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The (R)Evolution of Financing the Green Transition

An empirical study on green innovation efforts and how investors can accelerate the clean energy transition

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NORWEGIAN SCHOOL OF ECONOMICS

Acknowledgements

This thesis is written as part of finalizing our Master of Science in Economics and Business Administration within Financial Economics at the Norwegian School of Economics.

The motivation behind the thesis is to contribute to the discussion on how to most efficiently allocate capital for achieving the green transition. Despite the increasing popularity of ESG investments, limited empirical research investigating the potential consequences of the most common responsible investment strategies exist. Inspired by a study[1] conducted in the US, we analyze how the green innovation[2] efforts differ between sectors and whether ESG capital is flowing to the firms that are the greatest inventors of green technologies. We aspire to provide investors, firms, educational institutions, and other organizations with interesting and relevant discoveries.

Through econometric analysis and theoretical research, we have acquired valuable knowledge within sustainable finance and green innovation. Our analyses also required skills in Alteryx, Excel, and STATA, of which we have developed and improved our abilities substantially.

We would like to express the deepest gratitude to our supervisor, Konrad Raff, for his support throughout the process. By trusting our abilities to produce valuable research independently, and challenging our thoughts and methodologies, we believe the output has improved remarkably. We would also like to thank the associate professor, Steffen Juranek, for sharing valuable insights regarding patent systems and processes. Additionally, we give thanks to Ole Andreas Stensland Dahl at Carnegie Investment Bank for providing access to firms' historical financials. Finally, we want to express a special thanks to Finansforbundet Student and the Norwegian Association for Protection of Industrial Property (NIR) for their grants.

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[1] The ESG-Innovation Disconnect (Cohen et al., 2021).

[2] Patents classified as technologies or applications for "mitigation/adaptation against climate change".

Abstract

The purpose of the thesis is to investigate whether the current momentum of responsible investment approaches, hereunder the increasing adoption of excluding energy firms from investment portfolios, is the most efficient strategy for financing the clean energy transition. We investigate the green innovation efforts of the 250 largest European firms, divided into 12 sectors, by analyzing patent applications from 2000 to 2018. Concretely, we run pooled OLS regressions with year fixed effects to analyze sector differences in the relative efforts to produce green innovation, and the related innovation quality.

Our findings suggest that energy firms produce relatively more green innovation, and that this innovation is of equal, or higher, quality than the innovation produced by firms in other sectors. Our discoveries also suggest that energy firms have a higher focus on innovation within renewables and carbon capture and storage. Moreover, we find that the innovation efforts of the three sectors with most green patents are less directed towards green technologies and of significantly lower quality than other sectors, including the energy sector. Conclusively, energy firms are considered important contributors and enablers of the green transition.

Based on the empirical findings, we discuss the implications of excluding energy firms from investment portfolios. The strategy may impose higher cost of capital on firms that play a significant role in the green transition. Additionally, by pulling capital out of these firms, less responsible investors may invest and encourage the structural important energy firms to continue with carbon-intensive operations. Consequently, the energy firms may end up increasing their levels of greenhouse gas emissions instead of developing new, cleaner technologies. We therefore encourage responsible investors to invest in, rather than exclude, energy companies and actively engage to demand a green transformation of their operations.

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1. Introduction

Responsible investing is on the rise as increasing amounts of capital flow to sustainable projects worldwide (Global Sustainable Investment Alliance, 2020). In line with the growing trend, multiple new strategies and frameworks for sustainable investments have emerged. One of the most widespread approaches to responsible investing is the exclusion of firms that produce substantial negative externalities, including energy firms that are actively engaged in fossil fuels. Although this approach is increasingly popular, the broader implications of the exclusion of energy companies have, until recently, received little attention. Additionally, few empirical analyses that investigate the practical consequences of responsible investment strategies exist. Hence, by examining the effect of exclusion of energy firms on the generation of green innovation, we seek to empirically shed a light on the potential consequences of one of the most common responsible investment approaches. This thesis aims to answer the following question:

Does the current momentum in responsible investing enable the most efficient clean energy transition?

The thesis takes a deep dive into the green innovation produced by energy firms and investigate their contributions to the green transition by applying patents as a proxy for innovation. In light of the findings, we discuss the potential consequences of excluding energy firms from investment portfolios, and how it may affect the pace of the clean energy transition. The data covers patent applications of the 250 largest public European firms from 2000 to 2018.

2. Background

Climate change has been recognized as the greatest and most complex challenge of today (UN Security Council, 2021). The UN Secretary General, António Guterres, declared in his State of the Planet 2020-speech that “making peace with nature is the defining task of the 21st century” (Guterres, 2020). To address the negative consequences arising from climate change, multiple international agreements have been signed and wide-ranging collaborations have been established, such as The Paris Agreement of 2015 (UN FCCC, 2015). The objective of this agreement, after recent iterations in COP26[3], is to keep the rise in average global temperatures below 1.5ºC above pre-industrial levels (United Nations, 2021). However, sufficient progress and achievements from international collaborations is yet to be proved. The Intergovernmental Panel on Climate Change (IPCC) recently published an alarming report on climate change, declaring “code red” for humanity as the global rise in temperatures has already reached 1.2ºC (IPCC, 2021). Nevertheless, the scientists argue that a drastic reduction in the amount of greenhouse gases (GHG) in the atmosphere will limit the negative consequences and contribute to long-term stabilization of the global climate and ecosystems. However, to successfully reach the objective of the Paris Agreement, several changes must be done to the world as we know it. This includes a green transition of the global energy systems, which often is referred to as the clean energy transition.

The energy sector has been heavily impacted by the increasing awareness of climate change and will continue to see substantial changes in the coming decades. The sector is the largest single producer of global greenhouse gas emissions, where fossil fuels traditionally have been the dominating activity (United Nations, 2021). In recent years, energy companies have experienced major pressure from various stakeholders ranging from consumers and investors to governments and NGOs. The pressure to transition to clean energy production has resulted in energy companies accelerating investments in renewables and low-carbon technologies, with the objective of building more resilient businesses (McKinsey & Co, 2021). For example, Shell plans to invest 2-3 billion USD in cleaner energy solutions in the near term, and Equinor has an ambition of investing around 23 billion USD in renewable energy technologies by 2026 (Royal Dutch Shell, 2021); (Equinor, 2021). Another example of how these companies

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[3] The 26th edition of United Nations’ annual Conference of Parties to address and assess progress in combating climate change.

commit to the green transition includes the rebranding from oil and gas to energy companies. As an example, both Statoil and British Petroleum have changed their names to Equinor and Beyond Petroleum.

The clean energy transition is a major challenge as 80% of today's energy consumption comes from fossil fuels. In May 2021, the International Energy Agency (IEA) (2021) published a report that outlines a roadmap to achieve net zero by 2050. In the report, the IEA states that "as the major source of global emissions, the energy sector holds the key to resolving the world's climate challenge". The roadmap comprises a concrete strategy to transition to a net zero energy system while ensuring stable and affordable energy supplies, universal energy access, and robust economic growth. According to their strategy, the energy sector will in 2050 largely be based on renewable energy sources, with two-thirds of the total energy supply coming from solar, wind, bioenergy, geothermal and hydro energy. The report advocates that most of the reductions in CO2 emissions through 2030 come from technologies that are already on the market. However, in 2050, about 50% of the reductions are expected to come from technologies that are currently at the demonstration or prototype phase. This implies a major need for clean energy innovation. According to the IEA (2020), the oil and gas industry, with its extensive resources and capabilities, will be critical for quickly maturing key capital-intensive clean energy technologies.

To reach the objectives of the Paris Agreement and limit global warming, massive investments are needed over the next decade (Jørgensen, 2020). The IEA estimates that annual investments in renewable and clean energy must more than triple by 2030, to around 4 trillion USD, to reach net-zero energy emissions by 2050 (IEA, 2021). Thus, the energy sector represents significant opportunities for investors seeking capital returns and to contribute to a sustainable future.

Responsible investments, also referred to as ESG investments, captures the dual objective of returns on capital and positive impact. The fundamental idea behind ESG investing is that Environmental, Societal and Governance factors, traditionally not included in financial analysis, still may have financial relevance, and should be included in the overall investment analysis (Kell, 2018). The overall objective of ESG capital is to promote sustainable development while ensuring attractive returns by efficient capital allocation (Berger & Curry, 2021). From its modest prevalence in its early years, ESG analysis is today a widespread concept among stakeholders operating in the financial landscape. Global sustainable investment assets hit a record high of above 35 trillion USD in 2020 and is expected to hit 53 trillion USD by 2025, as the objective of net zero increasingly affects society (Global Sustainable Investment Alliance, 2021). According to the International Monetary Fund's Global Financial Stability Report (2021), sustainability-focused funds will play a crucial role in financing the transition to a greener economy. It is also estimated that by 2023, 80% of institutional investors will avoid investing in funds that do not consider ESG factors (EY, 2021).

A common approach to responsible investing is exclusion of companies and industries whose operations contradict the mandate of the investor or fund (Lanz, 2020). Due to its nature of carbon-intensive activities, the petroleum industry is a typical example of an industry historically excluded from receiving ESG capital. Following this approach, campaigns for divesting fossil fuels have gained substantial momentum in recent years (Statista, 2020). Already in 2013, the "Go Fossil Free" campaign was reported as the fastest growing divestment movement historically (Ansar, Tilsbury, & Caldecott, 2020). As of October 2021, around 1500 different institutions, representing asset values of almost 40 trillion USD, have divested a total amount of 14 trillion USD (The Divestment Database, 2021); (Rack, 2020). These numbers continue to rise as more investors, asset managers and intuitions around the world join the movement. As an example, Harvard University announced in September 2021 their decision to divest all fossil fuel companies from its 42 billion USD endowment. The following month, both New York City's pension fund and Europe's largest pension fund, ABP, announced the divestment of their 4 and 17 billion USD fossil fuel-related investments, respectively (Marsh, 2021). The figure below presents the historical development of cumulative divestment pledges in fossil fuels. Note that these numbers do not reflect the overall adoption of excluding fossil fuels, only the reported numbers from the "Go Fossil Free" divestment campaign (The Divestment Database, 2021).

Figure 1: Historical development of divestment pledges within fossil fuels

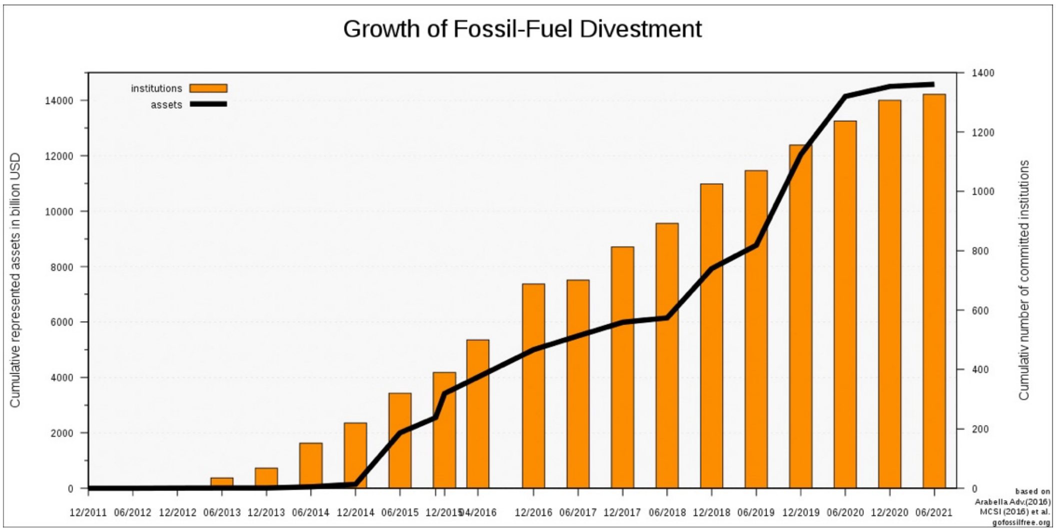

Figure 1 illustrates the development of the global trend of divesting fossil fuels, by showing the cumulative number of institutions and total assets in USD divested on a semiannual basis from 2011 to 2021 (The Divestment Database, 2021).

Human life is, and will continue to be, heavily energy dependent. Recently, criticism has been raised against the unconditional exclusion of investments in the energy sector, as their existing assets and capabilities may be important enablers for developing clean energy sources (Global Sustainable Investment Alliance, 2020). If the energy companies demonstrate a genuine commitment to the green transition, one may question whether unconditional exclusion of the sector coincides with the overall objective of promoting sustainable development.

3. Literature review

In this section, we introduce the relevant theory and empirical evidence for our regressions and analyses. We start by illustrating how sustainability impact the financial sector, before presenting the role of innovation in the green transition.

3.1 Sustainable finance

3.1.1 Climate risk

Climate change imposes a new set of risks on financial investments and may negatively affect the stability of the financial markets (Financial Stability Board, 2020). Although institutional investors perceive climate risk as of lower concern than traditional financial risks, the area has received increasing attention in recent years (Krueger, Sautner, & Starks, 2019). Addressing and understanding a company's changing risk picture is one of the reasons ESG analysis has become widely adopted by the financial sector (Kovacs & Masha, 2008).

Climate risks can be classified into two main categories: physical risk and transition risk. Physical risk refers to the exposure to acute events, such as extreme weather and chronic changes, exemplified by droughts and sea-level rise (Norges Bank Investment Management, 2021). Exposure to such events may entail asset write-downs for companies, higher insurance costs, negative changes in productivity or external shocks. Transition risk refers to the risk related to the transition towards a carbon-neutral economy. This includes regulations and policies, such as carbon pricing, or permanent shifts in preferences among consumers and investors towards greener solutions and technologies (Clapp, Lund, Aamaas, & Lannoo, 2017); (Norges Bank Investment Management, 2021).

Physical and transition risks may impact revenues, costs, and demand across the economy, which again will impact the valuation of companies (Norges Bank Investment Management, 2021). The companies that do not address this new set of risks and adapt to more sustainable business practices are expected to face lower cash-flows and higher cost of capital (Schoenmaker & Schramade, 2018). One example of how poor ESG risk management has resulted in considerable financial consequences is Volkswagen's rigging of diesel vehicles to pass new emission requirements. This incident resulted in costs of 27.4 billion EUR and did significant harm to their reputation and valuation (Hotten, 2015).

The traditional Efficient Market Hypothesis assumes all information is reflected in the price of a company (Teal, 2018). However, there is high future uncertainty related to the physical and transition risks arising from climate change. Therefore, researchers argue that this hypothesis is less likely to hold under today's market conditions (Lo, 2004); (Schoenmaker & Schramade, 2018). The Adaptive Market Hypothesis is a more recent theory that combines the traditional hypothesis with behavioral finance. The hypothesis assumes that investors and companies learn and adapt to changing environments, and therefore accept that all information is not yet fully incorporated into the prices (Lo, 2004). Krueger et al.'s (2019) findings support this hypothesis and suggest that institutional investors believe the traditional methodologies for equity valuation do not fully reflect the risk arising from climate change. Investors that follow the Adaptive Market Hypothesis may therefore require higher returns on investments they perceive as of high climate risk, and lower returns on investments with higher sustainability performance. It is also found that some investors even are willing to accept a lower risk-adjusted return for investments that may entail positive social and environmental impact (Schoenmaker & Schramade, 2018).

Sustainability and climate change are topics increasingly concerning the financial sector, as they may both negatively affect the picture of risk and return and provide a broader space of investment opportunities. Additionally, increased pressure from stakeholders and their expectations of acts of responsibility leaves climate change impossible to overlook for players in the financial sector (Fink, 2021).

3.1.2 Responsible investment strategies

Stages of Sustainable Finance

The sustainable finance practice can be divided into three different stages, based on the contribution to limiting negative and producing positive externalities, as outlined in the table below. At the lowest stage, Sustainable Finance 1.0, investors typically exclude companies that produce substantial negative externalities. At this stage, the overall objective of the investment is to maximize financial return, subject to limiting negative social and environmental externalities. At the middle stage, Sustainable Finance 2.0, externalities are internalized in the investment decisions to avoid risk. The overall objective of the investment at this stage is to maximize the integrated value of the financial, social, and environmental values. At Sustainable Finance 3.0, the overall objective is to maximize the social and environmental values, subject to satisfying a minimum level of financial return. Today, most responsible investors are at stage 1.0 (Schoenmaker & Schramade, 2018).

Table 11: The three stages of Sustainable Finance

Sustainable Finance typology	**Value created**	**Optimization**	**Horizon**
Finance as usual	Shareholder value	Max F	Short-term
SF 1.0	Refined shareholder value	Max F subject to S and E	Short-term
SF 2.0	Stakeholder value (triple bottom line)	Optimize I (F + S + E)	Medium-term
SF 3.0	Common good value	Optimize S and E subject to F	Long-term

Table 1 presents an overview and characteristics of the different stages of sustainable finance, including the related value creation, objectives of optimization and time horizon of the investments. In the optimization column, ***F = Financial value, S = Social value, E = Environmental value, and I = Integrated value of financial, social, and environmental values.***

Responsible investment approaches

Schoenmaker & Schramade (2018) present six typical approaches to sustainable investing in their research on sustainable finance. These approaches are rendered in the table below and well recognized across the sustainable investment space.

Table 22: The six different approaches to responsible investing

Approach	**Definition**	**Sustainable Finance**
Exclusionary screening	Exclusion of certain sectors or companies that contradict the investor's moral principles and values.	1.0
Best-in-class	Companies or projects selected based on outstanding ESG performance relative to industry peers. Only the best ESG performers of each industry are included in investment portfolios.	2.0
ESG integration	Systematic and explicit inclusion of ESG risks and opportunities into traditional financial analysis.	2.0

Sustainability themed investing	Selection of assets specifically related to sustainability themes (e.g., clean tech or agriculture)	2.0
Active ownership	Investors addressing concerns of ESG issues within the investees, e.g., proxy voting and engaging with corporate managers and the board to improve sustainability.	2.0
Impact investing	Targeted investments in companies addressing social or environmental challenges (e.g., in line with the UN Sustainable Development Goals).	3.0

Table 2 presents an overview of the six different approaches to responsible investing with corresponding definitions and stages of Sustainable Finance.

3.1.3 Sustainable investment trends

The different approaches for deploying capital with the purpose of achieving broader objectives than financial returns have seen a sharp rise in the latest years (Global Sustainable Investment Alliance, 2021). The graph below presents the adoption of the different strategies from 2016 to 2020. The two most widely adopted approaches are ESG integration and exclusionary screening. Active ownership is the third largest and considered the most influential strategy to improve sustainability performance (UN PRI, 2018).

Figure 2: Growth in the global adoption of sustainable investment strategies

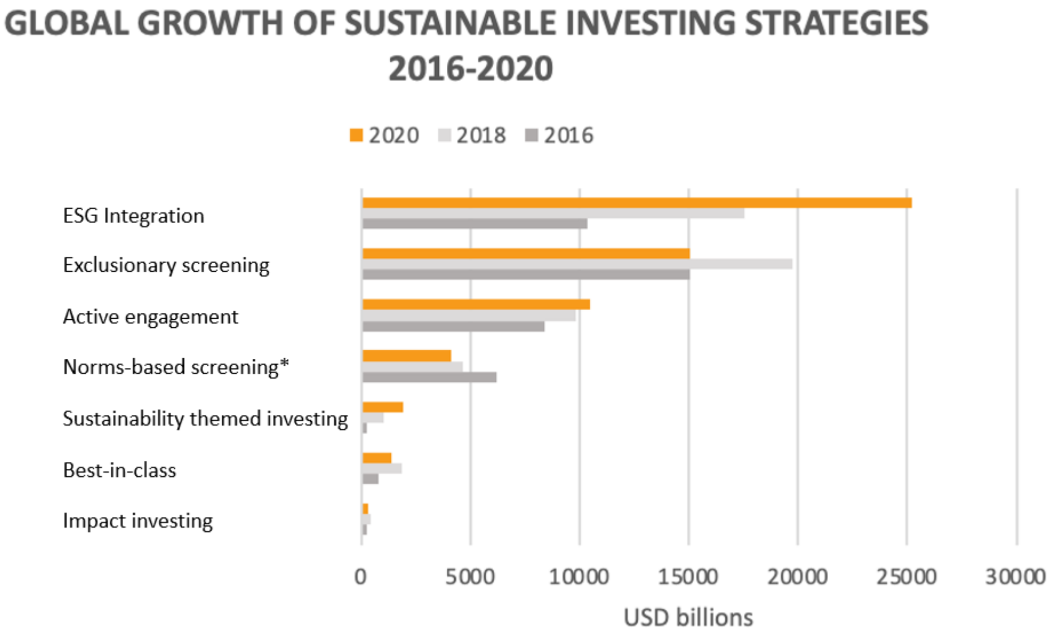

*Figure 2 illustrates the global adoption and growth of the different sustainable investment strategies in 2016, 2018 and 2020 (Global Sustainable Investment Alliance, 2021). *Norms-based screening is a sub-category of exclusionary screening which involves excluding companies on account of any failure to meet internationally accepted norm, such as the UN Global Compact, Kyoto Protocol, UN Declaration of Human Rights etc.)*

Exclusion

An investor that follows exclusionary screening prohibits certain industries, businesses, and products from her investment portfolio, based on values and principles. According to CFA Institute research (2015), there are two main reasons why institutional investors exclude companies. The first, and most common, is due to a clear investment mandate, defined by regulations, a moral stance and/or pressure from stakeholders. The second is due to financial considerations about the future of an industry, including management of transition and physical risk. Schroder's (2017) research suggests that the choice of excluding fossil fuels from investment portfolios is more about morals than money. Their study finds that almost 40% of responding investors exclude fossil fuel companies to potentially achieve positive impact. On the other hand, 30% of the investors proclaim they exclude fossil fuels to obtain higher returns.

Figure 3: The rationale for exclusion of fossil fuels from investment portfolios, by region

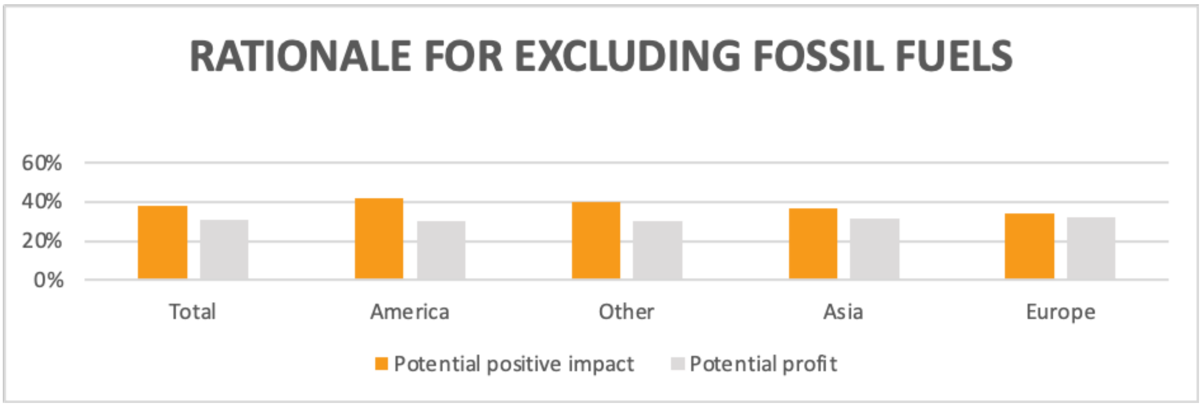

Figure 3 illustrates the different motivations for excluding fossil fuels from investment portfolios globally, with regional deep dives on America, Asia, Europe and Other (Schroder, 2017).

Divestment is the process of exiting investments or assets to maximize financial value and/or to assert social or political influence in line with underlying beliefs (Gan, 2019). The concept is closely related to exclusionary screening which requires the investors that are currently invested in blacklisted companies to sell down their share and thereafter continue to exclude these companies. The objective of fossil fuel divestment campaigns is typically to starve the industry for financial, social, and political support.

Research on the direct effects of exclusionary strategies has given ambiguous results. On the one hand, the divestments campaigns have shown to raise public awareness and negatively influence companies' reputations (Gan, 2019). Further, a study across thirty-three nations suggests that increased divestment pledges are associated with reduced debt and equity capital flows to fossil fuel firms (Cojoianu, Ascui, Clark, Hoepner, & Wójcik, 2020).

On the other hand, several studies suggest that the impact of exclusion is modest. Schroder (2017); (2019) finds limited evidence of successful capital restrictions and elimination of certain activities as a direct result of divesting. This builds on the argument that for each investor who chooses to exit a company, another investor will gladly supply capital given that the company delivers sufficient returns. Correspondingly, Pollin & Hansen (2018) find no empirical evidence that the campaigns for divesting fossil fuels have been effective for reducing CO2 emissions, nor that the strategy will become more effective over time. A study by Berk & Binsberken (2021) concludes that divestment campaigns have a marginal effect on the funding cost for companies with high emissions. Followingly, they argue that exclusionary screening has a limited impact on the unethical behavior of corporations.

Active ownership

Active ownership refers to "the act of employing shareholder power to influence corporate behavior, including through direct corporate engagement, filing or co-filing shareholder proposals, and proxy voting for promotion of ESG-positive activities" (Global Sustainable Investment Alliance, 2021). Active ownership is the direct opposite strategy to exclusion, as the investor actively influences the company to engage in more sustainable activities rather than eliminating them from the investment portfolio. Thus, the strategy is considered both comprehensive and demanding, but also to be more effective for implementing and achieving sustainable change (UN PRI, 2021).

Research suggests that active ownership, despite being associated with substantial costs, is beneficial for improving both the sustainability performance and market value of a company (Bekjarovski & Briere, 2017). Correspondingly, research commissioned by the UN PRI (2018) indicates that engaging with investees to improve their ESG risk management can impact the companies' operations in a way that creates value for both investors and companies. In 2013, the investor group of the Church of England actively encouraged companies with carbon-intensive activities to report emissions and to design and implement measures for reducing overall emissions. Consequently, the target companies improved their environmental-related performance by 72%. Subsequent empirical research shows that the initiative caused the greatest environmental improvement among the 250 FTSE companies at the time (Church Investors Group, 2015).

Another method for measuring the effect of active ownership is to assess the achievements of environmental-focused coalitions, e.g., Climate Action 100+. The initiative was established by major asset managers to actively pressure large emitters into more sustainable activities. The coalition is currently engaged in 167 companies that represent more than 80% of total global industrial emissions, including 39 oil and gas companies. By ensuring adoption of inter alia concrete decarbonization strategies, GHG reduction targets, and climate governance, they have achieved concrete and significant impact through active ownership. One of their many histories of successes is the forcing of Exxon, by proxy vote, to measure and report the carbon emissions of their increasing oil and gas activities (Climate Action 100+, 2020).

Exit and Voice

The two strategies of exclusion and active ownership can be translated into the more general concept of exit and voice, respectively (Hirschman, 1970). The theory provides suggestion on two alternatives available to an investor who seeks to express dissatisfaction about an investee's behavior. Hirschman advocates that exiting a company is a recommended final strategy for an investor who is dissatisfied with the company's operations and has tried raising her voice about her concerns without being heard.

Green bonds

A green bond is a fixed-income instrument that requires the money raised to exclusively finance projects with a positive climate impact (Patrick, 2021). Green bonds often come with tax benefits, which increases their attractiveness and incentivizes capital flows to sustainable development (Moskowitz, 2019). The annual amounts of green bond issuances have been growing exponentially over the past years, from less than 3 million USD in 2012 to nearly 270 million USD in 2020. Since the first issuance of a green bond in 2007, the efforts to create a global standard for verification and definition of "green projects" have increased drastically (Patrick, 2021).

3.2 Green innovation

3.2.1 Innovation in the green transition

In recent decades, the international community has increasingly recognized the importance of green innovation for promoting sustainable economic growth (Grazzi, Sasso, & Kemp, 2019). The concept of green innovation can be defined as the production, assimilation or exploitation of novel products or services that reduces environmental risk, pollution and other negative climate impacts (Kemp, 2008).

Several empirical studies substantiate the importance of innovation for the energy transition. According to research on environmental innovation and climate change in Europe, green innovation may increase CO2 emissions in the short term but will eventually result in long-term emission reductions (Mongo, Belaïd, & Ramdani, 2021). Consequently, the study highlights the need for policies favoring, incentivizing, and enabling green innovation. Research by Fethi & Rahuma (2019) correspondingly shows that investments in green innovation have a significant, long-term positive effect on carbon emissions. Additionally, Hashmi & Alam (2019) empirically advocates that the production of green patents is associated with lower carbon emissions.

Levelized cost of energy

To succeed with the clean energy transition, the levelized cost of energy (LCOE) of renewable energy sources must be reduced to competitive levels (CFA Institute, 2021). LCOE is a measure of the net present cost of energy generation for a production facility over its lifetime. The measurement is used to compare the profitability of alternative methods for energy production and to determine whether a project should be implemented or not. The LCOE is based on the operational capacity, the lifetime of the plant or asset, and the costs of investment, operations, and financing. Thus, the LCOE reflects the unit cost of energy generation and allows for comparison between projects with different capex, opex, risk, size, and lifespan. To reduce the LCOE of renewable energy sources, there is a need for technological developments and investments in green energy innovation (CFA Institute, 2021).

The LCOE is calculated by:

$$\mathrm{LCOE} = \frac{\text{NPV of total costs over lifetime}}{\text{NPV of eletrical energy produced over lifetime}}$$

3.2.2 Measuring green innovation

Several frameworks are developed to enable the measurement and evaluation of sustainable technological development. One example is OECD's "Green Growth Indicators Directly Related to Technology and Innovation" (GGI) (OECD, 2017). The GGI divides the measurement of green innovation into two subsections of indicators: 1) green R&D spending and 2) green patents. The first indicator paints a picture of the aggregate efforts related to green development, while the latter allows for a detailed, micro-level analysis of green innovation efforts. Hence, for a comprehensive picture of a company's innovation focus, it may be beneficial to assess the two factors in tandem.

Both patent data and R&D spending are widely adopted in empirical analysis for measuring innovation. According to Cohen et al. (2020), R&D expenditures and patents have a mutual causation, where increased levels of patenting seem to stimulate R&D. Correspondingly, research on alternative energy production in the US suggests that R&D spending and patents are strongly correlated (Lanjouw & Mody, 1996). Patent data capture flows of innovation and knowledge spillovers between nations and industries, enabling richer analysis of the widespread effects of the inventions (Engelsman & Raan, 1994); (Verspagen, 2005). As the market value of a company is tightly linked to its knowledge assets, patent data may also be perceived as superior to R&D (Hall, 1998). Additionally, detailed information about patents is publicly available over time, making patents a unique proxy for analyzing the historical development of innovation (Oltra & Vries, 2009).

A patent is an exclusive right to exploit (make, use, sell, or import) an invention over a limited period, typically 20 years from filing, within the country where the application is made (OECD, 2009). Patents are granted for inventions that are novel, inventive, and have a useful industrial application. The technological field of a patent is defined through patent classification systems, which inter alia define patents on technologies that combat climate change as "green patents". Classification of patents transforms the somewhat intangible concept of green innovation into a concrete and easily measurable concept. It is therefore an expedient tool for analyzing green innovation and technological development.

Despite the applicability of patents, there are several limitations, weaknesses, and biases to the validity of patent data as a measure of innovation. Not all innovation is patentable, and in certain cases, patents may be perceived as an inefficient strategy for protecting the innovation

(Levin, Klevorick, Nelson, & Winter, 1987). Several studies suggest that the propensity to patenting varies between sectors, and estimate pharmaceuticals and chemicals to have the highest degree of patenting (Pavitt, 1985); (Mansfield, 1986); (Brouwer & Kleinknecht, 1999). Additionally, Popp (2005) finds that product innovation is more likely to be patented than services and processes, introducing a bias to the patent proxy. Consequently, whether patent data is the best suited proxy for analyzing innovation depend on the object and purpose of the investigation.

Value of patents

All innovations and technological developments contain different degrees of quality and value, which can be measured in various ways (Griliches, 1990). Regarding the value of patents, one can distinguish between the patent's economic and social value. The first relates directly to the economic value creation, while the latter reflects the patent's contribution to society. One can further distinguish between the value of the patent itself, i.e., the value of blocking others from the space, and the value of the underlying invention, referring to the technological quality of the patent. A common technique for measuring the quality of a patent's underlying innovation is patent citation analysis. The technique works similarly to the citations and references of a science paper and suggests that patents with higher numbers of forward citations are of higher value (OECD, 2009).

In empirical studies, forward citations are found to be strongly correlated with a patent's social and economic value (Trajtenberg, 1990); (Cremers, Harhoff, Narin, & Scherer, 1999). When the technological information and specification of a patent is published, other inventors can leverage it to improve existing technologies or to develop new inventions. Hence, patents with significant contributions to the state of the art will positively impact future technologies and have a higher value.

4. Hypotheses

In this section, we present our hypotheses, representing the starting point of our analyses. We investigate three main hypotheses related to green innovation in the energy sector, and two supplementary hypotheses digging into the three sectors with the highest number of green patent applications.

Green innovation is one of the most essential prerequisites for successfully achieving a clean energy transition and net zero by 2050. Based on the common responsible investment approach of excluding energy firms, one should believe these firms have a marginal contribution to the green transition. We therefore want to test whether green innovation efforts are lower in the energy sector than in other sectors. Our first hypothesis is:

1) The relative green innovation effort is lower for firms in the energy sector than for firms in other sectors.

Another, perhaps even more relevant, aspect to consider for the energy sector is their green innovation efforts within energy generation, transmission or distribution, and carbon capture and storage (CCS). In other words, technologies material to the core operations of energy firms. A potential scenario is that energy firms are active developers of green technologies in areas that have limited impact on their main operations. Hence, they may be perceived as sustainability-oriented without phasing out fossil fuel activities. If this is true, the exclusion of energy firms may still make sense from a green innovation point of view. We want to investigate this through our second hypothesis:

2) *The share of green innovation within energy production and CCS is lower for firms in the energy sector than for firms in other sectors.*

A further argument supporting the exclusion of energy firms is that the green innovation and technologies developed by energy firms are of lower quality than for other firms. If energy firms produce green technologies of lower quality, their innovation will have less importance and relevance for the green transition. We will test this through our third hypothesis:

3) *The quality of the green innovation is lower for firms in the energy sector than for firms in other sectors.*

In addition, we test two supplementary hypotheses regarding the three sectors with the highest total numbers of green patents: industrials, non-energy materials, and consumer cyclicals. We first want to investigate whether the large numbers of green patents are a result of high overall patent production or if they intentionally target a significantly higher share of green innovation than other sectors. In the other hypothesis we want to test whether the innovation in the top three green sectors is of higher quality. Hence, by testing the quality of the innovation, we investigate whether there is a trade-off between patent quantity and quality in these sectors.

These supplementary analyses will provide a more comprehensive overview of the sectors that contribute the most to the green transition in terms of total patents. Additionally, the analyses will reveal differences between these seemingly best-in-class sectors and the energy sector with regard to innovation.

Hypothesis i: The relative green innovation effort is higher in the top three green sectors than in other sectors.

Hypothesis ii: The quality of the green innovation is higher in the top three green sectors than in other sectors.

5. Data

In this section, we describe the process of selecting and preparing the data for quantitative analyses. We describe the underlying data sources, justify our choices, and explain the process of preparing the raw data for regressions. Ultimately, we discuss the limitations of the data set.

5.1 Data selection

The analyses build on data from 2000 to 2018 for the 250 largest European public companies, extracted from OECD statistic bank, Orbis, and FactSet. From OECD we extract patent application data, including data on the patents' forward citations. In the analyses, green patents are applied as a proxy for green innovation, and citations as a proxy for innovation quality. To supplement our analyses with relevant control variables, we extract firm-specific data from Orbis and FactSet.

The sample is limited to public European companies. Europe is an interesting region for researching sustainability topics, with its steadily growing focus on the green transition and the recent introduction of the EU Taxonomy[4] (European Commission, 2021). The rationale behind the choice of only including publicly listed companies in our sample is the rich availability of standardized, firm-specific information.

The processing of patent applications requires a substantial amount of manual work and control. Thus, by limiting the number of companies addressed, we also reduce the likelihood of errors and bias in the data. Therefore, the analyses only focus on the 250 largest European companies, including their subsidiaries as of 2020.

5.1.1 Firm-specific data

We extract the firm-specific information, including each company's founding date, sector, market capitalization, and historical financial figures from Orbis and FactSet. The sector classification is based on the FactSet Revere Business Industry Classification Standard, which

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[4] The EU taxonomy is a classification system, providing companies, investors and policymakers with appropriate definitions of environmentally sustainable economic activities

divides public companies into 12 anchor economic sectors based on their operating footprint (FactSet, 2021). A list describing the activities of each sector can be found in appendix 11.2.

5.1.2 Patent data

The process of applying for a patent is tedious and complex. First, one must file an application to one of the many patent offices. The largest regional patent offices comprise the European Patent Office (EPO), the Japan Patent Office (JPO), and the United States Patent and Trademark Office (USPTO). Many applications are filed to several national and regional offices to obtain patent rights in various regions. Combining data from several patent offices will therefore entail many duplicated values that are difficult to detect. To avoid considerable bias, OECD recommends not combining data from the different offices when performing statistical analyses of patents (OECD, 2009).

Our analyses convey the 250 largest public companies in Europe, and it is therefore most relevant to analyze the applications filed to the EPO. The EPO examines patent applications and offers protection of inventions in European countries, including all 27 EU member states and inter alia Norway, Switzerland and the UK. There are three main routes to obtain a patent under the EPO; one can (1) file an application directly to the EPO, (2) file an extension of a national patent application within 12 months of first filing, or (3) file to the EPO through the Patent Co-operation Treaty (PCT). The two first routes are known as the Euro-Direct, while the final is known as the Euro-PCT (European Patent Office , 2021) (OECD, 2009).

The main source for the patent data in our analyses is OECD’s Directorate for Science, Technology, and Industry Microlab. Their databases are derived from the EPO Worldwide Statistical Database which fully covers the Euro-Direct and Euro-PCT applications back to 1978. OECD has complemented this raw data with other indicators to enable more comprehensive statistical analyses. The most recent available data is from 2018, as there is a 31-month lag from the date of first filing (priority date) until the application is included in OECD’s databases. It should also be noted that a patent application is not made public until 18 months after the priority date (OECD, 2009). To conduct our analyses, we have extracted information from three of OECD's patent databases:

1) OECD, REGPAT database, updated July 2021. The database covers relevant information at the patent-specific level, including the name of the applicant, the priority date, and the technology classification code.

2) OECD, HAN database, updated July 2021. The database contains a grouping of patents based on the applicants' names, where OECD has done a comprehensive cleaning and harmonizing of the names.

3) OECD, Citations database, updated July 2021. The database provides information on citations of patents filed to the EPO, PCT, and USPTO, in addition to non-patent literature citations. OECD has filtered this data to avoid duplicates.

The process from application to granting of a patent may take years and varies from application to application, based on the type and complexity of the patent. The average processing time of applications to the EPO is five years but has in some cases exceeded ten years before the final patent is granted. To reduce the bias in our sample arising from time lag, we use patent applications instead of grants. Patent applications are also costly and do often require large amounts of resources. As our analyses convey large, public companies, we assume they are familiar with the process and costs of obtaining a patent. Thus, we assume that they only apply for patents that are considered relatively innovative and within a realistic likelihood of being granted.

5.2 Data processing

We use Alteryx and Excel to process and combine the various data sets. In the following section, we explain the process of preparing the data for the regressions.

5.2.1 Combining OECD patent databases

In the first step of the processing, we combine various files from the three OECD patent databases and select the relevant information for performing the analyses. This includes information about the applicant, application number, priority date, technology classification codes, forward citations, and a proposed standardized applicant name. We remove all applications that are filed before 2000 as we want to investigate recent trends.

5.2.2 Defining green patents

There are two main methodologies available for classifying the technology of a patent: the International Patent Classification (IPC) and the Cooperative Patent Classification (CPC). All patent applications receive both classification codes. The IPC is administered by the World

Intellectual Property Organization (WIPO), whereas the CPC is established as a partnership between the EPO and the USPTO. The objective of the partnership is to jointly develop a common, internationally compatible classification system to standardize and reduce the complexity of the existing patent systems (CPC, 2021).

The CPC has a unique category for “green patents” under the code Y02: technologies or applications for mitigation or adaptation against climate change. The CPC Y02 class is further divided into 8 subclasses that enable technology-specific analyses of the patents. A detailed list of the subclasses under the Y02 code is included in appendix 11.2. We apply the CPC classification system as it provides a clearer definition of green patents than the IPC system.

First, we define all patents in our data set under Y02 as "green”. Further, all patents with the subcode Y02C “Capture, storage, sequestration or disposal of greenhouse gases” and Y02E “Reduction of greenhouse gas emissions, related to energy generation, transmission, or distribution”, are marked as relevant to the core operations of energy firms. It should be noted that one patent application obtains several classification codes, as the invention may have multiple purposes. Therefore, we remove the duplicated values from the data set and ensure to keep the green and energy-related observations.

5.2.3 Combining patent and firm-spesific data

The most challenging part of the data processing is to match the patent applications with the firm-specific data. As there is no unique firm-ID in the patent applications, no key to properly match the applications with company data exists. The only indicator available for matching the data is the applicant's name. However, this name is written manually by the applicants and is prone to misspellings, different abbreviations, and variations of the company names. Additionally, the patent databases are not updated when a firm changes its juridical name. Therefore, patents granted to e.g., Statoil before 2015 do not appear as Equinor in the database. The inconsistency of the registered applicant names may introduce a bias to the sample if it is not addressed properly.

Another challenge arises when the application is filed by a subsidiary or a subdivision of a company, as these applications are not possible to directly match with the parent company. One example demonstrating the challenge of matching applications using exact and fuzzy matching with the company name is the applications of Royal Dutch Shell PLC. Most of their applications are filed by one of the subsidiaries named “SHELL Internationale Research

Maatschappij B.V.”. Hence, to discover all patent applications it is necessary to conduct a multiple-step approach, which is explained in the following.

First, all firms are matched with their above 12 000 subsidiaries, based on a list extracted from Orbis. In the case of duplications, the subsidiary is allocated to the company with the highest stake of direct ownership, as we believe this company is the most involved in new technology development. This data set is further linked to a data set containing firm-specific information on the sector, age, market capitalization, and historical financial figures.

We follow the OECD’s recommendations and general methodology for cleaning names to overcome the issue of inconsistent names (OECD, 2009). This includes capitalizing letters and standardizing names and abbreviations. OECD further recommends matching the standardized names with an external company database, and to create groups based on subsidiaries and ownership structure. The OECD HAN database contains a suggestion of standardized applicant names, which we use in our matching process. Additionally, Orbis has performed comprehensive matching of patent applications with the firms in their register for applications filed to the EPO until 2017. By using this list, we identify historical name variations used in applications, which further enables identification of more recent applications to the EPO and the Euro-PCT.

After the tedious process of cleaning and matching, the final data set comprise patent applications filed between 2000 and 2018 for 186 of the 250 largest public European companies, divided into 11 sectors. Firms that have not engaged in any patenting are excluded. Due to a low number of total patent applications, the companies in the 12th sector, consumer services, are also excluded from the analysis. In total, the sample contains 879 051 unique patent applications.

5.3 Limitations of the dataset

There are several limitations to our final data set and applying it for analysis purposes. First, the list of subsidiaries does not reflect historical ownership structures. Consequently, a patent that was applied for by a company before a merger or acquisition will appear under the current owner in our data set. However, one can argue that this covers engagement in green activities from a different angle – a company investing in, or acquiring, another company that produces green patents is also an approach to contribute to the green transition.

Other limitations arise from the complexity of the global patent systems, including the deviating practices and challenges of standardization. The most significant challenge is the identification of the company of an application. We addressed this issue by following what is perceived as the international best practices for matching applications with companies, as recommended by the OECD and Orbis. Also, we further limit the bias of unidentified observations by converting the number of green patents into a relative measure.

For the purpose of the analyses, it should be noted that not all types of innovation are covered by patent data. Although the energy sector typically files for patents to protect its innovations, some of the other sectors that mainly operate within services may prefer different means of protection. Thus, another relevant angle could be to investigate a company's share of R&D investments directed toward green innovation. However, this data is difficult to obtain at standardized levels. One can further argue that much of the groundbreaking and essential technologies in the green transition are product innovations that will be patented.

6. Methodology

In this section, we present the methodology applied for performing the quantitative analysis of our data. We first introduce the variables included in the analyses, before presenting the specific regressions models. Then, we present the underlying assumptions for the ordinary least squares methodology (OLS) and run the relevant tests to validate our methodology.

6.1 Variables

6.1.1 Dependent variables

To test our hypotheses, we run regressions on three dependent variables: Green Ratio, Energy & CCS Ratio, and Average Citations. The first variable enables analysis of differences between sectors in their relative efforts to produce green innovation. The second takes a deep dive into the green innovation space, to understand variations in the focus on innovation that is relevant to the core operations of energy firms. The third dependent variable enables analysis of differences between sectors in green innovation quality.

Green Ratio

$$Green\ Ratio\ = \frac{\sum_{i=1}^{t=19}\sum_{i=1}^{n=250} Green\ patents}{\sum_{i=1}^{t=19}\sum_{i=1}^{n=250} Total\ patents}$$

The green ratio is defined as the number of green patent applications filed by each company per year, divided by the total number of patent applications by the respective company and year. By transforming the number of green patents into a relative share of total innovation, we adjust for potential large variations in terms of total numbers of patents between companies. Our data set is limited to 186 companies, where the number of companies included in each sector varies from 6 to 39. Further, the number of total patents per sector varies from ~1000 to more than 200 000. Thus, by converting the measure of green innovation into a relative share of the total innovation, the bias arising from the large differences between firms and sectors is reduced.

Energy and CCS Ratio

$$Energy\ and\ CCS\ Ratio = \frac{\sum_{i=1}^{t=19}\sum_{i=1}^{n=250} Green\ patents\ in\ energy\ and\ CCS}{\sum_{i=1}^{t=19}\sum_{i=1}^{n=250} Total\ green\ patents}$$

The energy and CCS ratio is calculated by dividing the number of patents in technologies related to green energy and CCS by the total number of green patents per company per year. This allows us to understand the differences between sectors in their relative efforts to develop technologies material to energy firms.

Average Citations

$$Average\ Citations = \frac{\sum_{i=1}^{t=19}\sum_{i=1}^{n=250} Green\ patent\ citations}{\sum_{i=1}^{t=19}\sum_{i=1}^{n=250} Total\ green\ patents}$$

The average citations variable is calculated by dividing the sum of green patent forward citations by the number of green patents produced in the respective firm and year. This variable reflects the quality and inherent value of the patents and allows us to analyze differences in the green innovation quality between sectors. The analysis will also reveal whether the patents produced by the energy sector represent irrelevant, low-quality innovation.

6.1.2 Control variables

To analyze the three dependent variables, we include several control variables representing firm-specific characteristics. The choice of control variables is based on a combination of the variables included in the US study “The ESG-innovation disconnect” by Cohen et al. (2020) and our assessment of relevant variables. Some of the variables are log transformed to account for skewed values and extreme observations.

Energy

Energy is the main variable of interest in our analyses, as the purpose of our thesis is to understand how the characteristics of green innovation in the energy sectors differ from other sectors. The variable is a dummy variable, taking the value 1 if the firm is in the energy sector, and 0 if the firm belongs to another sector.

Top3 Green

The Top3 Green variable is a dummy variable, taking the value 1 if the observation belongs to one of the three sectors with the highest number of total green patent applications, and 0 otherwise. The top three green patent-producing sectors are industrials, non-energy materials, and consumer cyclicals. The variable is included in the supplementary analyses to better understand the uniqueness of the energy sector.

Log Firm Age

The Firm Age variable is determined by subtracting each company's year of establishment from 2021. The variable will reveal whether there is a significant difference between older and younger companies in terms of production of green innovation and the related quality. There are several justifications for controlling for firm age, both in the analyses of the green ratio and in terms of patent quality.

First, younger companies may be characterized by having more modern values and a stronger focus on sustainability than older companies. They may also have shorter decision paths and less hierarchy, facilitating up-to-date innovation. On the other side, older companies may have initiated the transition to greener and more sustainable operations decades ago, steadily increasing their share of green patents among overall innovation.

Second, older companies may have obtained more citations as a direct result of being an old, recognized trotter in the patent space. Thus, the patents obtained by older companies may achieve a higher number of citations than those of young companies, because of the company age.

As some sectors may be characterized by older (younger) companies, the inclusion of the age variable enables separation of the age-effect from the variables of interest.

Log Capex

The Capex variable reflects the companies' yearly capital investments. The historical data on capital expenditures is extracted from FactSet. The variable will display whether companies with higher capex levels invest more in green innovation, relative to overall innovation, than companies with lower levels of capex. The fundamental investment levels needed to operate varies between sectors, as some sectors are capital intensive while others may be mainly labor-intensive. Thus, we include the variable to separate the direct effect of capex on innovation and associated quality from the variables of interest.

Log Market Capitalization

Market capitalization is a measure of the market value of the equity of a company. The historical data on market capitalization is extracted from FactSet. We include the variable to examine whether companies of higher value are more engaged in green innovation and sustainability than companies of lower equity value. Furthermore, we include the variable to investigate whether high-value companies produce innovation of higher quality than companies with lower market capitalization.

Debt-to-Capitalization

The Debt-to-Capitalization variable reflects the financial leverage of a company. The data on the historical debt levels of the firms is extracted from FactSet and divided by the respective market capitalization to generate a relative, comparable measure. The variable is included as a control variable to examine whether the companies' individual levels of debt affect their ability to produce green high-quality innovation. The variable is also relevant as several studies find that companies with environmental innovations are more financially constrained (Jensen, Schäfer, & Stephan, 2019). Additionally, some sectors are characterized by a higher degree of financial leverage than others. Thus, the variable may introduce an interesting nuance to the analysis of the direct effect of leverage on green innovation and quality.

6.2 Model specification

Our sample contains observations of patent applications for 250 companies over 19 years and is characterized as panel data. Panel data requires statistical methods of higher complexity than cross-sectional or time-series data but may be beneficial when conducting empirical analyses, as it enables e.g., dynamic models (Woolridge, 2012). The most common panel data estimators include first differences, within-group/fixed effects, random effects, and least square dummy variables (LSDV).

A pooled Ordinary Least Squares (OLS) estimator is an alternative when the traditional panel data estimators are inappropriate for conducting the analysis, as the estimator enables analysis of multiple units and time periods (Woolridge, 2012). In practice, the OLS estimates are obtained by minimizing the sum of the squared residuals between the actual observations and the fitted equation. By supplementing the pooled OLS with dummy variables, it is also possible to control for different unobservable effects, both between units and between time periods (Woolridge, 2012).

We run several tests to identify the best fitted estimator for our data and analyses. We start by conducting a Hausman test to determine whether the fixed effect (FE) or the random effect (RE) is a preferred estimator. The result of this test is presented in appendix 11.2 and suggests that the FE model is superior to the RE as there may exist an endogeneity issue. However, the FE model eliminates all constant effects, and one can therefore not include dummy variables in the regressions. As our main variable of interest is a dummy variable – the energy sector – it is necessary to explore other more suitable estimators.

We next investigate the best fitted model by comparing the LSDV model with firm and year fixed effects, to a pooled OLS with year fixed effects. Both models derive coefficient estimates through the same methodology, and the difference is therefore the controlling of firm fixed effects in the LSDV. It seems fair to believe that sector fixed effects are encompassed within firm-specific effects, and as we want to investigate these effects rather than eliminating them, we assess the pooled OLS as superior to the LSDV. Furthermore, the box plot of the green ratio, presented in appendix 11.2, provides support for the pooled OLS estimator. The choice is also supported by the study of inspiration by Cohen et al. (2020), in which they apply a pooled OLS with year fixed effects to perform similar analyses.

In all our analyses we estimate three different regression models, where we introduce increasing numbers of control variables, as illustrated below. All the models are constructed using the same independent variables, and estimated as the following:

$$Y_{it} = \beta_0 + \beta_1 D_{it} + Year\ Fixed\ Effects_t + \varepsilon_{it}$$

$$Y_{it} = \beta_0 + \beta_1 D_{it} + \beta_2\, Log\ Capex_{it} + Year\ Fixed\ Effects_t + \varepsilon_{it}$$

$$\begin{aligned} Y_{it} = \beta_0 &+ \beta_1 D_{it} + \beta_2\, Log\ Capex_{it} + \beta_3\, Log\ FirmAge_{it} \\ &+ \beta_4\, Log\ MarketCap_{it} + \beta_5 Log\ Debt_{it} + Year\ Fixed\ Effects_t + \varepsilon_{it} \end{aligned}$$

Where;
$\mathrm{Y} = \text{Green Ratio; Energy \& CCS Ratio; Average Citations}$
$\mathrm{D} = \text{Energy; Top3 Green}$
$\varepsilon = \text{Error term}$
$\text{Year Fixed Effects represent dummy variables for the years } 2001 - 2018$

6.3 Model testing

The OLS methodology requires several assumptions to be satisfied to verify the interpretation of the estimated coefficients: i) linearity in parameters, ii) zero conditional mean, iii) homoskedasticity, iv) no multicollinearity, and v) normality. Additionally, when the data contains a time dimension, the assumption of vi) no autocorrelation must be included. When these assumptions are satisfied, we assess our estimates as BLUE – Best Linear Unbiased Estimates.

We run the relevant tests to examine the assumptions underlying the OLS. A comprehensive overview of the formal tests and the discussions of the assumptions is included in appendix 11.3.2. To summarize, we perform some minor adjustments to our models to ensure satisfaction of the assumptions. This includes the elimination of extreme outliers and log transformations of some of the variables to improve the normality of the model, and implementation of clustered robust standard errors to cope with heteroskedasticity. It should be noted that it is difficult to conclude on exogeneity and satisfaction of the zero conditional mean assumption as they are not possible to investigate through formal tests. However, based on the discussion attached in appendix, we perceive the model as satisfactory, but warn that one should be careful with causal interpretations.

7. Results

In this section, we present the results from our analyses. We first illustrate the relevant characteristics of our data through descriptive statistics, to understand the overall trends and variations within green innovation and patents. Descriptive statistics are also included to paint a picture of the data underlying the empirical analysis. Next, we present the results from the OLS regressions and investigate whether we can establish any empirical relationships supporting our hypotheses.

7.1 Descriptive statistics

Table 3 presents an overview of the green and total patent applications per sector. The table also displays the average green ratio and the total corresponding number of companies included in the data set for each sector. The industrials sector is the most active both in total and in green patent applications. However, despite their large production of patents, the relative focus on green innovation is only at 14%, whereas the energy sector has an average green ratio of 21%. The energy sector has the second highest relative green innovation focus of all, only overcome by the utilities sector. In total, the energy sector produced 5 190 green patent applications from 2000 to 2018. The grand total shows that 10% of the applications are within green patent classes.

Table 3: List of sectors ranked by count of green patent applications

Sector	**Green**	**Total**	**Green Ratio**	**Number of companies**
Industrials	29 262	213 787	14 %	39
Non-Energy Materials	19 603	150 783	13 %	23
Consumer Cyclicals	17 402	100 983	17 %	16
Healthcare	14 472	248 040	6 %	14
Energy	5 190	24 664	21 %	17
Technology	3 172	73 297	4 %	6
Consumer Non-Cyclicals	1 010	37 387	3 %	20
Utilities	929	3 152	29 %	15
Telecommunications	666	22 762	3 %	9
Finance	261	2 824	9 %	17
Business Services	185	1 321	14 %	10
Consumer Services (Excluded)	*10*	*51*	*20 %*	*5*
Grand Total	**92 162**	**879 051**	**10 %**	**191**

Table 3 presents the ranking of the different sectors based on their total number of green patent applications. Additionally, the table presents the respective number of total patent applications, the green ratio, and the number of companies included in each sector in the sample. The energy sector is the main sector of interest in our analysis and is highlighted in orange.

Figure 4 shows the historical development of total green patent applications for the different sectors, based on our underlying data set. The total number of green patent applications reaches a global peak in 2011 for most industries, followed by a steady reduction in more recent years. The sector with the highest absolute number of green patent applications has traditionally been the industrials sector, followed by non-energy materials, and consumer cyclicals. Compared to these, the total number of green patent applications in the energy sector is substantially lower. It should be noted that, as illustrated in table 3, the sectors with the highest total numbers of patent applications also are the sectors with the highest number of companies included in the data set. Hence, the figure is included to illustrate the historical development of green patent applications and is less appropriate for sector comparisons.

Figure 4: Overview of green patent applications from 2000 to 2018, by sector

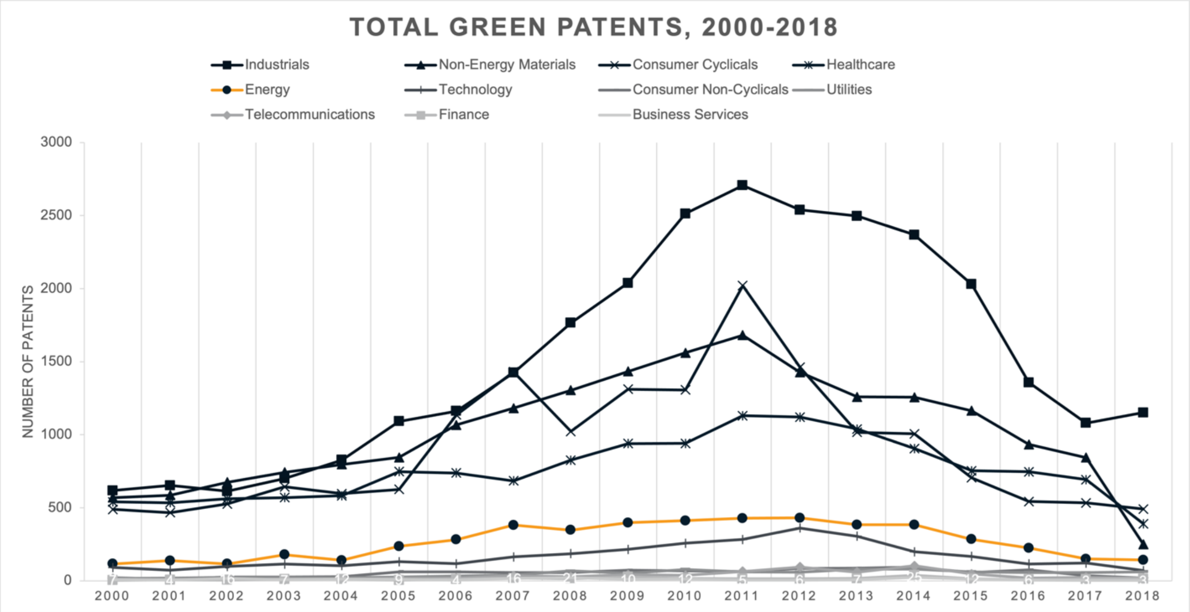

Figure 4 presents the historical development of green patent applications by the different sectors from 2000 to 2018. The energy sector is highlighted in orange.

Figure 5 illustrates the development of the green ratio over time for the different sectors. The green ratio enables sector comparisons as it reflects the respective sectors' average efforts to produce green innovation. Utilities is the sector directing most of their innovation efforts towards green patents, followed by energy, consumer cyclicals, and business services. By creating a relative measure and overcoming the inconsistency in the number of companies per sector, the energy sector appears to be an important green innovator. It should also be noted that the relative focus on green innovation in the energy sector has remained high throughout the entire period.

Figure 5: Overview of green ratio of patent application from 2000 to 2018, by sector

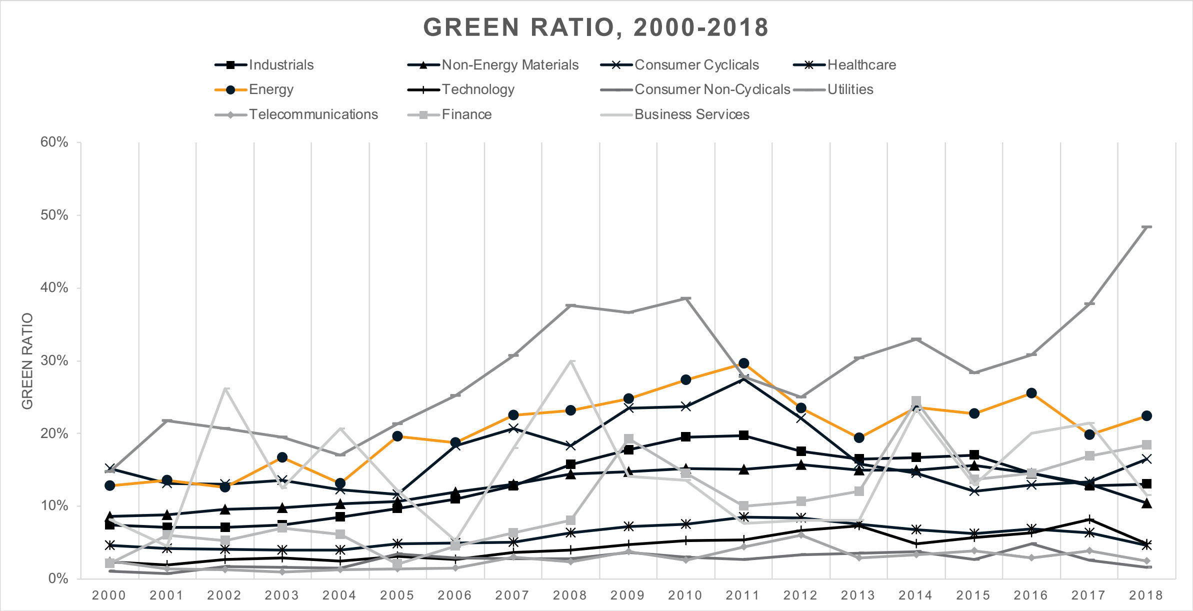

Figure 5 presents the historical development of the green ratio for the different sectors from 2000 to 2018. The relative measure enables sector comparisons of green innovation efforts. The energy sector is highlighted in orange.

Table 4 offers a more granular overview of the data by presenting the patents at a company level. The table lists the 50 companies with the highest amount of green patent applications. The energy sector constitutes 10% of the upper 50 companies, and includes TotalEnergies, Shell, Eni, BP, and Repsol. In total, these companies applied for 4 697 green patents from 2000 to 2018. The overview supports the previous statistics suggesting that the energy sector is a highly relevant player within the green innovation space.

Table 4: List of top 50 firms ranked by count of green patent applications

Rank	Company	Sector	Green Patents	Green Ratio
1	Siemens AG	Industrials	10931	12 %
2	Continental AG	Consumer Cyclicals	7594	25 %
3	Basf SE	Non-Energy Materials	6518	14 %
4	Bayer AG	Healthcare	4072	8 %
5	Koninklijke Philips N.V.	Healthcare	4007	5 %
6	Vestas Wind Systems A/S	Industrials	3524	61 %
7	Compagnie De Saint-Gobain	Non-Energy Materials	3266	12 %
8	Daimler AG	Consumer Cyclicals	2923	22 %
9	Solvay SA	Non-Energy Materials	2223	11 %

10	Airbus SE	Industrials	2205	23 %
11	Roche Holding AG	Healthcare	2019	6 %
12	Nokia OYJ	Technology	2008	4 %
13	Safran	Industrials	1813	22 %
14	Stellantis N.V.	Consumer Cyclicals	1689	23 %
15	Volkswagen AG	Consumer Cyclicals	1671	15 %
16	Compagnie Generale Des Etablissements Michelin	Industrials	1671	11 %
17	TotalEnergies SE	Energy	1641	27 %
18	Rolls-Royce Holdings Plc	Industrials	1618	24 %
19	Thyssenkrupp AG	Industrials	1574	13 %
20	Merck Kgaa	Healthcare	1532	16 %
21	Royal Dutch Shell Plc	Energy	1516	21 %
22	Johnson Matthey Plc	Non-Energy Materials	1376	18 %
23	Voestalpine AG	Non-Energy Materials	1360	12 %
24	Valeo	Consumer Cyclicals	1170	10 %
25	Telefonaktiebolaget Lm Ericsson AB	Technology	1010	5 %
26	L'air Liquide Societe Anonyme Pour L'etude Et L'exploitation Des Procedes Georges Claude	Non-Energy Materials	1000	18 %
27	Umicore	Non-Energy Materials	980	21 %
28	AB Volvo	Industrials	970	23 %
29	Glaxosmithkline Plc	Healthcare	928	8 %
30	Johnson Controls International Plc	Industrials	873	6 %
31	Aptiv Plc	Consumer Cyclicals	824	13 %
32	Abb Ltd	Industrials	771	15 %
33	Eni S.P.A.	Energy	684	28 %
34	Evonik Industries AG	Non-Energy Materials	670	10 %
35	Bayerische Motoren Werke AG	Consumer Cyclicals	622	10 %
36	Eaton Corporation Public Limited Company	Industrials	607	12 %
37	BP Plc	Energy	590	16 %
38	Astrazeneca Plc	Healthcare	586	5 %
39	Schneider Electric SE	Industrials	567	12 %
40	Sanofi	Healthcare	518	3 %
41	Te Connectivity Limited	Industrials	506	6 %
42	Koninklijke Dsm N.V	Non-Energy Materials	491	10 %
43	Schaeffler AG	Consumer Cyclicals	450	6 %
44	Orange	Telecommunications	371	2 %
45	Linde Plc	Non-Energy Materials	341	21 %
46	Veolia Environnement	Utilities	305	28 %
47	Covestro AG	Non-Energy Materials	297	6 %
48	Novartis AG	Healthcare	293	4 %
49	Lyondellbasell Industries N.V.	Non-Energy Materials	284	9 %
50	Repsol SA	Energy	266	35 %

Table 4 presents the top 50 companies with the highest total number of green patent applications and their respective green ratio. Energy companies are highlighted in orange.

7.2 Regression results

To further examine our hypotheses regarding the role of the energy firms in the green transition, we run several OLS regressions with year fixed effects. The objective of the regressions is to determine the potential significant relationship between the energy sector and the different aspects of green innovation.

7.2.1 Hypothesis 1: Relative green innovation

The green ratio reflects the firms' relative focus on green innovation by comparing their number of green patents to their total number of patents. The ratio enables us to understand differences in relative green innovation efforts across sectors, and thus, investigate our first hypothesis.

Hypothesis: The relative green innovation effort is lower for firms in the energy sector than for firms in other sectors.

The output from the analyses of the green ratio is presented in tables 5 and 6. Both tables suggest that a higher share of the innovation efforts in the energy sector is directed towards green patents than in the non-energy sectors, at a 1% significance level. This finding contradicts our hypothesis, as the evidence suggests the direct opposite of what we initially expected to find. The models in table 5 include observations of all firms that have actively engaged in patenting, either through applying for green or non-green patents. To assess the performance of the energy sector when only considering green innovators, the models in table 6 only include firms that engage in green patenting.

Table 5: Column (1) in table 5 suggests that the green ratio of the energy sector is 13 percentage points higher than for non-energy sectors. The average green ratio for the non-energy sectors in our model is 11%[5], implying that the energy sector has more than two times the relative focus on green innovation as other sectors. Furthermore, the analysis presents

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[5] Calculated by adding(subtracting) the coefficients of the dummy variables for each year to(from) the constant that represents the base year, 2000. The ratios for all time periods are then summed up and averaged, resulting in an overall non-energy average of 11%. The full regression table is presented in appendix 11.3.1

similar results when we include other factors relevant for the production of green innovation. These include annual capital expenditures, firm age, market capitalization and debt-to-market capitalization. As presented in column (3), the model suggests that all these factors are significant at 1%, except for firm age. According to the estimated coefficients, companies with higher annual levels of capex produce a higher share of green patents than those with lower capex levels. The same is true for companies that are less leveraged and of lower market capitalization.

Table 5: Green patent ratio, energy sector versus all other sectors

	(1) Green Ratio	(2) Green Ratio	(3) Green Ratio
Energy	0.13^{***}	0.13^{***}	0.12^{***}
	(0.01)	(0.01)	(0.01)
Log Capex		0.00	0.03^{***}
		(0.00)	(0.00)
Log Firm Age			-0.01^{*}
			(0.00)
Log MarketCap			-0.05^{***}
			(0.01)
Debt to Cap			-0.01^{***}
			(0.00)
N	2355	2191	2100
r2	0.07	0.07	0.15
Year Fixed Effects	YES	YES	YES

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5 presents the output from OLS regressions with year fixed effects. The dependent variable, the green ratio, reflects the share of green patents to total patents produced by a firm per year. To remove extreme observations of green ratios, the analysis requires a company to have filed for at least three patent applications in a year to be included as an observation in the specific year. The underlying data covers all patent applications filed between 2000 and 2018 by 186 of the 250 largest public European companies, as the companies not engaged in patenting are removed. The firms are divided into 12 sectors, but the analyses exclude the consumer services sector due to few patent applications. The energy sector contains firms that mainly operate within oil, gas, and coal. Green patents are classified under CPC code Y02 "Technologies or applications for mitigation or adaptation against climate change". Standard errors are heteroskedastic-robust and clustered by year.

Table 6 paints a similar picture as table 5 and suggests that energy companies have a 12 percentage points higher share of green innovation than the non-energy sectors. This difference remains constant when control variables are introduced in columns (2) and (3). Hence, the two models present relatively similar results also when we change the sample to only contain green innovation.

Table 6: Green patent ratio, energy sector versus all other sectors. Only including firms engaged in green patenting

	(1) Green Ratio	(2) Green Ratio	(3) Green Ratio
Energy	0.12***	0.12***	0.12***
	(0.01)	(0.01)	(0.01)
Log Capex		-0.00	0.03***
		(0.00)	(0.00)
Log Firm Age			-0.01***
			(0.01)
Log MarketCap			-0.06***
			(0.01)
Debt to Cap			-0.00
			(0.00)
N	1894	1772	1700
r2	0.06	0.06	0.16
Year Fixed Effects	YES	YES	YES

Standard errors in parentheses

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6 presents the output from OLS regressions with year fixed effects. The dependent variable, the green ratio, reflects the share of green patents to total patents produced by a firm per year. The analysis requires a company to be actively engaged in green patenting and have filed for at least three patent applications (where a minimum of one is defined as "green") in a year to be included as an observation in the specific year. The underlying data covers all patent applications filed between 2000 and 2018 by 186 of the 250 largest public European companies, as the companies not engaged in patenting are removed. The firms are divided into 12 sectors, but the analyses exclude the consumer services sector due to few patent applications. The energy sector contains firms that mainly operate within oil, gas, and coal. Green patents are classified under CPC code Y02 "Technologies or applications for mitigation or adaptation against climate change". Standard errors are heteroskedastic-robust and clustered by year.

7.2.2 Hypothesis 2: Energy-related green innovation

The Energy and CCS Ratio models investigate whether the green innovation produced by energy firms is within areas that are material to the core of their operations, namely energy production, and carbon capture and storage. Thus, the model enables analysis of our second hypothesis.

Hypothesis: The share of green innovation within energy production and CCS is lower for firms in the energy sector than for firms in other sectors.

The results in table 7 suggest that the energy sector produces significantly more green innovations that are material and strongly related to their core operations than the non-energy sectors. According to column (1) in the output table, the share of energy and CCS-related innovation is on average 5 percentage points higher for energy firms than for non-energy firms, with a significance level of 1%. The energy coefficient is also noticeably growing as we introduce the respective control variables and doubles from column (1) to columns (2) and (3). The finding contradicts the initial hypothesis of energy firms mainly producing innovation that does not affect their primary activities.

Table 7: Energy and CCS ratio, energy sector versus all other sectors. Green patents only

	(1) Energy & CCS Ratio	(2) Energy & CCS Ratio	(3) Energy & CCS Ratio
Energy	0.05^{**}	0.10^{***}	0.10^{***}
	(0.03)	(0.03)	(0.03)
Log Capex		-0.02^{***}	-0.02^{**}
		(0.01)	(0.01)
Log Firm Age			0.03^{***}
			(0.01)
Log MarketCap			0.00
			(0.01)
Debt to Cap			-0.01
			(0.01)
N	1941	1818	1745
r2	0.03	0.03	0.05
Year Fixed Effects	YES	YES	YES

Standard errors in parentheses

$^{*} p < 0.10$, $^{**} p < 0.05$, $^{***} p < 0.01$

Table 7 presents the output from OLS regressions with year fixed effects. The dependent variable, the energy & CCS ratio, reflects the share of green patents within energy and CCS by a firm per year. The analysis only investigates green patents. The underlying data covers all patent applications filed between 2000 and 2018 by 186 of the 250 largest public European companies, as the companies not engaged in patenting are removed. The firms are divided into 12 sectors, but the analyses exclude the consumer services sector due to few patent applications. The energy sector contains firms that mainly operate within oil, gas, and coal. Green patents are classified under CPC code Y02 "Technologies or applications for mitigation or adaptation against climate change".

7.2.3 Hypothesis 3: Patent quality

The average citation variable reflects the inherent quality of a patent by measuring the number of references and cites the patent has received. Hence, the model enables analysis of our third hypothesis, namely whether the quality of the green patents produced by the energy sector negatively deviates from those of firms in other sectors.

Hypothesis: The quality of the green innovation is lower for firms in the energy sector than for firms in other sectors.

From table 8, we do not find evidence that the patents produced by energy firms are of lower quality than in other sectors. The model rather indicates the opposite, that the quality of the green patents developed by the energy sector is higher than the average patent developed in other sectors. However, the result is only significant at 5% in column (2) when capital expenditure is introduced as a control variable. In this case, the findings suggest that the green patents in the energy sector on average receive 0.55 more citations than the average green patent of non-energy sectors. When we introduce the relevant control variables in column (3) the energy coefficient loses its significance, and we can therefore not conclude on any statistical relationship between the energy sector and the number of citations.

Table 8: Average citations of green patents, energy sector versus all other sectors

	(1) Average Citations	(2) Average Citations	(3) Average Citations
Energy	0.22	0.55**	0.27
	(0.17)	(0.24)	(0.21)
Log Capex		-0.22***	-0.28***
		(0.05)	(0.09)

Log Firm Age			-0.11*
			(0.06)
Log MarketCap			0.16*
			(0.09)
Debt to Cap			-0.02
			(0.04)
N	1938	1815	1742
r2	0.15	0.17	0.18
Year Fixed Effects	YES	YES	YES

Standard errors in parentheses

$^{*} p < 0.10$, $^{**} p < 0.05$, $^{***} p < 0.01$

Table 8 presents the output from OLS regressions with year fixed effects. The dependent variable, average citations, is calculated as the sum of green patent citations divided by the sum of green patents by a firm per year. The analysis only includes green patents, and three outlier observations are excluded. The underlying data covers all patent applications filed between 2000 and 2018 by 186 of the 250 largest public European companies, as the companies not engaged in patenting are removed. The firms are divided into 12 sectors, but the analyses exclude the consumer services sector due to few patent applications. Three outlier observations are also excluded. The energy sector contains firms that mainly operate within oil, gas, and coal. Green patents are classified under CPC code Y02 "Technologies or applications for mitigation or adaptation against climate change". Standard errors are heteroskedastic-robust and clustered by year.

7.2.4 Supplementary hypotheses: Top 3 green sectors

In addition to our primary analyses of the energy sector, our two supplementary analyses seek to understand the relative green innovation efforts and corresponding quality in the three sectors that produce the highest number of green patents. We use similar models as above to test the following hypotheses:

Hypothesis i: The relative green innovation effort is higher in the top three green sectors than in other sectors.

Hypothesis ii: The quality of the green innovation effort is higher in the top three green sectors than in other sectors.

Table 9 compares the green ratio of the top three sectors in terms of total green patent applications to all other sectors. The results in column (1) indicate that these sectors have a 3 percentage points higher relative focus on green innovation than other sectors, significant at a 1% level. Nevertheless, the coefficient is of a lower magnitude than the corresponding coefficient previously estimated for the energy sector. It also becomes insignificant when we introduce the control variables in column (3). Thus, the analysis indicates that a higher share of the innovation efforts of these firms is within areas that are outside the green space.

Table 9: Green patent ratio, top 3 sectors versus all other sectors

	(1) Green Ratio	(2) Green Ratio	(3) Green Ratio
Top 3 Green	0.03***	0.04***	0.01
	(0.00)	(0.00)	(0.01)
Log Capex		0.01***	0.04***
		(0.00)	(0.00)
Log Firm Age			-0.01**
			(0.00)
Log MarketCap			-0.05***
			(0.01)
Debt to Cap			-0.01***
			(0.00)
N	2355	2191	2100
r2	0.03	0.05	0.12
Year Fixed Effects	YES	YES	YES

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The table presents the output from OLS regressions with year fixed effects. The dependent variable, the green ratio, reflects the share of green patents to total patents produced by a firm per year. To remove extreme observations of green ratios, the analysis requires a company to have filed for at least three patent applications in a year to be included as an observation in the specific year. The underlying data covers all patent applications filed between 2000 and 2018 by 186 of the 250 largest public European companies, as the companies not engaged in patenting are removed. The firms are divided into 12 sectors, but the analyses exclude the consumer services sector due to few patent applications. The top three sectors (based on total green patents) include industrials, non-energy materials, and consumer cyclicals. Green patents are classified under CPC code Y02 "Technologies or applications for mitigation or adaptation against climate change". Standard errors are heteroskedastic-robust and clustered by year.

The analysis in table 10 suggests that there is a significant negative relationship between the average number of citations received per patent and being a firm in the top three green patent-producing sectors. The table shows that the patents produced by these sectors on average receive 0.33 citations less than in other sectors. The finding is significant at a 1% level and remains relatively similar when the relevant control variables are introduced to the model. This finding contradicts our second supplementary hypothesis, as the green innovation produced by these sectors seems to be of significantly lower quality than other sectors, including the energy sector.

Table 10: Average citations of green patents, top 3 sectors versus all other sectors

	(1) Average Citations	(2) Average Citations	(3) Average Citations
Top 3 Green	-0.33***	-0.44***	-0.31***
	(0.10)	(0.10)	(0.09)
Log Capex		-0.21***	-0.23***
		(0.04)	(0.08)
Log Firm Age			-0.09
			(0.06)
Log MarketCap			0.09
			(0.09)
Debt to Cap			-0.04
			(0.04)
N	1938	1815	1742
r2	0.16	0.18	0.18
Year Fixed Effects	YES	YES	YES

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10 presents the output from OLS regressions with year fixed effects. The dependent variable, average citations, is calculated as the sum of green patent citations divided by the sum of green patents by a firm per year. The analysis only includes green patents, and three outlier observations are excluded. The underlying data covers all patent applications filed between 2000 and 2018 by 186 of the 250 largest public European companies, as the companies not engaged in patenting are removed. The firms are divided into 12 sectors, but the analyses exclude the consumer services sector due to few patent applications. The top three sectors (based on total green patents) include industrials, non-energy materials, and consumer cyclicals. Green patents are classified under CPC code Y02 "Technologies or applications for mitigation or adaptation against climate change". Standard errors are heteroskedastic-robust and clustered by year.

7.2.5 Findings relative to study by Cohen, Gurun and Nguyen

The study “The ESG-innovation disconnect” by Cohen, Gurun, and Nguyen (2020) has relatively similar findings as this thesis. Their sample contains all patents granted to publicly traded firms in the United States from 1980 to 2017. They use OECD’s definition of green patents based on the patents’ IPC codes, whereas we apply the CPC’s classification of green patents. The CPC classification system has a clearer definition of green patents than the IPC system and is easier to apply as it requires less manual work. Furthermore, both methods are based on the same patent characteristics and are expected to include the same patents. Thus, whether one uses OECD’s or CPC’s definition of green patents is not expected to have any implication on the statistical results (N. Barbieri, personal communication, August 24th, 2021).

Cohen et al. find that the energy sector produces significantly more and higher quality green innovation than other sectors. Their green ratio in the energy sector is 13.95 percentage points higher than for other sectors, whereas our analysis suggests 12 percentage points. Additionally, in their analysis of energy-related technologies, they find that energy firms have a 2.21 percentage points higher focus on energy-related innovation. Our approach to analyze energy-related technologies differs from their approach, as they exclude CCS and solely focus on “Climate change mitigation technologies related to energy generation, transmission, or distribution”. Additionally, their sample contains both all green and non-green patents, whereas we believe it is more interesting to only include the green patents to gain a deeper understanding of the green innovation space. However, we have also performed the analysis following their approach in an unreported regression. In this analysis, we find that the energy sector has a 5.49 percentage points higher focus on energy and CCS-related innovation than other firms. Thus, both our analyses agree with Cohen et al.’s findings of energy firms having a significantly higher relative focus on green energy-related technologies. Regarding patent quality, they find that energy firms produce green patents of significantly higher quality, with each patent receiving 9.14% more citations than other sectors. Our analysis similarly indicates that the energy sector has higher patent quality, but not at a significant level.

In summary, our analyses have notably similar results, which may further validate our findings and conclusions. Cohen et al. push the analysis deeper by tracking specific ESG fund flows, ESG ratings, and the connection between innovation and ESG scores. Due to data limitations and the scope and capacity of the thesis, we do not consider these elements. However, to improve the depth of the analyses, this would be a relevant direction for further research.

8. Discussion

The exclusion of companies engaged in fossil fuels has become a widespread approach among responsible investors. At the same time, investments in renewable energy must triple by the end of the decade, as about half of the technologies required for the green transition are currently not on the market (IEA, 2021). This study aims to answer whether the current momentum of responsible investments enables the most efficient clean energy transition.

In this section, we first discuss the role of energy firms in the green transition based on their green innovation and technological contributions. Second, building on our initial findings, we discuss the implication of excluding these firms from the investment portfolio. We then provide suggestions of alternative investment strategies that may be more efficient for contributing to sustainable development. Finally, we discuss other perspectives for facilitating a transformation of the global energy systems.

8.1 Importance of the green innovation in the energy sector

Table 11 summarizes the main findings from our analyses on differences in green patenting between the energy and non-energy sectors (1-4) and the top three green sectors and other sectors (5-6).

Table 11: Summary of regressions

	(1) Green Ratio	(2) Green Ratio (green only)	(3) Energy & CCS Ratio	(4) Average Citations	(5) Green Ratio	(6) Average Citations
Energy	0.12***	0.12***	0.10***	0.27		
	(0.01)	(0.01)	(0.03)	(0.21)		
Top3 Green					0.01	-0.31***
					(0.01)	(0.09)
Log Capex	0.03***	0.03***	-0.02**	-0.28***	0.04***	-0.23***
	(0.00)	(0.00)	(0.01)	(0.09)	(0.00)	(0.08)
Log Firm Age	-0.01*	-0.01***	0.03***	-0.11*	-0.01**	-0.09
	(0.00)	(0.01)	(0.01)	(0.06)	(0.00)	(0.06)
Log	-0.05***	-0.06***	0.00	0.16*	-0.05***	0.09

MarketCap	(0.01)	(0.01)	(0.01)	(0.09)	(0.01)	(0.09)
Debt to Cap	-0.01*** (0.00)	-0.00 (0.00)	-0.01 (0.01)	-0.02 (0.04)	-0.01*** (0.00)	-0.04 (0.04)
N	2100	1700	1745	1742	2100	1742
r2	0.15	0.16	0.05	0.18	0.12	0.18
Year FE	YES	YES	YES	YES	YES	YES

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11 presents a summary of the OLS regressions with year fixed effects. The green ratio reflects the share of green patents to total patents. The energy & CCS ratio reflects the share of green patents within energy and CCS. Average citations are calculated as the sum of green patent citations divided by the sum of green patents. All observations are by firm per year. Models (1), (2), and (5) require a company to have filed for at least three patents in a year. Model (2) additionally requires that a minimum of one patent is defined as "green". Models (3), (4), and (6) are based on green patents only. In (4) and (6), three outlier observations are removed. The underlying data covers all patent applications filed between 2000 and 2018 by 186 of the 250 largest public European companies, as the companies not engaged in patenting are removed. The firms are divided into 12 sectors, but the analyses exclude the consumer services sector due to few patent applications. The energy sector contains firms that mainly operate within oil, gas, and coal. The top three sectors (based on total green patents) include industrials, non-energy materials, and consumer cyclicals. Green patents are classified under CPC code Y02 "Technologies or applications for mitigation or adaptation against climate change". Standard errors are heteroskedastic-robust and clustered by year.

As presented in the analyses of the green ratio, we find that energy firms have a significantly higher relative focus on green innovation than firms in other sectors. One possible explanation for this observation is that energy firms proactively respond to the uncertainty about the future of their industry by shifting towards a greener path. As the world increasingly demands clean energy and punishes dirty operations, a change of direction of the fossil fuel firms may simply be their natural solution to survive and remain in business.

Another possible explanation of the strong, observed green focus may be the increased pressure from stakeholders. The purpose of the innovation may be to obtain goodwill by society and appear increasingly sustainability oriented. However, producing a high share of green patents can allow energy firms to greenify their reputation while having no ambition of transforming their operations. Thus, one may question whether the observed green engagement is motivated by a genuine commitment or is an attempt at greenwashing, i.e., performing "green" activities that systematically mislead the public.

To better understand the motivation behind the energy firms' green innovation efforts, we compare the energy sector to the sectors that stand out as the main contributors to the green transition. The analyses of the green ratios reveal that the three sectors that produce the highest total number of green patents have a remarkably smaller share of their innovation within green technologies than the energy sector. Additionally, the patent quality analyses show that the innovation produced by these sectors is of significantly lower quality than all other sectors, whereas the quality of the energy sector is equal or higher. The combination of these two insights suggests that the energy sector has some unique characteristics. First, it indicates that the energy sector prioritizes developing green technologies over other technologies to a higher degree than other sectors. Additionally, energy firms seem to allocate more high-quality resources to the development of their green innovation. Hence, it is fair to believe that the energy firms have sustainability high on the agenda. Another interesting insight from these analyses is that producing a high number of patents is not necessarily associated with a stronger focus on green innovation. In summary, these findings indicate that the energy firms have a true commitment to the green transition, and that they genuinely aim to contribute with valuable, technological developments.

The energy sector seems to allocate a large share of their high-quality resources to green innovation, but one may question whether they in parallel try to shield their core fossil fuel activities from shutting down. If so, they would still partly greenwash their operations by developing green technologies that cannot replace their core activities and that enable the continuation of fossil fuels. However, as presented in column (3), we find that firms in the energy sector invent significantly more green technologies within renewable energy and CCS than other sectors. This result indicates that the engagement in green innovation is not a part of a greenwashing strategy nor a cover-up for fossil fuel activities. The findings rather contradict the hypotheses and imply that energy firms actively innovate to transform, or at least diversify, their core operations. Nevertheless, it could be argued that if the energy companies are truly committed to fully transform to net zero, they should have more ambitious targets than what our analyses reveal.

To further understand the motivation behind the energy sector's large share of green technologies, it would be interesting to analyze whether the technologies are commercialized or not. This would reveal whether energy firms really plan to transform their operations, or simply leverage their extensive capabilities to protect technologies and block other innovators from the clean energy space. By blocking out other players, a consequence could be a slower green transition, which in turn may let the fossil fuel players operate freely for a longer time. Due to inadequate availability of measurable data, it is challenging to perform these analyses. However, the analyses of forward citations indicate that the innovation is extensively applied in other players' technological developments, and that the energy sector is rather collaborating than blocking other players from developing new energy sources.

By looking into the pipeline of some of the ongoing sustainability projects, we can get a glimpse of the areas where energy firms are at the core of commercializing and bringing new solutions to the market. Examples include Equinor's currently largest project, which is not fossil fuel-related but aims at building the world's largest floating offshore windfarm. In this project, Equinor is leveraging its extensive offshore experience from the North Sea to develop new technologies for floating wind and unlock new opportunities for large-scale wind production (Equinor, 2021). Another example includes ENI's recent invention of three groundbreaking technologies for solar energy, developed at the Eni Research Centre for Renewable Energy and the Environment (ENI, 2021). As a third example, BP, Equinor, Shell, Total, ENI, and National Grid are all collaborating on leading global projects for commercializing large-scale CCS (BP, 2020).

Common for the above-mentioned projects is their contribution to leading the way for the energy transition through development and demonstration of new, green technologies. This continuous innovation may reduce capex and opex, and increase both the operational capacity and the lifespan of the solutions. Additionally, large-scale demonstration of new technologies reduces the risk associated with unproven solutions. All these elements will reduce the LCOE of clean energy solutions, which consequently improves the competitiveness and benefits the whole renewable energy industry. Our analyses indicate that the energy sector possesses key resources and capabilities for being frontrunners in the development of relevant and high-quality inventions. Hence, it may be challenging to see how the global energy system will reach net zero by 2050 without the traditional energy firms.

It should be noted that not all energy firms are frontrunners in the green transition, nor are all energy firms showing signs of changing strategies. Although our sample suggests that the energy sector is heavily engaged in green innovation relative to other sectors, it also includes energy firms with a limited sustainability focus and green activities. Yet, our results indicate that most of the large energy firms work actively to invent new sustainable technologies, and we therefore warn against underestimating their importance in the green transition.

8.2 Implications of excluding firms engaged in fossil fuels

The energy sector at large seems to be genuinely committed to a green transformation. In the following we discuss potential consequences of excluding energy firms from responsible investment portfolios, in the perspective of the clean energy transition.

The energy sector is among the most capital-intensive sectors and requires large investments to execute projects. By limiting the access to capital, the exclusionary strategies seek to impact the valuation of firms engaged in fossil fuels. As a consequence, the energy firms face increasing cost of capital, which negatively influence their ability to operate and realize projects. This includes reduced abilities to execute green projects and commercialize green innovation. Several energy firms announce that descending valuations pose a substantial risk to the firm, including Shell, declaring that the growing divestment movement has become a material risk to their business (Royal Dutch Shell, 2019). Thus, by harming the firms' abilities to develop green innovation, the exclusionary strategy may decelerate the clean energy transition.

While widespread and coordinated exclusion has the potential to impact valuations, and consequently the scope of the firms' overall activities, it requires extensive participation. However, in efficient markets, capital will flow to the investments delivering the highest risk-adjusted returns. Thus, when responsible investors exit the sector, less responsible investors might accept the invitation to replace them. It is fair to assume that these investors are less likely to strive for sustainability and believe in its impact on long-term value creation, and less likely to sacrifice risk-adjusted return for positive effects on climate. Research has shown that the oil and gas companies obtain far superior returns through their carbon-intensive projects than renewable projects (Christophers, 2021). Hence, an investor that does not implement climate risk in her investment considerations, may push the energy firms towards dirtier operations to achieve higher short-term returns. Consequently, the implications of responsible investors pulling out of the sector may have the opposite effect of the original intention behind the exclusionary strategy.

The roadmap to a successful clean energy transition is challenging as the global demand for energy continues to rise. Fossil fuels are currently the largest source of energy, and it can be argued that it is unrealistic to achieve an immediate transition of the global energy systems. It may therefore be perceived as problematic that many exclusionary strategies have no clear plan for reinvesting in the sector until the firms have completely phased out fossil fuels. Hence, we argue that the unconditional exclusion of energy firms without a plan for maintaining global energy supply, nor leveraging the existing resources of the sector, misses the bigger picture.

8.3 Alternative approaches to responsible investing

As debated above, exclusion may inhibit the level of green innovation in the energy sector. In the following, we therefore discuss other, potentially more efficient approaches to finance the green transition.

Influencing through active ownership

Active ownership has proven to be efficient in influencing companies' behavior. Not only does it enable influence over current decisions and activities but invites to shaping of long-term strategies and sustainable value creation. Applied directly to the case of fossil fuel firms, the investor may actively force the company in a more environmentally friendly direction by both phasing out fossil fuels and boosting green innovation. This will further contribute to combating climate change and reduce the climate risk related to the investment. Assuming there will be investors willing to supply capital regardless of carbon footprint in exchange for sufficient returns, active ownership is expectedly a more efficient approach for phasing out fossil fuels than any exclusionary strategy.

Active ownership is more demanding and requires more resources than passive strategies such as exclusion. However, as opposed to exclusion, which is associated with the lowest stage of Sustainable Finance, active ownership is in line with Sustainable Finance 2.0. At this stage, the overall objective is to maximize the financial, social, and environmental values. Thus, although active ownership requires more commitment from the investor, the strategy is perceived as of higher impact. Yet, for an investor seeking to minimize the necessary efforts while maximizing positive impact, none of these strategies may appear appealing. A more ideal approach may be to turn to other capital markets.

Green bonds

An inviting approach for the passive investor may be to invest in a company's green bond rather than buying equity. By investing in green bonds, the investor can overcome the issue of controlling whether the capital finances green projects or less sustainable activities. However, debt investments do not enable influence over future decisions nor long-term strategies. Yet, it represents an alternative for investors to allocate capital to green energy projects and create more impact than exclusion of fossil fuels alone.

8.4 Other perspectives for facilitating the green transition

Due to the complexity of transforming the energy sector into a green space, we include a short discussion where we take a step out of the mindset of a responsible investor. In the following, we briefly investigate what actions the companies and policymakers can undertake to ensure capital flows to green innovation and the energy sector.

Corporate perspective

The energy companies that are not prepared to immediately replace their entire oil and gas portfolio with renewable energies may still attract responsible investors by restructuring their juridical organization. By phasing out and establishing separate corporations for the respective green operations, the energy company can distinguish the green projects and innovation from their dirtier activities. Consequently, not only may the energy company advance from exclusion to inclusion in an investor's portfolio but may also become a preferred target of sustainability-oriented capital flows. One example of a successful separation of entities is the Aker group, which in recent years has expanded into numerous renewable verticals, attracting impressive amounts of capital, and overcoming the issue of fossil fuel exclusion (Aker Group, 2021).

Governments

The role of policymakers and governments is at the center of the transition to a greener economy, as they possess a wide-ranging toolbox of remedies and capital that can influence the speed and direction of the green transition. These tools may influence companies far beyond their ability to attract capital, but we limit the following discussion to investigate how governments can i) directly finance green innovation and ii) indirectly facilitate capital flows to green innovation.

On the one hand, policymakers and governmental institutions can directly provide financing to green innovation through subsidies and low-interest loans. The overall objective is typically to realize renewable projects, with the intention to reduce the LCOE and create ripple effects for the whole industry. Several innovative projects in renewable energy are postponed as they do not deliver a positive net present value (Christophers, 2021). Consequently, these projects will not be executed until carbon prices rise substantially and the willingness to pay for renewable energy increases. Following this, the clean energy transition may slow down as the development necessary to achieve economic competitiveness is postponed. In these situations, governments can speed up the development by providing the necessary funds for ensuring a positive net present value of the renewable projects. An example of how this is applied today is the EU Innovation Fund, which allocates more than1 billion EUR to innovative projects that contribute to decarbonizing the economy (European Commission, n.d.).

On the other hand, policymakers should use their power to facilitate and accelerate capital flows to green innovation. First, by designing and implementing policies such as the EU Taxonomy, investors are required to measure and report on sustainability KPIs, which in turn will increase the transparency of their investment actions. The directive, which has replaced previous subjective assessments of sustainable activities with multinational standardizations and requirements, also increases the transparency of economic activities. Thus, it becomes easier to distinguish greenwashing from actual impact, which may encourage more investors to supply capital to green innovation.

Second, governments should strive for increased predictability of current and future requirements and policies. This may improve the stability of the markets and lower the transition risk arising from climate change. By increasing the predictability of e.g., emission-specific requirements and infrastructure investments, and reducing the volatility of instruments such as carbon prices, the energy transition may play out more smoothly and be perceived as less risky. Consequently, investors that are currently abstaining from investing in green innovation due to uncertainty and risk may see greater upside potential and be stimulated to enter the space.

Although this topic is complex and far beyond the scope of the thesis, it should be noted that the solution to the profound challenge of transitioning to a sustainable economy will include some form of systematic interconnection between the policymakers, the public institutions, the private sector, and the capital markets.

9. Conclusion

The purpose of this thesis is to investigate whether exclusion of firms engaged in fossil fuels is the most efficient investment approach for accelerating the clean energy transition. By analyzing patents across sectors, we find that energy firms are essential contributors to the development of new, green technologies. This is further supported by the finding that energy firms innovate significantly more within clean energy-generating technologies. The analyses also suggest that the innovation produced by energy firms is of adequate quality compared to other sectors.

We recognize that exclusion of energy firms may contribute to phasing out fossil fuels by negatively impacting the firms' reputations and valuations. Nevertheless, we argue that exclusion alone misses the bigger picture. These strategies are often based on unconditional exclusion and lack a system for rewarding the companies that systematically develop green innovation to transform their operations. Consequently, the approach may rather result in a slowdown than an acceleration of the clean energy transition. First, the cost of capital faced by energy firms may increase, which harms their abilities to develop green innovation. Second, the remaining less responsible investors may seize the opportunity to realize short-term profits by pushing the firms towards carbon-intensive operations. A proposed better approach than exclusion is therefore to invest and engage, as it enables positive influence on the operations of the investee. Active ownership has shown to be efficient for improving the sustainability performance of high-emitting firms and combat climate change.

Conclusively, we advocate that responsible investors should reconsider the exclusion of energy firms, and rather strive for impact and long-term value creation through active ownership. As we find energy firms to be key innovators of green technologies, responsible investors should consider investing in the energy sector, based on a thorough ESG analysis of the investment object. If exclusion is motivated by a moral stance, and the objective is to finance the green transition, investing and engaging is likely to be more efficient and in line with the underlying beliefs.

9.1 Further research

This thesis is limited to investigating the energy sector's contributions to the green transition through green innovation, and consequently, whether it makes sense to exclude the sector from investment portfolios. To provide a rock-solid conclusion and recommendation, the findings should be complemented with research in other areas that can provide a holistic understanding of the topic.

First of all, the innovation created by the energy firms should be further investigated. This includes looking more closely at other factors for measurement of green innovation, such as green R&D spending or green innovation budgets. Considerations of other indicators of quality would also enable a more granular analysis of the technological, environmental, and commercial value of the innovation.

Secondly, one should investigate to what degree the energy firms implement and bring the developed and patented technologies to life. This analysis would deepen the understanding of whether green innovation is an actual component of their commercial, long-term strategies or just a complex means to obtain goodwill by society. Building on this analysis, investigating the historical developments of each company's carbon footprints may paint a clearer picture of the respective company's actual environmental contributions.

Additionally, the analyses could engage a broader group of investors by investigating the direct relationship between financial performance and green innovation. By performing a detailed analysis of the impact of green innovation on valuation and returns, in addition to how ESG issues influence the corporate risk picture, the magnitude of responsible investing may see a sharp increase. Furthermore, by assessing ESG scores and financial performance, the analysis may shed a light on, and improve, the current imperfections of ESG scores and rating agencies.

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11. Appendix

11.1 Abbreviations

CCS	Carbon Capture and Storage
CPC	Cooperative Patent Classification
EPO	European Patent Office
ESG	Environmental, Social, Governance
IEA	The International Energy Agency
LCOE	Levelized Cost of Energy
PCT	The Patent Cooperation Treaty
RBICS	Revere Business Industry Classifications System
UNFCC	United Nations Conventional Framework on Climate Change

11.2 Classifications

FactSet Revere Business and Industry Classification System

The information regarding the firms' sectors is extracted from FactSet and follows the FactSet Revere Business and Industry Classification System (RBICS). The categorization of sectors is based on the firms' main operating activities. The table below lists the 12 different sectors and corresponding activities (FactSet, 2019).

Table 12: FactSet Revere Business and Industry Classification System

Sector	**Description**
Business Services	Services targeted toward businesses, including administrative, support, janitorial, and professional services
Consumer Services	Services targeted toward individuals, including accommodation; food and beverage retail; gaming, arts, entertainment and recreation; and television, radio, film, and print media
Consumer Cyclicals	Products targeted toward individual or household use, including apparel, toys, school and art supplies, and electronics; motor vehicle sales and rental, and automotive parts and services;

	building materials, garden supplies, furniture, appliances, cabinetry, window treatments, and carpets
Energy	Oil and gas exploration and production, pipeline transportation, refineries, and oil and gas equipment and services; leasing, mining and processing of coal and coke; uranium, radium, and vanadium mining
Finance	Financial products and services offered by institutions involved in banking, insurance, investment, specialty finance, and real estate
Healthcare	Products and services that are designed, developed, and utilized in the promotion of health and well-being, including
Industrials	Products and services for industrial use or with applications in aero-space, defense or security; transportation, construction, and related infrastructure; or farming, including equipment and machinery manufacture, wholesale, rental, and distribution and related support activities
Non-Energy Materials	Basic and intermediate material products, including non-energy mining; forestry, timber logging, and lumber production; and chemical, plastic, paper, metal, and textile manufacturing
Consumer Non-Cyclicals	Products targeted toward individual and consumer needs, including groceries, beverages, health and personal care items, kitchenware, decorative items, and household cleaning products
Technology	Semiconductor, electronic, and optics based products and related software and services that directly or indirectly facilitate the creation, transfer, storage, manipulation, or interpretation of data, audio, and video
Telecommunications	Services designed to promote or enhance transmission of voice, data, and video over various communications mediums, including cable, satellite, terrestrial based wireless, and wireline mediums
Utilities	Gas, electricity, and water services delivered directly to residential and commercial users

Table 12 presents the sectors included in our analyses and corresponding business activities. The classification is based on FactSet Revere Business Industry Classifications System (FactSet, 2019).

CPC classification codes for green patents

In the CPC classification system, the code Y represents a general class that covers several cross-sectional technologies. The Y02 class is used to categorize green patents and refers to

“Technologies or applications for mitigation or adaptation against climate change”. Table 13 lists the technologies under Y02 with related descriptions (European Patent Office, n.d.).

Table 13: CPC classification codes for green patents

Y02	**Technologies or applications for mitigation or adaptation against climate change**
Y02A	Technologies for adaptation to climate change
Y02B	Climate change mitigation technologies related to buildings, e.g. housing, house appliances or related end-user applications
Y02C	Capture, storage, sequestration or disposal of greenhouse gases [ghg]
Y02D	Climate change mitigation technologies in information and communication technologies [ict], i.e. information and communication technologies aiming at the reduction of their own energy use
Y02E	Reduction of greenhouse gas [ghg] emissions, related to energy generation, transmission or distribution
Y02P	Climate change mitigation technologies in the production or processing of goods
Y02T	Climate change mitigation technologies related to transportation
Y02W	Climate change mitigation technologies related to wastewater treatment or waste management

Table 13 presents the CPC’s classification codes of green patents.

CPC classification codes for energy-related green technologies

There are multiple classes under the Y02 code, which further contains sub-classes, groups, and sub-groups. The sub-classes for Y02C and Y02E, as listed below, are used to categorize technologies relevant to the core business and operations of energy firms (European Patent Office, n.d.).

Continuation table 13: CPC classification codes for green patents

Y02C	**Capture, storage, sequestration or disposal of greenhouse gases [ghg]**
Y02C20/00	Capture or disposal of greenhouse gases

Y02E	**Reduction of greenhouse gas [ghg] emissions, related to energy generation, transmission or distribution**
Y02E10/00	Energy generation through renewable energy sources
Y02E20/00	Combustion technologies with mitigation potential
Y02E30/00	Energy generation of nuclear origin
Y02E40/00	Technologies for an efficient electrical power generation, transmission or distribution
Y02E50/00	Technologies for the production of fuel of non-fossil origin
Y02E60/00	Enabling technologies; Technologies with a potential or indirect contribution to GHG emissions mitigation
Y02E70/00	Other energy conversion or management systems reducing GHG emissions

The tables present the CPC's classification codes of green patents within carbon capture and storage and energy production, transmission, and distribution.

11.3 Model testing

11.3.1 Model spesification

Hausmans test for fixed vs random effects

Table 14 presents the results of a Hausman test performed to investigate whether fixed effects or random effects are a preferred panel data estimator in our analyses. The null hypothesis that there is no correlation between the time-constant unobserved individual-specific effects and the independent variables. If this is the case, and we do not reject the null hypothesis, the random effects is the preferred estimator. In the output table from the Hausman test, the p-value is below 5%, and we reject the null hypothesis. Consequently, the preferred estimator is the fixed effects estimator.

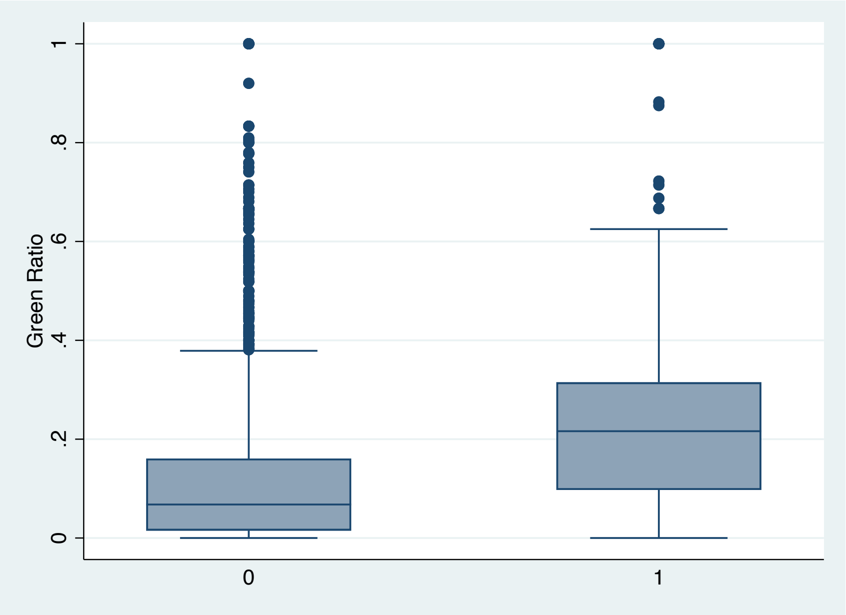
Table 14: Hausman specification test for fixed vs random effects

	Coef.
Chi-square test value	22.715
P-value	0.0001

Box plot of green ratio

The box plot in figure 6 visualizes the observations of the green ratio for energy firms, presented as 1, and all other firms, presented as 0. In the figures, the upper and bottom lines represent the 1% and 99% quartiles, respectively. The upper and lower edges of the boxes represent the 25% and 75% quartiles of the observations, respectively. Additionally, the line within the box represents the median of the observations. Hence, a comparison of the medians affirms that the median of energy firms is above the upper 75% quartile of firms in other sectors. Consequently, there is likely a statistical difference between the two groups. This plot also shows that the coefficient estimated through the pooled OLS model fits the data well. Hence, it provides support for the choice of this estimator.

Figure 66: Box plot: Green ratio



The figure illustrates the observations of green ratio for energy firms (represented as 1) and all other firms (represented as 0).

Regression 1: Complete output table

Table 15 presents the full regression output table from the first green ratio analysis, including all year dummy variables controlling for year fixed effects. The coefficients of all the year dummy variables in model (1) are used to calculate the average green ratio for non-energy sectors, as mentioned in section 7.2.1. We have removed the year dummy variables in the presentation of the main findings in the different models, as they are of limited interest. Essentially, also the constants are removed as they represent the base year, 2000.

Table 15: Green ratio on energy including presentation of year dummies

	(1) Green Ratio	(2) Green Ratio	(3) Green Ratio
Energy	0.13***	0.13***	0.12***
	(0.01)	(0.01)	(0.01)
Year=2001	0.02***	0.02***	0.01***
	(0.00)	(0.00)	(0.00)
Year=2002	0.01***	0.01***	-0.01***
	(0.00)	(0.00)	(0.00)
Year=2003	0.02***	0.03***	0.03***
	(0.00)	(0.00)	(0.00)
Year=2004	0.01***	0.01***	0.03***
	(0.00)	(0.00)	(0.00)
Year=2005	0.02***	0.03***	0.04***
	(0.00)	(0.00)	(0.00)
Year=2006	0.03***	0.03***	0.05***
	(0.00)	(0.00)	(0.00)
Year=2007	0.04***	0.05***	0.07***
	(0.00)	(0.00)	(0.00)
Year=2008	0.07***	0.08***	0.06***
	(0.00)	(0.00)	(0.00)
Year=2009	0.08***	0.08***	0.10***
	(0.00)	(0.00)	(0.00)
Year=2010	0.08***	0.09***	0.11***
	(0.00)	(0.00)	(0.00)
Year=2011	0.08***	0.09***	0.10***
	(0.00)	(0.00)	(0.00)
Year=2012	0.07***	0.07***	0.09***
	(0.00)	(0.00)	(0.00)
Year=2013	0.05***	0.06***	0.09***
	(0.00)	(0.00)	(0.00)
Year=2014	0.06***	0.07***	0.09***
	(0.00)	(0.00)	(0.00)
Year=2015	0.06***	0.06***	0.08***

	(0.00)	(0.00)	(0.00)
Year=2016	0.04*** (0.00)	0.05*** (0.00)	0.07*** (0.00)
Year=2017	0.05*** (0.00)	0.05*** (0.00)	0.09*** (0.00)
Year=2018	0.05*** (0.00)	0.05*** (0.00)	0.07*** (0.00)
Log Capex		0.00 (0.00)	0.03*** (0.00)
Log Firm Age			-0.01* (0.00)
Log MarketCap			-0.05*** (0.01)
Debttocap			-0.01*** (0.00)
Constant	0.07*** (0.00)	0.05*** (0.01)	0.40*** (0.03)
N	2355	2191	2100
R2	0.07	0.07	0.15
Year Fixed Effects	YES	YES	YES

Standard errors in parentheses
$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

11.3.2 OLS assumptions

In the following, we present the assumptions underlying the OLS estimator and discuss whether they are satisfied in our models.

Zero Conditional Mean

The assumption of zero conditional mean requires the average value of the error term to have an expected value of zero, given any value of the explanatory variables (Woolridge, 2012). In other words, the error term must be uncorrelated with other independent variables. Violation of this assumption complicates the interpretation of causal effects, as it creates difficulties in determining and separating each explanatory variable's influence on the dependent variable. It is important to keep the endogeneity issue in mind as a violation of this assumption creates omitted variable bias. If present, we cannot know whether a change in the dependent variable is driven by e.g., the energy sector firm variable or whether it is driven by unobserved factors in the error term. It is not possible to perform statistical tests to formally investigate violations of this assumption, but it should be addressed by adding variables that are likely to correlate with both the independent and dependent variables. We cannot be certain that the error term does not include any factors that are both correlated with the explanatory variables and the dependent variable. Consequently, we cannot establish any causal interpretation of the coefficients (Woolridge, 2012).

Homoskedasticity

Heteroskedasticity refers to a situation where the variance of the error term is inconstant for different values of the control variables (Woolridge, 2012). The presence of heteroskedasticity may invalidate the standard errors and the corresponding test statistics. The estimators are still unbiased and consistent but may have lower precision and incorrect p-values. To investigate whether heteroskedasticity may be a concern in our models, we run the Breusch-Pagan/Cook-Weisberg test, presented in table 16. The test result indicates violations of the assumption, in all models except the Energy & CCS Ratio, which we address by implementing clustered robust standard errors. Consequently, we obtain a more precise estimate of the true standard errors, resulting in improved test statistics and statistical interpretations (Woolridge, 2012).

Table 16: Breusch-Pagan/Cook-Weisberg test for heteroskedasticity

Breusch-Pagan/Cook-Weisberg test for heteroskedasticity
Assumption: Normal error terms
H0: Constant variance

Models	Chi2	P-Value
Green Ratio	459.18	0.0000
Green Ratio (green only)	387.11	0.0000
Green Ratio (top3)	326.08	0.0000
Energy & CCS Ratio	1.69	0.1942
Citations	840.96	0.0000
Citations (top3)	899.27	0.0000

No multicollinearity

Multicollinearity refers to the occurrence of strong or perfect intercorrelations between two or more explanatory variables (Woolridge, 2012). The presence of multicollinearity challenges the separation of each of the individual variables' effects on the dependent variable from each other. It further reduces the significance levels and reliability of the models. We test for multicollinearity by generating a correlation matrix and calculating variance inflation indicators. The results are presented in tables 17 and 18. Despite high correlation between some of the variables, which is somewhat expected due to their nature, the test results imply no violation of the multicollinearity assumption in our models. Additionally, our variable of interest is the sector dummy, implying that the occurrence of correlation between other control variables is of less concern (Woolridge, 2012).

Table 17: Matrix of correlations

Variables	energy	lfirmage	lmarketcap	debttocap	lcapex
energy	1.000				
lfirmage	-0.049	1.000			
lmarketcap	0.150	0.021	1.000		
debttocap	-0.065	-0.024	-0.027	1.000	
lcapex	0.283	-0.005	0.644	0.148	1.000

Table 18: Variance inflation factor

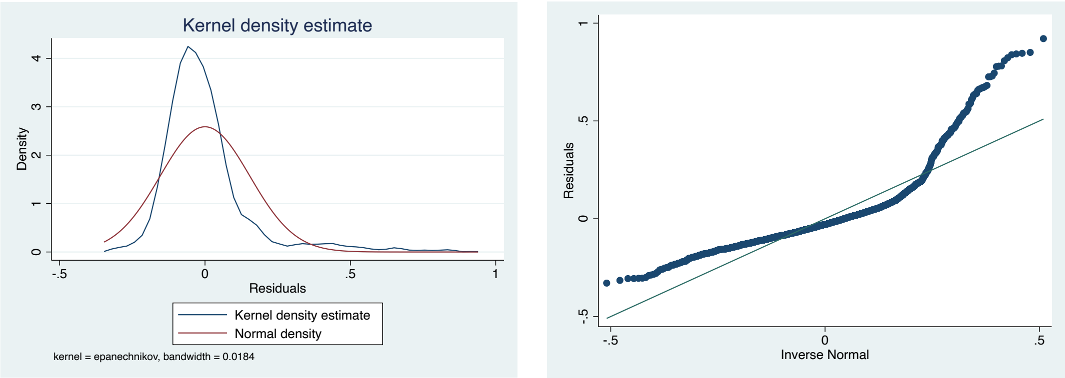
	Green Ratio	Green Ratio (green only)	Green Ratio (top3)	Energy & CCS Green Ratio	Citations	Citations (top3)
energy	1.144	1.192	1.274	1.183	1.184	1.25
lfirmage	1.01	2.253	1.867	2.276	2.281	2.068
lmarketcap	1.863	1.019	1.036	1.019	1.018	1.035
debttocap	1.095	2.05	2.252	2.095	2.1	2.449
lcapex	1.992	1.274	1.092	1.283	1.283	1.249
2001.year	1.908	1.944	1.908	1.945	1.971	1.971
2002.year	1.919	1.89	1.92	1.929	1.954	1.956
2003.year	1.923	1.989	1.923	1.978	2.006	2.006
2004.year	1.952	1.967	1.952	1.968	1.996	1.995
2005.year	2.015	2.087	2.015	2.085	2.118	2.118
2006.year	2.016	2.12	2.019	2.142	2.165	2.166
2007.year	2.039	2.067	2.043	2.087	2.12	2.121
2008.year	2.08	2.251	2.08	2.273	2.308	2.31
2009.year	2.046	2.207	2.047	2.239	2.275	2.275
2010.year	2.101	2.27	2.102	2.277	2.315	2.316
2011.year	2.079	2.297	2.079	2.305	2.342	2.342
2012.year	2.063	2.213	2.064	2.255	2.292	2.292
2013.year	2.079	2.255	2.083	2.262	2.3	2.302
2014.year	2.101	2.298	2.103	2.293	2.332	2.332
2015.year	2.08	2.342	2.083	2.36	2.4	2.401
2016.year	1.971	2.167	1.974	2.187	2.223	2.223
2017.year	1.967	2.156	1.974	2.188	2.224	2.227
2018.year	1.989	2.122	1.991	2.132	2.165	2.166
Mean VIF	**1.888**	**2.019**	**1.908**	**2.033**	**2.06**	**2.068**

Normality

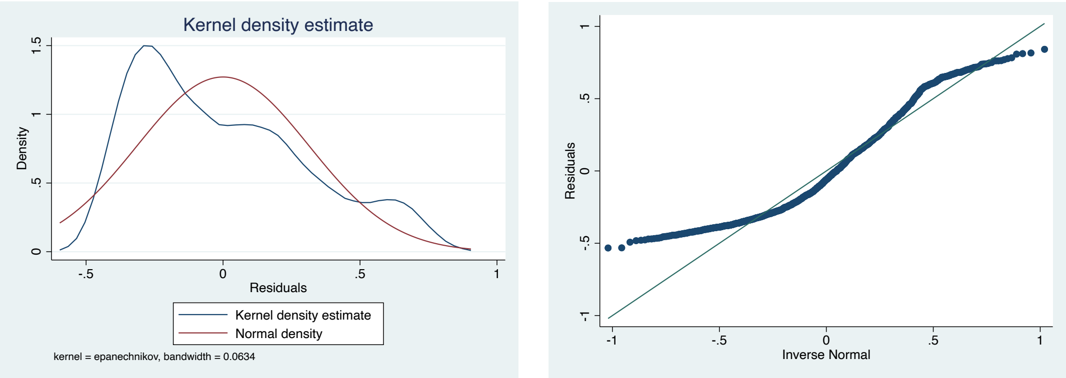
The fifth OLS assumption requires the residuals to be normally distributed, implying that the error term *u* has an average value equal to zero and variance equal to σ^2 (Woolridge, 2012). Violations of this assumption indicate that the estimated coefficients are not normally distributed and that there may be a model misspecification. Consequently, correct interpretations of the coefficients become challenging. We have generated Kernel Density Estimates for our models to investigate whether they satisfy the normality assumption. Based on these results, we have log transformed some of the control variables to improve the validity of the models. Additionally, we have removed outlier observations. Our findings suggest that the residuals are still not perfectly normally distributed, but that the deviations are likely to have limited practical effect on the analyses (Woolridge, 2012).

Figure 77: Residuals plot for normality

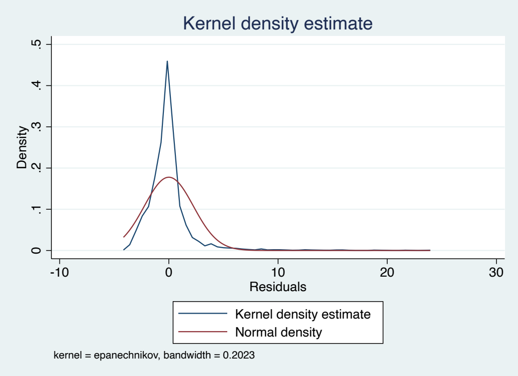
Green Ratio:

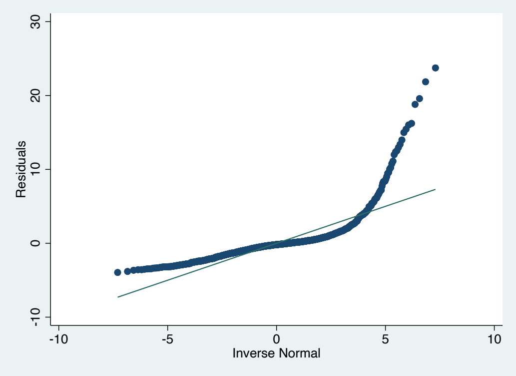


Energy and CCS Ratio:



Average citations:





Autocorrelation

Autocorrelation refers to the occurrence of correlation between the residuals over time, implying that the variance at time *t* partly can be explained by the variance at the previous period, *t-1* (Fabozzi, Focardi, Rachev & Arshanapalli, 2014). The existence of autocorrelation reduces the accuracy of the estimates, can lead to skewed standard errors, and may result in incorrect interpretations. One can perform a Woolridge test to discover the presence of autocorrelation, which is especially suitable for panel data (Woolridge, 2012). The test results, as presented in table 19, suggest that we do not have an autocorrelation problem, as we cannot reject the null hypothesis.

Table 19: Wooldridge test for autocorrelation

H0: no first order autocorrelation

Models	P-value
Green Ratio	0.5707
Green Ratio (green only)	0.1052
Energy & CCS Green Ratio	0.9230
Citations	0.2441