NOVA IMS Information Management School

MGI

Mestrado em Gestão de Informação
Master Program in Information Management

Patents in the energy sector

The connection between innovation and stock volatility in the context of Europe's largest utilities.

Student: Lars Frobel (m20200070)

Supervisor: Bruno Miguel Pinto Damásio, PhD.
Co-Supervisor: Sandro Miguel Ferreira Mendoça, PhD.

Master Thesis presented as partial requirement for obtaining the Master's degree in Information Management with specialization in Knowledge Management and Business Intelligence

NOVA Information Management School
Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa

BOOK SPINE

2022

Title: Patents in the energy sector

Subtitle: The connection between innovation and stock volatility in the context of Europe's largest utilities.

Student

Lars Frobel

MGI

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PATENTS IN THE ENERGY SECTOR

by

Lars Frobel

Dissertation presented as partial requirement for obtaining the Master's degree in Information Management, with a specialization in Knowledge Management and Business Intelligence

Advisor: Bruno Miguel Pinto Damásio, PhD.
Co Advisor*:* Sandro Miguel Ferreira Mendonça, PhD.

June 2022

ABSTRACT

The pressure on European energy Utilities to move their business activities in a more sustainable direction increased in the recent years. In order to measure innovation, factors such as research and development expenditures have often been used in the past. This study attempts to understand the corporate innovation process using patents. For this purpose, a comprehensive analysis of patenting dynamics of a selected group of companies is carried out and then the influence on the volatility of the associated stocks is estimated using a GARCH model. In this context, the impact of green patents on market capitalization will be examined in more detail. We find that the number of published patents has risen very sharply for the period 2000-2020 and that a large proportion of these patents can be classified as green patents. This suggests that Europe's energy Utilities are working on inventions to make their business models more sustainable. To answer the second part of this research, a GARCH model was used to measure the volatility and ultimately the impact of different patents on this. In some cases, significant results were found, but they were not sufficiently meaningful to draw a general conclusion for the entire industry. The insights are nonetheless suggestive and further research could look at the influence of positive and negative patents on volatility by using an EGARCH model.

KEYWORDS

Patent analysis, IPC Green Inventory, Utilities, GARCH

INDEX

1. Introduction 1
   1.1. Problem identification 1
      1.1.1. Background 1
      1.1.2. Research Questions 2
   1.2. Study objectives and relevance 2
   1.3. Structure of the Thesis 3
2. Literature Review 5
   2.1. The European Union Energy System 5
      2.1.1. Power Units 5
      2.1.2. Electric Power Grid 5
      2.1.3. Energy Trilemma 7
   2.2. Technological Change of Energy Utilities 8
      2.2.1. Innovativeness of the energy industry 8
      2.2.2. Digital Transformation 9
      2.2.3. Force to sustainable energy inventions 10
   2.3. Patent Analysis 10
      2.3.1. Patent as a measure of innovation strength 10
      2.3.2. International Patent Classification and Patent Families 11
      2.3.3. WIPO IPC Green Inventory 13
   2.4. Volatility Measurement 14
      2.4.1. Python as a user language for financial modeling 14
      2.4.2. Impact of patents on Volatility 14
      2.4.3. GARCH Modeling 15
      2.4.4. Exogenous variable in the mean equation 15
3. Patent Analysis of the largest energy Utilities in europe 17
   3.1. Technometric approach 17
   3.2. Research sample 17
   3.3. Data Collection and Preprocessing 18
      3.3.1. Data collection 18
      3.3.2. Exploratory Data Analysis 19
   3.4. Volatility Modeling 26
      3.4.1. GARCH Model 26
      3.4.2. GARCH with exogenous Variables 28
4. Results and Discussion 29

5. Conclusions 32
6. Limitations and recommendations for future works.....33
Bibliography.....34
Appendix 38

LIST OF FIGURES

Figure 1 – Electric Power system 6
Figure 2 – Energy Trilemma 7
Figure 3 – Hierarchy of IPC Codes 12
Figure 4 – Enel – Patents Timeline and per Section 20
Figure 5 – National Grid - Patents Timeline and per Section 21
Figure 6 – E.On - Patents Timeline and per Section 21
Figure 7 – Engie - Patents Timeline and per Section 22
Figure 8 – RWE - Patents Timeline and per Section 23
Figure 9 – Fortum - Patents Timeline and per Section 23
Figure 10 – Veolia - Patents Timeline and per Section 24
Figure 11 – EnBW - Patents Timeline and per Section 25
Figure 12 – Peer Group Returns and conditional Variances from 2000 to 2020 27

LIST OF TABLES

Table 1 – Characteristics of the most common energy-generation technologies 6
Table 2 – IPC Main Class Classification 11
Table 3 – IPC Subcategory Example 12
Table 4 – Energy Innovations covered by IPC Green Inventory 13
Table 5 – Energy suppliers sorted by market capitalization as of Jan, 3 2022 18
Table 6 – Data extraction queries for Patentscope 19
Table 7 – Peer Group overview 19
Table 8 – Share of green patents per Company 25
Table 9 – Parameters of the simple GARCH Model per Company 26
Table 10 – GARCH models per company 28
Table 11 – Patent activities including green Patents 29
Table 12 – P-values for number of patents in mean equation 30
Table 13 – P-values for dummy variables in the mean equation 30

LIST OF ABBREVIATIONS AND ACRONYMS

DSO	Distribution System Operator
EPO	European Patent Office
EU	European Union
ICT	Information and Communication Technologies
IPC	International Patent Classification
R&D	Research and Development
TSO	Transmission System Operator
WEC	World Energy Council
WIPO	World Intellectual Property Organization

1. INTRODUCTION

1.1. PROBLEM IDENTIFICATION

The purpose of this chapter is to provide the reader with an understanding of why the research activities in this area occurred and why it is important to answer the previously defined research questions.

1.1.1. Background

Sustainability is an ever-growing topic, which does not spare Europe's largest energy suppliers. A closer look at this topic quickly reveals energy as a key element for a greener world. A shift of importance from fossil fuels towards renewable sources can be witnessed. Nowadays, the use of renewables is widespread in many countries and is proving to be a good alternative to conventional energy sources like oil and gas (Bogdanov & Breyer, 2016). As the acceptance of green solutions increases, many energy suppliers are now under pressure to develop their portfolio in a sustainable direction (Wüstenhagen et al., 2007). The energy market is dominated by a handful of suppliers who are currently undergoing a major transformation in terms of sustainability.

Renewable energy is one of the keys to a more sustainable world and many energy Utilities are being forced into this. While some Utilities have already positioned their portfolio in this direction, there are also other companies that are currently still mainly focused on conventional energy production. All of these Utilities are incentivized to transform in a greener direction as the number of renewables rapidly increases, or they will lose reputation and major market share (Richter, 2013). There are two main reasons for this: First, the number of solar installations is rising sharply, so that private households suddenly become energy producers, which means that a large part of the total volume could be lost. Second, financial investors are on the rise and have the opportunity to enter the market directly through new technologies without having to invest in the big players (Richter, 2013). The attractiveness of this has risen sharply due to the high returns, which are not related to the financial market.

For Utilities, this change means more than just adapting the existing business model. Completely new business areas must be developed, which concentrate on the sustainability of energy production and transmission. Many of these new business areas require the use of advanced technologies, which first must be refined. In the process of the development, there are two different ways to deal with newly generated technologies. On the one hand a company may decide to keep these inventions secret, on the other hand a company could decide to protect these innovations by patents. If a company decides to protect their invention, it is usually protected by a patent. In the European Union (EU) all these patents are collected and published by the European Patent Office (EPO). However, with the disclosure by the EPO, the inventor secures the right to manufacture the good for a specific period of time as the exclusive manufacturer (Johnstone et al., 2010). To apply for a patent, the invention must be new, involve a non-obvious inventive step, and be commercially applicable (Dernis & Khan, 2004). Ultimately, when a company decides to formally protect its innovations, they make them public and thus accessible to everyone. Patents show which innovations the applicant has worked on and may want to release a related product in the future. It can be concluded that patent data can be used to gain insight into the future of a company and has often been used for this purpose in the past. Since the share of green patents, which can be taken from a classification of the World Intellectual Property Organization (WIPO), is constantly increasing, it will probably also be possible to analyze the innovative strength of companies in terms of green transition. This

approach could open up completely new possibilities for company valuations in the future and is gaining popularity in times when sustainability is becoming increasingly important.

Furthermore, in times of increasing competition, it has become more and more important for companies to monitor the activities of other companies in order to make strategic business decisions (Lee & Lee, 2013). As the green transition is one of the most important milestones for energy Utilities, it is important to measure it reliably and not only based on financial indicators. To further expand these activities of monitoring, it is necessary to develop new techniques of business valuation. The underlying source used for this purpose are patents as they provide the basic framework of data for this study to gain insights into future business activities and the innovative strengths of the European largest energy suppliers.

1.1.2. Research Questions

Predicting the innovative strength of companies based on published patents has been a common approach to evaluating a company for many years. Utilities are currently undergoing major changes and must invest heavily to continue to survive in their current environment. Measuring innovation by research and development (R&D) spending is one measure that can provide insight into the future. However, since it is not sufficient to look only at a company's R&D spending, this study goes beyond R&D spending and focuses on the actual innovation power through patents and its impact on volatility in the market. The main objective of this study is to evaluate the largest Utilities in Europe with the aim of understanding their corporate structure and innovation power. This is completed by analyzing the correlation between the published documents and the conditional volatility of the companies. A scheme applicable to all companies will be developed to identify patent activities. This will ensure better comparability.

To conclude this work, it is necessary to answer a research question. The answer should conclude the research gap previously identified and present new research opportunities. The main objective of this study is to answer the following research questions: 1. What patent activities have utilities undertaken in recent years, and what differences emerge in the patent portfolio structures? 2. Which impact do patent publications have on the returns of the market capitalization of energy Utilities?

1.2. STUDY OBJECTIVES AND RELEVANCE

Patent analysis has become increasingly popular in recent years and is used to identify trends in almost all industries, in addition to expenditures on research and development (Mendonça et al., 2021). The transformation in the energy sector, in terms of new technologies to be developed and those being phased out, is very fast and therefore requires increasingly rapid decision-making on investments in the R&D area (Margolis & Kammen, 1999). To keep up with the pace of things and withstand rapid change, companies should maintain a better understanding of their overall R&D activities. Next to this the analysis of patent data often provides a basis for political decisions and patent-based strategies and should be seen as an important innovation force (Margolis & Kammen, 1999). Some studies have already revealed similarities in patent publications, providing an overview of the entire spectrum. But in the past, patent analysis has only been used to a very limited extent to identify innovation strengths in the energy sector for specific companies (Lee & Lee, 2013). More specifically, there are currently no studies that focus on individual companies in the energy sector and their patent publication activities. Besides the fact, it should be noted that there are also no studies on green patents granted by Utilities. This is due to the fact that the classification of green patents is still in its early stages and has not attracted much attention yet. Therefore, there is a need for another research that deals with the analysis of green publications, focusing on individual companies.

The second part of this study focusses on the impact of patents on the returns of the corresponding stocks. This approach will be used to study the impact of patent publications on the market capitalization. Patent publications have been used in the past as a basis to predict the innovation power of a company, as the number of published patents correlates strongly with R&D expenditures (Griliches, 2007a). These analyses are often simplified and only look at the expenses incurred for patents. Moreover, most studies focus on the correlation between patent publications and market-based financial performance. None of the sources analyzed looks more closely at patents and makes the classification of green and gray technologies while looking at the conditional volatility.

In summary, there are two main steps that make this study unique. The first step is the analysis of patents for previously defined companies. This analysis is intended to provide a better overview of the current R&D activities of the largest Utilities in Europe and the current innovation activities of each company. It should be considered that the publication of green and gray patents serves the basis of this work. In the second part of this paper, the correlation of the companies' publications with the conditional volatility of the market capitalization will be shown. For this purpose, the correlation between the published papers will be considered and analyzed in three different contexts: First, the impact of all published patents. Second, the impact of patents previously identified as green. Third, the impact of specific patent classes. This is followed by a detailed analysis of the results. Here, the focus will be on the comparison between the three patent categories. The whole volatility analysis of this work will be done based on a GARCH (generalized autoregressive conditional heteroskedasticity) model. These models are used to measure volatilities and are mostly applied in the financial world. Volatilities measure the intensity of fluctuations and are good method to analyze the risk appetite of the market. Thus, such a statistical model offers the best prerequisites to measure the impact of publications on volatility.

1.3. STRUCTURE OF THE THESIS

In the following, the structure of this thesis is combined into an overall framework to simplify the interrelationship of the individual topics for the reader. At the beginning, the first chapter explains all backgrounds of this study. The chapter deals with the introduction to the topic and what specific questions it addresses. Hereby it should be brought closer to the reader, how the specific research gab was found and why it is important to close this and/or finally new fields for research purposes result. This leads to explaining the importance and uniqueness of this research to the reader.

The second chapter of this thesis serves as a basis for a better understanding of the following thesis. Important backgrounds in the following topics are explained in more detail with a scientific approach: energy market, patent analysis, sustainability, and volatility modeling. The first part of the second chapter serves the reader to better understand this scientific work. For this purpose, a narrative approach to literature research was chosen. Subsequently, the reader will gain a general understanding of the European energy industry, with this section providing a general overview of the players in the market and their positions. The next part will give a deeper insight into the technological change of the companies. Here, the current processes and innovative power in the context of the energy transition will be discussed. Based on the innovation power, sustainability and green change will be explained to the reader in more detail. To complete the theoretical basis, a deeper insight into the basis of patent analysis is necessary. This includes an explanation of patent analysis in relation to the energy sector, an understanding of patent families and IPC codes, and an insight into green patents. In order to better understand the findings of the patent analysis in relation to the stock returns of the company, a careful selection and explanation of model to measure volatility is required. Finally, the use of the user

language Python for financial modeling is described and the volatility measurement methods used in chapter 3 are analyzed in more detail.

The knowledge of the energy market, patent analysis, and Volatility modeling gained in chapter two will help the reader to better understand the patent analysis approach in the following section. This analysis can be described as a methodological approach, which can also be referred as the methodology of technometrics and will be described in more detail at the beginning of chapter three, as it's not the most common approach. Technometrics can be considered at the same level as bibliometric approaches, which belongs to the field of scientometrics. Another important part is the selection and analysis of the companies to be studied, which are described in more detail including their patent activities. A careful selection is required here, as there are many factors involved in identifying the right companies. The reader is then informed about the data sources, which includes an extensive analysis and preparation of the same. In the following part of the thesis, the previously described GARCH model is applied to the data sets. First, a simple model is used that does not take external factors into account. Subsequently, ten further models are analyzed, which include patents in the model. The main focus here is on the impact that patents have on the GARCH model and thus on volatility. This analysis provides the final results on the relationships between volatility and published patents. The following chapters address the written evaluation of the methods and provide an outlook for the future. Limitations that existed in the methodology and new areas of research that emerged during the process are summarized for the reader in a brief section.

2. LITERATURE REVIEW

2.1. THE EUROPEAN UNION ENERGY SYSTEM

The European energy market is a complex system with many individual actors. In order to get a better understanding of the following chapters, the individual components, the actors and their interrelationship in the European energy market are explained in the following. This should help the reader to understand the business model of energy Utilities and better integrate the patents, analyzed in chapter 3, into the overall context.

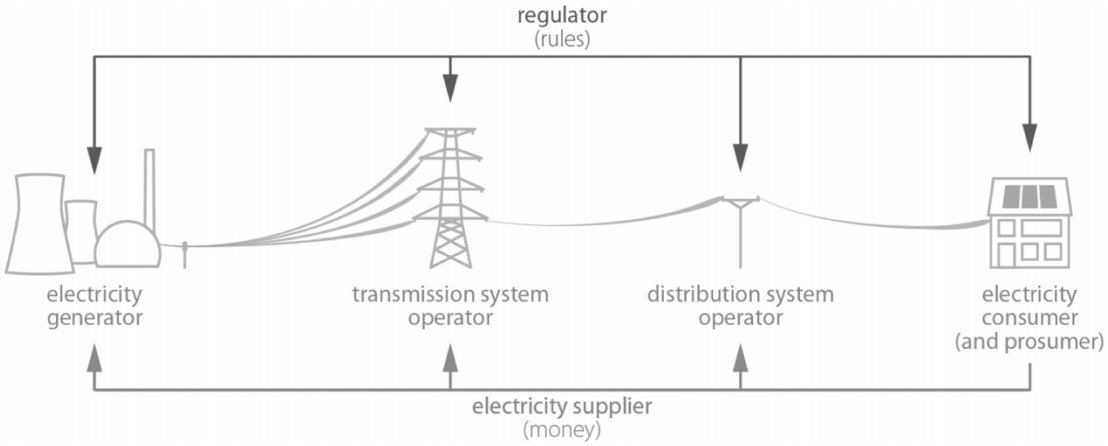
2.1.1. Power Units

To avoid misunderstandings regarding the units of measurement in the following, this chapter explains all common measurement units in the European electricity market. Essentially, there are three important units the reader should understand:
Volt (V) Volt is the voltage that corresponds to the 220V standard in European households. It describes the energy that circulates through an electrical power system and constantly exists between two points in the system (Blume, 2017). The unit of measurement for voltage is the Watt (W). There are three unconventional metrics for voltage, which are explained using a conventional example. During the operation of a modern energy-saving lamp there is a voltage of approximately 5 watts and for a conventional electric boiler approximately 2000 watts (2 kilowatts, kW). Another common used unit is gigawatt (GW), which is equal to one billion watts and occurs in an aluminum smelter (Erbach, 2016). The last unit is not often used in day-to-day life and is only used here for the sake of understanding. As the last important unit of measurement, the reader should understand Watt-hour (Wh), which represents the consumption of energy over a certain period. The unit of measurement should be understood as follows: 1 Wh corresponds to the consumption of 1 W per hour (Erbach, 2016). This means that 4 watts for 15 minutes is equal to 1 W per hour. The most common units for this in day-to-day life are kilowatt-hour for private use and megawatt-hour for the industry.

2.1.2. Electric Power Grid

The following figure provides a general overview of a power system as conventionally defined. Erbach (2016) divides the components in his generalization of the system into four main categories: Generation, Transmission, Distribution, and Consumer. Since the methodology of this study is a general patent analysis of energy utilites, the analyzed companies could be active in only some or all four business areas. Figure 1 shows a relationship between producers on one side and consumers on the other. In between these two groups exists a distribution network. The entire construct is considered by the U.S. National Academy of Engineering to be one of the most significant achievements of the 20th century (US National Academy of Engineering, 2021). The system can only survive due to external influences, which are represented by the two arrows. The gray arrow describes the regulatory influences which are applied to all four players and thus regulate the market. Another instrument for regulating the market is the flow of money, which can be seen in the blue arrow. Electricity producers, TSOs (transmission system operators) and DSOs (distribution system operators) all receive monetary inflows. Where given the end consumer money flows out to finance their electricity needs and all other actors.

Figure 1 – Electric Power system



Source: Erbach (2016, p.3)

The first group covers the production of electricity. Nowadays, there are many different ways to produce electricity and they differ from each other in some aspects (Erbach, 2016). One main attribute divides the production methods into two groups, where it has to be decided whether it is a renewable technology or a conventional technology. Table 1 assists the reader to understand the differences of the most used technologies. Flexibility refers to how flexible the generation of energy can be with the respective technology. The flexibility of renewable energies such as solar or wind is very low, because they are dependent on external factors. In contrast, the production of electricity by natural gas is very flexible, because it can be turned on or off as needed (Erbach, 2016). The group of generators of electricity will play one of the largest roles in the patent analysis, as this is where the industry expects to make the biggest advances with the most impact.

Table 1 – Characteristics of the most common energy-generation technologies

Energy Source	type of fuel	flexibility	CO^2 missions
Coal	fossil	medium	yes
Natural gas	fossil	high	yes
Biomass	renewable	medium	yes; regrowth of biomass compensates emissions
Nuclear	nuclear	low	considered as zero-emission energy source
Hydro with dam	renewable	very low	
Solar	renewable	very low	
Wind	renewable	very low	
Geothermal	renewable	high	

Source: Adapted from Erbach (2016)

By looking again at Figure 1, after electricity generation TSO can be found, which is responsible for the first step of transport. In the EU, these transmission lines are supported by an association of all companies active in the field. In order to better meet the supply and demand, the transmission networks are also used across national borders. The total length in

Europe is about 300,000 km, 95% of which is above ground (Doukas et al., 2011; Erbach, 2016). The reason for this are the costs, which is often 5-10 times higher for underground lines (Doukas et al., 2011).

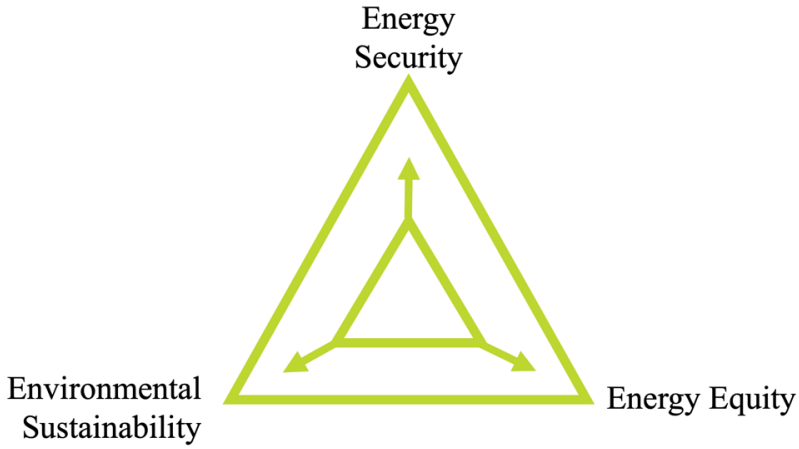
DSOs focus more on the end user than transmission systems and tend to run under the ground in urban locations in Europe (Erbach, 2016; Short, 2003). In suburban areas, Europe often has a mix of underground and overhead electricity lines. Smaller renewable energy sources, which are often installed by the consumer, are not fed into the system until this step of the cycle (Erbach, 2016).

The last actors of the Electric Power System in Europe are the consumers, who purchase electricity from DSOs through contracts with Utilities, which purchase electricity from generators. The billing for the final consumer is done according to the contracts and the amount of electricity consumed, which is determined by an electricity meter. In the case that a final consumer feeds his, for example by solar energy won electricity, into the grid, it can come depending on the region to the fact that the costs and yields are set off (Erbach, 2016; Techert et al., 2012). Since in the last years the number of private feed-in of electricity has risen sharply and this represents a strong demand for renewable energies, the power suppliers are currently under strong pressure. The investments of the power Utilities increase more and more and therefore it requires in the following a literature analysis on the change of European power Utilities.

2.1.3. Energy Trilemma

The Energy Trilemma is a conceptual model that describes a conflict between three energy policy goals: Energy Sustainability, Energy security and Energy equity. This conflict arises because these three axes are correlated and by modifying one axis, it often brings negative changes on another axis. The World Energy Trilemma Index is based on the model and is a tool for measuring the efficiency of energy markets. It has been conducted annually since 2010 by the World Energy Council (WEC) in collaboration with the consulting firm Oliver Wymann and analyzes 128 countries for their performance in the three disciplines (World Energy Council, 2020). The index is considered to be of great importance in times of rapid change towards a greener world. The following Figure 2 illustrates the dilemma for the reader and serves as an aid to understand the construct.

Figure 2 – Energy Trilemma



Source: World Energy Council (2020)

In the optimal case, these three aspects are always in balance in an energy market and show equal characteristics. However, as the development towards a more sustainable world also shifts the other aspects, this is referred to the trilemma.

Energy sustainability
A high degree of sustainability is the main focus of this work. It deals with the influences on climate change and covers all areas from production to transport and consumption.

Energy security
Energy security deals with providing the needed demand for energy at every time. The evaluation is based on the continuity that exists in the respective country. This also includes the continuity in case of unforeseen external events. The infrastructure of power grids plays a major role to achieve a stable energy security.

Energy equity
Energy equity means that energy Utilities should be able to offer their electricity at a stable price and thus provide all customers with the best possible service. Since energy should be a common good and not a luxury good, it is important to maintain a stable supply at a stable price.

This basic concept is important to understand in order to gain insights into the complexities of the market. In the last years the construct has gained increasing popularity and is cited in several sources. The trilemma forces to understand why it is difficult to develop a portfolio in a more sustainable direction and can therefore probably be made responsible for a slow shift towards a more sustainable energy industry.

2.2. TECHNOLOGICAL CHANGE OF ENERGY UTILITIES

As previously mentioned, this chapter will examine in more detail the transformation of Utilities in the recent years. Starting from the innovativeness, over the digital transformation of these corporations to sustainable energy innovations, which are likely to determine the future.

2.2.1. Innovativeness of the energy industry

The innovative power of energy companies is often described in terms of very high investments in new technologies, and nevertheless the greatest profits are still achieved using conventional power generating stations. In order to better understand the approach of energy Utilities, the differences between disruptive and sustaining innovations should be explained.

Disruptive innovations are new technologies or services that displace existing technologies or services from the market and can thus become the dominant strategy. Small companies often act with few resources and still challenge large companies with their innovations (Christensen et al., 2015). Thus, these innovations often pose a great threat to the business models of established companies. To avoid these problems, flexible structures are needed. This ensures that the existing business model can always be adjusted to innovation (Hansen et al., 2009).

Unlike disruptive innovations, sustaining innovations do not aim to displace existing technologies. They are more focused on improving existing models and are therefore often not perceived as innovations but as improvements of existing business models (Richter, 2013).

Energy suppliers generate their revenues mostly with their conventional methods of energy production and not with innovations. This is due to the theory of ambidexterity. This theory says that companies are only successful in a highly competitive environment if they develop new capabilities and at the same time use their core competencies as long as these are the most

profitable (Tushman & O'Reilly, 1996). This is exactly what is happening now with most of Europeans energy Utilities. The theory of innovation and ambidexterity will help the reader understand why the transformation of Utilities from traditional to green technologies is that slow. In addition, the size of the companies can also be seen as a factor influencing this. It often takes a lot of persistence to push innovations in a large corporation until the publication.

2.2.2. Digital Transformation

The digital transformation of Utilities is a process that brings more transparency to a market dominated by a few players and thus can help to create a stable and more cost-effective system (Akberdina & Osmonova, 2021). To achieve this stable and cost-effective market, the cooperation of energy generators, TSOs, DSOs and consumers is needed. This is a result of the fact that digital transformation in the energy sector encompasses many different areas and does not only relate to internal corporate structures or the development of renewable energy sources. In the following, some of the most important areas of digitization of the entire electric power system are described.

A closer look at the production of renewable energies shows that the costs are getting cheaper and more affordable and that these energy sources are becoming more and more important (Madonna et al., 2018).Due to the decreasing costs it is possible for more people to use their own house as a kind of mini power generator, for example by installing solar panels on their property (Dileep, 2020). Since the storage of electricity is currently still very costly, this privately generated electricity is fed back into the power circuit. By including consumers in the network of producers, a new relationship is created that is no longer based on unilateralism. Through the use of new information and communication technologies (ICT), decentralized networks can be created here, which represent an alternative to centralized power generation systems (Akberdina & Osmonova, 2021). This intelligent communication in a network called smart grid is the key element for success of those decentralized networks.

In addition to smart grids, there is another major factor driving digitization projects in the energy sector. When looking at smart grids, it quickly becomes apparent that the storage of energy is not yet considered. According to the current state of research, energy can only be stored in two ways (Erbach, 2016). The oldest method is storage in physical form. For this purpose, water is stored on a mountain, which can be drained as needed and generates the necessary electricity through turbines (Erbach, 2016; Stram, 2016). Another method is the storage in batteries, which is currently still very expensive but not locally bound (Almeida Silva et al., 2015; Erbach, 2016). Many industries are currently investing in the storage of energy and thus driving it forward. The progress in research can also be seen as a major driver for digitization.

One of the last major factors driving the digitization of Utilities is the sharp rise in the volume of data. For example, these are generated by an increasing number of installed sensors and growing interconnectivity. Advanced analytics is used in all areas of electric power systems today (Zayas et al., 2017). Be it to investigate damages of power lines or to regulate an optimal distribution of electricity in a smart grid. In general, the amount of data is increasing rapidly due to the strong rise in networking by use of smart grids. In order to control these smart grids sensibly, these large amounts of data are also necessary and are used for greater efficiency. For all these purposes, the application of advanced analytics is necessary and thus contributes significantly to the digitization of the industry.

In summary, the digitization of this industry is very complex and a key element to a green transition. Modern topics such as data analysis and data science are playing an increasingly important role and are a core element in almost all digitization projects, apart from energy generation and transmission (Akberdina & Osmonova, 2021). Some projects did not focus on

the shift towards a greener industry, but almost all digitization projects have a positive impact on the sustainability of the companies. Thus, it can be concluded that digitization shifts the industry towards a greener and more sustainable industry.

2.2.3. Force to sustainable energy inventions

Looking at the energy sector in Europe as a whole, the pressure on Utilities to make their business models more sustainable is a recurring topic. However, based on the theory of ambidexterity, Utilities are moving very slowly in a more sustainable direction and in some cases are still strongly holding on to their traditional business models. In order not to lose track, but to be able to meet the needs of both end consumers and politicians, enormous innovative power is required in this area. Making the entire industry more sustainable and with a reduced carbon footprint requires not only the development of new technologies on the part of energy providers, but also the development of new markets and a huge shift in thinking on the part of end users (Geels et al., 2017). Nevertheless, for this study, the focus will be on the reinventions of the Utilities, as they play the main role towards a decarbonized world. The following section explains why Utilities are facing these pressures at all and the driving forces behind a shift toward sustainable energy inventions.

Many research papers, dealing with the innovative power of energy suppliers, start their work with Schmookler's (1966) theory, which says that two factors must first be distinguished when considering the reasons for innovative power. On the one hand there are the push factors, which generate innovations from their own driving force, and on the other hand there are pull factors, which are given by the market. The market exerts pressure on companies to develop new inventions. Referring to the theory of ambidexterity already mentioned, it can be assumed that most of the inventions of energy suppliers' better suit to the pull factors.

Some innovations have emerged in the past as a result of the pull factors just described. Political regulations play the largest role among these pull factors. In addition to direct domestic political pressure, there is also a high level of peer pressure within the EU, which can have a direct but also an indirect effect on regulations (Rexhäuser & Löschel, 2015). In addition to the political factors as drivers for inventions, the strongly increasing energy costs should also be mentioned. The impact of this is mainly felt by the end consumers, who exert direct pressure on the energy suppliers or use political instruments to exert this pressure. Other studies have shown that sharply rising costs of conventional energy could also be a driver of innovation (Rexhäuser & Löschel, 2015). One example is the change in the automotive industry. (Aghion et al., 2016) found out that the research activities in and the associated costs increase strongly if the prices for conventional fuel rise.

2.3. PATENT ANALYSIS

2.3.1. Patent as a measure of innovation strength

Measuring the innovative strength of a company is a very complex task and there is no standardized approach. Basically, a distinction is made between two different methods, which differ fundamentally in their approach. In the first method, input factors are used as a measure of how much effort or expenditure is invested in inventions. The most popular example for this are R&D spending. And as a second method for measuring innovative power, output factors can be analyzed in order to draw conclusions about the innovations (Mendonça et al., 2021; Rogers, 1998). For this purpose, published documents such as patents or papers are analyzed after they have been made available to the public. In the past, for an analysis based on output factors, mainly patents were used (Griliches, 2007b; OECD, 2009).

The analysis of patent data has proven to be a reliable method in the past because of the wide availability and transparency in the data (Albino et al., 2014). By collecting patents at a central office, the EPO, the consistency of the data over a long span of time is ensured, and patent data can be viewed over many decades. In addition to consistent accessibility, the correlation to cost-effectiveness should be mentioned here. Studies have shown that increasing R&D expenditures are associated with an increase in the number of patent applications, which indicates a correlation (Albino et al., 2014; Griliches, 2007b). This finding is valid, but on closer examination it can also be used against patents as an instrument for measuring innovative strength.

Since it is very costly to apply for a patent, it can be assumed that the applicant will only apply for the patents in which he hopes to see an economic return in the future. Thus, it can be assumed that only inventions, which are promising success are published and thus again a certain part at innovation strength remains in the secret and never comes to public. In addition to the aspect of economic efficiency, it should also be mentioned that not all inventions are patentable (Archibugi & Planta, 1996). An invention must be liable to various criteria in order to be patentable. If it is not covered by these criteria, it is not possible to protect it with a patent.

However, there are other methods to obtain parts of this inventive power without considering input factors (Mendonça et al., 2019). Besides patents, all kinds of publications can be used for this output-based measurement of innovative power. In the past, it has been shown that patents are the most suitable for this purpose and are thus the most commonly used (Griliches, 2007b; OECD, 2009). Thus, the following will be limited to patents and the structure of patents, and their classifications will be explained in more detail in the next chapter.

2.3.2. International Patent Classification and Patent Families

The IPC (International Patent Classification) is a unified system for classifying patents. It is the largest system of its kind in the world and is used in more than 100 countries (WIPO, 2020). Already more than 110 million patents can be found and analyzed with the help of the system (WIPO, 2020). The IPC system is a user-friendly tool, which is easy to understand and can be applied not only to patents, but also to other technical documents. The unified system was created as early as 1971 and is part of the Strasbourg Agreement on International Patent Classification (BGB l. 1975 II P. 283, 284). Currently, 64 countries are members of the Agreement (WIPO, 1971).

An IPC code always starts with a letter followed by Arabic numerals and a further letter. The length of the code determines the length of the path and thus the number of subcategories. The following table shows the main groups with their technical area.

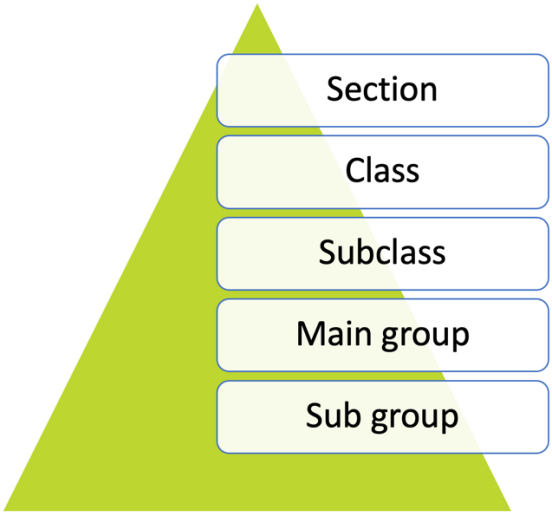
Table 2 – IPC Main Class Classification

IPC - Section	Technical Field
A	Human Necessities
B	Performing Operation, Transporting
C	Chemistry, Metallurgy
D	Textiles, Paper
E	Fixed Constructions
F	Medical Engineering, Lighting, Heating, Weapons, Blasting
G	Physics
H	Electricity

Source: Adapted from WIPO (2020)

The classification always refers to the patent and never to the applicant, thus it is impossible to predict at this stage which classes the patents to be analyzed belong to. After the main section is selected, further subsections are possible, which describes the following figure in more detail.

Figure 3 – Hierarchy of IPC Codes



Source: Montillot (2021)

To understand the exact structure of these codes, the following table will explain the sub-classifications in more detail, with the help of an example: H02J 7/14.

Table 3 – IPC Subcategory Example

Code	Hierarchy	Description
H	Section	Electricity
H02	Class	Generation, Conversion, or Distribution of Electric Power
H02J	Subclass	Circuit Arrangements or Systems for Supplying or Distributing Electric Power; Systems for storing Electric Energy
H02J 7/00	Main group	Circuit arrangements for charging or depolarizing batteries or for supplying loads from batteries
H02J 7/14	Subgroup	… for charging batteries from dynamo-electric generators driven at varying speed, eg. on vehicle

Source: Own work based on WIPO (2021b)

In addition to the classification of individual patents, the concept of patent families frequently occurs while research. Patent families are, as the name implies, a group of patent applications which comprise the same or similar technical content (Materne et al., 2019). The main reason why it is so important to understand patent families is because otherwise very similar or even the same patents can appear several times and thus influence research. With the help of patent families, double counting of patents in research can be avoided (Martínez, 2011). However, since the definition of a patent family is not clearly regulated, it is up to the respective database which criteria it considers.

2.3.3. WIPO IPC Green Inventory

The IPC Green Inventory is a tool that makes it easy for researchers to find patents dealing with green technologies. Based on the United Nations Framework Convention on Climate Change (UNFCCC), this tool was developed by the IPC Committee of Experts and has subsequently gained rapid popularity (León et al., 2018). The tool was published by WIPO in 2010 and includes IPC codes in all sections. This is necessary since green technologies are found in all sections and thus can only be identified by their IPC codes. Patents belonging to this classification are described as green patents in the following.

The following table is intended to give the reader a better understanding of the IPC Green Inventory topics and their subtopics. It shows all necessary fields of interest and focuses on inventories in the energy sector. Therefore, it is only an excerpt from the entire table, which can be found in the appendix. Furthermore, a list of all IPC codes covered by the IPC Green Inventory can be found in the appendix.

Table 4 – Energy Innovations covered by IPC Green Inventory

Energy Innovation Topic	Sub-topics
Alternative Energy Production	Bio-fuels
	Integrated gasification combined cycle (IGCC)
	Fuel cells
	Pyrolysis or gasification of biomass
	Harnessing energy from manmade waste
	Hydro energy
	Ocean thermal energy conversion (OTEC)
	Wind energy
	Solar energy
	Geothermal energy
	Other production or use of heat, not derived from combustion, e.g. natural heat
	Using waste heat
	Devices for producing mechanical power from muscle energy
Transportation	Vehicles in general (e.g. hybrid vehicles, electric propulsion)
	Vehicles other than rail vehicles
	Rail vehicles
	Marine vessel propulsion
	Cosmonautic vehicles using solar energy
Energy conservation	Storage of electrical energy
	Power supply circuitry
	Measurement of thermal energy
	Low energy lightning
	Thermal building isolation, in general
	Recovering mechanical energy
Nuclear power generation	Nuclear engineering (e.g. Fusion reactors, nuclear fission reactors, nuclear power plants)
	Gas turbine power plants using heat source of nuclear origin

Source: León et al. (2018)

2.4. VOLATILITY MEASUREMENT

The aim of this chapter is to explain to the reader the relevance of volatilities using the GARCH model as a sample case. These models for measuring volatilities are referred as conditional heteroskedastic models in the literature. For this purpose, the user language Python is described first and then volatility and GARCH modeling are explained in detail. Finally, the statistical analysis of the work is declared in a short chapter.

2.4.1. Python as a user language for financial modeling

There are two user languages (R and Python), which are mainly used for financial modeling. Where R is limited more to the area of the data analysis also regarding statistic evaluations Python is the more powerful language, which still reaches far beyond the possibilities of R (McKinney, 2013). In addition, Python is a platform independent language, which is usable on nearly all operating systems without having to install software (McKinney, 2013). The user language is built with packages, which are partly preinstalled in the standard library of Python. Beside these standard packages, there are other libraries which can be used from external providers as open-source software. In the following, the packages are described in more detail, which are needed for the evaluation of the patent data and the measurement of the patent publications on the volatility.

Pandas is one of the most widely used libraries for financial modeling because it builds its data in a two-dimensional table with labels for each row and column. These tables are called data frames. Pandas provides many possibilities to modify and analyze the data in the table (Unpingco, 2019). The time series possibilities offered by this two-dimensional table form are ideal for financial analysis (McKinney, 2013). The library matplotlib, which sits on top of python, is perfect for displaying the data graphically.

Another library that should be mentioned here is yfinance. It is an open-source library, which allows you to download all current financial data from Yahoo®Finance via an API (Aroussi, 2021). These downloads contain the most important data for all stocks which are accessible on Yahoo finance and store them in a dataframe which allows an easy processing of the data afterwards.

The next library that is needed for this work is also open source and called arch library. With the help of this library the volatilities of time series can be easily analyzed (Sheppard, 2021). It contains the GARCH model, which allows to calculate several types of autoregressive conditional heteroskedasticity models.

2.4.2. Impact of patents on Volatility

Volatility is a term commonly used in economics, especially in finance. Since the term is not only used in economics, no general definition is available. In finance, the term can be generalized as the variance of returns, which means that volatility is a measure of variance. In this context, high volatility implies higher risk and low volatility implies lower risk. The literature showed that the measurement of volatility has been a popular field of research in the past. Several studies have already shown the relationship between publications and volatility.

One of the most significant studies developed a model in the context of the research, which is called the news impact curve. This curve can be used to measure how information impacts the estimation of volatility (Engle & Ng, 1993).

In 2004, a study by Veldkamp found that a higher number of news can have a positive impact on the volatility of a stock. Another study in this area showed that there are big differences whether the releases were already announced or whether they are ad hoc announcements. This

study showed that unplanned news has a more significant impact on volatility than previously announced releases (Ederington & Lee, 1996).

Besides measuring the influence of news, there is another study by Griliches from 1981 that analyzed 157 US companies and their correlations between market value, research and development expenditures and patents published in a time series. A positive correlation was found between patent activity and the market value of the respective companies (Griliches, 1981).

Measuring market changes based on news has been used in many studies, but there are only a few sources that consider patents as the primary source for this. In the past, most studies have focused on the relationship between news and volatility, using the number of published news as a variable (Donders & Vorst, 1996; Ederington & Lee, 1996; Veldkamp, 2004). Since this approach has proven to be successful, the number of patents per day will be the data basis in this study as well. In addition, a GARCH model has been used in almost all previous studies on the relationship between publications and volatility (Donders & Vorst, 1996). Thus, it can be stated that this research was conducted based on the number of patents published and a GARCH model. The following subsection explains the basics of a GARCH Model. In this context, the model and its components are first described in order to better understand the research later on.

2.4.3. GARCH Modeling

In the past, ARCH models were often used to measure volatilities, but they require many parameters to accurately describe volatility. The GARCH model is a further development of the ARCH model and was developed by Bollerslev (1986) to serve as a measurement of volatility that can be used for financial decision making (Ruslan & Mokhtar, 2021; Tsay, 2005). It is described in the literature as a generalized ARCH model because it is a simplification of it. The variance of the GARCH model is defined as follows:

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j \sigma_{t-j}^2$$

High estimates for α_i indicate high sensitivity of volatility to external shocks, whereas high estimates for β_j indicate resistance to external shocks (Ruslan & Mokhtar, 2021).

The GARCH model finds a wide range of applications, which explains the extensive use of the model in the literature. However, the literature also reports the negative aspect of the model, which is the same response of the model to all kinds of shocks. It is not possible for the model to distinguish between negative and positive shocks (Tsay, 2005).

According to a study, a GARCH model has proven to be one of the most successful models for calculating conditional variance in the past (Engle & Ng, 1993). Due to this and all the other studies, a GARCH model is also applied in this project.

2.4.4. Exogenous variable in the mean equation

Exogenous variables can be included in the mean equation (for explaining mean returns), in the variance equation (for explaining and predicting volatility) or in both equations(Tsay, 2005). If an additional variable is included in the model, it is called a GARCH-X model, where the X stands for the exogenous variable. The following formula describes the mean equation, where r is the return in a specific time.:

$$r_t = \mu + ce_t$$

$$e_t = \sigma_t a_t$$

The parameters μ and c represent unchanging factors (Tsay, 2005).

By taking a closer look at the three different possibilities an exogenous variable can be implemented, different effects can be captured. If the new variable is included in the variance equation, this only influences the variance and thus the fluctuation measure. However, if the variable is included in the mean equation, this has an effect on the returns. Thus, this also has indirect effects on the volatility. Furthermore, the returns reflect the actual change rate and not only the range of volatility.

Furthermore, a study from 2020 found that GARCH models with exogenous variables in the mean equation can make better predictions than general GARCH models (Zha et al., 2020). It was found that these models provide better prediction accuracy and also make fewer errors. This study was focused on a specific problem, but the authors agree that it can be generalized. Since this study also considers only one exogenous variable, it can be considered as a valid basis for this work.

3. PATENT ANALYSIS OF THE LARGEST ENERGY UTILITIES IN EUROPE

3.1. TECHNOMETRIC APPROACH

The methodology chosen for this work belongs to the category of scientometric methodologies, since it deals with the statistical analysis of publications. The most common approach belonging to this methodology is bibliometrics, which deals with the analysis of publications of scientific documents. However, since this study does not deal with publications in the classical sense, not a bibliometric methodology is chosen but the technometrics methodology, which belongs to the same level as bibliometrics underneath scientometrics. Since this approach is not clearly defined, several different definitions of technometrics were used in the past (Coccia, 2005). However, all approaches have in common that they deal with the statistical analysis of technical publications, which include patents. Furthermore, it should be noted that this approach can be used to measure the technical performance of innovations (Sahal, 1985).

To answer the research questions of this thesis with the help of the technometrics approach, first of all an extensive literature research was conducted, which summarizes the current state of research and explains to the reader the most important basic concepts in the context of this the energy market. As a further step regarding the quantitative research, the companies to be analyzed were identified. This was necessary because unfortunately not all companies are suitable for this analysis. The identified companies were compared to previously published literature to ensure comparability with these studies. Subsequently, the patent publications of the previously identified companies were taken from a database and the associated financial data was extracted from another database using an Application Programming Interface.

Once the data for this study has been collected, an initial analysis of the data is required. An exploratory data analysis was conducted to answer the first part of the research question. For this purpose, many charts are used, which should give the reader a better understanding. Next, the research goes deeper into the topic of financial mathematical models. A GARCH model which does not include patents was applied to all data sets. Subsequently, a model was applied which included all patents in the mean equation of the GARCH model. The same procedure was repeated for each of the eight patent sections and then another model was analyzed which included only green patents. Since this procedure was repeated for all eight companies, a total of 88 GARCH models were calculated. Subsequently, the p-values were compared to draw conclusions on the significance of the variables and to answer the second part of the research question.

The quality criteria of this research have been strictly observed, as all data sets have been checked for correctness in advance and the research has been carried out several times to avoid refraction errors.

3.2. RESEARCH SAMPLE

This study focuses on individual energy Utilities in the European Union (EU). Since the expected outcome of this research are correlations between patents and the market capitalization of the major energy Utilities in Europe, only publicly tradable companies are included. Therefore, an extensive pre-selection of energy suppliers considered as traditional energy suppliers and based in Europe is necessary.

The sample created for this research is an extraction of the largest European Utilities and is mainly based on two investment indices, as all those companies are tradable. For this purpose, the most important indices, in this field, MSCI European Utilities and the STOXX Europe 600

Utilities were analyzed, and their top 10 positions were identified (MSCI, 2021; STOXX, 2021). Since the data situation is very difficult, a further selection is required. This means that the selected company must have published at least 100 patent families in the specified period. Six companies could be clearly identified. To remain valid, the sources to be analyzed were compared with the study of Pereira et. al. (2022) and two further companies were included. The following table shows all eight identified companies including their market capitalization and the number of patents published between 2000 to 2020. In the following, the selected companies are described as a peer group.

Table 5 – Energy suppliers sorted by market capitalization as of Jan, 3 2022

Company/ Country	Market Cap in B€	Traditional Patents	Green Patents	Total Patent Documents
Enel (Italia)	73.104	366	145	511
National Grid (Great Britain)	52.086	87	43	130
E.On (Germany)	36.295	976	130	1106
Engie (France)	32.019	281	86	367
RWE (Germany)	24.256	519	575	1094
Fortum (Finland)	23.726	204	209	413
Veolia (France)	22.393	647	1513	2160
EnBW (Germany)	20.477	92	119	211

Source: Own work based on WIPO (2021a) & Yahoo (2021)

3.3. Data Collection and Preprocessing

3.3.1. Data collection

Once the peer group has been defined by selecting the energy Utilities, it is necessary to look deeper into the data sources used for this study. It is important to select the right patents and take a trusted source. The data set on which this study is based comes from the WIPO, which compiles and manages all published patents from PAPSTAT, which is one of the main databases for patents regulated by the EPO. WIPO Patentscope is one of the largest databases for patents with more than 4.2 million published international patent applications. It was decided to work based on this database, as the Green Inventory IPC classification is also published by WIPO. The WIPO IPC Green Inventory is also the second data source for this study, as it contains the classification for green patents. The complete list with all IPC codes can be found in the appendix. In addition, it was necessary to include a third source in the evaluation, which forms the basis for the financial ratios. For this purpose, it was decided to use the Yahoo finance data interface for Python, since this source is always up to date and offers a suitable interface for Python.

To limit the study, it was decided to analyze a time window of 20 years in more detail. Here, the time window from 2000 to 2020 was chosen and added to all extraction queries. The following table shows one query for each utility in the peer group, where each query extracts the specific data for each company.

Table 6 – Data extraction queries for Patentscope

Company	Query	Total number of results
Enel	PA:(ENEL) AND DP:([01.01.2000 TO 31.12.2020])	511
National Grid	PA:(NATIONAL GRID) AND DP:([01.01.2000 TO 31.12.2020])	130
E.On	PA:(EON) AND DP:([01.01.2000 TO 31.12.2020])	197
Engie	PA:(ENGIE) AND DP:([01.01.2000 TO 31.12.2020])	367
RWE	PA:(RWE) AND DP:([01.01.2000 TO 31.12.2020])	1094
Fortum	PA:(FORTUM) AND DP:([01.01.2000 TO 31.12.2020])	413
Veolia	PA:(VEOLIA) AND DP:([01.01.2000 TO 31.12.2020])	2160
EnBw	PA:(ENBW) AND DP:([01.01.2000 TO 31.12.2020])	211

Source: Own work based on WIPO (2021a)

Renaming and subsidiaries of Companies are included for the majority, as these have already been covered by Patentscope. Furthermore, it was decided to include all patent publications and not to use only one document per patent family. This was decided because patent families, as previously explained, are handled differently by each platform and therefore it is not obvious which publication of the family will have an impact on the volatility.

3.3.2. Exploratory Data Analysis

This data exploration is intended to provide the reader a better understanding of the individual companies by explaining the most important key figures relating to their patent activities using illustrations. For the sake of simplicity, the classification of green IPC codes by maingroup and subgroup has been omitted and only the Section, Class and Subclass sections have been included in the analysis. The following table is intended to give the reader a general overview of the research sample. In the following sections, each company will be described in detail.

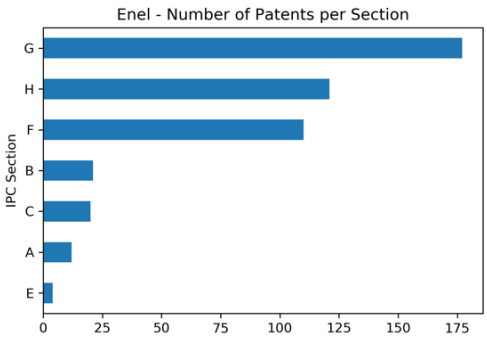
Table 7 – Peer Group overview

	Enel	National Grid	E.On	Engie	RWE	Fortum	Veolia	EnBW
Headquarter	Rome - Italy	London - U.K.	Essen - Germany	Courbevoie - France	Essen - Germany	Espoo - Finland	Aubervilliers - France	Karlsruhe - Germany
Revenue 2020 in B€	62.3	14.5	60.9	55.7	13.7	49.0	26.0	19.6
Employees	66279	23683	63227	154264	18246	18470	179718	24519
Mkt Cap.	73.104	52.086	36.295	32.019	24.256	23.726	22.393	20.477

Own work based on: (Yahoo, 2021)

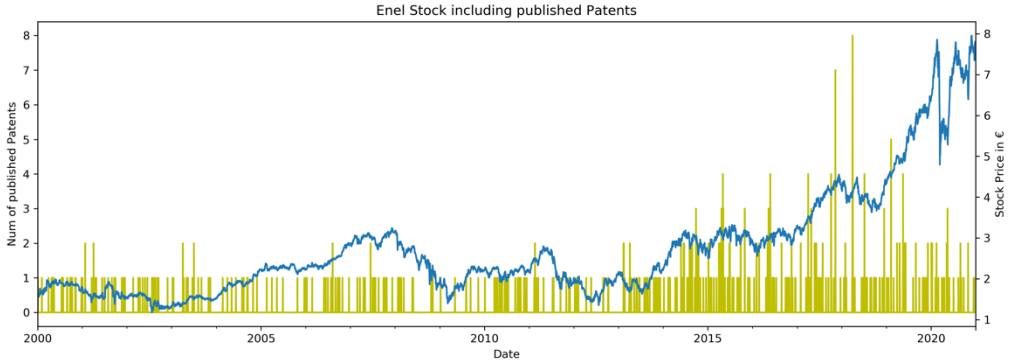
3.3.2.1. Enel

The company Enel is headquartered in Rome and is Europe's largest energy supplier with a market capitalization of 70,104 B€.



In addition, Enel is also one of the world's largest companies in the whole electric industry. The operational business of the company is, in addition to electricity generation, the gas supply. Since these areas are very technical, Enel has been very active in patent publications in the recent past. The following graph shows the share price and the patent publications in the period from 2000 to 2020. Here it can be clearly seen that several patents were already published in the past. From around 2015, an increase in patent activity can be seen as well as the sharp rise in the share price. In the following years, up to 8 publications occurred in one day. Furthermore, an analysis has shown that the time from application to publication of patents at Enel is 737 days on average and 549 days on median.

Figure 4 – Enel – Patents Timeline and per Section



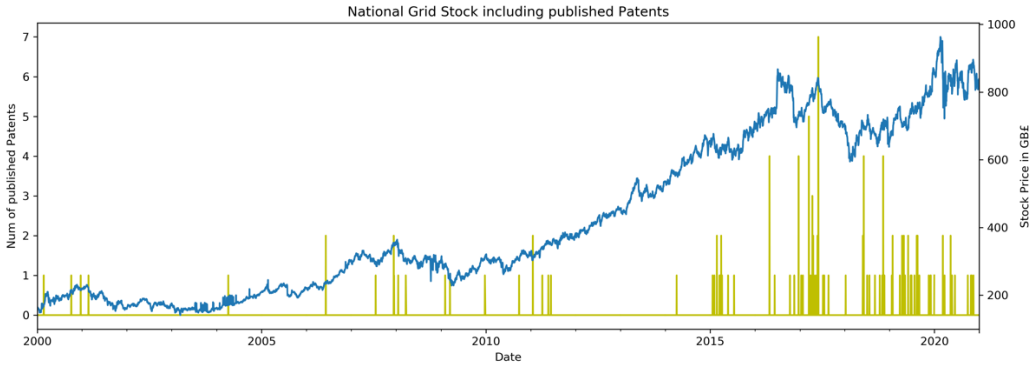
Looking at Figure 4, conclusions can be drawn about Enel's patent activity. Three sections stand out in particular: Physics (G), Electricity (H) and Medical Engineering, Lighting, Heating, Weapons, Blasting (F). Furthermore, the analysis of the patent data has shown that a publication contains on average about 3 IPC codes, of which the first code will be considered as the main code for these publications in the future.

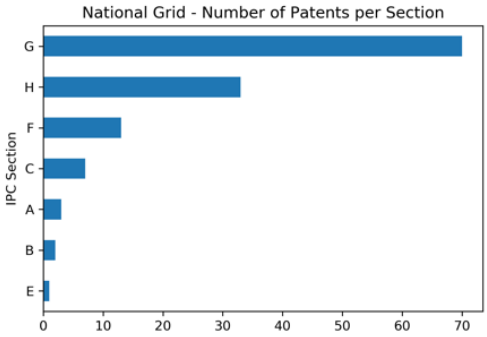
3.3.2.2. National Grid

National Grid is one of the largest energy Utilities in Europe with a market capitalization of 52.086 B€. The company, which has its headquarters in London, is mainly active in the field of electricity transmission grids. The patent activity in the period under analysis is the lowest of all companies in the peer group, with only 120 publications. Nevertheless, it is worth mentioning that National Grid has a very short time span of 247 days on average between application and publication. The median for this is even significantly lower at 181 days.

For the following analysis, it should be taken into account that National Grid is listed on the London Stock Exchange and therefore the share prices for the company are given in GB£. This was deliberately chosen as the trading volume is usually highest on the home stock exchange and therefore a more accurate analysis can be carried out in the following chapter.

Figure 5 – National Grid - Patents Timeline and per Section





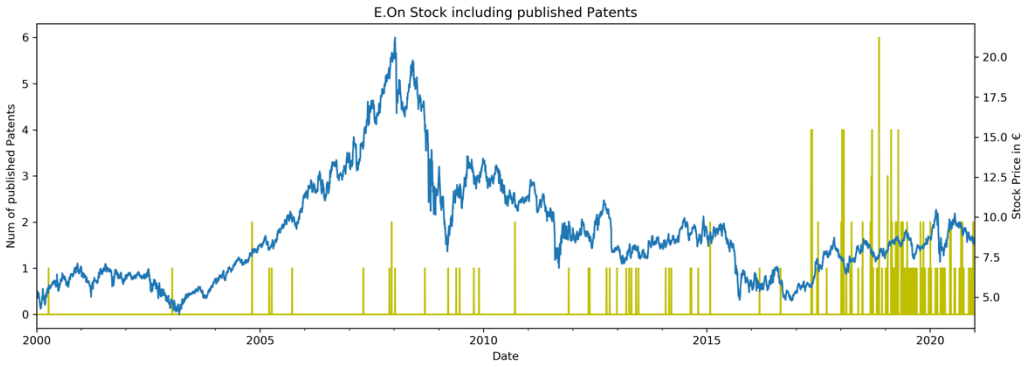
The activity compared to the share price shows that only a few publications were made at the beginning of the 2000s. However, the density increases sharply from 2015 onwards, leading in some cases to up to seven patents being published in a single day.

Looking at the sections, it is easy to see that the Physics (G) and Electricity (H) classes account for the largest share of all published patents.

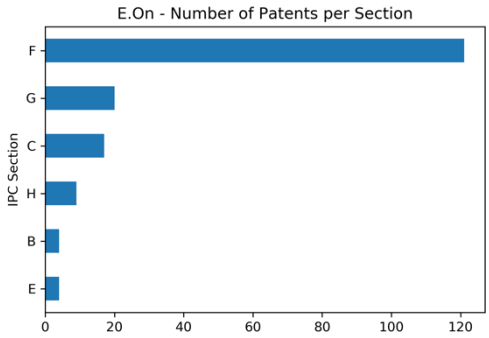
3.3.2.3. E.On

E.On is the largest German energy utility by market capitalization and is active in almost all areas of electricity supply. However, the core business is focused on energy networks and other sufficient services for this area. In addition, E.On has been very active in renewable energies in recent years. Research activities have increased strongly, which is also reflected in the density of patent publications in Figure 06.

Figure 6 – E.On - Patents Timeline and per Section



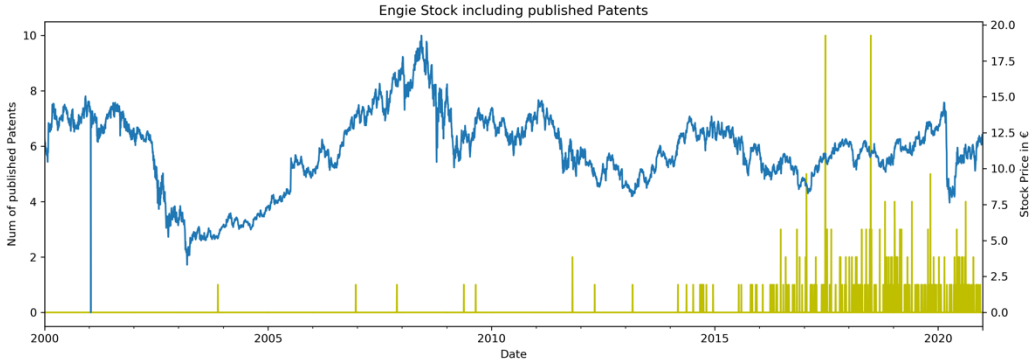
In terms of distribution across different sections, one group stands out clearly. Section F, which deals with Medical Engineering, Lighting, Heating, Weapons, Blasting, has by far the highest number of patent publications. On average, E.On needs only 209 days until a patent is published. Due to some outliers, this is distorted to a median value of 498 days.



3.3.2.4. Engie

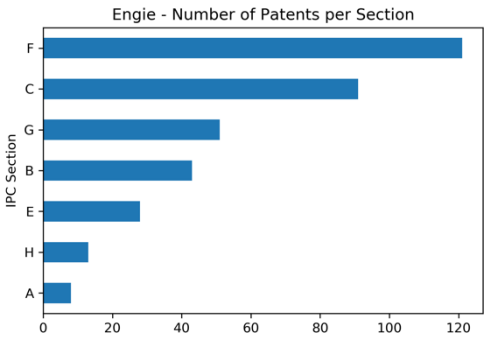
Engie is an energy supply company based in Paris and was formed by the merger of Gaz de France and Suez. Only in 2015, the group was renamed from GDF Suez to Engie. This restructuring was followed by a flurry of patent publications. However, the number of patents has increased sharply in recent years. With an average time from filing to publication of 605 days and a median of 555 days, the company is in the middle of the peer group.

Figure 7 – Engie - Patents Timeline and per Section



Before 2015, Engie shows a very low patent activity and has only a few publications.Two days can be highlighted in the figure, where up to 10 patents have been published that days.

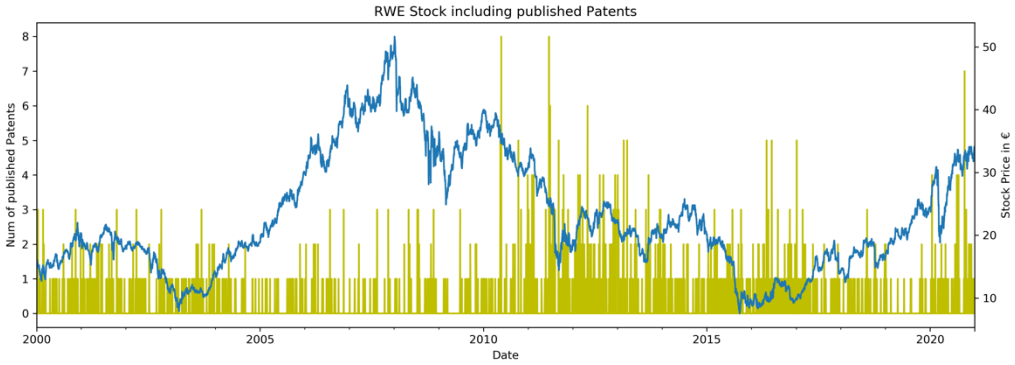
Engie has shown a very high patent activity in recent years, which is dominated by two sections. Groups F (Medical Engineering, Lighting, Heating, Weapons, Blasting) and C (Chemistry, Metallurgy) are clearly dominant with more than 80 publications each.



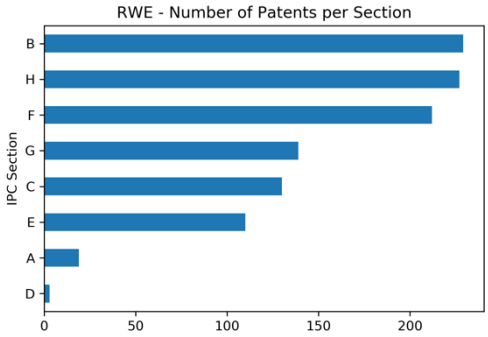
3.3.2.5. RWE

RWE is another energy supplier with its headquarters in Germany. However, the company is not only active in Germany but also in many other European countries. With more than 1000 patent publications, RWE is one of the companies with a very strong activity in this area. As can be seen from the graph below, this activity is constant throughout the years. In the second half of the time series, a slightly higher density can be seen and, in some cases, up to 8 publications in one day have been possible.

Figure 8 – RWE - Patents Timeline and per Section



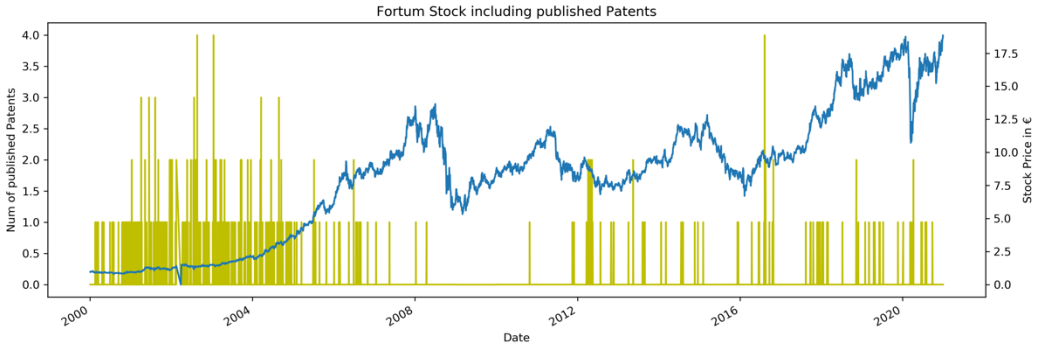
On average, RWE took 600 days (median: 549) to bring a patent from application to publication. Three groups strongly dominated with more than 200 publications each. The groups Performing Operation, Transporting (B), Electricity (H) and Medical Engineering, Lighting, Heating, Weapons, Blasting (F) are by far the most published sectors of RWE.



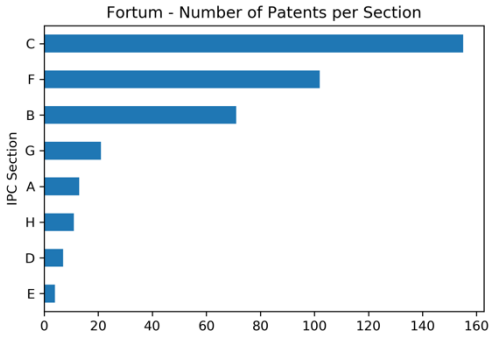
3.3.2.6. Fortum

Fortum is the largest energy supplier in the northern countries of the EU, with a market capitalization of 23,726 B€. The main business of the group is the generation of electricity. In the past, Fortum has always been able to increase its share price, while the activity of patent publications has decreased. In the early 2000s, the activity was much higher than in the following years. Nevertheless, Fortum has continued to publish a small number of patents over the time.

Figure 9 – Fortum - Patents Timeline and per Section



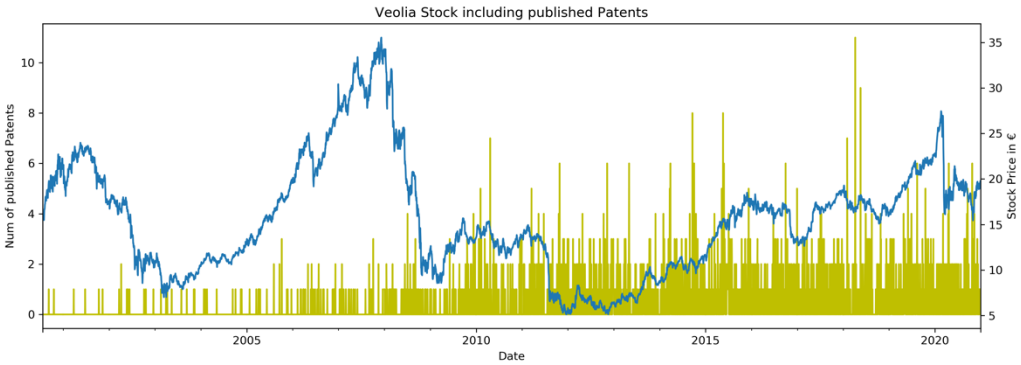
In terms of the duration between registration and publication, Fortum is rather slow with an average of 767 days. However, this is justified by some outliers, as the median for this is 550 days. In its patent applications, Fortum was active in all 8 sections, whereby the group Chemistry, Metallurgy (C) is strongly dominant with more than 150 patent applications.



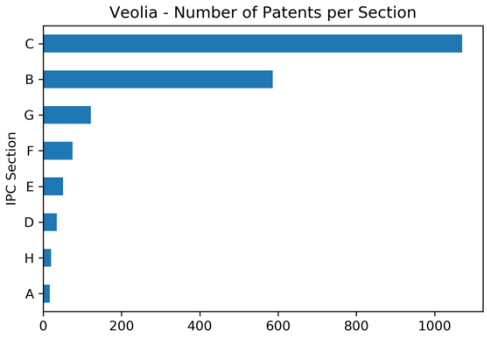
3.3.2.7. Veolia

Veolia is the second largest French company by market capitalization (22.393 B€) in the peer group. It is headquartered in Paris and, in addition to energy supply, is also involved in water and waste disposal. Figure 10 quickly shows that Veolia has a very high volume of patent publications over the whole period. However, the patenting activity has increased in the second half of the time series.

Figure 10 – Veolia - Patents Timeline and per Section



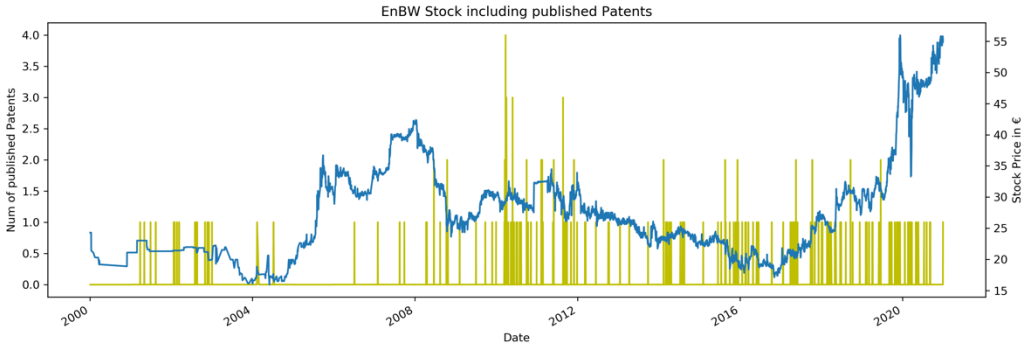
Veolia is by far the company with the highest patenting activity. They published 2160 patents between 2000 and 2020. On average it took 659 days to publish a patent, which is slightly above the peer groups average. Among the 2160 published patents, there were two sections that clearly stand out. Chemistry, Metallurgy (C) and Performing Operation, Transporting (B) are the leading groups here, with C counting almost twice as many patents as section B.



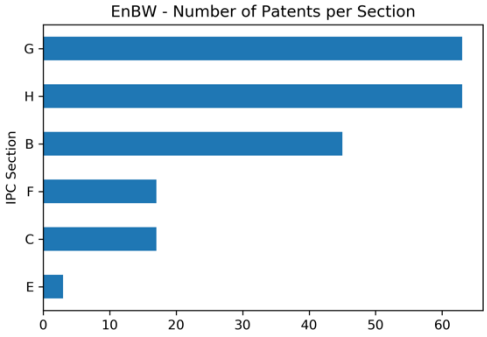
3.3.2.8. EnBW

EnBW is the smallest energy supplier of the peer group with a market capitalization of 20.477B€ and is also based in Germany. In total, EnBW has published 211 patents in the period. The distribution is very balanced over the years, with a slight increase in the last years. In addition, EnBW has shown a strongly increasing share price with higher volatility in the last few years.

Figure 11 – EnBW - Patents Timeline and per Section



A closer look at the distribution of patent publications shows that EnBW has published many patents in three specific sectors. The Physics (G) and Electricity (H) sectors are particularly prominent, as more than 60 documents have been published in these areas. But also the area Performing Operation, Transporting (B) plays a major role with more than 40 patents.



In summary, this analysis provides a brief insight into the patent activities of the individual companies in the peer group. The overall picture is that the number of publications is higher in the second half of the analyzed period than in the first half. Furthermore, it is easy to see that each company has certain patent classes in which it shows a particularly high level of activity. However, since in addition to the individual patent classes, the green patents are also of importance for this study, the following table provides information on the number of green patents according to IPC Green Inventory.

Table 8 – Share of green patents per Company

Company	Share of green Patents
Enel (Italia)	28.38%
National Grid (GB)	33.07%
E.On (Germany)	11.75%
Engie (France)	23.43%
RWE (Germany)	52.55%
Fortum (Finland)	50.60%
Veolia (France)	70.04%
EnBW (Germany)	56.39%

3.4. VOLATILITY MODELING

3.4.1. GARCH Model

To answer the second part of the research question, the calculation of the GARCH(1,1) model described in chapter 2.4.3. is now required. First, the closing prices of stocks for the period from 2000 to 2020 were collected for this purpose. Due to the fact that for all stock prices opening, low, high and closing prices are available, it is necessary to restrict the calculation to one of these parameters. Since the minima and maxima are mostly far above or below the daily average, these prices are not suitable for volatility analysis (Tsay, 2005). As the closing prices were assumed in most of the literature on volatility analysis, they also serve as the data basis for this analysis.

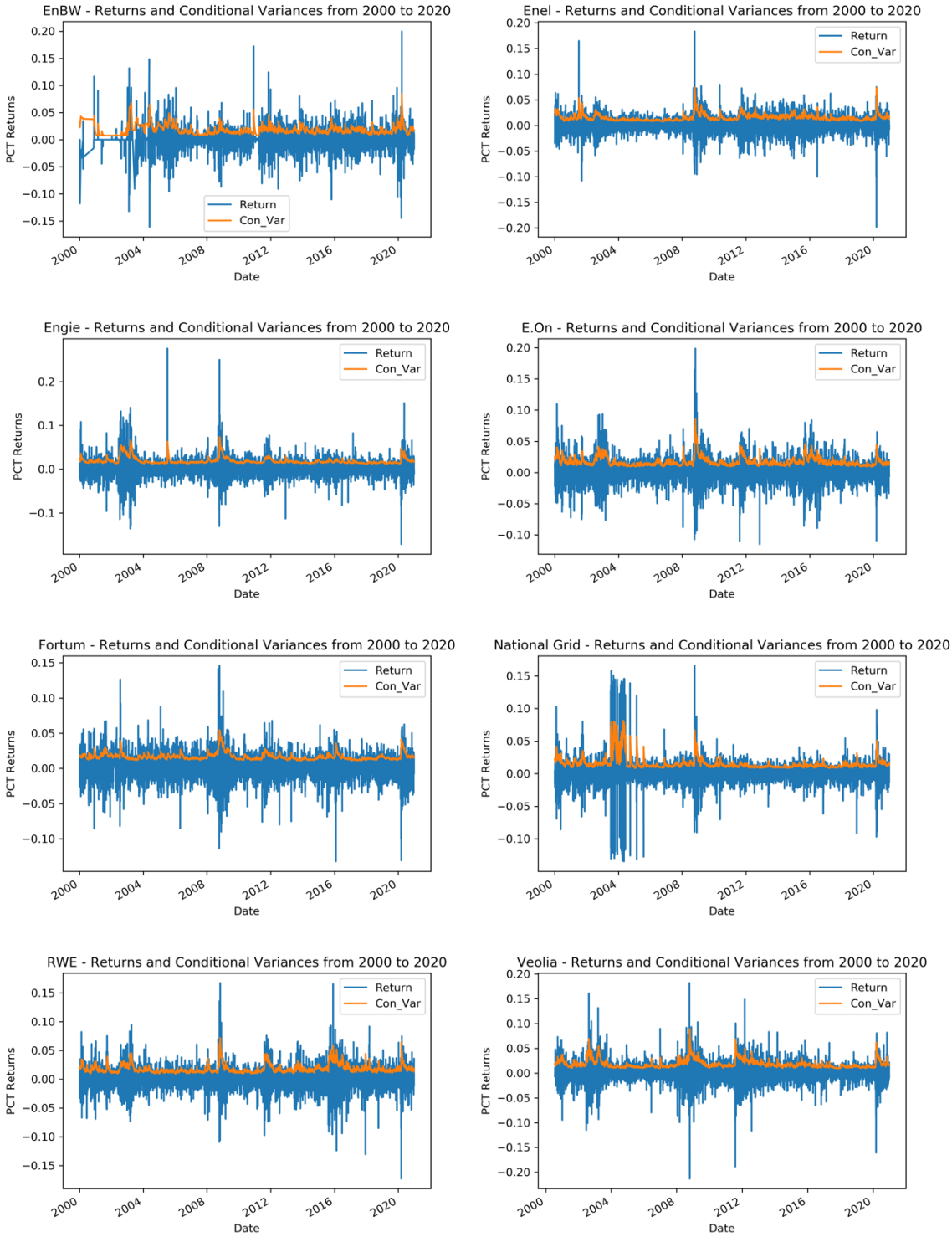
To calculate the simple GARCH model, the returns of the respective closing prices were calculated first. Then, based on the returns, the corresponding conditional variances were calculated using the GARCH(1,1) model. The parameters estimated using the maximum likelihood method are summarized in Table 7. These parameters together with the previously calculated returns form the basis for calculating the corresponding conditional variances by using a GARCH.

Table 9 – Parameters of the simple GARCH Model per Company

Company	Omega		Alpha		Beta	
	coef	std err	coef	std err	coef	std err
Enel	5.5477e-6	2.158e-11	0.1000	1.117e-2	0.8800	9.598e-3
National Grid	6.8757e-6	3.899e-12	0.1000	2.741e-2	0.8800	2.360e-2
E.On	6.9895e-6	1.031e-12	0.1000	1.329e-2	0.8800	1.094e-2
Engie	8.5731e-6	1.823e-11	0.0498	5.334e-3	0.9264	6.059e-3
RWE	7.6908e-6	8.685e-11	0.1000	1.236e-2	0.8800	1.044e-2
Fortum	6.1596e-6	9.291e-12	0.0500	7.236e-3	0.9300	5.952e-3
Veolia	8.1206e-6	2.528e-10	0.1000	1.438e-2	0.8800	1.186e-2
EnBw	6.8075e-6	7.148e-12	0.1000	2.860e-2	0.8800	2.651e-2

Since the alpha and beta coefficients add up to almost 100% in all cases, it can be conducted that ARCH-GARCH effects are existing (Sidorov et al., 2014). The following figures on page 27 show the returns and the associated conditional variances, which were calculated using the GARCH(1,1) model. In all charts, conspicuous events are visible at three key positions. The dotcom bubble at the beginning of the 2000s, the financial crisis in 2008 and the Corona Crash in 2020 are reflected in strong spikes of the returns. The return time series shows very strong fluctuations for these three events.

Figure 12 – Peer Group Returns and conditional Variances from 2000 to 2020



3.4.2. GARCH with exogenous Variables

After the calculation of a simple GARCH(1,1) model for each company, a closer look at the relationship between patents and returns is needed. To determine whether patents have a significant impact on volatility, they must be included in the GARCH model. For this study, it was decided to implement the exogenous variables in the mean equation of the GARCH model and measure their impact. Including the variable in the mean equation was done for the sake of simplicity, since the inclusion in the mean equation reflects the actual changes in the returns and this function is included in the arch library for Python.

In order to draw finally more exact conclusions between different patents, 10 different models were defined. For this first all patents were included into the mean equation. In the further procedure only the patents of a specific section were considered and finally only green patents of a company. The approach of looking at individual patent sections was chosen to ultimately find out if there are differences between the individual patent sections. It should be noted that the number of published patents is implemented as an exogenous variable. The following table summarizes all models performed in this thesis:

Table 10 – GARCH models per company

Name	Exogenous Variable in Mean Equation
GARCH	GARCH
GARCH_pat	GARCH + all patents
GARCH_A	GARCH + patents section A
GARCH_B	GARCH + patents section B
GARCH_C	GARCH + patents section C
GARCH_D	GARCH + patents section D
GARCH_E	GARCH + patents section E
GARCH_F	GARCH + patents section F
GARCH_G	GARCH + patents section G
GARCH_H	GARCH + patents section H
GARCH_green	GARCH + green patents

In order to establish comparability, whether there are significant differences between the number of published patents, it was decided in the further procedure to change the exogenous variable. For this procedure, the exogenous variable was transformed into a binary dummy variable. This procedure helps to remove complexity from the model and ultimately to find out whether differences exist if a company has published many patents on one day or not.

In the following section, all these results are summarized in tabular form. First, a verbal analysis will determine the general patent activities of the peer group and finally the quantitative analysis will provide information on the impact of patent publications on the returns and thus the volatility.

4. RESULTS AND DISCUSSION

The first part of this thesis deals with the general patent activity of energy Utilities in Europe. It is intended to give the reader an insight into the patent activities of this industry over a period of the last 20 years. The first thing to notice is that the companies of the peer group show big differences in the total number of publications. While Veolia has published more than 2000 patents in the selected period, National Grid shows a much lower activity with 130 publications. Table 8 summarizes the main characteristics of patent activity per company. There are also large differences in the number of green patents according to the IPC Green Inventory, which are summarized in Table 8 below. In general, it can be recognized that the entire industry is taking the change to a more sustainable world into account in its patent activities. Veolia not only has the highest patent activity overall, but also focuses strongly on sustainable new technologies. 70% of its publications belong to the IPC Green Inventory catalog. Given that Veolia's patent activity has increased sharply since 2010 and that they have a very high rate of green patents, it can be assumed that Veolia is pursuing a strategy of adapting its business model to changes in the industry, also with the help of patenting. With the help of these patents, Veolia is trying to drive innovation in its business. This conclusion can be drawn here, as the study by Griliches (1981) has already shown that patent publications can be taken as a measure of innovative strength.

Table 11 – Patent activities including green Patents

Company	Number of Patents	Min	Max	Share of green Patents
Enel (Italia)	511	0	8	28.38%
National Grid (GB)	130	0	7	33.07%
E.On (Germany)	1106	0	6	11.75%
Engie (France)	367	0	10	23.43%
RWE (Germany)	1094	0	8	52.55%
Fortum (Finland)	413	0	4	50.60%
Veolia (France)	2160	0	10	70.04%
EnBW (Germany)	211	0	4	56.39%

A closer look at the patent sections quickly reveals that sections G and H are clearly dominant. Most of the activities can be found in these sections. Since the G and H classes deal with physics and electricity, most of the patent activity takes place in the main business area. The main business field of Utilities deals, as in chapter 2.1 described, with the production and distribution of energy. Although there are always exceptions and activities in other fields at individual Utilities, the focus is generally on electricity and physics.

In summary, the patent activities of the peer group have been much stronger in recent years than in the early 2000s. The patents deal mostly with traditional technologies, but during the period there has been a shift towards green technologies. Approximately 40% of all patents cover green technologies in the area of energy Utilities. Such a high rate of sustainable patents can be considered a success. From this it can be concluded that this share of about 40% deals with the topics hydro, solar, wind and geothermal (Erbach, 2016).

In order to answer the second part of the research question, all models mentioned above were calculated with the help of the arch package. Since the peer group comprises eight companies, a total of 88 model calculations were performed. To evaluate the impact of the patents on the model and thus on the returns, a closer look at the p-values of the exogenous variables is

important. The following table includes all these p-values. If a p-value is smaller than 5%, it represents a significant result.

Table 12 – P-values for number of patents in mean equation

	Enel	National Grid	E.On	Engie	RWE	Fortum	Veolia	EnBW
GARCH_ pat	0.774	0.496	6.760e-2	0.864	0.692	0.155	8.968e-3	0.267
GARCH_A	0.982	3.619e-2	-	0.719	0.699	0.520	4.340e-02	-
GARCH_B	0.234	5.991e-2	0.986	0.671	0.797	0.911	0.212	0.565
GARCH_C	0.154	0.560	0.364	0.505	0.642	0.220	0.381	0.990
GARCH_D	-	-	-	-	0.496	-	0.669	-
GARCH_E	0.964	1.046e-5	0.399	0.339	0.174	0.407	0.125	0.569
GARCH_F	0.896	0.300	0.196	0.420	0.377	0.382	0.368	0.404
GARCH_G	0.617	0.808	0.335	0.563	0.747	0.475	2.207e-2	0.949
GARCH_H	0.718	0.743	0.417	0.747	0.682	9.188e-2	0.582	2.405e-5
GARCH_ green	0.902	0.460	0.257	0.372	0.700	0.374	0.374	1.909e-14

In the further proceeding, it was decided to calculate further models, which do not differ too much in structure from the previously calculated models, but they could bring a big change. In order to remove complexity from the model, the exogenous variable in the mean equation was modeled by a dummy variable in the following. This gives the GARCH model only the information whether a patent was published on that specific day or not. The exact number of publications was not considered for the following models.
Table 11 summarizes all p-values for the model and ultimately serves the purpose of comparison with the previously calculated models.

Table 13 – P-values for dummy variables in the mean equation

	Enel	National Grid	E.On	Engie	RWE	Fortum	Veolia	EnBW
GARCH_ pat	0.672	0.517	0.161	0.529	5.968e-2	0.262	0.779	0.615
GARCH_A	0.982	3.618e-02	-	0.719	0.698	0.612	2.823e-02	-
GARCH_B	0.550	5.988e-02	0.538	0.546	0.586	2.850e-09	0.215	0.552
GARCH_C	0.150	0.362	0.460	0.618	0.822	8.787e-02	0.590	0.518
GARCH_D	-	-	-	-	0.654	-	0.537	-
GARCH_E	0.964	1.100e-5	0.308	7.861e-03	0.327	0.470	0.194	9.261e-02
GARCH_F	0.580	0.303	0.831	0.662	0.494	8.361e-03	0.394	0.761
GARCH_G	0.809	0.713	0.374	0.122	0.560	0.475	3.849e-05	4.658e-29
GARCH_H	0.438	0.937	0.966	0.994	0.832	9.189e-02	0.640	1.053e-09
GARCH_ green	0.591	4.871e-02	0.497	0.199	0.248	3.569e-02	0.649	0.407

A closer look at the p-values quickly reveals that individual values are missing from the calculation. This is due to the fact that the respective company has not published any patents in this category. In order to determine the impact of patents on volatility, a more detailed analysis of these p-values is required. It can be quickly seen that only a few models provide significant

results. When looking at individual companies, it always comes to individual sections that show a significant result, but this can never be projected to the entire peer group. It is noticeable that Veolia and RWE have the highest number of publications and both show significant results for the GARCH_pat model. Looking at the models GARCH_A to GARCH_H, the exogenous variable turns out to be a significant variable in some cases, but not in all cases. With reference to the GARCH_green model, no general conclusions can be drawn for the entire industry, but the green patents at EnBW proved to be a significant variable.

Looking at the p-values for models with dummy variables applied to patents, it can be seen at a glance that there are no significant differences. For Fortum does the dummy variable become a significant exogenous variable in many cases. Also for EnBW, the models with dummy variables seem to provide more significant results than without. In the first case there are a total of eight significant variables and in the second case 14. Thus, it seems that the information about how many patents were published does not have a large impact on the significance of the exogenous variables.

Although some studies in the past have found a significant correlation between published news and volatility, this cannot be generally applied to the publication of patents. The data for studies on the correlation between news releases and volatility are mostly based on larger data sets, since the number of press releases of a company is much higher than the number of patents published. Furthermore, the better performance is due to the fact that standard GARCH models have not performed as well as EGARCH models in the past (Engle & Ng, 1993). EGARCH models are able to divide the exogenous variable into positive and negative effects and thus allow for a more targeted significance. One study also found that negative news has a much larger effect than positive news (Ho et al., 2013). Unfortunately, since it is not possible to divide patents into good and bad patents, this model has no appeal for this problem.

Nevertheless, single significant variables can be identified for individual companies, which means that specific conclusions can be drawn for them. However, these conclusions cannot be transferred to the general public. Further research is needed to draw conclusions about the industry as a whole. Additional ideas on how to tackle this issue are summarized in a short section in chapter 6.

In summary, no consistent significant results can be identified with this model. However, the activities generally include a very high proportion of green patents. In addition, the total number of patent publications has increased more in recent years than at the beginning of the period. As these are often green patents, it can be stated that European energy Utilities take the pressure of politics seriously and try to move their business model into a more sustainable direction with the help of patented innovations.

5. CONCLUSIONS

The study presented here focused on the patent publication activity of the most important energy suppliers in Europe. A major focus was placed on the topic of sustainability, which can be seen as a driver for innovative strength. The aim was first to reflect the general situation in the industry and to conduct a detailed analysis of patent activity. Then the next step was to analyze the influence of patent publications on the volatility of the respective stocks. For this purpose, a narrative literature review approach was used first, followed by a general statistical analysis of the underlying data sets and finally the impact of these publications on volatility was performed using a GARCH model.

From the results, it can be concluded that Utilities have been under enormous political pressure in recent years to make their business model more sustainable. This means that they cannot rest on their achievements from the past, but that innovation power had to be and must continue to be increased. To measure this, patents were used in this research as the data basis for determining innovative strength. This approach has only been used sporadically in the past, but can be classified as a suitable measure for this purpose. In general, it can be stated that the general activity of patent publications has increased more strongly in recent years than in the early 2000s. Where once there was only sporadic patent publication activity, today there are sometimes up to 10 patents published on individual days. The proportion of green patents in the peer group is very high at around 40%. This reflects the innovative power regarding sustainable inventions, which is partly driven by political pressure. Furthermore, it could be determined that the patents of the Utilities relate for the most part to their main business areas and are to be classified in the classes of physics and electricity. This also shows that the patent activity is concerned with moving the business models and the associated core activities in a more sustainable direction.

Looking at the second part of this study, which deals with the impact of these inventions on volatility, some partial successes can be observed. When a patent is published, this usually does not happen in connection with a press release and thus the effect on returns and the associated volatility cannot be determined in general terms. In individual cases, the model shows significant results, but these cannot be generalized to the entire peer group. It was found that the significance is more reliable for companies that have published a high number of patents. Furthermore, it was found that the effects are better captured when complexity is taken out of the model. This means that the information about the number of publications has less significant impact than the general statement that an invention was patented on a specific day.

This research has thus provided a general overview of patent activity in this sector in Europe. From a sustainable perspective, the developments in the period from 2000 to 2020 can be considered positive. Due to the continuing strong political pressure on these corporations, it can be assumed that a high number of patents will continue to be published in the near future. Furthermore, it was found that in individual cases this patent activity has an impact on the fluctuation of the stocks. However, further research is needed to draw a general conclusion on this. Ideas for further research are partly summarized in the following chapter.

6. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORKS

One of the central limitations of this work deals with simplified assumptions, which had to be chosen in order to be able to present a generally valid overview. IPC codes are very complex and have many subcategories. In order to create a consistent and comparable study, it was necessary to take complexity out of these IPC codes and make simplified assumptions. Only in this way was it possible to create standardized groups.

The second major limitation is the arch package in the Python library. With the help of this package, it was only possible to implement the exogenous variable in the mean equation. Implementing the exogenous variable in the volatility equation is not possible in python. If the variable is taken into account in the mean equation, this provides conclusions about the effects on the actual returns, but an implementation in the volatility equation could have provided even more information about the range of fluctuation. This is also the first recommendation for further research in this area.

To further investigate the impact on volatility, a study should be conducted that analyzes the range of volatility and thus implements the exogenous variable into the volatility equation of a GARCH model. Furthermore, it was found in the past that EGACH models show better results. However, since it is necessary to capture positive and negative news, a system that classifies patents into two categories could be developed for a subsequent study.

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APPENDIX

Appendix A: IPC Green Inventory topics and sub-topics in a hierarchical order

Topic	Sub-topics		
Alternative Energy Production	Bio-fuels	Solid fuels	Torrefaction of biomass
		Liquid fuels	Vegetable oils
			Biodiesel
			Bioethanol
		Biogas	
		From genetically engineered organisms	
	Integrated gasification combined cycle (IGCC)		
	Fuel cells	Electrodes	Inert electrodes with catalytic activity
		Non-active parts	
		Within hybrid cells	
	Pyrolysis or gasification of biomass		
	Harnessing energy from manmade waste	Agricultural Waste	Fuel from animal waste and crop residues
			Incinerators for field, garden or wood waste
		Gasification	
		Chemical waste	
		Industrial waste	Using top gas in blast furnaces to power pig-iron production
			Pulp liquors
			Anaerobic digestion of industrial waste
			Industrial wood waste
		Hospital waste	
		Landfill gas	Separation of components
		Municipal waste	
	Hydro energy	Water-power plants	Tide or wave power plants
		Machines or engines for liquids	Using wave or tide energy

Topic	Sub-topics			
		Regulating, controlling or safety means of machines or engines		
		Propulsion of marine vessels using energy derived from water movement		
	Ocean thermal energy conversion (OTEC)			
	Wind energy	Structural association of electric generator with mechanical driving motor		
		Structural aspects of wind turbines		
		Propulsion of vehicles using wind power	Electric propulsion of vehicles using wind power	
		Propulsion of marine vessels by wind-powered motors		
	Solar energy	Photovoltaics (PV)	Devices adapted for the conversion of radiation energy into electrical energy	Using organic materials as the active part
			Assemblies of a plurality of solar cells	
			Silicon; single-crystal growth	
			Regulating to the maximum power available from solar celles	
			Electric lighting devices with, or rechargeagle with, solar cells	
			Charging batteries	
			Dye-sensitised solar cells (DSSC)	
		Use of solar heat	For domestic hot water systems	
			For space heating	
			For swimming pools	
			Solar updraft towers	
			For treatment of water, waste water or sludge	
			Gas turbine power plants using solar heat source	
		Hybrid solar thermal-PV systems		

Topic	Sub-topics		
		Propulsion of vehicles using solar power	Electric propulsion of vehicles using solar power
		Producing mechanical power from solar energy	
		Roof covering aspects of energy collecting devices	
		Steam generation using solar heat	
		Refrigeration or heat pump systems using solar energy	
		Use of solar energy for dying materials or objects	
		Solar concentrators	
		Solar ponds	
	Geothermal energy	Use of geothermal heat	
		Production of mechanical power from geothermal energy	
	Other production or use of heat, not derived from combustion, e.g. natural heat	Heat pumps in central heating systems using heat accumulated in storage masses	
		Heat pumps in other domestic- or space-heating systems	
		Heat pumps in domestic hot-water supply systems	
		Air or water heaters using heat pumps	
		Heat pumps	
	Using waste heat	To produce mechanical energy	
		Of combustion engines	
		Of steam engine plants	
		Of gas-turbine plants	
		As source of energy for refrigeration plants	
		For treatment of water, waste water or sewage	
		Recovery of waste heat in paper	

Topic	Sub-topics		
		production	
		For steam generation by exploitation of the heat content of hot heat carriers	
		Recuperation of heat energy from waste incineration	
		Energy recovery in air conditioning	
		Arrangements for using waste heat from furnaces, kilns, ovens or retorts	
		Regenerative heat-exchange apparatus	
		Of gasification plants	
	Devices for producing mechanical power from muscle energy		
Transportation	Vehicles in general (e.g. hybrid vehicles, electric propulsion)	Hybrid vehicles, e.g. Hybrid Electric Vehicles (HEVs)	Control systems
			Gearings therefor
		Brushless motors	
		Electromagnetic clutches	
		Regenerative braking systems	
		Electric propulsion with power supply from force of nature, e.g. sun, wind	
		Electric propulsion with power supply external to vehicle	With power supply from fuel cells, e.g. for hydrogen vehicles
		Combustion engines operating on gaseous fuels, e.g. hydrogen	
		Power supply from force of nature, e.g. sun, wind	
		Charging stations for electric vehicles	
	Vehicles other than rail vehicles	Drag reduction	
		Human-powered vehicle	
	Rail vehicles	Drag reduction	
	Marine vessel propulsion	Propulsive devices directly acted on by wind	

Topic	Sub-topics		
		Propulsion by wind-powered motors	
		Propulsion using energy derived from water movement	
		Propulsion by muscle power	
		Propulsion derived from nuclear energy	
	Cosmonautic vehicles using solar energy		
Energy conservation	Storage of electrical energy		
	Power supply circuitry	With power saving modes	
	Measurement of electricity consumption		
	Storage of thermal energy		
	Low energy lighting	Electroluminescent light sources (e.g. LEDs, OLEDs, PLEDs)	
	Thermal building insulation, in general	Insulating building elements	For door or window openings
			For walls
			For floors
			For roofs
			For ceilings
	Recovering mechanical energy	Chargeable mechanical accumulators in vehicles	
Nuclear power generation	Nuclear engineering	Fusion reactors	
		Nuclear (fission) reactors	
		Nuclear power plant	
	Gas turbine power plants using heat source of nuclear origin		