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Solar Energy | The Rising Star of Renewable Energy

A Panel Data Analysis of the European Union’s Solar Energy Market

Master of Science in International Business and Politics

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Abstract

This thesis examines the relationship between the deployment of solar photovoltaic capacities and market orientated institutions – measured by the index of economic freedom – in the European Union by using a panel data analysis. Furthermore, it examines how technological developments, namely the prices for solar panels and for lithium ion battery storage have influenced the deployment of capacities in the EU.

Solar energy photovoltaic capacities have been one of the major drivers in the deployment of renewable energy capacities in recent years. Prices for panels reduced significantly and enabled solar energy to become increasingly competitive with fossil fuel capacities. Especially the EU has been on the forefront of deploying solar capacities to achieve their 2020, 2030 and 2050 goals.

The findings of this thesis show a positive relationship between investment and trade freedom, and the deployment of solar energy capacities. Furthermore, the thesis' results indicate a positive relationship between the amount of government spending and the deployment of solar capacities. With regards to technological aspects, the results indicate a positive relationship between decreasing prices for solar panels and the deployment of capacities in the EU.

The thesis aims to contribute towards the currently available research on solar energy deployment by utilizing an interdisciplinary approach that accounts for various aspects. This approach can support a better understanding of the dynamics present in the European solar photovoltaic market, both out of an economic and a political perspective.

Content

1. Introduction

Taming the effects of Climate Change will undoubtedly be one of the major challenges for humanity in this century. While the discussion in 1900s and the early 2000s was mainly about whether it really exists or not, Climate Change progressed unimpressed to its stage where it now causes havoc all over the world. For instance, from 2015 on each year was increasingly hotter and characterised either by heavy rainfalls, droughts or storms (IPCC, 2018). Such extreme weather conditions are likely to continue if there will not be a radical shift in global politics, economics and society. The IPCC reports made clear that climate change is mainly driven by the emission of so-called climate gases such as CO_2 or methane and therefore, reducing its emissions is one of the most promising actions to reduce the progression of climate change and limit global warming as it was agreed on during the Paris climate conference in 2015 (IPCC, 2018).

A major emitter of climate gases is the energy sector. Shifting from burning fossil fuels to relying on renewable energy sources such as wind or solar energy will be an essential step towards decarbonizing the energy sector. In the recent past, many countries of the developed and developing world changed their energy mix to become more renewable, however there seem to various obstacles to overcome related to availability and storing energy.

Because of those obstacles, hydro energy has been a major source of renewable energy for decades because it is storable and controllable. Some countries such as Norway managed to create an energy-mix, relying almost entirely on hydro power to generate electricity however, it requires country specific characteristics and not every country provides suitable circumstances. Solar and wind energy on the other side have been a growing source of renewable energy in the past decade and countries like Denmark or Germany managed to create substantial renewable capacities (EuropeanUnion, 2018). While wind grew strongest at the beginning of this massive capacity building, the situation changed, and solar energy appears to be now the rising star in the renewable energy sector. Nonetheless, both technologies share the same characteristics of facing very high complexity that requires innovation and a paradigm-shift of how to use energy.

Out of a global perspective, the European Union needs to play an essential role in the shift towards renewable energy. The EU accounts for about 12% of global CO_2 emissions (IEA, 2018a) and at the same time represents the second largest economic region (measured by absolute GDP) after the US and before China, worldwide (WorldBank, 2019a). Unlike the US or China though, the EU consists of 28 nation state with different political systems and economic capacities. Nonetheless, the EU promotes a transnational strategy for reducing CO_2 emissions and creating an overall renewable energy mix (European Commission, 2015). Therefore, if the EU succeeds with their 2020, respectively 2030 or 2050 targets, it will be a role model for transnational cooperation and how to challenge the progress of climate change with a multi-state approach.

Therefore, this research focuses on the development of Solar Energy in the European Union. Solar energy was chosen to be the independent variable because it has been the strongest growing capacity in recent years. It is examined, what aspects resulted in this growth.

The EU provides a diverse dataset of countries with different populations, political systems and different economic capabilities. Independent of those circumstances, all states of the EU agreed on reducing CO_2 emissions and promoting renewable energy capacities. Currently, some states have been very successful reducing their emissions and creating renewable energy capacities while others are lacking behind (IEA, 2018a). There are various studies available that examined what drives renewable energy capacity building. Most of them rely either on economic and/or policy data – for instance how wealthy a country is or whether feed-in tariffs exist. This research, however, aims at examining this topic out of a yet underrepresented perspective of liberal market perspective, using the index of economic freedom as regressor to explain the growth of solar energy. Furthermore, it is argued that renewable energy and more specifically solar energy, needs to be examined out of a multi- and interdisciplinary perspective that include economic factors as well as political and technological. Therefore, this thesis argues that solar energy growth can be explained by economic and political circumstance that promote effective market mechanisms and furthermore, is constraint by technological developments such as solar PV module prices and battery storage prices.

RQ1: “Is the degree of market liberalisation to attract investors a factor of growth for installing solar PV capacities in the EU?”

RQ2: “Which influence does technological development have on solar PV capacity building in the EU?”

This thesis is structured as follows: In chapter 2, arguments for the relevance of this research are presented. This includes current developments in the energy sector, as well as an extensive elaboration of the current state of research to provide an overview what has been researched and how this thesis is filling a research gap Furthermore, the overall research design is described. Chapter 3 provides theoretical arguments for this research; which theories are applicable and how they can be utilized for this research. In chapter 4, the methodological considerations are thoroughly explained. It is explained why panel data analysis was chosen, how data was acquired and which criterions where considered to create reliable and valid results Furthermore, the data is analysed descriptively. In chapter 5, the analysis’ results are presented followed by thorough discussion of results in chapter 6. Chapter 7 covers the limitations of this thesis and how further research could be conducted. In chapter 8, the thesis is summarized, highlighting the most important results.

2. Relevance, Literature Review, and Research Design

Explaining the research’s relevance is an essential part of any scientific project (Saunders, Lewis, & Thornhill, 2012). Hence, this chapter provides arguments what can be observed in the reality that allows to deduce how this research is relevant and what promising implications it can provide. The chapter is divided into two subsections. The first one provides a brief overview what can be observed in the reality that promotes the interest for this research. The current state of renewable energies and solar energy specifically is presented and what developments are observable. The second subsection provides an overview about current research considering aspects of growth of renewable and solar energy. It aims to explain what has been researched already and contrasts how this research can contribute to the current stream of available research.

2.1. Relevance

Changing the energy system from fossil fuels to renewable energy sources represents a major global challenge which requires collaboration of various actors of several disciplines (Sivaram, 2018). The arguments for renewable energy are strong. They provide endless energy, only consume resources for installation and avoid further emissions of noxious climate gases while providing extensive energy. Additionally, they are more easily to install and can provide electricity both for remote and urban areas. In the past decade, renewable energy capacities have been built extensively in the EU (IEA, 2018a) and solar energy appears to be one of the strongest growing technologies of renewables (Philipps & Warmuth, 2019). However, while there are many convincing arguments for renewable energy it still does not provide a major share of the energy mix for most countries, especially for those, which cannot rely on hydro power to meet their energy demands.

Furthermore, it seems that renewable energy capacities are reaching a non-specific limit in the energy mix and capacities are only built until a certain share is reached. This is for instance the case for countries like Germany or Italy with PV installation or the state of California (Sivaram, 2018). One promising explanation for this development lies in the character of renewable energy technologies. They produce energy – unlike fossil fuels – accordingly to the conditions of their environment. Sunny and windy days provide extensive energy while cloudy and windless days only create a fraction of energy. Therefore, it is argued that renewable produced energy must be stored accordingly to account for this different character of energy production (Comello, Reichelstein, & Sahoo, 2018) that is contrary to the current perception of energy supply. A thorough explanation of this development, the constraints of solar energy and how they could be solved is provided in chapter 3.

Besides those technological constraints, building and running renewable energy capacities need to be observed out of economic and political perspective. In the past years, installing renewable energy capacities, and specifically solar energy, was not economically reasonable. The costs for installing production sites and the expected revenue did not break even and shifting from fossil fuel energy production to renewable energy did not seem to be reasonable out of an economic perspective. Renewable energy did not provide a "competitive advantage" (Wernerfelt, 1984) over fossil fuels. Various governmental actors anticipated this market dynamic and decided to provide several types of subsidies for renewable energy capacities (Eyraud, Clements, & Wane, 2013; Marques & Fuinhas, 2012; Schallenberg-Rodriguez & Haas, 2012; Thapar, Sharma, & Verma, 2016) to provide incentives for investors to install capacities. One of the most effective type of subsidies was to provide so-called feed-in tariffs (Pyrgou, Kylili, & Fokaides, 2016). There, purchase to a fixed price is guaranteed for each unit of produced renewable energy. It allows to compensate for price volatilities and dissolves the risk of non-profitable investments. Most countries that provided such subsidies have been subject to strong increases in renewable capacities (Polzin, Egli, Steffen, & Schmidt, 2019; Pyrgou et al., 2016). However, as capacities increase the required amount for subsidies needs to increase as well. Therefore, in the mid- and long-run, renewables need to be competitive out of a market perspective and solar PV appears to be one of the most promising candidates to achieve market competitiveness.

Relying on prices per silicon panel as a unit of measurement for the required capital to build solar PV facilities, prices decreased substantially over the past years (Philipps & Warmuth, 2019). Simultaneously, the effectiveness of silicon solar panels increased considerably (Zhao, Wang, & Green, 1999), measured by how much of the sun's energy can be used to create energy. Therefore, it is argued that solar PV bears the potential to become an essential part of renewable capacities and a more comprehensive analysis of the past, current and future developments of solar PV energy is provided in chapter 3.

Because of the increasing maturing of solar energy as a competitive industry, in this thesis it is argued that the overall investment landscape, respectively the degree of investment-openness, measured by the index of economic freedom could determine whether investors are incentivised to create solar PV facilities. A more investment-friendly environment could provide more incentives for investing capital. Since the overall situation is of installing renewable capacities is determined by various factors, such as available energy sources, characterised by solar irradiance for solar PV, available energy infrastructure and specific characteristics of each individual energy market, examining the relationship between investment openness and solar PV installation adds another dimension to the issue of determinants of renewable growth. For policy makers a positive relationship between investment-openness and solar capacity building could lead to articulating better investment conditions and therefore, a novel approach instead of providing very market interfering instruments such as subsidies.

This subchapter provides information about the development of renewable energies in general, how its capacities increased especially in Europe and provided arguments why specifically solar PV is a subject of interest because of its decreased prices and increased effectiveness. Additionally, it is argued that solar energy could benefit from good investment conditions because it increasingly becomes an economic competitive product.

2.2 Current state of research and literature review

Providing explanations and analyses to understand what drives the installation of renewable energy resulted in a numerous strand of literature. Some of the most insightful analyses for this research are presented in this subchapter. Their core arguments are provided and set into context to this research approach.

Aguirre and Ibikunle (2014) examined which factors determine the growth of renewable Energy in general. They conducted a time-series analysis (t=20) with countries from the EU, OECD, as well as the BRICS states (n=38). Their approach was to determine which factors influence the growth of renewable energy and assumed that factors such as CO_2 emissions, energy use, institutional aspects (Kyoto Protocol ratification) and public policies promoting RE do have a positive impact on RE growth. Their findings suggest that the amount of CO_2 emissions does have a positive effect on the growth of RE as well, while increasing use of energy, measured by oil use per capita, decreases the growth rate of RE. They did not find any significant relations between energy policies which could be related to the overall design of this research. Furthermore, they suggest a positive relationship between renewable energy growth and biomass and solar energy availability, while wind availability has a negative impact on renewable energy growth. This paradox result is most likely related to the overall research design, that asks for renewable growth in general but does not account for each technology specifically, while observing individual aspects of each technology.

Consequently, this paper represents how careful the research design must be created, to acquire valid and reliable results that determine factors of growth for renewable energy. Each technology requires different preconditions and asking for renewable growth in general does not account for the complexity of each technology. Chapter 3 about the technological aspects of solar energy explains this assumption and it is likely to expect a similar set of specific circumstances for wind or hydro energy.

Therefore, in this thesis, solar energy PV is the dependent variable instead of renewable growth in general. This accounts for the assumption that renewable energies might have a negative impact on each other. When a country decides to invest in wind energy it might not invest in solar with the same magnitude. Furthermore, it is more reasonable to expect time-lagged effects in certain cases. Increased solar irradiance for instance is unlikely to have an immediate effect on the deployment of solar facilities, considering time for measurement of irradiance, its analysis, as well as planning and deployment of facilities. However, in years of continued increasing irradiance a growth of solar facilities in the upcoming years might be observed. Nonetheless, the article provides insights about how to structure a study examining factors of growth and some variables have been adopted for this research.

Sivaram and Kann (2016) argue in favour of a more ambitious cost target for solar power. According to their arguments, research is an essential part of implementing solar energy as a primary source of energy. Currently, most companies aim towards maximizing the efficiency of conventional technologies like silicon solar PV cells. In the long run though, they will reach their maximum efficiency that might not be strong enough to compensate for the value deflation of solar energy. The issue of value deflation is described in detail in chapter 3 along with other materials that could be used for solar panels. Furthermore, they argue that storage technologies need to become more advanced to compensate for the high volatility of energy production. During the day when consumption is relatively low while solar energy production reaches its peak, the excess energy needs to be stored to be available for low production and high consumption times, for instance during the evening. Their article provides reasonable technology related arguments to account for the struggles related to renewable energy that need to be overcome. Currently, a pure solar and/or wind energy mix is not feasible unless enough storage is available, and the deployment is cheap enough to compensate for value deflation. For this research their arguments have been adapted by expecting solar energy capacities to reach a limit of growth that could be explained by this concept. Furthermore, it is examined to what extend the price decrease for lithium ion batteries and solar PV panel module, promotes the deployment of solar PV capacities

Polzin and colleagues (2019) provide a semi-structured literature analysis of 96 studies related the question: “How do policies mobilize private finance for renewable energy?”. Their approach is to provide an overview of the currently available literature to structure and present the arguments available. FFIn their conclusion, they argue that effective policies incorporate the reduction of investment risk as a key feature. Following this argument, one of the most important aspects for investors is the guarantee that their investment in renewable energy yields enough return to create profit. Policy makers therefore should aim for minimizing risk, but there is a trade-off to be considered. Taming risk by providing extensive subsidies with feed-in tariffs are not feasible long-term. Additionally, the authors argue that policy makers can either favour renewables in general, and the most advanced technology will be installed, or they can support a specific technology to promote its growth. Assuming, solar energy currently provides the most profitable supply of renewable energy, the hypothesis is supported that solar energy will be especially installed in countries where a strong investment support is present. As Polzin (2019) and colleagues further elaborate, investment risk could be reduced by providing political stability, an indicator that is covered by the index of economic freedom by asking for integer rule of law, judicial strength or government integrity. Furthermore, it is argued, supporting policies should fade out gradually instead of stopping support from one period to another. This could be especially relevant for technologies that did not reach market maturity at the moment of diminishing support. Overall, they provide many arguments for this relevance of this research. The majority of publications focuses specific regions such as the EU, developing or developed countries and therefore, supports the decision for this research to focus on the EU because a worldwide sample might include too many biasing unobservable effects, considering the available resources for this research project, that could lead to less valid results.

Best and Burke (2018) analysed the influence of carbon pricing and aggregated policy support on the deployment of solar and wind facilities. Their study includes economic measures as well as survey data about the perception of climate change. Their interdisciplinary approach allows to account for the various factors that could have an influence on the deployment renewable energy facilities. The results show that perception and awareness of climate change is positively correlated with renewable capacities, leading to the assumption that countries with higher public awareness of climate change are more likely to install renewable energy. Furthermore, this allows to assume that beside policies supporting the growth of renewables, the overall political landscape of each country – therefore society-related factors – could explain RE growth. Hence, by examining the effect of economic freedom for renewable growth, which asks how the country is governed, a new perspective can be further explored, by including country specific characteristics. The index and its variables allow to provide explanations beyond the economic freedom term, understood as a complete orientation towards market liberalization and instead provides a way of assessing the overall country integrity.

(Jacqmin, 2018) provides a comparable approach that has been used as an important source for this research project. There, a panel data analysis assuming fixed effects was conducted to measure the effect of economic freedom on renewable growth in general for Europe between 2003 and 2012. The analysis provides evidence to conclude that investment-friendly market conditions promote the deployment of renewable energy. However, as elaborated above, the decision to use renewable energy as dependent variable in general could limit the explanatory power and treating each technology could lead to more valuable result. Furthermore, he relied on the economic freedom index by the Fraser Institute (Gwartney, Lawson, & Hall, 2015) while this research relies on the Heritage Index[1]. Besides using the Index of Economic Freedom, control variables related to whether the government was leftist, how many RE policies were present and the degree of deficit per country were included. The results of this study show that there can be a positive relation between the degree of investment-openness and the deployment of renewable energy. The study's main limitations lie in ignoring any technology related aspect of renewable energy. RE is treated as a function of political and economic measures, ignoring aspects of feasibility and how RE capacities need to be managed differently than fossil energy facilities. Additionally, the focus on RE in general does not account for the complexity of each technology. Another limitation lies in the chosen time frame. Renewable energies increasingly became competitive to existing fossil technologies primarily in the 2010s while Jacqmin's (2018) focused mainly on the previous decade (t = 2003-2012). Those limiting aspects have been anticipated in the design for this study. Nonetheless, Jacqmin's (2018) study provides valuable insights about the influence of economic freedom on renewable energy deployment and the study created an entry point for the research project conducted in this thesis.

The examples above were chosen to provide an overview what can be observed empirically and in the available strand of literature regarding the deployment of renewable energy and solar energy specifically. It was made clear that most available research focuses on policies and purely economic aspects to analyse the deployment of renewable energy. This thesis, however, aims at providing a more interdisciplinary approach that allows to account for the complexity of the solar PV capacity deployment. It is argued in order to understand what factors determine the deployment of solar capacities, neither a complete political and/or

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[1] Arguments for choosing one of the indexes of the other is provided in chapter 3.2

economic approach or a pure technological approach is feasible. Instead it is argued that solar energy deployment is a function of technological, political and economic constraints. Solar energy is unlikely to be installed if the technology to provide a stable grid is not provided and vice versa, even if it is available, economic vitality with or without political support is an essential part of solar capacities being sustainable[2].

2.3 Research Design

The aim for this research has been to investigate factors that determine the growth of solar energy PV capacities and the following sub-chapter provides a description how this research project was handled, which considerations were made and what factors determined certain choices.

The first consideration was about determining the overall research approach. After identifying the topic of solar PV growth as topic of interest a thorough literature research was conducted to gain insights about the current state of research and to identify what has and has not been researched. Sources for research included: ScienceDirect, Taylor & Francis, Scopus, Google Scholar, Statista, Wiley Online Library or Cambridge University Press, among others. It became evident that the topic of solar capacity growth has been covered by several different disciplines and out of various perspectives. However, it was identified that at least three aspects have been underrepresented.

The first one covers a political economic perspective that investigates the effect of market orientated institutions. After all, renewables are subject to various market dynamics and share many similarities with other investments as it is further elaborated in chapter 3. Albeit renewables have been subject of various studies related to the effect of indirect or direct policy

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[2] It could be argued that a renewable energy market then would be feasible if it would be excluded from the currently present market mechanisms. However, this is currently very unlikely, highly debatable and therefore was not considered as an alternative for this thesis.

support, the effect of overall market orientated policies – measured by the heritage foundation's index of economic freedom in this research – appeared to be underrepresented. Therefore, it has been identified as a subject of interest to be further investigated how market orientated institutions affect the growth of solar PV.

The second aspect relates to the technological feasibility of renewables and solar PV specifically. In many publications related to economic and political factors, technological aspects have been treated as invisible, exogenous factors and if mentioned, were only treated as side notes. For this research however, technological constraints were identified as a major influencing factor because many discussions about political and economic instruments to support solar energy growth would remain hypothetical, if the technological feasibility is not achievable. Besides the technological feasibility, it became evident that renewables, specifically wind and solar, were often treated as equal technologies with equal challenges which seemed to understate the complexity and specific requirements for each technology. Chapter 3 therefore provides a general discussion about the current state of renewables, and the specific requirements of solar energy. Because of this underrepresentation of technological aspects, it was decided to include technological variables for this analysis that have been assumed to be related to the growth of solar energy.

However, while identifying potential technological variables, I concentrated on choosing and utilizing adequate variables and aspects that serve the specific purpose of this research, leading to extensive considerations that were made for this thesis. This is exemplified by the issue of solar irradiance which was not included because of two reasons. First, it has been subject of many different studies already and second, the measurement of irradiance can be to some extend difficult, respectively its value for generalisation is limited. Either solar irradiance data is used for very narrow regions (Worldbank, 2019b) which would have only allowed implications for those specific regions because solar irradiance is very scattered across countries or it would have been used as a general value were its explanatory power would have been limited to make general assumptions. If a country is subject of high irradiance, yet this irradiance is rather concentrated in remote areas it would distort the general explanatory power of the variable.

The third aspect relates to the specific circumstances found in each country for renewables. Renewables and therefore, solar PV seems to be the subject of country specific attributes, related to certain policies and the overall structure of the electricity market. This was accounted for by concentrating on the specific region of the EU. As explained further in chapter 3, the EU provides a unique global sample by consisting of different nation state that are subject to the same EU wide directives of increasing the share of renewables and reducing climate gases.

As a result of those consideration it was decided to delimitate the research's scope to analyse the EU's solar energy PV market account for variations in market liberalisation and overall technological developments. This indicates that this research can only contribute towards a better understanding of the EU's solar PV market and its transferability to other regions might be restricted.

The research design of this thesis follows the characteristics of quantitative research and a positivist approach. The sample consists of quantitative data that is not influenced by a spectrum of interpretation. Hence, it is very likely that every observer of the data will come to the same conclusion without specific reliability instruments such as coding schemes(Saunders et al., 2012). Out of a positivist perspective, the data is treated as representation of reality. The used data consists of variables which are unlikely to be highly discursive. It can be argued that the selection of data itself is a process of value addressing however, this research adopts the proceedings of previous research, extends them and therefore, aims to reduce noise in the most feasible way.

While initiating this research project, it was considered to follow a mixed methods approach, examining economic freedom and technological aspects quantitatively and specific policies related to solar energy qualitative. However, as the research project progressed, it became clear that this path was not feasible because of several reasons. For instance, the current available literature provides a vast amount of policy analysis, both quantitatively and qualitatively and it appeared to be more reasonable to include their results as part of the overall analysis of this research's results. Furthermore, it was decided to use a single method and not follow a mixed method approach because it did not appear to be reasonable considering answering the research questions. Instead, policies, respectively the available results of policy implementation became part of the discussion of this research's results.

This research follows an explanatory approach where certain outcomes are expected and tested accordingly. The research questions ask for specific effects such as whether the degree of Economic Freedom affects the deployment of Solar PV facilities and how do technological developments need to be considered.

The research's purpose, therefore, is to provide a better understanding of the dynamics between market conditions, solar PV deployment and technological constraints for the

3. Theory

The market of renewable energy needs to be understood out of many different disciplines and perspectives to account for its complexity and to provide an explanation which factors have been identified for this study to answer the research questions. This chapter presents the most relevant theories available to provide the context for this study. It is structured by the three categories accounting for technological, economic and political aspects that could determine the effects of solar capacity growth. Each aspect is introduced, its relevance deduced for this thesis and the most relevant theories presented, to create a comprehensive understanding of the topic and its application in this thesis.

3.1 Technological Aspects of Solar Energy Growth

Explaining the technological development of solar energy can create a better understanding why capacity deployment should be examined out of economic and a technological perspective. This chapter introduces the technological aspects and sets them into the context of economic and political considerations.

Renewable energy technologies require a profoundly different understanding of energy generation, consumption and storage, compared to fossil fuels (Sivaram, 2018). Their main advantage of endless available resources such as wind, water currents or sun radiation, is also their biggest challenge. Renewable energy needs to be generated where energy is available while fossil fuels are used anywhere, where energy is required. Consequently, shifting the energy consumption from fossil to renewable energy sources requires a fundamental paradigm shift. The generation of energy needs to take place where energy is available, the generated energy needs to be transmitted where it is required, and it must be storable to create a stable grid. Renewable energy sources in general share many similar challenges, but each technology has its specific set of encounters.

This chapter focuses on the development of solar based energy generation, highlighting the technology behind solar energy, the history of its development and the current state out of a technological and economic perspective. There are generally two technologies available to generate electricity from solar energy, CSP and PV. However, CSP currently accounts only for a fraction of Solar Energy and therefore, the focus lies on PV.

3.1.1 Generating energy with PV and CSP

There are essentially three different approaches to use sunlight for energy generation (Sivaram, 2018). The sun’s heat can be used to move an engine, its radiation can be transformed into electric energy and lastly, its energy can be stored in portable fuel. The most common used approach today, however, is to use solar energy to create electricity, while in the previous centuries, solar energy's primary field of action was to generate heat, either domestically for households or on a larger scale, commercially (Perlin, 2013).

The development of CSP towers indicates the transition from solar energy's heat generating application to its use for electricity generation. CSP towers essentially use the same mechanics that are applied in fossil fuel power plants (Perlin, 2013). A CSP tower consists of an array of mirrors that allows to concentrate the sun's radiation on a single medium such as water or molten salts, creating immense heat. As a result, steam is generated which in turn, drives a generator to create electricity. Depending on the chosen medium and the tower's design, it is possible to store the heat beyond sunset to create electricity around the clock (Sivaram, 2018), independent from day and night. Building and maintaining CSP towers requires high investments and its ratio of revenue per MW is lower compared to PV though. This could explain why CSP only accounts for approximately 5GW of energy capacity, while PV accounts for more than 300 GW, globally (IEA, 2018a). Nonetheless, CSP follows the same trend of PV and its costs decreased substantially over the past years (Sivaram, 2018).

3.1.2 Solar PV as technology

PV allows to directly absorb the sun's energy and transform it into electric energy. The basic principle behind the technology lies in the attribute of light, consisting essentially of photons of energy. The ability of photons to hit electrons out of their nucleus-based orbit in metal or semiconductors, freeing them and creating a steady flow of electricity.

Two aspects, therefore, determine the amount of electricity generated in this process. On the one hand side, the light's energy must be high enough to create electric current, why high energy blue and violet light is most suitable for generating energy while lower energy light only goes through PV panels without any reaction (Sivaram, 2018). On the other side the material's sensitivity to light determines how much energy is created. If a material such as silicon is highly sensitive to light, many of its electrons are freed, creating electric energy. The benchmark for materials used for PV panels is their efficiency. The first in 1953 invented silicon-based PV panels were 2.3% efficient, which means they were capable of absorbing 2.3% of the light's total energy (Gertner, 2012). In 1999, silicon panels reached more than 25% efficiency and therefore, became ten times more efficient (Zhao et al., 1999). Since then, the efficiency only marginally improved for silicon PV panels (ITRPV, 2018). In the meantime, several other materials such as gallium arsenide (GaAs) or cadmium telluride (CdTe) were developed which share silicon's ability to create electricity (Sivaram, 2018). However, while GaAs proved to be more efficient than silicon, it is a lot more expensive and therefore, only used in market independent circumstances such as space missions. CdTe shares many similarities with silicon but while its costs appeared to be similar a decade ago, the massive price drop of silicon since 2010 led to its diminishing relevance for commercial use. Therefore, silicon-based PV panels are currently the most economically most reasonable technology to create solar energy (Fickling, 2018).

3.1.3 Economic considerations of solar PV

China plays a major role in the case of silicon PV panels' price fall and they became the biggest producer of panels during the past 10 years (Yuanyuan, 2016). The Chinese PV market started in the early 2000s, when Chinese companies began to acquire technologies and equipment from foreign western markets to create a domestic solar production. At this time, the US and Germany were dominating the market of solar PV production (Sivaram, 2018). While the Chinese government initially did not anticipate a domestic use of PV because of its high costs, they did expect high potential for exporting panels. Their assumption was based on the fact that in countries with high incentives for deploying solar energy, such as feed-in tariffs, the demand for PV was very high and policy agendas aiming towards creating a sustainable and ecological friendly energy supply, were likely to continue. This led to heavy subsidies by the Chinese government for domestic PV industry and allowed to scale up their production vastly

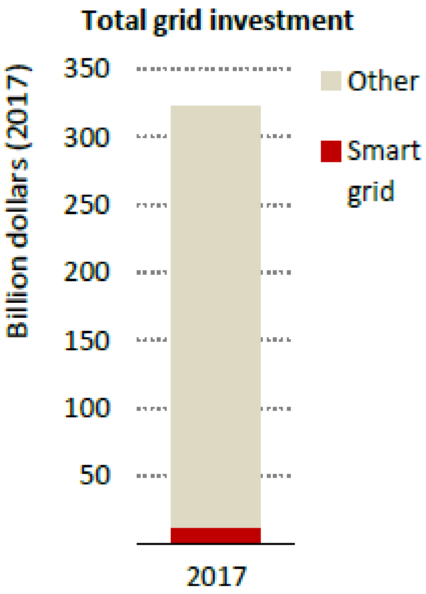
(Deutch & Steinfeld, 2013). In 2005, they accounted for about 11% of the global PV module production, though twelve years later in 2017, Chinese products accounted for more than 70% of the global production while North America and Europe only accounted for 6.8%, combined (Philipps & Warmuth, 2019). The Chinese dominance is mainly the result of their heavy subsidy policies and the financial crisis of 2008 (Sivaram, 2018). Almost all western solar producers went bankrupt during or after the crisis because of diminishing demand, lower availability of capital and reduced subsidise in Western countries. Chinese producers on the other side were kept-up by their government, providing loans and subsidies (Blakewell, 2011). The diminishing of western producers led to a void of market share that was filled by the Chinese companies. However, the reduced demand in Western countries created a heavy overproduction of solar panels and the Chinese government decided to deploy their panels domestically (Wan, Yang, & Zhao, 2015). In 2016, half of all solar panels have been deployed domestically in China (Sivaram, 2018) while in 2010 only about 6% were deployed in China (Deutch & Steinfeld, 2013).

Chinas involvement, therefore, transformed the solar PV industry from a heavy subsidy-based niche industry to a mature and competitive industry that is capable to assert itself against fossil fuel energy production. But there are still issues related to storing and transmitting solar energy that the industry needs to overcome as well as the issue of annual shifts in radiation.

3.1.4 Storage and other challenges for solar PV

While the PV production market grew into maturity and became increasingly competitive with fossil fuel energy production, the aspects of storage and transmission remain to be a serious threshold for its success (Sivaram, 2018). Unlike fossil fuel plant, PV panels must be deployed in areas with sufficient radiation. PV panels can be installed either domestically/commercially e.g. on the roof of building or they can be installed to be used as utility facilities where they compete with other power plants (Lewis & Nocera, 2006). For those solar utility facilities, adequate radiation is critical both economically and to guarantee a stable source of electricity; this limits the choice of placement substantially (Sivaram, 2018). Hence, there is a fair chance that facilities are deployed where they can achieve high output but in regions where there is only a small demand for energy. This requires extensive transmission infrastructure to transmit the generated energy into the existing grid. Additionally, solar energy is less balanceable compared to fossil fuel because of inconsistent radiation throughout the day and the year, thus its output is difficult to regulate. Peak energy demand is usually in the morning and evening while during the day, the demand is lower. Solar energy on other side is most likely to reach its peak during the day. Consequently, sufficient storage is essential to account for varying demand of energy (Fickling, 2018).

Figure 1 Total Grid Investment in USD bn. - Worldwide



The issue of adequate transmission infrastructure is better solvable because the technology is already available, thus it is only a matter of careful planning, available funds and effective execution (IEA/OECD, 2014). Furthermore, the development of smart grids – grids that are capable of monitoring demand and supply and that allow more accurate distribution – is continuously improving. Although in 2017 for instance, the vast majority of infrastructure investments worldwide accounts for conventional transmission compared to smart grids as shown in figure 1, (IEA, 2018b).

The issue of storage on the other side is faced with much higher complexity which requires a diversified response and technological development. In 2012, over 90% of electricity storage has been based on pumped hydro plants (IRENA, 2012). Using this technology means excess energy is used to pump water in an elevated storage and in times of demand it is released to power a generator to compensate for power deficiency. Although it is a versatile technology, it requires specific conditions such as adequate water supply that are only available in certain areas. Furthermore, installing hydro plants can have a major impact on biosystems and it would require an extensive expansion to account for the storage demands of solar energy. Therefore, other technologies such as lithium-ion batteries, are increasingly discussed to be used to store excess energy (Gaudard & Madani, 2019; Luo, Wang, Dooner, & Clarke, 2015). This technology does not provide a unified solution for the storage problem because they are not completely adequate for the use of storing utility energy. Thus, a combined storage approach is suggested that accounts for various needs of capacity and time to discharge. Some technologies are more suitable to store high amounts of energy but discharge rather quickly while others are providing steady energy with low capacity. However, lithium is subject of various applications in the industry and therefore, represents a new type of battery storage, that is already used widely. Storage and infrastructure are therefore both indicators that are very likely related to the success of installing PV energy which leads to the assumption that storage capacity prices of lithium ion batteries do have a positive impact on creating solar energy. There is data available on the development of the electricity grid, however, this data was not acquirable for this thesis because of financial limits[3].

3.1.5 Limits of solar energy

This last chapter represents the transition between solar PV perceived as technology to produce energy and its position as economic resource to generate income. Solar PV very likely requires reforming the way electricity is sold (Sivaram & Kann, 2016).

For fossil fuels the price can be calculated with a function of fixed costs plus the variable costs per generated MW. The distribution of electricity can be either on a day-to-day market basis or by negotiating long-term power purchase agreements, for instance by auctions. In the

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[3] The only identified source would have costs a couple of thousand Euros.

day-to-day scenario, the surplus is determined by the amount of electricity available on the market, so it varies depending how much energy is required at a given moment. In the scenario of long-term purchase agreements, there is an agreement between those who produce the energy and those who distribute it to consumers, about how much each produced MW is worth. This provides price stability for electricity. In a fossil fuel market, the price for the generating resources, such as coal and gas, determines the surplus while the distributor is protected from price variations.

For renewable energies such as solar PV however, there are no more variable costs because sunlight or wind is no resource that needs to be acquired compared to coal or gas. Furthermore, the amount of produced energy cannot be adjusted to the market’s demand (Sivaram, 2018). During the middle of the day, demand for electricity is relatively low. Simultaneously, solar PV reach their peak performance during this time and therefore, the market is flooded with energy leading to an excess of supply and thus, prices will fall. This could eventually lead to a situation where prices have been plunged to an amount when installing new solar PV only creates losses (Sivaram & Kann, 2016). This would be the case if the price per KW/h is more decreasing compared to the decrease of Solar PV Panels costs and its associated costs.

Out of an investment perspective this explains why institutional investors have been adverse of investing in solar energy in a pure market situation. The more capital is invested, the lower the return of capital is going to be. The increased capacities can cannibalize their additional revenue because, the overall increased capacity leads to decreased electricity prices in general and in times of peak supply can even be negative. Thus, every solar PV facility build on top of the existing system promotes its reduced revenue, leading to an overall value deflation of solar energy (Sivaram & Kann, 2016). This represents a major constraint for amortizing the investment for solar PV. Additionally, seasonal and meteorological variations limit the predictability of the facilities' potential outcome both for power purchase agreements and market-based distribution.

Furthermore, the more solar energy is available in the energy mix of a region, it becomes a more serious problem to secure a stable grid. Those circumstances are portrayed in the so-called “duck curve” (CAISO, 2013) that illustrates the increasing imbalance between produced and consumed energy in a time dimension. In an increasingly solar based energy-mix the maximum output must be either stored or the lack of available power during the evening and night must be compensated by more adjustable energy sources such as gas or nuclear power. This dynamic could be coped with by shifting the understanding of the use of electricity. Electricity could be used for heating buildings, to power coastal desalting plants so the energy would be stored in fresh water or more advanced to create synthetic fuels, to name only a few examples (Sivaram, 2018).

Consequently, those constraints of Solar Energy represent serious obstacles for a fully integrated solar supply and could explain why solar energy capacity growth potentially follows the s-curve pattern, until a disruptive innovation is integrated. Therefore, in the future, technological, financial and systematic innovations could compensate for the dynamics of solar energy.

European policymakers addressed this issue of unpredictability with providing instruments such as feed-in tariffs (Pyrgou et al., 2016). They allowed to cope with the supply-related price volatility because solar energy producers were guaranteed a certain subsidized amount per kw/h they produce, independently whether it was required or not. While this policy was reasonable when solar PV was still in its beginning, with more capacity installed the incentives scale up to an unjustifiable amount which is why solar promoting policies that guarantee fix prices are decreasing substantially. For a more mature solar PV market consequently, the rules of the market become increasingly important and are likely to determine the success of this technology (Eleftheriadis & Anagnostopoulou, 2015).

This subchapter framed the current situation of solar PV capacities and provided some information about the solar PV market's history. The main argument is that determining what drives the growth of solar PV as an energy source, can only be accomplished by incorporating its technological constraint. Econometric models can create prediction about the future development of the market, assuming prices will fall, and policy support will be gradually provided. If, however, technological improvements will not take place, the chances of accurate predictions are rather low (Sivaram, 2018). The main arguments for this thesis therefore are: Solar PV suffers from a diminishing growth when a certain limit of capacities is reached and the prices for solar PV panels and battery storage can explain the growth of solar energy. All three assumptions are tested in this model which is explained further in chapter 4.

Considering RQ2, the effects of technological variables on solar capacities are examined. Therefore, my approach is to provide a more interdisciplinary perspective on the issue, arguing that renewable energies are on the one hand side very different from conventional technologies, with regards to energy availability and storage. On the other the renewable energy technologies appear to be less comparable than conventional fossil fuels. Which is also the reason why I am arguing that it is more reasonable to focus on one technology – in this case solar PV – instead of renewables in general.

3.2 Economic Aspects of Solar Energy Growth

This chapter introduces the considerations behind research question 1. How economic freedom could be an indicator for the growth of solar PV capacities in Europe.

The growth of solar PV is highly influenced by the amount of capital, invested in its deployment (Polzin et al., 2019). The following chapter therefore focuses on the economic aspects that were considered for this research. The overall effects of Economic Freedom are discussed and its implications for this research project are deduced. It covers several topics, beginning with introducing the term economic freedom and followed by providing arguments how it has been adopted for this research. The subchapter concludes by highlighting the important implications for this research to provide an overall context for this thesis.

3.2.1. Economic Freedom and the Economic Freedom Index

The term Economic Freedom is rather discursive (Bjørnskov, 2016; Brunnschweiler, 2010; Carlsson & Lundström, 2001; Gwartney & Lawson, 2003) and therefore, needs to be defined accordingly to frame how it was utilized for this thesis. The history of the term is briefly described, and it is elaborated which aspects of Economic Freedom were anticipated for this thesis.

The term Economic Freedom is closely related to Adam Smith's (Smith, 2007) concept of the "invisible hand" were he argues that unregulated market forces will create an optimal solution. From its origin, the term has evolved to a more neo-liberal perspective relating to Keynes (Keynes, 1936) were the state's purpose is to provide the regulatory framework for economic goods and individuals to move and to participate freely on the market. An economy is understood of being free in the sense of the index, when it promotes trade and exchange, as well as personal ownership (Gwartney & Lawson, 2003). Therefore, individuals and collective entities, such as firm, are free to choose how to use their own resources and capabilities and those of others, to improve their situation. Hence, if two parties reach an agreement of exchange, they can be certain that this agreement will be valid against the law and do not need to fear aggressive or unlawful behaviour, such as expropriation or discrimination. This also indicates that economic freedom specifically focuses on any type of economic transactions and thus, is not adequate to deduce any implications about the political or civil freedom. It neither provides information whether the government was elected under democratic and just circumstances nor does it allow to make any conclusion about how citizens can pursue their "citizenship" (Marshall & Bottomore, 1950) as responsible entities in a collective assembly of individuals in a democratic state. This implication is noteworthy because it allows a more specific definition about what economic freedom can and cannot explain. Although there are aspects covered by the index related to government integrity, those variables need to be seen under the umbrella term of economic freedom and cannot provide a fully comprehensive picture of the overall status of each individual state (Gwartney & Lawson, 2003). Furthermore, it means that a state can be political free, with a well-functioning and just democratic system and at the same time very restrictive with regards to economic freedom; and vice versa. Consequently, there is no definite causality between economic, political and civil freedom. Instead, it can be likely that a state which emphasises the values of individual freedom, promotes all three types of freedom, but it is not a necessity.

Therefore, the term economic freedom is understood for this thesis – along with several other publications – as promoting entrepreneurial activity and the freedom to do business with regards to an effective rule of law, government size, regulatory efficiency and promotion of open markets (Miller, Kim, & Roberts, 2019). Those indices are not contradictory to an extensive welfare state as for instance, all EU-member Scandinavian countries are ranked in the top 20 of the Economic Freedom Index of 2019 (Miller et al., 2019). Therefore, a high score in Economic Freedom indicates an effective business environment with good access to capital, effective government and an independent juridical system that protects property rights; all of which could provide a good investment environment for solar PV.

3.2.2 Negative and positive aspects of economic freedom

There is a vast strand of literature available arguing for or against Economic Freedom, ranging from complete liberal markets with almost no state intervention to a communist approach of a complete state-owned market were the economy is exclusively subject of government planning (Bjørnskov, 2016).

An extensive Economic Freedom, understood in the sense of a very liberal market system were the state only provides property rights, cannot provide the same support compared to more state-inclusive economies for the labour market (Bjørnskov, 2016). Providing unemployment insurance for instance allows to compensate for external shocks that could lead to a cascading effect were unemployment increases steadily, thus consumption is reduced which leads to even more unemployment because of reduced economic growth (Feldmann, 2011). The same principles account for providing capital. In times of recession, capital providers such as banks become more averse in providing capital leading and at same time firm values decrease so they can offer less securities leading to so-called credit crunch (Bernanke, Lown, & Friedman, 1991). Governmental interventions in this scenario could compensate for market's deficiency and provide support to buffer the effects of any recessive phase. The same scenario also applies to renewable energies. The market for renewables for a long time could not compete with fossil fuels. The capital invested did not yield the same return as conventional energy resources. Therefore, it appeared to be unreasonable to invest in renewables. However, this calculation does not incorporate the long-term costs of burning fossil fuels – which will increase substantially (Drummond et al., 2017) – and the emission of climate gases promoting climate change. Climate Change could, besides its more obvious threats like rising sea levels, droughts and extreme weather conditions, also result in massive economic costs (Stern, 2007) – so fossil fuel energy production is only economically reasonable short-term.

The main reason why state intervention is required, hence, lies in the fact that the concept of the rational behaviour – respectively the concept Homo Oeconomicus – is not applicable (Thaler, 2000; Thaler & Sunstein, 2009). Irrationalities occur in economic systems in the same way as they occur in other areas as well, as is exemplified by panic selling on stock exchanges (Bjørnskov, 2016) or the examples provided above. Furthermore, neither economic actors nor any other actor has access to all information to make pure rational choices (Munger, 2008). Therefore, political actors are unlikely to provide a natural compensation (Pennington, 2011) for market deficiencies which is controversial to Keynes approach. There is no explanation about the nature of the compensating effects provided by government and the assumption that governmental actors naturally provide the right answers to the economic failures (Pennington, 2011)

Economic Freedom thus, understood as a set of principles were individuals can pursue business in an effective but also stable way can be perceived as positive aspect. It is unlikely and empirically not verifiable that highly restricted economic freedom leads to more effective markets. This assumption includes non-economic aspects such as overall welfare and wealth distribution across a nation. The desired state of Economic Freedom that is aimed for by using the EFI, analyses the state effectiveness to provide a positive environment for economic activities. The state can be influenced –as much as private actors – by special interest groups that undermine the efforts towards increased general welfare and consequently, a high EFI score in areas such as government integrity does not provide information about whether a government is highly market liberal and instead, measures if the government is acting integer to welfare principles. A high score in this regard can be achieved both in very welfare-state orientated nations such as Denmark (Rank 14) as well as more liberal markets such as the US (Rank 12) (Miller et al., 2019).

3.2.3 Economic Freedom and Renewables

Referring again to the findings of (Polzin et al., 2019), it is worthwhile to closely examine what findings are already available that provide empirical evidence which factors and/or instruments promote the deployment of renewable energies. Their overall findings suggest that investors tend to seek for investments with high predictability and highest possible return. Feed-in tariffs appear to match those criterions and have been adapted by various countries (REN21, 2018), creating a safe and predictable energy market. Feed-in tariffs provide a guaranteed fixed price and purchase over a specific period. There is a clear and significant positive correlation between providing feed-in tariffs and the deployment of renewable energy capacities (Criscuolo & Menon, 2015; Schallenberg-Rodriguez & Haas, 2012). This policy instrument reduces the risk significantly because investors do not need to fear high price volatility because of the imbalanced availability of renewable energy. Furthermore, the return of investment is highly predictable and there is a clear timeline when the investment will be amortized and create profit.

Other prominent instruments related to the deployment of renewable energy, such as Carbon/DHG certificates on the other hand side do not lower any investment risk. Their effect on return is only positive, if, compared to fossil fuel energy generation, renewables can outpace fossil fuels in a highly restrictive carbon market (Abolhosseini & Heshmati, 2014). Therefore, the currently available literature does not find strong evidence for the positive effect of emission trading on the deployment of renewables (Zhang & Wei, 2010). This, however, can be subject to change and is very likely related to the overall structure of the policies which means that the policy is not effective per se. Instead, it suggests that the current implementation of carbon trading is not effective; a delamination that is important to consider.

Another positive policy example on the other side are auctions for power-purchase-agreements (PPA) which also has been adopted by a variety of countries (REN21, 2018). There, investors can sell their potential capacities under pre-defined circumstances which allows guaranteed purchase and predictability about prices and duration. But a careful auction design is essential for its success (Winkler, Magosch, & Ragwitz, 2018). The auctions' purpose needs to be to reduce risk for investors and to guarantee a stable revenue which according to the available empirical evidence, the policy is capable of.

Lastly, subsidies appear to be less effective than expected. There is mixed evidence for their effectiveness (Marques & Fuinhas, 2012) because they tend to be useful for the early stage investment by reducing the burden of debt. Furthermore, tax deductibility has a positive effect on the early revenue (Carfora, Pansini, Romano, & Scandurra, 2018). However, after the investment is installed and producing revenue, it is subject to the given market conditions and the effect of the subsidies diminishes substantially (Xiong & Yang, 2016).

Examining the provided evidence, which policies appear to be effective and which are rather less effective, there becomes a pattern evident. The initial situation for renewables is that they are perceived as risky investments and investors are likely to be attracted by policies providing secure and predictable circumstances; as Polzin (2019) and colleagues findings suggest. The most effective appear to be feed-in tariffs and effective PPA auctions. Both have in common that investors are provided with information how much revenue they will achieve and how much capital is needed. The policies provide a market situation with perfect information and consequently, if there is a high return of investment to be expected it is only reasonable to invest in renewables and it is likely to expect this behaviour for any investments. One conclusion from these findings is to assume that policymakers only need to provide feed-in tariffs and effective PPA to promote their renewables market, but the situation appears to be more complex. While at an early stage of a technology, those policies can be reasonable to promote its maturing, the financial burden for mature technologies can become unbearable at higher levels of market penetration. At the same time, a more mature technology becomes naturally more competitive because of increased effectivity and efficiency such as economies of scale (Krugman, 1980). This development is evident for solar PV where prices decreased significantly over the past years, as described in the previous chapter about the development of solar PV. The principle of low-risk and high-return remains though and the more the technology is capable of competing in a free market, it is assumed the more likely it will be invested in.

There is evidence that there are increased investment activities in countries with higher economic freedom, respectively with higher economic freedom scores (Herrera-Echeverri, Haar, & Estévez-Bretón, 2014; Jacqmin, 2018). Consequently, for this thesis it is argued that in countries with a higher EFI score it is more likely to expect that investments in solar PV took place because the overall investment environment is better suited compared to countries with lower scores. Nonetheless, each of EFI variable needs to be analysed carefully since the overall score covers a variety of aspects while focusing on each variable individually could provide more insights about growth determining factors.

Considering RQ1, economic freedom is assumed to influence solar energy capacity growth in the EU. The argument relates to a stable economic environment, considering aspects like a functioning rule of law, integer government, access to capital, trade openness besides other factors. This assumption is supported for instance, by a semi-structured literature review (Polzin et al., 2019) that identified policies providing stability and predictability are one of the major drivers for renewable capacity deployment.

3.3 EU Energy Market

The following chapter explains the current state of the European Energy Policies by providing information about historic events and decisions that led to its current state. It is meant to set the context why the EU is of interest to be examined. Furthermore, arguments are provided to determine which role the EU holds in the global and regional context of energy generation. Additionally, questions of relevance and importance are addressed to explain why the EU provides an interesting research sample.

3.3.1 EU Energy Market in a global context

According to data provided by the World Bank, the European Union ranks second – after the US and before China – in their share of the global GDP accounting for about 22% of all generated value in 2017 (WorldBank, 2019a). Furthermore, they accounted for 12% of all energy consumption in 2016 (IEA, 2018a), while reducing their overall consumption by 11% from 2006 to 2015 (Faure-Schuyer, Welsch, & Pye, 2017). This can be explained by the shift in energy supply technologies. In the past 15 years the EU’s energy mix changed substantially towards renewable energy. The EU has become one of the most influential global actors in promoting renewable energy production to create a more sustainable and eco-friendly energy-mix (IEA, 2018b). In 2016, they ranked second on renewable energy production – in absolute numbers – globally, behind China and ahead of the US (IEA, 2018a). While China and the US represent specific countries, the EU consist of many different states and therefore the EU stands for a globally unique example how to harmonize the power market across borders.

On the other side, while renewable energy capacities are the strongest growing energy technology in the EU, renewables only accounted 13.2% in 2016 of the overall energy productions in the EU (EuropeanUnion, 2018). Fossil fuels along with nuclear power still account for most electricity sources and the EU still ranks third on greenhouse gas emissions worldwide (IEA, 2018a). Those emissions are strongly associated – about 85% – to energy production (IEA, 2018a). This can be partly explained by the EU's market structure because while the EU reduced the amount of exploiting primary energy resources significantly, at the same time, imports of fossil fuels increased substantially. In 2014, about 53% of gross inland consumption of fossil fuels was covered by imports which explains why fossil fuels in 2014 accounted for 40% of all energy generation in the EU (Aoun et al., 2017). The remaining energy was produced by Nuclear (26%), hydro (19%). Thus, while the situation has improved, it pace appears to be insufficient if the EU wants to continue their commitment to fulfil the COP21 goal to limit the effects of climate change to 2°C, respectively 1.5°C (IPCC, 2018).

This becomes evident by examining the situation out of a more global perspective and including the aspect of carbon budgets, respectively non-burnable carbon. There has been a growing amount of pressure that burning fossil fuels needs to be reduced significantly by the EU in order to meet the criterions of the 2°C goal (McGlade & Ekins, 2015). Although there is still an abundance of fossil fuels available at least until the mid of this century (Scott, Haszeldine, Tett, & Oschlies, 2015) and new technologies such as fracking make them available more easier – thus, creating havoc for the environment (Meng, 2017) – the issue of how much fossil fuel can be burned to mitigate climate change is essential. McGlade & Ekins (2015) calculated a carbon budget for various regions worldwide and concluded that more than 50%

of global gas reserves, 4/5th of coal reserves and about a third of oil reserves needs to remain unburned by 2025 to achieve the 2°C target. Europe, though, only should leave 20% of their oil and 11% of gas reserved unburned, only 22% of their coal reserves could be used for energy production. However, as mentioned above, out of a global perspective this development indicates that shifting from fossil fuels to renewables for energy generation is crucial, and especially coal needs to be abandoned as energy source (van Vuuren et al., 2018). The EU's strategy, to source their fossil fuels increasingly from outside the EU therefore represents only a potential necessity to an inevitable long-term path towards a renewable energy system.

Thus, the EU28 is one of the major actors on a global scale, out of an economic, political and energy perspective of renewable energy deployment and facilitation. To account for their role, the EU agreed on several policies to reduce their emissions and create a more sustainable energy production landscape. However, there are substantial differences between the member state, succeeding in transitioning their energy systems. States such as Denmark, Germany or Italy have been extensively deploying renewable energy capabilities in recent years, while others such as Finland or the Netherlands lack behind their deployment goals. This chapter provided information about the

3.3.2 EU Energy and Renewable Energy Policies

Since the 1990s, three major energy policy packages have been introduced (Faure-Schuyer et al., 2017; Nicolini & Tavoni, 2017). The first policy package enabled competition in the industry. Previously, energy production and distribution were dominated by monopolistic structures. The introduced directive aimed to unbundle these activities and create a more competitive environment. The second policy bundle in 2003 expanded the market liberalisation and introduced a strict separation between energy production and its supply, respectively transmission. The latest energy policy, which still accounts for today was introduced in 2009. It initiated the creation of the Agency for Cooperation of Energy Regulation (ACER) as well as the European Network of Transmission System Operations (ENTSO). Both organisations represent the increasing disentanglement of energy production and supply and allowed an increasingly integrated coordination of production and supply across Europe. Additionally, the framework from 2009 included the Renewables Directive. Member states agreed on to “achieve a 20 % share of energy from renewable sources in the Community’s gross final consumption of energy […]” (European Parliament, 2009, p. 26). Each state within the Union was mandated to create an action plan how to achieve this goal and therefore, contribute towards a more renewable energy sector. Some states however, as mentioned above, were more successful while others are unlikely to achieve this goal until 2020.

In 2015, the EU released its latest far reaching policy which is called “Energy Union”. Essentially, the EU reached an agreement together with Norway and Switzerland to create a fully integrated European electricity market; “… unlocking the full potential of renewables in the energy system” (European Commission, 2015). The concept of the Energy Union, addresses 5 core principles namely, (1) Energy security, solidarity and trust, (2) a fully integrated European Energy market, (3) energy efficiency contributing to moderation of demand; (4) decarbonizing the economy, (5) research, innovation and competitiveness (Faure-Schuyer et al., 2017, p. 33) It represents a transnational cooperative approach to face the challenges of climate change and the transition to renewable energy on a continental scale instead of focusing on a nation state centred perspective.

However, as for now there appear to be many differences between the nation states to achieve their climate goals and this indicates that national policy agendas appear to be more important than transnational policies by the EU. Those polices have been the subject of certain converging trends over the decades (Knill, Sommerer, & Holzinger, 2008). Until the 2000s, subsidies, tax reductions and commitments to allocate a quota of renewable energy were the dominant sources for renewables policy support in the EU (Knill et al., 2008). During the 2000s, there is clear evidence for feed-in tariffs[4] to become the dominant source of policy support. Feed-in tariffs reached their peak in 2010 and have been diminishing since then (Kitzing, Mitchell, & Morthorst, 2012; Strunz, Gawel, Lehmann, & Söderholm, 2018). The reasons for their reduction can be attributed to several developments. At some point feed-in tariffs become too costly to deploy as has been explained in the previous chapter. Other reasons could lie in the EU's directives though. With establishing the Energy Union in 2015 (European Commission, 2015), and its goal to harmonize the European energy market, individual promotions of technology, apart from the EU-wide polices, could be unfavourable (Strunz et al., 2018). If one country provides feed-in tariffs for renewables in a fully integrated European energy market, concentrating effects could appear where certain countries would be favoured for deployment, simply because of those policies, which in turn would reduce the effectiveness of an integrated energy market where capacities and transmission lines are allocated to maximize efficiency.

Therefore, the European Union provides a very interesting sample. On the one hand side there is a common understanding of promoting renewable energies and reducing climate gas. On the other side, there are very different approaches how to achieve this goal. Some states such as Spain or Germany provide heavy subsidies in the form of feed-in tariffs for renewables and specifically solar energy (Pyrgou et al., 2016; Schallenberg-Rodriguez & Haas, 2012). While others such as the United Kingdom rely on heavy carbon taxing which reduced their amount of coal-based energy production significantly (Evans, 2018). Consequently, the European Union is an interesting sample to examine the effects of liberal market policies and technological developments on the deployment of solar PV energy capacities.

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[4] Their effectiveness and economic mechanism have been discussed in chapter 3.2.3 however, it is worthwhile to examine their development – out of a policy perspective – further.

4. Method

The overall structure of this research is to examine which effects determine growth in solar capacity in the sample of the EU28 in a ten-year time span from 2008 to 2017. To answer those questions, a secondary data panel analysis approach was chosen to provide information what determined the solar capacity growth. The next sub-chapter clarifies which assumptions were made during the research design and what criterion need to be considered when working with secondary data. The chapter is followed by introducing the method of analysis and afterwards, data sources and variables are presented.

With regards to reliability and validity, the sample, data sources and method was highly influenced by previous studies which used comparable datasets and methodological approaches (Aguirre & Ibikunle, 2014; Best & Burke, 2018; Jacqmin, 2018).

4.1 Secondary Data Analysis

Relying on secondary data provides several advantages and appeared to be especially applicable for this research (Saunders et al., 2012). The main advantage lies in the availability of a vast amount of data over a long period of time that would be hardly gatherable within the possibilities of this research. It allows to compare various types of data such as economic, environmental or political data and investigate how they may affect each other. Using secondary data provides several other advantages. With primary data it would not be possible to work on this topic as these data cannot be accessed. Further, using the data that is already available only makes sense out of perspective of available resources for this thesis. Lastly, using the available data ensures that longitudinal perspective on this topic. However, when working secondary data, an extensive due diligence is essential.

This issue was addressed by carefully evaluating every data source and asking questions such; how the data was used in previous studies, were any data-related limitations identified and how could this affect this research project. Furthermore, the data sources were carefully selected, relying on prestigious and renowned institutions that could be trusted to provide unbiased data. The data was available either because it was public or because it was accessible through the licences provided by CBS: This also means that some datasets were identified that were not used such as data about the grid development because it was only available by paying for the data set. The ratio between costs and benefits (Saunders et al., 2012) was not in favour in acquiring the data and therefore its acquisition was rejected.

The issue of potential measurement bias was addressed in the evaluation of the data as well. This is especially relevant for the data provided by the Heritage Foundation who provides the data for the index of the economic freedom. It was acknowledged that their conservative political standpoint could result in a biased perspective, while other data providers, such as the Eurostat likely do not have a political bias. This issue is addressed in the discussion of the results, but it was not identified as an obstacle that would have a major biasing effect on the overall research outcome and many other researchers relied on their data as well. Furthermore, their data acquisition process is transparent and reasonable (Miller et al., 2019). Consequently, the index was used consciously with acknowledging its origin.

The technological data from Bloomberg represents a reliable data source as well and their estimation for capital expenditures for solar PV and the prices for lithium-ion battery packages were evaluated to be reasonable. Bloomberg data has been the subject of various studies related to renewable energy and therefore was perceived to be reasonable.

For the analysis of economic freedom and answering research question 1 and 2, a panel data regression approach was chosen. Research question 2 has been subject of a careful evaluation to use another approach for research question 2 but the only other feasible method would have been to apply a time series analysis to one subject, in this case the EU as one subject. However, after testing the model the results appeared to be highly deficient because of the sample size and the short time span, measured in years. Therefore, it was decided to use another approach for this assumption instead of tying a method to this project that does not provide very reasonable nor insightful result.

As described in chapter 2.3, policies were not included in this research. It could have been feasible to quantify policies and include them into the economic freedom model of research question 1. However, transferring the qualitative nature of policies into quantitative data can be subject of inaccuracy and requires careful coding. It was decided that this requirement of quality was hardy achievable within this research project. Other procedures, such as counting the amount of policies related to a certain topic of interest on the other side, did not promise to provide any useful insights. Policies are rarely equal in their magnitude and while one policy related to solar PV capacity building might provide an extensive support for the technology, others only provide support on much smaller magnitude; thus, they would have been treated as equal, although they are hardy the same. Hence, policies are included in the discussion chapter, as exogenous influencing factors.

4.2 Data Sources and Collecting

Three data sources have been used for this analysis, namely Eurostat (Eurostat, 2019) the Heritage Foundation (HeritageFoundation, 2019) and Bloomberg New Energy Finance (BNEF, 2019). Eurostat is a database provided by the European Commission and is likely to provide accurate data. Their data has been subject of several studies and complies to high standards of measurement. The Heritage dataset on Economic Freedom relies on objective criterions to determine the score of each variable (Miller et al., 2019). The index provides transparent information about the methodology used for every one of the 12 components that are considered in the index. Their data sources are for instance the World Bank, Transparency International, the OECD or the IMF (Miller et al., 2019). Therefore, it is considered to be a reliable source for the purpose of this research. Bloomberg New Energy finance is part of the Bloomberg group and therefore, represents one of the state-of-the-art data sources for economic data. Hence, it was considered to be a reliable and unbiased data provider. The dataset is provided in appendix 3.

4.3 Variables

The following chapter introduces the used variables for this research. The determination of which variables and from which source is essential for the analysis and therefore, it took some time to make adequate decisions. There are various sources available such as the World Bank database or the OECD database. Eventually I decided to choose Eurostat as source for capacity data because it appeared to be most reasonable considering the sample of the EU28. However, other sources most likely provides similar data. I searched several possible sources providing the needed variables and decided based on previous studies (Dobrotkova, Surana, & Audinet, 2018; Jacqmin, 2018; Sivaram, 2018) which source would be best. The two indexing variables are country and year.

Countries. I selected the EU-28 countries for examination. Furthermore, I provide arguments why the EU is of interest because all member states are subject to the same directives to deploy renewable capacities and reduce their climate gas emissions. Nonetheless, there is a very distinct gap between the member states success to provide renewable energy, which seems to be of interest to investigate.

Time frame. For the economic freedom model, a timeframe ranging from 2008 to 2017 was chosen. The decision was made to account for the most recent available data on the subject. The ten-year time frame was chosen to account for an expected bias for a longer period of time because some countries of the EU joined in the 2000s and therefore, they were not subject to the same policies over an extended period of time. For the technological model a time frame from 2010 to 2017 was chosen because of the availability of data. There was no data on the technological variables available before 2010.

4.3.1 Economic variables from the Heritage Foundation

The 12 variables of economic freedom are divided into four different categories namely, Rule of Law, Government Size, Regulatory efficiency and Market openness. Each variable is measured in relative terms, therefore ranging from 0 to 100, by normalizing the value of each country’s score for better comparability. The definition of each variable is based on the methodical appendix of the 2019 Index of Economic Freedom Report (Miller et al., 2019). Each variable is lagged by one year. The value of 2017’s property rights for instance, represents the status of property rights in 2016.

The **Rule of Law** category includes two variables to assess to what extend a country can provide an integer rule of law system. It is examined how property rights are protected and if the judicial system is fair and effective.

Property Rights: This variable asks for the effective protection of property rights, to what extend they are enforced legally, and private property will not be a subject of infringement. The score is a subject of five sub-factors asking for issues such as physical and intellectual property rights, risk of expropriation or quality of land administration. The information has been sourced by the World Economic Forum, the World Bank and Credendo Group.

Government integrity: This variable measures the biasedness of governments by non-governmental actors. It consists of aspects such as trust in politicians, bribing, governmental transparency or absence of corruption. The score is measured in relative terms compared to the overall results. Sources include the World Competitive Report by the World Economic Forum, the Rule of Law Index by Transparency International or the TRACE matrix by TRACE international.

Judicial Effectiveness: This variable asks to what extend the judicial system within a country is well functioning. It includes aspects of judicial independence, any sign of favouritism of government-related entities and an overall assessment of judicial independence. Therefore, the variable provides information about the fairness and effectiveness of the judicial system in each observed country. Sources for the index included for instance, the World Economic Forum, the World Justice Project, Transparency International or TRACE International.

The category **Government Size** provides information about the governmental responsibilities in an examined country. It is assessed how much influence is practiced by the government and to what extend regulation takes place.

Tax Burden: It is meant to provide information about the marginal tax rates for corporate and individual entities. Furthermore, the tax expenditures are set into context with the GDP by assessing a ratio of total amount of taxes and GDP, providing information about how much of the GDP is the result of taxation. The results are subject of a quadratic function and a high score of 90 and above counterintuitively represents low tax burden. Their argument is that a high tax burden has a negative impact on economic freedom. They relied on a vast strand of sources to assess the tax burden of private and public origin such as reports by Deloitte, Price Waterhouse Cooper, the IMF or the World Bank.

Government Spending indicates how much the government in each observed country spends, relative to the country's GDP. A score of 100 indicates no government spending. They argue, there is no right or wrong amount of government spending, but it can be assumed that high government spending has a negative on economic freedom because the government is likely to inhibit roles that could be filled by private institutions. The aspect of high scores for underdeveloped countries because of limited available funds for spending is addressed by arguing that they most likely will in turn perform worse in most of the other indices and therefore will not achieve a high overall rank. Sources for the index included the OECD, the IMF, Eurostats, several development banks and country specific policy publications.

The variable **Fiscal Health** provides information the fiscal situation of each observed country measured by the average deficit over three years as ratio between absolute deficit and GDP, and the ratio between debt and GDP. A high score represents a low deficit. The deficit ratio is weighted with 80, while the debt ratio only accounts for 20 percent of the score. Their argument is, high debt and deficit can lead to instability and uncertainty and therefore, reduced economic activity, because in times of uncertainty, investment activities are dampened. Their sources include the IMF, several Development Banks and government publications.

The **Regulatory Efficiency** provides three variables providing information how much regulatory influence is executed by the examined state. This includes aspects of bureaucracy and market flexibility.

Business Freedom provides information how effective and efficient business activities can be pursued in an observed country. A high score indicates no restriction of business activities while a low score indicates the presence of many hurdles that need to be overcome. The variable is the result of 13 sub-factors. Those factors cover aspects such as starting a business, obtaining a license, closing a business and getting electricity. For comparability, the final score is result of comparison with other countries. Their data were sourced e.g. by the Doing Business report of the World Bank and government publications provided by the observed countries.

The **Labor Freedom** variable indicates the overall flexibility and effectivity of the observed countries labour market. It is a quite far reaching measure compared to the other variables provided by the Economic Freedom index because it includes measure of workforce effectiveness, by comparing minimum wage with the average value added per worker, labour force participation rates or the protection against dismissal. A high score indicates an effective labour market with a high degree of flexibility and efficacy. Sources include among others again the Doing Business report and data provided by ILO and the U.S Department of Commerce.

Monetary Freedom assess issues of price stability and price control. A high score indicates a stable inflation rate without any governmental price intervention such as minimum or maximum prices. The values for inflation are normalized to avoid too much bias by extreme values. Their argument is that a stable price development and the freedom to set prices accordingly to the demand promotes economic activity and is therefore positive. Their data relies on sources such the IMF, the World Bank or individual data provided by each country.

The **Open Markets** category provides three variables to examine how open each observed market is for trade, financial transactions and investments. A high score in each variable indicates a globalized market structure with low restrictions for capital flows.

The **Trade Freedom** indicates how many trade barriers exist. The barriers are measured by a trade-weighted average of tariff rates and trade barriers that are not related to tariffs. Those barriers are represented by restrictions such as quantity, price, or customs and furthermore, by direct government intervention such as subsidies and competition policies. The barriers are treated as penalties. Hence, every country's score is 100, subtracted by the existing barriers. A high score indicates therefore low trade barriers. To determine the score, sources such as the World Bank, the World Trade Organization or the World Economic Forum, were used.

A high score in **Investment Freedom** indicates a free flow of capital for investments, regardless of factors such as domestic or foreign origin. It is argued that a free flow of investments is positively associated with growth and allows efficient capital flows. The same principle as for trade freedom applies for this variable as well. Each observed country is scored with 100, subtracted by various investment restrictions. These restrictions cover issues such as the national treatment of foreign investments, a foreign investment code, restriction on land ownerships, capital controls and foreign exchange controls. Their sources include – among others – mainly official government publications along with data provided by the World Bank and the OECD.

Financial Freedom indicates to what extend the banking sector in each country is efficient and how independent it is, respectively how much influence is exerted by the government. A high score indicates an efficient banking sector that is independent from government control. The variable is determined by aspects such as the degree of government regulation concerning financial services, the extend of state interventions by governmental ownership of banks or other financial actors, how open the financial market is for foreign competition and how much influence is exerted by the government concerning allocation of credit. A score of 90 and above indicates almost no governmental interference while of a score of 50 and lower, indicates strong amount of governmental interference where credit allocation for instance is highly influenced by government control. Their sources include the Economist Intelligence Unit, the IMF, the OECD and the World Bank.

4.3.2 Technological Variables from Bloomberg

The two main technological variables have been sources by Bloomberg New Energy Finance. Bloomberg is a distinguished and renowned institution that provided data for hundreds of studies. Their branch of New Energy Finance provides data on various issues concerning renewable energy. Both datasets cover a timeframe from 2010 to 2017 (t=8). Data from previous periods was not available. Consequently, the time frame of analysis is two years shorter, compared to the analysis for economic freedom and its potential impact for the analysis is acknowledged accordingly.

Price per watt for solar modules: As Bazillian and colleagues (2013) point out, the way how to calculate the costs for PV panels is highly discursive. It can be a function of levelized costs of electricity (LCOE), which accounts for individual factors of each unit of observation, e.g. prices for solar PV for individual cities within the same country (Singh & Singh, 2010).

Furthermore, it can be calculated as grid parity, where prices are set into context to conventional energy sources and represent a state were solar PV is more cost efficient than conventional energy production. For this research, it was decided to rely on the measure of **price-per-watt for solar modules** and therefore, follows Bazillian and colleagues' (2013) arguments. The price is calculated by assessing, how much capital, in USD, needs to be invested to generate 1W of energy. Compared to the other two measures, it provides a more simplistic approach that is more suitable for comparison. The LCOE need to be calculated for every observation individually and while this can be reasonable for individual decisions it is unreasonable for this research project. Hence, price per Watt has been chosen as variable to represent factors of increasing economic and technological efficiency and to demonstrate how the maturing of solar PV technology can have an impact on the deployment of solar PV panels.

Price for lithium-ion battery packages: Chapter 3 provides several arguments how the development of storage will determine the success of solar PV technologies. Without sufficient storage, a transition to renewable energy sources will be very unlikely to be achievable. For this research therefore, **the price for lithium-ion battery packages** has been chosen to examine, to what extent the declining development in price for storage influences the individual deployment of solar PV capacities. Lithium-ion battery storage is treated as a representative variable for a new strand of storage technologies (IEA, 2014) besides conventional storage technologies such as hydro. The decision, to use data on lithium-ion batteries was made because of the availability of data. Lithium-ion batteries are utilized in various technologies, ranging from electric cars to smartphones, and therefore, it is a technology that has been researched and developed for a longer time, compared to less mature battery technologies, such as aluminium-ion batteries (Lin et al., 2015) or silicon dominant lithium-ion batteries (Ji, Lin, Alcoutlabi, & Zhang, 2011). Hence, for li-ion battery storage, there is already data available, covering an analysable time frame that potentially allows to make assumptions about the relationship between maturing of new storage technologies and the deployment of renewable energy.

4.3.2 Energy capacities data from Eurostat Data

There are numerous databases available, providing data on the generation of solar energy and other relevant variables. Initially, the OECD’s database was chosen as data supplier, covering variables relates to solar PV energy supply, energy supply in general and CO_2 emissions. After a careful evaluation though, it was decided to rely on data from Eurostat, because it appeared to be more convincing, to use a European data supplier with regards to the sample selection of only EU member states. Eurostat is a database by the European Commission covering various topics. Their “mission is to provide independent high quality statistical information at European, national and regional levels and to make this information available to everyone for decision-making, research and debate“ (Eurostat, 2018, p. 6). In their code of practice, Eurostat (2018) provides convincing arguments how they address issues of reliability and validity, summarized into 15 core principles. Those principles range from “Professional Independence”, “Sound Methodology“, and Accuracy and Reliability” to “Coherence and Comparability” (Eurostat, 2018, pp. 8,13,16,17). Hence, it was decided to trust Eurostat of being a reliable and valid source for this research.

Furthermore, **hydro** and **wind energy** have been included in the analysis, both measured in MW. Furthermore, for both a log transformation has been applied for similar reasons as for solar PV. Hydro energy has been the dominant source for renewable energy for decades. Besides its energy supplying characteristics, it also functions as a storage technology. Therefore, a relationship between solar PV deployment and hydro is very likely to be expected. Wind energy on the other side is a more recent technology, comparable to solar PV. A relationship between solar energy and wind energy was expected, because it reasonable to assume that countries which invest in wind energy also invest in solar PV energy because of a general positive awareness of renewables.

GDP is a commonly used variable to explain the deployment of renewable energies. It is argued that growing economies are more likely to deploy renewables because of their economic vitality. The variable has been therefore included, to create a more robust model. GDP has been log() transformed as well to account for very different values across the sample.

Furthermore, the amount of **energy taxes**, measured in relative terms to GDP, is added to the model to control for its influence. Energy taxes represent a traditional incentive to reduce emissions by appealing to the market's dynamic of striving for efficiency and effectivity. With energy taxes, conventional energy capacities become less favourable and a shift to renewables turn out to be more reasonable.

Greenhouse gas emissions are also included in the model to frame the relationship between the deployment of solar energy PV capacities and their attributes of reducing greenhouse gases.

Additionally, the amount of **combustion energy capacities** is included in the model, to assess the dynamic between renewable energy sources such as solar PV and conventional energy technologies. It has been expected to be a negative relationship between both variables – when combustion capacities are reduced, solar PV capacities increase.

Finally, as dependent variable, energy **supply of solar PV** has been chosen. The variable is measured in MW, a standardized energy unit (Eurostat, 2016) While analysing the raw data, it was evident that the amount of production varies heavily between the member states leading to a skewed distribution. Therefore, it was decided to apply a log (x+1) transformation to the variable to create a more evenly distributed dataset; a practice that has been applied in various studies related to the capacities of renewable energy (Field, Miles, & Field, 2012; Wooldridge, 2016).

4.4 Method of Analysis

The following chapter provides an elaboration why the method of panel regression analysis was chosen for this thesis and how it is applicable. First the method and its characteristics are described referring mainly on Wooldrigde (2010, 2016) to provide an overview about the method; how it can be used and what needed to be considered. This section is followed by explaining how it was applied for this research.

Linear Regression

The simple or bivariate linear regression model is used to examine the relationship between one dependent variable and one independent variables at a given moment. Equation 1 exemplifies this relationship.

$$\text{EQ1} \qquad y = \beta_0 + \beta_1 x + u$$

The outcome of y is a function of x and the error term. As an example, the growth of solar capacity could be a function of GDP growth. For every positively changed unit of GDP, solar capacities would be installed. The error term u represents any factor that is not included in this model and represents a constant. For this model three outputs can be expected. GDP growth could have a positive effect on solar capacities, a negative effect or no effect. This model offers hardly any value and is used to illustrate the basic principles behind panel data regression.

Panel data regression

Panel data modelling is based on the linear regression, only accounting for the time and cross-sectional characteristics of the variables. Hence, it is the perfect method for this approach and enables a longitudinal perspective and therefore, can be used to determine the development of solar energies and how the different influencing factors play a role in it. The panel model is based on OLS regression, the ordinary least squares regression (Croissant & Millo, 2008).

The panel linear model is:

$$\text{EQ2:} \quad y_{it} = \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + a_i + u_{it} \text{ ,}$$

(Wooldridge, 2016, p. 413)

with $a_i$as the unobserved effect, u_{it} is the error, *i* referring to the indicators, and *t* referring to the time.

In my case, *i* refers to the countries from the EU-28 and *t* refers to the years ten-year span from 2008 to 2017. Of course, other unobserved effects a_i may play a role in predicting the model (Woolridge, 2016). These are a systematic variance, that are across all countries the same. However, there may be an error because of country-and time-specific variances (u_{it}) and therefore not possible to infer (Woolridge, 2016). These factors could be for example country size, wealth, effectiveness of electricity distribution or general perceptions of renewables that are not included in the model but have been subject of other research. While EQ2 represents a generic panel function, EQ3 represents the specific relationship applied for this research.

$$\text{EQ3} \quad solar\_cap\_log_{it} = \beta_1 econfree_{it1} + \beta_2 X_{it2} + a_i + u_{it}$$

Therefore, solar capacity growth is a function of economic freedom, control variables (X) such as GDP, unobserved effects (a_i) and the (u_{it}) error term.

As Wooldridge (2016) argues, panel data projects need to be optimised and reasonable, respectively need to fulfil the requirements to create reasonable results. In order to assesses to what extend the provided model fulfils those requirements, several tests and modifications can be conducted. Those, which are relevant for this research are now presented in its generic form, to argue why it is reasonable to include them. The results of each procedure, however, are explained in the following chapter about the actual analysis. This approach has been chosen to provide more distinct arguments for the theoretical and empirical application of each test.

Perfect collinearity

In order to create an accurate OLS model, it is essential that there is no perfect collinearity present in the sample which means that “no independent variable is constant nor a perfect linear combination of the others“(Wooldridge, 2016, p. 318). Therefore, there can be a correlation between the independent variables, however, as soon as they are perfectly correlated, they violate the assumptions for the model. For this research it could be by measuring solar energy growth in MW and thousand tons of oil equivalent or including renewable energy in general and all technologies that determine renewable capacities.

Transforming to log function

The log(x), respectively log(x+1) transformation for values = 0, is a valid method to account for skewed and wide distributions. By applying this transformation, the data becomes more evenly distributed and therefore, better analysable. However, the overall characteristics of the data remain the same. This method is often applied for datasets to create a more evenly distribution of values and therefore more reliable results and furthermore, it reduces heteroskedasticity.

Heteroskedasticity robustness test

For cross sectional and therefore also for panel data, a crucial assumption is: “that the variance of the unobservable, u, conditional on x, is constant” (Wooldridge, 2010, p. 45). In this case the variance is homoscedastic. Usually, perfect homoskedasticity, where the error term’s variance = 0, is rarely found in empiric samples, therefore, heteroskedasticity is measured as a degree, to what extend the variance of u on x is constant. A high degree of heteroskedasticity can provide a serious issue for the explanatory power of a model. For each observation, the explanatory power of the model is different and therefore, hardly any general assumptions can be made because of a high bias for each individual observation, assuming an equal weight for each individual observation. If heteroskedasticity is detected in a sample, a reasonable approach is to use robust standard errors or generalised least square, since standard OLS could create unreasonable results. Another approach could be to use FGLS (Feasible Generalized Least Squares) estimators (Wooldridge, 2010)

Autocorrelation test Durbin Watson test

Autocorrelation, also called serial correlation, is an issue specifically relevant for time series and panel data. Autocorrelation is present, if at a given time, the dependent variable depends on its value of an observation of the past. Therefore, it correlates with itself – is autocorrelated. A common way of testing for autocorrelation is the Durbin Watson test (Durbin & Watson, 1950). It is deduced by the residuals of an OLS and assumes only exogenous explanatory variables (Wooldridge, 2016). Its value (DW) is closely related to the p^ value and therefore, indicates whether autocorrelation is present on a significant level. If the autocorrelation is present, the explanatory power of the model is biased because much of the growth or decrease of the dependent variable is subject of its past values instead of changes in the explanatory/independent variables. As a general assumption, a DW-value that is smaller than 2, on a significant level, characterises positive serial correlation while a DW value between 2 and 4 characterises negative serial correlation (Wooldridge, 2016). A value of 2 therefore, represents no serial correlation

Pooled, fixed or random effects

For panel data there are several possibilities to conduct a regression analysis. One of the most prominent is the so-called pooled cross section that is not a “real” panel data and sources its observation from a large population across a given time. Those time periods are treated as dummy variables and then analysed by the same procedure as a cross-section analysis. Since this research relies on a specific population, the EU, this method was not applicable. The random effects model assumes non-specific effects of each of the observed induvial relating to the error term $u_{it,}$ (Wooldridge, 2010) So in a random effects model, there are factors involved, that cannot be explained by the individual or time. Fixed effects on the other side assume specific effects by the observed unit *i*, the time *t* or both. A way to test for either random or fixed effects is to conduct the so-called "Hausman-Test" or "Durbin-Wu-Hausman-Test" (Hausman, 1978) "which is based on the difference of the vectors of coefficients of two different models" (Croissant, 2019, p. 75)

4.4.1 Data preparation

The data was collected all at the same time, but time variances were unlikely to be expected because of the data's historic character. The datasets were acquired either in .csv or .xlsx format directly of the data creator. The Eurostat data needed to be manually collected to guarantee a similar data structure, while the economic freedom and the technological datasets were acquired automatically. The calculations and preparations are in R with the package plm (Croissant, 2019) and ExPanDaR (Gassen, 2019). The function plm from the package plm conducts a linear regression for panel data. The ExPanDaR package is used for visualizations of the panel data. The R documentation is included in the appendix 2.

Firstly, I loaded the data which is in the form of a csv table into the R Workspace using the function read.csv() and the data in excel format using read_excel(). Next, I renamed the variables referring to the country and year so that both were written exactly the same / used exactly the same syntax. Further, the data type needed to be changed so that year is a numeric variable and country a factor variable using the functions as.integer() and as.factor() respectively.

After collecting the datasets, they were harmonized using the R merge () function to create a consistent panel data set that was balanced. However, this step needs to be undertaken with great caution, because the variables that serve as identifiers for merging the data sets need to be exactly similar. Nonetheless, there were inconsistencies identified before creating the final dataset for analysis. They occurred for instance in varying names for countries such as Czechia and Czech Republic, different labelling of variables, or types of separators. The resulting data set is a combination of energy data on the countries over the selected time span together with the belonging economic freedom indexes.

While examining the dataset and the distribution of solar energy capacities, it became clear that there is a high discrepancy between the different member states. While some states did not deploy any solar PV capacities, such as Estonia, others such as Germany or Italy, included solar energy capacities as crucial part of their energy mix. As a consequence, it was decided to create a sub-sample consisting of the 5 countries which provide the most solar PV energy capacities. Although this mostly allows conclusions about those 5 countries, it appeared to be reasonable to use them as representative countries for more mature solar energy markets.

In preparation for the panel analysis, I convert the data in an object pdata.frame from the plm package which assigns the index to the data. In my case, country and year are defined as the indexing variables. This has been done for both the full EU data set as well as for the Top5 solar energy producing countries.

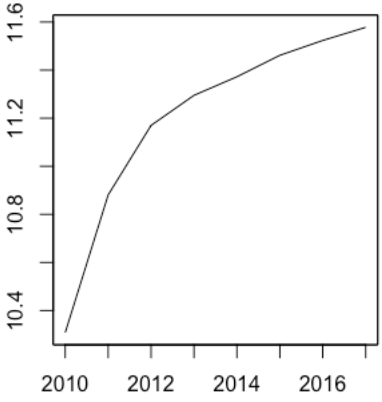
Additionally, the variables for the energy capacities as well as the control variables GPD and energy greenhouse gas emissions have been log transformed. According to Wooldridge (2016) it is a common technique of econometrics to normalize the observations and account for issues of unevenly distributed observations – skewedness and kurtosis – and furthermore reduces the impact of potential heteroskedasticity which was expected to be a biasing aspect for this sample. There was a high variation expected between the different state and their solar capacities. Especially because solar capacities were measured with their actual value in MW instead of relative measures, such as the share of solar PV of the overall energy mix.

Furthermore, regarding the technological variables, I had to take a slightly different approach because it would not be feasible to conduct a panel analysis were very subject of observation – in this case countries – would have the same value at any given point of time. The prices for PV panels and lithium ion batteries are all the same for every country at every time of observation. According to Wooldridge (2011) this is a strict violation of the assumption made for panel data analysis with multiple units of observation. Therefore, I created a second data set and matched these variables with the solar capacity values for the EU in total. Again, the identifying variable year had to be the same in both data sets. Data for the prices for PV panels and lithium ion batteries are available from 2010 to 2017.

4.4.2 Descriptive statistics – Examining the data set

Firstly, in order to gain an overview of the data set, I conducted descriptive data analysis beginning with the large data set for the individual EU countries. The data set contains 280 observations, emerging from the 28 EU countries over the time span of 10 years. On average across all countries and all years, 2325.92 (*SD* = 6533.21) MW solar energy using PV was produced, ranging from 0 to 42337 MW.

Figure 2. Development of solar PV capacity for the EU.



The overall EU solar PV capacities were rapidly growing (figure 2) within the time frame from 2010 to 2017. Similar to the country-individual data on solar PV capacities, it becomes evident that growth in solar PV capacities started rapidly but stagnates over time.

Figure 4. Histogram of solar PV capacities for all countries over time.

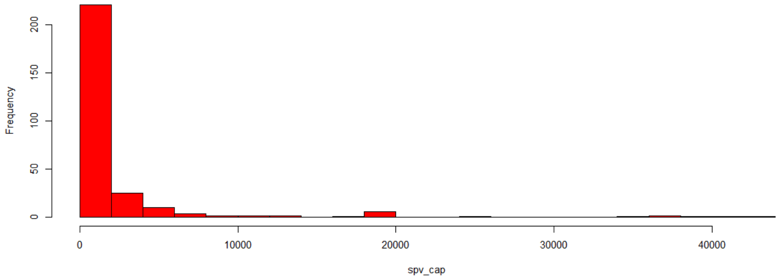
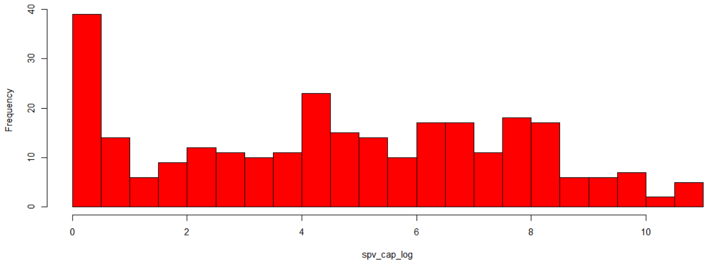


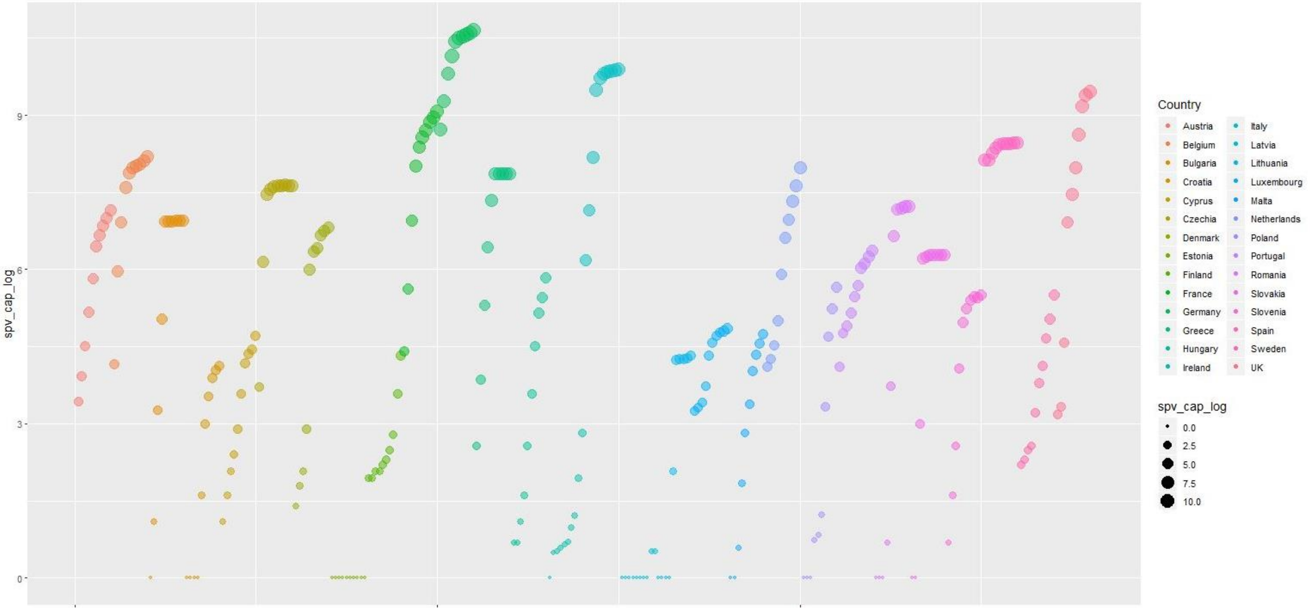
Figure 3. Histogram of log transformed data for social PV capacities for all countries over time.



When looking at the main variable, solar energy capacity, it is interesting to note that using the log transformed data is of great relevance. The raw data of the solar PV capacities is very broadly spread; frequency refers to observations which is a combination of the countries and time points with zero solar energy production. With a lot of countries (observations) producing none or only very small amounts of solar energy while on the other hand, there are a few countries generating large amounts of solar energy. Utilizing a log transformation leads to more comparable data and creates a more evenly distribution. Now, calculations with solar PV capacities are more feasible.

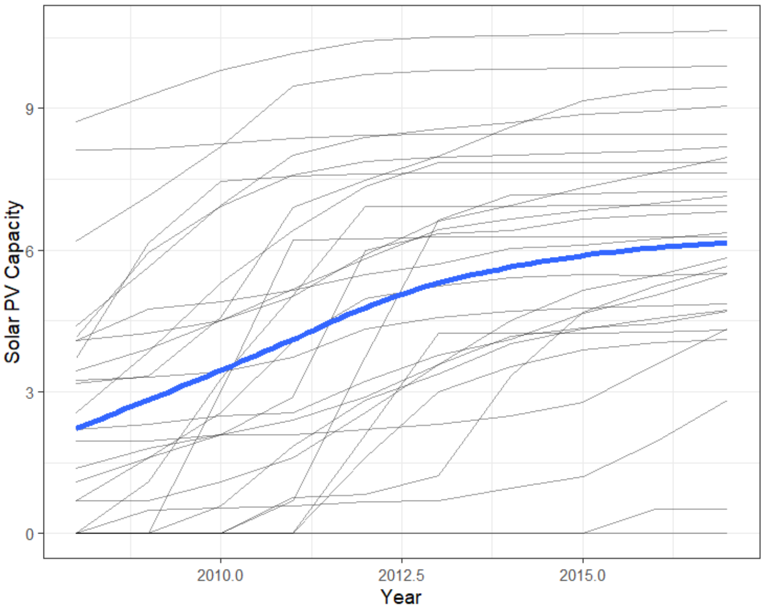
The following scatterplot (figure 5) displays the solar PV capacities for each country (indicated by the different colours) over time (indicated by same-coloured points sorted by time) with increasing dot size representing greater capacities of solar PV. It becomes evident that solar PV capacities are increasing over time, however, there are differences how much. Great differences can be observed as the starting point of solar PV capacities in 2008 but also by how much the capacities have grown over the ten years of observation.

Figure 5. Scatterplot displaying solar PV capacity (log) for each country over time.



When examining the development of solar PV capacities over time for all countries individually, the rising tendency can be observed. Every state with a mature solar PV industry faces declining growth at a certain threshold. Figure 6 displays more accurately the development of each country over time. It can be observed that countries already providing much solar PV capacities in 2008 still increased their solar PV capacities for the following years, however by far not as rapidly as the countries with lower solar PV capacities in 2008.

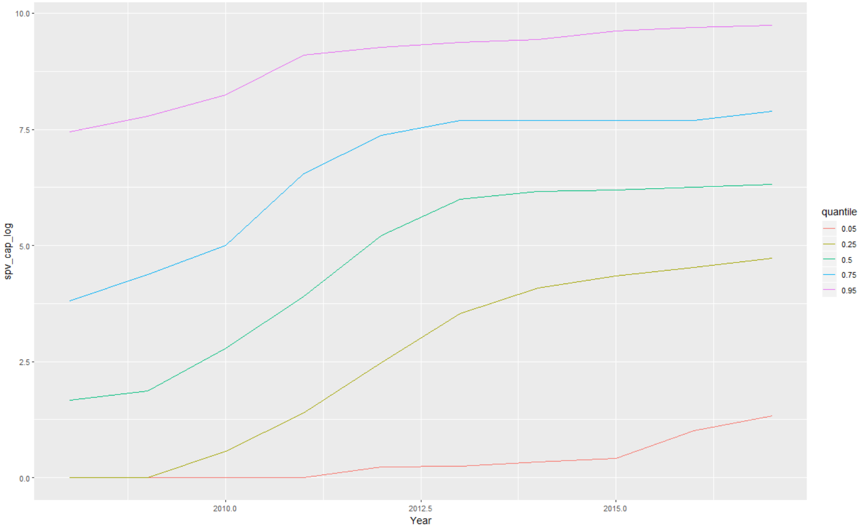
Figure 6. Development of solar PV capacity over time. Each line represents a country with the blue line showing the overall trend.



For those, at the beginning lower capacities providing countries, an increased growth of solar PV capacities can be observed. The overall trend of solar PV capacities appears to be that at some point, the possible capacities are exploited, and growth of capacities stagnates. The previously stated assumption that solar PV capacity development would behave in the form of an S-curve can be examined in this data (at least the last part of the S).

This trend of greater growth in countries with lower solar PV capacities in the beginning of this examination can also be observed in figure 7. Countries with very limited or no solar PV capacities in 2008 are rapidly increasing their solar capacities, while countries already generating a lot of solar PV are declining in their growth of solar energy production.

Figure 7. Quartiles of the development of solar PV capacity over time.



In table 1, descriptive values from all energy-related variables are displayed. Comparing solar PV capacities with the other renewables wind and hydro it can be observed that solar PV capacities are on average far lower than the others (table 1).

Table 1. Descriptive statistics of the energy variables.

	N	M	(SD)	Min	Max
Energy data					
Solar PV capacities	280	2325.924	(6533.207)	0.000	42337.000
Hydro capacities	280	5358.026	(7137.425)	0.000	25706.055
Wind capacities	280	4048.744	(7953.711)	0.000	55718.000
Combustion capacities	280	15380.235	(21361.856)	61.466	87747.000
Energy greenhouse gases	252	128140.183	(179468.925)	1426.850	820242.380
Log transformed data					
Solar PV capacities (log)	280	4.632	(3.067)	0.000	10.653
Hydro capacities (log)	280	6.902	(2.847)	0.000	10.155
Wind capacities (log)	280	6.341	(2.679)	0.000	10.928
Combustion capacities (log)	280	8.763	(1.412)	4.135	11.382
Energy greenhouse gases (log)	252	10.876	(1.407)	7.263	13.617

Note. All values for the raw energy data are in MW (megawatt), M = mean, SD = standard deviation, Min = Minimum, Max = Maximum.

However, when looking at the time trends across all countries, it becomes evident that solar capacities have grown rapidly while hydro and wind capacities were not growing as much. It seems as if solar PV capacities are on the edge of catching up to the capacities of these renewables.

Figure 8. Time trend for the renewable energies across countries.

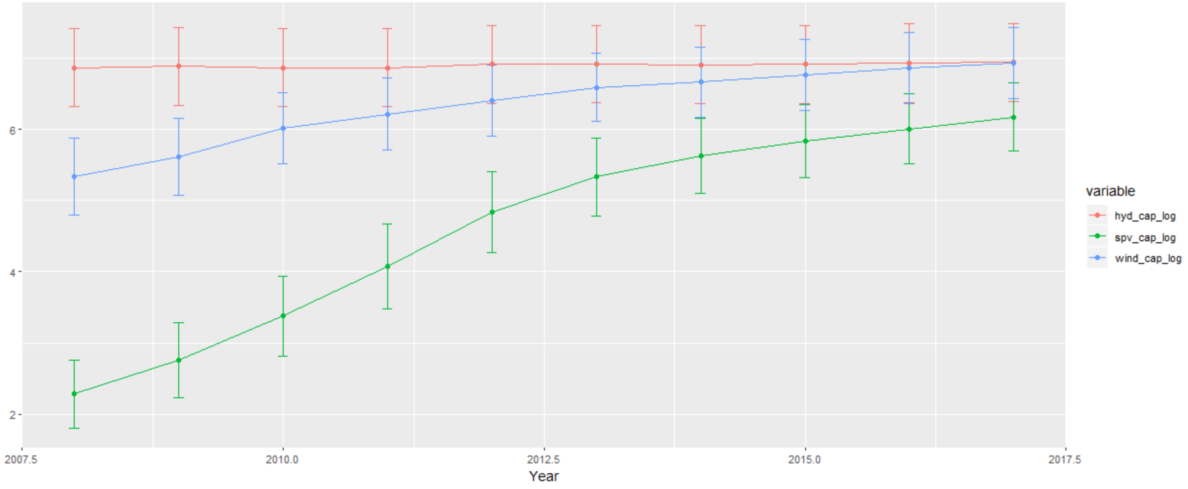


Table 2 summarizes the descriptive statistics of the economic variables that might influence solar PV capacities across all countries over time.

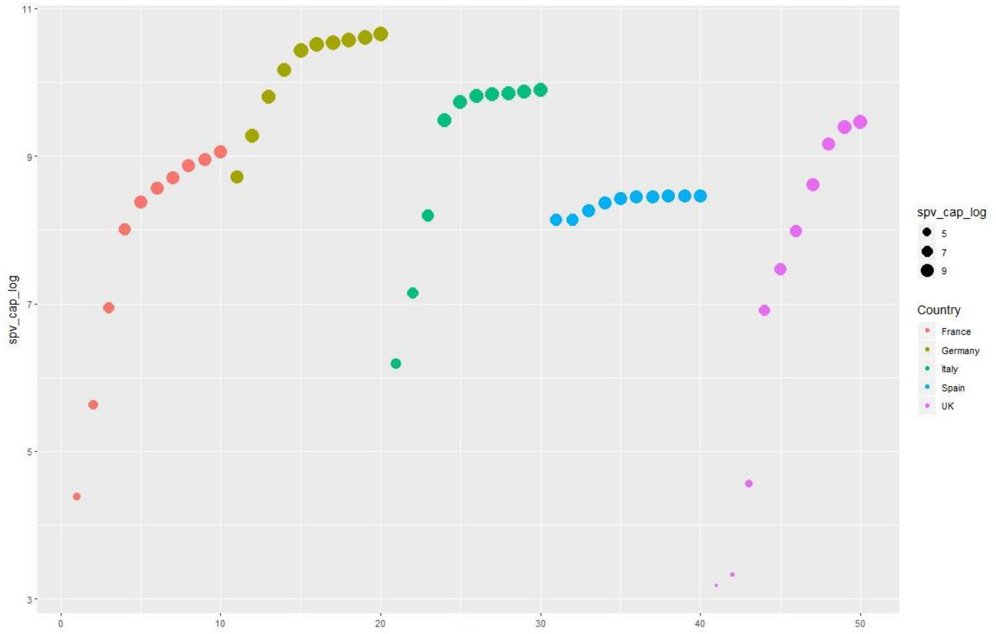
Table 2. Descriptive statistics for all economic variables.

	N	M	(SD)	Min	Max
Economic freedom					
Property rights	280	70.628	18.670	30.000	95.000
Government integrity	280	63.205	17.559	31.000	96.000
Judicial effectiveness	28	65.382	13.505	38.000	93.000
Tax burden	280	66.236	14.782	32.700	94.000
Government spending	280	36.740	17.556	0.000	70.800
Fiscal health	28	72.518	24.096	6.100	99.800
Business freedom	280	79.031	10.038	53.700	100.000
Labour freedom	280	60.225	13.525	31.000	91.700
Monetary freedom	280	80.419	3.790	67.000	88.000
Trade freedom	280	86.654	1.738	80.800	95.000
Investment freedom	280	77.696	11.094	50.000	90.000
Financial freedom	280	68.893	11.447	40.000	
Extended economic variables					
GDP (log)	280	12.018	1.569	8.721	15.003
Energy taxes	280	2.594	.611	2.510	4.170

Note. M = mean, SD = standard deviation, Min = Minimum, Max = Maximum.

Now, to acquire a deeper understanding after looking at the whole data set, it is of interest to examine the top 5 solar PV capacity producing countries: Germany, Italy, UK, France, and Spain. Figure 90 shows the development of solar PV capacities for each year (colors) over time (from 2008 – 2017).

Figure 9. Scatterplot displaying solar PV capacity (log) for the Top 5 countries over time.



Regarding the technological variables (table 3), it can be observed that prices for lithium-ion batteries as well as prices per watt for solar modules both sank over the observed time frame from 2010 to 2017. Figure 10 shows the development for Li-ion prices over time and figure 11 shows the development of PV capacity prices; both decreasing.

Figure 10. Prices for Lithium-ion batteries.

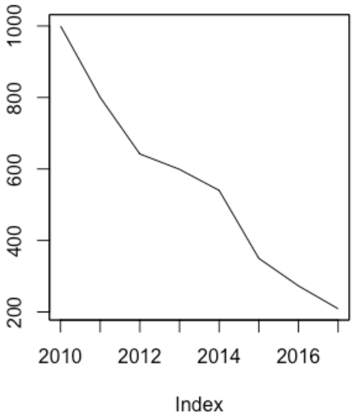


Figure 11. Prices for PV solar modules

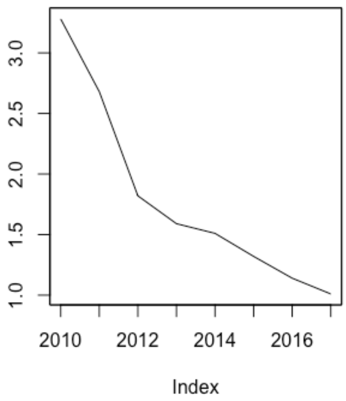


Table 3. Descriptive statistics for the technological variables.

	N	M	(SD)	Min	Max
Technology					
Prices for PV solar modules	8	1.794	0.791	1.010	3.280
Prices for Li-ion batteries	8	551.625	269.644	209.000	1000.000

Note. Price per watt PV solar module in US$, price for lithium-ion battery package in US$, M = mean, SD = standard deviation, Min = Minimum, Max = Maximum.

5. Results

The method `plm` is used in R to calculate a panel model is based on the linear model (Croissant & Millo, 2008). The basic formula is similar to that of `lm` and uses an analogous notation. The panel regression model is used to examine the effects of economic, energy factors influencing solar PV capacities. Besides those main predictors, I include several other variables, such as the deployment of other renewables, CO_2 emission and size of economy, measured by GDP. These are included in a more exploratory model. Prior to the analysis, the balance of the data has been proven by the plm is.pbalanced() function. There is an observation for every unit (country) at any given time of the observation. The modelling process follows the process described by Wooldridge (2015), consisting of model creating and model testing. The model was first created, and country specific fixed effects were expected by relying on an OLS estimator. The fixed effects assumption is supported by conducting a Hausman test. Additionally, an FGLS estimator model has been used to account for heteroskedasticity.

5.1 Economic model

Regarding RQ1 examining economic freedom, I calculated a panel data regression predicting the amount of solar energy capacity deployment, considering all variables of the index. In a second, advanced model, the control variables GDP and energy taxes per capita were additionally included in the analysis.

First, the indices of economic freedom are included in the plm as predictors of solar PV capacity for each country over time. Due to lacking data in the timespan from 2008 to 2015 for fiscal health and judicial effectiveness, these dimensions of economic freedom have been excluded from the analysis. Table 3 shows the result of the panel regression. The overall model explains 51.16% variance in the data and is significant, $F(10, 242) = 23.35, p < .001$. Tax burden is a significant of solar PV capacities, with increasing tax burden solar PV capacities decrease. This means investors in solar PV seek for countries with rather low taxes. Labour freedom is significantly predicting solar PV capacities and shows a relationship between decreasing labour freedom and solar capacity growth. Therefore, in countries with higher labour protection, solar energy is more likely to be installed, compared to highly flexible labour markets.

Monetary freedom, trade freedom and investment freedom are also significant predictors of solar PV capacities, with increasing values of each variable, solar energy capacities are more likely to be installed. This finding promotes the arguments provided in chapter 3. All three variables relate to a good investment environment, with easy access to capital and a globalized market structure, solar PV capacities grow. Government spending is also a significant predictor, with increasing government spending the solar PV capacities increase (high values mean low government spending). This highlights the importance of subsidies and other government interventions in the renewable energy market. Solar PV growth is negatively related with the government spending variables which provides evidence that more government spending could lead to better market situations for solar PV investors. Comparing those results to other studies, this relationship is reasonable and shows that solar PV does not seem to be vital independent from state intervention. This assumption is based on assuming government spending makes it more likely that solar PV promoting policies, such as feed-in tariffs are implemented.

Property rights, government integrity, business freedom as well as financial freedom are no significant predictors of solar PV capacities in the model. This indicates on the one hand that individual business factors do not have an impact on the deployment of capacities. On the other hand, the overall government structure seems also not related to the growth of solar energy capacities.

Table 4. Results of the panel regression for the economic freedom model and extended economic model.

	Solar PV capacities (log)			
	Economic freedom model		Extended economic model	
Economic freedom				
Property rights	.026	(.015)	.020	(.014)
Government integrity	- .015	(.021)	- .032	(.020)
Tax burden	.142***	(.031)	.139***	(.029)
Government spending	- .046***	(.010)	- .038***	(.010)
Business freedom	- .011	(.025)	.029	(.025)
Labour freedom	- .046**	(.017)	- .050**	(.016)
Monetary freedom	.128***	(.026)	.047	(.028)
Trade freedom	.477***	(.088)	.308***	(.087)
Investment freedom	.077***	(.015)	.047**	(.015)
Financial freedom	- .017	(.021)	- .020	(.020)
Extended economic variables				
GDP (log)			6.218***	(1.00)
Energy taxes			1.075**	(.394)
R^2	.512		.580	
Adj. R^2	.437		.511	

Note. Panel regression with OLS, within model. Values represent the *b* values. Standard errors are in parentheses.
* p < .05,.** p < .01. *** p < .001

In order to test the robustness of the model, tests for heteroskedasticity (Breusch & Pagan, 1980), serial correlation (Durbin & Watson, 1950) and fixed or random effects (Hausman, 1978) were conducted. The conducted tests show that there is heteroskedasticity present in the OLS model, Furthermore, minor positive serial correlation is present and fixed effects modelling is confirmed. The issue of heteroskedasticity however does not represent a major obstacle for the prediction capabilities of this model (Field et al., 2012; Wooldridge, 2010) because the selected sample is covering every state in the EU and therefore, does not represent a random sample of a population. The detailed values for each test are included in the appendix 1.

Because the tests detected some issues with heteroskedasticity, the panel regression has been calculated using FGLS instead of OLS (table 5). Results however, are similar to those of the other regression model. For the economic model, tax burden, government spending, monetary freedom and trade freedom are significant predictors of solar PV capacities.

Table 5. Results of the panel regression using FGLS for the economic freedom model and extended economic model.

	Solar PV capacities (log)			
	Economic freedom model		Extended economic model	
Economic freedom				
Property rights	.008	(.008)	.011	(.006)
Government integrity	- .006	(.014)	- .013	(.011)
Tax burden	.048*	(.019)	.042*	(.017)
Government spending	- .020**	(.007)	- .015*	(.006)
Business freedom	- .017	(.016)	- .004	(.013)
Labour freedom	- .019	(.011)	- .020*	(.009)
Monetary freedom	.042**	(.016)	.007	(.015)
Trade freedom	.208***	(.059)	.114*	(.054)
Investment freedom	.025	(.013)	.016	(.011)
Financial freedom	- .002	(.016)	- .011	(.014)
Extended economic variables				
GDP (log)			5.100***	(7.02)
Energy taxes			.987***	(.265)
Multiple R^2	.80		.580	

Note. Panel regression with FGLS, within model. Values represent the *b* values. Standard errors are in parentheses.
* p < .05,.** p < .01. *** p < .001

Second, the extended model is calculated including GDP and energy taxes as control variables besides the variables of economic freedom (table 4). Both variables are enhancing the model, now accounting for 57.97 % of the variance and is significant, $F(12, 240) = 27.59$, $p < .001$. GDP is a significant predictor of solar PV capacities. With increasing GDP, the more the solar PV growth over time within a country. This indicates that wealthier countries are more likely to deploy solar PV capacities

Additionally, energy taxes per capita is significantly predicting solar PV capacities, with increasing energy taxes, solar PV capacities also increase. This indicates that energy taxes could be a promising policy to promote solar PV capacities. A test for robustness is included in appendix 1. Again, a panel regression using FGLS instead of OLS has been calculated (table 5).

5.2 Energy model

With regard to other renewable energy capacities, I calculated a further panel regression with plm(). A panel regression model was calculated to predict solar PV capacities based on hydro and wind capacities, combustion capacities and energy greenhouse gases (table 6).

Table 6. Results of the OLS panel regression for the energy model.

	Solar PV capacities (log)	
	Energy model	
Hydro capacities (log)	.899	(.966)
Wind capacities (log)	.794***	(.117)
Combustion capacities (log)	.232	(.503)
Energy greenhouse gases (log)	- 8.227***	(.945)
R^2	.542	
Adj. R^2	.477	

Note. Panel regression with OLS, within model. Values represent the *b* values. Standard errors are in parentheses.

* p < .05,.** p < .01. *** p < .001

This model is significant, *F* (4, 220) = 65.06, *p* < .001, and helps explain 54.19% variance. Hydro capacities are no significant predictor of solar PV capacities. This mean solar capacities are not related to hydro capacities; the capacity growth of these two renewable energies seems to not influence each other. However, wind capacities significantly predict solar PV capacities. This means that with increasing wind capacities also solar PV capacities increase. The non-significant effect of hydro power could be related to the observed time frame and to the fact that hydro power is a well-established and mature technology. Another model, predicting whether high solar capacities influence solar growth, might create another relationship.

Combustion capacities, furthermore, do not significantly predict solar PV capacities. One might infer that combustion capacities are provided anyways, and solar PV is not influenced by this. Energy greenhouse gases are a significant predictor of solar PV capacities. With increasing solar PV capacities, energy greenhouse gases decrease. This means, solar PV capacities contribute to decreasing greenhouse gases. Tests for robustness are included in appendix 1. Results of the panel regression using FGLS are in table 7. The results are very similar to the previous model using OLS.

Table 7. Results of the panel regression using FGLS for the energy model.

	Solar PV capacities (log)	
	Energy model	
Hydro capacities (log)	.996*	(.966)
Wind capacities (log)	.796***	(.117)
Combustion capacities (log)	.257	(.503)
Energy greenhouse gases (log)	- 4.281***	(.945)
Multiple R^2	.860	

Note. Panel regression with FGLS, within model. Values represent the *b* values. Standard errors are in parentheses.

* p < .05,.** p < .01. *** p < .001

5.3 EU's top five solar PV energy producer model

Similar results can be observed for the panel regression using only the top 5 countries. Within this subset of the top 5 solar PV capacities producing countries, the same panel regression models have been calculated to examine whether similar dynamics emerge, helping to explain solar PV capacities (table 8). In this sub-sample, the panel regression with the economic freedom indices on solar PV capacities is significant, F (10, 35) = 5.79, $p < 0.001$, and helps explain 62% of the variance. Within this subset, property rights are significantly predicting solar PV capacities, with increasing property rights, the solar PV capacities also increase. This indicates that for those countries the protection of intellectual and actual properties promotes the deployment of solar PV capacities. However, property rights as significant predictor is unique to this sample, within the overall sample of all EU countries, this has not been significant (yet marginally significant). Similar to the previous model, with decreasing government integrity solar PV capacities increase.

Calculating an extended economic panel regression model as before including GDP and energy taxes, the overall model is significant, F (12, 33) = 15.29, $p < 0.001$, and helps explain 85% of variances. In this model, besides the two previously mentioned factors, also labor freedom and GDP are significant predictors of solar PV capacities.

Table 8. Results of the panel regression for the Top 5 solar PV capacity producing countries for the economic freedom and extended economic model.

	Solar PV capacities (log)			
	Economic freedom model		Extended economic model	
Economic freedom				
Property rights	.102*	(.046)	.080*	(.014)
Government integrity	- .187*	(.086)	- .142*	(.020)
Tax burden	.064	(.072)	- .012	(.029)
Government spending	- .038	(.039)	- .004	(.010)
Business freedom	- .100	(.069)	.043	(.025)
Labour freedom	- .071	(.038)	- .083**	(.016)
Monetary freedom	- .098	(.065)	- .054	(.028)
Trade freedom	.130	(.194)	.019	(.087)
Investment freedom	- .032	(.048)	- .010	(.015)
Financial freedom	- .031	(.048)	- .004	(.020)
Extended economic variables				
GDP (log)			11.511***	(1.00)
Energy taxes			.390	(.394)
R2	.623		.848	
Adj. R2	.473		.773	

Note. Panel regression with OLS, within model. Values represent the *b* values. Standard errors are in parentheses.
* p < .05,.** p < .01. *** p < .001

Similarly, for this subset, other energy variables have been examined in a panel regression (table 9). The overall model is significant, F (4, 36) = 91.37, $p < 0.001$, and helps explain 91% of the variance. Only wind capacities are significantly affecting solar PV capacities. With increasing wind capacities, solar PV capacities are also increasing. However, unlike the EU sample, in this subset energy greenhouse gases are not significantly predicting solar PV capacities and also not negatively associated. This means, contrary to the findings above, despite increasing solar PV capacities, energy greenhouse gas emissions are not decreasing. This indicates that the top 5 solar PV capacity producing countries might (still) relay on conventual energy sources producing greenhouse gases that lead to this effect. This trend can be observed in figure 12 which displays the development of solar PV capacities compared to energy greenhouse gases.

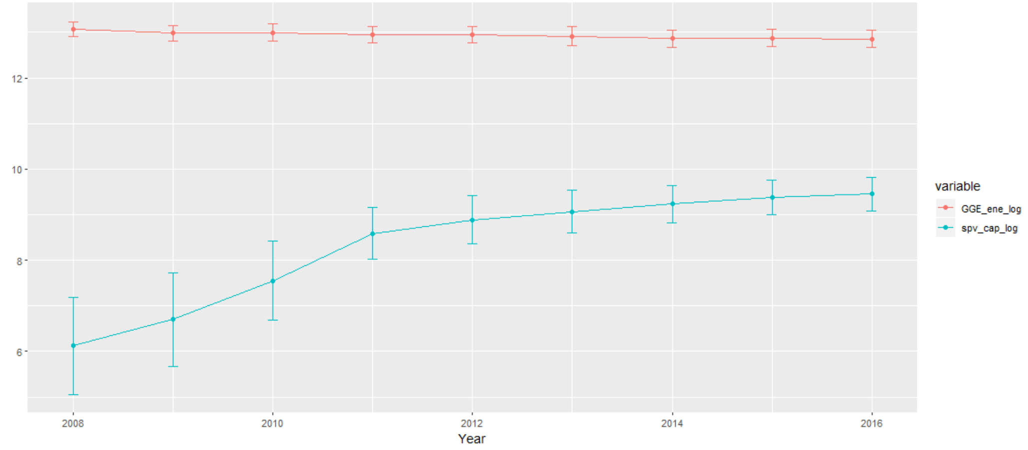
Table 9. Results of the panel regression for the top 5 solar PV capacity producing countries for the energy model.

	Solar PV capacities (log)	
	Energy model	
Hydro capacities (log)	.720	(-5.209)
Wind capacities (log)	4.156***	(.344)
Combustion capacities (log)	.078	(1.120)
Energy greenhouse gases (log)	1.498	(1.925)
R2	.910	
Adj. R2	.890	

Note. Panel regression with OLS, within model. Values represent the *b* values. Standard errors are in parentheses.

* p < .05,.** p < .01. *** p < .001

Figure 12. Time trend for solar PV capacities and energy greenhouse gases over time



5.4 Technological Model

With regards to RQ2 assuming prices per watt for solar modules and prices for lithium-ion batteries affect solar PV capacities, I calculated a multiple regression (table 10). The overall model is significant, F (2, 5) = 83.73, $p < 0.001$. Results of the regression indicate a significant effect of prices for PV capacities on solar PV capacity, with decreasing prices for PV capacities, solar PV capacities grow. There is no significant effect, however, of lithium-ion batteries. This means the continuously decreasing prices for solar modules significantly affect growth in solar PV capacities within the EU. However, the decreasing prices for lithium-ion batteries do not significantly affect solar PV capacities. The overall model design though, could also be an influencing factor for this development. As mentioned in the previous chapter, lithium ion battery prices have been used as a proxy for an overall development of new storage technologies, but they are mainly used for a variety of other technologies such as phones or cars and as Sivaram (2018, p. 82) puts it, they are no “silver-bullet” for the capacity problem .

Table 10. Results of the regression for the technological model.

	Solar PV capacities (log)	
	Tech model	
(Intercept)	.121***	(.008)
Prices for PV solar modules	- .534*	(.140)
Prices for Li-ion batteries	.000	(.000)
Multiple R2	.971	
Adj. R2	.959	

Note. Regression with OLS, within model. Values represent the *b* values. Standard errors are in parentheses.

* p < .05,.** p < .01. *** p < .001

6. Discussion

Research question 1 asks if market liberalization can predict the deployment of solar energy PV capacities in the EU. By evaluating the results of this analysis, the answer to this question is neither yes nor no. Instead, a careful analysis shows that there are factors of market liberalisation that apparently have a positive and significant effect on the deployment while other factors appear to be negatively associated with the deployment of solar PV. Therefore, it is worthwhile to examine those associations more specifically and discuss its implications.

Both the OLS and the FGLS models predict a negative association between a high EFI government spending score and the deployment of solar energy capacities. This means that countries were the government is spending more, the chances solar PV capacities growth are higher. The implications for this dynamic are manifold. It could indicate that solar PV panels did not reached its maturity and therefore grow stronger in states where they can be more easily subject of subsidies, including feed-in tariffs. The link between the government spending value and supporting policies lies in the assumption that states which are more willing to spend, are more likely to interfere in the market. However, this could serve as one explanation amongst others. Less controversy lies in the assumption that solar PV needs government support in order to grow in Europe. Although there have been many advancements in the technology solar PV, it still seems to be insufficient to create a completely integrated technology that is competitive without extensive government support.

The model further shows that lower tax burden is associated with solar PV capacity grow. This indicates that solar energy PV investors appreciate market conditions where the tax burden is decreased, and their expected revenue is a higher. This dynamic provides further evidence for understanding solar energy PV as an investment good that is subject to dynamics which also affect other investments good.

Labour freedom on the other side is negatively associated with solar energy PV growth. Therefore, it can be expected that in countries who offer high labour protection solar PV capacities are more likely to be deployed. The reason for this dynamic could lie in the nature of required interventions for the solar PV market. In markets where state provides an extensive labour support, governmental intervention could be more likely in general. Hence, when PV capacities are deployed, they will be more likely the subject of policies, supporting the deployment. This dynamic provides further arguments that solar energy does not appear to be fully mature to exist without government support.

Interestingly, business freedom is not significantly associated with solar PV capacity deployment. This could be related to the nature of investment type for capacity building. Since they represent an infrastructure investment, aspects such as obtaining licenses or starting a business are most likely no issues of concern for investors because they are already more institutionalized actors instead of start-up companies that most likely will not deploy significant solar PV capacities. Albeit, solar PV offers several possibilities for decentralized deployment of small but numerous capacities.

The model shows a positive association between trade freedom and solar PV capacity growth. Since solar PV panels are mainly produced in China (Philipps & Warmuth, 2019), this dynamic appears to be reasonable. Trade-barriers would reduce the attractiveness to import PV panels and consequently, would make them less interesting as subject of investment. Unless Europe recovers its own solar industry, this aspect is likely to be an essential part of PV deployment. The situation could change for the EU thus, by introducing a new technology that outpaces the qualities of China's silicon-based panels. Still, this association provides clear arguments for the EU's dependence on imports for the deployment of solar PV capacities.

Investment freedom is positively associated with the deployment of solar PV capacities. This relationship confirms the assumption of solar energy capacities as a versatile investment. Attractive conditions for domestic and foreign investors therefore seem to promote the deployment of solar energy capacities in the EU. Considering the other results, it seems that renewable energy capacities are especially perceived as interesting investment opportunities, when there is a sufficient governmental support. Although this analysis took a different path to explain the relationship between market liberal policies and the growth of solar PV capacities, it creates a comparable picture where deployment appears to be attractive especially in supporting countries (Polzin et al., 2019) and therefore, there is are convincing arguments that solar energy PV did not reach competitive maturity in the years from 2008 to 2017. Nonetheless, there are supportive arguments that solar energy grows in countries with an effective and liberal investment system. This dynamic puts the case of solar PV capacity growth in a hybrid state, where it can develop either in one or the other direction. If there is sufficient support, aspects of an effective investment environment have a positive effect, while in an unsupportive environment, solar capacities might be treated as unattractive investment.

In the controlling model, GDP and environmental taxes are both positively and significant associated with the deployment of solar PV capacities. This dynamic confirms previous studies (Abolhosseini & Heshmati, 2014; Polzin et al., 2019) related to both indicators and additionally, provides some interesting implications for European policy makers. First it appears that solar energy capacities are more likely to deployed in stronger economies. This is reasonable considering the fact that they are still subject of government support. If a country is wealthier it can be realistic to assume that they are more willing to support renewable capacities while for less wealthier countries it is more difficult to support solar PV compared to conventional capacities. Since the log values of GDP have been used, it has been accounted for the differences in magnitude for the sample and instead focuses on growth. Expanding the perspective outside the EU, a comparable pattern seems to be evident, at least for India and China. Both currently represent major growing economies and both are heavily investing in solar PV domestically (IEA, 2018b; Thapar et al., 2016; Yuanyuan, 2016). A reason for this dynamic could also lie in the circumstances described in chapter 3, how it becomes more rational to invest in renewables when accounting for the long-term costs of climate change (Stern, 2007). Therefore, out of a short-term perspective with a constraint government budget, it appears to be reasonable to avoid support for solar PV in favour of conventional fuels. Thus, considering a situation with more available funds and an adequate anticipation of long-term costs it is only reasonable to invest in renewable energy capacities. Consequently, it can be argued that solar PV capacity support is especially possible for those countries which inhibit the luxury to plan for future generations without constraining the current generation’s comfort. Relating to environmental taxes, the applied model provides evidence for the positive effect of taxes as method of intervention to correct the market towards more solar energy capacities. This relationship could be interesting for policy makers, since it promotes the argument that effective intervention in the market can steer it into the desired direction. But it needs to be carefully assessed and designed.

Furthermore, wind and solar PV energy capacities appear to have a reinforcing effect. If wind energy capacities grow the same accounts for solar PV capacities. This dynamic implies that countries which are in favour of renewable energy technologies, besides hydro, are more likely to create combined capacities instead of focusing on one technology. By examining for instance, the energy plan of Germany for 2030, they explicitly state a joint energy support of wind and solar energy (BMWI, 2017). Therefore, an energy mix of several renewable energy technologies could be reasonable however, in Germany, the solar PV capacities are stagnating since 2015[5] (IEA, 2018a).

Regarding research question 2 there have been several dynamics identified. The decreasing prices for solar energy panels seem to predict some of the deployment of solar PV capacities in the EU but they do not seem to be the essential driver. Lithium-ion battery prices, furthermore, do not offer significant value to predict the development of solar PV capacities in the EU. However, a clear pattern became evident, that solar PV capacity are reaching a natural limit, when they represent a certain share of the country's energy mix. This was especially evident for Germany and Italy. In general, this leads to the conclusion that solar energy in Europe is only capable to reach a certain market penetration and decreased prices do not seem to be capable to compensate for this dynamic. As is described extensively in chapter 3.1. the reasons could lie in issues of grid stability, value deflation, or as described in chapter 3.3 in the diminishing policy support. This thesis cannot provide an empirical justifiable answer why this dynamic is observed and instead offers hints that could be further examined.

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[5] Furthermore, it is interesting that while Germany increased their share of renewables dramatically, their amount of emitted climate gases remained almost constant (Eurostat, 2019).

Considering the results of this study, it can be argued that a general paradigm shift is required for the understanding of solar energy PV capacities. One perspective can relate to acknowledging that solar energy is only feasible to a certain extend of market penetration. Every state, examined in this thesis, with extensive solar capacities showed a clear trend of exponential growth, followed by stagnation when a certain market share was achieved; most likely because of issues of value deflation grid stability. However, this dim perspective can be advanced by adding the argument of insufficient current technological capabilities to the discussion. As Sivaram and Kann (2016) argue, silicon panels – at least at their current stage of development – might not be capable to achieve cost efficiency long term. Therefore, new and advanced technologies related to generation and storage could change the situation dramatically. There are various technologies available both for generation (Philipps & Warmuth, 2019) and storage (Luo et al., 2015). Presently though, there seems to be a trend of exploiting current technologies to their limit instead of utilizing a more disruptive (Schumpeter & Stiglitz, 2010) approach that could even lead to renunciation of currently available technologies. Furthermore, a different understanding of energy consumption that promotes the role of energy storage could change the situation. There are various ideas discussed how energy could be used differently to account for the volatile energy supply of renewables, ranging from using electric cars as mobile storage, heating with excess electricity, synthesizing fuels or desalting ocean water. Furthermore, it should be anticipated that renewables are unlikely to work as a one technology solution, meaning that instead of concentrating on one technology, as has been the case with coal for a long time, a mix of different technologies could account for various challenges, both related to generation and storage. A new European policy approach, accounting for this different understanding of energy and the market mechanisms for renewable energy, therefore, could be very reasonable to face the imminent challenge of climate change.

7. Limitations and Further Research

This thesis provides some interesting and valuable insights about the relation between economic freedom, technological aspects and the deployment of solar PV capacities in the EU. But there have been several limitations identified that need to be accounted for.

The thesis focuses only on the European Union and it could be interesting to expand the scope of the research to make it more comparable to other markets. A comparison between different regions could be interesting for instance. However, by expanding the perspective, it needs to be carefully evaluated to what extend different regions are really comparable. As mentioned in chapter 3.3. the EU represents a unique sample with exclusive, common, policies and this would need to be acknowledged when designing a study comparing different regions. Though, it could be interesting to examine regions and their effective deployment of solar that are to some extend comparable like the EU, China and India; acknowledging their different approaches. Additionally, considerations related to the newly established European Energy Union have been to some extend underrepresented in this thesis. Since it has only been established since 2015 though, there was not enough data available to provide convincing arguments about their effects. Future research relating the energy market of Europe should anticipate this development though because a wholly integrated electricity market for Europe changes the perception of country-specific capacities dramatically.

Furthermore, this thesis can only provide information about the effects of very general market mechanisms present in the EU. The Economic Freedom Index can provide general information about the degree of liberalisation, but at the same time represents an index that reduces the very high complexity of various aspects into 12 variables. Therefore, anticipating the thesis' results, it could be valuable to dig deeper into the identified dynamics. How do trade policies and/or government spending activities specifically influence the deployment of solar

PV capacities? A specific country-related case study could be conducted, following a holistic approach to provide further insights about the dynamics.

Specific policies have been to some extend neglected in this thesis which can represent a limitation for this thesis. As elaborated in the thesis’ research design (ch.2.3) there have been various considerations about whether including policies or not. In the end, I decided to not follow policies deeply because it appeared that this would require an entire additional research pathway that would have only be achievable by reducing the overall depth of the analysis. Nonetheless, it remains to be a crucial aspect and future research though, could relate to the specific policies in more detail while utilizing the results of this thesis.

Furthermore, it can be implicated that the chosen technological variables might not have been sufficient to provide an overall answer to question 2 but with regards to data availability and the research’s design, it appeared to be reasonable. It is a limited data set because only one observation (EU) over the time of 8 years (2010 – 2017) is conducted. But the approach could function as a starting point for further research in this area including data such as transmission lines, more storage data and different storage technologies. Furthermore, it could be valuable to examine the effect of R&D activities on storage and solar PV capacities technologies.

8. Conclusion

The thesis purpose has been to provide information about the relationship between economic freedom, technological constraints and the deployment of solar PV capacities in the European Union. It provided an extensive explanation about the challenges that solar PV faces out of the perspective of technological feasibility and provided several arguments that the current available technology is not capable of providing a stable and economically reasonable energy supply. Furthermore, the market conditions for solar PV have been explained, which mechanism have a positive effect on the deployment and how the countries of the European Union address the issue differently.

Additionally, it has been explained under which criterions the variables for this research have been selected and why it appeared to be reasonable to include them. Additionally, the source for each set of variables have been introduced along with the method that has been utilized for the analysis.

The descriptive analysis showed that capacity growth is the subject of diminishing growth with increasing capacities. As soon as a certain threshold is reached, the growth of solar capacities slows substantially. Moreover, there are substantial differences in the deployment of solar PV capacities across the EU.

The thesis' findings suggest that solar PV capacity growth in the EU can be partly explained by determinants of liberal market policies, measured by the EFI. The results show that some aspects of liberal markets, such as trade or investment freedom do have a positive effect on the deployment while other aspects such as more government spending also affect government spending positively. Additionally, for the sample of the top 5 solar PV producers, the protection of property rights, both material and immaterial, are a factor of growth. Furthermore, the thesis provides evidence that reduced prices for solar panels can support the development of PV capacities in the EU.

Therefore, the thesis provides an interdisciplinary and far reaching approach to create a better understanding of the EU's solar PV market under the conditions of market liberalisation and technological development.

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Appendix 1 Robustness Tests

Table A1: Robustness Tests

		DW	BP	Hausman
Model - all countries				
	Economic freedom	1.001 ***	10.153 ***	33.396 ***
	Extended economic	.938 ***	7.466 ***	44.186 ***
	Energy	.857 ***	3.594 ***	81.354 ***
Model - Top 5				
	Economic freedom	.803 ***	.610	
	Extended economic	1.528 *	2.119 *	
	Energy	1.153 ***	2.343 *	

Note. DW = Durbin-Watson test for serialcorrelation in panel models; BP = Breusch-Pagan Test of corss-sectional dependence, reporting z; Hausman = Hausman's test for models - comparing within and between,reporting Chi2

* p < .05,.** p < .01. *** p < .001

Appendix 2 R Documentation

Appendix 3 Dataset