management, pollution abatement, and environmental monitoring. Their progressive methodology has established them as pioneers in the green technology domain, encouraging not only economic expansion and worldwide competitiveness but also environmental preservation.

However, some EU countries, including Malta, Cyprus, Estonia, Lithuania and Croatia, are still in the early adopters of green patent programs. Funding green patents may boost economic expansion and generate new employment opportunities (Hasna, et al., 2023). The article continues by stating how EU nations can strengthen their economies and increase their resilience to future challenges by promoting innovation and spearheading the development of sustainable technologies. Meanwhile, moving away from fossil fuels and towards a low-carbon economy powered by green technologies may result in long-term cost savings. In addition to reducing environmental risks, this would improve energy security and advance the cause of social equity.

5. Methodology

5.1 The Regression model

A panel data approach is used in the regression analysis to look at the relationship between Green Innovation and ESG ratings across EU Member States. The following describes the regression model:

Equation 3. Empirical Model

$$\ln\left(GreenPatent_{it}\right) = \beta_0 + \beta_1 \ln\left(ESGRating_{it-1}\right) + \delta_i + \beta_3 Year_t + \epsilon_{it}$$

where $GreenPatent_{it}$ represents the number of green patents issued by country *i* in year *t*. In the same manner $ESGRating_{it-1}$ denotes the ESG rating of country *i* in year *t-1*. By doing so we are lagging the ESG rating by at least one year since it is normal to assume that the effect of ESG rating on the number of green patents issued will manifest with a time delay. Furthermore, δ_i captures country-specific fixed effects, accounting for individual variations across EU Member States. Moreover, $Year_t$ is a continuous variable representing the years, while ϵ_{it} symbolizes the error term which accounts for unexplained variance.

The validity and reliability of the regression model is supported by a number of key assumptions. First of all, the linearity assumption states that there is a linear relationship between the dependent variable (green patents) and the parameters of the model (among which ESG ratings are included). This is implying that, holding other factors constant, changes in the parameters correspond to changes in the number of green patents. Furthermore, the model residuals are assumed to be independent of one another under the independence of errors assumption. This guarantees the integrity of the regression results, by indicating that the occurrence of one error does not interfere with the occurrence of another.

Following, the homoscedasticity assumption states that for all levels of the independent variable (ESG rating), the variance of the errors is constant (Stock & Watson, 2020). Robust regression estimates are favored by homoscedasticity, as it ensures that the predicted power of the model is constant at various levels of the independent variable. Besides, the errors of the regression model must have a normal distribution as they ensure an accurate interpretation of the regression results.

Lastly, the hypothesis that there shouldn't be perfect linear relationships between the independent variables is known as the assumption of no perfect multicollinearity (Stock & Watson, 2020). Multicollinearity must be carefully taken into account when defining the model because it has the potential to skew coefficient estimation and impair the interpretability of the regression findings. By controlling for country-specific effects, it is possible to derive robust interpretation and inference from the regression analysis and gain insight into the relationship between Green Innovation and ESG ratings in EU Member States by ensuring that these assumptions are met.

5.2 Estimation Strategy

In estimating the regression model, this research took into account a number of important factors to ensure the validity and robustness of the analysis. It was first explained in the previous chapter that each indicator that was required for the development of the ESG score was normalized according to the Min-Max pattern, so that the same weight could be assigned to analyze the results on a scale from 0 to 1, and thus the sensitivity could be better measured. It also became imperative to lag the ESG variable by one year in order to better achieve this study. As confirmed by the findings in the Literature Review chapter, this step is critical since the ESG rating effect on the number of green patents issued occurs with a time lag, since the R&D process requires time.

As all data, of both the ESG rating variable and green patents, were positive and skewness, it was applied a log-log model were both variables has been specified in logarithms (Stock & Watson, 2020). The log transformation within the regression helped normalize the data, stabilize the variance, linearize the relationships, and thus we can say that it helps improve the performance of the model.

The choice of regression model was made using the fixed effects method. As the book authors Stock and Watson (2020) acknowledge, Fixed-effects regression is a method to control for omitted variables in panel data when the omitted variables vary between entities (countries) but do not change over time, and therefore the presence of heterogeneity in treatment effects and clustering in the sample requires clustering of standard errors by country. Hence, it is ensured that the estimation incorporates potential heteroskedasticity and serial correlation within the data, improving the robustness and reliability of the regression analysis.

6. Empirical Analysis

6.1 Hypotesis

In this section, the relationship between environmental, social and governance (ESG) ratings and green patenting activity in European countries is explored over a 15-year period, that is from 2005 to 2020, using a panel fixed effects multiple regression model. The model incorporates a linear time trend and country fixed effects to control for unobserved heterogeneity between countries and over time. The robust standard errors, in particular the HC3 method, is used to cluster the standard errors and address potential heteroskedasticity, as this guarantees the robustness of our assumptions.

The following is the hypothesis under analysis:

H: *Is there a positive relationship between ESG ratings and Green patenting?*

6.2 Parameter Estimates

The dependent variable in our analysis is the natural logarithm of green patents (logGreenPatents), while the key independent variable is the natural logarithm of ESG ratings (logESG). The regression parameter estimates are shown in Table 5.

The intercept is estimated at -46,274, with a t-value of -4,113 and a p-value of less than 0,001. This significant negative intercept indicates that the baseline level of green patenting is low when all other variables are kept at zero. Hence, the negative intercept suggests that factors not captured by the model play a significant role in influencing green patenting activity.

Similarly, Table 5, allows us to know the relationship between the variables Years and Green Patents. The coefficient for the variable 'Years' is 0,026, with a t-value of 4,949 and a p-value of less than 0,001. This positive and statistically significant relationship implies that there has been a consistent increase in green patents over the study period. Time is associated with an increase in green patent activity, reflecting the growing emphasis on environmental innovation.

Drawing further on Table 5, we see that ESG Rating, logESG, has a significant t-value of 2,443 (p = 0,015), explaining how ESG evaluations are able to exert a positive influence on the granting of green patents. This is of key importance to this research as it demonstrates the importance of environmental, social and governance considerations in promoting sustainable innovation practices.

The main variable of interest, logESG, has a coefficient of 0,324, with a t-value of 2,443 and a p-value of 0,015. This indicates a positive and statistically significant relationship between ESG ratings and green patenting. Specifically, a 1% increase in ESG ratings is associated with a 0,324% increase in green patenting, holding all other variables constant. This result underlines the importance of ESG considerations in promoting sustainable innovation. Higher ESG ratings appear to incentivize green patenting activities, highlighting the role of robust environmental, social and governance practices in promoting environmentally friendly technological advances. Therefore, the positive coefficient for logESG suggests that when countries improve their ESG rating, they experience a corresponding increase in green patents. Aside from being statistically significant, this relationship also has practical relevance. Although the coefficient (0,324) may seem modest, its impact can be substantial when aggregated over multiple countries and over time. Incremental increases in green patents contribute to the achievement of broader sustainability and environmental goals.

Another central aspect is the recognition of all control variables included in the regression model and their impact on the relationship between ESG ratings and green patents. In this research, the model takes country-level factors into account, as evidenced by the coefficients associated with individual countries. This enables to isolate the unique effect of ESG ratings on green patenting. Controlling for time (years) further validates that the observed increase in green patents is not just a time trend but is significantly associated with ESG improvements.

Dependent Variable: logGreenPatents

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-46,274	11,252	-4,113	<,001	-68,393	-24,155	,040
logESG	,324	,132	2,443	,015	,063	,584	,015
Years	,026	,006	4,672	<,001	,015	,037	,052
[Country=Austria]	-,173	,072	-2,383	,018	-,315	-,030	,014
[Country=Belgium]	-,574	,080	-7,167	<,001	-,732	-,417	,113
[Country=Bulgaria]	-3,757	,234	-16,091	<,001	-4,216	-3,298	,392
[Country=Croatia]	-3,986	,216	-18,466	<,001	-4,411	-3,562	,459
[Country=Cyprus]	-5,381	,361	-14,894	<,001	-6,092	-4,671	,356
[Country=Czechia]	-2,099	,111	-18,933	<,001	-2,317	-1,881	,471
[Country=Denmark]	-,006	,071	-,088	,930	-,145	,132	,000
[Country=Estonia]	-4,284	,250	-17,130	<,001	-4,776	-3,793	,422
[Country=Finland]	-,529	,077	-6,892	<,001	-,680	-,378	,106
[Country=France]	1,296	,075	17,307	<,001	1,149	1,443	,427
[Country=Germany]	2,368	,069	34,158	<,001	2,232	2,504	,744
[Country=Greece]	-2,816	,259	-10,855	<,001	-3,326	-2,306	,227
[Country=Hungary]	-2,623	,165	-15,848	<,001	-2,948	-2,297	,385
[Country=Ireland]	-1,992	,109	-18,244	<,001	-2,206	-1,777	,453
[Country=Italy]	,230	,166	1,389	,166	-,096	,556	,005
[Country=Latvia]	-4,693	,250	-18,759	<,001	-5,184	-4,201	,467
[Country=Lithuania]	-4,482	,195	-23,025	<,001	-4,864	-4,099	,569
[Country=Luxembourg]	-3,332	,113	-29,577	<,001	-3,553	-3,110	,685
[Country=Malta]	-5,503	,330	-16,687	<,001	-6,152	-4,855	,409
[Country=Netherlands]	,196	,058	3,375	<,001	,082	,310	,028
[Country=Poland]	-1,862	,177	-10,492	<,001	-2,211	-1,513	,215
[Country=Portugal]	-2,594	,138	-18,740	<,001	-2,866	-2,322	,466
[Country=Romania]	-3,287	,263	-12,477	<,001	-3,804	-2,769	,279
[Country=Slovak Republic]	-3,323	,150	-22,172	<,001	-3,618	-3,029	,550
[Country=Slovenia]	-3,417	,155	-22,058	<,001	-3,722	-3,113	,548
[Country=Spain]	-,360	,114	-3,153	,002	-,585	-,136	,024
[Country=Sweden]	0[b]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 5. Parameter Estimates

It is a normal practice in regression analyses with categorical variables, such as countries, to select one category (in the case of this study, Sweden) as the reference measurement against which the coefficients of the other categories are compared. The choice of Sweden as the benchmark is an arbitrary one and does not necessarily imply that Sweden has the highest value of green patents. Furthermore, the decision to put Sweden at 0 was mainly made to avoid multicollinearity problems, when the coefficient of one category can be perfectly predicted by the coefficients of other categories.

6.3 Robustness analysis

6.3.1 Re-estimate the Model

A robustness analysis that this study applies is the re-estimation of the model. This means that the model will be analysed first by only the environment variable, then the social variable and then the governance variable as covariance, while keeping green patents as the dependent variable. This will make it possible to analyse which factor (environmental, social or governance) mainly drives the positive relationship between ESG score and green patents.

Before conducting the robustness analysis, it is required to apply a lag function to all three parameters as we did for the ESG variable. Afterwards, we will continue by analysing the parameter estimates for each model as the parameters represent the effect of each variable on the dependent variable (logGreenPatents).

The environmental model, lagEnvironment, is statistically significant (Sig. = 0,003), suggesting a positive relationship between environmental factors and green patents. Moreover, the coefficient (2,765) is positive, and this means that an increase in the Environmental variable, leads to an increase in Green Patents. Delving more deeper, the effect size (Partial Eta Squared[14]) as shown in Table 6, is small (0,022).

Dependent Variable: logGreenPatents

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-49,281	10,671	-4,618	<,001	-70,258	-28,303	,050
Years	,028	,005	5,201	<,001	,017	,038	,063
lagEnvironment	2,765	,917	3,015	,003	,962	4,569	,022
[Country=Austria]	-,087	,169	-,512	,609	-,420	,246	,001
[Country=Belgium]	-,623	,173	-3,602	<,001	-,963	-,283	,031
[Country=Bulgaria]	-3,532	,171	-20,615	<,001	-3,869	-3,195	,514
[Country=Croatia]	-3,806	,168	-22,704	<,001	-4,135	-3,476	,562
[Country=Cyprus]	-5,293	,178	-29,788	<,001	-5,642	-4,943	,688
[Country=Czechia]	-2,102	,173	-12,132	<,001	-2,442	-1,761	,268
[Country=Denmark]	,019	,167	,116	,908	-,308	,347	,000
[Country=Estonia]	-4,245	,169	-25,092	<,001	-4,578	-3,912	,610
[Country=Finland]	-,539	,167	-3,218	,001	-,868	-,210	,025
[Country=France]	1,286	,169	7,623	<,001	,954	1,618	,126
[Country=Germany]	2,364	,168	14,082	<,001	2,034	2,694	,330
[Country=Greece]	-2,518	,167	-15,082	<,001	-2,846	-2,190	,361
[Country=Hungary]	-2,322	,169	-13,766	<,001	-2,654	-1,991	,320
[Country=Ireland]	-2,045	,176	-11,598	<,001	-2,392	-1,698	,251
[Country=Italy]	,440	,167	2,633	,009	,111	,768	,017
[Country=Latvia]	-4,455	,167	-26,720	<,001	-4,783	-4,127	,640
[Country=Lithuania]	-4,286	,167	-25,667	<,001	-4,615	-3,958	,621
[Country=Luxembourg]	-3,321	,169	-19,624	<,001	-3,654	-2,988	,489
[Country=Malta]	-5,531	,185	-29,827	<,001	-5,896	-5,167	,689
[Country=Netherlands]	,235	,167	1,412	,159	-,092	,563	,005
[Country=Poland]	-1,793	,173	-10,359	<,001	-2,133	-1,453	,211
[Country=Portugal]	-2,371	,167	-14,183	<,001	-2,700	-2,042	,334
[Country=Romania]	-2,801	,170	-16,523	<,001	-3,134	-2,468	,404
[Country=Slovak Republic]	-3,197	,167	-19,108	<,001	-3,526	-2,868	,476
[Country=Slovenia]	-3,293	,167	-19,726	<,001	-3,621	-2,964	,492
[Country=Spain]	-,221	,167	-1,327	,185	-,549	,106	,004
[Country=Sweden]	0[a]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 6. Re-estimate the Model, lagEnvironmental parameter estimates, Parameter Estimates

[14] The amount of influence the independent variable(s) had on the dependent variable is shown by the partial eta squared. A minor influence is indicated by η2 = 0.01. With η2 = 0.06, the effect is medium. A large influence is indicated by η2 = 0.14.

On the other hand, when analysing the social model, we note that the parameter estimate for lagSocial is statistically significant (Sig. = 0,046), indicating both an even stronger relationship than the environment variable, between social factors and green patents. It must be highlighted that, even if this relationship is stronger as demonstrated also by the effect size being larger than the environment model (0,010), the coefficient of the Social variable is negative (-0,925). The latter means that a 1% increase in the Social variable is associated with a 0,925% decrease in green patents (Table 7).

Dependent Variable: logGreenPatents

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-43,359	10,412	-4,164	<,001	-63,828	-22,889	,041
Years	,025	,005	4,778	<,001	,015	,035	,054
lagSocial	-,925	,462	-2,000	,046	-1,833	-,016	,010
[Country=Austria]	-,188	,177	-1,066	,287	-,536	,159	,003
[Country=Belgium]	-,577	,174	-3,313	,001	-,920	-,235	,027
[Country=Bulgaria]	-3,693	,219	-16,852	<,001	-4,124	-3,263	,414
[Country=Croatia]	-3,950	,196	-20,204	<,001	-4,335	-3,566	,504
[Country=Cyprus]	-5,296	,193	-27,483	<,001	-5,675	-4,918	,653
[Country=Czechia]	-2,050	,174	-11,795	<,001	-2,392	-1,709	,257
[Country=Denmark]	-,007	,168	-,043	,966	-,337	,323	,000
[Country=Estonia]	-4,277	,178	-23,998	<,001	-4,627	-3,927	,589
[Country=Finland]	-,557	,171	-3,249	,001	-,893	-,220	,026
[Country=France]	1,285	,173	7,449	<,001	,946	1,624	,121
[Country=Germany]	2,323	,176	13,225	<,001	1,978	2,668	,303
[Country=Greece]	-2,731	,208	-13,107	<,001	-3,141	-2,322	,299
[Country=Hungary]	-2,634	,204	-12,939	<,001	-3,034	-2,234	,294
[Country=Ireland]	-1,976	,176	-11,248	<,001	-2,321	-1,630	,239
[Country=Italy]	,237	,207	1,148	,252	-,169	,644	,003
[Country=Latvia]	-4,708	,203	-23,175	<,001	-5,107	-4,308	,572
[Country=Lithuania]	-4,480	,203	-22,055	<,001	-4,879	-4,080	,548
[Country=Luxembourg]	-3,322	,174	-19,121	<,001	-3,664	-2,981	,476
[Country=Malta]	-5,398	,177	-30,518	<,001	-5,746	-5,051	,699
[Country=Netherlands]	,216	,168	1,290	,198	-,113	,546	,004
[Country=Poland]	-1,832	,191	-9,615	<,001	-2,207	-1,458	,187
[Country=Portugal]	-2,616	,196	-13,365	<,001	-3,001	-2,232	,308
[Country=Romania]	-3,240	,240	-13,477	<,001	-3,713	-2,768	,311
[Country=Slovak Republic]	-3,292	,182	-18,065	<,001	-3,650	-2,934	,448
[Country=Slovenia]	-3,382	,178	-18,953	<,001	-3,733	-3,031	,472
[Country=Spain]	-,392	,189	-2,074	,039	-,765	-,020	,011
[Country=Sweden]	0[a]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 7. Re-estimate the Model, lagSocial parameter estimates, Parameter Estimates

Finally, the governance model shows a parameter estimate for lagGovernance that is not statistically significant (Sig. = 0,570), suggesting that governance factors taken alone may not have a significant influence on green patents. Also in this case, the effect size is minimal (0,001) (Table 8).

Dependent Variable: logGreenPatents

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-38,401	10,163	-3,779	<,001	-58,380	-18,422	,034
Years	,022	,005	4,389	<,001	,012	,032	,046
lagGovernance	-,264	,464	-,569	,570	-1,177	,648	,001
[Country=Austria]	-,132	,183	-,719	,472	-,492	,228	,001
[Country=Belgium]	-,514	,178	-2,896	,004	-,863	-,165	,020
[Country=Bulgaria]	-3,504	,235	-14,935	<,001	-3,965	-3,043	,357
[Country=Croatia]	-3,836	,228	-16,857	<,001	-4,284	-3,389	,414
[Country=Cyprus]	-5,190	,223	-23,254	<,001	-5,628	-4,751	,574
[Country=Czechia]	-2,021	,201	-10,052	<,001	-2,416	-1,625	,201
[Country=Denmark]	-,001	,170	-,004	,997	-,334	,333	,000
[Country=Estonia]	-4,207	,191	-22,015	<,001	-4,583	-3,831	,547
[Country=Finland]	-,497	,170	-2,933	,004	-,831	-,164	,021
[Country=France]	1,340	,175	7,662	<,001	,996	1,684	,127
[Country=Germany]	2,414	,170	14,188	<,001	2,079	2,748	,334
[Country=Greece]	-2,593	,255	-10,155	<,001	-3,095	-2,091	,204
[Country=Hungary]	-2,488	,225	-11,036	<,001	-2,931	-2,045	,233
[Country=Ireland]	-1,915	,186	-10,318	<,001	-2,280	-1,550	,209
[Country=Italy]	,397	,223	1,782	,075	-,041	,835	,008
[Country=Latvia]	-4,555	,216	-21,112	<,001	-4,979	-4,131	,526
[Country=Lithuania]	-4,327	,216	-20,023	<,001	-4,752	-3,902	,499
[Country=Luxembourg]	-3,275	,186	-17,646	<,001	-3,640	-2,910	,436
[Country=Malta]	-5,372	,227	-23,641	<,001	-5,819	-4,925	,582
[Country=Netherlands]	,204	,175	1,165	,245	-,140	,548	,003
[Country=Poland]	-1,722	,209	-8,224	<,001	-2,133	-1,310	,144
[Country=Portugal]	-2,485	,209	-11,878	<,001	-2,896	-2,074	,260
[Country=Romania]	-3,006	,257	-11,688	<,001	-3,512	-2,501	,254
[Country=Slovak Republic]	-3,225	,215	-14,982	<,001	-3,649	-2,802	,358
[Country=Slovenia]	-3,332	,211	-15,797	<,001	-3,747	-2,917	,383
[Country=Spain]	-,271	,194	-1,400	,162	-,651	,110	,005
[Country=Sweden]	0[a]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 8. Re-estimate the Model, lagGovernance parameter estimates, Parameter Estimates

By first only comparing the effect sizes of the parameter estimates, it appears that social factors, followed later by environmental factors, have a greater influence on green patents than only ESG ratings. On the other hand, if we take into consideration the coefficient, we see that the Environmental factor is the only positive one, therefore, an increase in the variable is actually correlated with an increase in green patenting.

These results are confirmed by research conducted at a firm level by Eccles and Serafeim (2013). They analysed how governance performance had a less direct impact to innovation and financial performance rather than the environmental and social ones. This goes hand in hand with the results we have just analysed in this subchapter.

6.3.2 Using different Time Lags

As it is shown through the analysis conducted, the study of ESG rating on the number of green patents issued occurs with a time lag. For this reason, another robustness analysis that will be conducted as part of this research concerns the comparison of different lag periods for the impact of ESG rating on green patents. A 1-year lag (Table 5), a 2-year lag, log2ESG, (Table 9), and a 3-year lag, log3ESG, (Table 10) will be applied to compare the ESG variable.

To begin with, it can be seen that the coefficient of the ESG variable increases with each additional year of lag, as for log2ESG it is 0,390, and for log3ESG 0,395, respectively. This suggests an increasing impact on green patents over time where the greatest impact occurs with a 3-year lag.

Dependent Variable: logGreenPatents

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-42,488	10,050	-4,228	<,001	-62,246	-22,731	,043
Years	,024	,005	4,819	<,001	,014	,034	,055
log2ESG	,390	,114	3,415	<,001	,166	,615	,028
[Country=Austria]	-,176	,174	-1,010	,313	-,518	,166	,003
[Country=Belgium]	-,585	,169	-3,461	<,001	-,917	-,253	,029
[Country=Bulgaria]	-3,794	,200	-18,922	<,001	-4,188	-3,399	,472
[Country=Croatia]	-4,033	,186	-21,694	<,001	-4,399	-3,668	,540
[Country=Cyprus]	-5,432	,192	-28,340	<,001	-5,809	-5,055	,667
[Country=Czechia]	-2,115	,172	-12,263	<,001	-2,454	-1,776	,273
[Country=Denmark]	-,008	,166	-,046	,963	-,335	,319	,000
[Country=Estonia]	-4,296	,171	-25,087	<,001	-4,633	-3,959	,611
[Country=Finland]	-,531	,167	-3,184	,002	-,859	-,203	,025
[Country=France]	1,294	,168	7,723	<,001	,965	1,624	,129
[Country=Germany]	2,362	,167	14,114	<,001	2,033	2,691	,332
[Country=Greece]	-2,855	,199	-14,370	<,001	-3,246	-2,465	,340
[Country=Hungary]	-2,668	,183	-14,542	<,001	-3,028	-2,307	,345
[Country=Ireland]	-2,014	,171	-11,745	<,001	-2,351	-1,677	,256
[Country=Italy]	,201	,185	1,087	,278	-,163	,565	,003
[Country=Latvia]	-4,737	,183	-25,929	<,001	-5,096	-4,378	,626
[Country=Lithuania]	-4,519	,184	-24,570	<,001	-4,880	-4,157	,601
[Country=Luxembourg]	-3,347	,170	-19,724	<,001	-3,681	-3,013	,492
[Country=Malta]	-5,535	,182	-30,474	<,001	-5,892	-5,178	,698
[Country=Netherlands]	,194	,167	1,163	,245	-,134	,521	,003
[Country=Poland]	-1,886	,180	-10,482	<,001	-2,240	-1,532	,215
[Country=Portugal]	-2,625	,177	-14,801	<,001	-2,974	-2,276	,353
[Country=Romania]	-3,355	,214	-15,690	<,001	-3,775	-2,934	,380
[Country=Slovak Republic]	-3,346	,176	-19,018	<,001	-3,691	-3,000	,474
[Country=Slovenia]	-3,445	,175	-19,700	<,001	-3,789	-3,101	,492
[Country=Spain]	-,379	,173	-2,193	,029	-,719	-,039	,012
[Country=Sweden]	0[a]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 9. Different Time Lags, 2 years, Parameter Estimates

Furthermore, it is feasible to highlight how both 2-year and 3-year lag hold a high statistical significance of $p < 0,001$, respectively, indicating that the relationship between ESG rating and green patents is robust across different lag periods. Breaking it down even further, it is enough to look at the partial eta square value where we see that ESG lag 1 possesses 0,015, while lag2 0,028 and lag3 0,035. The 3-year lag shows the highest partial eta squared value, and thus that the effect size increases with longer lags. This implies that the explanatory power of ESG rating on green patents becomes steeper with longer lag periods.

Dependent Variable: logGreenPatents

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-37,930	9,945	-3,814	<,001	-57,481	-18,380	,035
Years	,022	,005	4,403	<,001	,012	,031	,046
log3ESG	,395	,105	3,782	<,001	,190	,601	,035
[Country=Austria]	-,160	,177	-,909	,364	-,507	,187	,002
[Country=Belgium]	-,575	,168	-3,428	<,001	-,905	-,245	,029
[Country=Bulgaria]	-3,758	,190	-19,818	<,001	-4,131	-3,386	,495
[Country=Croatia]	-4,037	,183	-22,113	<,001	-4,396	-3,678	,550
[Country=Cyprus]	-5,428	,186	-29,116	<,001	-5,794	-5,061	,679
[Country=Czechia]	-2,103	,170	-12,350	<,001	-2,437	-1,768	,276
[Country=Denmark]	-,005	,166	-,029	,977	-,331	,321	,000
[Country=Estonia]	-4,280	,169	-25,306	<,001	-4,613	-3,948	,616
[Country=Finland]	-,525	,166	-3,160	,002	-,852	-,199	,024
[Country=France]	1,309	,167	7,858	<,001	,982	1,637	,134
[Country=Germany]	2,368	,167	14,210	<,001	2,041	2,696	,335
[Country=Greece]	-2,828	,189	-14,944	<,001	-3,200	-2,456	,358
[Country=Hungary]	-2,671	,180	-14,803	<,001	-3,026	-2,317	,354
[Country=Ireland]	-2,011	,170	-11,829	<,001	-2,346	-1,677	,259
[Country=Italy]	,222	,179	1,236	,217	-,131	,574	,004
[Country=Latvia]	-4,737	,179	-26,398	<,001	-5,089	-4,384	,635
[Country=Lithuania]	-4,511	,180	-25,105	<,001	-4,864	-4,158	,612
[Country=Luxembourg]	-3,342	,169	-19,834	<,001	-3,674	-3,011	,496
[Country=Malta]	-5,527	,178	-31,082	<,001	-5,877	-5,178	,707
[Country=Netherlands]	,199	,166	1,201	,230	-,127	,526	,004
[Country=Poland]	-1,868	,176	-10,641	<,001	-2,213	-1,523	,221
[Country=Portugal]	-2,619	,175	-15,006	<,001	-2,962	-2,276	,360
[Country=Romania]	-3,343	,204	-16,406	<,001	-3,744	-2,942	,402
[Country=Slovak Republic]	-3,335	,173	-19,274	<,001	-3,675	-2,995	,482
[Country=Slovenia]	-3,442	,173	-19,922	<,001	-3,782	-3,103	,498
[Country=Spain]	-,368	,171	-2,154	,032	-,703	-,032	,011
[Country=Sweden]	0[a]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 10. Different Time Lags, 3 years, Parameter Estimates

It is for this reason that by the coefficient values, significance levels, and partial eta square values, it can be made the conclusion that the 3-year lag reveals the strongest relationship between ESG ratings, and the number of green patents issued. An upward trend in the coefficient and effect size with longer lags supports the idea that the impact of ESG ratings on green innovation is not immediate but grows over time. Therefore, the 3-year lag period can be considered the most robust and effective for capturing the influence of ESG ratings on green patents.

6.3.3 Weight countries by GDP

A further robustness analysis that was carried out allows the different countries to be weighted according to their GDP. This made it possible to give more weight to larger countries. This was accomplished by using the World Bank database for GDP (2024) values where for each year, a total GDP of all the countries in the dataset was calculated (Equation 4).

Equation 4. Sum of GDPs for each year

$$Total\ GDP_{year} = \sum_{i=1}^{n} GDP_{i,year}$$

Subsequently, each country's weight was computed as the ratio of each country's GDP to the GDP of all countries for each year (Equation 5).

Equation 5. Calculate Weight for each country

$$Weight_{i,year} = \frac{GDP_{i,year}}{Total\ GDP_{year}}$$

This was followed by a final step where both green patents (logGreenPatents) and ESG ratings (logESG) were multiplied by the corresponding weights (Equation 6).

Equation 6. Calculate Weighted Values

$$Weighted\ Green\ Patents_{i,years} = Green\ Patents_{i,year} \times Weight_{i,year}$$

$$Weighted\ ESG\ Ratings_{i,years} = ESG\ Ratings_{i,years} \times Weight_{i,year}$$

With the weighted values calculated, the regression analysis was performed using GDP-weighted green patents as the dependent variable and GDP-weighted ESG ratings as the independent variable (Table 11).

Dependent Variable: GreenP_GDP

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	59,626	95,277	,626	,532	-127,676	246,928	,001
ESG_GDP	1388,407	190,039	7,306	<,001	1014,816	1761,999	,117
Years	-,030	,047	-,626	,532	-,123	,063	,001
[Country=Austria]	,031	1,600	,020	,984	-3,114	3,177	,000
[Country=Belgium]	-,090	1,600	-,057	,955	-3,235	3,054	,000
[Country=Bulgaria]	-,563	1,599	-,352	,725	-3,707	2,581	,000
[Country=Croatia]	-,324	1,603	-,202	,840	-3,475	2,826	,000
[Country=Cyprus]	-,530	1,600	-,331	,741	-3,676	2,615	,000
[Country=Czechia]	-,839	1,597	-,526	,599	-3,978	2,300	,001
[Country=Denmark]	-,060	1,598	-,037	,970	-3,202	3,082	,000
[Country=Estonia]	-1,242	1,596	-,778	,437	-4,380	1,896	,002
[Country=Finland]	-,182	1,600	-,114	,910	-3,327	2,964	,000
[Country=France]	1,164	1,602	,727	,468	-1,985	4,313	,001
[Country=Germany]	9,024	1,599	5,644	<,001	5,881	12,166	,073
[Country=Greece]	,220	1,613	,136	,892	-2,951	3,390	,000
[Country=Hungary]	-,561	1,599	-,351	,726	-3,704	2,583	,000
[Country=Ireland]	-1,902	1,603	-1,187	,236	-5,053	1,249	,003
[Country=Italy]	-,645	1,609	-,401	,689	-3,809	2,519	,000
[Country=Latvia]	-,822	1,598	-,515	,607	-3,964	2,319	,001
[Country=Lithuania]	-1,097	1,596	-,687	,493	-4,235	2,042	,001
[Country=Luxembourg]	-1,154	1,596	-,723	,470	-4,292	1,985	,001
[Country=Malta]	-1,563	1,596	-,979	,328	-4,701	1,576	,002
[Country=Netherlands]	,209	1,599	,131	,896	-2,934	3,351	,000
[Country=Poland]	-,793	1,596	-,497	,619	-3,931	2,345	,001
[Country=Portugal]	-,091	1,606	-,057	,955	-3,248	3,066	,000
[Country=Romania]	-,586	1,599	-,366	,714	-3,729	2,557	,000
[Country=Slovak Republic]	-1,287	1,596	-,806	,421	-4,425	1,851	,002
[Country=Slovenia]	-,718	1,598	-,450	,653	-3,861	2,424	,001
[Country=Spain]	-,117	1,603	-,073	,942	-3,269	3,035	,000
[Country=Sweden]	0[a]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 11. Weight countries by GDP, Parameter Estimates

The coefficient for ESG in the GDP-weighted model (1388,407) is significantly higher than in the unweighted model (0,324). However, this is due to the scaling effect of GDP, which amplifies the impact of ESG on green patents in proportion to the economic size of each country. Both models show high statistical significance indicating a robust relationship between ESG ratings and green patents regardless of GDP weighting.

The effect size in the GDP-weighted model (0,117) is larger in comparison to the unweighted model (0,015). This indicates that the weighted model explains a greater proportion of the variance in green patents, hinting at the fact that the relationship between ESG and green patents is more pronounced when taking into account the economic size of countries. The intercept in the GDP-weighted model (59,626) is positive but not significant, while in the unweighted model it is negative and significant (-46,274). Also, the coefficient for years is negative and not significant in the GDP-weighted model (-0,030), while it is positive and significant in the unweighted model (0,026). Indeed, this indicates that the time trend effect varies when considering economic size, perhaps reflecting different growth dynamics in larger versus smaller economies.

Weighting by GDP shows the greater influence of ESG assessments on green patents in economically larger countries. This suggests that ESG policies and investments in these countries have a more pronounced effect on green innovation, likely due to greater resources and capacity for R&D and patenting activities. For policymakers, the GDP-weighted analysis suggests that focusing ESG-related policies and investments in larger economies can produce substantial gains in green innovation. However, it also underscores the need to support smaller economies to ensure a balanced and inclusive approach to global sustainability.

6.3.4 Omitting Outliers

The last robustness analysis that it will be conducted in this research permits to exclude the outliers, Germany and France, since they are the two countries with the highest number of green patents in relation to the mean of the European countries took under consideration.

Most importantly, the intercept remains significant and negative in both models, indicating a similar base level of green patent activity when other factors are taken into account. Successively, a positive and significant effect of the year's variable suggests a steady trend in green patent growth over time in both Table 5 and the analysis carried out in Table12, although its coefficient increases slightly when excluding Germany and France, as it rises to 0,027 from 0,026, indicating a slightly stronger time trend when excluding these outliers.

Moreover, the coefficient for logESG remains significant and positive in both models, indicating a strong relationship between ESG ratings and green patenting. Nonetheless, the level of significance decreases slightly after excluding outliers, suggesting that the presence of Germany and France may have strengthened the relationship observed in the initial model.

Dependent Variable: logGreenPatents

Parameter	B	Robust Std. Error[a]	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-48,174	11,456	-4,205	<,001	-70,700	-25,647	,045
Years	,027	,006	4,744	<,001	,016	,038	,057
logESG	,325	,139	2,345	,020	,052	,597	,015
[Country=Austria]	-,173	,179	-,967	,334	-,526	,179	,003
[Country=Belgium]	-,575	,178	-3,236	,001	-,924	-,226	,027
[Country=Bulgaria]	-3,759	,228	-16,484	<,001	-4,207	-3,310	,422
[Country=Croatia]	-3,987	,201	-19,857	<,001	-4,382	-3,592	,515
[Country=Cyprus]	-5,382	,209	-25,699	<,001	-5,794	-4,971	,640
[Country=Czechia]	-2,100	,183	-11,448	<,001	-2,461	-1,739	,261
[Country=Denmark]	-,006	,173	-,036	,971	-,347	,335	,000
[Country=Estonia]	-4,285	,182	-23,580	<,001	-4,642	-3,928	,599
[Country=Finland]	-,529	,174	-3,040	,003	-,872	-,187	,024
[Country=Greece]	-2,817	,224	-12,573	<,001	-3,258	-2,377	,298
[Country=Hungary]	-2,624	,197	-13,311	<,001	-3,011	-2,236	,323
[Country=Ireland]	-1,992	,181	-11,020	<,001	-2,348	-1,637	,246
[Country=Italy]	,229	,204	1,126	,261	-,171	,629	,003
[Country=Latvia]	-4,693	,196	-23,943	<,001	-5,079	-4,308	,606
[Country=Lithuania]	-4,482	,200	-22,466	<,001	-4,875	-4,090	,576
[Country=Luxembourg]	-3,332	,179	-18,667	<,001	-3,683	-2,981	,484
[Country=Malta]	-5,504	,197	-27,976	<,001	-5,891	-5,117	,678
[Country=Netherlands]	,196	,174	1,128	,260	-,146	,538	,003
[Country=Poland]	-1,863	,195	-9,538	<,001	-2,247	-1,479	,196
[Country=Portugal]	-2,594	,189	-13,692	<,001	-2,967	-2,222	,335
[Country=Romania]	-3,288	,241	-13,652	<,001	-3,762	-2,815	,334
[Country=Slovak Republic]	-3,324	,189	-17,630	<,001	-3,695	-2,953	,455
[Country=Slovenia]	-3,418	,186	-18,391	<,001	-3,783	-3,052	,476
[Country=Spain]	-,361	,184	-1,963	,050	-,722	,001	,010
[Country=Sweden]	0[a]	.	.	.	.	.	.

a. HC3 method

b. This parameter is set to zero because it is redundant.

Table 12. Omitting Outliers, Parameter Estimates

Thereby, it can be concluded that through the exclusion of Outliers, the overall explanatory power of the model is slightly reduced (as reflected in the adjusted coefficients and significance levels), but the key relationships (time trend and ESG impact) remain robust. This robustness analysis confirms that the positive relationship between ESG ratings and green patents is not exclusively driven by the largest green patent producers but is a more widespread phenomenon across Europe.

7. Results and Discussion

7.1 Interpretetation of Results

Within this research, the favorable correlation between ESG ratings and green patents was highlighted through the 'Parameter Estimates' (Table 5). Through this table, it is clear that ESG ratings represent in fact a powerful catalyst for sustainable innovation practices, allowing it to reveal what is a significant impact on sustainability efforts on a broader scale. Besides, through the development of Table 5, it was possible to emphasize the considerable disparity in the response of EU countries to green patenting compared to Sweden, which serves as the reference country during the analysis. In doing so, we can summarize as an overall trend that certain countries, for example France, Germany, Finland and Spain emerge as frontrunners in promoting green innovation initiatives. In contrast, there are countries facing economic constraints and regulatory restrictions where green innovation is heavily hampered.

To this extent, the research is illustrating the importance of what should be cohesive policy frameworks and collaborations between stakeholders to accelerate the transition to a greener and more sustainable future in European countries. Each nation, and thus each of its policymakers, can develop a strategy to achieve growth in its environmental stewardship, thereby ushering in sustainable prosperity for generations to come, capitalizing on the close connection between ESG assessments and green innovations.

7.2 Implication for Policy and Practice

7.2.1 Policy Recommendations

Following the conducted analysis and discussion, in this part of the research we will focus on certain recommendations and directives that the European Union could develop in order to succeed in promoting both green innovation and sustainability within the 27 countries. First of all, the European Commission should prioritise the strengthening of regulations regarding ESG information. Indeed, by providing for mandatory ESG disclosure and imposing environmental standards, the EU can create a more regulated environment that encourages companies and organizations to invest in green technologies and adopt sustainable practices. Indeed, strengthening regulatory frameworks is in line with the EU's commitment to achieving the goals outlined in the European Green Deal[15], including transitioning to a zero-carbon economy and promoting sustainable growth. According to the article published by the European Council (2024), one might draw the conclusion that the European Union is starting to take an increasing interest in ESG ratings and their implications, insofar as an adjustment to the provisional agreement that the Commission is developing on ESG ratings took place on February 14, 2024, which includes clarifying their scope and establishing authorization and supervision by ESMA[16].

Since regression analysis revealed a positive and statistically significant association between the year variable and the granting of green patents, this suggests that there has been a significant increase in the granting of such patents in European countries over the fifteen year period. This trend underscores the emphasis on both continuous learning, but more importantly on adaptation and capacity building to keep pace with technological change and sustainability challenges. When implementing capacity building programs, the European Commission can equip stakeholders with the knowledge, skills and resources needed to take advantage of emerging green innovation opportunities and contribute to sustainable development goals. Accordingly, technical support and training materials can be provided to develop the European Commission's directive to help companies incorporate green innovation principles into their operations, but also to establish networks and cooperation platforms to promote information sharing and the formation of alliances between companies, universities and countries.

To sustain this continuous and positive trajectory, demonstrated by our regression, of innovation in sustainable technologies over time, investment in research and innovation is essential. Through the allocation of resources for research initiatives, it is possible for the European Commission to support the development of innovative solutions to address pressing environmental challenges and promote sustainable development goals. The latter is also a matter of collaboration and sharing of resources and knowledge between countries, as sustainability challenges are global in nature and require collective action. By promoting international partnerships and cooperation, the European Commission can use the expertise

[15] The European Commission approved the European Green Deal in 2020 as a collection of policy initiatives with the primary goal of achieving climate neutrality for the European Union by 2050.

[16] The independent EU body known as the European Securities and Markets Authority (ESMA) works to strengthen investor protection and encourage stable, orderly financial markets.

and resources of different stakeholders to accelerate progress towards common sustainability goals.

Investments in research and innovation for sustainable technologies can also boost economic growth, create jobs and improve Europe's competitiveness in the global market (Giordano, et al., 2024). The same articles highlight that European businesses are spending less on research and development (R&D) as a percentage of revenue than American companies are (Figure 20). This is causing slower growth and lower returns on capital. In fact, in order to remain competitive, Europe must make significant investments in R&D due to the growing challenges it faces in the areas of innovation, energy, capital, supply chains, and competition.

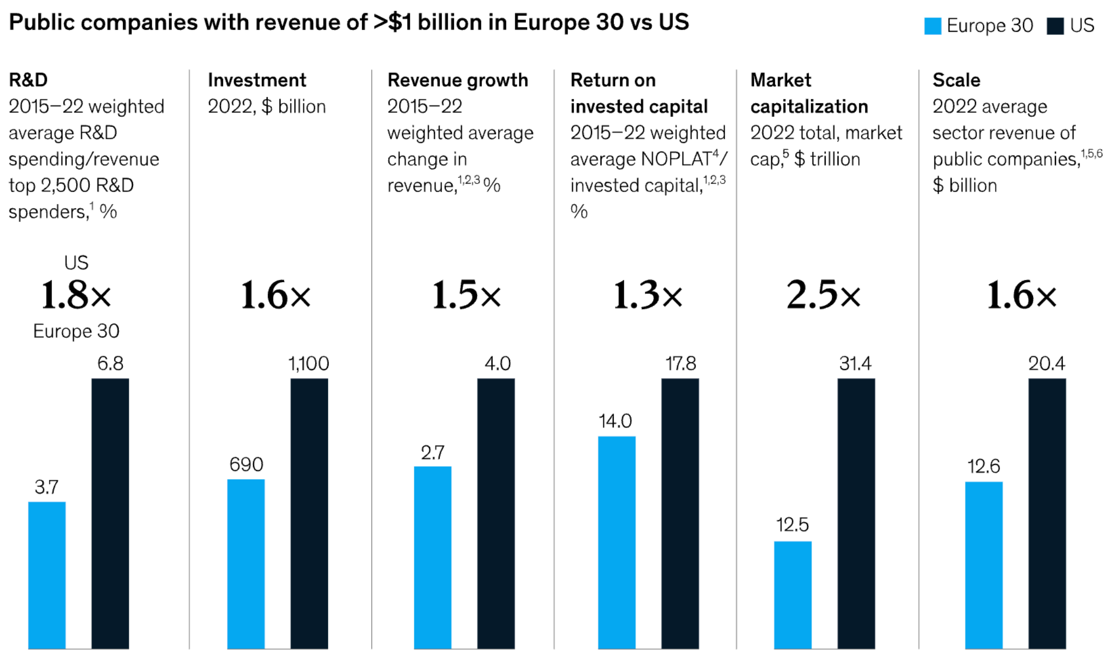

Figure 20. European corporations lag on scale and performance, Source: Giordano, et al., (2024)

Therefore, in light of increasing competitive pressures and changes in the economic landscape, Europe must increase investment in R&D to protect its future growth, prosperity, sustainability, and inclusiveness.

7.2.2 Practical Implications for Businesses

Companies should prioritize the integration of environmental, social, and governance (ESG) considerations into their business strategies. Importantly, this involves the integration of sustainability starting as early as management and continuing through to stakeholder engagement. As a matter of fact, the regression analysis underscores the importance of ESG ratings as indicators of sustainable business practices and performance. That's why companies are already beginning to use these ratings to compare their performance with industry peers, so that they can identify areas for improvement and demonstrate their commitment to sustainability to investors, customers, and other stakeholders (Giese, et al., 2019). In addition, the analysis shows that integrating ESG principles can stimulate innovation and thus generate what will be a competitive advantage for the company.

Another practical implication that companies will need to address after the results of the analysis conducted concerns the integration of circular economy principles into business strategies. Indeed, if circular business models are embraced, it is possible to redesign not only products but also processes and business models to minimize waste and promote resource efficiency, in line with the sustainability goals identified through the regression analysis (Murillo, et al., 2021). In fact, adopting circular business practices allows the company's activities to be aligned with the efforts the country is taking to keep up with the environmental sustainability goals outlined by the European Union. By leveraging the results of the analysis, we can identify countries where companies have the greatest impact on sustainable technology investments, ensuring that efforts are directed toward maximizing environmental benefits while promoting business growth. But also, again through the same results, it is possible to identify which countries need greater commitment and culture toward ESG ratings and green patents.

This situation should be analysed using game theory, because this is the only way to understand how the collective action problem is a fundamental concept that arises when, in this case, companies in EU countries are faced with a dilemma in which their self-interest conflicts with the collective interest. When it comes to ESG ratings and green patents, the collective action problem manifests itself through free riding incentives. In fact, companies in each country are tempted to exploit the efforts of others when it comes to improving ESG ratings and promoting green innovation. Countries such as Malta, Cyprus, and Estonia may prioritize short-term economic gains, and thus avoid the costs associated with sustainability measures, hoping that other countries (such as Sweden, Germany, or France) will take on the burden of environmental responsibility. That said, if each country adopts a free-rider strategy, overall progress toward sustainability goals will be limited, and individual countries that have so far pursued the promotion of green patents may feel that their efforts alone will not make a significant difference, leading to inaction or underinvestment in sustainability initiatives.

To overcome this problem, Europe must commit to aligning the incentives of individual companies with the collective goals that the EU is trying to promote. This can be done through the implementation of incentives. By doing so, companies in some countries can be encouraged to prioritize sustainability efforts. In addition, to mitigate the risk of free riding, the establishment of strong regulatory frameworks can create conditions can ensure that all companies in EU countries adhere to minimum environmental performance standards, thereby imposing penalties or sanctions on those who fail to meet their sustainability obligations.

7.3 Implications for ESG as an Incentive for Green Innovation

According to Laffont and Martimort's (2002) Incentive theory is widespread in many areas of economics but is not central to economic thought. For this reason, it will be pointed out how the three economic theories analyzed in the literature review, combined with the results of the study conducted, will results in incentive theory.

In an incentive theory we face a principal-agent model where a principal (the country) assigns a task to an agent (firms, organizations or institutions responsible for green innovation) and the agent's decisions influence the principal's utility (Laffont & Martimort, 2002). We had already analyzed a similar model in the agency theory where the principal (citizens) can monitor, through ESG ratings, the performance of the agent (government) in promoting sustainable practices and green innovation. In addition, through stakeholder theory, it has been shown that stakeholder interests possess intrinsic value, and through incentive theory, the control of information asymmetry between the principal and the agent is deepened. Regarding green innovation, this may imply that the nation does not have complete knowledge of sustainability initiatives or the environmental effects of agents. To be effective, incentives must be created in contracts that support the agents' desired behavior (Laffont & Martimort, 2002). In addition, we know that the EU uses the theory of institutional pressures to model the behavior of organizations (Arranz & Arroyabe, 2023). This can expand into a context where a country with a high ESG rating can shape the idea of potential innovators by promoting that generating environmentally friendly innovations will be profitable. This is consistent with the incentive compatibility notion, which aims to balance the interests of the agents, or innovators, and the principal, or nation.

To ensure that agents are inclined to participate in green activities, incentives for green innovation must also address the trade-off between efficiency and revenue extraction (Laffont & Martimort, 2002). In the case of green innovation, this means striking a balance between the need to support innovation and the need to ensure that innovators do not profit at the nation's expense. Countries are seen as rational actors motivated by the desire to maximize their own utility or benefits within the framework of incentive theory in economics (Laffont & Martimort, 2002). The Word Economic Forum (2019) highlights how investing in technologies enables nations to achieve long-term success and profitability, and if moreover such innovations are green, social welfare and environmental conservation will be promoted at the same time. Therefore, nations that take the lead in the development of cutting-edge green technologies can benefit from reduced production costs through the implementation of more efficient and environmentally friendly procedures. This benefit can increase a nation's overall economic vitality and competitiveness in the EU and global market.

The results of the analysis are perfectly in line with the economic incentive theory just described. Consequently, we can say that countries would find themselves motivated to integrate ESG principles into their business strategies if this were done through a recognition of the potential associated benefits. This proactive approach not only creates an acceleration for future sustainable innovations and patents, but also produces real financial gains for EU-based companies and associations.

8. Limitations and Conclusion

8.1 Limitation of the Study

The research methodology has several limitations. First, the decision to include variables with complete data from the World Bank's ESG data may have led to the exclusion of some important factors that influence ESG ratings. While this approach ensured data integrity, it may have overlooked dimensions relevant to the study. In addition, relying exclusively on two databases, World Bank ESG Data and OECD. Stat may not adequately capture the full scope of ESG activity and innovation in the EU. This is due to the possibility that other data sources, particularly in the case of green innovation, may provide additional insights that would expand the depth of the study.

From a methodological point of view, we know that ESG assessments were expressed with a time lag of at least one year, nevertheless, the effect could manifest itself over a longer period of time. This time bias may not have been fully captured, reducing the accuracy of the analysis. In addition, the inclusion of country-specific fixed effects helps reduce unobserved heterogeneity but may fail to identify all country-specific factors that influence both ESG ratings and green innovation. This limitation demonstrates the complexity of country comparisons in the EU context.

In addition, the quantitative focus of the study limits the ability to explore the qualitative aspects of the relationship between ESG ratings and green innovation. Consequently, the ability to draw firm conclusions about the causal impact of ESG ratings and green innovation is therefore limited, as the study mainly examines correlations rather than causal relationships between them.

The ESG ratings landscape poses further limitations, as the lack of standardization, and thus harmonization, on the definition of ESG ratings at the country level could cause inconsistencies and distortions. This could occur when it is necessary to deal with other ESG ratings derived from other data sets, as in the latter case the complication in cross-country comparisons will increase.

An important limitation is also the potential for reverse causality. Although the analysis shows the positive association between higher ESG ratings and an increase in green patents, it is also possible that companies with more green patents receive higher ESG scores. This reverse causality complicates the interpretation of the relationship between ESG performance and innovation.

Also worthy of note is the circumstance whereby the analysis is conducted at the country level even though innovation activities are typically undertaken at the firm level. This is due to data restrictions, as the study approximates the relationship between firms' ESG scores and green patenting using country-level data.

8.2 Summary of Fundings

In this investigation, an in-depth analysis of EU member states' ESG performance and its connection to green patents over a 15-year time period, which is 2005 to 2020, was conducted.

The results of the study lead to the conclusion that environmental, social and governance management within the EU member states varies significantly from country to country. In fact, Finland, Sweden, and Denmark possess high ESG ratings due to their sustainable policies, significant investments in health care, and strong institutional frameworks. In contrast, countries such as Bulgaria, Poland, Romania, Malta and Croatia struggle to address the challenges of air pollution and social inequality. However, the latter countries are still only in the early stages of implementing green patenting policies, and following the results expressed in this research that show the positive correlation between EU member states' green patents and ESG ratings from 2005 to 2020, there is a drive towards ensuring that most countries will be able to report the same results as the countries that are now leading the way.

The robustness analysis conducted validates the strength of the results, suggesting that they are not disproportionately influenced by a single country. Overall, the results underscore the central role played by ESG assessments as catalysts for sustainable innovation, highlighting the potential for economic growth, competitiveness and environmental conservation in the EU.

8.3 Contribution to Existing Knowledge

Through the conducted research, it was possible to broaden the discussion on the relevance of green innovation in the context of environmental, social and governance (ESG) factors. In such a manner, the various aspects of green innovation, including definitions, applications, and significance for organizations and countries, were explored in depth. The study provides a complete overview of the role of these innovations in promoting sustainability and economic development.

In addition, through the use of agency and stakeholder theory, the roles of governments, institutions, and stakeholders in promoting green innovation and sustainability were explored. This theoretical framework enhances the understanding of governance dynamics and stakeholder involvement in sustainability initiatives. Indeed, through institutional theory it was also possible to understand how the institutional pressures succeed in shaping sustainability practices, and green innovation efforts, providing insights into the broader institutional context that influences sustainability initiatives.

It can therefore be concluded that the study provides insight into existing knowledge, emphasizing the importance of sustainable practices in driving innovation and economic prosperity over time. In particular, it proposes strengthening ESG regulations, promoting collaboration and increasing R&D investment as effective policy measures to promote sustainable practices and foster green innovation.

8.4 Recommendations for Future Research

In terms of future research on similar topics, addressing the limitations identified in both methodology and data sources will be critical to improving the knowledge of the relationship between ESG ratings and green innovation in the EU.

This involves broadening the scope of data collection, both in terms of the variables required to calculate ESG ratings and the data used to assess green innovation. This letter deeper approach to data collection would increase the comprehensiveness of analysis.

Given that the effects of ESG ratings on green innovation may take longer to materialize, methodologically speaking, future research could investigate longer time frames to fully capture these effects. Furthermore, more advanced techniques that account for country-specific factors in addition to fixed effects might enhance the quality of comparative analyses within the EU.

Additionally, by working to standardize the definition of ESG ratings, governments are reducing biases and inconsistencies in cross-national comparisons and enhancing the validity of research findings in the future.

Future research projects that take these suggestions into consideration are probably going to increase the knowledge of ESG ratings and how they affect green innovation, which will lead to better sustainable practices and policy both inside and outside of the EU.

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