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# Title: The Integration of Renewable energy Sources in the Electricity Mix in Europe and Virtual Power Plants

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## Abstract

New energy trends are emerging in line with the goal of combatting climate change. The way electricity is produced is greatly affected by these changes, mainly as the sources of generation gradually shift from fossil fuels to renewable energy. This thesis analyzes the integration of renewable energy sources in the electricity mix of EU members. It highlights some of the inefficiencies of the current system such as the inability of regulatory measures to adequately foster the integration of renewables in the electricity mix of Europe. The thesis also examines cases, in which these ineptitudes can be illustrated. It goes on to propose a viable solution in the face of virtual power plants. In the end, this thesis proposes possible future developments, e.g. the integration of new technologies, which would enable better monitoring, efficiency, and economic viability of the new energy sources. All these are in line with global trends such as security, the Internet of Things, and the Digital Revolution.

# 1 Introduction

Energy supply will be one of the major problems that our society will have to face. In June 2015, after a G7 meeting the leaders of the participating countries declared a commitment to have the world running on clean energy by 2100 (The Economist, 2015). The fulfillment of this promise will be an uphill battle. The need for more energy, and the ever-growing population will pose a serious challenge to governments around the world. As it stands today, the structure of energy supply is mainly based on fossil fuels. According to the IEA 76% of the primary energy used is divided between oil, gas, and coal. The rest is made up from nuclear, hydro, bioenergy, and other renewables (IEA , 2014). Of that, around 40% is used to produce electricity (IEA , 2014). There are significant issues that arise when the current situation is compared to the vision that world leaders have for the future. In other words how will the world progress from its current state to where it should be in 2100? Achieving the ambitious goal of having the world run on clean energy poses a true challenge for human ingenuity especially when it comes to electricity, which is the major focus of this thesis.

The energy supply is threatened by two major factors. First, there are complex geopolitical relations and an askew distribution of fossil fuel production and usage. Troublesome times in the Middle East raise questions of oil supply security, and the Russian-Ukrainian conflict has put the supply of gas, especially to Western Europe at risk. These factors have been one of the main driving forces behind the emergence and development of shale oil and gas, especially in the US. Second, comes climate change, an issue to which scientists have drawn attention for decades, but for which the emergence of a global solution has been tedious. The differences in economic development between countries further exacerbate the issues. For example, access to electricity in the developed countries is around 100% (The World Bank , 2014) with few exceptions, while "two out of three people in sub-Saharan Africa" do not have access to electricity (IEA , 2014, p. 3). The discrepancies in economic development between countries have further exacerbated these issues, especially the possibility of reaching a consensus on how best to deal with the issue of climate change. OECD members are adamant that dependence on fossil fuels has to get lower, however, many developing countries have argued that they need a fair chance in order to develop their economies. Fossil fuels are still more reliable and much cheaper that the cleaner alternatives. A look at the distribution of the resources used for power generation in Europe and China puts this concern into perspective. While the EU uses far more renewables, China's economy is dependent on the most polluting and cheapest alternative – coal. Still, progress has been made at the recent COP21 meeting in Paris. After years of careful negotiation and diplomacy an agreement between 190 countries has been reached to fight climate change and limit emissions in order to keep the increase in temperature to 2 degrees Celsius. Another important settlement that has been reached at the Paris conference is that "developed" countries have pledged to provide a fund of $100bn a year to "non-developed" countries in order to assist them in the transition. Still, there is a long way to go from the agreement being reached to the actual implementation of measures and achievement of results. To say the least only parts of it are legally binding and that only after each nation ratifies them (C2ES, 2015). The measures that need to be implemented in order to achieve the 2 degrees limit of global warming will surely change the way we produce and use energy.

Electricity is one of the most important supplies for society. We depend on it for everything from communication, business, sustenance, warmth, to transportation. The security of the supply of energy and consequently electricity is amongst the top priorities for governments.

## 2 Research Question and Methodology

This thesis is structured around the central idea that the current model of support mechanisms, implemented in different EU countries in order to integrate Renewable Energy Sources (RES) in the electricity mix is flawed and not sustainable in the long run. It further investigates the notion of Virtual Power Plants and what the expected benefits of integrating such entities could be.

The main focus is on the investigation of the current electricity markets' state in different countries in the EU. In order to answer this question, this thesis first looks at the official information available on both support mechanisms and the efficiency of their implementation on the basis of different examples. Then, in order to examine further the economic viability and stability of renewable projects two examples are taken under closer consideration. First, a financial model is developed in order to determine whether investment in offshore wind makes economic sense in the second biggest economy in Europe – the UK. The model is based on public information available on the project details and assumptions made based on industry standards and insights. The second case study that serves to examine the efficiency of renewable energy integration, tells the story of a biomass power plant in the poorest country in Europe, Bulgaria, and the devastating result that the change in regulation has had on the renewable energy sector and biomass in particular. Both cases are developed specifically for this thesis and serve to reinforce the main theme, i.e. that the current model for integrating renewable energy generation in Europe has to be reimagined in order to ensure the continent's energy security.

In more detail this thesis is structured in the following way. A brief overview of the different generation sources is given in regards to how renewable energy sources can be used to generate electricity and what their pollution profile is. Next, the different scenarios for our energy future are analyzed, mainly on the basis of IEA estimates and projections. The various available support mechanisms for the integration of renewables are analyzed both in general terms and with particular examples from EU member states. Then the thesis continues with concrete evidence on the basis of the two cases and proposes a solution – Virtual Power Plants (VPP).

For the most part the evidence of the impact of VPPs is drawn from secondary sources. The focus is on peer review works, which examine diverse aspects of VPPs and their impact compared to the current solutions. By compiling this evidence, this thesis aims to show that the benefits of aggregating different energy sources far outweigh the initial costs and complexity, which are apparent at first glance. The reason for focusing on secondary evidence is that, although beneficial, VPPs, in the sense that they are described in this thesis, are in their nascent stage. There need to be further developments that will aid the wider integration of such technology. These are outlined in the "Future Outlook" section of this thesis. Furthermore, it draws on different examples, where VPPs have already been implemented and the nuances in the understanding of this recently emerged term.

In outlining the problems with the current solutions for RES implication, this thesis uses both secondary sources, such as papers and reports from reputable sources, as well as primary evidence. The main focus of the thesis is Europe; however, global trends that impact the old continent are also taken into consideration when necessary. The weaknesses of the current models of support mechanisms are also exposed both through secondary sources and an examination of the economic viability of the two very different renewable generation projects.

Last, the thesis draws on broader developments both from the energy industry and technology in general in order to outline a more exhaustive way forward. It also touches briefly on the possible new threats and challenges that a distributed energy future could pose.

# 3 Conventional and Renewable Resources

In order to understand the challenges that the need for a change in energy generation poses, the characteristics of the different sources need to be examined with a focus on their use for electricity production.

## 3.1 The Merit Order Curve

An important concept to have in mind when talking about different types of electricity generation is the merit order curve shown in Figure 1. On the merit order curve, different generation sources are ranked by their Short Term Marginal Costs (STMC), or in other words, the cost, which is needed to produce one more MWh of electricity. STMC calculations do not take into account the initial investments for building the facility. Instead, this cost is the result of the price of the fuel needed, the price for emissions, and the operational and maintenance costs stemming from the production of electricity. Logically, on this curve renewable energy sources come first, as there are no or very low STMC associated with this type of generation. The reason is there are no costs for the "fuel" used for renewable energy generation and no emission costs. This is beneficial for these alternative energy sources as most of the profit generated by energy sales can be used to cover the initial investment. The market price of electricity is set by the cost of the cheapest possible MWh that is needed to satisfy demand. All electricity sources to the left of the demand curve are in the market and all to the right are out of the market. The graphic below, illustrates the ranking of generation sources in a typical example of a merit order curve.

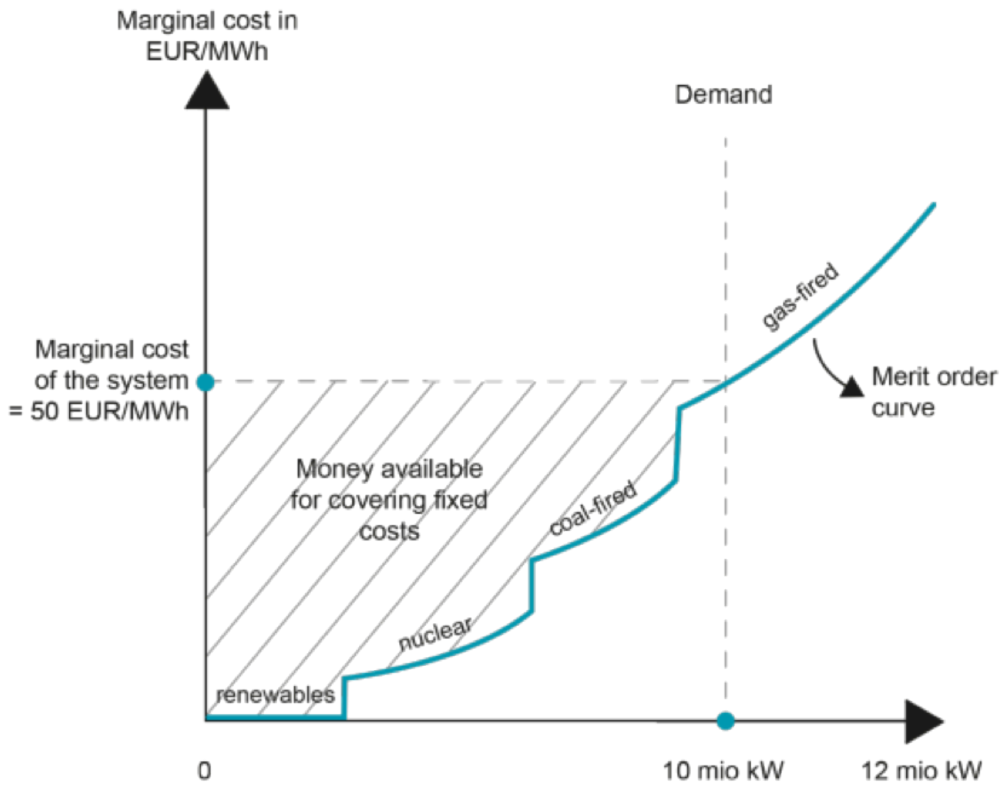


**Figure 1: The Merit Order Curve, Source: (E&C Consultants, 2014)**

One of the most important problems with the integration of renewable energy sources in the electricity mix can also be explained by using the merit order curve. Due to the fact that generation from most RES can be qualified as intermittent and unreliable, the merit order curve would look different depending on the circumstances for any particular region, country, or moment in time. To elaborate, if all RES are producing at full capacity, then, as mentioned, some of the power plants will be out of the market, as their energy would not be needed. However, once RES are not available, those same power plants will once again be needed. This does not only disturb electricity prices but also supply, as most power plants are not suited to ramp up production from zero to full capacity quickly. Therefore, traditional sources of energy are still predominant in world markets. To understand the trends further, each source's characteristics must be examined.

## 3.2 Conventional Resources, Fossil Fuels

As already mentioned fossil fuels are the predominant source of electricity production; currently accounting for 68% of generation in Europe (IEA , 2014). The reason for this dominance is the reliability and economic viability of electricity production from these types of resources. Still the mix between countries' varies greatly; the reasons for this can be explained by the different characteristics of different fuels.

### 3.2.1 Coal

Coal is the cheapest resource for production of electricity; it is easily transported and stored because it is a solid and, despite the differences in quality, has an overall high calorific value especially relative to cost (IEA Statistics , 2014). However, it is also the most polluting fuel used to generate electricity. Even newly installed capacity is not being constructed according to the highest standards and goals of emission abatement, mainly due to the low carbon prices (IEA, 2014). Currently slightly more than 25% of electricity produced in the EU comes from coal-fired power plants. The importance of this fuel varies depending on the electricity mix of the specific countries. The Nordics rely greatly on hydropower because of the geographical specifics of these regions, but for countries like Germany and Poland coal remains an important source of electricity. The cases of the two countries are slightly different. Poland, on the one hand, has historically been dependent on coal. In the case of Germany, this type of generation has gained in importance because of two trends: the increase of renewable energy generation, mainly wind and solar, and the phasing out of nuclear energy. It is clear that with such an electricity mix paradigm, base load coverage has to come from somewhere; current economic conditions dictate that source to be coal fired power plants (EEA, Europe Enviroment Agency , 2012). The IEA predicts that coal will be phased out gradually and will make way for gas. That shift can be accomplished with a higher emission price, which would switch coal and gas in the merit order curve by incorporating the price of pollution in the STMC of production.

### 3.2.2 Natural Gas

Natural gas will gain in importance in the coming years especially if combined with Carbon Capture and Storage (CCS) technologies. Today around 23% of the electricity in the EU comes from gas-powered power plants (EEA, Europe Enviroment Agency , 2012). While it is true that production of electricity from gas is much less polluting than that from coal, should green-house gas emissions be substantially reduced and the 2DS be followed, gas power plants will have to be equipped with CCS. Currently gas is the more expensive option for production of electricity. The main reason behind that is, although investment in the power plants themselves are comparable, the price of the raw materials are quite different. Not only is gas more expensive it is also more difficult to store and transport. In the case of transport, depending on the distance, either large costly pipelines, or, should the distance exceed 5000km, liquefaction and regasification plants have to be built allowing for the transfer of liquefied natural gas (LNG) (EIA , 2008). What is more, when LNG is transported some of the fuel is consumed in order to keep the rest in a liquid state. These facts lead to the conclusion that it is not only the price of the resources but also its proximity and availability that determine its presence in the electricity mix of a country. Still, recent oil price developments have indeed pushed the price of natural gas down as well, as the two are strongly correlated.

### 3.2.3 Nuclear Power

When ranking energy sources by polluting factor, somewhere between fossil fuels and renewables is nuclear power. This kind of generation fairs very well on the merit order curve, as STMC are low. Another benefit is that both uranium and plutonium do not have the same logistical issues as other types of fossil fuels. However, there is a considerable threat of disaster should a malfunction occur, as the recent events in Fukushima have proven. Although it could be argued that European countries have less reason to fear natural disaster, such global events can shift public opinion and cause fear in the eyes of the public. An example of such public pressure influencing policy is the case of Germany. Further enhancing the reluctance of some countries to embrace nuclear as a source of electricity are concerns for the storage of the waste material, as the half-life of the waste is far greater than the current time, for which we have the capability to store it (EEA, Europe Enviroment Agency , 2012). The geopolitical issues surrounding the usage of nuclear materials must be mentioned as well. As such materials can be used both for peaceful and military purposes there have been concerns over who can actually be trusted with the technology. The case of Iran shows that even countries which would like to use nuclear power, may be denied the right to because of security concerns and it might take years of negotiations to actually reach a deal on such a sensitive topic.  Hopes are high for another nuclear type of energy, namely fusion. Scientists have struggled for years, trying to develop a fusion reactor that generates more power than it consumes. Some R&D projects currently under construction are claiming they are close to a break-through. One such project is the French ITER, whose developers say that they could have an operating reactor in the next 15 years (ITER, 2016). Should fusion nuclear power be available, a lot of problems concerning electricity generation would be solved.

### 3.2.4 Oil

In the case of oil, it is rarely used for the production of electricity; it accounts for less than 3% of the electricity production in Europe (EEA, Europe Enviroment Agency , 2012). It is used widely for transportation and the synthesis of various useful hydrocarbons. Studies have shown that the price of electricity in Europe in directly correlated to the price of oil, all be it with a lag of several months (Cécile Kerebel, 2014). Still the impact of the changing oil prices on the price of electricity is not as great as the change of the price of gas, for example. As already mentioned the two are directly correlated as well (Cécile Kerebel, 2014). What is more, a 2015 McKinsey study showed that although the price of oil has dropped significantly in the last year and forecasts show that this trend will continue, investments in RES have actually been growing and doing quite well (Nyquist, 2015). This goes to further strengthen the argument, that although, oil is one of the most important commodities in today's economy, when it comes to electricity production and pricing it is not as essential.

## 3.3 Renewable energy Sources (RES)

In the last thirty years renewables have been growing steadily as preferred energy source, especially in Europe and other developed economies. The share of total electricity generated from renewable sources in the EU was 25.4% for 2013 (Eurostat, 2015). The mix and share, of course, varies from country to country as renewable sources are highly dependable on geographical and climate factors as well as the structure of the marker, as will be illustrated bellow. Still, Bloomberg predicts a large shift toward renewable generation by 2040 as seen by the Figure 2:

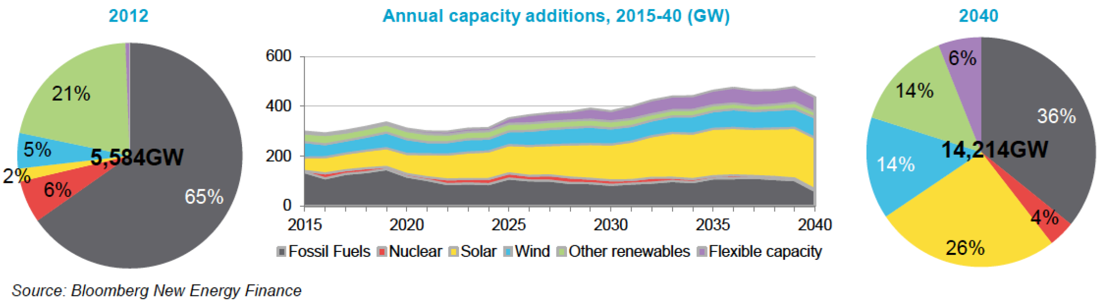


**Figure 2: Global Installed Capacity in 2012 and 2040 and Projected capacity Additions by Technology (GW) (Henbest, 2015)**

The highest growth comes from solar and on-shore wind, which are predicted to account for about 40% of global energy generation in 2040. While fossil fuels remain the dominant energy source the reduction of almost 30% is a significant shift.

Over the next 30 years RES will replace fossil fuels as the leader in installed capacity in Europe, following the union's goals to become an example of green economy. Figure 3 clearly illustrates this trend with the amount of renewable generation exponentially growing after 2020 and fossil fuel capacity slowly decreasing.

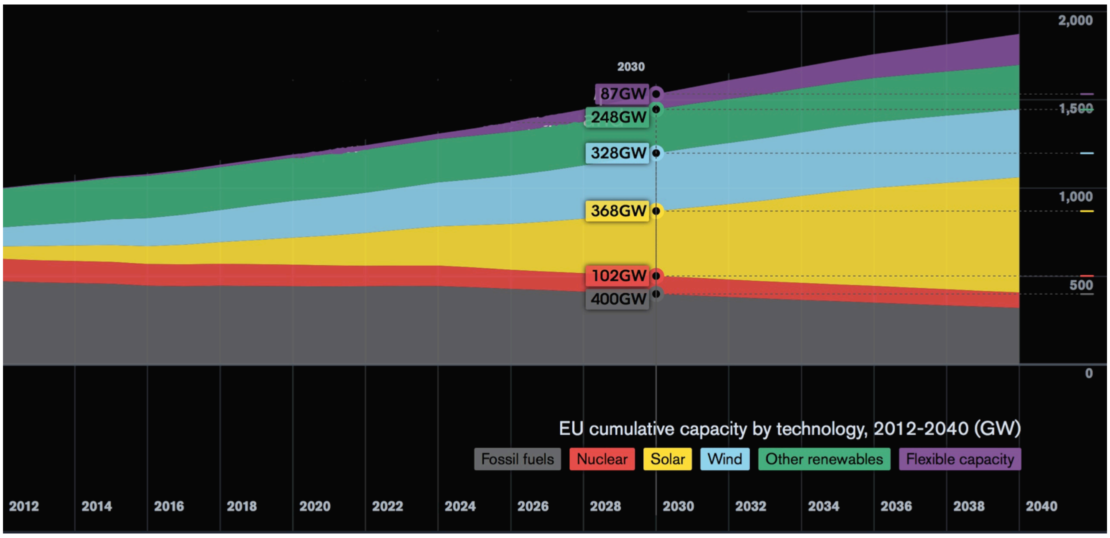


**Figure 3: EU cumulative capacity by technology 2012-2040 (Henbest, 2015)**

Of course as renewable sources vary in their characteristics there will be some that will dominate the market and some that will have a smaller role to play. That is mostly due to economic and geographical specifics of the different technologies. Here is a brief summary of the different type of technologies and their expected development in Europe.

### 3.3.1 Hydro

Hydropower is the most well established renewable electricity source. Currently it generates 45.5% of the total renewable electricity production in the EU (Eurostat, 2015). The main advantages are the lack of intermittency, the reliability of this type of generation, and the low green house gas emissions. There are two main types of hydro generation: small (under 10MW capacity) and large scale (over 10MW capacity) (EEA, Europe Enviroment Agency , 2012). They differ not only by the way electricity is generated but also in their ecological impact. While the former can be considered green and without significant impact the latter can cause harm to the system it is introduced in. These negative consequences include the disturbance of the hydrological balance, the destruction of flora and fauna and the possible release of methane if areas with vegetation are flooded for the building of a damn. Still hydropower is one of the major sources of electricity. In Europe most of the natural capacity for large-scale developments has already been used. Consequently the investments in this kind of generation are mainly targeted at improvements, better efficiency and more capacity through the implementation of new technologies. The main developments are expected to come from small-scale hydro power plants and pumped storage facilities. Currently this is the only commercially available way to store electricity. Estimates predict that the capacity for hydro storage can increase anywhere between double to ten fold possible added pumped storage capacity (Cécile Kerebel, 2014).

### 3.3.2 Solar

Solar is the renewable power that holds the most growth potential especially in Europe. Even currently Europe has the most installed solar capacity in the world, accounting for 59% of global installed capacity or 81.5 GW (EPIA, European Photovoltaic Industry Association, 2014). Still, the share of electricity produced from this source as compared to other renewable in Europe is only 9.6% (Eurostat, 2015). Bloomberg's report on the New Energy Outlook states that "in 25 years Europeans will see solar PV making up over a third of installed capacity while coal and gas and nuclear will decline by 30%" (Henbest, 2015). This is clearly illustrated in Figure 3, above.

There are two key downsides to implementing solar as a source of electricity: it is highly dependent on the whether and peak production often is not aligned with peak usage. There is one more problem that the implementation of solar in the electricity mix can cause: grid disturbances. To elaborate, there are a growing number of solar panels placed on houses or residential buildings – the so-called distributed generation. While these locations become more energy independent, they can cause a strain on the grid. The explanation behind this correlation is simple. While the sun is shining the solar panels produce electricity, this is either used by the house where the solar panels are mounted or is fed directly into the grid. When there is no sun then the house is dependent on the central grid for electricity. In both cases grid management becomes a more difficult task as fluctuations are increased.

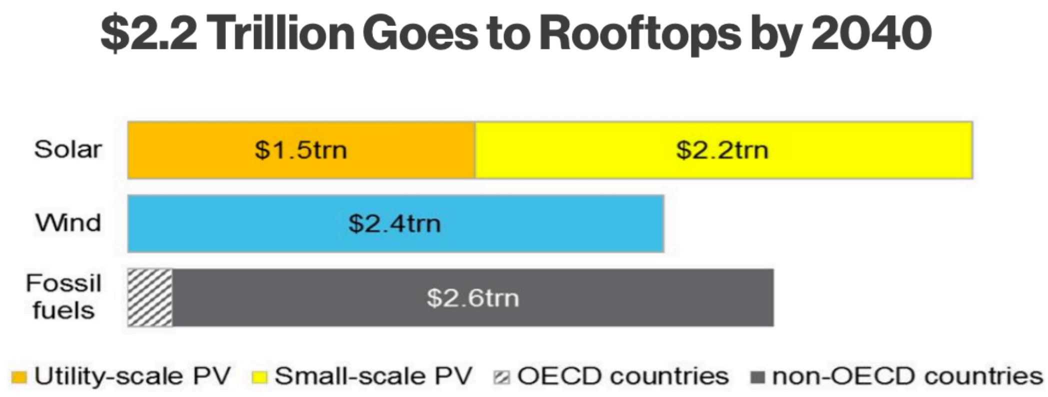


Figure 4: Investments in Energy Sources by 2040 (Randall, 2015)

Still, as the forecasts clearly show, solar is bound to grow in Europe over the next 20-30 years. The main reason behind this is that it is becoming more economical to install solar panels due to lower costs and better efficiency (Randall, 2015). By 2040 the prices of solar production will become competitive with such from fossil fuels (Randall, 2015). Not only that, but Bloomberg predicts that "electricity from "rooftop solar will be cheaper than electricity from the grid in every major economy" (Randall, 2015). As Figure 4 illustrates, distributed generation will be a significant part of energy generation. Although residential storage is also expected to come into play, without a centralized decision on how to incorporate these entities in the larger system, there will be significant difficulties for central grid operators.

### 3.3.3 Wind

Wind is another growing source of generation for electricity, especially in Europe. In 2013 it accounted for 26.5% of electricity generated by renewable sources (Eurostat, 2015). Along with solar it has and will continue to account for most of the growth in the sector. There are two types of wind generation: off-shore and on-shore. While the former requires additional investments for grid connection and is created solely as large scale projects, the latter can be used for single house generation as well as part of a large scale wind farm. The main issues with this type of generation are again the intermittency and the mismatch between generation and usage peeks. With wind there can be no production either when there is no wind or when there is too much wind. Although wind is less likely to not generate power when there are peak loads in consumption it is still not reliable enough to cover base-load demand and allow for controlled production as non-renewable sources. Still, as Figure 3 above shows, wind generation is going to grow and will account for almost as much as solar in 2030 (Henbest, 2015).

### 3.3.4 Biomass

Biomass is currently one of the more reliable renewable sources of electricity generation; its share of renewable generation in 2013 was 17.8% (Eurostat, 2015). This number is three times greater than the share it accounted for in 2003. Biomass generation uses organic material as a fuel to generate electricity, which can vary from waste to trees and plants (European Commission, 2015). Because this kind of generation still has some emissions and uses fuel (unlike solar and wind) the EU Commission has strict regulations on what is acceptable for a power plant that generates electricity in such a way. The most important ones are that: GHG emission are lower than those of fossil fuels, over the life-cycle, support is given solely to efficient installations, the use of bio-fuels that are obtained by the destruction of forest or bio-diverse areas is prohibited (European Commission, 2015). These along with the cost of building a biomass power plant outline the major concerns with such type of generation. Still, biomass, along with hydropower, is one of the only two types of renewable generation that are suitable for covering base-load consumption or such that occurs when the other types of renewable energy generation are not available.

### 3.3.5 Other

The other types of renewable energy include tidal and geothermal power. While these generation sources have the potential to supply energy, the state of the art technology is not yet at a level where they can be used as significant contributors. As of 2013 the total electricity share of such power in Europe was at a mere 0.05%. Tidal power is only used in France and the UK (Eurostat, 2015). Therefore, these kinds of generation remain outside the scope of this thesis. Still, it is worth noting that in the future it is expected that geothermal energy generation will gain in importance as the third non-intermittent renewable energy source along with hydro and biomass.

## 3.4 Additional Technologies and Mechanisms Connected to Electricity Generation

When considering the different types of generation, the cost associated and carbon emissions, it is also worth considering the additional technologies and mechanisms that are available in Europe. There are two main fields in particular, namely, Carbon Capture and Storage Technologies (CCS) and the European Union Emission Trading Scheme (EUETS). The two are connected to electricity generation and pricing as they both increase the price of generation from fossil fuels.

### 3.4.1 Carbon Capture and Storage

Carbon Capture and Storage is not a new technology, but it has yet to be adopted on a large-scale by electricity generators. In essence, CCS makes it possible to trap the $CO_2$ emissions from so called point emitters, such as a power plant. The harmful gas is captured, separated from other substances, compressed and then transferred to a storage location. Used oil or gas fields, mines, and underwater storage are a few of the options for depositing the compressed $CO_2$. A report by the Intergovernmental Panel on Climate Change has shown that such storage is 'very likely' to contain 99% of the deposits for up to 100 years and 'likely' thereafter (European Commission , 2016). The main barrier for CCS to be a widely adopted technology is the high cost. Although already in use for other industries, carbon capture for power generation is more costly because the amount of $CO_2$ is relatively low. In fact for gas power plants it is around 3-6% and for coal 10-12% (European Commission , 2016). Although Europe has ample capacity for storage mainly because of depleted mines and oil and gas fields in the North Sea, CCS penetration is non-existent. A study from 2013, launched by the EU Commission showed that there are no projects currently functioning on the Union's territory. The study further concluded that there is no incentive for generators to deploy this technology due to the low carbon price. The lack of incentive to invest in CCS can also be attributed to the fact that a "first generation CCS power plant is expected to be 60% to 100% more expensive than a similar conventional plant" (European Commission, 2016).

Even with these apparent obstacles in the deployment of CCS technologies, the EU Commission has identified it as one of the key elements needed in order for the Union to reach its energy goals. As renewables are gaining in the percentage of generated power, fossil fuel generation will still be needed in order to balance the system and ensure security of supply (Nichols, 2014). What is more, so far it has been possible for generators to rely on process optimization and efficiencies in order to reduce their emissions. As these methods reach their respective possible thresholds, CCS will gain in importance. In order to facilitate the integration of this technology in the EU, its member states will have to build a sound regulatory framework that will allow for R&D investments. Some countries have already set mechanisms in place that put CCS on par with renewable energy generation.

### 3.4.2 European Union Emissions Trading Scheme

The European Union Emission trading scheme was introduced in 2005. It creates a market for trading emission of $CO_2$ or its equivalent in other GHG such as $NO_2$ or Perfluorocarbons. The EU ETS is a cap and trade system, which includes about 45% of all the emissions in the Union from energy generation, heavy industry and aviation. This means that there is a cap, the highest volume of allowed emissions, and the allowance for these are either allocated or auctioned off. Should a company not have enough allowances to cover its emission it has the choice to either implement new technology to lower emissions, buy more allowances on the EU market, or pay a hefty fine (European Commission , 2016). The system is aimed at providing a clear economic incentive for companies to implement measures to lower emissions. The scheme has three phases, meant to ease the transition. Phase one was from 2005-2007; allowances were introduced in order to serve as a proof of concept and to gain practical insight on how the market should be structured. The second phase was between 2008 and 2012 when allowances were split on national bases. Each member state then could decide how many allowances to allocate to each company that would be affected (Department of Energy & Climate Change UK , 2015). This period had more industries participating in the trading scheme. The third period runs between 2012-2020. Major changes were introduced, based on learning from the previous stages. First, a union wide cap was introduced to replace individual member states' target. Second, a move toward auctioning of allowances is meant to gradually replace direct allocation (European Commission , 2016). Other changes include the addition of several gasses, harmonized union-wide allocation rules, and allowances being set aside for a New Entrants Reserve Fund (European Commission , 2016). The aim of the changes is to foster more competitiveness in the sector. The harmonization and implementation of a system that includes all the member states rather than having nation targets, is meant to incentivize the implementation of new technologies wherever it makes the most economic sense. Although the EU is on track for reaching its goals it is not only due to the introduction of the EU ETS. The EU Commission acknowledges that the economic crisis had a major role to play as it lowered production and thus emission levels (European Commission , 2016).

# 4 Trends in Electricity in Europe

## 4.1 EU 2020

For the near future Europe's plans are for 20% renewable share of the electricity mix, 20% less GHG emissions and 20% energy efficiency. The former two goals are already on track to be fulfilled, the latter, however, is lagging behind (European Commission , 2015).

With very generous subsidies schemes, such as 'feed in tariffs', the EU has managed to make renewable energy a worthy investment. The economic viability of such schemes is proving to be questionable. Still, prices for initial investment are dropping for many kinds of renewable energy generation; thus reinforcing the investments in the sector (Isola, 2013). The cost of grid balancing and the disruptions that renewable energy sources bring to the electricity supply systems are often not included in the calculation of the price. That is why the panning of investment in infrastructure is amongst the recommendations of the European Commission for the way forward. The two other factors that will influence the fulfillment of this particular target are the economic downturn and the effect of the existing policies. With these in mind, member states will have to put additional effort between now and 2020 in order to fulfill their commitment regarding the renewable share of generation in the respective energy mixes (European Commission , 2015).

As far as lower GHG emissions are concerned that is one of the few benefits that the economic crisis of 2008 brought. A slower economy meant less production and therefore fewer emissions. That is also the reason why the carbon price is so low in the EUETS. The emission caps where calculated before the crisis at expected growth rates for the economy. After the economic downturn, however, it was much easier for states and affected entities to reach their respective targets with few to no investment in abatement technology (Alberola, 2013). That does not mean that efforts are not being made and new technology put in place to curb GHG emissions. Even with these positive developments, currently only 14 member states will be able to reach their goals with the measures already installed (European Commission , 2015).

Energy efficiency is the one goal, which most EU countries are still not on track to fulfill until 2020. Industry and businesses have proven easier to motivate to implement more efficient technologies and refurbish buildings to fit to the requirements as the cost benefits there are direct and make for sound business decisions. This is illustrated by the fact that energy intensity dropped by 19% from 2001 to 2011 (European Commission, 2015). The greatest improvements need to come from the building sector. That is the reason why the European Commission has provided special incentives for government buildings to be refurbished and undergo energy management programs. The idea is that by showing a working business model, other large property owners will follow suit. The situation with private properties' efficiency, especially in countries from Eastern Europe, is dreadful. The two main factors behind that are that most buildings are old and the population is poor, so people cannot invest in insulation for their properties. Another reason adding to the inefficiency of the homes, is that people are not well informed when it comes to what the best ways to conserve energy at home are. From the supply side and transmission there are also significant improvements that need to be made. After all, as a rule of thumb around half of the energy produced is lost before it reaches the end consumer (European Commission, 2015). Energy efficiency is essential to the development of the energy sector in the European Union. It not only has its own merits but also has positive spillover effects for the rest of the economy. By achieving energy efficiency businesses and consumers will increase their cash flows and disposable incomes respectively. A greener economy also would mean the creation of new jobs. Perhaps what is most important is that energy efficiency also contributes to energy security. The European Commission estimates that for every 1% of increase in energy efficiency, gas imports drop by 2.6% (European Commission, 2015).

## 4.2 IEA Scenarios for 2050

As we move further away, forecasts tend to be less reliable and there are needs for adjustments, especially when talking about trends in electricity, a market dependent on a plethora of other factors from socio-economic development to geographical location. That is why the IEA has developed 3 scenarios for the future development of energy market. As climate change is intrinsically connected to the energy markets' development, so are the names of the three possible outcomes, namely the 2 Degree Scenario (2DS), the 4 Degree Scenario (4DS) and the 6 Degree Scenario (6DS). Figure 5 illustrates the difference between the best- and the worst-case scenario (IEA, 2014).

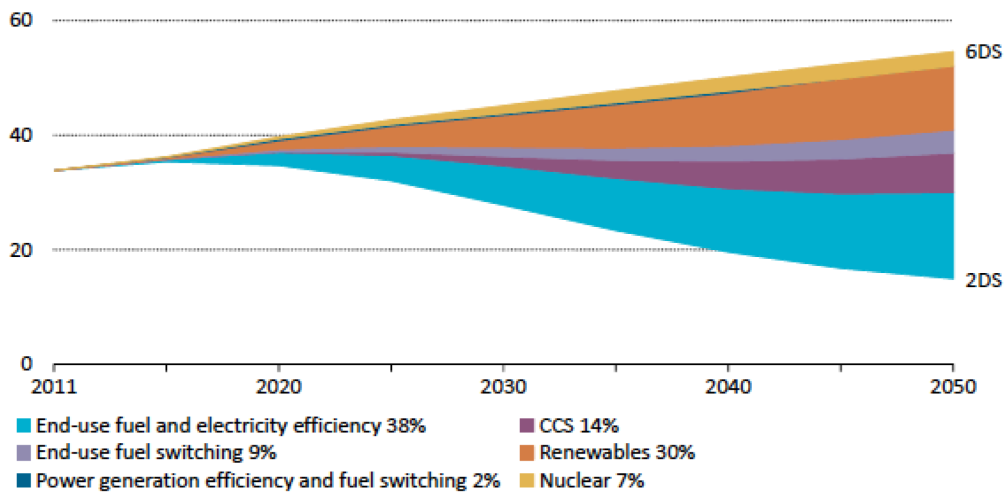


**Figure5: Carbon Intensity of Supply (Source: IEA)**

The main differences in the three options are dependent on the level of decoupling between economic growth and energy intensity, as well as the emissions resulting from the increase in demand for energy. Briefly explained the 6DS is characterized by a global energy demand growth of 70% and emissions increase of 60%. On the other end of the spectrum is the 2DS scenario, where energy demand increases only by 25% (without stifling economic or population growth) and emissions are decreased by 50% (IEA, 2014).

The major new developments that would need investment are efficiency, fuel switching, new power generation, and carbon capture and storage. According to the IEA in order to move from the 6DS, to which we are currently on track, to the more desirable 2DS an additional $44 trillion would be needed. As considerable as this amount seems, the resulting savings, mainly through efficiencies and fuel switching, are even more impressive standing at an estimated net of $71 trillion (IEA, 2014). These numbers refer to the consumption of energy as a whole; electricity is just a part of the mix, but it gains importance in all scenarios. Currently electricity is 17% of total energy consumption. In the 6DS it grows to 23% and in the 2DS to 26% of primary energy used (IEA , 2014). The variance between the two possible outcomes can be attributed to the different technologies used in the production of electricity. In the 2DS scenario technologies enable the production of electricity with significantly lower emissions through a shift from today's 68% coming from fossil fuel and 20% from renewable source to 65% from renewable sources and 20% from fossil fuels (IEA , 2014). The IEA outlines four main technologies that need to be developed to facilitate the switch: grid infrastructure, dispatchable generation, storage, and demand side integration (IEA, 2014). The need for such technologies becomes more evident when considering the already outlined main differences between generation sources.

# 5 Integration of Renewable Energy Sources

It is clear that fossil fuels will be replaced by cleaner energy sources in order to reduce the effect of climate change. The EU has long since committed to doing so, but after the Paris accord even more countries have recognized the need for system change (C2ES, 2015). In order for that to happen there has to be enough financial support in order to develop the new technologies, which would enable the transformation. The support mechanisms would have to also counterbalance the advantages that fossil fuel generation has historically had over renewables (Márton Herczeg, 2012). The range of government schemes covers the whole cycle of production from subsidies for research and development to financial instruments aimed at funding production. As technologies develop, learning curves would minimize costs and eventually diminish the need for government support. Clearly, this gradual process is indeed taking place as is evident from the levels at which renewable generation has grown and is expected to grow. To further support the possibility of new types of generation being added, electricity markets are undergoing the process of deregulation to allow for the exposure to market competition to incentivize efficiencies in technologies and costs of generation and transmission. This section first presents the different schemes that can be implemented and then goes on to explore their effectiveness and evolvement. It further gives examples of how these mechanisms were implemented in several countries from the EU.

## 5.1 Support Mechanisms

There are different criteria that can be used to classify and evaluate regulatory support instruments for the integration of RES. One main difference is the intended stage of the lifecycle of a technology that is assisted. One kind of subsidy helps the initial investments in the building of new technologies, while the other offers support for production. Another important aspect is whether the financial help is aimed at securing revenues for generators or increasing installed capacity in a country or region. Figure 6 summarizes the different types of support mechanisms and where they fit within this framework.

| | Price regulation | Capacity driver |
|---|---|---|
| **Supporting invest-ments** | ▪ Investments subsidies<br>▪ Fiscal instruments (tax incentives)<br>▪ Soft loans | ▪ Tender scheme |
| **Supporting energy production** | ▪ Feed-in tariffs<br>▪ Green pricing<br>▪ Advanced feed-in tariffs systems | ▪ Renewables obligation<br>▪ Certificates and guarantees of electricity origin |
| | ▪ Green certificates | |

**Figure 6: Support Systems for Renewable Energy Generation (Márton Herczeg, 2012)**

All these mechanisms need to be carefully implemented, while making sure to balance the best interests of all stakeholders, namely consumers, investors, industry, and regulators (Katy Hogg, 2010). Support schemes make for an additional financial burden, which has to be distributed properly in order to not jeopardize the acceptance of green energy (Anne Held, 2014). The goals that a government has set also play an essential part in the decision on which scheme is best suited. This thesis focuses on the most common types implemented in the EU, namely feed in tariffs, quota obligations, tax incentives, tender schemes, and investment subsidies (European Commission , 2013). These will later be illustrated by specific examples of implementation in different EU countries.

### 5.1.1 Feed in Tariffs

There are two main types of feed-in tariff (FIT) mechanisms, direct feed-in tariff and premiums. The first type promises fixed revenue for each MWh produced for a certain time period, usually between 15-25 years (European Commission , 2013). The life span of most renewable energy installations is considered to be close to that range. The amount granted to producers for each unit generated is usually calculated based on the Levelised Cost of Electricity (LOCE) for a specific generation type at the time of implantation. This method of calculation takes into account the STMC of production as well as the initial investment needed and the life span of the installation (IEA , 2015). As this cost changes with the development of technologies, regulators reserve the right to revise the amount given to producers. The European commission warns that revisions have to be made carefully and cannot have a retroactive element as such changes would undermine the trust of investors in the system (European Commission , 2013).

Still, as technologies evolve, this type of support schemes need to be adjusted. The options are either to reduce the subsidy by some regression factor over the life span, to have predetermined intervals at which the amount will be reevaluated, or to couple the support with the level of installed capacity (Anne Held, 2014). Despite the difficulties in choosing the correct amount, this type of support mechanism is characterized by high efficiency in increasing installed capacity while having a low administrative burden. However, FITs can also result in an increased price of electricity for the consumer, if the cost of subsidies is passed directly to the customers, or budget deficits if the government covers it. What is more, direct feed-in tariffs do not foster competition and efficiencies in the sector, as there is no market risk exposure (Márton Herczeg, 2012).

The second type of feed-in tariffs, feed-in premiums (FIP), is considered to be an evolved type as it allows producers to directly sell on the market, but with varying protection from market risks. For each MWh of green energy the generator will receive the market price plus either a fixed premium or an amount that covers the difference between the strike price and a set cap. Thus producers still have to directly sell their electricity to the market, allowing for a more efficient integration. The controls that can be set on FIPs allow for more flexibility in reacting to changing circumstances in the market (European Commission , 2013). As Anne Held puts it, they can be adjusted "to limit both the price risks for plant operator sand the risks of providing windfall profits at the same time" (2014, p. 4). In other words this type of mechanism still provides a good level of revenue predictability while allowing market signals to influence producers and drive increased efficiencies. FIPs are deemed to be more suitable for more mature technologies (European Commission , 2013). They are similar to FITs as they also increase installed capacity and are low in administrative burden, but they score better in driving efficiencies and competition (Márton Herczeg, 2012).

### 5.1.2 Quota Obligations

Quota obligations are a very different type of support mechanism. They call for additional levels of regulation in order to be implemented. First, the government has to set a specific obligation for utilities to have a certain amount of energy generated from renewables. This creates demand for green certificates, which become a part of a RES generator's revenue stream (European Commission , 2013). The level of obligation is usually connected to the national targets set in accordance with EU directives. Thus, while quota obligations are still directly connected to the levels of production, the remuneration process is less straightforward. The renewable energy generators receive the market price for electricity and the revenue from the certificates. There is clearly an additional incentive for green generation, but there is also double market risk exposure; on the one hand electricity markets and on the other the price of certificates. Price floors for certificates could be introduced to diminish the risk of market fluctuations (European Commission , 2013). Still, once a particular target is reached, demand for certificates would dry up and result in a price drop. This would, in turn, severely affect existing renewable energy installations (Anne Held, 2014). What is more, quota obligations are usually technology agnostic, which means that cheaper, more mature and efficient technologies get more support than others. This can be counteracted if prices for certificates were linked to the technology from which the energy was produced. However, should both price limits and technology banding be implemented, then quota obligations become very similar to FIPs (Anne Held, 2014). This would, in turn, diminish the positive effects that this particular support mechanism has on increasing efficiency and competitiveness. Quota systems are better suited for circumstances where renewables are already present in the electricity mix, as the incentive to increase installed capacity is low to medium. Additionally, they exert a high to medium administrative burden to implement due to the fact that a new market has to be created and maintained (Márton Herczeg, 2012).

### 5.1.3 Tax Incentives

Tax incentives are usually present in the form of tax exemptions. They can be targeted at investment or to production. Both can include income tax deductions or a former of credit, either for part of the initial investment or for each produced unit of energy. The former can also come in the form of allowance for faster depreciation (Anne Held, 2014). Arguably, tax incentives are also easier to implement from a regulatory perspective, as the cost burden is spread to the whole society rather than just energy consumers, and is therefore easier to defend (Katy Hogg, 2010). This type of support mechanism is characterized by low impact on the increase of installed capacity and low administrative burden. The main benefits are that there is a highly positive impact on efficiencies and competitiveness (Márton Herczeg, 2012). Tax credits may be used in supplement with other mechanisms to allow for the correction of some of the failures. They permit for very specific and targeted aid, allowing governments to steer the development of new technologies, which are deemed important.

### 5.1.4 Investment Subsidies

Investment subsidies are the most straightforward support mechanism. They constitute aid for the upfront capital costs and are most often implemented along side other measures. This mechanism is usually used when governments want to support less developed technologies, proof-of-concept projects, or those that require high capital investment (Anne Held, 2014). In many cases investment support is granted on a regional basis. The European Union has specific instruments dedicated to granting support to member states for such projects. Examples of these include the European Agricultural Fund for Rural Development (EAFRD) and the European Regional Development Fund (ERDF) (European Commission , 2013). The main benefit of such a scheme is that the support is decoupled from production, minimizing the risk from over production. Additionally, as it is aimed at aiding the initial investment and has no bearing on production, there is no need for reevaluation at some later point in time unlike production-oriented subsidies (European Commission , 2013). Investment support offers a high incentive on increasing capacity with a medium administrative burden. It has little to no effect on the efficiencies or market competitiveness (Márton Herczeg, 2012).

### 5.1.5 Tender Schemes

Tender schemes are arguably the most competitive subsidy available to regulators. Although a well-designed auction would require a higher administrative burden, it also carries significant benefits: one of the most obvious being that the level of control over the increase in capacity (European

Commission , 2013). There are two main types of auctions. Regulators may choose between a "price-based" auction, in which the only criteria is the price, or a "multi-criteria" one where the winner is chosen on a range of measures (Anne Held, 2014). While it is true that auctions are not always a practical support mechanism, as in the case of small-scale project or technologies in their nascent stages, they do provide a cost efficient allocation of resources, as the different contenders are exposed to competition. Designing a particular tender to accommodate technologies at different stages of maturity can avert the exclusion of certain projects (European Commission , 2013). Another risk associated with auctions is that projects under-deliver. To elaborate, since a major, if not the only, criteria for choosing a winner could be solely the cost of a proposal, in many cases the participants decide to underbid. They are therefore unable to deliver the project as a whole or partially. To avoid this careful crafting of qualification criteria and price floors can be introduced in the auction design (European Commission , 2013). Additional safeguards include, "bid bond guarantees" and penalties. The former constitute payments required form the winner or participants of the auction ensuring their commitment. Penalties can be introduced in various forms. A payment can be required if the project is not completed on time, does not deliver the agreed upon capacity, or is fully non-operational. As is evident there must be a good understanding of the goals of the tender and of the market conditions, in order for the regulators to utilize the positive effects that auctions can have as a support mechanism for the integration of renewables (Anne Held, 2014). Auctions are therefore characterized as having a high incentive for increasing capacity and a medium to high administrative burden. Additionally, they also have a medium effect on efficiencies (Márton Herczeg, 2012). Although tenders have no direct bearing on the electricity market competition, as they can be classified as a "one-off" measure, they do foster competition between technologies.

In many cases auctions are implemented simultaneously with other support mechanisms. Similarly to tax incentives, tenders are usually aimed at finding the initial investment in a project. When it comes to renewable energy integration, investors need additional guarantees for revenues in order to make a project appealing. Countries in the EU have had distinctive approaches when implementing support mechanisms.

## 5.2 Implementation and Development in the EU

As it is evident, the regulatory environment in a country is of extreme importance to the proliferation of new technologies, especially when considering a sector like electricity, which has historically been heavily regulated. It is worth examining the particular environment in several European economies and the benefits and obstacles that different legislative decisions can impose on the electricity system of a country and how the mechanisms developed over time. Although the EU has pan-national regulations when it comes to the production of energy they serve more as a guideline of goals, which the countries need to reach. The individual implementation is left up to each government and therefore leads to significant differences. Over the past several decades there has been a shift in the way countries attempt to integrate renewable energy sources and stimulate the proliferation of green energy. In the 90s and early 2000s the aim was to support the very capital-intensive new green energy resources. As technology progressed and the amount of installed capacity increased more and more governments decided to review the chosen approaches and incentivize producers of green energy to also seek efficiencies. Figure 7 represents the different schemes implemented across the EU as of 2013.

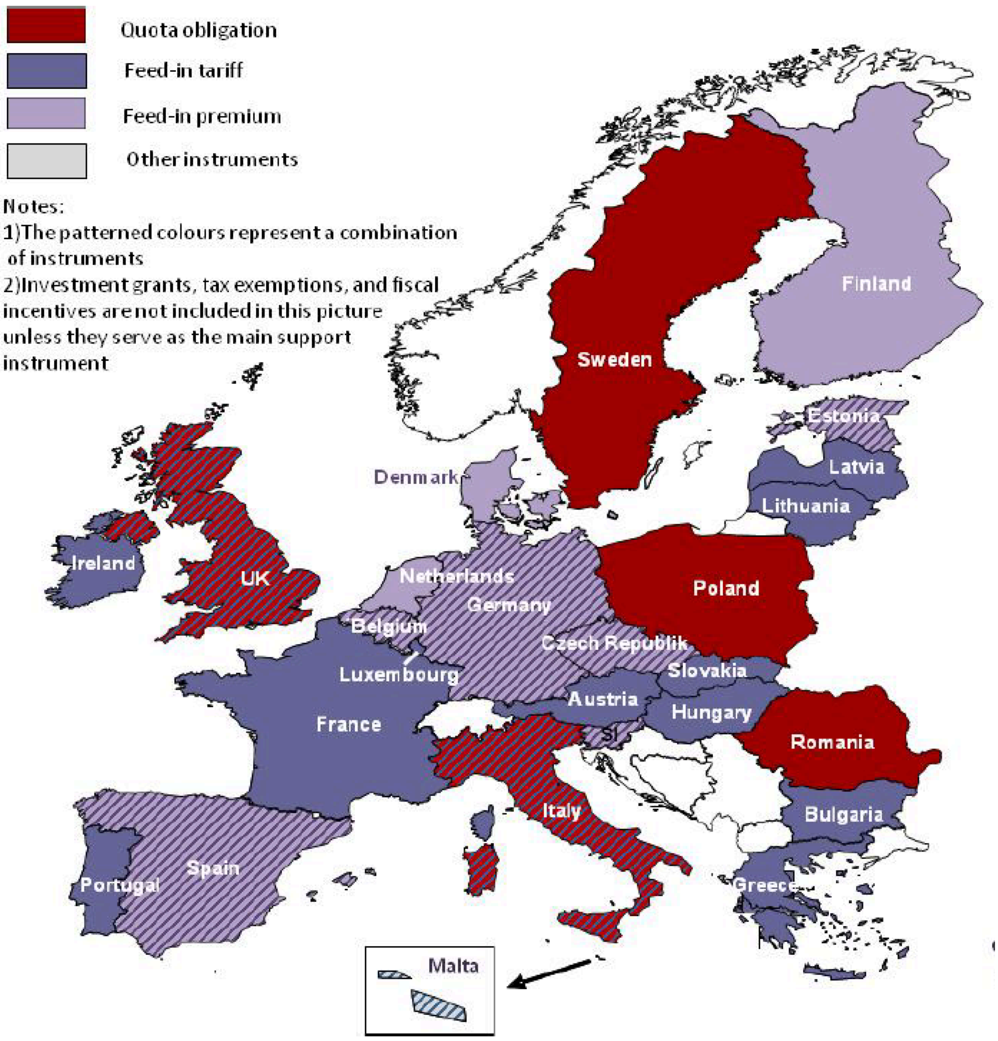


Figure 7: Support Mechanisms in the EU by Country (Ragwitz, 2013)

As is evident, feed in tariffs, feed in premiums or a system that at least includes this mechanism are predominant in the EU. The second most popular support scheme is quota obligations. In the next section this thesis explores these mechanisms based on the examples of the implementation in several European countries, which have chosen different approaches.

Before making a comparison between the realizations of support schemes it is important to recap several dependencies in an electricity system, which includes RES. In other words the goals of the regulators and the development of the electricity sector and economy will influence the decision as to which support mechanisms to implement and how. First of all a decision must be made as to the level of market exposure when integrating renewables in the system. Higher risk exposure could have a stifling effect on the development of new energy source because of increased costs and uncertain returns, but it can also result in a more efficient use and implementation (Corinna Klessmann, 2008). Another important aspect is that unlike conventional energy sources, renewables (without the introduction of commercial grade storage) have a limited ability to react to market incentive due to the intermittent characteristics of such generation (Corinna Klessmann, 2008). The make up of the market to which RES are being introduced is also of importance when evaluating regulatory approaches. Last, the different types of revenue generating streams also have to be considered. In a deregulated market the two trades types are made on the day-ahead market, where the price of electricity is determined after market settlement and the balancing market, which deals with ensuring the control and stability of the grid (EWEA, 2015). The cases of deployment of schemes for the stimulation of renewable energy in Germany, Spain and the UK are quite different and give a good overview of the possible approaches and results thereof. The three EU countries provide insight in the effects that feed-in tariffs, feed-in premiums, and quota obligation systems can have on the integration of renewables in the electricity mix. The changes and developments in regulatory decisions also shed light on the effectiveness of these measures.

### 5.2.1 Germany

In Germany the first version of the Renewable Energy Act was incorporated into law as early as 1991. Then the whole text consisted of only a few pages; its main aim was to make the proliferation of the new types of green energy possible (Dr. Matthias Lang, 2014). The regulators had opted for the lowest risk scenario and implemented direct feed in tariffs for green energy. In essence the producers could sell their electricity directly to the grid and get a fixed price for it over a fixed period of time. In the case of Germany the period was defined as 20 years. This was implemented through the Renewable Energy Sources Act in 2000. Between then and 2008 the generation capacity for wind increased ten fold. This system, however, increases the burden on the transmission system operator (TSO), since it will have to be the entity, which balances out the system when renewables are guaranteed access to the grid. Due to the fact that the TSO would have a large number of RES to account for forecasting becomes easier. Still, no motivation for the TSO existed to diminish inaccuracies in the forecasts as the balancing costs are passed to the end consumer. What is more the TSO is also responsible for transforming the load into a standard one and distributing it to the utilities that then sell electricity to the end consumer. Klessmann et Al. discovered that this is a major flaw in the German system. In essence the transformation costs are also passed down to the end consumers as part of the use of system charges. Therefore, there is no incentive for the TSO to aim at making the transformation more efficient (Corinna Klessmann, 2008). Last, the fact that there is assured access to the grid for renewables meant that the system will have to be amended to accommodate for the new energy suppliers. However, as such endeavors are costly and take a long time, the Energy Act allowed for the TSO to have control over the production of RES and be able to stop or ramp certain producers down should the system be overwhelmed. The so-called curtailment clauses were introduced into one of the amendments of the law (Dr. Matthias Lang, 2014). This in turn means that despite of the guaranteed payment producers might have to deal with lower revenues due to system overloads.

As renewables exited the nascent stage of development and grew to produce up to 25% of German electricity, the flaws in the initial law became apparent. That is why an amendment was introduced in 2012 and came into legislation in 2014. The new expanded Renewable Sources Act included some ambitious goals for the proliferation of renewable energy. “According to Section 1 paragraph 2 EEG 2014, renewable energy shall account for 40% to 45% of the share in the gross electricity consumption by 2025; 55% to 60% by 2035 and for 80% by 2050” (Dr. Matthias Lang, 2014). In order to seamlessly integrate such a large percentage of renewable energy in the mix the German regulators decided to opt for more market exposure of the renewable sector, so that producers not only invest in the technology itself, but also strive to bring efficiency to the system. Notable changes are that feed in tariffs will no longer be as readily available, especially for newly commissioned power plants, and that curtailment of RES is only allowed in cases where the extension of the grid is deemed economically impossible (Dr. Matthias Lang, 2014). While the industry is still being stimulated the focus has shifted to granting favorable terms for loans on investments in the sector (Bozsoki, 2014). As the German ministry of Economic Affairs and Energy put it: "The revision particularly aims to substantially slow any further rise in costs, to systematically steer the expansion of renewable energy, and to bring renewable energy more and more to the market" (Federal Ministry of Economic Affairs and Energy, 2016). As the technology progresses though, so does the complexity of the regulations needed. That is why the German government is planning further expansions to the Renewable Energy Act. The most pressing problem that remains to be tackled is the supply of sufficient reserve capacity, which can guarantee the stability of a system with an ever-increasing share of renewable energy. There are two main possible scenarios for the German regulators, either to opt for an optimization of the electricity market, or to create an adjacent one for reserve capacity (Dr. Matthias Lang, 2014). In order to have proper regulation more experience has to be gained as some effects take years to develop and advances could cause unforeseen obstacles.

### 5.2.2 Spain

In Spain the regulators opted for a choice system. Perhaps, due to the fact that the royal decree was implemented some time after the German law was drafted, it was aimed at including renewable energy producers in the market. Consequently, Spain was the first state in the EU to opt for a premium scheme. Producers could choose between a feed in tariff, similar to the German one or selling energy directly on the market, and receiving a premium in addition to the market price. Almost all of the wind producers in 2007 had chosen the latter method of remuneration, even thought the law was amended to limit the premium (Corinna Klessmann, 2008). When the law was introduced producers received a premium regardless of market prices. However, after significant increases in the spot price for electricity in Spain, the law was amended to guarantee a premium only in the cases where the sum of the market price and premium did not exceed a certain amount. In essence a cap and floor control system was introduced. This meant that there were 4 options of remuneration for a generator, depending on the market price of electricity. First, if the price is low and even with and added “reference premium” it still did not reach the minimum amount promised to generator, i.e. the floor, then the generator receives the additional revenue to equalize the amount to the floor. As long as the market price and the reference premium do not exceed the maximum amount, i.e. the cap, the generator gets wither the market price and the reference premium or the market price and what ever the difference between the cap and the market price is. In the last scenario where the market price alone exceeds the cap, the generator receives only that amount. This mechanism has two perceived benefits (Anne Held, 2014). First, it allows for control on the cost of new technologies and it includes generators of renewable energy in the electricity market. Second, it provides a positive investment climate, as generators are guaranteed protection against unfavorable market conditions through guaranteed minimum revenue.

As producers are selling directly to the market there is no need for special consideration for the inclusion of renewables and as far as grid optimizations are concerned that cost is split between the operators, the utilities, and the renewable producers (Corinna Klessmann, 2008). This approach turned out to be devastating to the electricity sector in Spain. The Régimen Especial, was completely suspended in 2011 (RES Leagal , 2012). The generous subsidy schemes created overcapacities in a mainly isolated system and the lack of cost transference lead to significant deficits. Still, some advantages are still in place for renewable energy producers, such as tax credits and guaranteed grid access, but the main source of revenue has been significantly curtailed forcing some operations out of the market completely (RES Leagal , 2012). The wind generation sector can serve as a good example to illustrate the effect that the suspension of the subsidies scheme has had. As per the new amendment wind farms built prior to 2005 would no longer be viable candidates for receiving preferential prices for the produced electricity. That caused an estimated reduction of the work force in the sector by 20,000 (Energy Skeptic, 2015). Considering the situation with unemployment in Spain, such a hit to any major sector cannot go unnoticed. The turmoil for green energy producers caused by the cap on revenues continues. Another aspect that is being discussed is the so-called “sun tax”. In essence regulators want to impose a tax on producers who use PV panels to make energy for their own consumption (Tsagas, 2015). What is more, solar power seems to be the least favored by the regulators who announced new tenders for both wind and biomass capacity, but none for solar. In a system defined by “over capacity” and “depressed demand” any such legislation will be sure to face significant opposition (Tsagas, 2015). Still having in mind the dire state that the subsidies have left the electricity sector in, it is quite clear that regulators will scramble to cover the substantially large deficit. The country’s lawmakers have to tackle a €26bn deficit (Buck, 2013) and any actions undertaken will not be popular. The reform although balanced, affects the state budget, consumers and, of course, electricity producers. The increase of the price to consumers and the burden taken by the state are almost equal, amounting to a little under a billion euros in the first year, while the industry is expected to cover €2.7bn (Buck, 2013). With these actions the government hopes to be able to fill the deficit gradually over the next 15 years. The case of Spain clearly underlines the severe effects inadequate and inappropriate regulation can have on a sector’s economics and development.

### 5.2.3 UK

The UK regulators opted for a quota system built on tradable green certificates. This scenario exposes producers to the most market risk as they receive the market price for electricity and then sell the “green component” on an additional market for certificates. The introduction of obligations for utilities to have green certificates, created the demand for them. The term used for these certificates is Renewable Obligation Certificates or ROCs (OFGEM , 2016). This system was introduced first in England, Wales and Scotland in 2002, and three years later in Northern Ireland. An extra incentive to actually meet obligation comes from the fact that all utilities that fail to meet the target for the respective period are required to pay a fine. All fines are gathered in a fund that is later distributed to suppliers depending on the level of obligations they have covered (OFGEM , 2016). The renewable energy suppliers were offered revenue consisting of two parts, one price for the sale of electricity and one for the sale of ROCs, much like the renewables premium introduced in Spain. The major difference between the two is that in Spain the premium amount was known with limits, whereas in the UK both components where flexible. Between 2002 and 2006 electricity wholesale prices ranged between £40-£50, and ROC traded for an average of around £50 (Corinna Klessmann, 2008). The additional cost for suppliers is directly passed down to consumers (John Constable, 2011). As lucrative as this almost double revenue provided to RES producers may seem, it did not have the expected effect. Between 1997 and 2005 the renewables share of wind, for example, grew from 1.7% to 4.1% (Corinna Klessmann, 2008). The fact that both the responsibility for market integration and for balancing fell onto the renewable energy producer combined with no exclusive rights for grid connection had a major role to play in this development. Feed in tariffs where introduced in 2010 for small-scale renewable energy generation, including wind, solar, and micro CHP (Energy Saving Trust, 2014). A study by the renewable energy foundation in 2011 found that the cost of the program meant to support the integration of renewables will amount to about £100bn by 2030, under the assumption that subsidies are only granted until the UK fulfills its obligations (John Constable, 2011). In order to extend the feed in tariff scheme, the UK opted for another switch. In 2013 they announced that the quota obligations scheme is to be replaced by a "feed in tariff with Contracts for differences" (CfD) (Anne Held, 2014). The two schemes are meant to run in parallel, with the gradual phasing out of quota obligations. The CfDs are meant to support low carbon technologies, which include a broader range: from generation such as renewables and nuclear to carbon capture and storage. The main goal of the introduction of this scheme is to set a control on the cost that the inclusion of new technologies will have. On the one hand, there is an internal control, as the scheme offers a "strike price" to generators. What this means is that a generator can sell the electricity to energy suppliers and depending on the price there are three options. Either the generator gets the strike price directly from the energy supplier, gets an additional revenue from the government, or pays back to the government the difference between selling price and strike price (Anne Held, 2014). On the other hand, the overall spent for the integration of new technologies is also capped on a national base by the Levy Control Framework. This mechanism is set into place so that there is a control over the total cost that can be passed down to consumers (Anne Held, 2014). The amounts are set on bi-yearly bases.

Even with the attempt at adding more controls in 2015, David Cameroon's cabinet still announced a halt to the feed in tariffs mechanism, a move that was met with great upheaval. The Labor party claimed that this would cause about 1000 wind turbines to not be commissioned, as they cannot be profitable without the direct subsidy (Patrick Wintour, 2015). This decision also comes after the European Commission warned the UK that is on track to miss its targets for renewable energy generation by 2020 (Patrick Wintour, 2015). Clearly the UK has struggled to find a coherent and reliable strategy to include renewable energy in the electricity mix. This combined with the fact that circa one forth of the UKs installed capacity will have to be decommissioned in the next decade, puts the country in a less than desirable position (Simon Currie, 2013).

## 5.3 Regulations Summary

From the overview of the different measures deployed in member states it is quite clear that the design of the support schemes needs improvement. The energy sector is one that is historically been constantly exposed to regulatory intervention. With the introduction of new goals that try to incorporate more than simple economic benefits to the electricity market, regulations have to be more precise and well designed than ever before. The European Commission defines several key aspects of support schemes that need to be implemented, namely transparency, predictability, proper design, flexibility to change in accordance with price developments, optimization, and cost sharing of the grid connection and maintenance (European Commission , 2013). Regulators have to accomplish all the above points, which essentially serve to keep system costs low, while operating in a system where there is abundant information asymmetry between "stakeholders and government authorities" (European Commission , 2013, p. 18). More market exposure and competition would force industry players to reveal more information on their true costs. This constitutes yet another consideration that regulating authorities have to make while considering the design of new support schemes.

In order to foster the seamless integration of renewables while considering all of the above aspects, a working single market throughout Europe has to be in place. Through the implementation of such a system new technology deployment will rely on market dynamics to make use of the most cost efficient distribution of new technologies. This would be further supported if there were a convergence toward similar support schemes throughout the EU member states (European Commission , 2013). In short, should the EU be able to meet its targets for renewable energy in a sustainable way without jeopardizing the dependability of supply, support mechanisms and system design have to foster both integrated electricity market cooperation and competition. In order to further examine the effect that support mechanisms have on the development of renewable energy generation projects, the nest section develops two cases.

# 6 Examples of Renewable Energy Support Shortcomings

The following section gives concrete examples of the shortcomings of support schemes in Europe. This is done on the basis of two cases. Both investment projects are analyzed by utilizing industry standards for evaluating project investments. The first one investigates the investment plan for an offshore wind farm off the coast of Scotland. A financial model is developed in order to determine whether the investment would be a sound decision based on market conditions and government support. The model looks at three scenarios for the outcome of the investments and evaluates the results. The second is a case of an already built biogas power plant in Bulgaria. This is more a descriptive case, as the project is in its last stages of development. However, the situation serves as a very bright example of the devastating effect that unexpected change in regulation can have on the investment projections for an industry sector. Both cases provide an overview of the risk associated with investments in renewable energy and the cost that poorly planned and executed support schemes can have. By no means does this analysis imply that support schemes are not needed to foster and ease the way for the implementation of new technologies. More accurately the purpose is to outline the inherent problems of the currently dominant system. In both cases uncertainties in the financial projections of the new generation units make them not economically viable under market conditions.

## 6.1 Beatrice Wind Farm

The Beatrice Offshore Wind Farm Limited (BOWL) is a two-stage project to build a wind farm off the coast of Scotland in the Outer Moray Firth (Land, 2016). The first stage was a demonstration project consisting of only two wind turbines with a cumulative capacity of 10MW. The idea of the demonstration project was to serve as a proof of concept for a larger development of a wind farm off the coast of Scotland. The project started in 2007, a cooperation between SSE and Talisman energy, it was meant to run for 5 years (Land, 2016). After the successful completion of the demonstration project, SSE decided to pursue the commercial development of the sight.

First, environmental impact studies had to be performed and the project had to apply for permission for development from the Joint Nature Conservation Committee (JNCC). The primary concern when it comes to the development of offshore wind is the disturbance caused to marine life and the bird population. In order to diminish the negative effect on the fish populations in the area the JNCC proposed that the jacket construction to be used for the support of each turbine. Moreover, the JNCC gave a range for the size of blades, according to which the final project had to be constructed. The final condition to the approval of the project limited the amount of servicing stations that could be located in the area of the wind farm to three (Joint Nature Conservation Committee, 2013). These provisions influence the cost and the design of the project, but are mandatory and have to be met. For example, the use of jacket technology to support the turbines would increase the initial cost of the project. Having fewer servicing stations may result in higher Operation and Maintenance (O&M) costs; the limitation on the size of the turbine blades would have a negative impact on the resulting load factor of the wind farm (Roland Berger , 2013). Still, the BOWL project received the first of the necessary documents, which would allow it to become a reality, in 2013.

Two important questions needed an answer before there could be a consideration for development: who would be involved in the development of the farm and whether the government would grant the CfDs to the project. As it currently stands the BOWL project is a joint venture between "SSE Renewables (40%), Copenhagen Infrastructure Partners (35%) and Repsol Nuevas Energias UK (25%)" (Land, 2016). The project was given a "contract for investment" as early as March 2014, allowing it to be developed. This decision was vital to the project, as it allowed the development of the onshore facilities that would serve as a connection between the farm and the grid (reNews, 2015). The connection to the grid is to be accomplished via two deep-water cables connected to an onshore transformation station (4C Offshore, 2016). The project capacity was reduced from 664MW to 588MW as an attempt to reduce the initial investment costs (4C Offshore, 2016). As far as the CfDs are concerned, that information is less likely to be made public. The currently functioning scheme in the UK states that the CfDs are a contractual deal between any "low-carbon" generator and the Low Carbon Contracts Company (LCCC). Consequently, each deal is decided on separately and therefore the levels of support may vary. An additional problem for investors when dealing with CfDs is that these subsidies to the market price are given for 15-20 years, whereas the lifespan of a typical wind farm is 25 years. What is available to the public is the best-case scenario, which limits the strike price for low carbon electricity to £0.14 per KWh (UK Government, 2015). There is still no final investment decision as of February 2016. The three main factors that SSE has stated would influence the decision on whether to develop the project are securing CfDs, reducing the stake it has in the project (already accomplished by the beginning of 2016) and lowering the amounts needed for initial investment and O&M (4C Offshore, 2016).

### 6.1.1 Financial Model – Overview and Justification

The following section serves to evaluate the financial viability of the development of the BOWL project. The full financial model can be found in the attached excel file, but this section provides an overview of the key information and calculations that went into the model in order to generate the results. Information is gathered from official project specific sources and assumptions are made on the basis of industry insights and best practices. The latter are deemed on the basis of different reports, lectures, and information provided on the evaluation of energy investment projects from leading companies such as Roland Berger and Societe Generale. Each of the assumptions is detailed below with a citation of the respective source. Based on this information and in order to examine the volatility of the financial performance of the project, three scenarios are developed. The variables chosen for the different cases reflect the uncertainties outlined by the need for assumptions and the risk associated with investment in renewable energy projects, already outlined. Figure 8 gives an overview of the project's key figures.

| Key Project Details | |
|---|---|
| Project Capacity | 588MW |
| Area | 131km$^2$ |
| Turbine Capacity | 7MW |
| Number of Turbines | 84 |
| Initial Investment | GBP(mill) 2.128 |
| Expected Life | 25 years |

**Figure 8: BOWL Key Project Details (4C Offshore, 2016)**

These figures are taken from the official sources on the project that are available to the public. Further information is needed in order to evaluate the financial viability of the investment. The following figures are also constant through the different scenarios, but are based on assumptions and industry standards, rather than project specific information. Some of the industry assumptions are based on information from In Financials, some are based on the framework that Societe Generale uses to evaluate energy investment projects, and the rest on different reports. These assumptions, with the respective sources are as follows. The project is assumed to be financed as 60% debt and 40% equity (Roland Berger , 2013). The loan is to be repaid over 15 years, starting in year 3 with fixed principal payments. The equity investor discount rate is set at 8%. This rate is based on the notion that should an investment be deemed as having a positive effect the Internal Rate of Return should be equal to or greater than the return of equity of the company (Bilot, 2014). The return on equity for SSE for 2105 is reported at 8% (Financial Times , 2016). Corporate tax is 21% (HMRC , 2015). Annual escalation of CfDs or electricity price is set at 2% to equal inflation. CfD level is £0.14 and electricity price projection for year one of the project is £0.11 (Department of Energy & Climate Change UK , 2015).

The financial model examines the possible outcomes of the development of the wind farm under three scenarios. The rationale behind the different values chosen is detailed below. The source of each of the metrics is given with the explanation of why the value was included as part of the calculations. The main numbers are detailed below in Figure 9.

| Scenario | Base | Low | High |
|---|---|---|---|
| Capacity | 35% | 25% | 40% |
| Availability | 98% | 95% | 98% |
| OPEX | £ 96/KW | + 10% | - 10% |
| Interest rate | 6% | + 2% | - 2% |
| Delay | - | 6 months | - |
| Electricity price | - | - | £ 0,14 after 15y |

**Figure 9: BOWL Scenarios**

The difference in capacity is based on the uncertainty of what the project can deliver. The expected capacity factor as given by the project overview is 35% (4C Offshore, 2016). Hence, this value is taken for the base case scenario. The demonstration project, however, has a measured capacity factor of 25% (LORC, 2012). This value is used in the low case scenario. There are also optimistic estimates, which claim that the capacity factor for offshore wind farms in the UK can be increased to 40%. This figure is used in the high case. Another variable examined in the model is the availability of the wind turbines. In the UK there is a mandate for offshore wind turbines to have an availability factor of 98%. That is why both in the base and high cases this value is used. Still, as the technology is relatively new and there could be complications a lower value of 95% is used in the low case. Next, operating expenses are also included as variable in the model. The base case value is derived from current estimates on the cost of maintenance for offshore wind (Roland Berger , 2013). The changes in the low and high cases serve to show how volatile the financial viability of the project is depending on O&M costs. These can fluctuate due to various reasons. Efficiency and better technology can cause the daily O&M cost to decrease, whereas unexpected events, such as natural disasters, can significantly increase them. The interest rate for debt repayment is set to 6% in the base case and there is a 2% fluctuation in the low and high case scenarios. The base case is derived from industry averages and information from the EU directives, which set minimum level of interest rates for support of renewable energy development (OECD, 2016). Industry insights show that there is a premium added according to the risk profile of the investment. Offshore wind is currently classified as medium risk; hence the fluctuation of the premium (Oxera, 2011). A six months delay is added to the low case scenario. This setback exposes the project to further risk, as there will be a delay in generated revenues. The assumption is made based on the fact that offshore wind farms at 30-40 miles of distance from the shore are quite new and delays could occur. Additionally, the jacket technology needed for the foundation of the turbines is also in its nascent stage of development (Roland Berger , 2013). Last in the high case scenario, it is assumed that the electricity wholesale price would rise to £0.14 without CfDs.

The calculations made in order to evaluate the economic viability of the project are based on the common corporate finance approach, which is simplified in order to accommodate for the valuation of an investment opportunity (Bilot, 2014). Figures 10, 11, 12, and 13 illustrate the calculations made for all the scenarios. These calculations provide the basis needed in order to perform a financial analysis of the project. The first column serves to show the operation performed (addition, subtraction, etc.) the second gives the element (revenue, expenses, tax, etc.) and the third provides either the formula based on which it is calculated or the source from where the value was taken.

| **Operation** | **Value** | **Base** |
|---|---|---|
| | Generated Electricity | (Number of Turbines) * (Turbine Capacity) * (Capacity Factor) * (Annual Hours) * (Availability) |
| * | CfD Price / Market Price (depending on the year) | CfD price given by the UK Government/ Forecasted market price |
| = | **Total Annual Revenue** | |

Figure 10: Revenue Calculation

| Operation | Value | Base |
|---|---|---|
| | Operations and Maintenance | Roland Berger Report |
| + | Decommissioning Fund | Roland Berger Report |
| + | Depreciation | (Total cost of the project)/ (Project Life) |
| + | Debt Interest Payment | (Interest Rate) * (Debt Principal) |
| = | **Total Annual Expenses** | |

Figure 11: Expenses Calculations

| Operation | Value | Base |
|---|---|---|
| | Depreciation | (Total cost of the project)/ (Project Life) |
| - | Taxable Income | (Total Annual Revenues – Total Annual Expenses) |
| = | **Annual Project Cash Flow** | |

Figure 12: Cash Flow Calculation

| Value | Base |
|---|---|
| **Free Cash Flow for Debt Service** | (Debt Interest Payment) + (Taxable Income) + (Depreciation) |
| **Free Cash Flow for Equity** | (FCF for Debt Service) – (Debt Principal Payment) + (Debt Interest Payment) |
| **EBITDA** | (Total Annual Revenues) – (Total Annual Expenses) |

Figure 13: Other Financial Calculations

There are some limitations to the model, which are also worth having in mind before analyzing the results. The lack of project specific information on some of the assumed values may skew the results. However, the use of reliable sources, such as Societe Generale's framework or Roland Berger's market insights, for deeming best and common practices in the industry is meant to mitigate that risk. Several costs are not included in the calculations. Examples of such are cost for grid balancing and cost of unplanned maintenance. The O&M cost component included in the model has some portion of those already incorporated, as it is based on an industry average for already running projects. Still, while in operation that number may vary. Last, it is also assumed that all the energy that BOWL will produce will be sold. This may not always be the case. These limitations have also served as the basis for building the three different scenarios in order to examine how the fluctuations would affect the bottom line.

### 6.1.2 Financial Model – Results

Figures 14, 15, and 16 give an overview of the key financial indicators of the BOWL project under the different scenarios. The chosen parameters are the internal rate of return, the O&M rate (as a percentage of revenue), and the Net Present Value based (NPV), and the Internal Rate of Return (IRR). These have been chosen based on the Framework provided by Societe Generale for evaluating renewable energy project investment; as a rule of thumb the leading bank suggest that a projects IRR should be higher than the company's return on equity (Bilot, 2014). The capital cost per kWh, is given to highlight the fact that the initial investment is not influenced by the fluctuations of the chosen variables. This value emerges when the total cost of the project is divided by the total capacity. O&M costs as percentage of revenues are calculated when the sum of annual O&M costs over the life span of the project is divided by the sum of total annual revenue over the same period. The NPV and IRR have been calculated on the basis of the net project after tax cash flow. More precisely, the NPV has been calculated based on the formula:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

(Investopedia , 2016)

Where $C_t$ is the annual project cash flow, $C_0$ is the initial capital investment t is the expected life of the project and r is the equity investor discount rate, which for SSE is 8% (Financial Times , 2016). The IRR is calculated, based on the NPV and using Excel to solve. The common explanation is that the IRR is the discount rate at which the NPV would be equal to zero (Investopedia , 2016).

| PROJECT RESULTS – BASE CASE | _ |
|---|---|
| O & M Rate (% of revenues) | 31.8% |
| Capital Cost per kWh | £3,619 |
| IRR (Years 1-25) | 5.0% |
| Net Present Value (Years 1-25) | -£538,574,046 |

**Figure 14: Base Case Results**

| PROJECT RESULTS – LOW CASE | _ |
|---|---|
| O & M Rate (% of revenues) | 50.5% |
| Capital Cost per kWh | £3,619 |
| IRR (Years 1-25) | -4% |
| Net Present Value (Years 1-25) | -£1,755,170,772 |

**Figure 15: Low Case Results**

| PROJECT RESULTS – HIGH CASE | _ |
|---|---|
| O & M Rate (% of revenues) | 22.5% |
| Capital Cost per kWh | £3,619 |
| IRR (Years 1-25) | 8% |
| Net Present Value (Years 1-25) | $10,552,567 |

**Figure 16: High Case Results**

Even at a first glance it is evident that the economic viability of BOWL is quite volatile. While it is true that the IRR is positive in two of the proposed scenarios the NPV is worryingly low, due to the high initial investment costs. Should all scenarios be given the same probability of occurring then the overall NPV of the project would certainly remain in the red. What is more, the IRR, even in the most optimistic scenario, is still not higher than the equity investor discount rate. This is never a good sign for a project, and would be probably lead to a negative investment decision.

Still there are additional factors that could influence the investment decision. The risk profile of the investors would be a good example. Another is the external environment. Since the government in the UK has set out to increase the percentage of renewable energy generation it could offer additional financial support to the project, in the form of preferential loans for example. These would then influence the results and a new valuation would be necessary.

## 6.2 Smolyan Biogas Power Plant

In the case of the Smolyan Biogas Power Plant or BARA project, there is no need for a complex financial model as this project is further down in its development and the inadequacy of the chosen subsidies scheme is easier to determine. Still it is important to view the matter in a larger context, in order to understand the significance of the decisions taken regarding this project. Therefore, this case will be more qualitative in nature than the previous one. The project manager, Mr. Alexander Keratsinov, has provided the information on the BARA project development.

### 6.2.1 Background Information

Bulgaria, as all EU member states, had a goal to reach in terms of energy generated from renewable sources. In order to incentivize the building of such generation the government decided to allocate a certain percentage of the national target to the three major utilities in the country. In other words the Bulgarian target was split amongst the large electricity companies, which could choose to either invest in generation facilities on their own or find generators from whom to buy the electricity. It is also worth to mention that the electricity market in Bulgaria is partially liberalized. This in turn means that independent generators need to rely on bilateral agreements in order to sell their electricity. In such a setting subsidies become even more important. The chosen form of support mechanism in Bulgaria for the fostering of RES generation is FIT. The subsidies are different for each "fuel" and the decisions are governed by the National Commission for Energy and Water Regulation (NCEWR). The feed in tariff for any power plant running on biomass is correlated to the price of the raw materials used as a fuel. In the case of the BARA project, that was wood and wood chippings. Estimated investment potential in the sector in 2011 was around €1Bn (Nikolova, 2015). As Bulgaria is the poorest country in the EU with a GDP per capita of a little less than $8000, such an investment potential in any sector would be very welcomed (The World Bank , 2016).

What is more, some cities like Smolyan, where the BARA power plant is situated, have an elevated level of pollution from fine particles in the air due to the fact that a lot of houses still use wood as a main form of heat generation (Energy Agency Plovdiv , 2013). Further contributing to the need for diversification is the fact that there is no power plant close to the city of Smolyan. This is important because the town is situated in a mountainous region and severe weather conditions are common. The latest incident occurred in the winter of 2015, when the city had to remain without power for several days because of a snowstorm that damaged the main grid connections (BGNES, 2015). On the other hand, the characteristics of the region provide ample fuel for a biogas power plant. These factors should be enough to make the city an ideal candidate for the development of a biogas power plant.

### 6.2.2 Project Developments

The BARA Biomass power plant was a project developed for CEZ, one of the three major utilities operating in Bulgaria, as a reaction to the government mandate for large utilities to have part of their respective supply of electricity generated from renewable energy sources. The project proposal was approved in 2012 and preparations started shortly thereafter. The power plant is planned to have a capacity of 4.5 MW and to operate 7,500 hours per annum, generating around 33,750 MWh of electricity. The grid connection will be accomplished through a steel lattice mast to the transformer post Byala, of the electric substation in Smolyan. The power plant is built on a 6,967 sq. m. area near one of the suburbs of Smolyan. The issuing of the project's construction permit took about 2 – 3 months; project installation took 12 months; and additional 3 months after commissioning were expected to be needed in order to make the power plant operational. The Figures 17 and 18 give an overview of the capital and expected operational costs of the project.

| Description | Costs in TSD EUR *VAT excl. |
|---|---|
| EPC | 15,300 |
| Acquisition of land and permits | 1,575 |
| Building permit for the grid connection and grid fees | 30 |
| Technical preparation | 100 |
| **Total** | **17,005** |
| **Cost per MWh** | **3,778** |

**Figure 17: CAPEX BARA Project (Keratsinov, 2015)**

| Description | Estimated costs in EUR *VAT excl. (per MW per year) |
|---|---|
| Maintenance | 235,000 |
| Labor | 22,500 |
| Feedstock | 420,00 |
| Other | 77,500 |
| **Total** | **955,000** |

**Figure 18: OPEX BARA Project (Keratsinov, 2015)**

The cost overview reveals that the BARA project represents a much smaller investment. Still, its development serves as a good example of a major risk, to which renewable energy investors could potentially be exposed; namely the change in regulations can negatively affect investment decisions even after a project is underway.

After CEZ green-lighted the project, construction began. The approval for the project was given based on the assumption that the price for electricity would be subsidized with a feed in tariff. As the OPEX of the project was near €1 Euro, a small portion would still be available to cover the CAPEX. There were some delays mainly due to sever weather conditions. However, the power plant was supposed to be ready to be commissioned in the spring of 2015, with a 3-month delay from the initial plan (Keratsinov, 2015). In January 2015 the NCEWR came out with a statement that it would lower the feed in tariffs for all biomass power plants that would be commissioned after April of the same year (Nikolova, 2015). The main motive behind the planned reduction was that the price for wood had fallen by more than 10%, and therefore the level of the subsidy was overestimated. In order to justify the decrease the regulator also published some estimates. Instead of appeasing the public opinion the published statistics caused more confusion. The president of the Bulgarian Biomass Association even came out with a statement saying that the decision was more political, then economical. Some representatives from the forest sector came out with their own estimates that the price had actually risen by around 20% compared to the previous year (Nikolova, 2015). Regardless of the reason for the 30% decrease in the subsidy for biomass power, it made the BARA project uneconomical to even run, let alone be able cover capital investments costs (Keratsinov, 2015). The project manager and the utility, along with other affected parties, entered into a formal discussion with the regulator. The main goal was to at least consider changing the new regulation and allowing projects that are almost complete to still be entitled to the amount before the reduction. Since March of 2015 the dispute has not yet been settled and the ready-to-use biogas power plant is waiting for a final decision on the matter. Mr. Keratsinov noted that should the final decision be that BARA does not qualify for the larger amount of subsidies then the project will most likely not be operational (Keratsinov, 2015).

This development has deterred investments in the once lucrative sector. Although Bulgaria is currently on track to reach its 2020 goals for the proportion of generation attributed to renewables, it could be more difficult to continue the growth in the sector after this period. The EU Commission is now setting new targets for the union to be met up to 2030. With investor confidence in the country shaken further by such unsubstantiated rash decisions, the regulators will have to face the challenge of restoring the trust. As the electricity market in Bulgaria is gradually being deregulated and more private entities start operating, it will certainly be an uphill battle to meet the new targets in the less than ideal environment that has been created.

## 6.3 Case Analysis Summary and Conclusions

Both cases clearly reiterate some of the risks that were pointed out in examining the different support mechanisms. One of the main risks that becomes even more evident when examining the cases is the insecurity of support. The BOWL project would incur a loss if support is lowered, and the BARA project is currently not operating because there was a cut in subsidies. What is more, the intermittency of wind as an energy source clearly increases the risk of investment in such projects, as is evident from the low case scenario of BOWL. These findings lead to the logical conclusion that support mechanisms need to be adjusted to fit the newly developed paradigm. As the installed capacity of RES grows, the clear-cut support schemes that are currently operating in Europe gradually start being inadequate and insufficient to promote further sustainable growth. Of course, for the time being it is not only the financial parameters that large generators take into consideration when evaluating an investment opportunity. If it were so then the levels of increase in capacity would not be where they are today. Considerations of public image and reputation, compliance and technological development are also made. However, these can affect decisions only to a certain point. As most electricity generators in Europe are public entities their purpose is to create value and generate profit. Therefore the resolution of the inadequacy of current support mechanisms will become a priority in the years to come.

As the complexity of the system increases so will the need for more flexible solutions. The notion that market dynamics foster efficiencies and result in the best state of the system, is one that most of the world holds true. Therefore, it is evident that although renewable energies may still need some regulatory assistance, the sector has to gradually be exposed to more market risks in order to foster efficiencies and economic viability. Large scale developments, such as the creation of a single European market for electricity will most certainly aid in overcoming some of the current problems. To say the least it will allow for renewable energy generation to be built in the most economically efficient places. Further developments and reengineering of the market structure, technologies involved, and regulatory measures will also clearly be needed.

The following section provides an overview of an already existent technological advancement that could contribute to the seamless integration of renewable energy in the electricity mix.

# 7 Virtual Power Plants

Virtual power plants in the sense used in this thesis are defined as an aggregator of different generation units combined and controlled by one central entity. This is not necessarily a new notion, but one that can definitely be implemented with better outcomes because of the advances in technology. The implementation of VPP in a system where RES are also introduced can lead to the alleviation of several problems, already outlined, that currently make alternative energy sources less attractive. These benefits will be illustrated in the next sections through the findings of different studies and examples.

First of all, virtual power plants can help with the strain on the grid that is caused by renewable energy because the system allows for production to be ramped up or down depending on demand and the conditions of the grid. Second, VVPs also provide a different remuneration scheme for distributed generation, alternative to the currently used subsidies or negative charges. The latter are implemented by some utilities in order to stimulate the proliferation of RES. In essence, this scheme provides consumers that also produce electricity discounts on their electricity bill equal to the amount of energy they have supplied to the grid, without taking into account whether that energy was actually needed or not. At first glance that might seem as a good enough solution, but it actually contributes to the strain on the gird. Last the integration of VPPs in the system will result in better forecasting. All of these benefits provide both an operational and an economic benefit to the system. Another advantage worth mentioning is the implication that storage will have when the technology is developed and it can be implemented on a commercial basis. Although this is not currently the status quo, there are significant advancements in the field. Virtual power plants also provide a bridge between distributed generation, demand response and energy efficiency; different tools that are currently being implemented to tackle the challenges of providing enough energy to society while adhering to the goal of diminishing climate change. Through the introduction of an instrument such as VPS, the impact of the aforementioned instruments can be amplified.

## 7.1 Definition

The term Virtual Power Plant is used with different literature depending on the source. In Europe it is used to describe an aggregation of different energy sources that can bid on a deregulated market as one and that are governed by a central IT system. In the US the term VPP can be used to describe a structure that does not even include any type of generation. Rather it is used to describe an entity, which can be defined as a power plant because it serves to deliver grid reliability or peak capacity through the aggregation of demand response and peak pricing programs (Asmus, 2010). The term virtual power plant is sometimes also used as a synonym to micro or smart grid systems. For the purpose of this thesis VPP is used with the European definition, although there is significant merit of combining it with the US model into one entity that can optimize a part of the system by managing both the supply and the demand side. The benefits of such a development will be discussed in a later part of this thesis. Figure 19 illustrates the possible structure of a virtual power plant.

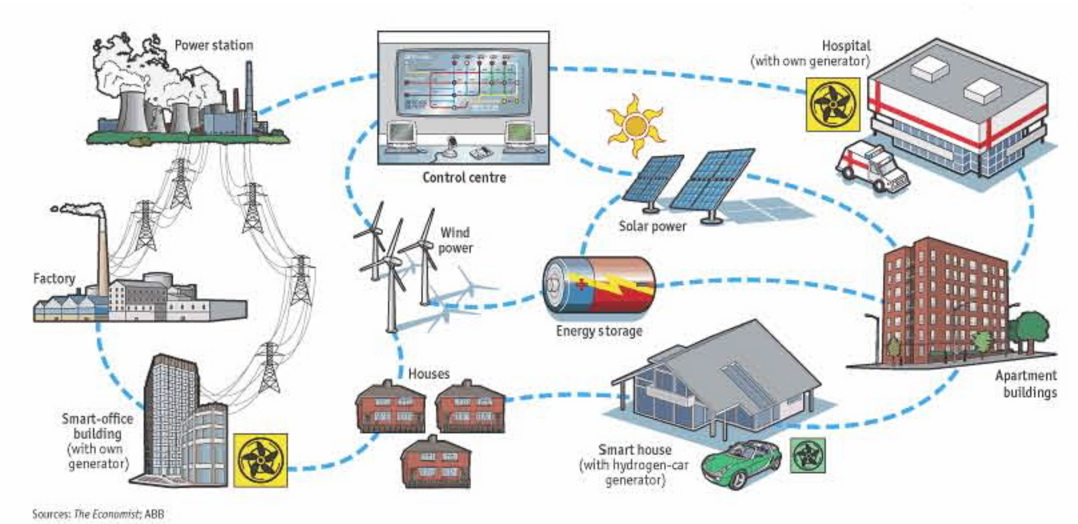


**Figure 19: Virtual Power Plant Structure (Navigant Research, 2014)**

As it is visible on the illustration above the aggregated system does not need to rely solely on renewable energy sources. In fact, it is easier to manage the system if both RES and conventional resources are used because that way, with limited storage capacity, there is still enough capacity to mange base loads. The integration of smart building and such with generating capacity also contributes to the overall system management. Take for example a hospital, which is required to have back up generators, should there be an outage. As any machinery those too have to be maintained and run occasionally so that they function properly when needed. These generators, therefore, can provide electricity to the grid at times when renewable generation is lagging or not available at all. This provides a benefit both to the system and to the institution that has rendered its services.

Building on this, a virtual power plant can be described as the incorporation of different energy source into one centrally controlled logical unit. An additional benefit of using VPPs as part of the electricity providing system is that it can be incorporated without the need of large-scale investments (Asmus, 2010). The building blocks needed to proliferate VPPs are already present, especially in European economies. Most electricity markets are deregulated allowing for bidding of energy directly on the market. The technology for forecasting and optimization is readily available. There are no regulations in most cases that would hinder the incorporation of a virtual power plant in the electricity system. In fact under the EU mandates for energy efficiency, most countries have regulations that demand from utilities to provide their users with smart metering capabilities. Once these kinds of measurements are introduced forecasting and optimization becomes even better, as with any statistical model, the more data points are present the more clear the result.

Still, as beneficial as VPPs can be to the system operation, no business model can survive if it does not make economic sense. Studies show that integrated systems have a better overall economic viability that the currently predominant schemes such as subsidies or negative charges.

## 7.2 Economic Viability

As already shown, the current support schemes for the integration of renewables have a high cost for society and the transmission operators and do not incentivize producers to improve the efficiency of the system. What is more, should countries want to reach the ambitious goals of having a large percentage of electricity generated from renewable energy sources then these have to be able to participate in the market. The economic viability of a VPP, the possible ways of combining different types of generation in order to maximize profit and the alleviation of pressure to the distribution system have been examined in diverse papers. All propose different models by which the optimal dispatch plan can be estimated as Stjepan Sucic et al examined the "VPP information Services design and optimal control" (2011, p. 1). Hrvoje Pandzic et al examined the profitability of a virtual power plant consisting of a wind farm, a conventional power plant and a pumped storage hydro plant (Hrvoje Pandzic, 2013). The study proves that even under uncertainty of production and price levels, the combined entity is profitable. Also such a combination allows for lower grid tensions as the balancing is transferred from the TSO to the VPP operator and is governed by market forces. In essence VPP allow for a decentralization of the control and support of the grid. Through having a singular unit bid on and supply to the market, they alleviate some of the problems that the integration of renewables cause to the system, while contributing to a more steady and secure revenue for generators even without the added benefit of support schemes. The development of renewable technology, coupled with the lower associated costs and electricity market developments allow for entities such as virtual power plants to enter the market and bring efficiencies to the whole system.

## 7.3 Examples

There are functioning versions of virtual power plants; the two most notable examples are from Germany and Denmark.

First, a look at the Danish model, Ostkraft, a distribution system operator in Denmark, has built a pilot project on the island of Bornholm. The whole electricity supply of the island is under the governance of a centralized virtual power plant. The system consists of wind turbines, a biodiesel combined heat and power and a fleet of electric vehicles (EcoGrid, 2015). There are ~28,000 customers on the island. The plant was developed as experimental ground and is connected to the university, its aim is to have a system that is 100% run on renewables. The use of the fleet of electric vehicles is one of the notable developments; they are used as a substitute to electricity storage technology.

Their implementation aims at maintaining the quality of power supplied by the system. On the one hand the vehicles can be used to take power from the grid when there is more production and less demand. On the other they can also be used to supply power to the grid should demand rise. Another important part of the island's electricity infrastructure is the presence of smart grid technologies that make the implementation of demand response programs possible. Although, this particular aspect of the Bronham power system deviates from the accepted definition of a VPP, it is a valuable addition to it. Through demand response the central management system is able to send messaged to the consumers, warning them of peak demand prices, and gives them the possibility to lower their consumption at that moment. The estimations are that a decrease of 20% can be achieved through such programs that help alter the behavior of customers when it comes to electricity usage (Kumagai, 2012).

An example of a virtual power plant is also functioning in Germany. In 2017 RWE and Siemens teamed up to develop a virtual power plant as part of the Smartpool project (Dietrich Biester, Siemens and RWE build next-generation virtual power plant, 2015). The pilot went online in 2008 and was meant to prove the economic viability and technical advantage of using a centralized control system to operate a portfolio of different generation types. The project included "hydro power plants, combined heat and power units and emergency power systems" (RWE , 2015). Four years later the decision was taken that the project should be expanded. Since yearly in 2012 the VPP is officially selling its electricity on the exchange in Leipzig. The centralized control allows for more than simply the opportunity for distributed generation units to vid directly in the energy exchange. Should there be a need of ramping down of production the VPP can control the assets under management and throttle production in order to provide grid security and power quality (RWE , 2015). The opposite is of course also true. Virtual power plants are very well suited to provide the needed minute reserve power to the grid. Since the system is mainly made up from RES, it is more economic lay viable to use those resources as reserve power since there are no immediate ramp-up or start-up costs associated with the immediate switching on. The expansion of the project meant that the MWs under control were to be increased from 20 in 2012 to 200 in 2015. (Dietrich Biester, Siemens and RWE to expand virtual power plant with additional energy sources, 2012). The increase is to come from different sources such as biomass, wind farms and hydro plants across Germany. The implementation of such technologies in Germany was also aided by the introduction of the Renewable Energy Source Act in Germany in 2012. Its main benefit is that it offers a market premium for the trade of energy produced by renewable directly on the market. Thus the decision of Siemens and RWE to choose this option became a very easy one. This is illustrated in Figure 20, which was taken from an official RWE presentation.

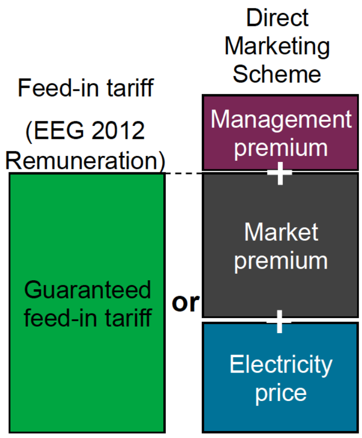


**Figure 20: Remuneration Comparison RES in Germany (Duvoor, 2012)**

The electricity spot price and the market premium are set up so that they equal the guaranteed feed in tariff; the management premium covers the cost of entering the energy exchange (Duvoor, 2012). Once on the market the VPP has several sources of revenue. First, as for any other actor, there is an amount of energy sold on the day-ahead market. Second, a VPP can be used for "providing capacity for minute and secondary reserve" (Duvoor, 2012, p. 9). Last the centralized system can provide both "negative and positive reserve power" (Duvoor, 2012, p. 9). Although the VPP in Germany is currently operating under the European model where it only focuses on supply side management, the ultimate goal of the RWE-Siemens project would be to expand the project into demand side management thus creating a mixed asset. This development will be aided by the proliferation of smart metering and smart grid technologies.

# 8 Future Outlook and the Way Forward

This thesis has aimed at identifying the inadequacies of the current predominant approach to the integration of renewable energy sources in the electricity mix of countries in Europe. It is quite evident that should governments want to adhere to the ambitious goals for combating climate change, set by the European Commission and commitments made at the Paris conference, there has to be a better way of preparing for the new energy future. Virtual Power plants are an example of how technological developments can assist in the proliferation of renewables without jeopardizing the soundness and security of the system. They offer a way of alleviating two of the major problems identified in this thesis, namely economic viability and grid overloads. Through the proper utilization of new technologies that complement renewable energy generation the main issue of intermittency and unreliability can certainly be tackled. Further developments and innovation will enable the spread of clean energy sources.

As the world is in the first years of the fourth industrial revolution – the digital one, more and more problems will be tackled with the help of technology. The vast quantities of data available and the ability to analyze this data will drive efficiency. GE has identified that the utilization of the IoT will have a 100% impact on the energy sector (GE, 2016). The Industrial Internet Consortium has identified that three aspects can be improved in the energy sector: maintenance, control, and safety. Through the implementation of predictive maintenance down time and cost of repairs can be substantially reduced. System performance can be improved through enhanced control and safety and security can be enhanced (Industril Internet Consortium , 2016). All this can be achieved though advanced data analytics. Advancements in technology allow for the integration of a plethora of sensors that can give real time information, which can then be used to improve the overall performance of a system, be it a conventional power plant or a renewable source installation. In order for these advancements to be commercial implementable the groundwork has to be laid first. As in the early days of the Internet, there need to be standards that govern the communication of sensors and standardization throughout the system. This, of course, would require further investment in R&D.

What is more business elite has recently united to form the Breakthrough Energy Coalition. Among its members are people like Bill Gates, Mark Zuckerberg, Ratan Tata, George Soros, Jack Ma, and Richard Branson. The goal of this coalition is to foster the faster development of technologies that would help ensure meeting growing global demand for energy while combating climate change. They have come out with a statement that sums up the problems of the current system, namely: "The existing system of basic research, clean energy investment, regulatory frameworks, and subsidies fails to sufficiently mobilize investment in truly transformative energy solutions for the future." The plan for the to be reached is two-fold. First the consortium will urge governments to support investment in R&D for new technologies. The main aim is to have governments provide the necessary environment and finds that will enable innovation. The second step of the plan is to provide a readily available pool of private capital in order to bridge the gap between prototypes developed in a lab and commercially ready products (Energy Breakthrough Coalition, 2016). In a recent interview one of the most prominent members of the coalition, Bill Gates, stated that he expects an "energy miracle" in the next fifteen years. What he meant is that there will be a breakthrough development in energy technology that will allow us to secure our energy future (Bennet, 2015). An aspect that goes hand in hand with advancement and digitalization is security. As more functions are controlled by technology the risk of an attack increases. It would be no longer needed to bomb or physically attack a power plant; rather a remote cyber breach could cripple supply of a region or even a country. Therefore, alongside with the development of the technologies that would enable us to meet the ever-increasing energy demand in a sustainable way, new security protocols and defenses have to be in place.

Clearly technology will drive the move from a fossil fuel based economy to a cleaner one. The whole energy sector will change and will join the ranks of other fields of our economy that have been completely reinvented due to new technologies. In order for that to happen governments and the private sector will have to cooperate.

# 9 Bibliography

4C Offshore. (2016). *Beatrice Offshore Wind Farm* . Retrieved from 4C Offshore : http://www.4coffshore.com/windfarms/beatrice-united-kingdom-uk53.html
Alberola, P. E. (2013 йил February). Cliamte Change Economics - EU ETS. *Lecture* .

Anne Held, M. R. (2014). *Design Features of Support Schemes for Renewable Electricity* . Retrieved 2016, from Ecofys : http://www.ecofys.com/files/files/ec-fraunhofer-isi-ecofys-2014-design-features-of-support-schemes.pdf

Asmus, P. (2010). Microgrids, Virtual Power Plants and Our Distributed Energy Future. *The Electricity Journal* .

Bennet, J. (2015). *We Need an Energy Miracle'.* Retrieved 2016, from The Atlantic : http://www.theatlantic.com/magazine/archive/2015/11/we-need-an-energy-miracle/407881/

BGNES. (2015). *The Snow Block continues for Kurdjali and Smolyan. Продължава снежната блокада в Кърджали и Смолян.* Retrieved 2016, from Vesti : http://www.vesti.bg/bulgaria/prodylzhava-snezhnata-blokada-v-kyrdzhali-i-smolian-6032792

Bilot, O. (2014, May). Renewable Power Industry and Project Financing . Paris .

Bozsoki, I. (2014). *Germany: Summary.* Retrieved 2016, from RES Leagal Europe : http://www.res-legal.eu/search-by-country/germany/summary/c/germany/s/res-e/sum/136/lpid/135/

Buck, T. (2013). *Spanish Energy Reforms Slash Subsidies to Suppliers* . Retrieved 2016, from Financial Times : http://www.ft.com/cms/s/0/a7e539a8-eb0c-11e2-bfdb-00144feabdc0.html#axzz3yH1ZVkJx

C2ES. (2015). *Outcome of the UN Climate Change Conference in Paris* . Retrieved 2016, from Center for Climate and Energy Solutions: http://www.c2es.org/international/negotiations/cop21-paris/summary

Cécile Kerebel, B. M. (2014). *The Impact of Oil Prices on EU Energy Prices* . European Parliamnt's Committee on Indutry Research and Energy .

Corinna Klessmann, C. N. (2008). Pros and cons of exposing renewables to electricity market risks— A comparison of the market integration approaches in Germany, Spain, and the UK. *Electricity Journal* .

Department of Energy & Climate Change UK . (2015). *Participating in the EU ETS.* Retrieved 2016, from UK Government: https://www.gov.uk/guidance/participating-in-the-eu-ets

Dietrich Biester. (2015). *Siemens and RWE build next-generation virtual power plant.* Retrieved 2016, from Siemens : http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2015/energymanagement/pr2015110068emen.htm&content[]=EM

Dietrich Biester. (2012). *Siemens and RWE to expand virtual power plant with additional energy sources.* Retrieved 2016, from Siemens : http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2012/infrastructure-cities/smart-grid/icsg201202012.htm&content[]=ICSG&content[]=EM&content[]=EMSG

Dr. Matthias Lang, A. L. (2014). *Overview Renewable Energy Sources Act.* Retrieved 2016, from German Energy Blog: http://www.germanenergyblog.de/?page_id=283

Duvoor, P. (2012). *Virtual Power Plants in Competitive Wholesale Electricity Markets.* Retrieved 2016, from Caltech: http://resnick.caltech.edu/docs/d-Siemens_Grid3.pdf

E&C Consultants. (2014). *Consumers: Be Ware of Capacity Payments.* From eNergetics by E&C Consultants: https://energytics.wordpress.com/2014/06/16/end-consumers-beware-of-capacity-payments/

EcoGrid. (2015). *The Bornholm Test Site*. Retrieved 2016, from EcoGrid EU : http://www.eu-ecogrid.net/ecogrid-eu/the-bornholm-test-site

EEA, Europe Enviroment Agency. (2012). *Electricity Production by Fuel .*

EIA . (2008). *EIA U.S. Energy Information Administration.* From About Natural Gas Pipelines : http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/process.html

Energy Agency Plovdiv . (2013). *Plan for the Diminishing of Fine Particle Polution .* Retrieved 2016, from Energy Agency Plovdiv : https://circabc.europa.eu/webdav/CircaBC/env/ambient/Library/extension_notifications/application_extensions/bg_1/notification_anonymised/notification_30062011/bg0005_smolyan_pm10/REF_SM_01.pdf

Energy Breakthrough Coalition. (2016). *Introducing the Energy Breakthrough Coalition.* Retrieved 2016, from Energy Breakthrough Coalition: http://www.breakthroughenergycoalition.com/en/index.html

Energy Saving Trust. (2014). *Feed-in Tariff scheme.* Retrieved 2016, from Energy Saving Trust: http://www.energysavingtrust.org.uk/domestic/feed-tariff-scheme

Energy Skeptic. (2015). *Renewable subsidies in Spain, Germany, Italy, and the UK.* Retrieved 2016, from Energy Skeptic: http://energyskeptic.com/2015/renewable-subsidies-in-spain-germany-italy-and-the-uk/

EPIA, European Photovoltaic Industry Association. (2014). *Global Market Outlook for Photovoltaics 2014-2018.*

European Commission . (2016). *Carbon Capture and Geological Storage .* Retrieved 2016, from European Commission: http://ec.europa.eu/clima/policies/lowcarbon/ccs/index_en.htm

European Commission . (2013). *European Commission guidance for the design of renewables support schemes.* Retrieved 2016, from European Commission : https://ec.europa.eu/energy/sites/ener/files/com_2013_public_intervention_swd04_en.pdf

European Commission . (2015). *Progress towards 2020 targets: the European Semester.* From European Commission : http://ec.europa.eu/clima/policies/g-gas/progress/index_en.htm

European Commission . (2016). *The EU Emissions Trading System (EU ETS).* Retrieved 2016, from European Commission Climae Change : http://ec.europa.eu/clima/policies/ets/index_en.htm

European Commission. (2015). *Biomas.* Retrieved 2015 from Europen commission: https://ec.europa.eu/energy/en/topics/renewable-energy/biomass

European Commission. (2016). *Carbon Capture and Storage.* Retrieved 2016, from European Commission Energy : https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/carbon-capture-and-storage

European Commission. (2015). *Energy Efficiency.* From European Commission: http://ec.europa.eu/energy/en/topics/energy-efficiency

Eurostat. (2015). *Renewable Eenergy statistics .*

EWEA. (2015). *Power Markets.* Retrieved 2016, from Wind Energy the Facts: http://www.wind-energy-the-facts.org/power-markets.html

Federal Ministry of Economic Affairs and Energy. (2016). *2014 Renewable Energy Sources Act: Plannable. Affordable. Efficient.* Retrieved 2016, from Federal Ministry of Economic Affairs and Energy:

http://www.bmwi.de/EN/Topics/Energy/Renewable-Energy/2014-renewable-energy-sources-act.html

Financial Times . (2016). *SSE PLC .* Retrieved 2016 , from Financial Times : http://markets.ft.com/research/Markets/Tearsheets/Financials?s=SSE:LSE

GE. (2016). *Industrial Internet of Things .* Retrieved 2016, from GE : https://www.ge.com/digital/industrial-internet

Henbest, S. (2015). *New Energy Outlook 2015.* Bloomberg Finance LP .

HMRC . (2015). *Rates and Allowences: Coroprate Taxation .* Retrieved 2016 , from HMRC : https://www.gov.uk/government/publications/rates-and-allowances-corporation-tax/rates-and-allowances-corporation-tax

Hrvoje Pandzic, J. M. (2013). Offering model for a virtual power plant based on stochastic programming. *Electricity Journal* .

IEA . (2014). *Harnessing Electricity's Potential .* From EIA : https://www.iea.org/media/140512_ETP_SLIDES.pdf

IEA . (2015). *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015.* Retrieved 2016 , from EIA : https://www.eia.gov/forecasts/aeo/electricity_generation.cfm

IEA . (2014). *World Energy Outlook 2014 .* Paris.

IEA. (2014). *Energy Technology Perspective 2014.* From EIA: http://www.iea.org/Textbase/npsum/ETP2014SUM.pdf

IEA Statistics . (2014). *Electricity Information 2014 .* Paris : IEA.

Industril Internet Consortium . (2016). *Productivity and the Industrial Internet.* Retrieved 2016, from Industril Internet Consortium : http://www.iiconsortium.org/vertical-markets/energy-utility.htm

Investopedia . (2016). *Net Present Value .* Retrieved 2016, from Investopedia : http://www.investopedia.com/terms/n/npv.asp

Isola, J. (2013). *Strong Growth for Renewables Expected Trhough to 2030.* From Bloomberg New Energy Finance: http://about.bnef.com/press-releases/strong-growth-for-renewables-expected-through-to-2030/
I
TER. (2016). *ITER in France .* Retrieved 2016, from ITER : https://www.iter.org/org/iterinfrance

John Constable, L. M. (2011). *The Probable Cost of UK Renewable Electricity Subsidies 2002-2030.* Retrieved 2016, from Renewable Energy Foundation :

http://www.ref.org.uk/publications/238-the-probable-cost-of-uk-renewable-electricity-subsidies-2002-2030

Joint Nature Conservation Committee. (2013). *Beatrice Offshore Windfarm Proposal .* Aberdeen: Scottish Natural Heriatge .

Katy Hogg, R. O. (2010). *Renewable energy support mechanisms: an overview.* Retrieved 2016, from Global Wand Business: http://www.globelawandbusiness.com/RN/sample.pdf

Keratsinov, A. (2015). (S. Boeva, Interviewer) Sofia .

Kumagai, J. (2012). *Virtual Power Plants, Real Power.* Retrieved 2016, from The Spectrum : http://spectrum.ieee.org/energy/the-smarter-grid/virtual-power-plants-real-power

Land, K. (2016). *Beatrice .* Retrieved 2016, from SSE : http://sse.com/whatwedo/ourprojectsandassets/renewables/Beatrice/

LORC. (2012). *Beatrice Demonstration Offshore Wind Farm .* Retrieved 2016, from LORC Knowledge : http://www.lorc.dk/offshore-wind-farms-map/beatrice-demonstration

Márton Herczeg. (2012). *Renewable energy support schemes in Europe.* Retrieved 2016, from Corpus : http://www.scp-knowledge.eu/sites/default/files/Herczeg%202012%20Renewable%20energy%20support%20schemes%20in%20Europe.pdf

Nichols, W. (2014). *Carbon capture and storage "stalling" in Europe, industry warns.* Retrieved 2016, from Busineess Green : http://www.businessgreen.com/bg/analysis/2329809/carbon-capture-and-storage-stalling-in-europe-industry-warns

Nikolova, R. (2015). *NCEWR tries to preemptively slow down biomass power plants. ДКЕВР опитва да укроти централите на биомаса превантивно .* Retrieved 2016, from Kapital : http://www.capital.bg/politika_i_ikonomika/bulgaria/2015/01/07/2449562_dkevr_opitva_da_ukroti_centralite_na_biomasa/

Nyquist, S. (2015). *Lower oil prices but more renewables: What's going on?* Retrieved December 2015, from McKinsey and Company : http://www.mckinsey.com/insights/energy_resources_materials/lower_oil_prices_but_more_renewables_whats_going_on

OECD. (2016). *OECD: The Arrangement for Officially Supported Credits .* Retrieved 2016 , from OECD : http://www.oecd.org/trade/renewable-en.pdf

OFGEM . (2016). *Renewables Obligation (RO).* Retrieved 2016, from OFGEM: https://www.ofgem.gov.uk/environmental-programmes/renewables-obligation-ro

Oxera. (2011). *Discount Rates for Low-Carbon and Renewable Generation Technologies .* Retrieved 2016 , from Committee on Climate Change : https://www.theccc.org.uk/archive/aws/Renewables%20Review/Oxera%20low%20carbon%20discount%20rates%20180411.pdf

Patrick Wintour, A. V. (2015). *Tories to end onshore windfarm subsidies in 2016.* Retrieved 2016, from The Guardian: http://www.theguardian.com/environment/2015/jun/18/tories-end-onshore-windfarm-subsidies-2016

Ragwitz, D. M. (2013). *EU Renewable energy support schemes.* Retrieved 2016, from European Commission: http://ec.europa.eu/competition/state_aid/modernisation/ragwitz_en.pdf

Randall, T. (2015). *The Way Humans Get Electricity Is About to Change Forever*. Retrieved January 2016, from Bloomberg : http://www.bloomberg.com/news/articles/2015-06-23/the-way-humans-get-electricity-is-about-to-change-forever

reNews. (2015, November 2 ). Beatrice Good to Go Onshore . *ReNews* .

RES Leagal . (2012). *Spain: Overall Summary .* Retrieved 2016, from RES Leagal : http://www.res-legal.eu/search-by-country/spain/

Roland Berger . (2013). *Offshore Wind Toward 2020 .*

RWE . (2015). *Virtual Power Plant .* Retrieved 2016, from RWE : http://www.rwe.com/web/cms/en/237450/rwe/innovation/projects-technologies/energy-application/distributed-generation/virtual-power-plant/

Simon Currie, A. H. (2013). *European renewable energy incentive guide - United Kingdom.* Retrieved 2016, from Norton Rose Fulbright : http://www.nortonrosefulbright.com/knowledge/publications/66174/european-renewable-energy-incentive-guide-united-kingdom

Stjepan Sucic, T. D. (2011). Economic dispatch of virtual power plants in an event-driven service-oriented framework using standards-based communications. *Electricity Journal* .

The Economist . (2015, June 13). Banishing the clouds. *The Economist* .

The World Bank . (2014). *Access to Electricity* . Retrieved from The World Bank Data : http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS

The World Bank . (2016). *GDP per Capita .* Retrieved 2016, from The World Bank : http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

Tsagas, I. (2015). *Is the Spanish Government Putting the Brakes on Solar PV?*

Retrieved 2016, from Renewable Energy World : http://www.renewableenergyworld.com/articles/print/volume-18/issue-4/features/solar/is-the-spanish-government-putting-the-brakes-on-solar-pv.html

UK Government. (2015). Electricity Market Reform: Contracts for Difference.