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GREEN PATENTS AND ESG SCORES: EVIDENCE FROM THE WORLD'S TOP R&D INVESTORS

BREVETTI VERDI E PUNTEGGI ESG: EVIDENZE DAI PRINCIPALI INVESTITORI IN R&S DEL MONDO

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INTRODUCTION

In recent times, there has been increasing attention to sustainability by companies and investors. Environmental, social, and governance (ESG) factors have become prominent in the realm of investment choices. Investors are progressively searching for companies that introduce sustainable practices.

As a result, companies that invest in Research and Development (R&D) to develop sustainable technologies and products, are more likely to attract investments and achieve better innovation performance in the long run.

This work delves into the relationship between green patents, ESG scores, and corporate sustainability within the context of the world's top 2000 R&D investors. The study will analyze how these elements influence the innovation performance of companies during the years 2016-2018. The primary goal is to explore and analyze this correlation, shedding light on its implications and significance within the domain of innovation performance and environmental awareness.

The study undertakes a thorough examination of the literature review, carefully delineating the methodologies and resources used to gather the necessary information.

The analysis also looks into the benefits of creating a collection of environmentally friendly patents for both companies and society as a whole. It delves into the synergy between green patents and corporate sustainability, while also considering the broader societal benefits arising from efforts in green patenting.

Throughout the research, I will reference different existing works that elucidate the dynamic connection between ESG scores and patents. At the same time, the study addresses the drawbacks of existing research and identifies the areas that this work tries to improve.

The thesis is structured in the following chapters: Chapter 1 introduces the topic of green patents, emphasizing their importance in the context of corporate sustainability. This chapter explores the challenges and opportunities in developing a green portfolio as well as the main relationships existing between patenting and the R&D component, analyzing overall benefits and opportunities.

Chapter 2 offers a literature review that includes an introduction to ESG scores, reference agencies, and the metrics they use. It analyses the various definitions and notions related to these topics and identifies the main gaps in the literature which, in part, this thesis attempts to fill.

Chapter 3 presents a general overview of the existing literature on the relationship between ESG scores and green patenting, to provide examples and details proposed by economic researchers on this particular topic.

Chapter 4 delves into the formulation of the dataset used for the empirical analyses, detailing the procedures of data collection, linkage, and preparation, highlighting the crucial variables contained in the final dataset.

Ultimately, Chapter 5 presents the results of the empirical analysis. This section examines the interplay between green patents, ESG scores, and corporate sustainability, performing econometric analysis with the aim of obtaining results that show whether or not there is a relationship between these components and, if so, in what direction this correlation moves.

Chapter 1

Green patents and eco-innovation

The purpose of this study is to examine the connection between R&D investment, green patent applications and Environmental, Social and Governance scores (ESG scores) specifically analyzing the interdependencies between eco-sustainability scores and green patenting activities and their impact on innovation performance over the years 2016 to 2018 of the top investors in R&D globally.

Research and development refers to systematic and creative efforts to advance the existing knowledge base, which includes various aspects of humanity, culture, and society. The primary goal of R&D is to use this knowledge to devise innovative applications (OECD, 2012). In detail, R&D activities encompass three main areas: basic research, applied research, and experimental development.

Basic research involves acquiring new knowledge and understanding phenomena and observable facts without immediate practical application. Applied research strives to attain innovative insights tailored for specific practical applications.

Experimental development builds on existing knowledge to create new materials, products, devices, introduce innovative processes, systems, and services, or enhance existing ones.

For international comparisons, gross domestic expenditure on R&D (GERD) is the key metric used. It includes total investment in R&D by resident entities like companies, research institutes, universities, and government labs, considering R&D funding from abroad but excluding domestic funds allocated for R&D conducted outside the domestic economy (OECD, 2021).

Research shows that companies prioritizing R&D investment are more likely to develop sustainable technologies and engage in green patent applications (Arya et al., 2018).

Patents are intellectual property rights that grant its holder an exclusive right to takes advantage of an invention in a specific territory and for a specific period, and serve as protection mechanisms for inventions created by companies, institutions, or individuals, making them indicative of innovative developments.

Specifically, green patents relate to products or designs that provide environmental advantages, encompassing items or phenomena contributing to reduced energy consumption or a positive environmental impact (OECD, 2021). Furthermore, green patents can be used as a measure of a company's commitment to environmental sustainability (Zhang et al., 2019).

ESG scores are metrics assessing companies' environmental, social, and governance performance. Rating agencies evaluate and rate companies based on ESG performance, considering the operational impact on the environment, society, and internal governance. Such scores help investors measure sustainability and ethics, impacting investment decisions (Refinitiv, 2022).

Companies with high ESG scores tend to invest more in R&D, develop more sustainable products, and have a better environmental performance (Chen et al., 2022; Wang et al., 2019). Additionally, companies with high ESG scores are more likely to attract sustainable investments and have a better innovation performance in the long run (Grewal et al., 2019; Kusi-Sarpong et al., 2019).

In this chapter, I will explore the existing literature on the relationship between investments in R&D, green patents, and eco-innovation, with the aim of providing a comprehensive overview of this highly topical issue.

1.1 Green patents: exploring ecological innovations

According to European Patent Office (EPO)[1], green patents refer to patents filed by applicants with the European Patent Office pertaining to technology related to waste management, wind power, geothermal energy, solar energy, tidal energy, and biomass. The selection of patents falling under these technology areas is determined by the international patent classification code.

These intellectual property rights can serve as an indicator of a company's attention to environmental sustainability.

The classification of each patent, for my area of interest, is carried out based on a technology class (i.e., the field to which the patent applies). If the patent has the potential to contribute to environmental solutions, it is referred to as a "green patent."

The Organization for Economic Cooperation and Development (OECD), specifically created guidelines for this purpose and used them to classify "green patents."

According to this classification, patents related to environmental technologies are distinguished among various environmental technology categories, including environmental management, water resource adaptation technologies, biodiversity protection, ecosystem health, climate change mitigation technologies related to energy production, and waste water treatment or waste management (WIPO, 2022).

The OECD classification system is designed to provide a standardized approach to the classification of green patents, which is essential for monitoring the development and diffusion of environmentally friendly technologies.

The classification system allows researchers to identify trends in the development of green technologies, as well as the companies and countries that are leading the way in this area.

[1] EPO is an european organization responsible for granting European patents. Founded in 1977, the EPO now has 38 member countries and is one of the world's leading patent offices, providing a unified patent system for Europe. Headquartered in Munich, Germany, the EPO is responsible for granting and administering European patents internationally, as well as publishing information about European patents, and maintaining a database of European patents.

In addition to the OECD classification system, other organizations and databases provide information on green patents and their classification. For example, the Joint Research Centre (JRC[2]) and the OECD maintain the JRC/OECD Corporate R&D Investment (COR&DIP[3]) database, which provides information on corporate R&D investments and the green patent portfolios of individual companies. The Worldwide Patent Statistical Database (PATSTAT[4]) also provides information on the classification of green patents, as well as other patent-related data.

Overall, categorizing green patents serves as a significant instrument to monitor the progress and dissemination of eco-innovation technologies.

1.2 The challenges and opportunities of developing a green portfolio: patents and trademarks

As per the European Commission's 2019 Scoreboard, differentiating between patents and trademarks is essential due to their specific applications. This evaluation offers a comparative analysis of Research and Innovation achievements among EU Member States, other European countries, and regional neighbors. It supports nations in assessing the pros and cons of their national innovation systems, empowering them to identify and confront potential challenges.

The portfolios of the top 2,000 global investors exhibit variations based on their respective operating sectors, influencing the utilization and adoption of their intellectual property assets. Intellectual property, encompassing patents and trademarks,

[2] JRC is the European Commission's Joint Research Centre (JRC). It employs scientists to carry out research in order to provide independent scientific advice and support to EU policy-making.

[3] COR&DIP stands for Corporate R&D Investment and Patenting database, which is a joint initiative of the European Commission's science and knowledge service and the Organisation for Economic Co-operation and Development (OECD). The database provides comprehensive information on corporate (R&D) investments and patenting activities, including green patents related to environmental technologies.

[4] PATSTAT is a worldwide patent statistical database maintained by the European Patent Office (EPO). The database contains information on more than 100 million patent documents from around the world, including information on green patents.

grants exclusive rights to its proprietors. Nevertheless, significant distinctions exist between these two forms of protection.

An invention or novel concept, such as a method or device, is given temporary exclusive protection by a patent. The use of words, phrases, symbols, designs, logos, or even sounds to indicate the source of goods or services or to distinguish a product or service from those of rivals is protected by a trademark (Kotler, 2016).

A patent generally only lasts for a specific amount of time, which varies based on the kind of patent and the nation where it is registered, typically having a lifespan of 10 to 20 years. On the other hand, a trademark can be extended indefinitely as long as it is actively used and is renewed on a regular basis (Keller, 2008).

Patents and trademarks have separate registration procedures. Securing a patent requires a thorough application detailing the invention, which is then assessed by the appropriate patent office. Conversely, to register a trademark, applicants need to submit an application containing relevant information about the trademark and its intended use. In brief, trademarks protect names, symbols, and other distinctive marks connected to goods and services, whereas patents protect inventions.

Elaborating on this concept, it is also important to think about another aspect related to offices that handle intellectual property, especially within the IP5 group.

IP5 patent families are patents filed in at least two offices worldwide, including one of the five largest IP offices: the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), and the United States Patent and Trademark Office (USPTO) (OECD, 2023).

The establishment of IP5 aimed to enhance the effectiveness, caliber, and collaboration in the patent examination process among these offices, making IP5 patents a prominent subject in the realm of research and innovation and often serving as benchmarks for intellectual property worldwide.

The OECD, in collaboration with the JRC, aggregates IP5 patent data for the world's largest R&D investors. Despite the European Commission's 2019 Scoreboard identifying the top 2,500 R&D investors, this study specifically focuses on the top 2,000, as these are the investors who hold at least one patent in their portfolio.

Box 1 illustrates the distinguishing characteristics of these major investors.

BOX 1: Key Features of World's Top R&D Investors

• The World's Top R&D Investors are described as the top 2,000 companies that each invested more than €30 million in R&D in 2018. These companies are grouped into five main sets: the top 551 companies from the EU, 769 companies from the US, 318 from Japan, 507 Chinese companies and 355 companies from the Rest of the World group

• The total amount of R&D investment of the world's top R&D investors in the 2019 Scoreboard (€823.4 billion) is equivalent to almost 90% of the total expenditure on R&D financed by the business sector worldwide (Eurostat, 2019).

• The top 2,000 R&D investors account for 87% of global business R&D expenditure by the private sector and 63% of patent filings across all technologies.

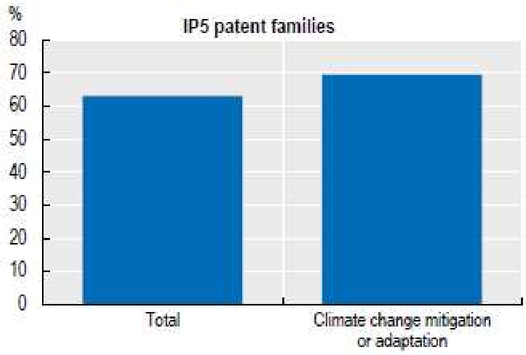
• R&D is highly concentrated within a few economies and sectors. The United States, EU27, China, and Japan together represent nearly 85% of the total R&D invested.

• The United States is the largest R&D-investing economy. The top three sectors, namely 'Computers & electronics', 'Pharmaceuticals', and 'Transport equipment', make up 56.5% of the overall R&D investment.

• Over the years, China has significantly increased its presence among the top 2,000 R&D investors, with the number of companies rising from 147 in 2012 to 365 in 2018, and the R&D share increasing from 3.7% to 11.3%.

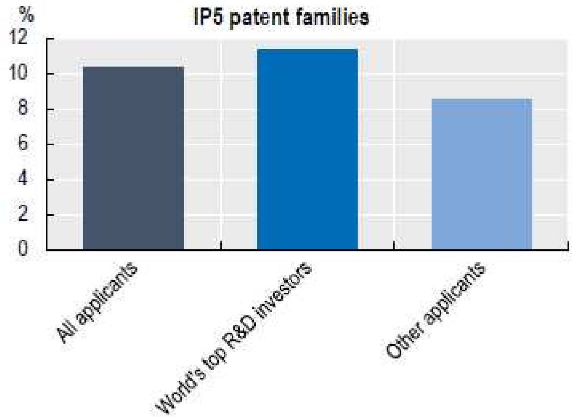
• The top R&D investors are major contributors to global climate-related innovation, owning 70% of climate change mitigation or adaptation patents and over 10% of climate-related trademarks.

Figure 1.1: Share of patents owned by the world's top R&D investors



Source: *JRC-OECD, COR&DIP©* database v.3, 2021.

Figure 1.2: Patents for climate change mitigation and adaptation



Source: *JRC-OECD, COR&DIP©* database v.3, 2021.

Leading global investors specialize in technologies, products, and services pertaining to climate change, as depicted in Figures 1.1 and 1.2, which highlight the importance ascribed to green patents by these R&D investors.

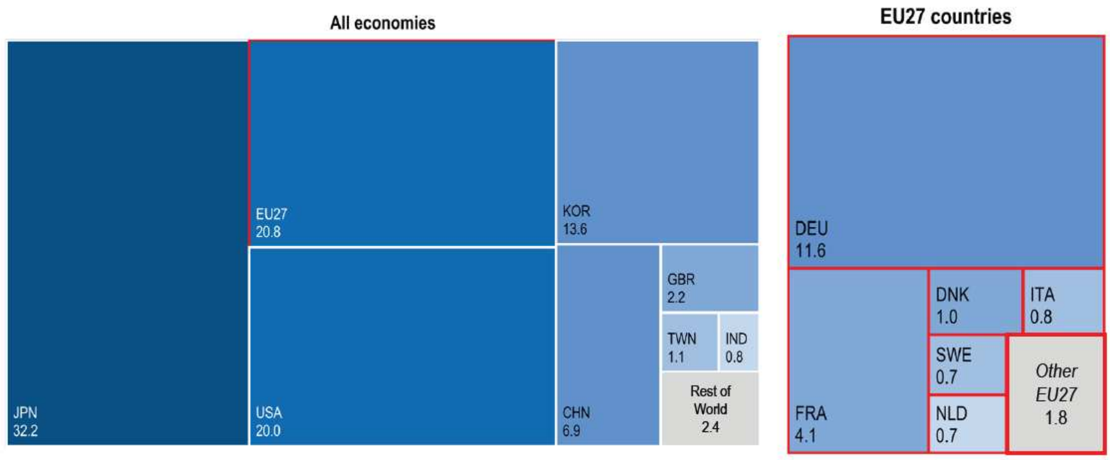
Figure 1.1, illustrates the percentage of patents filed by the top 2,000 corporate R&D investors worldwide during 2016-18, encompassing both general technologies and climate-related ones. The figure shows a substantial contribution of the top R&D investors to climate-related innovation. While they account for 63% of the total IP5 patent families globally, this percentage increases to 70% for climate change mitigation or adaptation (CCMA) patents, suggesting a focus on climate-related technologies and products.

Figure 1.2 confirms the focus of the top R&D investors on eco-friendly technologies, goods, and services. It shows the percentage share of climate change mitigation and adaptation patents for the period 2016-18, comparing the top R&D investors with other applicants.

Among all IP5 patent applications worldwide, around 10% are focused on addressing climate change through mitigation and adaptation technologies.

The leading 2,000 R&D investors put a greater emphasis, with over 11% of their patents dedicated to climate-related innovations, while other applicants allocate to them a share of about 8%.

Figure 1.3: Geographical distribution of IP5 patents among the top R&D investors, 2016-2018.



Source: *JRC-OECD, COR&DIP©* database v.3, 2021.

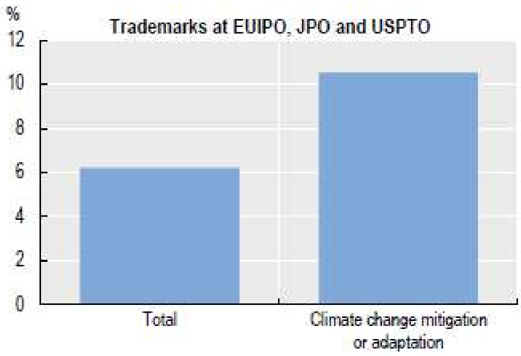
The majority of top R&D investors have complex corporate structures with multiple subsidiaries spread across various countries. Consequently, the inventors and research facilities involved in developing their inventions may be located in different parts of the world. Figure 1.3 illustrates the distribution of inventor locations for patents owned by these top R&D investors across countries and regions.

Inventor locations are determined by the address provided in published patent documents. Fractional counts are utilized to attribute equal shares of a patent to each inventor when the invention involves contributors from different countries, and this is then aggregated at the country level.

The top five economies in terms of inventive activity are Japan (32.2% of patents), the United States (20%), the EU27 (20.8%), Korea (13.6%), and China (6.9%).

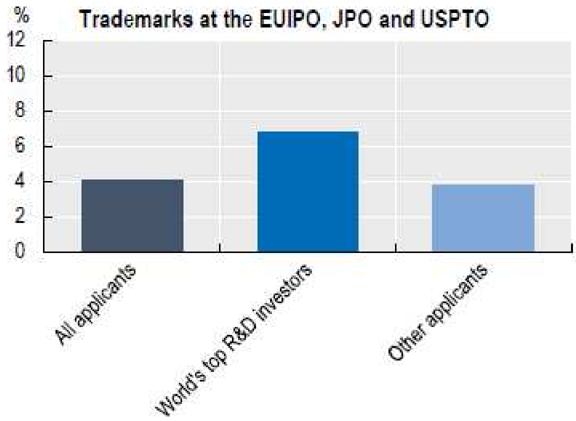
Remarkably, Germany accounts for more than 50% of patents invented within the EU. This shows that the world's top R&D investors draw knowledge from both their home economies and overseas locations.

Figure 1.4: Share of trademarks owned by the world's top R&D investors



Source: *JRC-OECD, COR&DIP©* database v.3, 2021.

Figure 1.5: Trademarks for climate change mitigation and adaptation



Source: *JRC-OECD, COR&DIP©* database v.3, 2021.

To provide a comprehensive overview of property rights, Figures 1.4 and 1.5 display the percentage of total trademarks owned by top R&D investors, along with trademarks related to climate change mitigation and adaptation.

Figure 1.4 illustrates that the top 2,000 corporate R&D investors globally possess over 10% of the CCMA trademarks, in contrast to slightly over 6% of the total trademarks. This greater ownership percentage highlights their specialization in climate-related technologies, goods, and services.

In the adjacent figure, number 1.5, the focus on the specialization for climate change mitigation and adaptation is extremely evident. Among the three majors intellectual property offices (EUIPO, JPO, and USPTO), the share of CCMA trademarks is approximately 4%. However, for the top 2,000 R&D investors, this share rises to 7%, while other applicants show slightly less than 4% dedication to climate-related trademarks.

1.3 The relationship between R&D and green patenting

The best way to assess the prospects for the diffusion of clean energy technologies is to measure the level of private investment in Research and Development and understand the relationship between these investments and technological innovation.

According to the 2019 EU Industrial R&D Investment Scoreboard, there is a connection between R&D activities and patenting. The report indicates that the top R&D investors possess 50% of the patents filed in the EPO and USPTO offices from 2012 to 2015. Additionally, the analysis of patents reveals that 9% of them are green patents, and out of this portion, 53% are owned by the top R&D companies.

However, the report also mentions that the correlation between the rankings of companies based on green patents and R&D expenditures is relatively weak, with Spearman's ρ not exceeding 0.51[5].

This suggests that the relationship between R&D and patenting is intricate and influenced by various factors, such as regulations, scientific advancements, demand factors, and firm capabilities.

Investments in R&D and research infrastructure are strongly correlated with innovations in energy technologies, according to a study that mainly focused on the United States as one of the leading global economies (Kammen, 2002).

Additionally, the authors of the report argue that "green patents" serve as a valuable indicator for shaping energy policy and that a correlation exists between companies linked to the world's largest economies, their total R&D expenditures, and the granted patents' count. This offers support for the theory indicating a substantial connection between R&D spending and the quantity of filed patents (Fekete et al., 2021).

[5] Spearman's ρ is a non-parametric rank correlation measure between two variables. It assesses the strength and direction of the monotonic relationship between data rankings without relying on specific data distribution assumptions. A ρ value close to 1 indicates a strong positive monotonic correlation, while a value close to -1 suggests a strong negative monotonic correlation. In this context, a ρ of 0.51 shows a relatively weak positive monotonic correlation between companies' rankings in terms of green patents and their R&D expenditures.

Pasimeni et al. (2019) propose and analyze the existence of a relationship between patents and R&D spending, and suggest that this relationship is stronger in the energy sector, where the impact of spending on R&D is most relevant.

Furthermore, the authors explain how patents function as a mechanism for safeguarding inventions, although not all inventions undergo the patenting process. The determination to patent inventions is contingent upon business strategies and the potential industrial application of the innovation. Patents are assets for organizations, so they can be acquired or licensed depending on the agreement between the parties.

More Research and Development does not automatically imply an increase in patenting activity: this is shown in Pasimeni et al. (2019), where it is illustrated that in the pharmaceutical sector, an increase in R&D activity could result in higher patent quality rather than an increase in companies performing patenting activities.

Patents, therefore, play a dual role in the innovation process, both as an incentive and an obstacle, as they prevent others from using protected inventions.

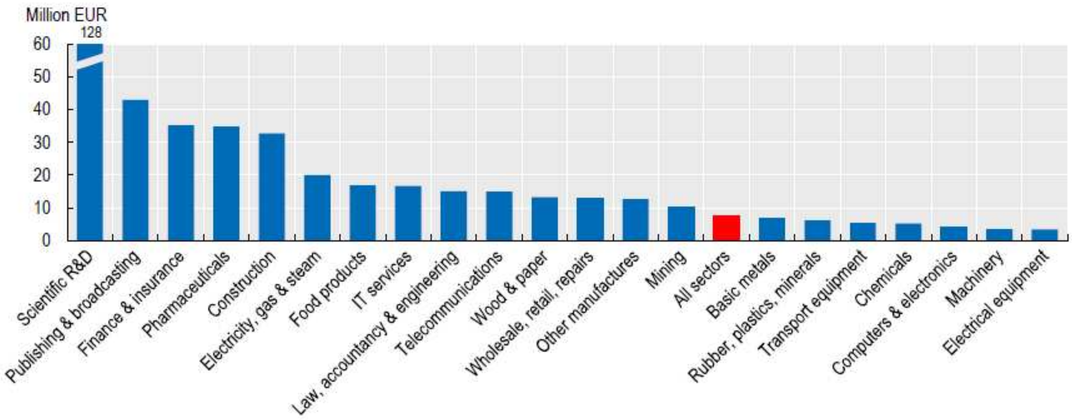
In order to provide a comprehensive understanding of the following Figure 1.6 below, it is important to note that it depicts the average R&D investment per patent across various sectors. This measure should be approached with caution because not all R&D investments directly result in patents. Companies may invest significantly in R&D without necessarily seeking patent protection, opting instead to safeguard their research findings through other means, such as trade secrets[6]. Additionally, some research outcomes may not be suitable for patenting or may not yield valuable patentable outputs.

It is crucial to acknowledge that R&D investments and patent applications are not simultaneous, as there is a time delay between the initial R&D investment and the eventual filing of patents. As such, directly correlating a specific R&D investment

[6] Trade secrets are confidential business information that provides a company with a competitive advantage and is not generally known to the public or easily accessible by others. These can include formulas, processes, methods, techniques, or other valuable information that gives a company a unique edge in the marketplace. In contrast to patents, trademarks, or copyrights, trade secrets are kept confidential and not disclosed to the public, which renders them a valuable and safeguarded asset for businesses (Lai, E. 2020)

made at time t to a specific patent filed at time $t + x$ is practically unfeasible. Nonetheless, this indicator serves to illustrate how R&D activities within an industry lead to patentable outputs.

Figure 1.6: R&D investment per patent for the leading global R&D investors by sectors, 2016-2018.



Source: *JRC-OECD, COR&DIP©* database v.3, 2021.

As an indication of the effort devoted to patent production, Figure 1.6 presents the average R&D investment per patent by sector. Despite the cautionary information already discussed, the indicator is meaningful as it conveys the idea of how easily R&D activity within an industry leads to patentable outputs.

Considering R&D investments per patent as a measure of R&D cost, the "Scientific R&D" sector leads in this area with €128 million spent per patent, to the extent that it is literally off the chart. The "Publishing and broadcasting" sector comes in second with just over EUR 40 million, closely followed by "Finance & insurance," "Pharmaceuticals," and "Construction," all of which record one patent for approximately every €35 million of R&D expenses. On the opposite end of the spectrum, sectors like "Chemicals" and "Machinery" register investments well below €5 million per patent.

Overall, researchers highlight the significant impact of national policies on multinational corporations, particularly those analyzed in this study. Regulators need to consider how these policies affect the international operations of companies. Hence, it is crucial to have extensive evidence regarding the allocation of R&D budgets and the internationalization levels of multinational corporations.

1.4 The social and economic benefits of green growth for companies and society

The pursuit of sustainable development and the transition to a low-carbon economy have become paramount in addressing global environmental challenges. As part of this transition, green technology and innovation play a key role in mitigating the negative impacts of climate change and ensuring environmental sustainability.

The economic and social benefits of green patents affect not only companies but also society as a whole, promoting technological progress, environmental protection, and economic growth. By providing inventors with commercialization opportunities and legal protection, green patents encourage further investment in R&D in the field of green technologies.

The concept closely linked to the economic benefits of adopting green patents is the idea of green growth. Green growth is suggested as a key element in sustainable development: on the one hand, it protects the environment, while on the other hand, it allows for economic development.

Undoubtedly, this is a feature that makes the concept increasingly attractive to policy-makers and other decision-makers, as traditional approaches to environmental protection argued that such protection would lead to economic stagnation.

Governments around the world have increasingly embraced the process of green growth to underline and promote their ambition for cleaner economies. The central principle of this narrative is that of economic opportunities rather than challenges arising from the pursuit of environmental sustainability (Capasso et al., 2019). In fact, the OECD (2011) defines green growth as promoting economic growth and development while ensuring that natural assets continue to provide the environmental resources and services on which our well-being depends, a notion consistent with the natural-resource-based view (NRBV[7]).

Several studies highlight the idea that unsustainable growth driven by most human activities, particularly the consumption levels of higher income classes, degrades the environment (IPCC, 2014).

The most widely accepted solution to prevent environmental degradation is green growth which decouples the use of natural resources and environmental impacts from the continuation of economic growth (Sandberg, Klockars, & Wil, 2019).

It is evident that continuous economic growth will not contribute to the sustainable use of natural resources. Therefore, economic growth cannot drive green growth, but the reverse is possible. Green growth brings about structural changes in the organization and behavior of businesses and society, including substantial reductions in unsustainable production and consumption levels in developed countries (Jackson, 2016).

In situations where limited space is available to curtail private demand, it becomes crucial for governmental initiatives to guide technological advancements and investments toward environmentally sustainable growth. This approach aims to avert the diversion of investment funds into short-term, environmentally detrimental technologies, as highlighted by Capasso et al. (2019).

An emphasis on and a corresponding set of policies for green growth can then rectify areas of the economy where markets do not automatically function with concern for the environment.

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[7] NRBV is a strategic management theory that emphasizes the significance of natural and environmental resources as a source of competitive advantage for businesses. It posits that natural resources, such as control over raw materials, sustainable resource management, and adoption of eco-friendly technologies, can positively influence both economic and environmental performance of an organization.

Green growth can help economies overcome these and other needs sustainably, respecting the environment and achieving economic growth by rejuvenating declining industries or transitioning to new areas of (green) industrial growth. Thus, policies for green growth are the basis of a new technological revolution and industrial leadership in emerging green industries that, at least in theory, should enable new forms of long-term growth (Bowen & Fankhauser, 2011).

Therefore, we predict that green growth promotes economic growth by catalyzing investments and innovations that will maintain sustainable development and give rise to new opportunities for economic growth (Jacobs, 2013).

Among the hypotheses formulated by Fernandes et al. (2021), one is of particular importance, stating that green growth has a positive direct impact on economic growth. The research has found partial support for this hypothesis, suggesting that green growth does not hinder economic development but rather has a positive impact on it. However, the paper emphasizes that there are significant challenges in implementing green growth policies and that it is not a flawless solution for environmental sustainability. Overall, the study suggests that achieving this type of growth is feasible but demands substantial commitment from governments, businesses, and society at large.

Green patents can create business value for companies and contribute to the development of sustainable technologies: in addition, properly designed environmental regulations can stimulate innovation and lead to increased business competitiveness, with positive economic and social impacts. (Fabrizi et al., 2018).

These authors, stress what are called research networks. These can contribute to environmental innovation by facilitating the exchange of knowledge and expertise among different actors, such as businesses, universities, and public institutions.

The paper also notes that there is a positive and significant correlation between the total number of participants in European environment-related framework programs and green patents, suggesting that networks focused on green research play a crucial role in promoting environmental innovation.

In addition, the idea of research networks is extremely related to that of environmental regulation, which is analyzed by a hypothesis raised by Porter (Porter and Van der Linde, 1995).

This theory proposes that well-designed environmental rules can encourage new ideas and lead to stronger business advantages. The hypothesis has three versions: weak, narrow, and strong. The weak version argues that environmental regulation can stimulate innovation, the narrower version suggests that flexible regulatory policies are preferable to prescriptive forms of regulation, and the strong version asserts that environmental regulation can lead to an increase in the competitiveness of enterprises. Porter's hypothesis is relevant to environmental innovation because it suggests that environmental regulations can encourage companies to develop new technologies that reduce emissions and improve environmental performance.

In summary, green patents, research networks, and effective environmental regulations play a crucial role in promoting the transition to a sustainable and environmentally friendly future. The engagement of multinational companies in this area underscores the importance of global collaboration in addressing environmental challenges and promoting a greener world.

1.5 The implications of green patenting for investors and other stakeholders

There is no innovation without investment, and no company or sector can thrive in the global economy without embracing innovation. The key to successful innovation lies in identifying areas where the return on innovation capital is highest (Cohen et al., 2020).

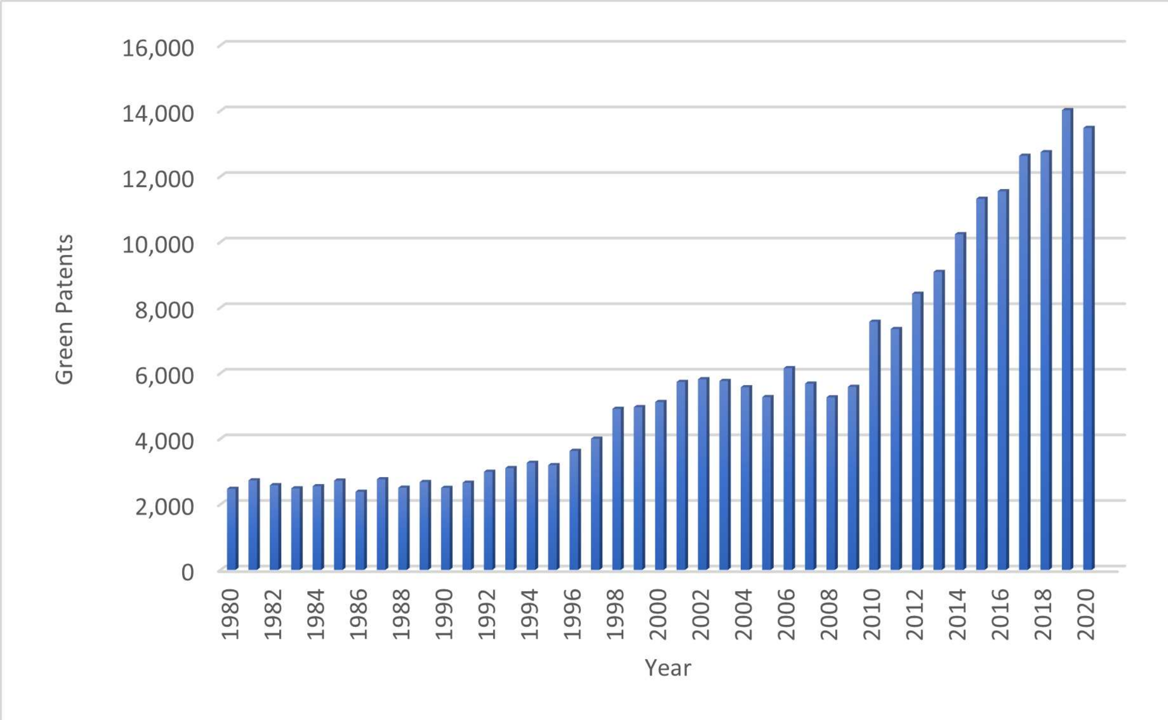
The implications of green patents for investors and other stakeholders are important as they reflect the growing importance of sustainable technology and green innovation in today's business landscape.

From the study conducted by Cohen et al. (2020), there is a strong relationship between ESG scores and green patenting. This correlation is also evident in Figure 1.7, where a distinct rise in granted patents for publicly traded companies is observable, starting in 2008 (the year in which ESG ranking data begins for the study considered by the authors themselves). A public company is an entity wherein shareholders possess a stake in the company's assets and earnings. Ownership of such a company is distributed among the general public through the unrestricted trading of stock shares on stock exchanges.

This progressive and growing importance of green technologies demonstrated by the above graph, shows an extremely positive trend in the number of green patents granted to publicly traded companies. Taking into account the year 2020, there has been a remarkable increase, causing the total count to triple over the last two decades.

There are, of course, a number of reasons driving investment in eco-friendly practices as well as the adoption of green patents. The direct approach is represented by investors who prefer ESG funds who are willing to sacrifice a small amount of risk-adjusted returns to achieve performance consistent with ESG goals. Other perspectives include consumers considering the value of ESG compliant products, who may be willing to pay more for such products, or the competitive advantage of ESG compliant companies by ways to attract skilled people or get better working conditions (Cohen et al., 2020).

Figure 1.7: Total number of green patents granted to publicly traded firms over time.



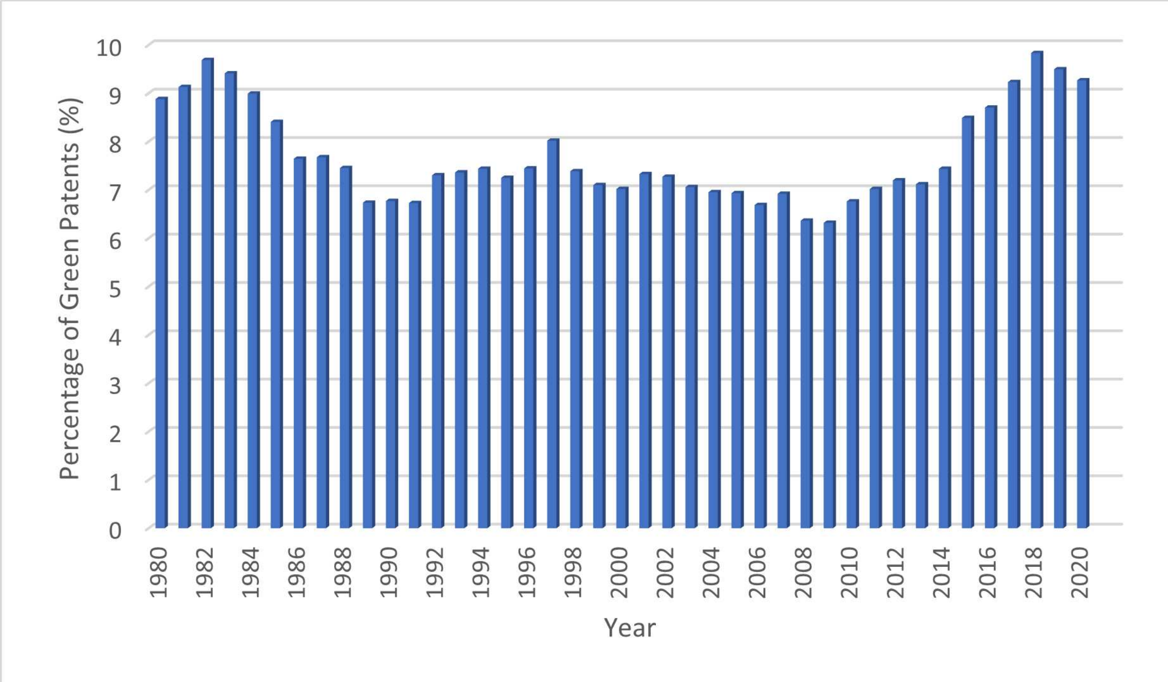
Source: *Own graph from Cohen et al. 2020: Working Paper 27990.*

The data reflects a significant increase in green patents over the years, indicating a growing focus on developing environmentally friendly solutions. This aligns with the observations made in the text regarding the implications of green patents for investors and stakeholders.

The year with the highest number of green patents is 2019, with 14,018 patents produced, making up 9.3 % of all patents produced by publicly traded companies in the same year. The upward trend of green patents suggests that companies are increasingly investing in sustainable technologies and innovations when looking at the data in absolute values.

Analyzing the observations in percentage terms, in light of the information provided in the figure above, a distinct scenario emerges.

Figure 1.8: Share of green patents compared to total patents over time.



Source: *Own graph from Cohen et al. 2020: Working Paper 27990.*

Figure 1.8 presents the share of green patents compared to total patents by year, from 1980 to 2020. The graph illustrates a pattern that has been predominantly favorable during specific periods, intermittent drops in the proportion of eco-friendly patents owned by publicly traded companies.

The peak reached in the early 1980s could be attributed to these companies' response to the crisis of rising oil prices, which occurred during the 1970s. Considering that the concept of renewable energy was not yet fully developed, it's possible that these companies adopted energy-efficient strategies, seeking to new processes and solutions allowing lower oil consumption.

The trend of environmentally friendly inventions experienced a slowdown towards the late 1980s, remaining relatively stable until 2010 with minor fluctuations. However, starting from 2010, a significant growth in green inventions emerged, peaking in 2018. In that year, the share of green patents reached approximately 10% of the total, returning to levels similar to those recorded in 1982.

Companies with a significant number of green patents are likely to be at the forefront of sustainable innovation, making them an attractive investment. These companies often have a competitive advantage in their industry because of their ability to meet the growing demand for environmentally friendly products and services: in addition, green patents can be a strategic barrier to potential competitors.

Companies with green technology patents can dominate the market by protecting their innovations from imitation and maintaining long-term profitability.
This dynamic creates a favorable investment environment for stakeholders seeking sustainable and stable returns. In addition to financial gains, sustainability investors can align their portfolios with their values by supporting companies that carry out sustainable activities.

As global environmental awareness continues to increase, companies that prioritize sustainability can gain recognition in the market and foster consumer loyalty. Such an atmosphere of cooperation can lead to accelerated development of green technologies that will benefit society as a whole by solving pressing environmental problems.

However, there are also problems. There are legal and intellectual property risks for companies applying for green patents. Stakeholders should be aware of potential patent disputes or infringements that may arise as the green technology market becomes more competitive.

Chapter 2

ESG scores as indicators of corporate sustainability

The formal definition of ESG was established in 2004 by the United Nations Global Compact[1]. Today, many companies are implementing ESG strategies, investors are developing ESG-focused products, and regulators are formulating corresponding policies. This growing interest in ESG is fueled by the increasing availability of consistent ESG data, leading to more comprehensive assessments that cover various actors, including companies, investors, countries, and even individual products.

The analysis of ESG ratings starts with understanding the fundamental aspects that constitute this framework.

The term *"Environmental"* refers to the natural world, with a focus on issues such as climate change, carbon emissions, air and water pollution, waste management, and deforestation.

"Social" considerations, on the other hand, encompass matters of equity, inclusivity, labor practices, investments in human capital and communities, and human rights. It is worth noting that environmental and social considerations often overlap and intersect.

As for the *"Governance"* component, it denotes the evaluation of a company's

[1] The United Nations Global Compact is a voluntary initiative launched by the United Nations to encourage businesses and organizations worldwide to adopt sustainable policies and practices.

leadership, decision-making processes, and overall corporate structure to assess its level of transparency, accountability, and ethical behavior. It plays a pivotal role in ensuring that companies integrate environmental and social concerns into their determinative procedures (Grewal et al., 2019). Effective governance practices can assist companies in mitigating risks and improving their ESG scores (Chen et al., 2022).

These indicators guide companies in achieving specific business outcomes and promoting ethical corporate governance. The business sector has increasingly recognized the importance of evaluating ESG criteria when managing different types of investments that prioritize social and environmental responsibility and governance founded on moral values. It is crucial for all companies, regardless of their mission or objectives, to undergo an assessment of these measures.

Multiple analyses have shown that companies with higher ESG ratings tend to outperform others and demonstrate greater resilience to risks arising from emergencies and crisis situations (Moalla & Dammak, 2023).

RobecoSAM[2], for instance, outlines in its 2018 publication that to earn a place in the sustainability yearbook, companies must demonstrate strong performance in corporate sustainability by scoring within 30% of the best performing companies in their industry.

This suggests that companies with ESG high ratings might be more likely to be recognized for their sustainability practices and could be more attractive to investors who place significant value on eco-friendly practices while at the same time being more financially able to cope with more challenging situations (RobecoSAM, 2018).

Companies can achieve long-term financial sustainability and enhance their reputation by incorporating ESG criteria into business processes, prioritizing sustainable practices that contribute to a greener future and improved business outcomes.

[2] RobecoSAM is an investment company specializing in sustainable investing and renowned for its expertise in ESG assessments. They provide sustainability data, research, and ratings to help investors make informed decisions based on ESG criteria. The Sustainability Yearbook acknowledges companies with strong sustainability performance. RobecoSAM applies ESG standards to all its investment processes, and its assessments are widely used by investors to evaluate sustainability practices and identify ESG-aligned investment opportunities. (RobecoSAM, *Sustainability Yearbook*)

2.1 ESG ratings and corporate green innovations: insights and implications

In the current landscape of global business, ESG ratings have garnered significant attention as tools to gauge corporate performance in terms of sustainability and social responsibility. Especially intriguing within this context is the interplay between ESG ratings and corporate green innovation.

Researchers have noted that the integration of ESG principles into corporate strategies has the potential to not only align business objectives with societal and environmental well-being but also foster innovation and competitiveness. Companies that embed sustainability considerations into their innovation processes can create new markets, products, and technologies that address environmental challenges while responding to changing consumer preferences (Porter & Van der Linde, 1995).

By leveraging ESG ratings to inform and guide innovation initiatives, companies can cultivate a culture of sustainability-driven innovation that transcends conventional practices.

The fusion of ESG ratings and corporate green innovations carries far-reaching ramifications for business dynamics. ESG ratings, which have transcended their role as mere assessment tools, now wield influence as drivers of sustainable and responsible corporate conduct. Embracing ESG metrics prompts companies to reevaluate their strategies with a sustainability-centered lens, initiating a sequence of proactive measures. This transformation often triggers a series of initiatives, including the integration of environmentally conscious principles into various operational facets.

This integration forms a cornerstone of a broader corporate commitment to environmental responsibility and innovation.

Some experts argue that ESG ratings provide an objective and effective measurement of companies' ESG efforts, offering comprehensive and comparable data to address information disparities, access resources, and mitigate regulatory and reputational risks (Cappucci, 2018).

Conversely, other researchers contend that ESG ratings lack efficacy, asserting that companies may merely conform superficially to external requirements to reap benefits without significantly enhancing their sustainability practices (Avetisyan & Hockerts, 2017).

These conflicting perspectives have sparked numerous research studies on the efficacy of ESG ratings, with many focusing on the correlation between ESG ratings and corporate financial performance or responses from the capital markets (Atan et al, 2016).

However, only a few studies have explored the impact of corporate investments in sustainability following the adoption of ESG ratings, and even fewer have investigated their influence on corporate green innovation.

For instance, Chouaibi et al. (2022) analyzed ESG practices in the British and German systems to enhance financial performance through leveraging eco-innovation.

On the other hand, Cohen et al. (2020) found an opposing relationship between ESG scores and green innovation in the energy sector. Nevertheless, existing studies are limited and predominantly focused on developed countries with more mature ESG systems.

As a result, companies in developing countries striving to enhance their environmental performance may consider adopting ESG ratings as a tool to drive green innovation and incorporate environmental considerations into their investment choices.

2.2 A review of the main categories of ESG metrics and rating agencies

The ESG rating assesses a company's performance across the alignment with sustainable development principles, social values and corporate governance. Rating agencies evaluate the sustainability practices of companies and institutions, providing ratings based on criteria related to the three ESG components.

A high ESG score reflects a high level of corporate social responsibility (CSR[3]), which can add value to the company. Therefore, ESG ranking is a useful indicator for assessing ESG's financial capabilities and identifying companies corresponding to investors' stability goals.

Investors also see sustainability as an attractive attribute of a fund, and funds with higher green scores receive a greater volume of investment. However, there are currently no clear standards on how to report ESG metrics, which makes it difficult to compare and evaluate companies' sustainability practices (Magnúsdóttir, & Berndtson, 2021). Despite this lack of standardization, I will present a general overview of the main ESG indicators commonly utilized by rating agencies and investors to evaluate a company's performance across the ESG framework.

Environmental Indicators

- **Carbon Emissions and Energy Efficiency:** This component comprises two distinct categories, each characterized by their unique attributes. The assessment of carbon emissions encompasses the meticulous measurement and analysis of greenhouse gas emissions, predominantly carbon dioxide (CO_2), emanating

[3] CSR is a business approach that involves a company's initiatives and actions aimed at contributing positively to society and the environment. Companies practicing CSR take into consideration the impact of their operations on various stakeholders, such as employees, customers, communities, and the environment. The goal of CSR is to go beyond mere profit-making and address social and environmental issues responsibly. (OECD, 2021)

from an organization's activities. These emissions are categorized into direct[4] and indirect sources[5]. This distinction provides a detailed understanding of an entity's carbon footprint, allowing for an assessment of its environmental impact. Simultaneously, the aspect of energy efficiency emerges as a strategic pursuit aimed at maximizing resource usage efficiency while reducing energy waste. This involves the adoption of practices and technologies such as the deployment of energy-efficient systems like LED lighting and advanced HVAC[6] systems, as well as process optimizations and the transition to renewable energy sources.

- **Water Management:** It implies systematic assessment, careful monitoring, and judicious conservation of water resources within business activities. It involves addressing both direct water use, which includes industrial processes and cooling systems, and indirect water use within the supply chain. In terms of optimizing water use within different production processes, there is the integration of water-efficient facilities, sophisticated recycling and reuse systems, and the adoption of advanced irrigation methods, especially in the agricultural sector. Prudent treatment and responsible disposal of wastewater from industrial processes are crucial imperatives. Companies, aware of the significant risk posed by water scarcity and quality problems, adopt strategies such as diversification of water sources, developing contingency plans, and integrating climate change considerations into operational frameworks.

[4] Direct emissions, categorized as Scope 1 emissions, stem from activities directly under the company's control, encompassing sources like on-site combustion and industrial processes.

[5] Indirect emissions capture both Scope 2 and Scope 3 emissions, including purchased electricity and the transportation of goods.

[6] Advanced HVAC, short for "Heating, Ventilation, and Air Conditioning," refers to more sophisticated and innovative technologies and solutions used to control the thermal environment and indoor air quality in buildings. These systems are designed to be more efficient, environmentally friendly, and intelligent compared to traditional HVAC systems.

- **Waste Management and Recycling:** This metric focuses on efficiently managing waste, recycling, and resource recovery across an organization's operations. It aims to reduce waste generation, improve waste management, and integrate circular economy principles to use resources more efficiently and reduce environmental harm. Key aspects involve separating waste, using advanced recycling tech, and repurposing materials to close the resource loop. In line with the circular economy concept, companies aim to get the most value from resources by adopting models like product-as-a-service and creating markets for refurbished items. In the digital era, responsible electronic waste management is crucial, encompassing strategies for collecting, dismantling, and recycling electronic devices to minimize environmental impact.

- **Biodiversity and Ecosystem Impact:** This indicator emphasizes biodiversity preservation through strategies like habitat restoration, protecting endangered species, and sustainable land use. It values ecosystem services that benefit humans, such as clean water and pollination. Companies are assessed on their efforts to support these services, and if they harm biodiversity, they must take steps to mitigate it, like habitat restoration and sustainable sourcing to avoid activities like deforestation or wildlife exploitation.

- **Renewable Energy Adoption:** It concerns on addressing climate change by transitioning from fossil fuels to renewable energy sources like solar, wind, hydro, geothermal, and biomass. It evaluates how much renewable energy a company incorporates into its operations, measuring its impact on carbon footprint and greenhouse gas emissions. The assessment looks at the capacity of renewable energy sources within the company, including investments in solar panels, wind turbines, and energy storage. It also considers the balance between renewable and nonrenewable energy sources.

Social Indicators

- **Diversity and Inclusion:** This indicator focuses on assessing a company's commitment to promoting diversity, equality, and inclusion in its workforce and leadership positions. Companies examine the demographics of their workforce, including gender, ethnicity, age, and other factors, aiming for a diverse representation that reflects society at large. Companies are evaluated based on the diversity of their leadership teams and board of directors, aiming for balanced representation.

- **Labor Practices:** It analyzes a company's approach to workers' rights, fair working conditions, and employee welfare. Wage levels are assessed against industry standards and living wage benchmarks to ensure that employees are adequately compensated. In addition, compliance with statutory working hours as well as workplace safety measures and policies are examined. Investment in employee training and skill development is also an integral part of this component.

- **Community Engagement:** It assesses a company's interactions and contributions to the communities in which it operates, starting with initiatives that have positive impacts on local communities, such as philanthropic programs, community development projects, and charitable activities. It also measures financial and non-financial contributions aimed at improving local infrastructure, education, health care, and quality of life.

- **Customer Welfare:** This welfare dimension focuses on the company's commitment to serving customers ethically and responsibly. The indicator contains the assessment of product quality and compliance with regulations to ensure customer welfare. Avoidance of predatory practices for pricing strategies and making services accessible to different customer groups are considered. Protection of customer data, privacy, and cybersecurity also fall into this category.

Governance Indicators

- **Board Composition and Indipendence:** This component evaluates the structure and independence of a company's board of directors in terms of gender, ethnicity, age, and skills in order to ensure a variety of perspectives in decision-making. The percentage of independent directors on the board is also considered to enhance the objectivity of decision-making and reduce conflicts of interest.

- **Executive Compensation and Accountability:** This metric relates to how a company compensates its top managers and ensures alignment with shareholder interests. Thus, it evaluates executive compensation linked to company performance, to encourage executives to make decisions that enhance long-term shareholder value, as well as the clarity and understandability of executive compensation information, to enable shareholders to understand the link between compensation and performance.

- **Ethical Business Practices:** This dimension assesses a company's commitment to ethical behavior and integrity. It examines policies and practices to prevent corruption, bribery, and unethical conduct within the company, as well as mechanisms to protect individuals who report unethical behavior by promoting transparency and accountability.

- **Shareholder Rights and Engagement:** It evaluates how a company engages with its shareholders and respects their rights by analyzing whether the company offers shareholders the opportunity to vote on key issues through proxy voting, allowing them to exercise their rights remotely. Furthermore, it considers the frequency and effectiveness of annual general meetings where shareholders can actively engage with the company's management and board members.

ESG rating agencies collect data on these indicators from a variety of sources, such as company statements, regulatory documents, and third-party data providers. This data forms the foundation for the rating process. Rating agencies identify key ESG issues relevant to a company's industry and operations through materiality assessment. This approach ensures a focus on issues with the greatest impact on value and sustainability.

ESG indicators within each category are assigned weights based on their significance (for example, carbon emissions indicators may carry more weight for environmental performance). Raw ESG data is often normalized to allow fair comparisons between companies of varying sizes, industries, and locations. After normalization, individual indicator scores are combined to calculate an overall ESG score, often using weighted averages.

ESG scores are typically displayed on numerical scales, usually ranging from 0 to 100, with higher scores indicating stronger ESG performance. Companies receive scores for each component—environmental, social, and governance—which provide insights into their performance in each dimension. The overall ESG score reflects a company's comprehensive performance across all three components, enabling comparisons of sustainability efforts. Peer group comparison benchmarks companies against industry peers, helping stakeholders understand relative performance.

Rating agencies often publicly disclose ESG scores and related information, fostering accountability and motivating companies to enhance their ESG practices.

In spite of the considerable effort from rating agencies to establish a transparent criterion in assigning these scores, the lack of standardization has led to the proliferation of a large number of rating agencies, each with its own methodology and criteria for evaluating companies.

Rating companies in the ESG field is a complex reality. Unlike credit ratings based on standard financial data, ESG ratings are based on inconsistent and incoherent reports. In addition, there are many variables, both quantitative and qualitative, used to assess ESG, just as there are many characteristics (environmental, social, corporate governance) observed for each criterion.

Therefore, it is important to develop common and unified standards that combine a company's goals, risks, and opportunities related to ESG aspects with objective, quantitative, and measurable values. Furthermore, ESG rating agencies must take a transparent and rigorous approach to corporate scoring to ensure the reliability of ratings and promote a sustainable corporate culture.

However, the ESG rating standardization process is still ongoing, and several initiatives are underway to promote the harmonization of rating criteria.

Sustainable business practices have become increasingly important, leading to the emergence of ESG rating agencies that provide information and tools to measure companies' contributions to sustainability.

These agencies are responsible for collecting and analyzing information on a company's ESG documents to provide investors with the information they need to make informed investment decisions. Nevertheless, the methods used by each ESG rating agency are different, and investors tend to check more than one ESG rating for a better understanding.

There are several ESG rating agencies in the world, the most famous are MSCI ESG Ratings, Sustainalytics, Refinitiv, Standard Ethics, Vigeo Eiris, EcoVadis, KLD, and RobecoSAM.

As per Berg et al. (2022), the current discrepancies among various rating agencies carry significant implications. This includes the likelihood of companies receiving conflicting signals from rating agencies regarding which stocks are expected to receive favorable market ratings, potentially resulting in reduced investments in formerly ESG improvement initiatives.

To highlight the divergence between the different ESG factors given by rating agencies, Figure 2.1 illustrates the main differences between the world's major rating agencies.

Figure 2.1: Correlations among ESG ratings at the aggregate level

	KL SA	KL MO	KL SP	KL RE	KL MS	SA MO	SA SP	SA RE	SA MS	MO SP	MO RE	MO MS	SP RE	SP MS	RE MS	Average
ESG	0.53	0.49	0.44	0.42	0.53	0.71	0.67	0.67	0.46	0.7	0.69	0.42	0.62	0.38	0.38	0.54
E	0.59	0.55	0.54	0.54	0.37	0.68	0.66	0.64	0.37	0.73	0.66	0.35	0.7	0.29	0.23	0.53
S	0.31	0.33	0.21	0.22	0.41	0.58	0.55	0.55	0.27	0.68	0.66	0.28	0.65	0.26	0.27	0.42
G	0.02	0.01	-0.01	-0.05	0.16	0.54	0.51	0.49	0.16	0.76	0.76	0.14	0.79	0.11	0.07	0.30

Source: *SSRN, "Aggregate Confusion: The Divergence of ESG Ratings"*.

As shown in the figure above, the weights assigned by each rating agency[7] to each component are compared. The agencies considered in this analysis are Sustainalytics, S&P Global ESG Ratings, Moody's ESG, Refinitiv, KLD, and MSCI.

Table 2.1 illustrates the pairwise Pearson correlations (ρ) between aggregated ESG ratings and between environmental (E), social (S), and governance (G) ratings, as well as among their ESG dimensions.

The ESG correlations have an average of 0.54 and range from 0.38 to 0.71. Sustainalytics and Moody's ESG have the highest level of agreement with each other, with a correlation of 0.71.

The environmental dimension has the highest correlation among the three dimensions, with an average of 0.53. The social dimension has an average correlation of 0.42, while the governance dimension has the lowest correlation, with an average of 0.30.

In this explanation, the focal and most significant column is the one corresponding to the Refinitiv agency (RE). As Chapter 4 will demonstrate, this platform facilitated the retrieval of ESG data for all the companies within the sample studied in this analysis.

According to Serafeim (2021), the surge in ESG activity has led to highly polarized opinions on its influence on corporate and investor behavior, performance implications, and the usefulness of ESG ratings and studies.

[7] SA, SP, MO, RE, KL, and MS are the abbreviations for Sustainalytics, S&P Global ESG Ratings, Moody's ESG, Refinitiv, KLD, and MSCI, respectively.

In the analysis of the link between ESG and corporate value, Serafeim's study demonstrates that ESG factors can positively impact financial performance, with several studies finding a correlation between ESG performance and outcomes such as increased profitability, lower cost of capital, and improved stock price performance.

Serafim's paper also discusses the limitations of ESG ratings, including challenges related to the multidimensionality of ESG factors and the difficulty in clearly observing associated outcomes. These issues make it challenging to assess the quality of ESG ratings accurately. Furthermore, disagreement among different raters can generate confusion and doubts about the reliability of ESG ratings.

Serafeim's study proposes that enhancing transparency and standardizing the evaluation process could lead to improved ESG ratings, thereby reducing confusion and increasing their reliability.

2.3 Exploring the nexus between ESG scores and R&D investments

ESG criteria and R&D investments are progressively recognized as interconnected aspects that drive corporate sustainability and social impact. The alignment of environmental, social, and governance considerations with Research and Development strategies offers promising opportunities for companies seeking to achieve sustainable innovation and competitive advantage.

As already mentioned in Chapter 1, R&D investments are essential for all companies competing in a market. An important indicator using this means of investment is R&D intensity (R&D expenditure divided by a firm's sales) which is becoming increasingly recognized as an important determinant of environmental quality (Gardiner & Hajek, 2020). Nevertheless, R&D investments can cause conflicts between stakeholders and managers due to their uncertainty regarding appropriability, the intensity of sunk costs, and the long pay-off period (Rodrigues et al., 2020).

Although the ESG literature field is rich with correlation research of ESG performance and financial performance, the literature on R&D investments, particularly on ESG, is scarce. However, ESG is considered a way to measure Corporate Social Responsibility, and there is a body of research that investigates CSR, specifically environmental performance, and R&D intensity.

Furthermore, Rothenberg & Zyglidopoulos (2007) discovered that companies with a strong focus on R&D are more inclined to achieve high levels of CSR performance.

Following that, Erhemjamts et al. (2013) found that firms with a strong focus on Research and Development were more likely to engage in socially responsible activities. Alam et al. (2019) found that R&D investment negatively impacts energy and carbon emission intensities, suggesting that such investment leads to efficient energy consumption and, consequently, lower carbon emissions.

Paramati et al. (2021) confirm that increasing R&D expenditures promote renewable energy consumption and play a key role in the reduction of CO_2 emissions. The correlation determined between R&D investment and environmental performance, or CSR performance is in line with the natural resource-based view (NRBV).

This is in line with what Hart (1997) argues, that volunteer environmental activities can often result in unexpected financial returns. Similarly, King & Lenox (2002) state that a firm's investment in R&D activities leads to improved productivity and reduced environmental costs. Corporate R&D achieves the reduction of environmental impact without compromising business performance in two distinctive ways.

Stimulating technological development not only enhances efficiency without escalating energy demand but also fosters the advancement and utilization of novel energy technologies, thereby reducing emissions and promoting the shift towards cleaner energy (Alam et al., 2019).

Magnúsdóttir & Berndtson, conducted a study in 2021 focused on exploring the potential relationship between ESG metrics and R&D expenditure, providing valuable insights for further research on the subject. The authors point out that if future research confirms a positive correlation between ESG metrics and R&D commitments, it would suggest that companies dedicated to sustainability may also be inclined to invest in innovation.

This finding could have significant implications for companies wishing to improve their sustainable practices, as investing in sustainability could foster innovation and increase competitiveness (Magnúsdóttir & Berndtson, 2021).

Moreover, ESG metrics provide valuable insights into the social and environmental risks that companies face. Integrating ESG considerations into R&D decision-making processes helps companies identify emerging sustainability challenges and develop innovative solutions that align with evolving stakeholder expectations.

The pursuit of ESG-oriented R&D investments not only demonstrates a company's commitment to responsible business practices but also enhances its reputation as a socially responsible and environmentally conscious organization.

In conclusion, the interdependencies between ESG and R&D present a compelling case for companies to embrace sustainable innovation and corporate social responsibility. By integrating ESG principles into their R&D strategies, companies can contribute to a more sustainable future while promoting business growth and social impact.

The next chapter will explore the relationship between ESG and green patents, offering a thorough review of the literature. Exploring the connection between ESG and green patents in more detail will provide a more comprehensive understanding, bringing attention to the potential alignment between sustainable innovation, corporate social responsibility, and intellectual property strategies.

Chapter 3

The interplay between ESG scores and green patents: an overview of existing studies

This chapter explores the intersection of sustainability and innovation, aiming to uncover the intricate relationship between ESG metrics, with a focus on the Environment component, and green patents.

Through a synthesis of empirical evidence and theoretical frameworks, it provides a comprehensive examination of how ESG metrics and green patents mutually influence corporate innovation, shedding light on their impact on innovative performance.

The chapter is organized into two sections that are divided into evidence for companies in Western countries and for companies in the Chinese market, aiming to offer an overview of the main implications of this intricate relationship in different contexts.

3.1 Evidence from Western countries

The trajectory of low-carbon technology innovation experienced a significant period of rapid expansion between 2005 and the early 2010s, followed by a subsequent global and country-level decrease in patents for clean energy technologies. However, this trend has been opposed by a growing interest in green patenting in recent years, supported by various studies, including the works of Pasimeni et al. (2019) and Grewatsch et al. (2016) which show a positive link between ESG and green innovation.

For instance, Grewatsch et al. (2016) discovered at the firm level that higher ESG ratings correlate with greater attention to green innovation. Flammer (2015) also noted a connection between high ESG ratings and more frequent green patent filings.

Moreover, Pasimeni et al. (2019) emphasize the surging interest in linking ESG and innovation. They identify green patents as valuable indicators and uncover mechanisms through which ESG can influence green innovation, including its impact on a company's reputation and stakeholder relationships. Furthermore, ESG ratings can significantly affect a company's access to capital, thus influencing its capacity to invest in innovation.

To contribute to the ongoing debate, research conducted by Cohen et al. (2020) delves into the intricate interplay between environmental factors and the realm of green innovation, particularly emphasizing their impact on the emergence of green patents.

The authors conducted an analysis of a sample comprising 11,397 publicly traded companies, encompassing European and American firms that obtained at least one patent between 1980 and 2020. These companies collectively generated a total of 3,032,611 patents, of which 7.76% were classified as green patents. From the perspective of the industries involved, the research examined green patents produced by a wide range of industries, including manufacturing, energy, services, transportation, utilities, finance, wholesale and retail trade, agriculture, fishing, and construction.

In addition, the study analyzed the differences between traditional energy companies and emerging renewable energy companies to assess their ability to compete in sustainable innovation.

The authors used a logistic regression model to estimate the probability of a company obtaining green patents, taking into account ESG scores and other control variables. These control variables included factors such as company size, market share, R&D investment and industry membership.

The estimates revealed that ESG scores do not have a significant correlation with the likelihood of producing green patents. In other words, companies with higher ESG scores did not show a higher propensity to produce green patents than those with lower ESG scores. However, analyses showed that companies with higher R&D investments and those operating in R&D intensive industries were more likely to produce green patents. Similarly, companies operating in high-carbon sectors, such as the energy sector, showed a higher propensity to produce green patents.

In summary, the authors concluded that ESG scores do not reliably indicate a company's ability to obtain green patents. Moreover, companies in the energy sector presented significantly lower ESG scores than companies in other sectors, suffering a substantial penalty in introducing green patents. Despite this penalty, energy companies appear to produce higher quality green patents than other companies, as evidenced by the citations[1] received for their patents, which are significantly higher.

The coefficient for the energy sector implies that, on average, energy companies had 85% higher citations for their green patents than other green patent holders in the same technological age group (year). Similarly, the reported Poisson model suggests that energy firms had a 13.7% higher incidence of citations than non-energy firms.

In the context of sectoral analysis, Cohen et al. (2020) explore whether the pro-

[1] Green patents citations occur when green patents are cited by subsequent patents, indicating that these innovations have been recognized as relevant and influential in the field. The more a green patent is cited, the more it is considered significant in the realm of sustainable technologies. For this reason, citations serve as an indicator used to assess the quality of patents in the field of green or sustainable technologies.

duction of green patents within the energy sector differs significantly from other industries. To conduct this analysis, the authors used an Ordinary Least Squares (OLS) fixed-effects model covering data from 2008 to 2020. This time frame was chosen to align with the availability of ESG data, which have become accessible since 2008.

The dependent variable of main interest in this analysis is the "Green Patent Ratio." This ratio was calculated by dividing the number of green patents granted in a specific industry by the total number of patents granted in that industry during the specific year.

The results of the analysis indicate that the energy sector devotes more than twice as much attention to green innovation as the average for other sectors. In numerical terms, 17.6% of all patents in the energy sector are devoted to green innovation, compared to 8.6% of other companies engaged in this type of innovation.

Moreover, it is important to note that in absolute terms, the energy sector seems to invest significantly in green innovation, allocating nearly 20% of its innovation resources to sustainable energy research.

A crucial issue that the authors consider is whether this intense green patent activity within the energy sector is a direct response to the increasing pressure from ESG activities and divestment campaigns. They examined this hypothesis, taking into account that data on green patents date back to 1980, well before the emergence of the ESG concept.

The results obtained indicate that the energy sector has consistently filed a significant number of green patents both before and after 2004. This suggests that energy companies may have invested in green innovation as part of their long-term strategy to meet growing global energy demand, regardless of ESG pressures.

Finally, Cohen et al. (2020) highlight the challenges and limitations of the existing literature, including the requirement for standardized metrics (discussed in Chapter 2) to measure ESG performance and the task of isolating the effects of ESG factors on innovation outcomes.

From an empirical perspective, Fabrizi et al. (2018) conduct an analysis to explore the relationship between ESG factors and green patents, focusing on the relationship between green innovation, regulatory policies, and research policies.

The authors, unlike the analysis conducted by Cohen et al. (2020), place more emphasis on regulatory and research policies to observe whether these have a more or less significant impact on green patents and environmental components. They found that regulatory and research policies have a positive and significant impact on green patents in Italy. Specifically, a 10% increase in regulatory policies is associated with a 2.5% increase in green patents, while a 10% increase in research policies is associated with a 1.5% increase in green patents. The paper also examines the limitations of current research (similar to the Cohen et al. study), including the challenge of standardizing ESG indicator measurement and the need for longitudinal studies to assess the long-term effects of green innovation.

Berrone et al. (2013) found that firms facing strong regulatory pressures and social expectations are more likely to develop environmental innovations, particularly in pollution and waste reduction, which leads to an increase in the environmental ESG indicator.

On the other hand, Horbach et al. (2012) emphasized the importance of regulatory and technological drivers, as well as market attraction, as catalysts for eco-innovation.

In summary, the literature review highlights that is not always evident a positive link between ESG factors and green patents, yielding results that are not entirely consistent with each other. The researchers recommend conducting further studies to delve into the mechanisms of ESG's influence on green innovation and the promotion of sustainable development.

3.2 Evidence from the Chinese market

Most existing research on this topic has centered on developed countries with mature ESG systems, leading the authors to urge for more investigations in emerging markets, where institutional differences may play a significant role.

In this section, I analyze the role of green innovation in driving sustainable development, focusing on the relationship between ESG rating performance and green patents in the Chinese market.

Wang et al. (2023) conducted a study initially focusing on the role of ESG ratings in green innovation and their relationship with corporate managers. In this context, ESG ratings can reduce investors' monitoring costs, thus promoting green innovation.

Investors can more effectively encourage managers to engage in green patenting activities when they are informed about companies' environmental performance, incentivizing them to focus more in green innovation.

In Whang et al. (2023), the researchers use panel data at the firm-year level. The final sample includes 18,790 observations from 3,301 publicly traded Chinese companies.

The rating agency used in this study differs from the one considered in Cohen et al. (2020). In this analysis, the data come from Syntao Green Finance (SynTaoGF[2]), which, as an independent agency, provides objective and comprehensive assessments of companies' ESG performance.

This study uses SynTaoGF's ESG rating event as a quasi-natural experiment and applies the DID (Differences-in-Differences) method to investigate the influence of ESG ratings on corporate green innovation. The authors created the variable "ESG" to capture ESG ratings as an indicator variable, taking the value 1 if the company is covered or has ever been included in a SynTaoGF ranking, and 0 otherwise.

[2] SynTao Green Finance is a leading Chinese agency that specializes in providing ESG ratings and services. It evaluates and ascertains the environmental and social performance, as well as governance practices, of companies and organizations

Regarding control variables, this study considers factors that influence patent development, including firm size, profitability, revenue growth rate, R&D intensity, net cash flow from operations, and years since the initial public offering. The average ESG value is 0.128, meaning that about 13% of the company's year observations are covered by SynTaoGF. This suggests a relatively low coverage of ESG ratings among companies in the A-shares[3] market.

The ESG coefficient results indicate that firms tend to significantly increase their green innovation after being covered by an ESG rating agency. This effect is statistically significant and the magnitude of the coefficient suggests that, compared to other companies, those covered by an ESG rating agency experience a 3.9% increase in green innovation after receiving an ESG score. Thus, the results showing that ESG ratings have a positive impact on firms' green innovation.

To further explore the impact of ESG ratings on green innovation behavior, green patents were categorized as invention patents and utility patents[4]. This distinction follows the categories in Chinese patent law. Regarding these two types of patents, green invention patents have a higher technological content and better reflect the scientific and innovative capabilities of companies. The findings highlight that the impact of ESG ratings on green innovation is mainly observed for green invention patents, signifying that the effects of ESG ratings primarily enhance the quality of a company's innovation.

The authors conclude that ESG ratings play an important role in enhancing firms' green innovation. Moreover, they suggest that policymakers and investors should pay more attention to ESG ratings as a tool to promote green business in-

[3] China A-shares are the stock shares of mainland China-based companies that trade on the two Chinese stock exchanges, the Shanghai Stock Exchange (SSE) and the Shenzhen Stock Exchange (SZSE).

[4] Invention patents are the most common type of patent and cover new and useful processes, machines, artifacts or compositions of matter. These patents protect the way an invention is used or works and have a broad scope. To obtain them, the inventor must show that the invention is new, useful and not obvious to an expert in the field, which requires a high degree of innovation and creativity. Invention patents are thus a strong indicator of the quality and originality of a patented idea. Utility patents, on the other hand, are a subset of invention patents and focus on new and useful inventions, but with a narrower scope, specifically relating to processes or machines.

novation. They also recommend that future research should explore the mechanisms through which ESG ratings influence green innovation and investigate the heterogeneity of effects across different types of companies and sectors.

In the context of studies centered on the Chinese market, Liu & Lyu (2022) provide further insights into the relationship between ESG ratings and green patents.

The study analyzed the impact of ESG rating announcement on green innovation for companies listed on the Shanghai and Shenzhen Stock Exchange from 2009 to 2020. Therefore, the sample encompasses a variety of businesses operating in different economic sectors.

The authors make three hypotheses to test the relationship between ESG ratings and corporate green innovation. Hypothesis 1 states that ESG ratings have a positive impact on corporate green innovation. Hypothesis 2 argues that the more favorable the institutional environment, the stronger the positive relationship between the ESG rating and green innovation.

The last hypotesis emphasizes the completeness of the institutional environment and the abundance of redundant organizational resources reinforce the positive impact of ESG ratings on corporate green innovation.

All three hypotheses were confirmed by the analysis of the collected data. The authors showed that ESG ratings have a positive impact on corporate green innovation and that the completeness of the institutional environment and the abundance of redundant organizational resources can further strengthen this positive relationship.

These results suggest that companies should invest in green innovation and maintain redundant resources to support and promote green innovation. Thus, the role of the institutional environment is confirmed as a very important element in supporting green innovation, as already stressed by Fabrizi et al. (2018).

However, the authors demonstrate the existence of a statistically significant positive correlation with both explorative[5] and exploitative[6] green innovation.

The significance of this positive correlation implies that companies with higher ESG scores are not just inclined to explore new eco-friendly solutions but also to make the most of current practices and technologies for achieving better green results.

Furthermore, understanding the dual impact of ESG ratings on explorative and exploitative green innovations can provide valuable insights for policymakers, managers, and stakeholders seeking to create a favourable environment for firms to invest in green innovation (e.g., by providing tax and financial incentives). In this way, companies can improve their ability to respond to unforeseen changes in the external environment and promote sustainable development.

Morover, the authors suggest that future research should focus on developing precise measures for ESG and green patents, and exploring different categories of green patents, such as those related to renewable energy or pollution control.

Tan & Zhu (2022) have also explored the connection between ESG ratings and green patents by using the 2015 ESG ratings data from SynTao Green Finance agency, focusing on 8,630 Chinese publicly listed companies from 2010 to 2017.

Among these, the manufacturing industry represents 57%, and compared to other types of companies, it is more likely that green innovation originates from this sector. The average values for the quantity of green innovation (expressed by the natural logarithm of the number of green patent applications for firm i in year $t+1$) and the quality of green innovation (represented by the natural logarithm of the number of green patent citations for firm i in year $t+1$) among the sample companies are 0.22 and 0.93, respectively.

The maximum values are 6.1 and 7.5, indicating significant differences in green

[5] Explorative green innovations encompass pioneering and transformative initiatives that explore new technologies, practices, or solutions to tackle environmental issues. They are characterized by a higher degree of risk and uncertainty, as they push the boundaries of current knowledge and practices, all in the pursuit of environmental sustainability.

[6] Exploitative green innovations involve refining and improving existing environmentally friendly practices or technologies, focusing on enhancing their efficiency, reliability, and scalability. Unlike explorative innovations, these advancements are often seen as less risky and more predictable.

innovation among companies with a tendency towards polarization and highlighting a high number of companies with zero green patents. The average value of ESG is 0.14, indicating that 14.4% of the sample has received ESG ratings. The average value of ESG_Score is 2.95, suggesting that the average level of ESG scores falls between levels B and C on the scale adopted by SynTaoGE. (This scale ranges from a maximum rating of A+ to D, with a total of ten levels). Furthermore, when comparing standard deviations, ESG ratings vary significantly from one company to another.

The regression analysis conducted by the authors reveal that the coefficients of ESG ratings on the quantity and quality of corporate green innovation are positive and statistically significant. These results imply that, after receiving ESG ratings, corporate green innovation undergoes a significant improvement (the same conclusion reached by Wang et al., 2023). In particular, these results can be interpreted as an indication that companies with ESG ratings are associated with a 6.45% increase in the number of green patent applications and a 9.35% increase in the number of green patent citations.

Financial support plays a crucial role in promoting green innovation in the context of ESG ratings. Companies strive to achieve excellent ESG ratings, which significantly attract external attention and investments from financial institutions. These institutions, in turn, formulate credit policies that prioritize companies with remarkable ESG ratings. This preferential treatment includes the provision of favorable loans and active guidance of capital and technology flows, thereby creating a concentration of resources that more effectively promotes corporate green innovation.

The results related to this dynamic obtained by the authors demonstrate the mediating effect of financial constraints on the quantity and quality of green innovation.

Indeed, Tan & Zhu (2022) found a significant negative correlation with the financial constraint coefficient. Instead, the coefficients of ESG on the quantity and quality of green innovation are positive and significant. This indicates that ESG ratings significantly alleviate financial constraints, thereby promoting green innovation.

In conclusion, the interplay between ESG scores and green patents underscores the pivotal role of sustainability and innovation in the contemporary business landscape. Researchers have consistently found evidence supporting a positive relationship between ESG metrics and green innovation, emphasizing the importance of considering environmental factor in corporate strategies. While the impact of ESG ratings on green patents may vary across industries and regions, the overarching consensus is that higher ESG scores correlate with increased green innovation activity.

Studies in both global and Chinese markets have highlighted the significance of ESG ratings in promoting corporate green innovation. Moreover, the mediating role of financial constraints and the influence of the institutional environment provide a nuanced understanding of the mechanisms through which ESG factors drive innovation performance.

Policymakers, investors, and stakeholders are encouraged to consider ESG metrics as a means to incentivize and support sustainable development through innovation. Further research in this field, is crucial for refining the understanding of the complex relationship between ESG scores and green patents, ultimately advancing the goals of sustainability and green growth.

Chapter 4

Dataset construction

In this chapter, I will illustrate the construction of the dataset used for conducting the empirical analysis, which will be presented in Chapter 5.

Section 4.1 will provide an introduction to the data collection process, with a focus on the resources and methods utilized to gather the required data. The explanation of the data collection procedures will ensure transparency and reliability of the subsequent analysis.

Diving deeper into the dataset's composition, Section 4.2 will present a detailed overview of the ESG ratings data, outlining how these ratings were sourced and how they will be incorporated into the analysis. Understanding the origins and implications of ESG ratings will enhance the interpretation of the empirical results.

Moving forward, Section 4.3 will focus on the analysis of the matching and linking strategies employed to combine the diverse datasets into the final comprehensive dataset.

Lastly, Section 4.4 will provide an overview of the final dataset's composition, reporting the main descriptive statistics. Furthermore, this section will outline specific adjustments and modifications made to ensure the empirical analysis is based on accurate data, strengthening the validity and robustness of the empirical results.

4.1 Introduction to data collection: methods and sources

The JRC-OECD COR&DIP© database serves as a comprehensive repository of information regarding the R&D activities and patent portfolios of the top 2000 corporate R&D performers worldwide.

The patent-related data incorporated in this database originate from the Worldwide Patent Statistical Database (PATSTAT Global, Spring 2021) maintained by both the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO). For the purpose of this study, I independently accessed and downloaded the relevant datasets from the OECD website and used the software Gretl[1] to perform the necessary data preparation and analysis, ensuring that the data were appropriately processed and cleaned for my research investigation.

The database covers families of patent applications filed at the five top IP offices (IP5) in the world, namely: CNIPA (Chinese National Intellectual Property Administration), EPO, JPO (Japan Patent Office), KIPO (Korean Intellectual Property Office), and USPTO.

The names of the top corporate R&D investors and their subsidiaries (as of 2018) were matched to the applicants' names provided in published patent documents using a series of algorithms. The matching was carried out on a country-by-country basis, as described in Amoroso et al. (2021).

The database is organized as a set of relational tables that can be linked using two identifiers: *Company_id* and *Patent_Appln_id*.

The Company_id identifier should be used to match the 'Top Corporate R&D Investors' table with the 'Patent portfolio - 2016-18' table and the 'Top Corporate R&D Investors – Financial' table.

The patent identifier (Patent_Appln_id) contained in the 'Patent portfolio - 2016-

[1] Open-source statistical software package designed for econometric and statistical analysis. It provides a user-friendly graphical interface, along with a command-line interface, making it accessible to researchers, economists, and analysts for a wide range of data analysis tasks.

2018' table should be used to link the 'Patent classes' table.

To provide a more detailed overview of all the variables that make up this database, Box 2 illustrates its main features.

BOX 2: COR&DIP© v.3: Database structure

- ***Company_id***: Unique company identifier (from 1 to 2000).
- ***Company_name***: Company name, as listed in the 2019 EU Industrial R&D Scoreboard.
- ***Worldrank***: From 1 to 2000, as ranked in the 2019 EU Industrial R&D Scoreboard.
- ***Ctry_code***: ISO2 country code. Is a two-letter code that represents a specific country or territory as defined by the International Organization for Standardization (ISO).
- ***NACE2***: is a statistical classification system developed and used by the European Union (EU) to categorize economic activities within its member countries. Similar to ISIC, it classifies industries based on their economic activities. The "Rev. 2" indicates that it is the second revision of the classification system.
- ***ISIC4***: is a standard classification system developed by the United Nations to categorize economic activities at the global level. The "Rev. 4" indicates that it is the fourth revision of the classification system.
- ***RD***: Research and Development investment (€ Million).
- ***NS***: Net sales (€ Million).
- ***CAPEX***: Capital expenditure (€ Million).
- ***OP***: Operating profits (€ Million).
- ***EMP***: Number of employees.
- ***Patent_appln_id***: Patent application identifier (Appln_id from PATSTAT Global, Spring 2021).
- ***Is_green***: 1 for patent families in climate change mitigation or adaptation.

4.2 An overview of the ESG rating framework used by Refinitiv

Refinitiv[2] played a pivotal role in this research by providing an extensive collection of environmental, social, and governance data for the companies included in the JRC-OECD COR&DIP© database. By leveraging the Refinitiv ESG rating framework, renowned for its transparency and data-driven approach, I was able to evaluate the sustainability and ethical performance of these companies.

Accessing the ESG data was made possible through Refinitiv's exclusive platform, Eikon[3], which offers a wealth of information on the top investors of listed companies in the reference sample. With the platform's capabilities, I could extract specific ESG ratings, particularly those related to the environmental aspect, which proved crucial for the analysis. By obtaining data through the companies' Reuters Instrument Code (RIC[4]), I efficiently matched them with their corresponding names, effectively integrating the ESG scores into the dataset.

Refinitiv's ESG score stems from a comprehensive set of more than 630 ESG metrics at the company level, with 186 highly relevant and comparable metrics serving as the basis for the overall assessment and scoring process. To ensure data accuracy and completeness, Refinitiv employs a global team of over 700 content research analysts who meticulously gather ESG data from diverse sources, including annual reports,

[2] Refinitiv is a leading provider of financial data, analytics, and ESG ratings. It offers a comprehensive ESG rating framework that assesses companies' sustainability and ethical performance based on publicly available data (Refinitiv, retrieved from https://www.refinitiv.com/en/sustainable-finance/esg-data-scores).

[3] Eikon is a financial data platform developed by Refinitiv, offering a wide range of financial data, analytics, and news for global markets. It is widely used by financial professionals and researchers to access real-time and historical market data, financial news, economic indicators, and company information (Refinitiv, retrieved from https://www.refinitiv.com/en/products/eikon-trading-software). Special acknowledgment to Professor Camilla Mazzoli, who provided access to this valuable platform for data retrieval purposes.

[4] RIC is an identifying code utilized in the financial sector to uniquely identify financial instruments traded on international markets. It is a coding system developed by Thomson Reuters (now part of Refinitiv) and is predominantly used in the Eikon financial information platform to identify various financial instruments, including stocks, bonds, futures, options, currencies, and more.

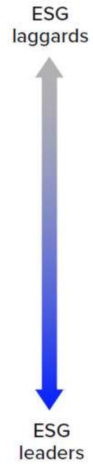
company websites, stock exchange filings, and news outlets.

The ESG rating framework provided by Refinitiv spans ten primary themes, encompassing aspects such as emissions, environmental product innovation, human rights, and shareholder practices. Appendix C provides a more detailed description of the methodology used by Refinitiv to assign ESG scores.

The score is expressed both as a percentage and a letter grade, spanning from D- to A+, making it easily understandable and interpretable.

Figure 4.1: ESG categories according to Refinitiv

Score range	Grade	Description
0.0 <= score <= 0.083333	D -	'D' score indicates poor relative ESG performance and insufficient degree of transparency in reporting material ESG data publicly.
0.083333 < score <= 0.166666	D	
0.166666 < score <= 0.250000	D +	
0.250000 < score <= 0.333333	C -	'C' score indicates satisfactory relative ESG performance and moderate degree of transparency in reporting material ESG data publicly.
0.333333 < score <= 0.416666	C	
0.416666 < score <= 0.500000	C +	
0.500000 < score <= 0.583333	B -	'B' score indicates good relative ESG performance and above-average degree of transparency in reporting material ESG data publicly.
0.583333 < score <= 0.666666	B	
0.666666 < score <= 0.750000	B +	
0.750000 < score <= 0.833333	A -	'A' score indicates excellent relative ESG performance and high degree of transparency in reporting material ESG data publicly.
0.833333 < score <= 0.916666	A	
0.916666 < score <= 1	A +	



Source: *Environmental, Social and Governance Scores from Refinitiv, May 2022*

Figure 4.1 illustrates the criteria adopted by the Refinitiv platform to assign scores to the companies under consideration. Based on this framework, the ESG scores are determined on a scale from 1 to 100, effectively categorizing companies into distinct ranges based on their scores. However, it is essential to note that different rating agencies may employ diverse methodologies and criteria for ESG score attribution, with no universally recognized standardization for determining such criteria (see Section 2.2). Therefore, the outcomes of my analysis may be influenced to some extent by the subjective aspects of the rating agency's methodology.

4.3 Matching strategies and linkage identification in dataset construction

The construction of the dataset involved several sequential steps to ensure its accuracy. Beginning with the JRC-OECD COR&DIP© database as the fundamental data source for the study, I compiled a comprehensive collection of information for analysis by performing a merge operation, commonly referred to as a "join," on two major datasets within the JRC-OECD COR&DIP© database.

These datasets are *"Top Corporate R&D Investors"* and *"Top Corporate R&D Investors - Financial."*

The first dataset, *("Top Corporate R&D Investors,")* contained essential variables such as *Company_id* (a unique identifier for each company), *Company_name*, *Ctry_code* (ISO2 country code), *Worldrank* (ranking of companies from 1 to 2000 based on the 2019 EU Industrial R&D Scoreboard), *NACE2* (NACE, rev.2 sectors), and *ISIC4* (ISIC, rev. 4 sectors aggregated into 38 sectors) as shown in Box 2 displayed in section 4.1.

On the other hand, the second dataset, *("Top Corporate R&D Investors - Financial,")* comprised crucial variables such as *Company_id*, *Year* (ranging from 2015 to 2018), *RD* (Research and Development investment in € Million), *NS* (Net sales in € Million), *CAPEX* (Capital expenditure in € Million), *OP* (Operating profits in € Million), and *EMP* (Number of employees).

The key step in creating the unified dataset was the join operation, which combined the relevant information from both datasets based on the common key *Company_id*. This process enabled the integration of company-specific data on research and development, financial performance, and all other relevant factors.

Subsequently, the unified dataset was further enriched through another join with the *"Patent portfolio – 2016-18"*database.

This additional join focused solely on the variable of interest for the study, denoted as *Is_green*, representing the presence of green patents: the join was performed using two key variables: *Company_id* and *Year*[5].

To analyze the presence of green patents for each company and year, I utilized the sum function. This tool allowed the calculation of the total number of green patents for each reference year (2016-2017-2018) as well as the total number of patents held by each specific company.

I applied a similar procedure for the join with the *"Trademark portfolio – 2016-18"*database, where the objective was to explore trademark-related data.

Lastly, as highlighted in section 4.1.1, data from the Eikon platform, owned by Refinitiv, was acquired to enhance the dataset with Environmental, Social, and Governance ratings.

This crucial join operation utilized the common *Company_identifier* and *RIC* variables, along with the *Year*, to incorporate the general ESG rating and the specific Environment score for each company-year combination in the dataset.

This careful procedure guaranteed the establishment of a consistent and comprehensive dataset, providing the basis for a rigorous empirical examination of the connection between innovation performance and ESG scores.

[5] The *Year* variable was extracted from the "Top Corporate R&D Investors - Financial" database, encompassing data from 2015 to 2018. However, to align with the availability of patent data for the years 2016 to 2018, the study focused exclusively on these three years.

4.4 Descriptive statistics

This section discusses descriptive statistics for the final panel[6] dataset, for 1051 companies observed for three years (2016-2017-2018). From the initial 2000 companies, I removed:

- Companies for which ESG scores were unavailable due to their absence from the stock exchange market. As a result, the Eikon platform, used to access ESG scores, could not be used to obtain data for these specific companies (92 companies in total).
- Companies having more than 1,500 green patents. This decision was driven by the uneven distribution of the dependent variable. To ensure the reliability of the analysis, only companies with less than 1,500 green patents were included, while the others were eliminated. For a complete overview of the excluded firms, see Section 4.4.1.
- Companies with missing values due to unavailability of some data for firm-specific variables.

The following table presents summary statistics for the main variables derived from the final dataset, providing valuable insights into the central tendency, spread, and variation of the data.

[6] Panel data refers to a type of dataset that involves observations collected over multiple units (cross-sections) and time periods. In panel data, each unit is observed repeatedly across different time intervals, allowing researchers to analyze both cross-sectional variations and temporal trends within the dataset. Although the dataset is a panel, during the econometric analyses that will be conducted, the dataset will be treated as cross-sectional.

Table 4.1: Summary Statistics

Variable	**Mean**	**Median**	**S.D.**	**Min**	**Max**
RD	478.4	121.8	1249	3.087	18271
NS	11299	3181	25693	0.003751	368500
CAPEX	725.4	136.1	2185	0.001947	34055
OP	1168	279.8	3124	-15270	61920
EMP	32882	12600	58491	25	664500
PT_num_green	29.54	1.000	108.8	0	1406
ESG_General	51.35	51.63	20.61	0.9100	94.64
Environment_score	45.21	49.54	31.11	0	98.72
N_tot_patent	265.1	39.00	748.7	1	11772
PT_share_green	0.09432	0.02309	0.1739	0	1

Note: Variables *RD*, *NS*, *OP*, and *CAPEX* are expressed in € Million (see Box 2).

Looking at the means, we observe that RD (Research and Development) expenditure averages at 478.4 million dollars, while NS (Net Sales) stands at an average of 11,299 million dollars. CAPEX (Capital Expenditures) averages around 725.4 million dollars, and OP (Operating Profit) is approximately 1,168 million dollars on average. The variable EMP (Number of Employees) shows a mean of 32,882 employees, indicating the workforce size of the companies. Notably, the variable PT_num_green (Total number of green patents held by the company) averages at 29.54, and ESG_General (Environmental, Social, and Governance General Score) has a mean of 51.35. The Environment_score variable, measuring the environmental performance, has an average of 45.21.

Turning to the variability of these indicators, the following considerations can be gathered: a high variability is observed, as indicated by the high standard deviation values, suggesting a substantial spread of data around the mean, for the RD, NS, CAPEX, and OP variables.

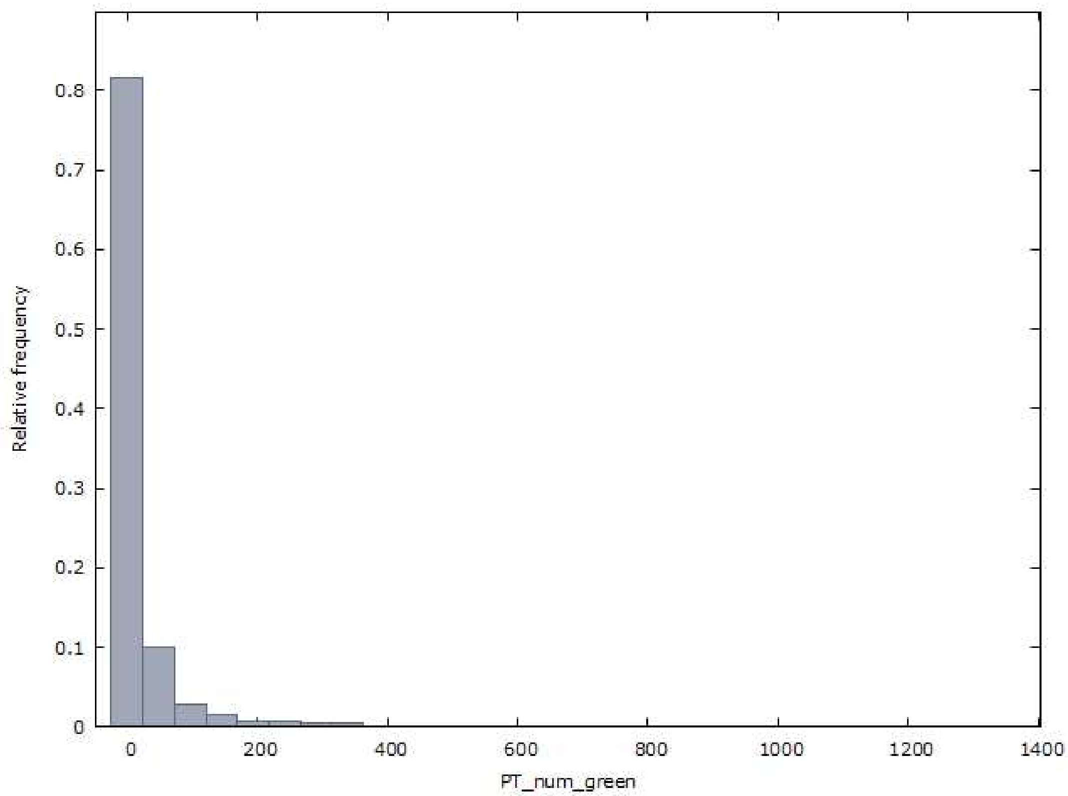
For the ESG_General variable, the variability is moderate, with a standard deviation value of 20.61, unlike the Environment_score variable, which presents a higher standard deviation (31.11), signifying notable variability in environmental scores.

Moderate variability is also observed for the proportion of green patents held by companies, with an S.D. value of 0.1739.

These statistics provide insights into the distribution and central tendencies of these variables within the dataset, shedding light on the characteristics of the companies under analysis.

To proceed with the analysis of descriptive statistics, I will show the frequency distributions of the dependent variables to clarify how they are dispersed across the range of observed firms. These statistics allow me to take a first look at the traits and patterns exhibited by the dependent variables, thus laying the foundation for the regression analyses that will follow.

Figure 4.2: PT_num_green aggregate frequency distribution



Source: *Own graphic made with Gretl.*

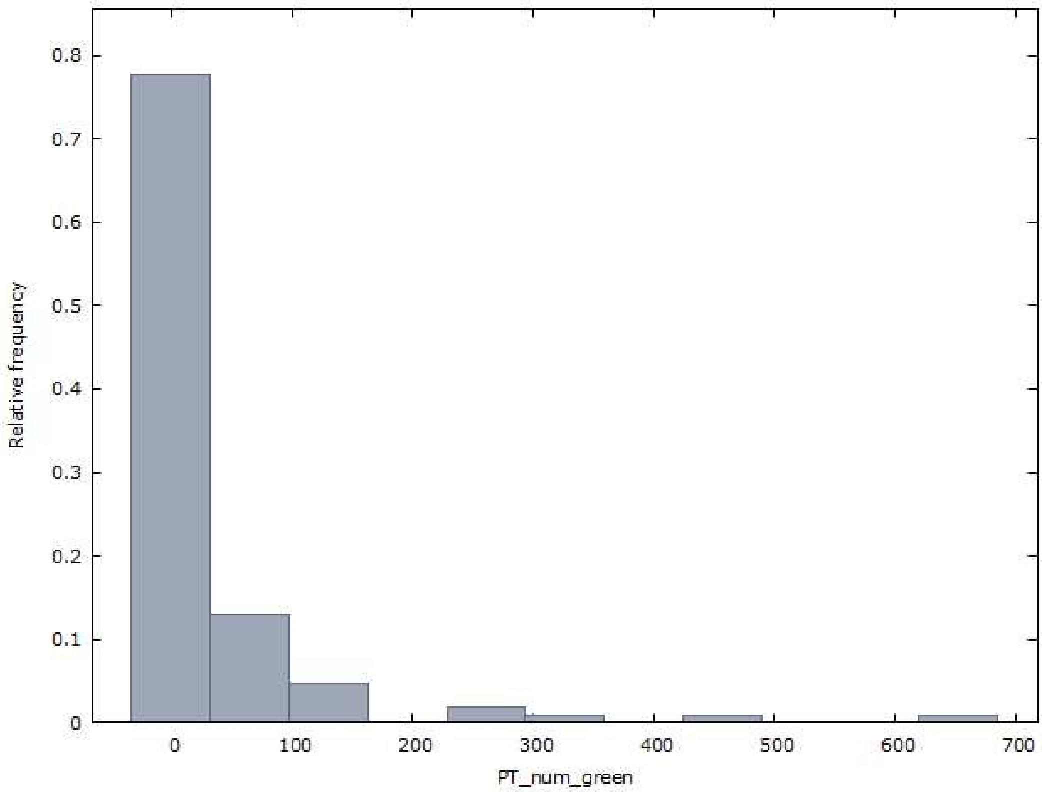
Figure 4.2 shows the distribution of the dependent variable PT_num_green (which I recall expresses the total number of green patents held by a company) in aggregate values, i.e., considering both the energy and non-energy sectors.[7]

[7] The way the sectors were aggregated will be seen in Appendix A, which will show the Energy and

The data are divided into intervals of varying width, and for each interval are given the relative and cumulative frequency. For example, 81.62% of companies hold fewer than 24.18 green patents, 10% have green patents between 24.18 - 72.54, while only 2.75% of firms hold between 72.54 and 120.9.

In this aggregate distribution, the total count of zeros amounts to 1,111, signifying that a substantial portion of companies do not hold any green patents within their portfolio. Overall, the distribution appears to have a long right tail, with a small number of companies holding a significantly large number of green patents.

Figure 4.3: PT_num_green Energy sector frequency distribution



Source: *Own graphic made with Gretl.*

Referring to Figure 4.3, the focus is on the energy sector. To illustrate, approximately 77.78% of total companies, hold a number of green patents less than 32.65. In contrast, 12.96% of the observations have values between 32.65 and 97.95.

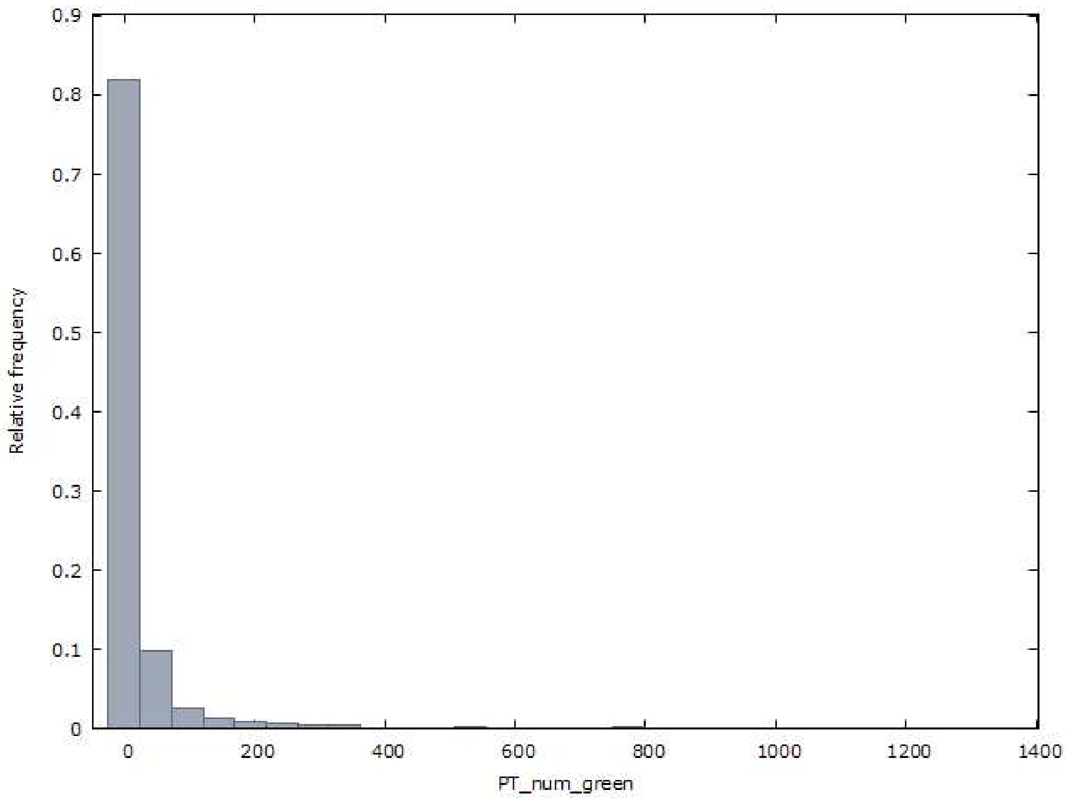
Interestingly, just under 1% of the companies fall in the final range that includes

Non-energy sectors based on the ISIC4 code provided in the source dataset.

values greater than or equal to 620.35, and thus have a particularly high number of green patents compared to the other observations.

In the case of companies in the energy sector, the total number of zeros is 30. Overall, the distribution is positively skewed, with a mean of 34.74 and a relatively high standard deviation of 81.4682, indicating a considerable spread of values around the mean.

Figure 4.4: PT_num_green Non-energy sector frequency distribution



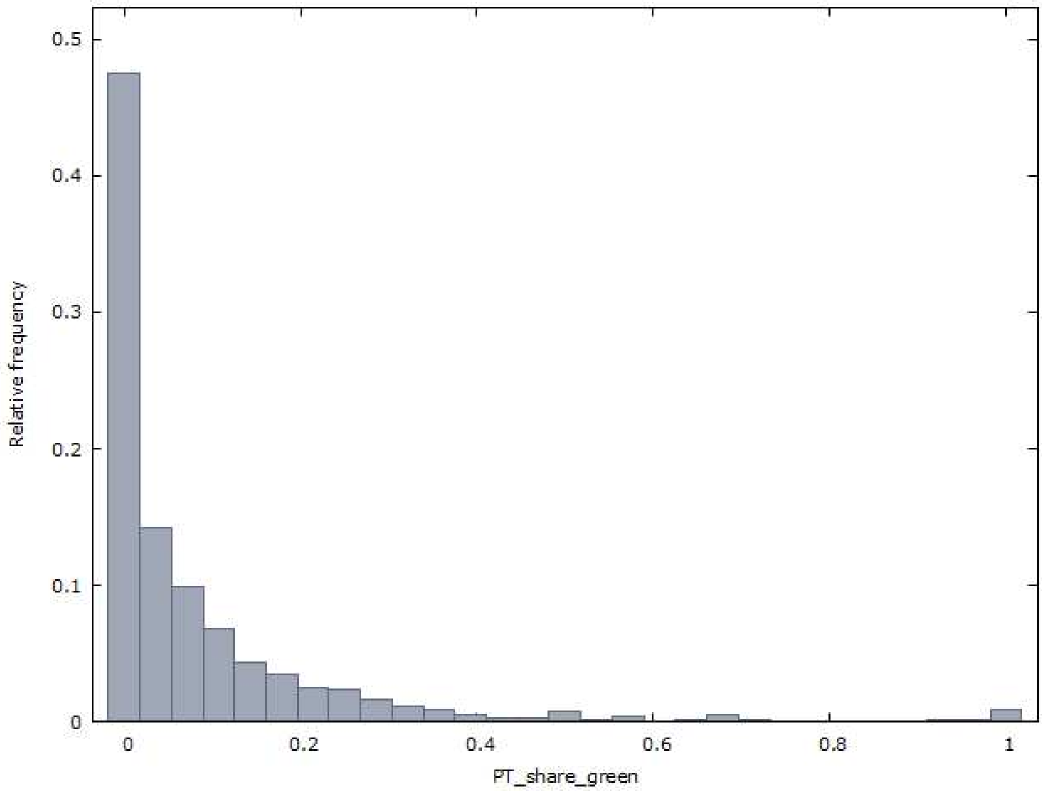
Source: *Own graphic made with Gretl.*

Considering Figure 4.4, it is possible to note that approximately 81.99% of companies have a count of green patents below 24.18, while about 9.96% of companies possess a count within the range of 24.18 to 72.5. This distribution underscores a prevalent trend where a majority of companies exhibit lower counts of green patents, yet there are outliers with notably higher counts.

The total number of zeros for the number of green patents is 1,081, emphasizing that many companies in these industries do not have green patents in their portfolio.

In this graph, the right-hand tail is less visible but still present, emphasising the concentration of companies that for the most part hold not too many green patents.

Figure 4.5: PT_share_green Aggregate frequency distribution



Source: *Own graphic made with Gretl.*

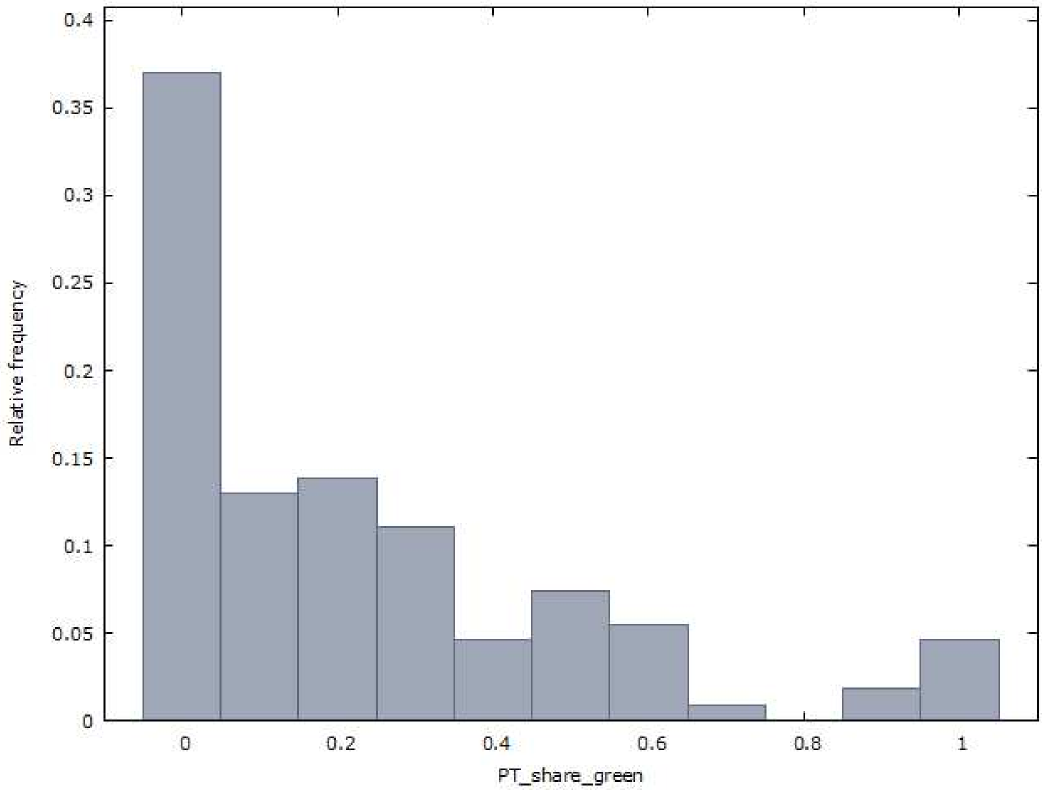
Figure 4.5 shows the distribution of PT_share_green variable, which indicates the percentage share of green patents within the total patent portfolio held by companies. The 47.5% of companies possess a share of green patents lower than 0.017, while about 14% of companies have a share ranging between 0.017 and 0.05.

The 9.8% of total observations fall within a range of 0.05 to 0.089, with the proportion of green patents varying in total by 3% within the same range.

Finally, just over 1% of the total observations include values greater than or equal to 0.98.

However, what's striking is the pronounced right tail in the distribution, signifying a subset of companies with significantly higher proportions of green patents relative to their total patent holdings. This emphasizes the presence of a group of companies strongly devoted to green innovation.

Figure 4.6: PT_share_green Energy sector frequency distribution



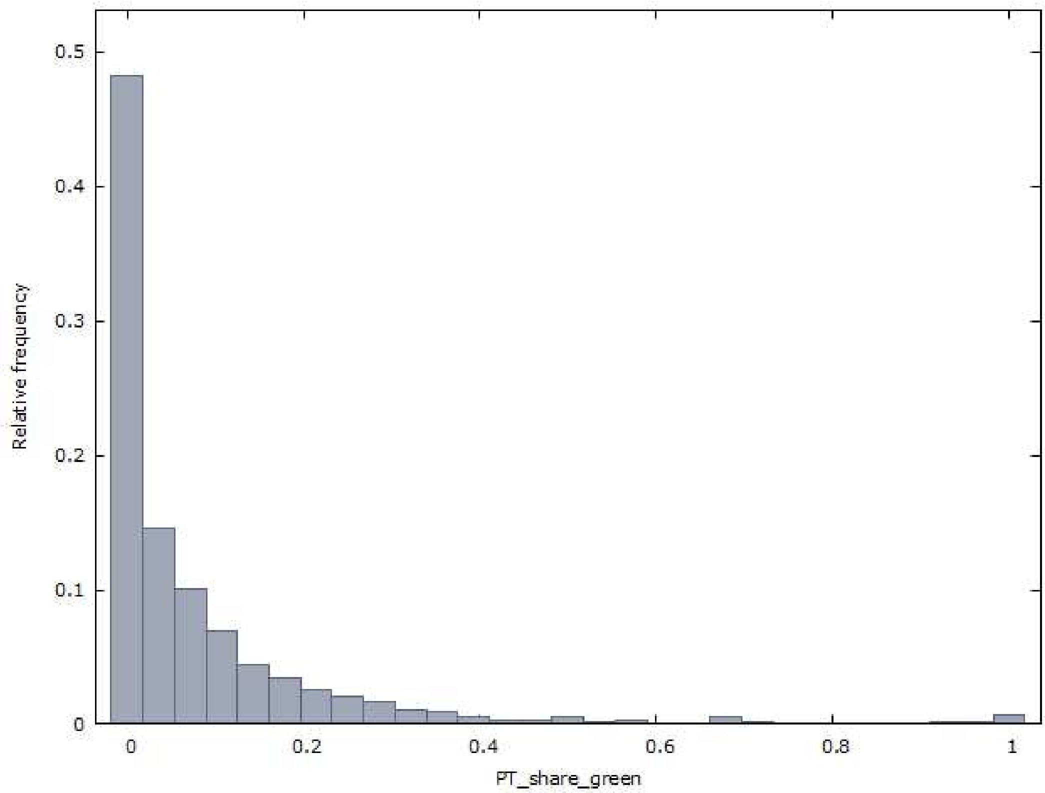
Source: *Own graphic made with Gretl.*

Referring to the previous graph depicting absolute patent counts in the energy sector, the current distribution illustrated in Figure 4.6 offers a compelling contrast. In this case, for example, around 37% of companies exhibit a share below 0.05, while approximately 13% of companies fall within the range of 0.05 to 0.15. This transformation to relative proportions allows to discern how companies allocate their patent efforts towards green innovation, presenting a nuanced view of commitment to sustainability.

In the case of the energy sector, there is a higher percentage of companies (4.6%) that hold a large number of green patent shares, compared to the aggregate sectors.

The distribution indicates that a significant portion of companies have a proportion of green patent shares which covers the first two intervals. The distribution is positively skewed, with a mean of 0.247 and a standard deviation of 0.286, suggesting a relatively wide dispersion of values around the mean.

Figure 4.7: PT_share_green Non-Energy sector frequency distribution



Source: *Own graphic made with Gretl.*

To conclude the descriptive analysis of the dependent variables, Figure 4.7 shows the distribution of the percentage share of patents, considering only the non-energy sector. It is interesting to note that about 48.3% of the companies have a share below 0.017 (which is much higher in the Energy sector), while about 14.53% of the companies fall in the range between 0.017 and 0.053.

In contrast to the Energy sector, in this case, the tail appears to be more constant to the right, underlining the lower interest of certain companies in patenting green inventions when the reference sector is not Energy.

4.4.1 Sample restriction: list of excluded companies

In this section, I provide a detailed account of the sample narrowing process, shedding light on the list of companies that have been intentionally excluded from the final dataset due to their potential impact on the econometric estimates.

Table 4.2 showcases the total number of patents and the number of green patents held by these companies in the year 2018.

Table 4.2: Companies with green patents greater than 1500 in 2018

Company name	Total Patents	Green Patents	Share of Green Patents
TOYOTA MOTOR	10016	3619	36%
TOYOTA INDUSTRIES	9098	3461	38%
SUMITOMO ELECTRIC	9435	1559	17%
PANASONIC	6434	1539	24%
DENSO	6186	1542	0%
LG CHEM	6028	3228	54%
SAMSUNG ELECTRONICS	20568	2102	10%
GENERAL ELECTRIC	4707	1642	35%

During the process of narrowing the sample, I meticulously considered various aspects, including the industry, business model, and scale of operations of each company. The dataset excludes massive companies, which often hold a considerable number of patents, and are located in different parts of the world being large multinational corporations. This approach helps ensure that my conclusions are grounded in a subset of the original data that accurately reflects the broader population.

Let me delve into some characteristics of the companies showed in the table:

- **Toyota Motor:** A prominent global automotive company known for manufacturing high-quality vehicles with a focus on technology and sustainability. In 2018, Toyota Motor held a total of 10,016 patents, with 3,619 dedicated to green technologies, comprising 36% of its patent portfolio. This demonstrates Toyota's commitment to sustainable innovation in the automotive sector. Headquartered in Japan, it has a global impact, and its dedication to eco-friendly solutions sets the company apart, emphasizing its pivotal role in shaping the future of sustainable transportation.

– **Toyota Industries:** Toyota Industries is one of the global leaders in the industrial vehicle sector, supplying its products to various industries such as logistics, material handling, manufacturing, and more. Positioned as a significant contender in the automotive industry, Toyota Industries boasts a total of 9,098 patents. Out of this total, a substantial 3,461 patents are dedicated to green technologies, constituting 38% of their entire patent portfolio. This strong commitment demonstrates their dedication to promoting environmentally friendly practices and driving sustainable advancements in the sectors they operate in. The company's headquarters is located in Japan, emphasizing its leadership role in developing a greener and more sustainable future.

– **Sumitomo Electric:** Sumitomo Electric operates in various sectors, including automotive, industrial electronics, energy, telecommunications, and materials. The company holds a total number of 9,354 patents, with 1,559 dedicated to green technologies, representing a significant 17% of the entire patent portfolio. Furthermore, the fact that the company's headquarters is located in Asia, specifically Japan, underscores its influence as a key player in the global technology and engineering sectors.

– **Panasonic:** Renowned for its exceptional expertise in consumer electronics, energy solutions, and other innovative technologies, Panasonic holds a total of 6,434 patents. Notably, 1,539 of these patents are dedicated to green technologies, constituting a significant 24% of the entire patent collection. Panasonic has made significant contributions in various sectors, including consumer electronics, home appliances, information and communication technologies, energy, automotive, and many others. This industrial giant also has its headquarters in Asia, specifically Japan, emphasizing the prominent presence of global leaders in this region.

- **Denso:** Denso is a notable company with a strong presence in the automotive and manufacturing sectors. With a diverse range of products and solutions, Denso has established itself as a global player in these industries. The company's headquarters is situated in Japan, emphasizing its roots in the heart of technological innovation. In terms of green patents, Denso holds a noteworthy share, amounting to 25% of their entire patent portfolio. This demonstrates their commitment to sustainable practices and their active role in driving advancements in eco-friendly technologies.

- **LG Chem:** The company specializes in manufacturing a wide range of chemicals, including polymers, lithium-ion batteries, screen materials, and electronic components. In the battery industry, LG Chem is a major global supplier, holding a total of 6,028 patents. A significant portion of these, precisely 3,228, is dedicated to sustainable technologies, making up an impressive 54% of its entire patent portfolio. This percentage is quite high, possibly influenced by the various environmentally sensitive sectors in which the company operates. The company's headquarters is located in Asia, specifically in Korea, emphasizing its global presence.

- **Samsung Electronics:** Samsung Electronics is a big South Korean company involved in various areas like consumer electronics, displays, mobile communications, and appliances. It is a global leader in making smartphones, TVs, mobile devices, and other electronic gadgets. This company is also a major player in the semiconductor industry, making memory and processing chips. With a significant 20,568 patents, Samsung Electronics shows its expertise in innovation and has the largest patent portfolio compared to others. Out of these patents, 2,102 are dedicated to green technologies, which is 10% of the total patent collection. Despite working in various sectors, Samsung Electronics has the lowest percentage of green patents compared to the others listed, even though they have the greenest patents overall.

- **General Electric:** General Electric (GE) is a major American company that operates in various sectors, including electricity, renewable energy, aviation, transportation, healthcare, lighting, and industrial automation. GE has a long history of technological innovation and was once one of the world's leading companies. The company holds a total of 4,707 patents, affirming its significance across diverse industries. Notably, 1,642 of these patents are dedicated to green technologies, accounting for a substantial 35% of their entire patent portfolio.

  While boasting a strong global presence, GE's headquarters are strategically located in the United States. This combination of worldwide reach and a strong focus on eco-friendly innovations underscores its pivotal role in driving both technological advancement and environmental progress on a global scale.

Although they are excluded from the empirical analysis, it is important to recognize the role of these companies in shaping a greener and more sustainable future. Notably, most of the excluded companies are based in Asia, with only one exception in the U.S, and this is certainly not a coincidence.

As illustrated in Figure 1.3, Japan accounts for a significant 32.2% share of green patents, while South Korea holds 13.5%, resulting in a combined total of 45.7%. The figure also emphasizes the importance of the United States, which holds a substantial 20% share.

Chapter 5

Empirical analysis

The empirical analysis presented in this chapter aims at investigating the factors influencing green innovation in companies, measured both in terms of the absolute number of green patents held by companies and as the share of green patents relative to the total number of patents. This analysis is based on a negative binomial model and an OLS regression, for the level and intensity respectively.

For the analysis, I use a negative binomial to model the number of patents, which is well suited to represent count data and accounts for overdispersion, characterized by a model parameter. Regarding the share of green patents relative to the total, I rely on Ordinary Least Squares (OLS) regression.

It is crucial to highlight that, throughout the empirical analysis, I will consider three different samples of companies: the entire sample, a subsample of companies belonging to non-energy sectors, and a subsample of companies belonging to the energy sectors. This division allows me to gain a deeper understanding of the influential variables in each sub-sample, and in particular on the potential different relationship between the environmental score and green innovation effort.

In my analysis, I performed estimations using alternative model specifications in which, as a proxy for the size of companies, I replaced the variable l_EMP, denoting the logarithm of the number of employees, with the variable l_NS, which represents the logarithm of net sales. The outcomes of these alternative models are shown in appendix B.

Additionally, it is important to note that in the empirical analysis, I treated the panel dataset as if it were composed of pooled cross sections, with the primary aim of focusing on the variability among different units in the dataset without specifically considering the temporal dynamics or dependencies among successive observations for the same unit.

5.1 Environmental score and the number of green patents

In the first model, I use the negative binomial model with robust standard errors, where the dependent variable is the number of green patents held by each firm. I first estimate the model using the whole sample and then repeat the analysis for the subsample of firms in non-energy and energy sectors.

Estimation results are shown in Table 5.1

Table 5.1: 1st Negbin Model PT_num_green: whole sample

Dependent variable: `PT_num_green`

	Coefficient	Std. Error	z	p-value
const	−6.05415	0.587771	−10.30	7.03e−025 ***
Environment_score	0.00391185	0.00182866	2.139	0.0324 **
l_RD	0.603204	0.0472986	12.75	3.00e−03***
l_EMP	0.339392	0.0450637	7.531	5.02e−014 ***
DYear_2017	1.10272	0.152487	7.232	4.77e−013 ***
DYear_2018	0.741669	0.148224	5.004	5.62e−07 ***
Electrical_equipment	2.46667	0.525037	4.698	2.63e−06 ***
Machinery	1.67609	0.451013	3.716	0.0002 ***
Computer_electronics	1.15049	0.445217	2.584	0.0098 ***
Basic_metals	1.21371	0.472864	2.567	0.0103 **
Basic_pharma	0.287288	0.472895	0.6075	0.5435
Chemicals	2.51182	0.525380	4.781	1.74e−06 ***
Food_products	−1.07537	0.560533	−1.918	0.0551 *
Transport_equipment	1.78399	0.465564	3.832	0.0001 ***
Rubber_plastic	1.31703	0.477784	2.757	0.0058 ***
Textiles_wearing	1.54781	0.696213	2.223	0.0262 **
Agriculture	−0.832005	0.533544	−1.559	0.1189
Water_supply	1.00578	0.495958	2.028	0.0426 **
ICT	−0.176592	0.474892	−0.3719	0.7100
Professional_services	1.54795	0.511177	3.028	0.0025 ***
Wood_and_furniture	0.626602	0.495077	1.266	0.2056
Other_services	−0.959636	0.929519	−1.032	0.3019
Trade	0.179206	0.498523	0.3595	0.7192
Energy	2.10718	0.538349	3.914	9.07e−05 ***
alpha	3.72216	0.144261	25.80	8.52e−147 ***

Mean dependent var	29.76735	S.D. dependent var	105.1895
Sum squared resid	17083820	S.E. of regression	81.77057
Chi-square (23)	1170.866	p-value	5.5e−233
Log-likelihood	−7624.735	Akaike criterion	15299.47
Schwarz criterion	15445.85	Hannan–Quinn	15352.53

The coefficient for the "Environment_score" variable is statistically significant and positive. This positive sign indicates that an increase in the environmental score is associated with a higher expected number of green patents. In practice, companies that prioritize their environmental performance and improve its quality may be more inclined to invest in and generate green patents, reflecting their commitment to environmental sustainability.

The "l_RD" variable, representing the logarithm of companies' R&D spending, has a positive coefficient and is highly significant. This suggests that companies with higher investments in R&D tend to have a higher expected number of green patents. This implies that allocating resources to Research and Development activities can lead to the creation of more patents, which could involve environmentally friendly innovations and technologies.

The coefficient for the company size variable ("l_EMP") has the expected significance and sign, as companies with a larger workforce (greater employment and, hence, greater size) tend to generate more green patents. This aligns perfectly with what is reflected in reality, as larger companies tend to contribute more to innovation as measured by the number of total patents and, hence, even green patents.

The dummy variables for the years 2017-2018 also have positive coefficients and are statistically significant. The positive coefficients suggest that, compared to the reference year (2016), companies in these years generated more green patents. This could mean that there was a surge in green innovation during those years, possibly due to regulatory changes or increased environmental awareness.

Regarding the coefficients for different industry categories, one sector had to be excluded to avoid collinearity issues (in this case, the reference sector is "Financial and Insurance activities ISIC4_64-66"). It is immediately noticeable that these coefficients vary significantly from sector to sector.

The coefficient associated with the "Energy" variable is highly significant and has a positive sign, suggesting that an overall increase in activities or investments in the "Energy" sector is associated with a significant rise in the number of green patents held by companies operating in that industry. The high value of the coefficient also indicates that companies involved in this sector are making a substantial contribution to the development of green patents. It is important to note that within the "Energy" sector, there are three distinct industrial sectors, which means that the observed effect could be attributed to one or more of these sectors (refer to Appendix A for sector details).

The coefficient associated with the "Electrical Equipment" sector is significantly positive, suggesting that companies in this sector are more likely to generate green patents. This sector includes companies involved in the production of electrical and electronic equipment, which often offer opportunities for green innovation, such as high-energy-efficient appliances or renewable energy technologies.

Similarly, the coefficient for the "Machinery and Equipment" sector is positive and statistically significant. This indicates that companies in this sector tend to generate more green patents, possibly because these companies engage in the production of industrial machinery used across various sectors, and innovations in eco-friendly machinery can contribute to green innovation.

The coefficient for the "Computer Electronics" sector is also positive and significant, indicating that innovations in energy-efficient computing devices or eco-friendly data center technologies play a crucial role in driving companies in this sector to generate more green patents.

The same positive trend is observed in the "Basic Metals and Metal Products" sector, suggesting that companies operating within it may generate more green patents related to sustainable metal production or recycling processes.

The positive and significant coefficient for the "Chemicals and Chemical Products" sector suggests that companies in this sector may want to develop environmentally friendly chemical processes or products, increasing their propensity to generate green innovation.

An interesting finding is in the "Food Products and Beverages" sector, where the coefficient is negative and statistically significant. This implies that companies in this sector tend to have fewer green patents. This could be because the primary focus of this sector is food production rather than green innovation, despite recent sustainability practices within the food industry.

The positive and significant coefficient for the "Transport Equipment" sector could be related to innovations in eco-friendly transportation solutions, such as electric vehicles or fuel-efficient engines, encouraging companies in this sector to focus more on generating sustainable innovations.

The same reasoning applies to the "Rubber and Plastic Products" sector, where the positive coefficient suggests that companies in this sector may generate more green patents due to innovations in sustainable materials and recycling processes.

The "Textiles and Wearing Apparel" sector also shows a positive coefficient, indicating that companies in textiles and wearing apparel may generate more green patenting activities, possibly due to eco-friendly textile innovations or sustainable fashion practices.

The positive coefficient for the "Water Supply, Sewerage, Waste Management" sector suggests that companies in this sector are more likely to generate green patents, possibly related to innovations in water and waste management technologies focused on environmental sustainability.

The "Professional Services" sector has a positive and significant coefficient, suggesting that companies in this sector are more inclined to generate green patents. It is crucial to note that within this sector are companies that deal with "Software and Computer services," among which are important names such as Google (a subsidiary of Alphabet Inc.), Microsoft and Alibaba.

These companies, which are primarily involved in software and IT services, stand out for their strong commitment to green technologies. An exemplar is Waymo, a subsidiary of Google, which has secured numerous patents for autonomous vehicles, promoting sustainable transportation solutions and road safety. Furthermore, Alphabet has made substantial investments in renewable energy projects, demonstrating a concrete dedication to eco-friendly activities. A tangible example of this commitment is the announcement in September 2019 of Google's CEO's intention to invest 2 billion in wind and solar energy, thus forming the largest renewable energy deal in the company's history, increasing its green energy profile by 40%. These tech giants extend their reach beyond software development, significantly investing in green technologies, driving the growth of sustainable endeavors.

Sectors such as "Basic Pharmaceuticals," "Agriculture, Hunting, and Forestry," "Water Supply, Sewerage, Waste Management," "Information and Communication," "Wood and Furniture," "Trade" and "Other Services" are all statistically non-significant. This underscores the fact that companies operating in these sectors do not exhibit a consistent trend in generating green patents, as they may not be strongly oriented toward green innovation compared to other sectors.

Finally, the coefficient associated with the alpha parameter (overdispersion parameter) is positive and statistically significant, supporting the need for an alternative model to the traditional poisson regression ($\alpha = 0$), where equidispersion is assumed.

Due to the high correlation between the explanatory variables OP[1] and CAPEX[2] with firm size (measured by the variable l_EMP), it was necessary to exclude these variables from the model presented in Table 5.1 because the size effect was already captured by the number of employees. An alternative specification is provided in the appendix B, where the variable l_NS is included as a proxy for firm size.

In tables 5.2 and 5.3, are shown the estimation results considering only the non-energy sectors first and then only the energy sectors to see the possible differences that emerge.

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[1] OP (Operating Profit) represents the operating profit of the companies involved in the study. It is a key measure of the profitability of a company's operations, calculated by subtracting operating costs from gross operating income.

[2] CAPEX (Capital Expenditures) indicates physical capital expenditures made by enterprises. It represents investment in long-term assets, such as the purchase of equipment, plant or other tangible assets intended to generate future benefits.

Table 5.2: 1.a Negbin Model PT_num_green: non-energy sectors sub-sample

Dependent variable: PT_num_green

	Coefficient	Std. Error	z	p-value
const	−6.07353	0.589379	−10.30	6.69e−025 ***
Environment_score	0.00390625	0.00184837	2.113	0.0346 **
l_RD	0.611654	0.0478625	12.78	2.14e−037 ***
l_EMP	0.337982	0.0454610	7.435	1.05e−013 ***
DYear_2017	1.09105	0.153834	7.092	1.32e−012 ***
DYear_2018	0.724012	0.149406	4.846	1.26e−06 ***
Electrical_equipment	2.47044	0.526385	4.693	2.69e−06 ***
Machinery	1.67377	0.451324	3.709	0.0002 ***
Computer_electronics	1.14747	0.445714	2.574	0.0100 **
Basic_metals	1.21359	0.472623	2.568	0.0102 **
Basic_pharma	0.287685	0.473628	0.6074	0.5436
Chemicals	2.51322	0.524359	4.793	1.64e−06 ***
Food_products	−1.07313	0.561381	−1.912	0.0559 *
Transport_equipment	1.77505	0.465616	3.812	0.0001 ***
Rubber_plastic	1.32227	0.478671	2.762	0.0057 ***
Textiles_wearing	1.55594	0.697460	2.231	0.0257 **
Agriculture	−0.834328	0.533720	−1.563	0.1180
Water_supply	1.01689	0.498180	2.041	0.0412 **
ICT	−0.180834	0.475646	−0.3802	0.7038
Professional_services	1.55652	0.512158	3.039	0.0024 ***
Wood_and_furniture	0.632774	0.495587	1.277	0.2017
Other_services	−0.956554	0.930169	−1.028	0.3038
Trade	0.182940	0.499221	0.3665	0.7140
alpha	3.71244	0.148502	25.00	6.23e−138 ***

Mean dependent var	29.44881	S.D. dependent var	105.8172
Sum squared resid	15736288	S.E. of regression	80.17620
Chi-square (22)	1158.214	p-value	3.7e−231
Log-likelihood	−7208.501	Akaike criterion	14465.00
Schwarz criterion	14604.50	Hannan–Quinn	14515.68

The results shown in table 5.2 are practically the same as those of the model estimated using the whole sample, suggesting that the energy sectors may not have a significant impact on the generation of green patents compared to the other sectors considered. More generally, the role of the determinants observed using the entire sample is consistent with what is observed in non-energy sector companies, suggesting that 'energy' firms do not introduce significant heterogeneity in the effects.

Table 5.3: 1.b Negbin Model PT_num_green: energy sectors sub-sample

Dependent variable: `PT_num_green`

	Coefficient	Std. Error	z	p-value
Environment_score	0.000545857	0.0109241	0.04997	0.9601
l_RD	0.225927	0.347170	0.6508	0.5152
l_EMP	0.182789	0.306307	0.5968	0.5507
DYear_2017	1.40944	0.804746	1.751	0.0799 *
DYear_2018	1.21001	0.778227	1.555	0.1200
alpha	3.71869	0.582744	6.381	1.76e−010 ***

Mean dependent var	37.05556	S.D. dependent var	89.75031
Sum squared resid	835243.7	S.E. of regression	90.49124
Chi-square (5)	6.573237	p-value	0.254362
Log-likelihood	−414.0342	Akaike criterion	842.0685
Schwarz criterion	860.8434	Hannan–Quinn	849.6810

Table 5.3 presents the results considering only the companies belonging to energy sectors. Unlike the previous two models, it is immediately noticeable how the only positive and significant coefficients are those related to the 2017 dummy variable and the alpha parameter.

Everything else becomes statistically insignificant, also eliminating the size effect of the company. It is important to note that the number of companies belonging to the sub-sample of energy sector companies is relatively small, totaling 108 observations. Consequently, it is expected that there may be a loss of significance due to the smaller sample size.

5.2 Environmental score and the ratio of green patents

Table 5.4: 2nd OLS Model PT_share_green: whole sample

Dependent variable: PT_share_green

	Coefficient	Std. Error	z	p-value
const	0.0457455	0.0360581	1.269	0.2047
Environment_score	3.47480e−05	8.76062e−05	0.3966	0.6917
RD_NS	−2.12223e−05	0.000460493	−0.04609	0.9632
CAPEX_NS	9.70345e−05	0.000596916	0.1626	0.8709
OP_NS	−1.47026e−05	0.000390203	−0.03768	0.9699
l_EMP	0.00484069	0.00204515	2.367	0.0180 **
DYear_2017	−0.00250883	0.00825172	−0.3040	0.7611
DYear_2018	−0.0117753	0.00803010	−1.466	0.1427
Electrical_equipment	0.120120	0.0427440	2.810	0.0050 ***
Machinery	−0.00946111	0.0274024	−0.3453	0.7299
Computer_electronics	−0.0207986	0.0272650	−0.7628	0.4456
Basic_metals	−0.00742928	0.0288484	−0.2575	0.7968
Basic_pharma	−0.0315515	0.0281955	−1.119	0.2632
Chemicals	0.000491592	0.0278725	0.01764	0.9859
Food_products	−0.0784707	0.0269691	−2.910	0.0036 ***
Transport_equipment	0.0909554	0.0293802	3.096	0.0020 ***
Rubber_plastic	0.0259635	0.0344878	0.7528	0.4516
Textiles_wearing	−0.0437267	0.0331129	−1.321	0.1868
Agriculture	0.0216831	0.0547373	0.3961	0.6920
Water_supply	0.361238	0.106238	3.400	0.0007 ***
ICT	−0.0279004	0.0289262	−0.9645	0.3349
Professional_services	−0.00483014	0.0317731	−0.1520	0.8792
Wood_and_furniture	−0.0576266	0.0278654	−2.068	0.0387 **
Other_services	−0.0585446	0.0332460	−1.761	0.0784 *
Trade	0.00634298	0.0360875	0.1758	0.8605
Energy	0.139911	0.0372881	3.752	0.0002 ***

Mean dependent var	0.087642	S.D. dependent var	0.159196
Sum squared resid	57.38861	S.E. of regression	0.149930
R-squared	0.121633	Adjusted R-squared	0.113032
F(25, 2553)	16.07923	P-value(F)	4.05e−64
Log-likelihood	1247.506	Akaike criterion	−2443.012
Schwarz criterion	−2290.778	Hannan–Quinn	−2387.831

In modeling the ratio of green patents, I consider a different specification, with CAPEX_NS and OP_NS. Their inclusion is due to the different nature of the dependent variable, which in this case does not focus on the patent count itself, but expresses the share of green patents held by firms. If a company is investing a significant percentage of its net sales in CAPEX (expenditure on physical capital investments) for sustainable projects and has a healthy operating profit from sustainable activities, this might suggest a strong commitment to green innovation. This could translate into a higher likelihood of developing green patents. In addition, a company with a high Operating Profit over Net Sales may have additional financial resources to support green innovation, including Research and Development of environmentally friendly technologies and green patent filings. Accordingly, I also use the variable RD_NS instead of l_RD.

One striking observation in Table 5.4 is the persistence of the size effect, represented by the significance and positivity of l_EMP coefficient. In other words, larger firms tend to have a higher intensity of green patents compared to smaller firms, aligning with real-world observations.

The coefficient associated with the "Energy" variable has a positive value and is statistically significant, as observed in model 5.1. This indicates a significant impact of the energy sector on the share of patents held by companies.

The fact that the coefficient is positive suggests that an increase in activities or investments in the energy sector is associated with a significant rise in the share of green patents held relative to the total patents, implying a greater inclination towards investments aimed at achieving green innovations.

"Electrical_equipment" sector is positive and statistically significant, emphasizing that companies in this sector tend to hold a higher percentage of green patents compared to other sectors.

The same applies to the "Transport_equipment" and "Energy" sectors, which also tend to have a higher share of green patents.

An intriguing aspect concerns the "Food_products_and_beverages" sector, which has a negative sign and is statistically significant.

As previously observed for the absolute number of green patents (with the negative binomial distribution), companies in the food sector tend to hold a lower share of green patents. The same pattern can be extended to the "Other_services" sector, which exhibits a similar behavior.

What is particularly captivating is the direction and significance of the coefficient associated with the "Wood_and_furniture" sector, mirroring the situation observed in the "Food_products_and_beverages" sector. Both are significant and exhibit a negative coefficient, implying a negative correlation between the share of green patents and activities and investments within these sectors. In essence, it suggests that companies operating in these sectors may not demonstrate a strong inclination toward investing in green technologies.

All other variables, including those expressed in intensity terms, are not statistically significant and therefore do not have a significant impact on the share of green patents held by companies.

The next step will involve dividing the sample into energy and non-energy sectors to verify if there are differences compared to what was observed with absolute values previously.

Table 5.5: 2.a OLS Model PT_share_green: non-energy sub-sample

Dependent variable: PT_share_green

	Coefficient	Std. Error	z	p-value
const	0.0498454	0.0359512	1.386	0.1657
Environment_score	−2.26032e−05	8.52382e−05	−0.2652	0.7909
RD_NS	−1.09868e−05	0.000459313	−0.02392	0.9809
CAPEX_NS	0.000107110	0.000595113	0.1800	0.8572
OP_NS	−6.38194e−06	0.000389242	−0.01640	0.9869
l_EMP	0.00481968	0.00202766	2.377	0.0175 **
DYear_2017	−0.00522149	0.00803828	−0.6496	0.5160
DYear_2018	−0.0125557	0.00789802	−1.590	0.1120
Electrical_equipment	0.120373	0.0427543	2.815	0.0049 ***
Machinery	−0.00929807	0.0274192	−0.3391	0.7346
Computer_electronics	−0.0211671	0.0272796	−0.7759	0.4379
Basic_metals	−0.00743335	0.0288620	−0.2575	0.7968
Basic_pharma	−0.0316006	0.0282100	−1.120	0.2627
Chemicals	0.000695851	0.0278903	0.02495	0.9801
Food_products	−0.0786359	0.0269971	−2.913	0.0036 ***
Transport_equipment	0.0911612	0.0293964	3.101	0.0020 ***
Rubber_plastic	0.0260300	0.0345194	0.7541	0.4509
Textiles_wearing	−0.0439198	0.0330417	−1.329	0.1839
Agriculture	0.0233789	0.0549839	0.4252	0.6707
Water_supply	0.364089	0.105568	3.449	0.0006 ***
ICT	−0.0283004	0.0289397	−0.9779	0.3282
Professional_services	−0.00485876	0.0317958	−0.1528	0.8786
Wood_and_furniture	−0.0574518	0.0278871	−2.060	0.0395 **
Other_services	−0.0597323	0.0334228	−1.787	0.0740 *
Trade	0.00691693	0.0361353	0.1914	0.8482

Mean dependent var	0.081280	S.D. dependent var	0.149254
Sum squared resid	49.47938	S.E. of regression	0.142228
R-squared	0.100759	Adjusted R-squared	0.091935
F(24, 2446)	14.55275	P-value(F)	3.83e−55
Log-likelihood	1325.624	Akaike criterion	−2601.247
Schwarz criterion	−2455.938	Hannan–Quinn	−2548.462

As observed in the analysis of patents in absolute terms, the results shown in Table 5.5 are roughly the same as those of the model with aggregated sectors, even though in this case, I am considering the shares of green patents over the total. The significance and direction of the coefficients are practically identical, and the effect of firm size continues to hold.

Now, I will examine the implications arising from the model presented in Table 5.6, where only the sub-sample with firms belonging to the energy sectors are considered.

Table 5.6: 2.b OLS Model PT_share_green: energy-sector sub-sample

Dependent variable: PT_share_green

	Coefficient	Std. Error	z	p-value
const	−0.0380922	0.245620	−0.1551	0.8771
Environment_score	0.00216542	0.000964577	2.245	0.0270 **
RD_NS	1.91837	5.10786	0.3756	0.7080
CAPEX_NS	0.0339068	0.289628	0.1171	0.9070
OP_NS	−0.200675	0.181896	−1.103	0.2726
l_EMP	0.0117266	0.0223752	0.5241	0.6014
DYear_2017	0.0575690	0.0658781	0.8739	0.3843
DYear_2018	−0.000167468	0.0619095	−0.002705	0.9978

Mean dependent var	0.233217	S.D. dependent var	0.272121
Sum squared resid	7.508720	S.E. of regression	0.274020
R-squared	0.052327	Adjusted R-squared	−0.014010
F(7, 100)	1.232486	P-value(F)	0.292231
Log-likelihood	−9.277783	Akaike criterion	34.55557
Schwarz criterion	56.01262	Hannan–Quinn	43.25562

The results of table 5.6 are particularly interesting and surprising because the only significant and positive coefficient refers to the variable "Environment_score."

When analyzing only companies in the energy sector, which are typically associated with higher environmental impact and the predominant use of fossil energy sources rather than renewables (think of sectors like oil extraction, refining, and electricity and gas production), a significant correlation can be observed between those that have a higher percentage of green patents relative to the total and the environmental indicator.

Within the sector of electricity production and distribution (ISIC4_35), there are also companies that use renewable energy sources. These companies are more likely to utilize these resources and probably have higher environmental scores, provided that they have invested significantly in renewable and sustainable resources.

To verify the presence of this potential effect, a final specification will be performed, in which the industry dummies related exclusively to the Energy sector will be divided.

Table 5.7: 2.c OLS Model PT_share_green with energy sub-sectors

Dependent variable: PT_share_green

	Coefficient	Std. Error	z	p-value	
const	0.0168364	0.273424	0.06158	0.9510	
Environment_score	0.00101129	0.000936924	1.079	0.2831	
RD_NS	0.202582	4.36666	0.04639	0.9631	
CAPEX_NS	−0.293873	0.317908	−0.9244	0.3576	
OP_NS	−0.116749	0.143599	−0.8130	0.4182	
l_EMP	0.0104416	0.0224118	0.4659	0.6423	
DYear_2017	0.0670866	0.0621999	1.079	0.2834	
DYear_2018	0.00968776	0.0604297	0.1603	0.8730	
Coke_and_refined_petroleum_products	−0.0654171	0.0534300	−1.224	0.2238	
Electricity_gas_steam	0.204092	0.0666294	3.063	0.0028	***

Mean dependent var	0.233217	S.D. dependent var	0.272121
Sum squared resid	6.237401	S.E. of regression	0.252283
R-squared	0.212780	Adjusted R-squared	0.140484
F(9, 98)	3.735095	P-value(F)	0.000456
Log-likelihood	0.739293	Akaike criterion	18.52141
Schwarz criterion	45.34273	Hannan–Quinn	29.39648

The "Mining and Quarrying" variable was chosen as reference dummy to avoid issues of collinearity. The results of the regression confirm the hypothesis formulated earlier, and this result has interesting implications.

The effect of the Environment score is entirely captured by the "Electricity" sector: within the energy sector, companies that generate electricity are the ones that invest more in green patents and tend to have a higher environmental score.

It is important to note that, in general, the Environment score usually does not capture the sectoral effect. However, in this case, we observe a result that goes against expectations. This is mainly because within the energy sector, there are companies that have made significant investments in renewable energy, triggering a percentage increase in green patents and, consequently, an increase in the ESG score.

A result of significant relevance emerged from Table 5.8, which highlighted the averages of environmental scores and the shares of green patents for companies in the electric and non-electric industries within the energy macro-sector.

Table 5.8: Electrical vs Non-Electrical

Category	Average	
	Environment Score	Share of Green Patents
Electrical (ISIC4 – 35)	63.26	37,36%
Non-Electrical (ISIC4 – 19, 05-09)	55.89	14,73%

The data confirmed the previously discussed relationships, emphasizing the significant difference between companies in the electric and non-electric sectors. In the electric sector, companies exhibited a notably higher average Environmental score, at 63.26, compared to the average of 55.89 for companies in the non-electric sector.

Furthermore, the electric sector held a green patent share of 37,36%, demonstrating a strong commitment to ecological and sustainable innovations, as opposed to the 14,73% of companies in the non-electric sector.

These results underscore the crucial role of the electric sector in environmental innovation and emphasize the urgency of intensifying efforts in non-electric industries to promote green practices.

CONCLUSIONS

Throughout the progression of this thesis, I conducted an analysis of the relationship between green patents and ESG scores, with a particular focus on the environmental component. The research has revealed a series of findings that can contribute to the understanding of the interplay between eco-friendly innovation and the imperative of environmental sustainability in a global context.

The study indicates that R&D investments promote eco-innovation and the development of sustainable technologies, and companies that prioritize R&D investments are more inclined to engage in green patenting activities. This aligns with the concept of green growth, which involves structural changes in the organization and behavior of companies and society, including the reduction of unsustainable production and consumption within the framework of ongoing economic progress.

The adoption of government initiatives and policies is essential to guide technological advancements toward environmentally sustainable growth. The formal definition of ESG, established in 2004, and the detailed articulation of its components accentuate the increasing interest among companies in ESG strategies, the emergence of ESG-focused investment products, and the development of corresponding regulatory policies.

Companies with high ESG scores exhibit superior innovation performance and attract sustainable investments, highlighting that high ESG scores are correlated with greater investments in R&D and green innovation.

Companies subjecting themselves to ESG evaluations tend to outperform others, demonstrating greater resilience to risks and crises. This emphasizes the importance of assessing these ESG criteria in all companies, regardless of their mission and objectives. The inclusion of ESG criteria into corporate processes can lead to long-term financial sustainability and a better reputation. Companies need to protect their green intellectual property by effectively managing their patent portfolios to achieve increasingly high ESG scores and stay informed about market developments.

The presence of a variety of rating agencies allows investors to gain diversified perspectives on the scores assigned to different companies, but it also highlights the urgent standardization of the scoring process on a global scale, by providing a clear and comprehensive view of the environmental and social impact that these companies have worldwide.

Several studies have shown a correlation between ESG scores and green innovation, particularly considering the environmental component, within Western companies. Despite this, the results are not uniform and indicate that the interaction between ESG factors and green innovation moves, in some cases, in different directions, stressing the difficulty in understanding this complex relationship.

Similarly, various studies conducted on publicly traded companies in China have revealed that companies with higher ESG scores tend to exhibit a greater quantity and quality of innovations related to ecological sustainability. However, the relationship between ESG scores and green patents in Chinese companies can be influenced by complex dynamics and does not always follow a linear positive correlation. Therefore, researchers recommend further studies aimed at exploring in detail the specific mechanisms through which ESG scores influence green innovation and contribute to the promotion of sustainable development.

In the final chapter of the thesis, after describing the type of data collected for green patents and ESG scores, I performed an econometric analysis concerned with companies representing the major R&D investors of the world.

The results show that companies investing significantly in the development of sustainable technologies and green patents tend to exhibit a stronger correlation with ESG scores. One noteworthy finding concerns the important role played by firm size and sectors in determining the number of green patents owned. These findings emerged when considering the total sample of companies, significantly highlighting the importance of such factors in promoting green innovation.

Instead, when considering the share of green patents among non-energy sector enterprises, the Environment score did not emerge as a significant determinant of companies' green patent holding.

Shifting the focus upon companies in the energy sector, traditionally associated with greater environmental impact and predominant use of fossil energy sources, an interesting finding arose. Within the sector of electricity production and distribution (ISIC4_35), I identified companies utilizing renewable energy sources. These companies achieved higher environmental scores, provided they had made significant investments in renewable and sustainable resources.

Companies within the energy sector engaged in electricity production exhibited a higher commitment to green patents and higher ESG scores. This result within the energy sector provides strong backing for the initially formulated hypothesis.
Additionally, it highlights the challenges faced by companies engaged in the extraction and distribution of oil and gas in demonstrating their commitment to environmental sustainability.

Overall, this analysis provides additional and interesting empirical evidence concerning the relationship between green patents and ESG scores. However, it is essential to acknowledge the inherent limitations of this study, such as sample selection and omitted variables (due to the low number of available explanatory factors). Accordingly, several questions still remain to be answered, highlighting the need for future research to deepen the understanding of this complex relationship.

In conclusion, this study emphasizes the fundamental role of sustainable innovation from an international perspective, particularly in an evolving landscape where sustainability is gaining ever greater prominence. The implications of these findings hold significance for both corporate and investment decision-making, emphasizing the need of embracing eco-friendly and sustainable practices as we strive to construct a more promising future.

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Appendix A

A ISIC4 sectors aggregation: energy and non-energy

Given the vast number of sectors in the initial dataset, on the basis of the ISIC4 codes associated with each sector, I aggregated the sectors, separating the energy sector from all the other (non-energy) sectors, which were aggregated as far as possible, in case they belonged to the same ISIC4 code family.

The table below illustrates the division and aggregation of the different sectors, to which the corresponding ISIC4 code is attached.

By utilizing the "STAN Industry List", it became possible to perform a precise aggregation of economic sectors within the JRC-OECD COR&DIP© database. This document provides a standardized classification of economic activities, identifying each sector with a unique ISIC code. Leveraging this classification, the information within the dataset could be categorized and organized in a consistent and structured manner.

The use of the "STAN Industry List" enabled the grouping of similar sectors based on their core characteristics, allowing for an in-depth analysis of economic trends and industrial performance. This standardized classification methodology facilitated a clearer understanding of the data and provided a solid foundation for informed decision-making by policymakers, researchers, and analysts, optimizing the assessment and interpretation of economic dynamics within the JRC-OECD COR&DIP© database

Table A1: ISIC4 Sectors and Corresponding Codes

SECTOR NAME	ISIC4 CODES
Agriculture, hunting and forestry	01-03
Energy sector	05-09: Mining and Quarrying
	19: Coke and refined petroleum products
	35: Electricity, gas, steam and air conditioning supply
Wood and Furniture	16-18, 31-33
Textiles and wearing apparel	13-15
Chemicals and chemical products	20
Basic pharmaceutical products	21
Rubber, plastic, and other non-metallic mineral products	22-23
Basic metals and fabricated metal	24-25
Computer, electronic and optical products	26
Electrical equipment	27
Machinery and equipment n.e.c.	28
Transport equipment	29-30
Water supply, sewerage and waste management	36-39
Construction	41-43
Trade	45-56
Information and Communication	58-63
Financial and Insurance activities	64-66
Professional Services	69-82
Other Services	90-99

Appendix B

B Alternative specifications

In this appendix, I will present the results of regression analysis conducted on the alternative specification employing the natural logarithm of Net Sales (l_NS) rather than the natural logarithm of the number of employees (l_EMP).

Table B1: Negbin Model PT_num_green: whole sample

	Coefficient	Std. Error	z	p-value
const	−5.13108	0.572156	−8.968	3.02e−019 ***
Environment_score	0.00373657	0.00180863	2.066	0.0388 **
l_RD	0.613095	0.0609744	10.05	8.74e−024 ***
l_NS	0.279354	0.0562219	4.969	6.74e−07 ***
DYear_2017	1.06154	0.153765	6.904	5.07e−012 ***
DYear_2018	0.702916	0.148188	4.743	2.10e−06 ***
Electrical_equipment	2.58322	0.518963	4.978	6.44e−07 ***
Machinery	1.67389	0.444443	3.766	0.0002 ***
Computer_electronics	1.18504	0.442023	2.681	0.0073 **
Basic_metals	1.33543	0.483589	2.762	0.0058 ***
Basic_pharma	0.219866	0.478066	0.4599	0.6456
Chemicals	2.28871	0.515914	4.436	9.16e−06 ***
Food_products	−1.22622	0.512827	−2.391	0.0168 **
Transport_equipment	1.80344	0.463655	3.890	0.0001 ***
Rubber_plastic	1.36411	0.468874	2.909	0.0036 ***
Textiles_wearing	1.54639	0.687544	2.249	0.0245 **
Agriculture	−0.810097	0.540290	−1.499	0.1338
Water_supply	1.33884	0.492194	2.720	0.0065 ***
ICT	−0.178082	0.471160	−0.3780	0.7055
Professional_services	1.68376	0.532310	3.163	0.0016 ***
Wood_and_furniture	0.646454	0.493082	1.311	0.1898
Other_services	−0.985056	0.940599	−1.047	0.2950
Trade	0.251408	0.482973	0.5205	0.6027
Energy	1.85239	0.547083	3.386	0.0007 ***
alpha	3.74945	0.145784	25.72	7.14e−146 ***

Mean dependent var	29.76735	S.D. dependent var	105.1895
Sum squared resid	16897402	S.E. of regression	81.32321
Chi-square (23)	1046.620	p-value	1.6e−206
Log-likelihood	−7634.984	Akaike criterion	15319.97
Schwarz criterion	15466.35	Hannan–Quinn	15373.03

The results for the whole sample show substantial indifference to those shown by Table 5.1, where l_EMP was used as a proxy for firm size compared to l_NS.

The signs and significance of the coefficients remain almost identical between the two models, emphasizing the significance of the Environment_score, l_RD, l_NS as well as the dummy variables of the years.

The coefficient alpha always remains positive and significant, emphasizing the overdispersion of the data.

Table B2: Negbin Model PT_num_green: non-energy sub-sample

	Coefficient	Std. Error	*z*	p-value
const	−5.15245	0.574303	−8.972	2.92e−019 ***.
Environment_score	0.00380766	0.00182350	2.088	0.0368 **
l_RD	0.623320	0.0618386	10.08	6.79e−024 ***.
l_NS	0.276292	0.0568018	4.864	1.15e−06 ***.
DYear_2017	1.04991	0.154960	6.775	1.24e−011 ***.
DYear_2018	0.686227	0.149167	4.600	4.22e−06 ***.
Electrical_equipment	2.58724	0.519892	4.977	6.47e−07 ***.
Machinery	1.67192	0.444175	3.764	0.0002 ***.
Computer_electronics	1.18221	0.441919	2.675	0.0075 **.
Basic_metals	1.33581	0.481974	2.772	0.0056 ***.
Basic_pharma	0.218113	0.478480	0.4558	0.6485
Chemicals	2.29318	0.514692	4.455	8.37e−06 ***.
Food_products	−1.21976	0.513246	−2.377	0.0175 **.
Transport_equipment	1.79561	0.462954	3.879	0.0001 ***.
Rubber_plastic	1.36887	0.469095	2.918	0.0035 ***.
Textiles_wearing	1.55673	0.688102	2.262	0.0237 **.
Agriculture	−0.817431	0.540031	−1.514	0.1301.
Water_supply	1.35030	0.493875	2.734	0.0063 ***.
ICT	−0.181828	0.471278	−0.3858	0.6996
Professional_services	1.68919	0.533437	3.167	0.0015 ***.
Wood_and_furniture	0.651962	0.492921	1.323	0.1860.
Other_services	−0.981770	0.940913	−1.043	0.2968.
Trade	0.257071	0.482982	0.5323	0.5945.
alpha	3.74293	0.150027	24.95	2.22e−137 ***.

Mean dependent var	29.44881	S.D. dependent var	105.8172
Sum squared resid	15749312	S.E. of regression	80.20937
Chi-square (22)	1031.326	p-value	4.2e−204
Log-likelihood	−7219.153	Akaike criterion	14486.31
Schwarz criterion	14625.80	Hannan–Quinn	14536.98

Table B2 highlights the results obtained using the subsample of firms belonging to the non-energy sector. The results highlight the significance and positivity of the coefficient of the Environment_score variable as well as the significance and positivity of the size of firms expressed by l_NS. Again, alpha has a positive and significant sign, and as for the coefficients of the other variables they all have the same direction and significance as those observed in the model with l_EMP, in Table 5.2.

Table B3: Negbin Model PT_num_green: energy sub-sample

	Coefficient	Std. Error	z	p-value
const	−1.07275	2.27308	−0.4719	0.6370
Environment_score	−0.00312316	0.0110376	−0.2830	0.7772
l_RD	0.114955	0.356238	0.3227	0.7469
l_NS	0.310452	0.268037	1.158	0.2468
DYear_2017	1.40800	0.789437	1.784	0.0745 *
DYear_2018	1.20431	0.764644	1.575	0.1153
alpha	3.68397	0.571492	6.446	1.15e−010 ***.

Mean dependent var	37.05556	S.D. dependent var	89.75031
Sum squared resid	852408.7	S.E. of regression	91.41634
Chi-square (5)	8.138015	p-value	0.148792
Log-likelihood	−413.4933	Akaike criterion	840.9866
Schwarz criterion	859.7615	Hannan–Quinn	848.5991

Finally, Table B3 shows the results for the subsample of the Energy sector, which again confirms the results obtained in the models used in the analysis with the variable l_EMP as a proxy for firm size, in Table 5.3. The alpha parameter is positive and significant, again showing the overdispersion of the data, and the only significant variable with a positive sign along with it is that for the year 2017.

Although the size variable considered is different from the models considered in Chapter 5, the choice of l_EMP or l_NS does not significantly affect the direction and significance of the explanatory variables considered.

Appendix C

C Methodology used by Refinitiv for assigning the Environment score

This appendix aims to clarify the methodology used by the Refinitiv platform to calculate ESG scores, with a primary focus on the Environment component, which is of significant interest in my study. First and foremost, it is important to specify that Refinitiv associates three primary reference categories with the Environmental Pillar, which are shown in Table C1.

Table C1: Environmental Pillar Categories and Themes

Environmental Categories	**Themes**
Emission	- Emissions (CO_2) - Total Waste - Biodiversity - Environmental Management Systems
Innovation	- Product Innovation - Green Revenues - Research and Development (R&D) - Capital Expenditures (Capex)
Resource Use	- Water - Energy - Sustainable Packaging - Environmental Supply Chain

The *emission* score measures a company's commitment and effectiveness towards reducing environmental emissions in its production and operational processes.

The *innovation* score reflects a company's capacity to reduce environmental costs and burdens for its customers, thereby creating new market opportunities through new environmental technologies and processes, or eco-designed products.

The *resource use* score reflects a company's performance and capacity to reduce the use of materials, energy or water, and to find more eco-efficient solutions by improving the supply chain management.

The process of assigning ESG scores is divided into several phases. The first phase involves data collection (see section 4.2). Once the data is collected, the next step is data normalization.

To assess the relative importance of various ESG categories to a company's industry, Refinitiv uses two different weighting methods along with so-called data points. The "data points" used by Refinitiv, represent specific indicators or metrics, that are used to evaluate the environmental performance of companies. These indicators focus on various aspects related to the environment and environmental data reported by companies. For example, TR.AnalyticCO_2 represents the estimated total CO_2 and CO_2 equivalents emission in tonnes, while TR.AnalyticTotalWaste indicates the total amount of waste generated.

The methods for assigning weights to the Environment component are the "quant industry median" and the "transparency weights" method.

Starting with the former, this method is mainly applied to numerical data with environmental and social impact. Specifically, the "quant industry median" method relies on the relative industry median to assign a relative weight to a company's numerical data. The relative industry median is determined by comparing a company's numerical values with those of other companies in the same industry. Depending on a company's position to the industry median, a relative weight is assigned to the company's numerical data, which is then utilized to calculate the company's overall ESG score.

On the other hand, the "transparency weights" method, mainly applies to boolean data, which consists of data points that can have only two values: "yes" or "no." Specifically, the "transparency weights" method is based on the level of disclosure of boolean data within a specific domain. The disclosure percentage is identified for each domain relevant to the boolean data, and the decision is made based on the disclosure level of the boolean data.

For example, the answer to 'Does the company have a water efficiency policy?" can be 'Yes' (equivalent to a value of 1) if this is the case, or 'No' if the company in question does not have such a policy or reports only partial information. In such cases, the system automatically assigns a default value of 0. In other words, a default value of 0 is assigned for boolean data points when no relevant information is found in the companies' public disclosure.

Each measure has a polarity that indicates whether a higher value is positive or negative. For example, having a policy to reduce emissions is positive, but having environmental controversies is negative.

Based on the polarity of the data (i.e., whether a higher value is 'better' or 'worse'), boolean data points are converted into numerical values for percentile score calculation.

Figure C1 provides a view on the ESG themes covered in each category, with the respective data points evaluated as proxies of ESG magnitude per industry group.

Figure C1: Environment category weight method

Pillars	Catagories	Themes	Data points	Weight method
Environmental	Emmission	Emissions	TR.AnalyticCO2	Quant industry median
		Waste	TR.AnalyticTotalWaste	Quant industry median
		Biodiversity*		
		Environmental management systems*		
	Innovation	Product innovation	TR.EnvProducts	Transparency weights
		Green revenues, research and development (R&D) and capital expenditures (CapEx)	TR.AnalyticEnvRD	Quant industry median
	Resource use	Water	TR.AnalyticWaterUse	Quant industry median
		Energy	TR.AnalyticEnergyUse	Quant industry median
		Sustainable packaging*		
		Environmental supply chain*		

Source: *Environmental, Social and Governance Scores from Refinitiv, May 2022*

In determining relevance and category weights, Refinitiv considers only mediumand large-sized companies, because smaller companies often report less data, which can affect both the percentage of relevance and the assigned weights.

The stage of data normalization, ensuring data comparability between companies and various data sources becomes necessary. Refinitiv employs a scale ranging from 0 to 100, where 100 represents the highest score. Data is normalized using a formula that takes into account the data distribution within each ESG category.

The fourth phase pertains to the weights allocation; Refinitiv assigns weights to the various ESG categories based on their relative importance within the company's industry.

Refinitiv employs a "materiality matrix" to determine the relative importance of different ESG categories in calculating a company's overall ESG score. This assessment takes into account the categories' relative significance within the company's industry, the severity of ESG impacts, and stakeholder perceptions. Taking these factors into account, Refinitiv assigns values to each category. By integrating the materiality matrix with the scores of the ESG categories, the company's overall ESG rating is determined.

Additionally, Refinitiv utilizes the "TRBC Industry Group Name" and "Industry Group Code" to classify companies based on their industry. This classification helps compare ESG performance among companies within the same sector, enabling a more accurate and relevant analysis of ESG performance within a specific industry.
Industry codes and names are standardized, facilitating global company comparisons and assessments.

Figure C3 provides an indicative ESG magnitude (materiality) matrix based on assessment of sample ESG data

Figure C3: Indicative ESG materiality matrix

		Environmental			Social				Governance		
TRBC Industry Group Name	Industry Group code	Emission	Innovation	Resource use	Human rights	Product responsibility	Workforce	Community	Management	Shareholders	CSR strategy
Telecommunications Services	574010	4	4	4	8	9	8	5	10	3	2
Textiles & Apparel	532020	3	4	4	8	7	8	5	10	3	2
Transport Infrastructure	524070	7	2	7	6	3	9	5	10	3	2
Uranium	503010	10	1	10	1	3	3	5	10	3	2
Water & Related Utilities	591030	9	8	9	3	2	8	5	10	3	2

Source: *Environmental, Social and Governance Scores from Refinitiv, May 2022*

Figure C4 shows the calculation to derive Pillar scores and the assignment of weights for each category.

Figure C4: Calculations to derive Pillar scores

Pillar	Category	Category scores*	Category weights	Sum of category weights	Formula: sum of category weights	New category weights*	Formula: new category weights	Pillar scores	Formula: pillar scores
Environmental	Emissions	0.98	0.15			0.35	(0.15/0.44)		
Environmental	Resource use	0.97	0.15	0.44	(0.15+0.15+0.13)	0.35	(0.15/0.44)	0.94	(0.98*0.35)+ (0.97*0.35)+ (0.85*0.29)
Environmental	Innovation	0.85	0.13			0.29	(0.13/0.44)		

Source: *Environmental, Social and Governance Scores from Refinitiv, May 2022*

The fifth and final step in Refinitiv's ESG score calculation methodology pertains to the computation of the company's overall ESG score. This is achieved by utilizing a formula that takes into consideration the scores of the ESG categories and the weights assigned to each category. Subsequently, the overall ESG score is normalized using the same scale ranging from 0 to 100, as employed for normalizing individual ESG category data.