Profitability & Sustainability of Renewable Energies – with a Focus on Wind Power

From a European Perspective

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Abstract:

Sustainable energy is growing worldwide but has been facing criticism. Therefore how humankind will create energy in the future is subject to much speculation. This thesis investigates the profitability and sustainability of chosen renewable energies in order to understand the advantages of sustainable energy with facts and numbers. Technical explanations are limited to their relevance to the financial analysis. The collected data is from European companies in the energy industry, as those countries are more likely to have similar weather conditions, policies, political stability etc, which are factors that influence financial analyses. Two case studies are inspected (an onshore and an offshore wind farm) whereas additional data is used to backup the results and argumentation. The case studies are built up similarly: an analysis of the production/installation process versus the energy outcome and what the profitability and sustainability balance of each looks like. The results are then compared to non-renewable energies. In the end, we see that renewable energies are worth investing in compared to non-renewable energies and have great potential to become more profitable and more sustainable if implemented right.

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Abbreviations

Energy

kWh	kilowatt per hour
MWh	megawatt per hour, 1000 kWh
TWh	Tetrawatt per hour, 1000 000 MWh.
SE	Sustainable Energy
RE	Renewable Energy

Europe

EU	European Union
EC	European Commission
EWEA	European Wind Energy Association
Ofgem	

Financial methods

LCoE	Levelised Cost of Energy
SCoE	Society's Cost of Energy
NPV	Net Present Value
IRR	Internal Rate of Return
EROI	Energy Return On Investment
CF	Cash Flow

Other

O&M	Operation and Maintenance
CO2	Carbon Dioxide
FIT	Feed-in-Tariff
OFTO	Offshore Transmission Owners (OFTOs
Ofgem	Office for Gas and Electricity Markets UK
R&D	Research & Development

1 INTRODUCTION

1.1 Research topic & aim

It is crucial to provide energy to fulfil today's needs without compromising the sources of tomorrow's needs. Especially in the energy industry, resources are limited and highly desired. The shortage of energy-providing resources has been in the societies' minds for decades and yet no worldwide change in the energy industry has occurred. Until today, most energy created comes at a price (carbon dioxide emissions, radioactive and long-lasting nuclear residue, overuse of scarce resources...).

Two main principles of sustainability are:

1. Leave everything in the pristine state, or return it to its pristine state
2. Develop so as to not overwhelm the carrying capacity of the system. (Peter P. Rogers, Kazi F. Jalal, John A. Boyd, 2008).

Even though the facts on world oil consumption and oil resources differ a lot depending on the source, it is sure that it takes millions of years for dead buried organisms to form into energetic fossil fuels and the world consumes billions of crude oil barrels each year. This is an obvious contradiction to the sustainability principles listed above. Most resources, particularly fossil fuels, are reaching their limits- which lead to several energy crises and the conflicts are not over. Even less politically controversial resources, such as nuclear power, also have provision limits. Nuclear power for instance, produces power through the fission of heavy atoms and atoms, especially heavy ones, are also limited.

Sustainable energy (SE) represents the chance of developing an energy system that is able to provide enough energy worldwide using natural elements which can be found anywhere on Earth. Some representative examples are EU aims to get 20% of its energy from renewable sources by 2020 (EC, 2014). The EC (European Commission) categorizes energy from wind, solar, hydroelectric and ocean (tidal) as well as geothermal energy, biomass and the renewable part of waste as renewable sources (EC, 2015).

Energy is the central aspect of our societies, as well as to sustainable development and poverty reduction efforts. The need of abundant and cheap energy is continuously the centre of corporate and political decision making, it has lead countries to war (Klare, 2014). Energy affects all aspects of life and development -- social, economic, and environmental - including livelihoods, access to water, agricultural productivity, health, population levels, education (UNEP, 2007). According to the United Nations Development Programme, “none of the Millennium Development Goals (MDGs) can be met without major improvement in the quality and quantity of energy services”.

In Germany -one of the leaders in solar energy (European Solar Thermal Industry Federation, 2014)-, companies are more efficient as they have ever been. On May 26th, 2012 the International Economic Platform for Renewable Energies (IWR) director Norbert Allnoch assumed that 22.000 Megawatt had been generated by the German solar industry on that sunny day, which corresponds to the energy created by more than 20 nuclear power plants (Finanacial Times Deutschland, 2012).

Nevertheless, in the end of 2012, many solar technology companies went bankrupt (Q-Cells, Solon, and many smaller firms) and Siemens sold its subsidiary Solel October 10th that year. Joe Kaeser, Siemens’ chief financial officer, told analysts in July 2012 that the solar business is not reaching its expectations and some material has to be realigned in that industry. The SE industry is still facing major issues, mostly related to financial aspects. That is why this thesis investigates the profitability of renewable energies, with a focus on wind power.

We have reached the quantity of energy needed in the western world through fossil oil, gas and nuclear power plants; now the focus is more and more directed to the qualitative aspect of energy production (Holm, 2015), mostly low-carbon energies. The European Union has set “ambitious climate and energy targets for 2020” (European Commission, 2014). The three key objectives of the European “20-20-20” targets are:

1. a 20% reduction in EU greenhouse gas emissions from 1990 levels;
2. a 20% raise of the share of EU energy consumption from renewable resources;
3. a 20% improvement in the EU's energy efficiency. ” (EC, 2014)

The goal of this work is to understand how profitable and how sustainable renewable energies are and how they will develop according to their potential, by taking a closer and analytical view to the wind power industry. The aim is then to understand what the biggest problems and challenges are and investigate whether renewable energies are worth investing in compared to non-renewable energies as well as their potential to become more profitable and more sustainable if implemented right. The research should provide a helpful simplified overview with relevant information for anyone interested in RE, in particular potential investors and entrepreneurs.

1.2 Research questions

The main question to be answered in this research is: How profitable and sustainable are the chosen renewable energies (onshore and offshore wind power), in comparison to each other, and to non-sustainable energies? This work also takes into consideration other renewable sources of energy such as solar power.

Following is a list of more specific questions that are to be answered in this research:

-How profitable are RE? How is the balance between their production, installation and maintenance cost with the energy outcome?

-How competitive are they in comparison with non-sustainable energies?

-What are the environmental costs of producing, installing and maintaining wind turbines and how is the balance with the energy outcome?

-What is the potential of RE and what are its future prospects?

-Why is it that we are still mostly relying on the non-renewable fossil fuels (coal, oil and natural gas) and nuclear power?

1.3 Limitations

SE, especially from a financial point of view, is closely linked to policy-making. Because each government has its own strategy, which might interfere with its neighbours' policies, the countries of the European Union are forging policies towards a common goal. For instance, one of the main regulation systems is the EU Emission Trading System (EU ETS) launched in 2005. Companies in the European Union have to lower their carbon dioxide emissions to a certain grade, if they accomplish to lower their emissions even further than the requirements, the companies can trade their "surplus" to other companies that did not fulfil the expectations. The regulations of this new market are following the free capital market rules (offer versus demand) and have no geographical limitations (if a European company lowers its emissions in Asia, it counts as a global reduction and is tradable on the EU ETS). Because environmental policies vary a lot from different regions in the world, this research focuses on European policy. Therefore this research is geographically limited to Europe, a few global or non-European sources are included too.

The chosen case studies are in Denmark and England and the interviews conducted by the author are made in Finland and Germany. Therefore, even though the interviewed persons work for companies, banks or research institutes that are active in many more European countries (e.g. UK, Spain, France…), this research has mostly a northern and central European perspective.

In order to evaluate a project, the technical challenges have to be well understood. Anyhow this research attempts to clarify the financial aspects of SE, therefore technical facts are limited to their relevance to the case.

Energy and politics are closely linked. Except for energy legislation and regulation set by the European Union and the European governments, this work focuses on financial analysis and leaves speculation and politics out (as much as possible).

1.4 Theoretical Framework

SE is a vast topic, even from a financial perspective. In finance they are a few typical actors that deal with the information. This research will deal with the topic as accurately and as similar to a real analysis as possible.

In SE, the main actors are the manufacturers, the developers and the investors. Manufacturers sometimes share information on the production process, the implementers are project management orientated and the investors provide information on cash flows and returns. On a more general level, governments, economists, engineers and journalists are active in the field of SE and provide information to the public in different forms: academic literature, official documents, articles, press releases etc.

They are many forms of SE, not to speak of sustainable technology. In order to provide a more specific analysis, tractable argumentation and provide a better energy comparison, this research limits itself to on- and offshore wind power (with a case study in each). Those are using the unlimited resource that is the wind, therefore their sustainability is less controversial than other sustainable energies, such as biomass, biofuel or tidal (which has consequences on the water flows, temperature, bio system).

Also, there is a wide range of companies and therefore products, especially in the solar industry, as most companies focus on a private rather than a corporate use of the energy. This thesis analyses a range of products in the market, but focuses on the corporate use of SE- power plants that are connected to the grid. It simplifies the analysis and provides the reader with a more insightful research.

1.5 Definitions

The World Commission on Environment and Development (WCDE)'s report in 1987 defines sustainable development as a development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". There are three different dimensions: social equity, economic development, environmental quality, and now a days "sustainability is the term chosen to bridge the gulf between development and environment" (Peter P. Rogers, Kazi F. Jalal, John A. Boyd, 2008 p.22&42).

According to the Oxford Dictionary energy is the "power derived from the utilization of physical or chemical resources, especially to provide light and heat or to work machines". Energy can be measured in different ways, as this research focuses on electricity-providing energies, the standard energy measure is MWh (MegaWatt per hour).

It is not clear where the demarcation between natural resources and other goods can be drawn. However the World Trade Organization defines typical natural resources as follow:

"Natural resources are "stocks of materials that exist in the natural environment that are both scarce and economically useful in production or consumption, either in their raw state or after a minimal amount of processing". Most natural resources share a number of important characteristics, including uneven distribution across countries, exhaustibility, externalities (market failures in the form of unprized effects resulting from consumption and/or production), dominance in output and trade, and price volatility." (World Trade Organization, 2010)

It can be noted that REs such as wind and solar power have a slightly different definition, as they are not scarce but abundant, and are not unevenly distributed across nations.

Financing in the energy industry can be seen as project financing. It is commonly energy plants such as the launching of a solar panel system or a dam. The Organization for Economic Co-operation and Development defines project financing as:

"A form of financing projects, primarily based on claims against the financed asset or project rather than on the sponsor of the project. However, there are varying degrees of recourse possible. Repayment is based on the future cash flows of the project."(OECD, 2006)

This works repeatedly mentions Europe and the European Union, unless specified otherwise; it includes the current 28 member countries, with the accession of Croatia in July 2013 (European Union, 2014) after 2013 and EU-27 for data from before 2013.

1.6 Methods

The main material used for this work is found online. Academic literature in forms of books and official publications is used for general sustainability and finance theories only. Online publications from the European Commission and European governments, research institutes, companies and wind power magazines are the main material used, as they provide up-to-date numbers on costs and revenue of renewable energies - particularly wind power, current European policies, statistics and reports. Most statistics on European energy are retrieved from official publications of the European Union, for instance Eurostats or the European Wind Energy Association.

After a first draft based on empirical data is done, two case studies, one in onshore and one in offshore wind power, are used to apply the findings on real wind farms and see if the results are in line with information provided. The numbers used for the case studies are partly retrieved from direct publication on the wind parks and partly taken from average industry numbers that fit the case studies. Therefore this work only mentions and applies the most useful and reality-close ones (as chosen by the author) out of all the investigated numbers.

The currencies vary due to the different countries of the case studies (UK and Denmark), this thesis uses the Euro as the standard currency. The exchange rates used are from the year of construction in the onshore case study and from March 2015 in the offshore case study.

In a third time, interviews with various players in the industry of SE are used as back up to the analysis, results and findings. Potential for RE and its future prospects are mostly based on the results of the conducted interviews, quoted directly, or inspired by the interviews.
The interviewees are several professionals in the industry of SE: two producers/implementers of wind farms, one financial institution that finances clean energy and one research institute active in low-carbon energy among other things, respectively:
- Patrik Holm, founder and CTO of Mervento Oy and Chairman of the Board of the Swedish-speaking Wind Power Association in Finland, Helsinki, Finland.
- Anders Stenberg, from the European and German-based wind developer WPD, Helsinki, Finland.
- Christian von Olnhausen and Alexander Kuhn, from the financial institution youmex AG, Frankfurt, Germany.
- Erkka Rinne, from VTT Technical Research Centre of Finland, Helsinki, Finland.
The interview questions as well as the transcripts of the interviews can be found in the appendices. The interview with Erkka Rinne is fully transcribed, the one with Anders Stenberg is partly fully transcribed and partly summarised, the interviews with Patrik Holm and youmex AG are summarised, due to the length of the interviews.

1.7 Structure

The next chapter presents general but relevant background information that helps to comprehend the topic. It starts with historical factors that have influenced the SE industry and ends with an overview of the industry's current characteristics. It also explains how the profitability and sustainability analyses are conducted.

The third chapter is the analysis of the chosen energy sources. First, technical insights are given, to enable the reader to fully understand how the energy is produced. In a next step the profitability of the product is analysed. For instance, what are the costs of building a wind farm (material, machines, engineers, transport…) versus its efficiency (energy production, earning from the grid). Finally the product's sustainability is analysed: energy consumption, CO_2 emissions and so on versus "clean" and sustainable energy produced.

The fourth chapter presents the findings and results of the previous chapter. It analyses the cash flows and returns, reflects on the sustainability analyses by comparing the sustainable products to other sources of energy and concludes with overall performance and potential of the products.

The last chapter ponders upon the potential of SE based on the previous chapters and how tomorrow's energy industry could look like. It draws back lines from the introduction of the chapter and answers the question: how profitable and sustainable are RE and what is their potential and main challenges?

2 LITERATURE REVIEW

2.1 Sustainable Energy Industry

The United Nations Conference on the Human Environment that took place in Stockholm in 1972 was the beginning of the global political change concerning the global environmental problem. 113 countries and more than 400 inter-governmental and non-governmental agencies gathered for a discussion about the state of the global environment lead by the Swedish Prime Minister O. Palme. As a result, the United Nations Environment Program (UNEP) was established (Baylis, Steve Smith, Patricia Owens, 2011).

The concept of environment protection first appeared in European treaties in the seventies, but it was not before the 90's that policies were explicitly written down. In Single European Act of 1987, environmental issues were first given a full article and in 1993 environment protection became one of the formal EU aims. After the Treaty of Lisbon – that formed the constitutional basis of the EU- signed in 2007, European Environmental Law became one of the priorities (Dr. Douma Wybe Th., 2014). Since after the European policies, especially when the European Commission recognized "a need to integrate environmental aspects into the booming energy sector" in 1998, sustainability discussions in the energy sector spread and the first practical changes were inserted in the industry (Czeberkus M.A., 2013).

Energy sources have been the focus of R&D (Research & Development) worldwide, but the discovery of relatively cheap resources like petroleum and nuclear energy put debates and R&D on hold. Indeed the first large scale use of photovoltaic (PV) solar energy was linked to satellite's technology and was developed in the 1950's in the United States (product:Vanguard I) (Carnegie Mellon University, 2003). And a while after the oil crises in the early 70's nuclear power plants were invented, which put most environment debates to an end. After the Chernobyl disaster in 1986, concerns for the environment rose again and have reached their peak now a days (see Lauber V. & Mez L., 2004).

Even though environmental issues have been recognised as crucial, the EU-27 energy mix in 2009 was as follow:

Table 1 Energy Mix 1995, 2009, 2012 (European Commission, 2014 and Langsdorf S., 2011)

%	Oil	Solid Fuels	Nuclear	Gas	Renewable Energy	Waste	Total (Mtoe)
2012	34	17	14	23	11	1	1682
2009	37	16	14	24	9	0	1703
1995	39	20	14	22	5	0	1669

From the table we see that the energy mix has been very stable since the 90ies, even with an increasing number of energy policies. Corporations increasingly promote their "Green Thinking" in their company report under CSR (Corporate Social Responsibility) and yet Europe mainly relies on oil and gas, followed by nuclear and solid fuels (coal, pellets…). The year of 2012 was the first to include waste as one of its energy sources, which reflects the beginning of a shift in the energy industry. Nevertheless RE have been struggling to grow as one of the main sources of energy. Below is a figure that reflects how far apart EU policies, aims and plans (blue line) are from the actual implementation of RE (red line), in this case wind energy.

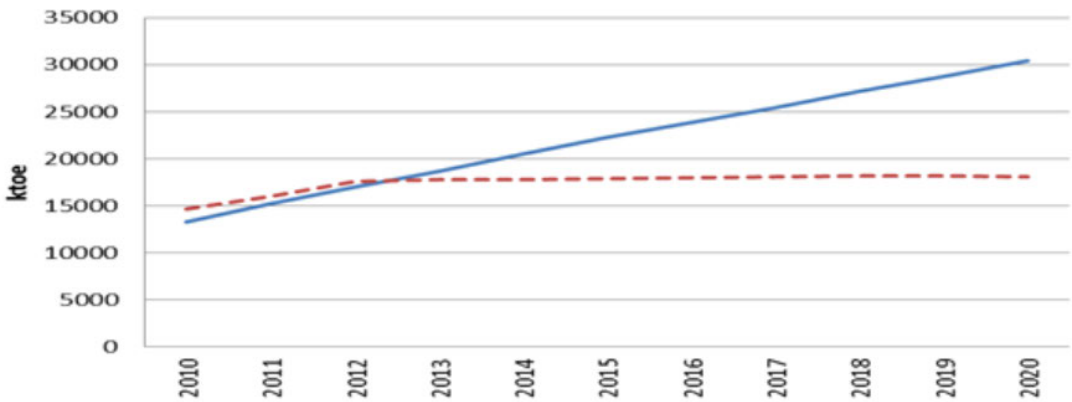


Figure 1 Planned (blue) versus estimated (red/dotted) trend in EU offshore wind energy (EC, 2013)

2.2 "How to do a Profitability analysis"

In order to do a profitability analysis, all the costs attached to the wind turbine are taken into consideration (material, machines, engineers, transport…), then the outcome, in this case, energy outcome, are calculated and estimated. According to many different sources that the author came across when researching (i.e. articles, energy magazines, company websites, European publications, qualitative research etc.) today, the basis for this type of profitability calculation is the Levelised Cost of Energy (LCOE). It is the constant unit cost, per kWh (kilowatt per hour) or MWh (MegaWatt per hour), of a payment stream (revenue minus operating cost, including fuel) that has the same present value as the total cost of building and operating a generating plant over its life, therefore the project's NPV (Net Present Value) equals zero. In other words, the LCOE looks at a power plant's costs in terms of its expected useful life (See Figure 2 below). Typically, LCOEs are calculated over 20 to 40 years, and are given in the units of currency per kWh or MWh. (see Black & Veatch, 2012 and Siemens, 2014).

Figure 2. LCOE (Siemens, 2014)

This work also calculates the NPV and the IRR (Internal Rate of Return), as those methods are the typical profitability calculations.

The NPV is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyse the profitability of an investment or project (Investopedia, 2015).

The IRR is the discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero (Investopedia, 2015).

2.3 "How to do a Sustainability Analysis"

In a sustainability analysis, the product's total environmental costs (water, energy, electricity consumption and CO2 emissions) are compared to the "clean" energy produced or how many externalities are avoided compared to other sources of energy. For instance, if a solar farm repays its total costs after 12 months of producing solar energy, how long does it take to "repay" its environmental costs? In this section of the research, facts and standards are not yet widely published. Co2 emissions are taken more and more into considerations, for example in the LCOE calculations. CO2 is now an official commodity that can be traded on the EU ETS (EU emission Trading System) platform. Anyhow, there is still a lack of information on how to make representative simulations. Therefore there is no Excel calculations demonstrated in the sustainability analysis; instead it is a discussion on how sustainable and renewable energies -especially wind farms- are.

For example, a wind power manufacturer knows the transportation cost for delivering a wind turbine, but often does not know the amount of CO2 the transportation emits. In this case, the sustainability costs -also called externalities, because they are not part of today's calculations- could be precisely calculated, but no one does- yet. As the fragility of our environment becomes clearer to today's societies, sustainability analysis are investigated and pondered upon, anyhow there are no global standards yet. Because of the lack of research and data in this field, this work will rely on assumptions, when data cannot be found.

Nevertheless, as mentioned before, more and more organisations do research in the field. Sustainability parameters are being added to LCOE calculations, but are not widely spread. This makes it easier to compare energy types and clearly shows the effect on the calculations when considering sustainability. The calculations do not only include sustainability as in the environment, but also sustainable development, as in social effects (i.e. human health, political risk or effect on unemployment rates).

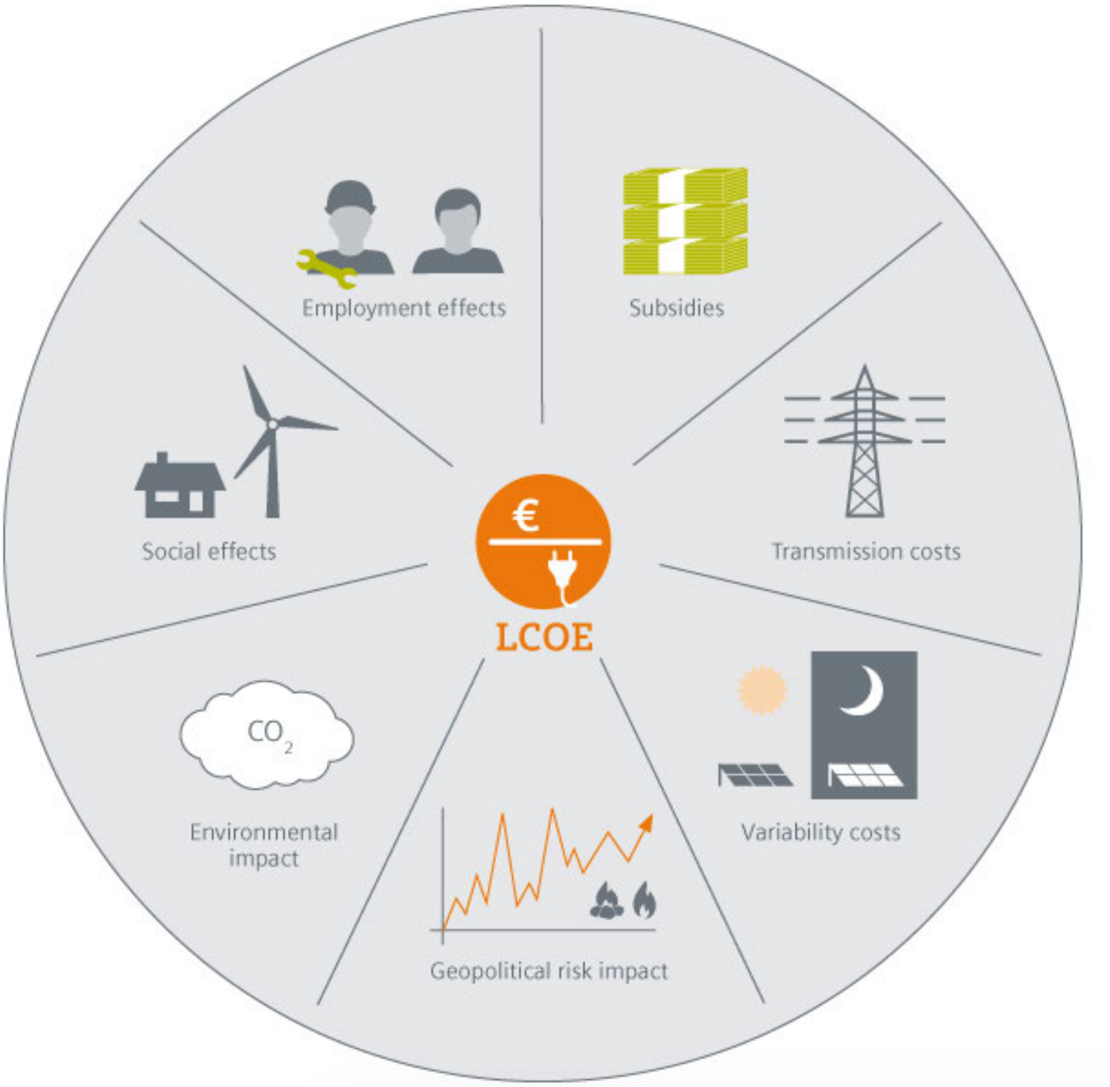


Figure 3. SCOE: Total of LCOE and all cost factors relevant to society as a whole, (Siemens, 2014).

Figure 3 above shows typical social factors of energy production. When these parameters are added to the LCoE calculation, it becomes the SCoE (Society's Cost of Energy). In the SCoE transmission costs refer to the changes that have to be made to the grid in order to transfer the energy from RE onto the local grid (this cost is used in the regular profitability analysis of he offshore wind farm case study). The variability cost refers to the fact that solar and wind farm create energy when there is respectively sunlight or wind, large scale storage is not yet available, in such case, non-renewable energies are needed as a "back-up". The Geopolitical risk is in favour to RE, it means that wind and sunlight are inexhaustible resources and therefore reduce dependencies and political tensions.

The environmental impact is the most important to this work. As the CO2 commodities market is too complex to be explained in this work, the assumption is that because of external factors such as the EU debt crisis, financial crisis or political crisis have a direct effect on the CO2 certificate prices that can't be corrected through regulations, as EU rules so far did not permit a correction of free allocations. The price is expected to rise soon, which will give RE a competitive advantage -which is why the EU implemented the CO2 commodities market in the first place (see Emmissionshaendler, 2014).

The social effect is the impact of power plants on property value in the surrounding area. The employment effect, as it states, is how much personnel is needed through the whole supply chain of a power plant. Finally, "subsidies" refers to the effect of subsidies on enterprises in the supply chain of the power plant (Siemens, 2014).

3 PROFITABILITY & SUSTAINABILITY ANALYSIS

3.1 Onshore wind power

The chosen case study for the on-shore wind power analysis is the Tanderup wind farm –located on Samsø island, in the middle of Denmark- that includes three wind turbines. Samsø was chosen as one of the Renewable Energy Islands in 1997: the goal was for the island to be self-sufficient in RE in 10 years; the wind farm was erected in 2000.

3.1.1 How does it work?

Wind turbines have been used across planet Earth for centuries in order to pump water and grind grain. It was around 1910 that the first wind turbines were built in Europe to produce electricity. Due to advances in technology and the growing need for RE sources wind is becoming a major source of electricity.

Wind turbines basically consist of a foundation, a tower, a nacelle and a rotor. The tower holds up the rotor and a nacelle and the foundation keeps the wind turbine stable**.** A box, known as a nacelle, is located at the top of the wind turbine, attached to the nacelle are three propeller-like blades connected to a rotor. The kinetic energy (energy produced by an object/element in motion) of the wind turns the turbine blades around the rotor, which creates mechanical energy. Depending on the direction of the wind, the nacelle rotates so that it always faces the wind. The rotor connects to the main shaft, which turns inside the generator housing, where a magnetic rotor spins inside loops of cooper wire. This causes electrons inside the cooper to flow; creating electrical energy.

The electricity generated then travels down large cables from the nacelle, through the tower, and into an underground cable. Typically, wind turbines are connected to the grid, and the energy created redistributed locally. (see Foundation for Water & Energy Education, 2014 and European Wind Energy Association, 2014).

3.1.2 Profitability analysis

A study by the US based National Renewable Energy Laboratory (NREL) investigated the average cost of onshore and offshore wind power. Figure 4 shows the share of costs and Figure 5 is the baseline numbers used in the LCoE calculation, with a result of 71$ or 83€/MWh.

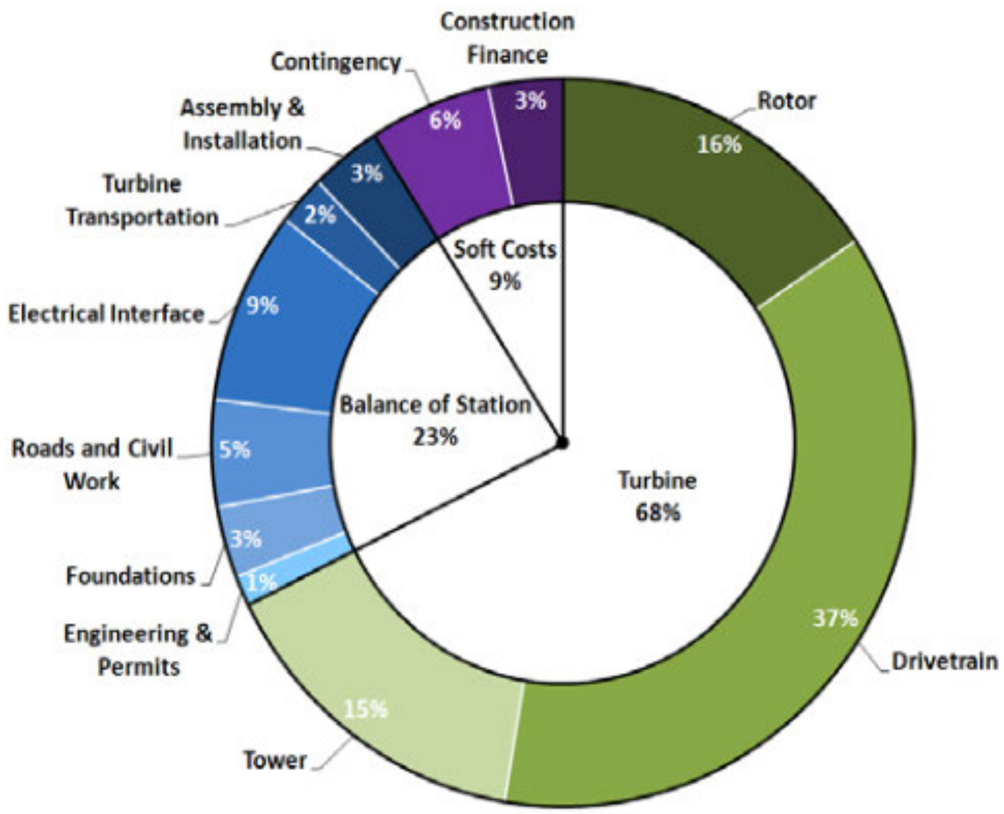


Figure 4. Installed capital costs for the land-based wind reference turbine. (NREL, 2012)

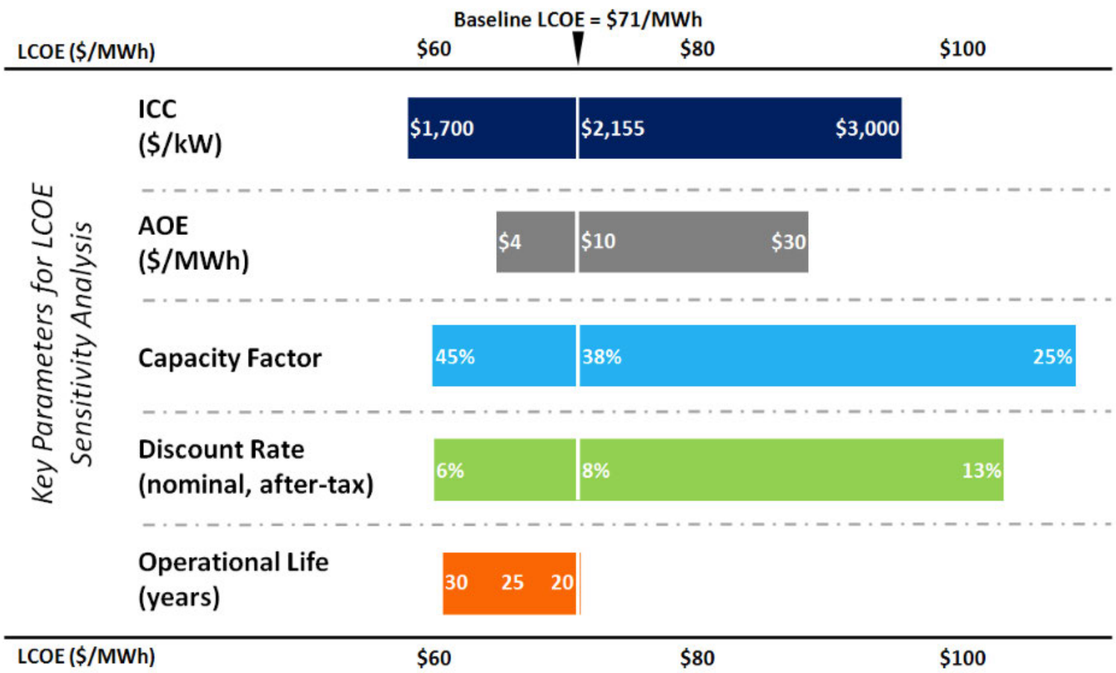


Figure 5. Land-based wind assumptions and sensitivities for key LCOE input parameters. (NREL, 2012)

In Figure 5, ICC is the Installed Capital Cost, AOE are the Annual Operating Expenses and the capacity factor is the amount of time the wind is strong enough to generate electricity, it is calculated by dividing the average power by the maximal capability of a wind turbine (Hazlehurst, 2009); it varies depending on the wind speed of the location. These figures are representative of how the typical wind farm costs and LCoE calculations, but since it is an American study, the numbers are not used in the actual calculations of this work.

The European Wind Energy Association (EWEA) states in its report on the Economics of Wind Power, published in March 2009, that based on the International Energy Association (IEA)'s methodology the wind energy generating cost is of 53€/MWh, whereas EWEA calculates the levelised cost of onshore wind energy to range between 60€/MWh at a discount rate of 5% to 80€/MWh at a discount rate of 10% at a medium wind site.

The discount rate of the Tanderup wind farm can be assumed to be quite low, as the revenue source is a FiT (Feed-In-Tariff), a safe source of income, backed-up by the Danish Government. As financing experts in the field von Olnhausen and Kuhn state, FiTs lower the risk of a project (Interview, 10.02.15). Furthermore, Denmark is a safe and stable country, also ranked as one of the least-corrupted countries, with a national discount rate of DK 5,77% in 2015 (EC, 2015). Also, onshore wind power is a long-known technology. Therefore this paper assumes a discount rate of 5%.

In Samsø's onshore wind farm of three turbines, each came at a cost of DKR 6 mil., which was an equivalent of EUR 800 000 in 2000. The local wind association calculated that each turbine can power 600 households and each was rated at 1 MW (Samsø Energy Academy, 2011). Typically, the wind turbine cost includes the turbine production, transportation and installation of the turbine (Irena, 2011).

On the other hand, wind turbines need a support structure. As it is unsure what exact costs are included in the wind turbine used for the Tanderup wind farm, this work assumes that the foundation and installation of the turbines is included, as various sources state that the turbine cost is the total cost. But for the representativeness of a typical profitability analysis a low support structure cost is included. A European study calculates an average of EUR 350 000, EUR 65 000 and EUR 74 000 /MW for respectively building the support structure, the electrical infrastructure and the construction of the site (includes all construction costs not included in the wind turbine and the support structure) (KIC InnoEnergy & Bvg Associates, 2014). The same study measures an average of 770,5 k€ for a wind turbine, in accordance to Tanderup's wind turbine cost of EUR 800 000 for each wind turbine. This work assumes a low cost of EUR 200 000 /MW for the support structure, EUR 65 000 /MW for the electrical infrastructure and EUR 74 000 /MW for the construction. All costs are listed in Table 2.

According to the Danish Energy Academy (2011), the total annual production of the Tanderup wind farm is approximately 7,600 MWh (megawatt per hour). This work calculates that this is equal to a capacity factor of 28,90%. According to Holm (2015), onshore wind turbines have a capacity factor between 30 and 40%. If we take a capacity factor of 30%, the Tanderup wind farm produces 7 888,5 MWh per year (installed MW x hours per year x capacity factor = 3 x 8766 x 30%). This work uses the published data of 7 600 MWh/year for the calculations.

Wind Measurement International assumes wind turbines of older generations to have an annual maintenance cost of approximately 3% of the original cost and between 1,5 and 2% for modern wind turbines. The Tanderup turbines are modern Siemens-built wind turbines, and as the project was erected in 2000, a medium cost of 2% of the original wind turbine price is selected.

Tanderup got a state guaranteed minimum FiT for the first 12.000 full load hours (ca. 5 years) of 60 000 øre/MWh or 80 €/MWh, and for the first 10 years of 43 000 øre/MWh or 58 €/MWh (Energy Academy, 2011; Energy development in Island nations, 2008).

Table 2 Summary of Numbers used for the Onshore Profitability Calculations

	Source	Amount	Explanation	Type
Electricity Generation	This work	7 600 MWh	Capacity factor (28,9%)*Installed MW (3MW)*Hours/year (8766 hours)	N/A
Revenue	FiT provided by Danish Energy Academy & Energy development in Island nations	-631 k€ /year for the first five years -458 k€/year for the following five years	FiT 80€ (first five yeas) & FiT 58€/MWh(following five years) * Electricity generation	FiT
Discount rate	NREL, EC, IEA, EWEA	5%	Based on EU data on Denmark and onshore wind power discount rates. Low discount rate because of a very low risk and very stable income	Applied to all numbers over the project lifetime
Overall cost	This work	-3.417 k€ for year 0 -64 k€ afterwards	Sum of all costs, annually	Upfront one time cost
Wind turbine	Danish Energy Academy	800 k€/Turbine: 2 400 k€	Given data. Total cost of wind turbines	Upfront one time cost
Support Structure	This work, ISE Fraunhofer	200 k€/MW: 600 k€/3MW	Low cost because the cost is probably already included in the wind turbine cost, but because of a lack of data, still accounted separately	Upfront one time cost
Electrical Infrastructure	KIC InnoEnergy & Bvg Associates	65 k€/MW: 195 k€	Applied average number on the case study	Upfront one time cost
Installation/ Construction	KIC InnoEnergy & Bvg Associates	74 k€/MW	Applied average number on the case study	Upfront one time cost
O&M	Wind Measurment International	2% of wind turbine cost	Applied average number on the case study	Fixed annual cost

Table 3 below, shows the two first and two last years of the CF (Cash Flows) analysis, the complete calculation can be found in the appendix. It is clear that wind farms have a high front capital cost but little costs (only O&M) once they generate electricity. When looking at the cumulative discounted CF, it can be seen that the total CF become positive after 9 years of generating power, in 2009.

Table 3 Discounted Cash Flows for the Onshore Tanderup Wind Farm, Extract

Tanderup Wind Farm, Disc. CF

Ink €	2000	2001	2009	2010
Cash outflow				
Wind turbine	2.400			
Support Structure	600			
Array eletrical	195			
Installation/ Construction	222			
Maintenance (2%)		48	48	48
Transmission Cost		16	16	16
Total annual expenses	3.417	64	64	64
Disocunted total annual expenses	3.417	46	31	29
Revenue in k € with a discount rate of 5%				
Annual MWh production		7.600	7.600	7.600
Feed-in tariff 5 years (EUR 80/MWh)		608		
Feed-in tariff 10 years (EUR 58/MWh)			441	441
Total cash inflow	0	608	441	441
Discounted cash flow per year 5% in k€	-3.417	536	264	253
Cumulative Cash Flow in k€	-3.417	-2.881	166	419

Table 4 shows first seven years, the complete calculation can be found in the appendix. 2000 is the year of construction, 2001 is the first year in which the three turbines generate electricity. The 2% maintenance cost remains the same over the years. This simplified profitability calculation over 10 years, shows that the Tanderup wind farm, that benefitted of a feed-in tariff of 80 €/MWh for the first 5 years and 58 €/MWh for the five following years, has a NPV of EUR 1 027 584, over a project lifetime of 10 years. Typically the project lifetime of a wind farm is at least 20 years. Due to a lack of information on the revenue after the first ten years or FiT and to show that such project is already profitable on a shorter scale, this work chose a project lifetime of only 10 years. Assuming O&M costs do not increase much after 10 years, the returns of the wind farm are most likely higher than the results presented in this work

Table 4. Net Present Value & Interbal rate of Return for the Tanderup Onshore Wind Farm, Extract 2000-2003

Tanderup Wind Farm, NPV, IRR, LCoE

	2000	2001	2002	2003	2004	2005	2006	2007
Annual MWh production 7 600								
Feed-in tariff 5 years (EUR 80/MWh)		608	608	608	608	608		0
Feed-in tariff 10 years (EUR 58/MWh)		0	0	0	0	0	441	441
Income in k €		608	608	608	608	608	441	441
Discounted income in k €	0	579	551	525	500	476	329	313
Total disc. revenue	4.128							

Costs in k €								
Wind turbine	2.400							
Support Structure	600							
Electrical Infrastructure	195							
Installation/Construction	222							
Maintenance (2%)		48	48	48	48	48	48	48
Transmission Cost		16	16	16	16	16	16	16
Total annual cost	3.417	64	64	64	64	64	64	64
Total annual disc. cost 5%	3.417	61	58	55	52	50	48	45
Total disc. Cost	3.909							

NPV	218	IRR=	1,35%
LCOE in €/MWh	51,40		

3.1.3 Sustainability analysis

On the basis of the case study, a hypothetical sustainability analysis is provided. As this section questions the sustainability of RE, data, especially specific to one case, is non-existent. Anyhow as the need for pondering upon the negative impacts on our environment increases, sustainability effects are taken into consideration, even for RE. It is typically not a separate investigation, but the sustainability factor is included more and more into financial calculations. As mentioned in the beginning of this work, the EU established a commodities market of CO2 certificates. This was one of the first methods to internalise the externality that environmental impact is. As it is not as easy to put a price on greenhouse effects, as it is to put a price on physical objects or services, no global method has been adapted yet.

According to Siemens (2014), the cost of CO2 certificates is included in the LCOE, but as explained before the CO2 price fell below 10 €/ton, which does not properly reflect the long-term consequences of greenhouse gas emissions. In Siemens' SCOE calculation, the price is 81 €/ton, as they assume this to be the "lifetime value of CO2 for a power plant starting operations in 2025, given by the carbon price floor". In the SCOE calculation, this results in 45 €/MWh added for greenhouse gas damage, in the case of coal power plants. This permits to internalize green house emissions into the profitability of RE. When the same carbon emission level is used as for the offshore analysis, which is 430 kg of CO2 emitted per 1 MWh of energy produced, Tanderup avoids 3 268 tonnes of CO2 being emitted every year. No data is officially published on the carbon avoidance of the wind park though.

In The Guardian's article on onshore wind energy, written in cooperation with the Grantham Research Institute on Climate Change and the Environment, the authors come to the conclusion that the emissions created in the manufacturing, transportation and installation of wind turbines are considered fairly low. But the main aspect they bring to light is the fact that wind power is intermittent. It generates electricity only when the there is enough wind. In the case it is not, fossil-fuel-based power supply is needed as "backup". The further argue that in the small market share of wind power, such backup is not yet that important, but if the industry were to grow, the need for non-renewable energy backup would increase, making the overall sustainable performance of wind energy decrease. Alternatives are better performing energy storage or inter-linkages with other countries' grids. Finally, the authors consider this to be no threat. Nevertheless this affects sustainability analyses.

According to Energy Education (2014) and the European Wind Energy Association (2014), a wind turbine's tower is mostly tubular and made of steel or concrete and the blades are made of fibreglass, reinforced polyester or wood-epoxy. Those are elements/materials that are cheap and easy to produce, and therefore, as explained in the previous chapter, the environmental impacts are fairly low.

Using Siemens' SCOE calculations (see Figure 6 below), the Tanderup project would have a total cost of EUR 60/MWh, this equals EUR 4 560 000 over 10 years. This is a decrease in cost of EUR 1.748.000. In this case the profitability of the project is the same as in the previous analysis, but factors such as employment though the project are added to the analysis, those factors have a positive mostly long-term impact, therefore the total cost decreases. The SCOE analysis is especially well conceived to bring positive society and environmental factors to light. As it can be seen in Figure 6 below, RE turn out to be more cost-friendly than non-RE in the SCOE calculation.

Figure 6. Comparison of LCOE and SCOE for all primary energy sources in UK. (Siemens, 2014)

3.2 Off-shore wind power

The chosen case study for the offshore wind power analysis is the London Array wind farm that includes 175 wind turbines. It is the largest offshore wind farm created so far. It is located in the Thames Estuary, North Sea, in Great Britain (Siemens AG, Ofgem, 2011). According to London Array Ltd. (2014), within the year of 2012, all the 175 turbines were installed, power was first generated in October of that year and the wind farm became fully operational in April 2013. Figure 7 shows the London Array wind farm as of 2013.

3.2.1 How does it work?

Offshore wind turbines work the same way as onshore wind turbines (see p.21). As they are placed up to 40 km away from the shore, offshore wind turbines are typically in more hostile weather conditions than onshore wind farms. Therefore offshore wind turbines are to be more robust, which makes the production, transportation, installation and maintenance more difficult and expensive. The four typical stages of implementing wind turbines from the producer's perspective are: components delivery to port, pre-assembly of components, storage of rotor blades, load out (Siemens, 2011).

Figure 7 London Array Wind Turbines. Model: SWT 3.6-120, 3,6MW (London Array Ltd., 2013)

The offshore wind farm is more complex than the onshore one, especially for the large-scale implementation of the London Array project. On top of the 175 wind turbines, the site includes one onshore and two offshore substations (see Figure 8 & 9). The project construction started in July 2009 and was completed in the end of 2012 (Power Technology, 2012).

Figure 8 Offshore Substation (London Array, 2013)

Figure 9 Onshore Substation: Cleve Hill (London Array, 2013)

In the London Array project, the 175 wind turbines are located 35 km away from the shore and placed at 21-28 m water depth. The supplier of the 175 "SWT-3.6-120" wind turbines (see Figure 7 above) is Siemens. London Array Limited, a consortium of Dong Energy, E.on and Abu Dhabi investment company Masdar, is responsible for the operation and maintenance of the wind farm (Wind Power Offshore, 2014; London Array Ltd., 2014) and La Caisse de dépôt et placement du Québec, a financial institution managing funds primarily for Québec's public- and parapublic-sector pension and insurance plans (La Caisse de depot et placement du Québec, 2015), has bought 25% off DONG Energy's stake in the project for a fee of £644 million (EUR 781 million) in the end of 2013 (Wind power offshore, 2014), leaving DONG Energy with an equal stake of 25% of the project. DONG Energy is one of the leading energy groups in Northern Europe, headquartered in Denmark, that produces oil, gas and electricity and heat through its offshore wind power generation (DONG Energy, 2014).

3.2.2 Profitability analysis

The profitability analysis is similar to the one on onshore wind power, but more complex. According to the European Wind Energy Association (EWEA, 2014), "approximately 75% of the total cost of a wind farm is related to upfront costs such as the cost of the turbine, foundation, electrical equipment, grid-connection and so on. Fluctuating fuel costs have no impact on wind power generation costs." As you can see in Figure 10 below, a study made by NREL (National Renewable Energy Laboratory) supports the argument (same study showed in the onshore case study). The cost of the turbine itself (32% of all costs) and installation costs of the wind farm (ex: electrical infrastructure, 10%, and support structure 18%) make up to 80% of the costs. This shows that investments in wind energy are to be long-term orientated, as most costs come before any income can be made. Figure 10 and 11 are form the same American study, the graphics represent the cost share of an offshore wind turbine and the different parameters used for a typical LCoE of an offshore wind park. Again, the NREL study is used to show these key factors and compare them to the onshore ones, but the numbers are not used in this work's calculations, as it is an American source, and this work focuses on the EU.

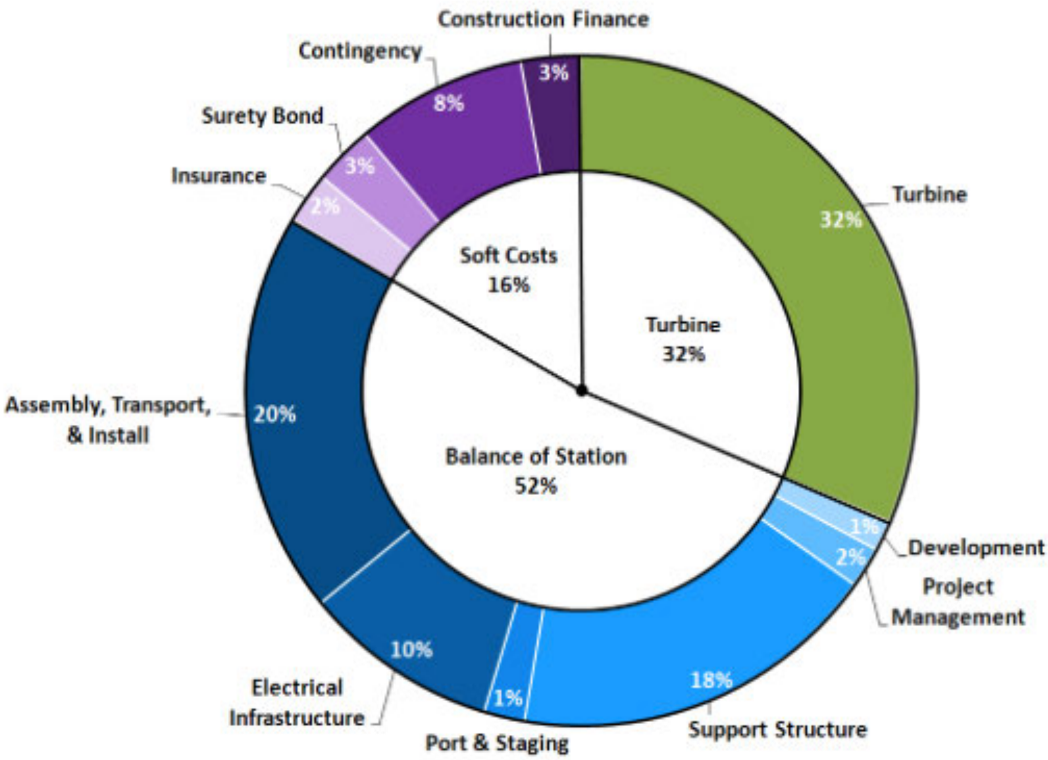


Figure 10 Example of Installed Capital Costs for an Offshore Wind Turbine (NREL, 2012)

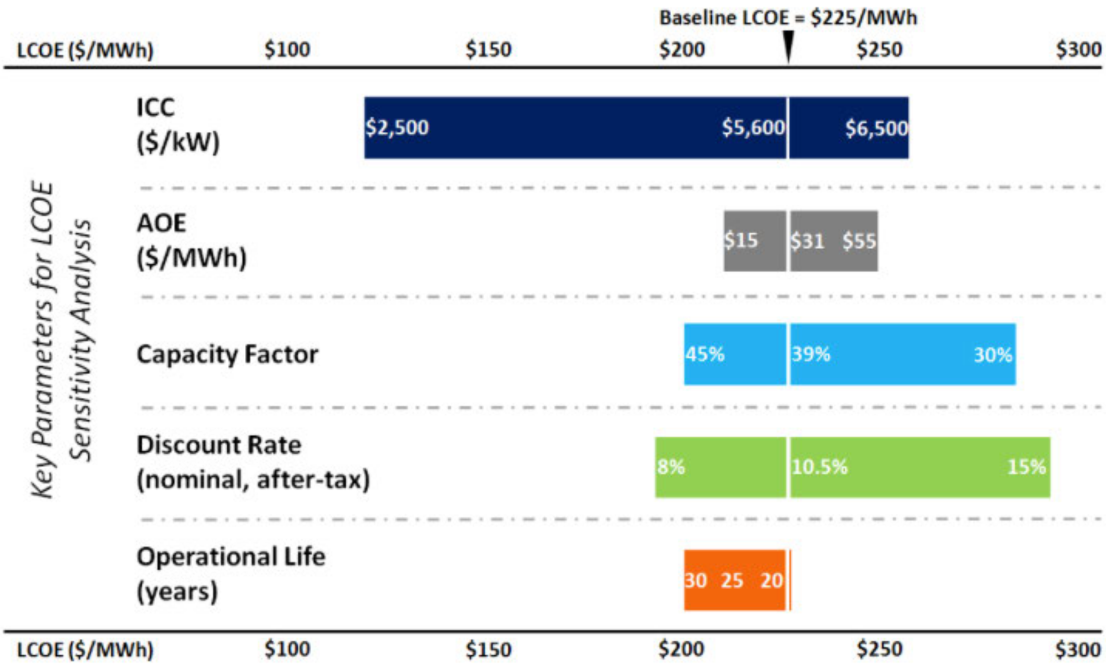


Figure 11 Offshore Wind Assumptions and Sensitivities for Key LCOE Input Parameters (NREL, 2012)

As it can be seen from Figure 11, in contrast to Figure 5, that is the same calculation on onshore, offshore wind power has higher costs, a greater capacity factor (the factor at which the plant produces electricity) and a slightly higher discount rate. According to NREL, the LCoE for offshore wind power is over three times higher as for onshore wind power. The LCoE calculation contains the energy produced over a lifetime, therefore the study shows that even though offshore turbines produce more electricity, it does not proportionally reduce the costs. Anyhow different studies show otherwise, but it can be noted that offshore power is more expensive, for reasons that will be explained in this section and the findings of this research.

Electricity Generation

The London Array wind farm comprises 175 wind turbines; each wind turbine can produce up to 3,6 MW, therefore the peak electricity production of the whole wind park is 630 MW, which is equivalent to power around 500,000 British homes (London Array Ltd., 2014). In its first full winter of operation (in the six months from October 2013 to the end of March 2014), the wind farm produced 1 500 000 MWh of energy, with a capacity factor of 56%; those results surpassed the expectations (Offshore Wind & Wind Power Offshore, 2014). This work finds an electricity production of exactly 1 546 146 MGh, slightly more than 1 500 000 MWh stated by the two wind power magazines

sources. This result comes from applying the 56% capacity factor to the 630 MW that can be produced by the 175 turbines in half a year, or 4382,5 hours (4382,5 hours * 3,6 MW * 175 turbines * 56% capacity factor).
Another report sates that according to the project's management company, London Array has produced 2 000 000 MWh of electricity in 2013, the project was fully operational in April 2013 (Wind Power Offshore, 2014). This equals 75% of a year or 6 574 hours of power production at an average capacity factor of 48,29%. It is obvious that the wind is stronger in winter and weaker in summer time. Data for a full year of operation is not published yet, therefore this work will consider an average capacity factor of 50%. This results in an electricity production of 2 760 975 MWh per year.

Revenue

„Notionally, wind turbines produce two products: electricity, which is sold in electricity markets and green certificates, which are sold in a market for fulfilling the political obligation to supply renewable energy.“ (EWEA, 2009, p.79).

The electricity produced by London Array is connected to the British grid in partnership with Statkraft (50%) and UK National Grid (50%) (Power Technology, 2012). The Power Purchase Agreement (PPA) between DONG Naturgas A/S (co-owner of London Array Ltd.) and Statkraft signed for London Array and other projects was based on current power spot prices (“the current price at which a particular security can be bought or sold at a specified time and place”, Investopedia, 2015), which were not revealed (Statkraft, 2011). The UK power spot prices vary everyday, but an average of around 40 pounds per MWh can be assumed over the last year, according to the independent Anglo-Dutch energy exchange operating the spot markets for electricity (see Figure 12 below). This work takes a revenue of 40 pounds per MWh as a basis, so 55,21 € per MWh (Oanda Currency Converter, 2015).

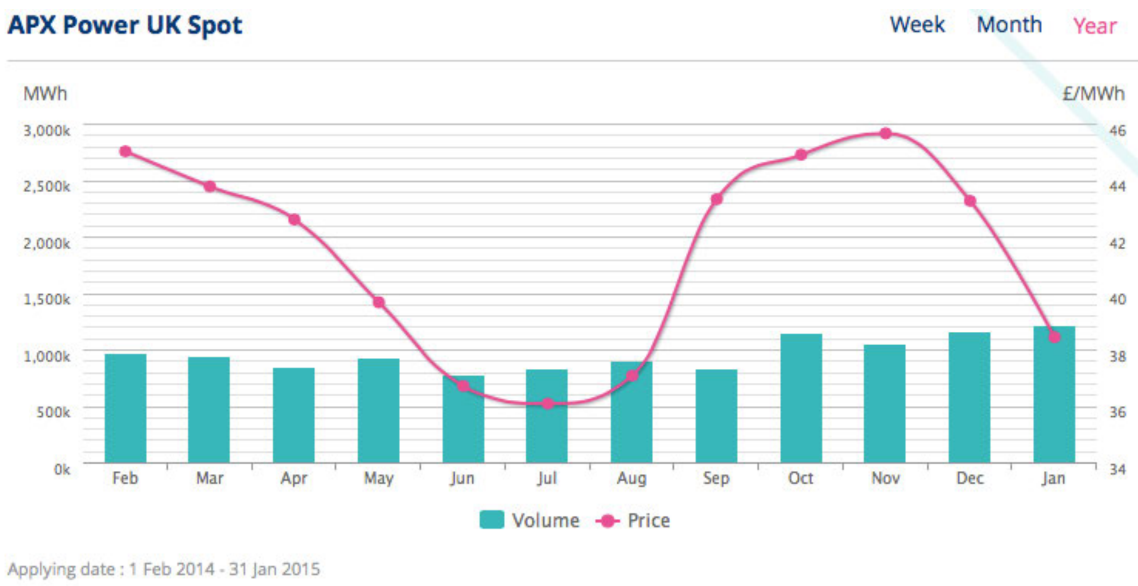


Figure 12 APX Power UK Spot, 02.2014-01.2015 (APX Group, 2015)

On top of the revenue from power market prices, London Array also receives subsidies of GBP 90 /MWh or EUR 122,2 /MWh (Oada Currency Converter, 2015) (Telegraph UK, 2013). Thus EUR 122,2 /MWh are added to the EUR 55,21 /MWh market price in this work's calculations, in order to compare the profitability of the project without and with subsidies. The market price and the subsidies together result in a revenue of EUR 177,41 € /MWh, which is rounded up to 178€ /MWh.

The calculations also include the current German FiT of 90 €/MWh and the current Finnish FiT of 105 € /MWh, in order to demonstrate the influence such a pricing system has on a wind farm project. (Kuhn, 2015 & Stenberg, 2015). Wind power is less spread in Finland, which may explain the higher FiT level; it is set to decrease to 83€/MWh in 2016 (Stenberg, 2015).

This paper explains the typical different pricing possibilities for wind power and then explains the chosen method for London Array. Financing experts in the field, von Olnhausen and Kuhn from youmex AG (Interview, 10.02.15), clarify the options:
-Price Based Incentives: in the form of FiTs, Feed-in-Tariffs (and net metering), in this case the German and Finnish comparison.
-Quantity Based Incentives or Quota Obligations: in the form of Renewable Portfolio Standards/Certificates or Competitive Procurement (auctions).

-Fiscal and Financial Incentives: in the form of Tax Credits, Government Subsidies and Loan Guarantees, in this case the subsidies given to London Array Ltd. in addition to the revenue from the market prices.

As Kuhn further explains, it is typical in Poland and UK to have a mix of the variable market price and fixed subsidies on top of the market price. This was the case for the London Array wind park.

The simplest pricing method is the Feed-in-Tariff (FiT), which is a long-term agreement, typically over a period of 20 years. FiT is an economic policy created to promote active investment in and production of renewable energy sources. This method of governmental-backed guaranteed pricing shelters energy producers from some risks in renewable energy production (Investopedia, 2015).

According to Kuhn, in the past years the FiTs have come closer to free market prices. In Germany, the wind power prices in the form of FiTs, which are around 90 €/MWh, are still higher than the electricity prices on the market. Kuhn assumes this price to be stable in the upcoming years, even though auction models are expected to enter the major wind markets such as Germany, Italy or France. So far no country has gained major experience with that new model but more and more wind farms in the UK are being auctioned. All interviewees, who are all active in the field of wind power, have only heard of the model and have all agreed it is no simple pricing tool.

As mentioned at the beginning of this section on revenue, there is two products that can be generated through wind farms, the first is the electricity, which can be given a basis price (through FiTs or power market prices) and the green certificates, that fall under the pricing system of Quantity Based Incentives or Quota Obligations. These can be acquired in two forms, as Renewable Obligation Certificates also called Renewable Energy Certificates or as Competitive Procurement, also called auctions (von Olnhausen & Kuhn, 2015). It was the second option used for London Array's electricity transmission rights, but as tis method is new and complicated, this work does not focus on this type of pricing but rather the market price, subsides and FiTs. Nevertheless the next paragraphs attempt to give the reader insights on the system and how it was used for London Array.

Separate OFTOs (Offshore Transmission Owners) take responsibility for offshore transmission assets under long-term OFTO licences in the UK since 2009. It is underwritten by a transparent regulatory framework overseen by the CSE (Centre for Sustainable Energy) and Ofgem (Office for Gas and Electricity Markets), (KPMG, 2012). An OFTO is an entity licensed to provide transmission services and the owner and operator of the assets relevant to provide the transmission services (Mc Gregor, 2011).

When London Array was granted a governmental license in September 2013, the Office for Gas and Electricity Markets (Ofgem) valued London Array's transmission assets at GBP 459m, „the highest value assets […] tendered under the offshore regime to date " (Ofgem, February 2014). The assets include the total cost of transmission assets, off-shore substation, offshore substation (platform and electrical), submarine cable supply and installation, transformer, reactive equipment and finally the cost of development (Ofgem, 2013).

Since the end of 2013, Blue Transmission, a consortium of Barclays Infrastructure Funds Management Limited and a UK subsidiary of Mitsubishi Corporation, maintains and operates the transmission assets for the next 20 years. The purchase was funded by bank debt with half of the debt provided by the European Investment Bank (EIB) (Ofgem, 2014). According to Ofgem, the London Array project "demonstrated how the competitive tender process continues to ensure value for money for consumers - the cost of running the transmission link was a quarter less than for the Tender Round 1 [off-shore wind power] projects completed at the time the OFTO was appointed". In its first tender round, Ofgem auctioned nine wind parks to OFTOs. All interviewees agreed that the auctioning model is new and not well in place yet. Many factors can destabilise such a model, such as the lack of competition in the implementation period.

In the tender offer for London Array, ("an offer to purchase some or all of shareholders' shares in a corporation [where] the price offered is usually at a premium to the market price", Investopedia, 2015), OFTO UK has signed an off taker contract of an annual revenue of around GBP 35 million for the fiscal and financial year from April to March, so a Proportion of Revenue of 53,3% (Ofgem, 2014). This equals GBP 65,5 million for

100%, so an annual revenue of EUR 90,4.million. When dividing the annual revenue, EUR 90,4 million, by the energy produced, 2 995 705 MWh at 100% (calculated from 1 602 702 MWh at 53,5%, Ofgem, 2014), we find the price of electricity. In this case it is EUR 28 /MWh. It is almost half the price of the market power prices of EUR 55,4 /MWh (GDP 40 /MWh, see Figure 12). It is therefore not at a premium to the market prices, as tender offers usually are.

A separate calculation applies the Ofgem's slightly different numbers (power generated and revenue) to the offshore wind power case study.

Discount rate

The EWEA (European Wind Energy Association) states that depending on the risks involved one should use different discount rates; some power plants have a possibly lower, but predictable rate of return rather than others that have a possibly higher, but unpredictable rate of return. Unpredictable income has to be discounted at a higher rate than predictable income, just as for financial markets (EWEA, 2009, p.22). Therefore FiTs have a very positive affect on a wind power plant's financing, as they provide income security. Therefore financial analysis on the wind farm can use a lower discount rate, which results in better returns. London Array does not get its revenue from FiT, but it is given generous subsidies and the auction of the transmission rights were bid under Ofgem, a governmental institution that ensures the transparent and "safe" bidding of offshore wind farms. Furthermore, just as the onshore case study, London Array is based in central/northern Europe, where inflation rates and corruption rates are low, the political situation is stable and the credit worthiness is high. The country discount rate for UK is 7,31% (European Commission, 2015). This paper therefore choses a discount rate of 8%.

Overall cost

According to the independent research and analysis centre Clean Energy Action Project, the total of the London Array wind farm is $3 329 billion (EUR 2 967 mil., Oanda Currency Converter, 2015). But according to another research and analysis institute, Kable Intelligence Limited, the project received financial backing from the European Investment Bank (EIB) for GBP 3 000 million (EUR 4 017 million, Oanda Currency Converter, 2015), which is the total cost of the project (Power Technology, 2012). This study analyses the Phase One of London Array, while it can be assumed that the EIB (European Investment Bank) funded both phases of the project, that were to have 341 wind turbines altogether. Nevertheless, Phase Two of the London Array project was cancelled, due to environmental issues. Therefore this study orientates its calculations towards the first amount, **EUR 2.967 mil**., provided by the Clean Energy Action Project.

According to Holm (2015), the wind power plant cost for offshore wind power in similar conditions as London Array is between EUR 2,5 and 3,5 /MW, so an average of EUR 3 million /MW. The wind farm has a total capacity of 630 MW, which corresponds to EUR 1 890 mil (EUR 3 million x 630MW). Another source, an offshore wind magazine, publishes an overall cost of GBP 2 000 million, equivalent to EUR 2 200 million. These results are both lower than other sources that are closer to the project and will not be used for the calculations but reflect the industry average costs.

When summing up all the different costs of London Array, this work finds a total cost of **EUR 2 752 mil.**, which is similar to Siemens' publication of EUR 2 715 mil (converted from GBP) and to Clean Energy Action Project, EUR 2 967 mil.

Wind Turbines

According to Renewable Energy consultant David Milborrow, prices of offshore wind turbine are 10-15% more expensive than onshore turbines; the price range is therefore EUR 0,9 to 1,15 million /MW. Nevertheless other experts argue that offshore wind turbines can be up to triple the price of onshore ones, depending on the model, year of construction and brand. Because Siemens produces London Array's wind turbines, this work assumes a rather high cost of EUR 1,1 million /MW, which results in **EUR 693 million** for the 175 wind turbines. Siemens' SWT 3.6 120 offshore wind turbine is "generally regarded as the best turbine in the offshore sector" (Wind power monthly, 2014).

Installed cost

In this case the installed cost includes all costs related to the construction of the wind park, i.e. transportation, support structure and onsite electrical infrastructure. Apart from the wind turbine itself, offshore wind turbines need an undersea structure. A monopile foundation was used for the London Array wind farm (Power Technology, 2012); it has the advantage of being a simple and cost-efficient construction (Strabag SE, 2014) and is the most common structure used in Europe (EWEA, 2015). Figure 13 below shows the four major offshore foundation systems; the monopile structure is the one on the left.

An assessment by Deutsche Bank Climate Change Advisers (2012) suggests that the lowest installed cost is around EUR 2,4 mil. /MW. According to that assessment, the maximum installed cost remains at EUR 3,5 mil. /MW. This work first took the average number, which is EUR 2,95 mil. /MWh and results in **EUR 1 858,5 mil.** for the whole wind park. Once all the costs were added, the overall cost was much higher than the official publications of London Array's overall cost. This work uses Clean Energy Action Project's estimation of EUR 2 967 mil. as a reference number. After adjusting the installed cost, that is still by far the biggest cost, to EUR 2,4 mil. /MW instead of EUR 2,95 mil. /MWh, the overall cost results in 2.751.673 k€, which is very close to the published overall cost of the project.

Therefore the used installed cost for the calculations is **EUR 1 512 million** based on a installed cost of to EUR 2,4 mil. /MW.

Transmission cost

As the share of renewables in the energy mix grows, grids often need to be reinforced on both the transmission and distribution levels, since renewable sources are either not centrally located (photovoltaics, biomass, onshore wind) or are remote and installed at sea (offshore wind). For offshore wind, grid optimization costs amount to around 2€/MWh, (Siemens, 2013, Global Wind Energy Council, 2014), which results in **EUR 5 521 950** of annual transmission cost.

Furthermore, in order to connect the generated electricity to the local grid, the London Array cabling connects groups of turbines and the two offshore substations (see Figure 8), which step up the voltage of the electricity to be transported to the shore and reduces losses before reaching the grid. Nexans, a French company, which manufactures copper and optical fiber cable products, was chosen to supply EUR 100 million worth of power cable; MPI and A2SEA, two respectively British and Danish Offshore wind installation and service solutions providers, supply marine crew and vessels (Power Technology, 2013, Backwell, 2010).

The electricity produced by the wind turbines is transformed to 150 kV (kilovolt) at the offshore substations and is then taken to the onshore substation Cleve Hill (see Figure 9) by four high voltage export cables, each weighs more than 4,500 tonnes, which makes the export cables the heaviest items in the wind park (see Figure14 on the next page). They run for more than 50km from the offshore to the onshore substation. Altogether, the site has 450km of offshore cabling (London Array Ltd., 2015). Once the energy reaches the shore, it is distributed into the national grid distribution network. The 187 cables on site (200 km of cabling), connecting wind turbines to each other and to the offshore substations weights 50 kg per meter. They carry the 33kV electricity generated by the turbines to the offshore substations and contain fibre optic cores, such as the export cables, allowing the turbines to be monitored and controlled remotely. The Scottish cable producer, JDR Cable Systems, manufactured those onsite cables (London Array Ltd., 2014). The exact costs for the electrical infrastructure are not published.

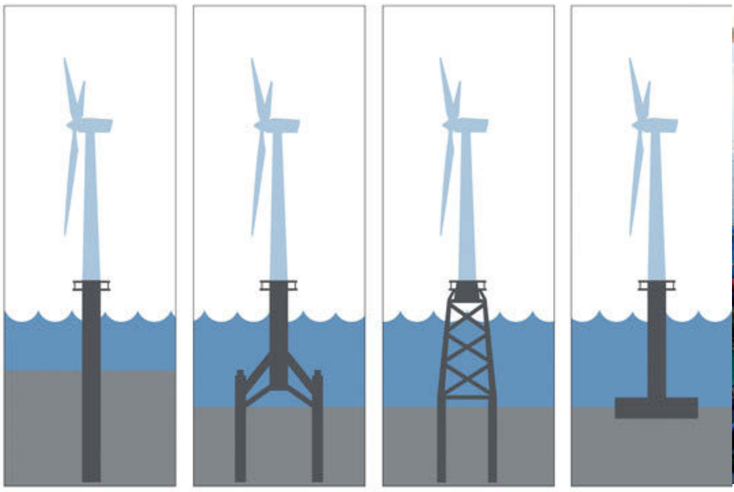


Figure 13 Offshore Foundation Systems (Strabag SE, 2014)

Figure 14 London Array Export Cables (London Array Ltd., 2013)

According to Fraunhofer Institute for Solar Energy Systems ISE, offshore wind farms at very good sites reach costs between EUR 114 and 140 /MWh, but when a wind farm is further off the coast and the sea depth of the site varies, as it does in the London Array site, costs are higher: EUR 123 to 185 /MWh (p.21, ISE Frauenhofer, 2013). By applying the cost of EUR 185 /MWh to London Array, the upfront transmission costs amount to **EUR 510 780 375.** This work uses ISE Frauenhofer's data for the calculations.

Variability costs

Because large-scale storage technologies are not yet available at an industrial scale, the variability of wind power plants must be offset using regulated conventional power stations. This incurs additional costs for renewables in the order of EUR 13-15 /MWh because of grid compatibility issues (Siemens, 2014), it equals **EUR 35,9 million**.

Operation & Maintenance

The EWEA states that "once the investment is covered, the income from selling the electricity only has to be higher than the (very low) O&M cost, for the turbine to keep running" (p.38, 2009), at least in proportion to the overall cost.

Because of the difficulty of servicing wind farms at sea, offshore turbines involve more remote monitoring and automated systems than their land-based counterparts, but even with only a few visits to each turbine per year, operation and maintenance costs are considerably higher than those for onshore wind projects. (Union of Concerned Scientists, 2010). For instance, wind turbines rotate, therefore the odds of pieces breaking are higher than static machinery. Furthermore, offshore wind turbines are subject to corrosion and under-water operating and maintaining procedure are complicated and therefore expensive (von Olnhausen, 2015).
According to Holm's calculations, this type of offshore wind farm has an operation and maintenance cost of EUR 30 to 40 /MWh. Applied to the case study, using EUR 30 /MWh, it results in **EUR 82,8 million per year.** This number is used in the profitability analysis.

Summary

Table 3 Summary of Numbers used for the Offshore Profitability Calculations

	Source	Amount	Explanation	Type
Electricity Generation	This work based on diverse sources	2.760.975 MWh	Capacity factor (50%)*Installed MW (3,6 MW*175 turbines)*Hours/year (8766 hours)	N/A
	Ofgem	2.995.705 MWh	Given data	N/A
Revenue	This work, Telegraph UK	-Market price: 55,21€/MWh (= 152 903 k€ / year -Subsidies: 122€/MWh -Total: 177,4 €/MWh (= 491 453 k€/ year	-Market price*Electricity generation -OR subsidies* Electricity generation	Free market rules + Subsidies
	Interviews	-FiT 90€/MWh in Germany -FiT 105€/MWh in Finland	Given data. FiTs ar included in order to compare the profitability depending on the national energy policies	FiT
	Ofgem 30€/MWh	84.244 k€ / year	Given data	Auction
Discount rate	This work, EU, EC	8%	Higher risk than onshore because newer technology and UK slightly higher discount rate than Denmark	Applied to all numbers over the project lifetime
Overall cost	This work, Clean Energy Action Project	EUR 2 752 million	Sum of all costs in year 0.	Upfront one time cost
Wind turbine	Siemens	EUR 693 million	Cost of purchasing the wind turbine, typically includes insurance, delivery, assembly etc.	Upfront one time cost
Installed cost	This work, Deutsche Bank Climate Change Advisers	EUR 1 512 million	Includes all construction costs linked to the erection of the wind park that are not included in another section	Upfront one time cost
Transmission cost	ISE Frauenhofer 123 to 185 €/MWh	185 €/MWh, EUR 511 million	High upfront cost, for the project is large and electric infrastructure is to be build from scratches	Upfront one time cost
	Siemens, Global Wind Energy Council	2€/MWh, EUR 5 521 950	Given data. Transmission costs that occur annually over the lifetime of the project.	Fixed annual cost
Variability	Siemens, 13-15 €/MWh	13€/MWh 35.893 k€	Wind energy is not constant and has to work together with other sources of energy; The grid compatibility measures due to that effet are called variability costs.	Upfront one time cost
O&M	Holm, 30-40€/MWh	30€/MWh	Economies-of-scale, unproportional results when using 40€/MWh	Fixed annual cost

Results

The extracts of the full Excel calculations are presented in this section. The input numbers are the ones discussed in this chapter and the formulas applied are the ones discussed in the methods chapter. Discussion over the results can be found on the next chapter, Findings & Results. Because the Excel files are too long to be fully integrated in this part of the thesis, only the first two years and the last two years of the calculations are displayed for the cash flow analysis and the first seven years for the NPV, IRR and LCoE analyses, in one single table.

Table 4 Discounted Cash Flow for the Offshore London Array Wind Farm, Extract 2012-13 & 2031-32

London Array Wind Farm, CF

In k €	2012	2013	2031	2032
Cash outflow				
Wind turbine	693.000			
Installed cost	1.858.500			
Transmission	510.780	5.522	5.522	5.522
Variability	35.893			
O&M		82.829	82.829	82.829
Total annual expenses	3.098.173	88.351	88.351	88.351
Total annual disc. expenses 8%	3.098.173	81.807	20.472	18.956
Total disc. Expenses	3.965.618			
Cash Inflow in k € discounted at 8%				
Annual MWh production		2.760.975	2.760.975	2.760.975
Market price 55,21 €/MWh		141.142	35.321	32.704
Subsidies 122,2 €/MWh + Market Price = 178 €/MWh		453.541	113.498	105.091
FiT 90 €/MWh		230.081	57.578	53.313
FiT 105 €/MWh		268.428	67.174	62.198
Total disc. Cash inflow	Market price	1.496.614		
Market price 55,21 €/MWh				
Cash flow per year	-3.098.173	59.335	14.849	13.749
Cumulative cash	-3.098.173	-3.038.838	-2.482.753	-2.469.004
Subsidies 178 €/MWh				
Cash flow per year	-3.098.173	371.735	93.026	86.135
Cumulative cash	-3.098.173	-2.726.438	757.416	843.552
FiT 90 €/MWh				
Cash flow per year	-3.098.173	148.275	37.106	34.357
Cumulative cash	-3.098.173	-2.949.898	-1.560.286	-1.525.929
FiT 105 €/MWh				
Cash flow per year	-3.098.173	186.621	46.702	43.242
Cumulative cash	-3.098.173	-2.911.552	-1.162.556	-1.119.314

Table 5 Net Present Value & Internal Rate of Return for the Offshore London Array Wind Farm, Extract 2012-2019

London Array Wind Farm, NPV, IRR, LCoE, 2012-2019

In k €	2012	2013	2014	2015	2016	2017	2018	2019
Wind turbine	693.000							
Installed cost	1.512.000							
Transmission	510.780	5.522	5.522	5.522	5.522	5.522	5.522	5.522
Variability	35.893							
O&M		82.829	82.829	82.829	82.829	82.829	82.829	82.829
Total expenses	2.751.673	88.351	88.351	88.351	88.351	88.351	88.351	88.351
Discounted total costs 8%	2.753.685	81.807	75.747	70.136	64.941	60.130	55.676	51.552
Total disc. expenses	3.621.130							
Revenue in k € with a discount rate of 8%								
Annual MWh production		2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975
Market price 55,21 €/MWh		141.142	130.687	121.007	112.043	103.744	96.059	88.943
Subsidies 122,2 €/MWh + Market Price = 177,4 €/MWh		453.541	419.946	388.839	360.036	333.366	308.673	285.808
90 €/MWh		230.081	213.038	197.258	182.646	169.117	156.589	144.990
105 €/MWh		268.428	248.545	230.134	213.087	197.303	182.688	169.155
Total disc. Revenue	Market price:	1.496.614	Subsidies+MP:	4.809.170	FiT 90€:	2.439.689	FiT 105€:	2.846.304
NPV with:	Market price 55,21 €	-2.124.516	Subs. 178 €	1.188.040	FiT 90 €	-1.181.441	FiT 105 €	-774.826
IRR with:	Market price 55,21 €	-13%	Subs. 178 €	5%	FiT 90 €	-6%	FiT 105 €	-4%
LCOE in €/MWh	65,58							

Table 6 Net Present Value & Internal Rate of Return for the Offshore London Array Wind Farm usinf Ofgem's data, Extract 2012-2019

London Array Wind Farm, NPV, OFTO Data

In k €	2012	2013	2014	2015	2016	2017	2018	2019
Wind turbine	693.000							
Installed cost	1.512.000							
Transmission	510.780	5.522	5.522	5.522	5.522	5.522	5.522	5.522
Variability	35.893							
O&M		89.871	89.871	89.871	89.871	89.871	89.871	89.871
Total costs	2.751.673	95.393	95.393	95.393	95.393	95.393	95.393	95.393
Discounted total costs 8%	2.751.673	88.327	81.784	75.726	70.117	64.923	60.114	55.661
Total disc. Cost	3.688.260							

Revenue in k € with a discount rate of 8%								
Annual MWh production		2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705
Market Price 55,21 €/MWh		153.613	142.234	131.698	121.943	112.910	104.546	96.802
OFTO 28 €/MWh		83.707	77.507	71.765	66.449	61.527	56.970	52.750
Total disc. Revenue	Market Price 55,21€	1.628.852	OFTO 28€	887.597				
NPV with:	Market price: 55,21 €	- 2.059.409	OFTO 28€	- 2.800.663				
IRR with:	Market price: 55,21 €	-13%	OFTO 28€	N/A				
LCOE in €/MWh	61,56							

3.2.3 Sustainability analysis

The most established sustainability analysis is the so-called displacing of CO_2, which is the CO_2 that is not being emitted but would have been with non-renewable energy.

According to Siemens (2014), the cost of CO_2 certificates (in other words the right to emit) is typically included in the LCoE, but at a CO_2 price of well below 10 €/ton. This level does not provide a reasonable reflection of the immediate and long-tem negative impacts of greenhouse gas emissions. When assuming a price of 81 €/ton for CO_2, as this is the lifetime value of CO_2 for a power plant starting operations in 2025, given by the carbon price floor, it gives an additional cost of 45 €/MWh for greenhouse gas damage in the case of coal power plants, for example (Siemens, 2014). On the other hand, once a wind farm is erected, the electricity produced is CO_2 free.

In this case study, London Array displaces over 900 000 tonnes of CO_2 a year — equivalent to taking nearly 300 000 cars off the road each year (London Array Ltd., 2014) and many other sources, including E.on, Masdar and the Clean Energy Action Project, calculate a carbon avoidance of 925 000 tons per year. These calculations were made using an average carbon intensity from grid supplied electricity of 430 000 g CO_2/MWh (London Array Ltd., 2014). According to a recent publication by London Array Ltd. from May 2014, the offshore wind farm has produced 3 million MWh of net output- a saving of around 1,29 million tonnes in carbon dioxide emissions since the first turbine became operational in October 2012.

This work calculated an annual electricity production of 2 760 975 MWh, which results in a carbon avoidance of 1 187 219 tonnes of carbon dioxide using an average carbon intensity from grid supplied electricity of 430 000 g CO_2/MWh.

As for the emissions created by the manufacture, transportation and installation of wind turbines, they are considered fairly low (The guardian, 2012). But as wind energy is intermittent, it generates electricity only when the wind is blowing, and at sufficient strength. It means that when wind strength is insufficient for turbines to operate, usually fossil-fuel-based power supply is needed as “backup”. Therefore additional emissions have to be added to the sustainability analysis of offshore wind power (The guardian, 2012). Nevertheless, one could use natural gas or other renewable energies instead of using fossil fuels as a back-up source of energy. No data on this matter is published for the London Array project but it is referred to as the variability cost in the profitability analysis.

A positive environmental factor of wind power is the fact that offshore wind turbines are increasingly bigger; the rotor diameter is getting wider. A study by Swiss and Dutch Scientists, led by Marloes Caduff from ETH Zurich's Institute of Environmental Engineering, showed that the larger the turbine, the greener the electricity. This effect can be traced back to both the size of the turbine as well as the learning and experience gained with the technology over time (Wind power monthly, 2014). The widest wind turbine so far is the SeaTitan 10MW Wind Turbine from the American energy technologies company American Superconductor Corporation (AMSC) with a rotor diameter of 190 meters. The SWT-3.6-120 used in the London Array project have a rotor diameter of 120 meters (Siemens, 2015). According to EWEA the "continued dominance of Siemens 3.6 MW turbine explains why the average size of turbines remains around the 4 MW mark [in 2013], despite numerous bigger models being commercialised (EWEA, 2014) and most new models having a wider rotor diameter than 120 meters (Power Technology, 2014).

According to Holm (2015), once a wind park is implemented, there is no fuel cost and low operating and maintenance costs. Furthermore there is no geo-political risks related to fuel or gas, no resource constraints, no CO2 emissions, no need for cooling water, no waste such as solid, ash or slurry, no particle emissions, no mercury or other heavy metal emissions from the energy production. And even though wind is volatile, the electricity production is very predictable (weather condition and wind speed).

It is therefore obvious that once a wind park is installed, except for the low energy consumption and emissions due to operation and maintenance activities, the electricity produced is 100% clean (Holm, 2015 & von Olnhausen, 2015).

Holm and von Olnhausen also agree on the fact that the recycling rate of wind turbines is very high, as a wind turbine can be fully dismantled and the different parts sold or/and reused (see Table 7 below) and the dismantling costs for the wind turbine is less than the recycling value (Holm). There is no doubt that the material used can be more sustainable and environmental-friendly (especially the plastic parts from the turbine blades), but compared to other sources of energy, the material used are very simple and renewable as in reusable (Wind Power Monthly, 2012).

Table 7 Removal Scenario for Wind Turbine Materials (Vestas, 2006).

Material	Scenario
Steel	100% recycling, (90% recovery and 10% landfilling)
Cast iron	100% recycling, (90% recovery and 10% landfilling)
Stainless steel	100% recycling, (90% recovery and 10% landfilling)
High-strength steel	100% recycling, (90% recovery and 10% landfilling)
Copper	100% recycling, (90% recovery and 10% landfilling)
Aluminium	100% recycling, (90% recovery and 10% landfilling)
Lead	100% recycling, (90% recovery and 10% landfilling)
Glass fibre components	100% incineration of composite material with heat recovery, glass content is hereafter landfilled
PVC-plastic	Deposit of fractions that can be disassembled, incineration of the rest.
Other plastic	100% incineration of waste with heat recovery
Rubber	100% incineration of waste with heat recovery

Stenberg (Interview 09.03.15) adds that wind turbines can also be reused as a whole, for instance some wind turbines in Finland were bought second-hand form Germany. Von Olnhausen points out that often wind turbines are left to produce electricity even after they are financially written off, as the maintaining costs are very low. Therefore the longevity of wind turbines is rather high.

As for the site on which the wind park is built, it can be fully restored and re-used for other purposes (Holm, 2015). A wind park is usually quite vast, depending on the amount of wind turbines. In the London Array wind park, the 175 turbines are located throughout 100 km2 at 20 km from the shore.

Finally, all interviewees agreed upon the fact that a wind turbine has produced the energy it took to manufacture and install in less than a year, according to Holm it takes 6 to 10 months. The next chapter discusses this issue further (4.2. Consumed energy during the production & installation process vs. produced energy).

The only pollution coming from a wind park is the noise in a 1 to 2 km radius from the turbine (Holm), but according to Stenberg there is no proper definition, measurement or standards on noise emissions from wind parks (onshore and offshore) by the governments. Wind turbines can also be seen kilometres away, but that does not count as a sustainability factor. So as in the onshore sustainability analysis, to-date, the main environmental impacts are on the ecosystem. It is surprisingly a problem in the vast and low-populated country of Finland, because even if there is no town, there is always a summer cottage "close by" that could see and hear the wind turbine (Stenberg).

Phase 2 of the London Array project was cancelled due to the impact on the ecosystems; more precisely birds (London Array Ltd., 2014), even though offshore wind parks typically are less sensitive to this factor than onshore wind parks.

4 FINDINGS & RESULTS

4.1 Profitability, Costs & Prospects

This section describes, explains and discusses the results of various profitability analyses conducted in this study. Each profitability analysis is shortly explained once more, the main results presented (the full Excel calculations can be found in the appendices) and discussed. The chosen numbers for the profitability calculations are partly published by the key players in the case studies, partly calculated in this work using the published information and partly calculated from average industry numbers that suit the case study in time and location of the wind parks. Therefore the analyses are based on facts but also assumptions and are simplified. This section also includes other literature than the case studies in the discussion over prospects of the profitability and costs of wind power, particularly when comparing the results of this work to other sources of energy.

4.1.1 Discounted Cash Flows

This section discusses the *discounted CF of the case studies; states that the cash flow in year 0 is not discounted and realistically all upfront costs are not actually paid before any electricity is produced (contracts, invoices, debt and equity), but the cash flows in this case study are simplified. Important is the fact that once a wind farm is erected, the only (pretty low) cash outflows are O&M, and little transmission cost. In London Array's case, transmission is transferred to an OFTO.*

The main cash outflow is in the starting year 0 of the projects, with EUR -4.37 million in the onshore farm and EUR – 3 098 million for the offshore case study. Nevertheless this high upfront cost that is needed in order to erect a project is all summed up in the first year of the analysis. Realistically not all costs are paid in beforehand (i.e. invoices and contracts) and projects are financed through debt and equity. Debt is spread over more years, with an interest (cost of capital). Therefore the costs would be realistically spread out to several years in the cash flow analysis and discounted at 5% for other onshore and 8 % for the offshore case study, as are the cash inflows. On top of that the transmission assets (i.e. electric substations, cabling…) and the transmission rights have been transferred in an auction round to an independent OFTO in London Array's case (offshore case study). Therefore transmission costs should be taken out of the calculations, and the transferred value of over GBP 400 million added as a cash inflow in 2013. This would results in more positive outcomes.

This study aims to show the overall process of profitability analysis conducted for wind parks, this is why it includes all costs related to a wind farm, despite the different owners and contracts, and simplifies the calculations in order to make them easy to understand.

After the high capital investment due to the high upfront costs of building a wind farm in year 0 and once electricity can be generated in year 1, the cash flows are positive. As O&M costs are quite low, especially in comparison to the initial investment, the cash flows are quite high for the while lifetime of a wind park.

4.1.2 NPV & IRR

This section discusses the NPV results of the case studies and points out that the calculations of this work are based on industry average numbers that are applied to the case studies because of a lack of information and transparency. The same cash flows are used as in the cash flow analysis, same problems apply to the NPV profitability analysis (not discounted high upfront cost vs. income discounted over 20 years). Subsidies are still needed in order to make wind power in large scale profitable – as it can be seen in the offshore case study. But smaller projects are already independently profitable, if implement at a right spot with enough wind speed (i.e. Åland has wind power but is not in the Finnish FiT system, Stenberg, 2015).

The Net Present Value NPV is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyse the profitability of an investment or project (Investopedia, 2015).

Table 9 below shows the results of the calculations from the previous chapter. The OFTO data in the last row of the table does not show an IRR result, as the given revenue does not cover the annual costs of transmission and O&M, therefore it has negative cash flows and the IRR formula cannot be applied.

Table 8 NPV & IRR results for both case studies (this work's calculations)

	NPV	IRR
Onshore 69 €/MWh	EUR 218 000	1,4%
Offshore		
- **Market price (MP) 55,21 €/MWh**	EUR- 2 125 mil.	-13%
- **MP + Subsidies (122,2 €/MWh) 177,41 €/MWh**	EUR 1.188 mil.	5%
- **FiT 90 €/MWh**	EUR -1.181 mil.	-6%
- **FiT 105 €/MWh**	EUR -775 mil.	-4%
- **OFTO revenue**	EUR -2 800 mil.	N/A

The onshore case study shows a NPV of EUR 218 000, which corresponds to an IRR of 1,35%. Therefore the project is reasonably profitable over 10 years. If the costs of the project were spread over the years and the project's lifetime was 20 years (10 additional years of revenue with low O&M costs), the wind park would be more profitable. There is no publication on the revenue after the first 10 years of FiT that the Tanderup received but as von Olnhausen has stated in an interview with the author, most wind parks are profitable even after their projected lifetime of typically 20 years. It can therefore be assumed that the Tanderup wind turbines still generate profits after the 10 years.

The exact income generated by the London Array wind farm is not published, but the contract between the wind farm and the national electricity distributors Statkraft and UK National Grid was based on current spot prices. This worked assumes an average UK power spot price of 40 pounds/MWh, which is equal to 55,21 €/MWh. According to this work's calculation, this results in losses of EUR 2 125 millions. Therefore the market power prices do not cover for the cost of offshore wind power.

In a second step, this work applied Germany's current FiT level of 90 €/MWh for wind power to the case study; this results in an NPV of over 1 000 million euros in loss. The same was done with Finland's current FiT of 105 €/ MWh, which results in an NPV of almost 800 million euros in loss.

The break-even point (an analysis to determine the point at which revenue received equals the costs associated with receiving the revenue, so where NPV equals 0, Investopedia, 2015) lays at an income of **133,585 €/MWh**. In other words London Array's electricity has to be sold at a price of **133,585 €/MWh** over 20 years in order to cover the costs.

Finally, this work looked at Ofgem's OFTO revenue report from December 2014 and applied the numbers (annual electricity production of 2 996 000 MWh and annual revenue of 90.984 million euros) in the Excel calculations (costs defined by this work). Ofgem's published revenue and assumed electricity production result in an income of EUR 28 /MWh and leads to a negative NPV of EUR 2.801. million. Using the same electricity generation but with the market price of EUR 55,21 /MWh, the NPV is EUR -2.059 million.

What can be noticed here is the fact that even though the offshore project's LCoE is relatively low (see next section), probably due to economies-of-scale, the project struggle to be profitable. This is as mentioned highly due to the high, undiscounted upfront cost, and also to the not transparent pricing system. The Director of Masdar Clean Energy, one of the owner companies of London Array Ltd., states that the investment in London Array will be repaid in less than 10 years while the UK manager for wind power for DONG Energy, another owner of the project, states that rates of return are "not stellar" but "acceptable". This work calculates an IRR of 5% when calculating with subsidies on top of the market prices.

The Internal rate of Return (IRR) is the discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero (Investopedia, 2015). The IRR results of the case studies can be seen in Table 9 in the previous section. The IRR results are closely linked to the NPV results, IRR is a different form to show the profitability of an investments. Therefore the same results apply: the profitability of wind power is still closely linked to subsidies, as the energy industry is in general.

UK Manager from Dong Energy stated that they would not implement London Array if "it wasn't good business, and further notes that it is not a lucrative business like oil (The Telegraph, 2013).

4.1.3 LCoE

This section discusses the LCoE of the case studies and briefly compares the results to the industry average and to other sources of energy.

As explained in the beginning of this work, the Levelised Cost of Energy (LCoE) is a typical analysis in the energy industry. It consists of dividing all the (discounted) cost over a lifetime by the produced electricity over a lifetime. In the case studies, the onshore wind park is given a 10 years lifetime and a 5% discount rate and the offshore wind park 20 years and a 8% discount rate.

Table 9 LCoE of various energy sources (European Commission, 2014, EWEA, 2014 and this work's calculations)

LCoE in €/MWh	Case study	EC	EWEA*
Onshore	57,52	80-90	105
Offshore	66,14		186
Offshore with Ofgem's data	62,16		
Sola Power		100-115	
Natural Gas		100	164
Nuclear		100	133
Coal		75	162-233

These results are below most published LCoEs. In the offshore case study this can probably be traced back to the fact that the wind park has been generating more electricity than expected.

4.1.4 Prospects on cost reduction

This section discusses the costs of RE and the prospects RE have in order to become more profitable.

As it can be seen from the financial results above, wind power is still facing very high production and implementation costs. This is mostly due to the fact that wind technology is still a rather new technology, especially offshore wind. As it is in any type of in-

* Including externalities cost

dustry, the first products are rather expensive. Prices settle down when the industry grows and the supply chain gets more efficient (i.e. more suppliers, more products, less delay) (Rinne, Interview 10.03.15).

Based on a report from the UK's Crown Estate, Renewable Enegy consultant David Milborrow assumes that the cost of offshore wind generation could fall significantly (from the current level of around EUR 172/MWh to around EUR 123/MWh). The top two reasons are cost reductions of the installation process- partly because of a more efficient supply chain – and higher wind speeds further offshore, as offshore wind parks are built further and further from the coast and higher wind speeds result in higher electricity generation (Wind Power Offshore, 2015).

On the other hand, some people in the industry, such as Holm (Mervento) and Stenberg (WPD) do not believe that wind power is in fact more expensive than other sources of energies. Due to an on-going cost reduction and improving efficiency levels, wind power is very competitive in comparison to other sources of energy. Figure 15 below shows the LCoE of various energy sources using fours different studies: the blue is a Finnish study, the yellow is a Swedish study, the res one is an American study and the green one is a European study. All studies show that onshore wind power is one of the cheapest sources of electricity and the LCoE level of offshore wind power is not that much higher than other sources of energy.

It can be further noted that this work's calculations, and probably the studies from Figure 15, do not include the cost of CO2. Results would have been different if the cost of CO2 emissions was included and included at a fair price. According to all interview respondents, green certificates have a far too low price due to many different factors; mainly because the market is new and not well implemented yet. As wind energy does not produce emissions from its electricity generation, the price of emissions would have a strong impact on the LCoE, in favour of renewable energies.

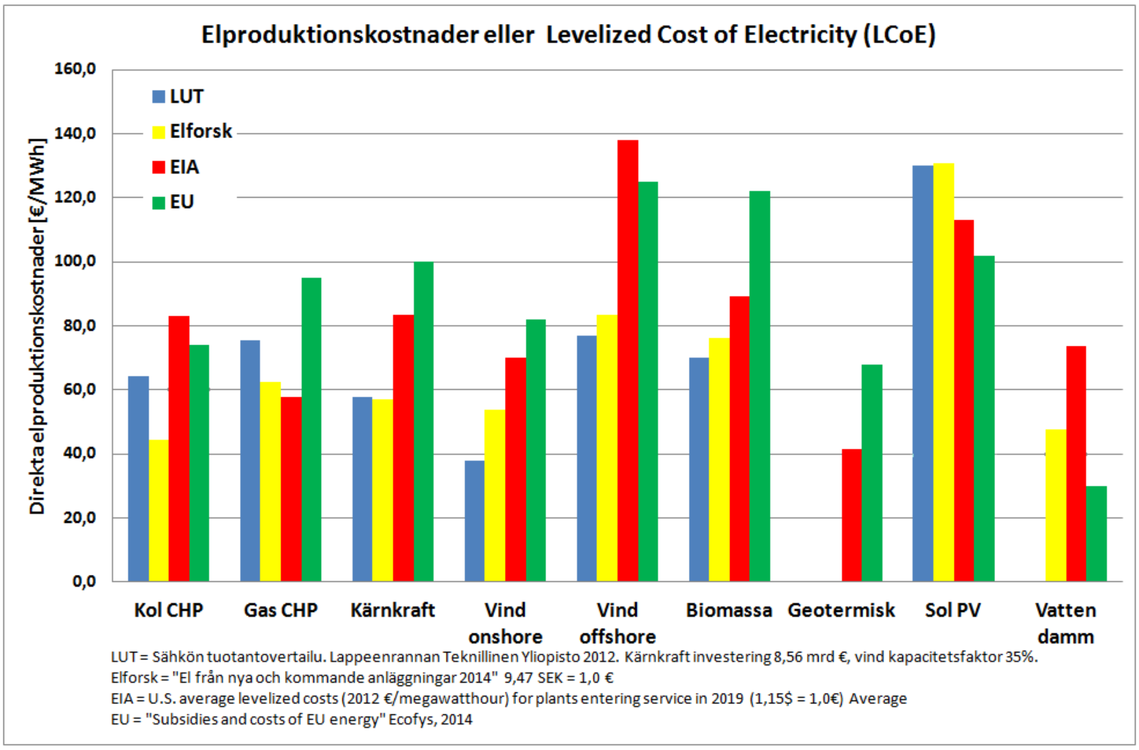


Figure 15 LCoE of several energy sources. (Swedish-speaking Association for Wind Power, 2014).

The outcome of a study conducted by EWEA on cost vs. price of wind power found that in order to form a fair basis of comparison between energy technologies (wind power, gas, coal and nuclear), one has to include the corresponding risk, which are fuel and carbon emission costs, in the LCOE calculations. There is a high volatility and uncertainty to forecast fuel and carbon costs, of which wind power is independent (EWEA, 2010).

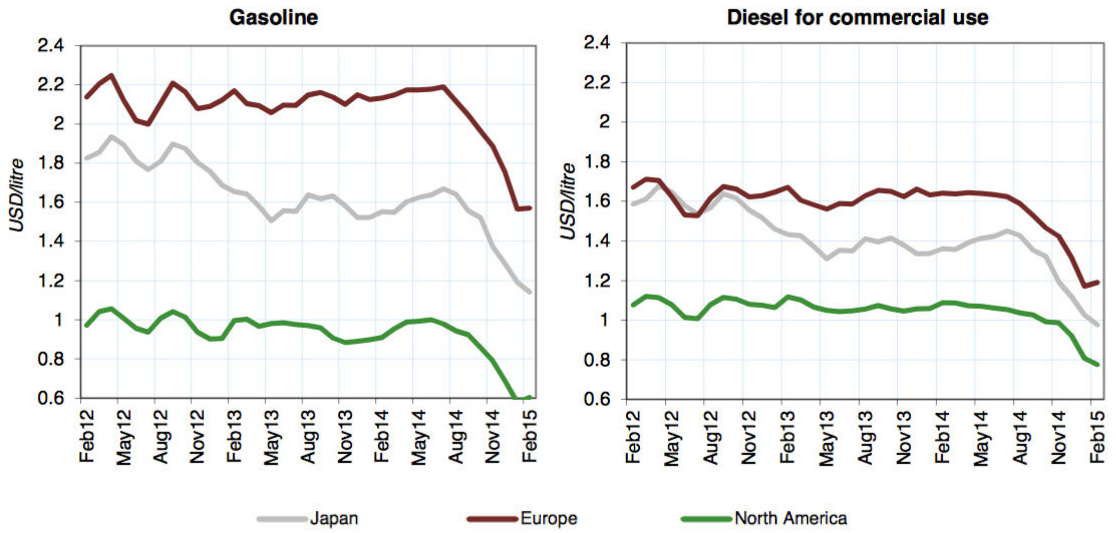
Another study conducted by EWEA the year before, entitled Economics of Wind Power, revealed that in the face of uncertainty in power markets, high capital intensity (due to high upfront costs) is a relative disadvantage to wind, hydro and nuclear compared to gas and coal, as a lot of capital is tied up, along with large fixed costs. As a result, if electricity prices drop on the power markets, the revenue drops and the wind, hydro or nuclear power plant is left with stranded interest costs and depreciation. On the other hand gas and coal face the uncertainty of fuel and carbon prices. Since 2013, all power plants in the EU are obliged to buy emission allowances to be allowed to release CO2 into the atmosphere (see 3.2.2. Profitability analysis – Revenue). The report further states that "Europe relies mostly on relatively low capital intensity fossil-fuel fired power plants, with a very high risk component in the form of very volatile and unpredictable fuel prices" and suggest "a diversified generating technology portfolio containing more capital intensive and low-risk wind power may indeed be a wiser choice for society than relying on fuel intensive high-risk fossil technology" (p.113).

Wind power can be sub-categorised within onshore and offshore power, and variations in between, such as near-shore wind power. A study by The Guardian and the Grantham Research Institute Onshore in 2012 showed that wind power has the advantage of being one of the most affordable renewable energy sources. Indeed, generating electricity from onshore wind turbines typically costs around 70–90 per MWh, which is around half the cost of offshore wind and a quarter of the costs of solar photovoltaic panels. It is also slightly cheaper, on average, than nuclear power. Onshore wind generation is still slightly more expensive than fossil fuels (generating electricity from gas power plants currently costs between 41 and 75 pounds /MWh), but its price is expected to fall in the coming years (The Guardian & Grantham Research Institute, 2012). As shown in this study, the gap of costs per MWh is lowering between onshore and offshore wind parks.

Nevertheless, the ISE Fraunhofer Institute, the largest solar energy research institute in Europe, stated in November 2013 that the scope for cost reduction for offshore wind parks is limited due to the higher cost for the installation and maintenance, making it difficult to reach similar costs as for onshore wind parks. However, future cost reduction effects are to be expected due an increasing market growth, as an extensive installation of offshore wind turbines is used in many other countries such as the North Sea neighbours in the upcoming years, for example London Array (p.21).

This work assumes that when looking at the cost of electricity, RE are not yet the cheapest options; nevertheless as they grow and more RE projects are implemented, the costs of those energies decrease. Besides, as non-RE energies become more and more scarce and the cost of emissions increase, their costs will increase. It can be seen that RE are more competitive in the European Union as the overall cost of energy is high (see Table 11 below that shows the End-use prices for gasoline an diesel, where European prices are shown in dark red). This has two effects: it results in higher installed, operation and maintenance costs than outside the EU (see Table 12 below) but it also sets RE on the same level of costs of non-RE. In other words the prices for renewable energy electricity is high, and as it can be seen in Table 12 that O&M costs are also higher in Europe than in the rest of the world and installed cost are still high, even if slightly lower than in the US, but as the end-user oil prices are higher in Europe than in many other countries (see Table 11), renewable energies are more competitive in Europe than in other countries. As this work focuses on renewable energies the reasons for energy prices to be higher in Europe than in other countries will not be discussed, but it an be assumed it comes from subsidies and international politics.

Table 10 End-use prices for selected oil products, International Energy Agency (IEA), 2015.



* Europe includes France, Germany, Italy, Spain and the United Kingdom; North America includes the United States and Canada.
Gasoline prices are: unleaded premium (95 RON) for France, Germany, Italy Spain and the United Kingdom; regular unleaded for Canada, Japan and the United States.
Weighted average price including taxes. For the two most recent months, consumption is estimated using growth rates for the same period of the previous year.

© OECD/IEA, 2015

Table 11 Typical new Wind Farm Costs and Performance in 2010 (International Renewable Energy Agency, 2012)

	Installed cost (2010 USD/kW)	Capacity factor (%)	Operations and maintenance (USD/kWh)	LCOE* (USD/kWh)
Onshore				
China/India	1 300 to 1 450	20 to 30	n.a.	0.06 to 0.11
Europe	1 850 to 2 100	25 to 35	0.013 to 0.025	0.08 to 0.14
North America	2 000 to 2 200	30 to 45	0.005 to 0.015	0.07 to 0.11
Offshore				
Europe	4 000 to 4 500	40 to 50	0.027 to 0.048	0.14 to 0.19

** Assumes a 10% cost of capital*

From a business and technological point of view, it is the further lowering of RE costs that is the main factor that will boost their competitiveness with conventional energy sources. The leader in wind turbines manufacturing in Europe, Siemens, states that offshore wind power is one of the most promising and climate-friendly energy-producing technologies (Siemens, 2014). As the main critic about onshore wind power is its environmental impact, mostly on aesthetics and birds' natural environment, offshore wind farms, usually located 5 to 30 kilometres away from the land, have minimal impact on the biological environment (The Guardian & Grantham Research Institute on Climate Change and the Environment, 2012) and noise pollution is less problematic as for onshore wind turbines (Stenberg, 2015).

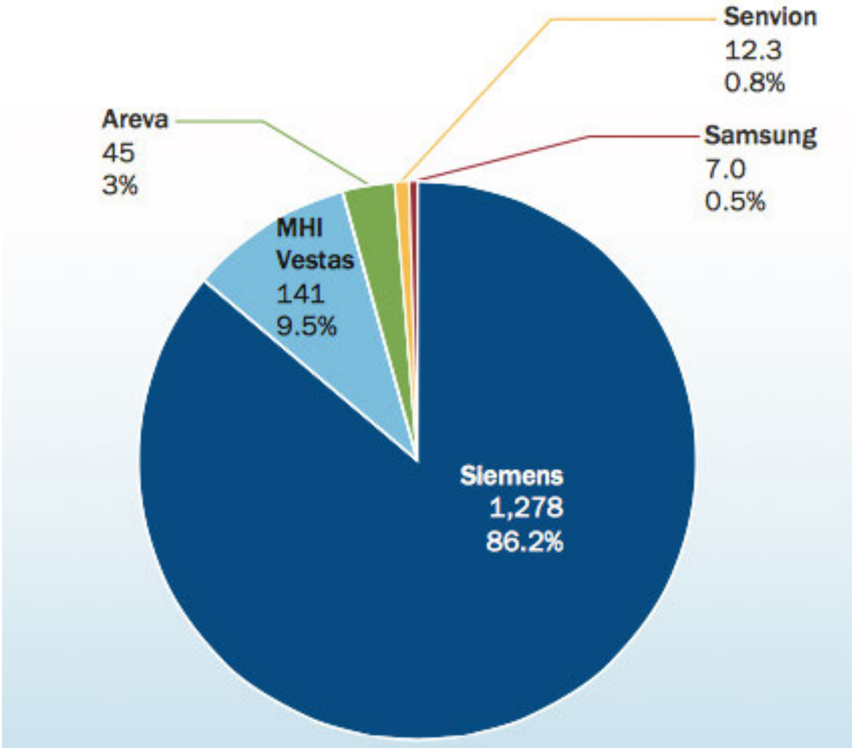


Figure 16 Wind Turbine Manufacturers' Share Of 2014 Annual Installations (MW), (EWEA, 2015).

Based on Siemens' SCOE (see Figure 17. Comparison of LCOE and SCOE for all primary energy sources in UK on p.29), offshore wind could be "the main pillar of tomorrow's energy supply" since it creates jobs, also locally, and reduces risks (such as exposure to particulate matter and security of supply through to susceptibility to the price volatility of imported fuel). Siemens further points out that "gas is the most efficient and lowest-cost backup solution for all renewables, as a means of achieving a reliable, low-emission energy supply system". Siemens' main argument for the competitiveness of

RE, especially offshore wind power is the redefinition of energy costs, that takes more factors into account than only CO2 emissions.

This argument is also backed up by the European Commission, which calculates the impact of external costs (typically sustainability issues such as pollution that are not included in the price) to lie between EUR 150 billion and EUR 310 billion. According to renewable energy trade groups, if these external factors were to be included in the energy price, RE would be more profitable than conventional sources of energy. The EWEA used external costs calculations made by Ecofys and ordered by the EC to calculate the "true" LCoEs of different types of energy. The results can be seen in Table 10 in the last column to the right. As expected the LCoE for coal triples and REs become the cheapest energy sources when including the externalities.

EWEA's deputy CEO, commented on the results that the report "*highlights the true cost of Europe's dependence on fossil fuels. Renewables are regularly denigrated for being too expensive and a drain on the taxpayer. Not only does the Commission's report show the alarming cost of coal but it also presents onshore wind as both cheaper and more environmentally-friendly*." (Renewable Energy World, 2014). Furthermore he adds that Europe is heavily subsidising coal (and fossil fuels overall) due to its affordability, which is proven wrong when including externalities into the LCoEs that proves coal to be the most expensive source of energy.

The European Photovoltaic Industry Association (EPIA)'s Policy Director noted that the Ecofys study ordered by the EC "proves that solar energy is cost effective today, and is improving competitiveness at a rate that conventional technologies will never be able to achieve. Despite decades of heavy subsidies, mature coal and nuclear energy technologies still rely on similar levels of public support as innovative solar energy is getting today. However, support to solar electricity is already coming down, in line with the rapid technology cost reduction, as opposed to coal and nuclear energy, which remain locked into subsidies, as they have been for the last 40 years. With its increasing cost-effectiveness, solar is set to overtake conventional technologies in the short term," (Renewable Energy World, 2014). Similar assumptions can be said about wind power.

UK manager for Dong Energy, one of the owners of London Array, explains that the profit margins are much slimmer compared to oil and gas. He believes his job to be to make offshore wind power an investable industry without being unfair to consumers and the high subsidies reflect the fact that offshore wind is a "young" technology (The Telegraph, 2013) in comparison to nuclear or coal power, the latest being over 200 years old.

According to the wind power magazine Wind Power Offshore (2015), offshore investment reached over $19.4 billion in the year of 2014, more than doubling 2013. The previous offshore record was set in 2010 when $12.8 billion was invested globally. Figure 17 below shows the development of the offshore wind power market in the EU, from left to right are projects: planned, consented, under consenting procedure, online and under construction as of January 2014 for the year of 2015 and 2016. This shows that London Array is one in many more wind parks to be installed in Europe.

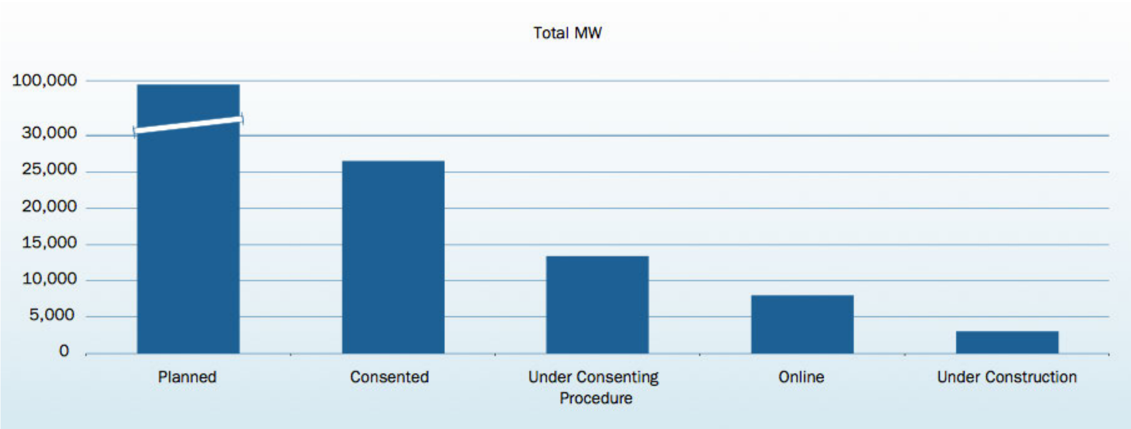


Figure 17 The Offshore Market: Projects Planned, Consented, Under Consenting Procedure, Online And Under Construction, (EWEA, 2015).

As Siemens Wind Power's Chief Technical Officer said, "No single company or institution can on its own bring down the cost of offshore wind power to the required level. However, through joint innovation and cooperation at many levels, as demonstrated by the Carbon Trust's Offshore Wind Accelerator, we will surely get there!"(Carbon Trust, 2014). The Carbon Trust is an independent British consultancy agency "with a mission to accelerate the move to a sustainable, low carbon economy" (Carbon Trust, 2014).

4.2 Consumed energy during the production & installation process vs. produced energy

This section discusses the energy used for the manufacturing and installation process of a wind farm versus the electricity generated by the wind farm once operational. The energy consumed for erecting a wind park are based on industry average, as no information is available from the case studies. Finally the results are compared to other sources of energy.

According to this study, the electricity produced by the onshore farm, which is from the early 2000's, so not the latest technology and has three wind turbines only, produces 7 888,5 MWh per year and 157 770 MWh over 20 years. This work used a capacity factor of 28,90% calculated from data published by the Danish Energy Academy (2011). As wind turbines become higher and bigger due to elevated hub heights and wider rotor diameter, modern wind turbines are more and more effective and produce more energy (see Figure 18 below). This means that the capacity factor increases constantly (EWEA, UpWind Consortium, 2011 & Rinne, 2015). According to Holm (2015), the typical capacity factor of an onshore wind turbine is between 30 to 40% nowadays, so an increase of over 10% point over 10 to 15 years.

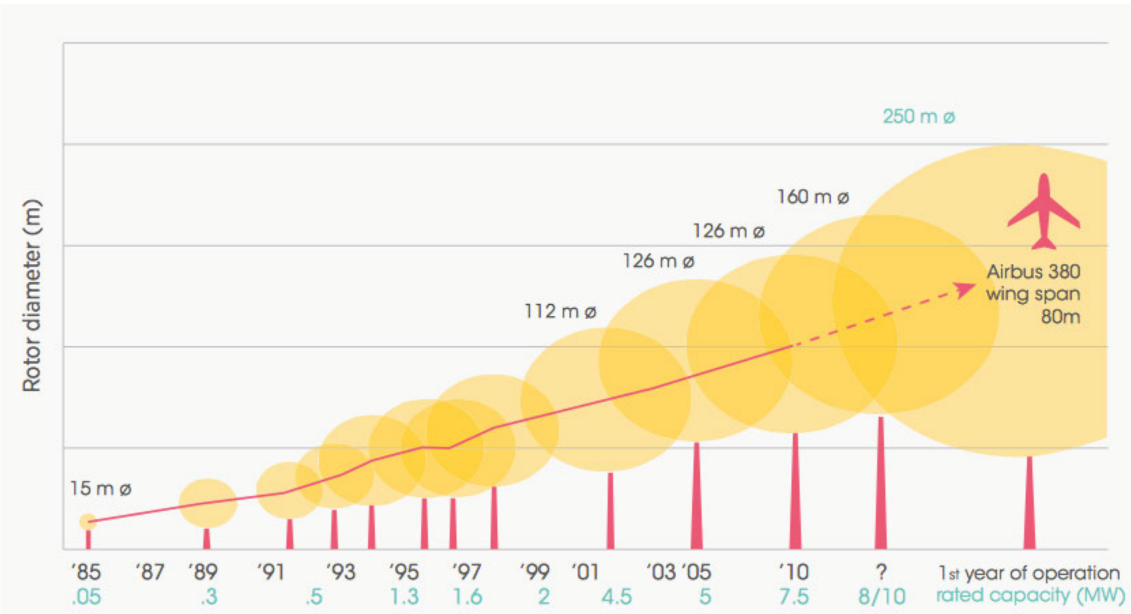


Figure 18 Evolution of Offshore Wind Turbines (EWEA, UpWind Consortium, 2011)

According to Samsø Energy Academy (2011), the three 1MW onshore wind turbines can power 1 800 households. The Danish Energy Academy stated in 2011 that the Tanderup wind turbines' produced energy could be exported outside the island, due to an overall over capacity of the island's electricity production.

As for the case study on the offshore wind farm London Array, the 175 3,6MW wind turbines have a rotor diameter of 120 meters (Siemens, 2015). As mentioned in the previous chapter, the widest wind turbine on the market as of March 2015 is the SeaTitan 10MW Wind Turbine from the American energy technologies company American Superconductor Corporation (AMSC) with a rotor diameter of 190 meters. As technology advances, wind turbines are bigger, higher and more powerful. London Array produced more energy than expected with a capacity factor of 56% in its first full winter of operation in 2013. It can be assumed that more powerful wind turbines than the 3,6MW that were used in this project can achieve even higher numbers.

According to this study, London Array produces 2 760 000 MWh per year and 55 220 000 MWh over 20 years and the World Energy Council calculates that a British household consumes an average of 4,19 MWh (in 2012). This means that London Array produces enough energy each year for 658 944 British households.

The study at the Center for Sustainable Energy (CSE) gives an Energy Return On Investment (EROI) of 25.2, this corresponds to 3,5 to 6,4 months, in other words a wind farm will have generated sufficient energy in half a year or less to "account for all the energy that is required in its construction and operation" (CSE, 2011). The Finnish offshore wind power manufacturer and implementer Mervento has performed a Life Cycle Assessment (LCA) calculation which results in an energy payback time in the range of 7 to 11 months depending on the tower design and wind conditions (Holm, 2015).

In comparison, the EROI for a coal power plant is around 8, resulting in an energy payback time of 2,5 years for a 20 years lifetime and 9 for a nuclear power plant, resulting in an energy payback time of 2,25 years for a 20 years lifetime (Holm, 2015).

Table 12 EROI for Case Studies (CS), Coal and Nuclear power plants. (CSE, Holm and this work's calculations)

	Onshore CS	Offshore CS	Coal	Nuclear
Power generation in 1 year	7 600 MWh	2,76 TWh*	1 TWh*	1 TWh*
EROI (CSE)	0,5 years	0,5 years	2,5 years	2,25 years
Consumed energy	3 800 MWh	1,38 TWh	2,5 TWh	2,25 TWh
In % of 20 years power generation	2,5 %	2,64 %	12,50 %	11,25 %

As it can be seen in Table 13, wind power plants consume less energy in relation of how much energy they generate. When applying CSE's expected 6 months of generating the consumed energy for wind power to the Tanderup onshore case study, the three wind turbines consumed 2,5% of their energy generation over 20 years. In the case of London Array, the consumed energy in relation to the produced energy is slightly higher, with a percentage of 2,64%, while coal and nuclear would consume 12,5% and 11,25% respectively. Therefore wind power "repays" the energy it has consumed to build a wind park faster than other sources of energy.

4.3 Is SE at its current state sustainable?

The energy produced is sustainable without questions, as sunlight and wind are unlimited resources and the solar and wind farms do not influence the sunlight or wind speed, therefore the energy sources are unlimited and the environment is not affected by the electricity production. According to Holm (2015), wind power is a very sustainable and renewable energy, as it creates jobs locally and wind is free, clean, indigenous and inexhaustible.

Anyhow, using unlimited resources are not the only factors of sustainability. Producing, transporting, installing and maintaining RE still require the use of conventional non-RE. The most emitting part in the supply chain of wind turbines is the construction process (see Figure 19 below, the construction phase is coloured blue) and it is also the most

* 1 TWh equals 1 million MWh

expensive one. As stated several times before, wind power requires a lot of upfront costs. Even though the construction of RE producing products does not emit as much as retrieving petroleum or building a nuclear power plant, the sustainability outcome is not equal to zero. Therefore more R&D is needed in the pre-installation process of RE.

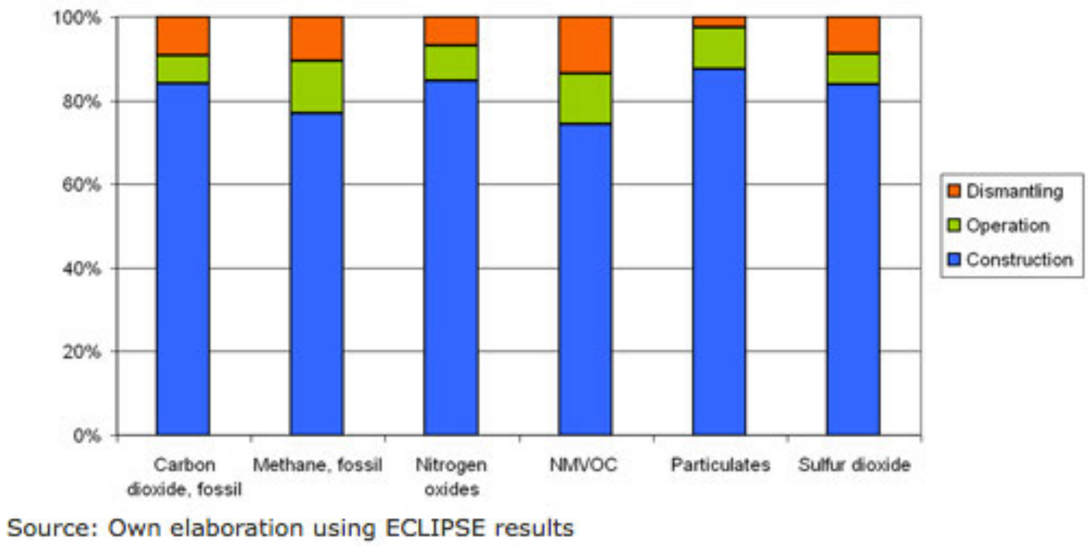


Figure 19 Contributions of the Different Life Cycle Phases to the Relevant Emissions (European Wind Energy Association, 2009)

According to a study made by Vestas in 2006 on one of their own wind turbines, the Life Cycle Assessment (LCA) shows that 1 MWh of electricity generated by a V90-3.0 MW **offshore** turbine has an impact of 5 230 grams of CO2 during the life cycle. For an **onshore** V90- 3.0 MW the corresponding figure is 4 640 grams of CO2. If this is compared to the CO2 emission of 548 000 grams per MWh from European average electricity it is clear that the environmental burdens are significantly lower for electricity generated by wind turbine.

So we can see that wind power is very sustainable for today's standards. A final aspect of wind power that is not discussed in this work is the fact that wind power has the lowest water consumption in its production and implementation process (EWEA, 2014). There is potential for improvement. For example the material used, especially for solar cells, could be more environmental friendly. Less plastic could be used for the wind turbines; transportation emissions could be reduced if using electric vehicles. In order to further increase the sustainability of REs, new technologies have to be invented or further developed.

5 CONCLUSION

The conclusion comprises of a short summary of the main findings of the thesis, examines the reliability of SE and lists recommendations for the profitability and sustainability of renewable energies.

5.1 Summary of the Main Findings

SE is profitable and sustainable but there is room for improvement. Wind power and other SE are still ”new” technologies, in the sense that they are not widespread yet, therefore their cost- and energy-efficiency can still be improved. Wind power plants are very capital intensive because of their high upfront costs and still depend on subsidies, but so do all sources of energy. Nevertheless wind power is much more sustainable than non-renewable energies and the energy used to erect a wind farm is ”repaid” within the first year of electricity production.

5.2 Can we fully rely on RE?

All interviews respondents answered that in fact we can rely completely on RE, but the system is not ready yet.

The main factors that slow down the profitability and sustainability amelioration are:
-Grid Compatibility: the electricity produced by wind and solar farms has to be connected to the local grids, this process is not yet “mainstream”, and therefore technical difficulties lead to higher costs than conventional energy sources. Moreover, wind and solar farms are not always close to where the electricity is needed (especially with off-shore wind turbines), therefore transporting the electricity to the local grid is also still problematic and costs.
-Energy Storage: the energy from RE is not as stable as conventional energy sources, as they depend on wind speed and sunlight. Because large-scale energy storage is still a challenge, REs need conventional energy as a back up, which is also called variability cost.
-High Costs: because RE are not well-established yet, the costs are still higher than they could be.

According to The Guardian and the Grantham Research Institute on Climate Change and the Environment (2012), the final decision on which RE is the most suitable for an area is "ultimately a societal and political one". They further argue that "given the economic and environmental trade-offs, technological uncertainty and the absence of one clear winner when it comes to energy sources, many economists suggest the best approach is a portfolio of different technologies to balance the cost to consumers and environmental concerns".

5.3 Recommendations

Make RE more energy- and cost-efficient

In order to make RE the majority of our energy production, "we need energy technology that is suitable for industrial mass production" (Lund, 2013). This phenomenon is happening for solar cells, which are now more and more produced in China, for the same quality, at lower costs than in Europe (von Olnhausen, 2015). Wind power still faces an oligopoly in the manufacturing and implementation of wind power plants. As can be seen on Figure 16 on page 60, Siemens, MHI Vestas and Areva are the main manufacturers of wind turbines, with a market share of respectively 86,2%, 9,5% and 3%, accounting for a total of 98,7% of the market in EU in 2014 (EWEA, 2015). Anyhow, there is also many small and medium-sized companies active in the field, as well as communities, as can be seen in the onshore case study Tanderup, that was mostly financed by the inhabitants of the Samsø island. Owners and developers of wind farm projects are very diversified across Europe (see Figure 20 below).

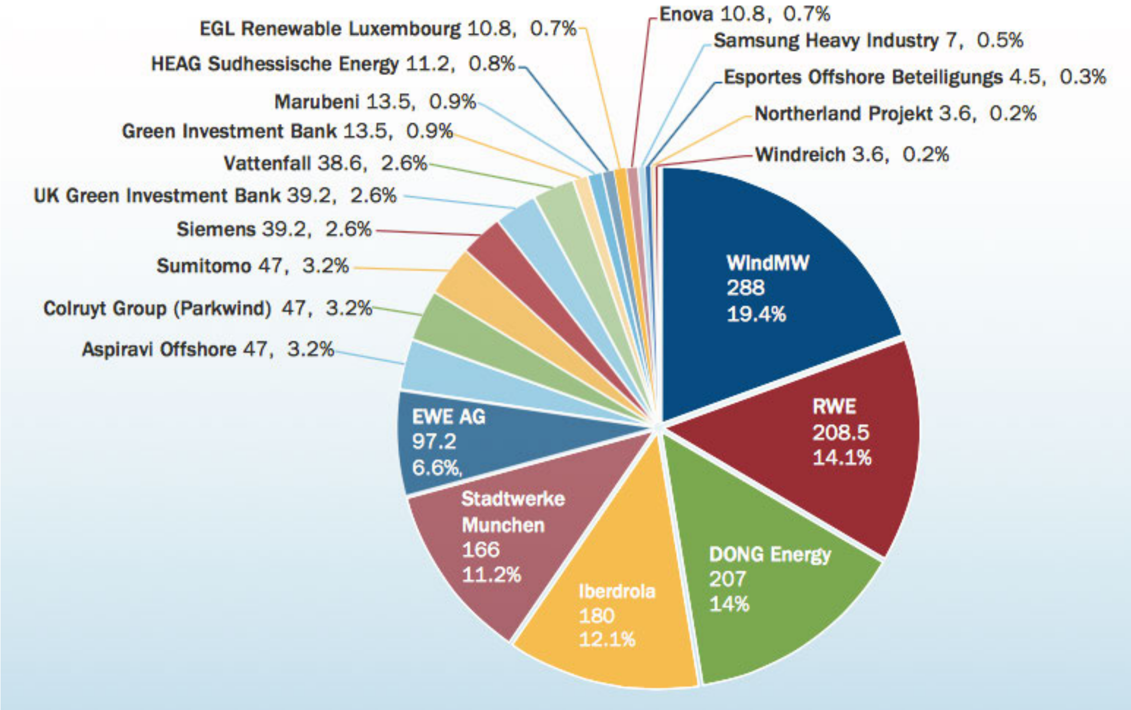


Figure 20 Developers' Share of 2014 Annual Installations (MW), EWEA, 2015.

While sources argue on the exact prices of wind power, all agree that costs are decreasing rather fast over the years. Through bigger and more efficient wind turbines and a more developed and therefore efficient supply chain, a meaningful cost reduction of the industry can be achieved (all interview respondents, 2015).

From a financial point of view, it is the high capital-intensive upfront costs that weigh heavily on the profitability of the projects. If these costs can be driven down, the profitability of projects will increase accordingly. It can be noted at this point that wind power is already more efficient than other sources of energy, such as coal and nuclear, when looking at the energy consumption versus the energy produced (see 4.2. Consumed energy during the production & installation process vs. produced energy, p.63). As analysed in this study, the energy used to create a power plant is produced in less than a year for wind power and at least 2,5 years for coal and nuclear power. Without explaining the specifics, oil also requires high upfront costs: drilling, transporting, transforming the crude oil all require high capital investments and a lot of energy.

Improve the electrical infrastructure for RE

RE has the best potential when interconnected. For instance the larger a wind park, the smaller the variability of the power production (Rinne, 2015). On a bigger scale, it means that if wind parks were to be interconnected, the variability of wind power would be significantly reduced, as there is almost always sufficient wind speed somewhere in Europe. There has been planning on a North Sea grid, officially called the North Seas Countries' Offshore Grid Initiative (NSCOGI), which is "a regional cooperation of 10 countries to facilitate the coordinated development of a possible offshore electricity grid in the greater North Sea area. It seeks to maximize the efficient and economic use of the renewable energy resources as well as infrastructure investments […] and is supported by the energy ministries, the regulators and transmission system operators of the 10 participating countries, and the European Commission" (Secretariaat-Generaal Benelux, 2015).

The same is applies for solar panels, even though the private market is well developed, which means that many private households have installed a solar panel on their roof and create their own energy. As it can be seen in Germany, the excess solar power coming from a household can be redistributed into the grid quite easily.

Beyond wind and solar power, if energy sources were better interconnected through infrastructure and information sharing, say natural gas and biomass could be used as energy backup without compromising the profitability and sustainability of RE. Rinne suggest a smart grid. The EC (2015) defines a smart grid as "energy networks that can automatically monitor energy flows and adjust to changes in energy supply and demand accordingly". The EC further adds that when the smart grid is coupled with smart metering systems, information on real-time consumption can be provided to suppliers and consumers, therefore consumers can adapt their energy consumption in time and volume. Furthermore smart grids can also help to better integrate renewable energy. While the sun does not always shine and the wind does not always blow, combining information on energy demand with weather forecasts can allow grid operators to better plan the integration of renewable energy into the grid and balance their networks. Smart grids also open up the possibility for consumers who produce their own energy to respond to prices and sell excess to the grid. Therefore the energy system can be controlled in a situation in which societies are taking advantage of large amounts of fluctuating renewable-source electricity production. By combining heating, air conditioning and transportation, nearly 75 per cent of Helsinki's electricity needs could be powered using wind power. In order to realise this ideal and be bale to make improvements in the energy system that would facilitate diversified and flexible energy production, we need an overall reform of our current energy system (Lund, 2013), including an energy market redesign (Rinne, 2015).

Those arguments would not be needed if sufficient storage capacities were to be installed. But current electricity storage technologies are not advanced enough to store the required amount of electricity (see Rinne, 2015).

Stop subsidizing the energy industry that heavily

As it can be seen in the analyses of this work, wind power still relies a lot on subsidies, and even though those subsidies are decreasing (Kuhn & Stenberg, 2015) they are still needed. The main problem in decreasing the subsidies for RE is that other sources of energy, particularly fossil fuels and nuclear, receive even higher subsidies from the European Governments. Therefore the competitiveness of the various sources of energies are not based on equal ground, see Table 13 below. RE receive less subsidies than nuclear or fossil fuels, and yet they are already profitable and spreading at a high rate, which positively impacts the efficiency of the production, installation, O&M and the supply chain of the industry.

Table 13 Comparison Renewable, Nuclear & Fossil sources of Energy (European Commission, European Wind Energy Association & Mervento)

Statistics for 2011	Renewables	Nuclear	Fossil	Total
Subsidies [billion €]	30 billion €	35 billion €	70 billion €	135 billion €
Subsidies [%]	22 %	26 %	52 %	100 %
Installed capacity [MW]	32 043 MW	331 MW	12 565 MW	44 939 MW
Installed capacity [%]	71 %	1 %	28 %	100 %
Cumulative capacity [MW]	357 993 MW	122 328 MW	419 933 MW	900 254 MW
Cumulative capacity [%]	40 %	13 %	47 %	100 %
Assumed capacity factor	45 %	85 %	85 %	69%
Subsidies [€/MWh]	21 €/MWh	38 €/MWh	22 €/MWh	25 €/MWh

On a global scale, the IEA (International Energy Agency) calculates subsidies worldwide in 2012 to be $544 billion to fossil fuels and $101 billion to renewables, so more than five times more for fossil fuels than for RE (Holm, 2015).

As subsidies are unevenly distributed, they have a negative effect on RE, when compared to other sources of energy. If the energy subsidies were to decrease overall, RE would most likely be more competitive (EWEA, IEA, Siemens, Holm and more).

Integrate externalities

Another major aspect is the externalities of power production. European Governments have already set limits on certain pollution factors such as local emissions (sulphur, nitrogen…) and the EC has introduced a market place for CO2 emissions, making a commodity out of carbon dioxide pollution. This system is only a few years old and still struggles due to different factors. This results in the price of CO2 certificates being to low to have an impact on companies: it is cheaper to buy the right to pollute rather than invest in more environmental friendly systems, be it transportation, production etc. All sources and interview respondents agree that if the green certificates trading system was better established, RE would be much more competitive and cheaper than other sources of energy.

Beyond the CO2 emissions, RE has other societal benefits. It reduces the geopolitical tensions as it brings energy independency to the local area and the country as a whole. Indeed as the share of RE grows, other sources of energies such as fossil fuels (oil and gas mostly) decrease. Many European countries do not have those resources and need to import energy. Solar and wind power can be built almost anywhere where sunlight and wind speed are sufficient. RE also affects general human health positively. Beyond the CO2 emissions, of which nuclear does not emit in its electricity generation, it does create radioactive residue, of which society has not yet found a way to safely dispose of. Wind energy requires no particular chemicals, and consists of more or less easily disposable and recyclable materials, as seen in the sustainability analyses. Furthermore a wind park can be fully dismantled and almost all material can be recycled. Wind turbines can also be resold, as their lifetime usually surpasses their projected time life. Other sources of energies are less flexible (i.e. dismantling a nuclear power plant takes a lot of resources, a coal power plant cannot be transported and relocated that easily after the end of its projected lifetime…).

One more aspect of the societal effect is that RE is implemented locally rather than in a centralised manner away from the population, such as all other sources of energy are. This means that RE, especially wind power, creates jobs locally. Also, even though bigger companies such as Siemens, Vestas, Dong Energy, E.On and so on are main players in the field of wind power, there is a lot of small and medium-sized companies in the that industry.

This type of externalities and benefits is harder to include in the price of energy, which gives it a disadvantage compared to other sources of energy (p.113, EWEA, 2007). If some of these externalities that are currently not reflected in market prices, such as climate and health costs, were included in the price of energy, as CO2 emissions are starting to be, once more RE would be more competitive and cheaper compared to other sources of energy. These results are backed up by a study made by the EC in 2012 (Renewable Energy World, 2014) and the EWEA (2009).

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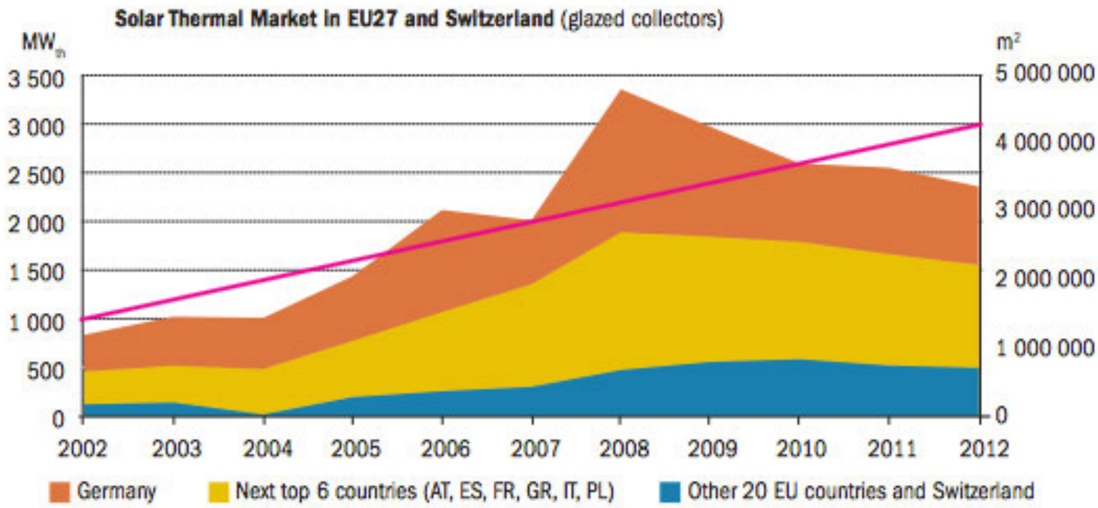
APPENDICES

The appendices contain a graph on the solar markets in Europe, the full calculations used in this thesis, in the order of appearance in the main text and finally the questionnaire used for the qualitative research and the transcripts of the interviews.



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Tanderup Wind Farm, Discounted CF

Ink €	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Cash outflow											
Wind turbine	2.400										
Support Structure	600										
Array eletrical	195										
Installation/ Construction	222										
Maintenance (2%)		48	48	48	48	48	48	48	48	48	48
Transmission Cost		16	16	16	16	16	16	16	16	16	16
Total annual expenses	3.417	64	64	64	64	64	64	64	64	64	64
Disocunted total annual expenses	3.417	46	44	41	39	38	36	34	32	31	29
Revenue in k € with a discount rate of 5%											
Annual MWh production		7.600	7.600	7.600	7.600	7.600	7.600	7.600	7.600	7.600	7.600
Feed-in tariff 5 years (EUR 80/MWh)		608	608	608	608	608					
Feed-in tariff 10 years (EUR 58/MWh)							441	441	441	441	441
Total cash inflow	0	608	608	608	608	608	441	441	441	441	441
Discounted cash flow per year 5% in k€	-3.417	536	512	489	468	447	302	289	276	264	253
Cumulative Cash Flow in k€	-3.417	-2.881	-2.370	-1.880	-1.412	-965	-663	-374	-98	166	419

Tanderup Onshore Wind Farm, NPV, IRR, LCoE

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Annual MWh production 7 600											
Feed-in tariff 5 years (EUR 80/MWh)		608	608	608	608	608		0	0	0	0
Feed-in tariff 10 years (EUR 58/MWh)		0	0	0	0	0	441	441	441	441	441
Income in k €		608	608	608	608	608	441	441	441	441	441
Discounted income in k €	0	579	551	525	500	476	329	313	298	284	271
Total disc. revenue	4.128										
Costs in k €											
Wind turbine	2.400										
Support Structure	600										
Electrical Infrastructure	195										
Installation/Construction	222										
Maintenance (2%)		48	48	48	48	48	48	48	48	48	48
Transmission Cost		16	16	16	16	16	16	16	16	16	16
Total annual cost	3.417	64	64	64	64	64	64	64	64	64	64
Total annual disc. cost 5%	3.417	61	58	55	52	50	48	45	43	41	39
Total disc. Cost	3.909										
NPV	218	IRR=	1,35%								
LCOE in €/MWh	51,40										

London Array Wind Farm, CF 2012-2019

In k €	2012	2013	2014	2015	2016	2017	2018	2019
Cash outflow								
Wind turbine	693.000							
Installed cost	1.858.500							
Transmission	510.780	5.522	5.522	5.522	5.522	5.522	5.522	5.522
Variability	35.893							
O&M		82.829	82.829	82.829	82.829	82.829	82.829	82.829
Total annual expenses	3.098.173	88.351	88.351	88.351	88.351	88.351	88.351	88.351
Total annual disc. expens-es 8%	3.098.173	81.807	75.747	70.136	64.941	60.130	55.676	51.552
Total disc. Expenses	3.965.618							
Cash Inflow in k € discounted at 8%								
Annual MWh production		2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975
Market price 55,21 €/MWh		141.142	130.687	121.007	112.043	103.744	96.059	88.943
Subsidies 122,2 €/MWh + Market Price = 178 €/MWh		453.541	419.946	388.839	360.036	333.366	308.673	285.808
FiT 90 €/MWh		230.081	213.038	197.258	182.646	169.117	156.589	144.990
FiT 105 €/MWh		268.428	248.545	230.134	213.087	197.303	182.688	169.155
Total disc. Cash inflow	Market price	1.496.614	Subs. +MP:	4.809.170	FiT 90€:	2.439.689	Fit 105€:	2.846.304
Market price 55,21 €/MWh								
Cash flow per year	-3.098.173	59.335	54.940	50.871	47.102	43.613	40.383	37.391
Cumulative cash	-3.098.173	-3.038.838	-2.983.897	-2.933.027	-2.885.925	-2.842.311	-2.801.929	-2.764.537
Subsidies 178 €/MWh								
Cash flow per year	-3.098.173	371.735	344.199	318.703	295.095	273.236	252.996	234.256
Cumulative cash	-3.098.173	-2.726.438	-2.382.240	-2.063.537	-1.768.442	-1.495.206	-1.242.210	-1.007.954
FiT 90 €/MWh								
Cash flow per year	-3.098.173	148.275	137.291	127.122	117.705	108.986	100.913	93.438
Cumulative cash	-3.098.173	-2.949.898	-2.812.607	-2.685.486	-2.567.780	-2.458.794	-2.357.881	-2.264.443
FiT 105 €/MWh								
Cash flow per year	-3.098.173	186.621	172.798	159.998	148.146	137.172	127.011	117.603
Cumulative cash	-3.098.173	-2.911.552	-2.738.754	-2.578.756	-2.430.610	-2.293.438	-2.166.426	-2.048.823

London Array Wind Farm, CF 2019-2026

In k €	2020	2021	2022	2023	2024	2025	2026
Cash outflow							
Wind turbine							
Installed cost							
Transmission	5.522	5.522	5.522	5.522	5.522	5.522	5.522
Variability							
O&M	82.829	82.829	82.829	82.829	82.829	82.829	82.829
Total annual expenses	88.351	88.351	88.351	88.351	88.351	88.351	88.351
Total annual disc. expenses 8%	47.733	44.198	40.924	37.892	35.085	32.487	30.080
Total disc. Expenses							

Cash Inflow in k € discounted at 8%							
Annual MWh production	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975
Market price 55,21 €/MWh	82.355	76.255	70.606	65.376	60.533	56.049	51.898
Subsidies 122,2 €/MWh + Market Price = 178 €/MWh	264.637	245.034	226.884	210.077	194.516	180.107	166.766
FiT 90 €/MWh	134.250	124.306	115.098	106.572	98.678	91.368	84.600
FiT 105 €/MWh	156.625	145.023	134.281	124.334	115.124	106.597	98.700
Total disc. Cash inflow							

Market price 55,21 €/MWh							
Cash flow per year	34.622	32.057	29.682	27.484	25.448	23.563	21.818
Cumulative cash	-2.729.916	-2.697.859	-2.668.176	-2.640.692	-2.615.244	-2.591.681	-2.569.864
Subsidies 178 €/MWh							
Cash flow per year	216.904	200.837	185.960	172.185	159.431	147.621	136.686
Cumulative cash	-791.051	-590.214	-404.254	-232.069	-72.638	74.983	211.669
FiT 90 €/MWh							
Cash flow per year	86.517	80.108	74.174	68.680	63.592	58.882	54.520
Cumulative cash	-2.177.926	-2.097.818	-2.023.644	-1.954.964	-1.891.372	-1.832.490	-1.777.969
FiT 105 €/MWh							
Cash flow per year	108.892	100.826	93.357	86.442	80.039	74.110	68.620
Cumulative cash	-1.939.931	-1.839.105	-1.745.748	-1.659.306	-1.579.268	-1.505.158	-1.436.537

London Array Wind Farm, CF 2027-2031

In k €	2027	2028	2029	2030	2031	2032
Cash outflow						
Wind turbine						
Installed cost						
Transmission	5.522	5.522	5.522	5.522	5.522	5.522
Variability						
O&M	82.829	82.829	82.829	82.829	82.829	82.829
Total annual expenses	88.351	88.351	88.351	88.351	88.351	88.351
Total annual disc. expenses 8%	27.852	25.789	23.879	22.110	20.472	18.956
Total disc. Expenses						
Cash Inflow in k € discounted at 8%						
Annual MWh production	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975
Market price 55,21 €/MWh	48.053	44.494	41.198	38.146	35.321	32.704
Subsidies 122,2 €/MWh + Market Price = 177,4 €/MWh	154.413	142.975	132.384	122.578	113.498	105.091
FiT 90 €/MWh	78.334	72.531	67.159	62.184	57.578	53.313
FiT 105 €/MWh	91.389	84.620	78.352	72.548	67.174	62.198
Total disc. Cash inflow						
Market price 55,21 €/MWh						
Cash flow per year	20.201	18.705	17.319	16.037	14.849	13.749
Cumulative cash	-2.549.663	-2.530.958	-2.513.638	-2.497.602	-2.482.753	-2.469.004
Subsidies 178 €/MWh						
Cash flow per year	126.561	117.186	108.506	100.468	93.026	86.135
Cumulative cash	338.230	455.416	563.922	664.390	757.416	843.552
FiT 90 €/MWh						
Cash flow per year	50.482	46.742	43.280	40.074	37.106	34.357
Cumulative cash	-1.727.488	-1.680.745	-1.637.465	-1.597.391	-1.560.286	-1.525.929
FiT 105 €/MWh						
Cash flow per year	63.537	58.831	54.473	50.438	46.702	43.242
Cumulative cash	-1.373.000	-1.314.169	-1.259.696	-1.209.258	-1.162.556	-1.119.314

London Array Wind Farm, NPV, IRR, LCoE, 2012-2022

In k €	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Wind turbine	693.000										
Installed cost	1.512.000										
Transmission	510.780	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522
Variability	35.893										
O&M		82.829	82.829	82.829	82.829	82.829	82.829	82.829	82.829	82.829	82.829
Total expenses	2.751.673	88.351	88.351	88.351	88.351	88.351	88.351	88.351	88.351	88.351	88.351
Discounted total costs 8%	2.753.685	81.807	75.747	70.136	64.941	60.130	55.676	51.552	47.733	44.198	40.924
Total disc. expenses	3.621.130										
Revenue in k € with a discount rate of 8%											
Annual MWh production		2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975
Market price 55,21 €/MWh		141.142	130.687	121.007	112.043	103.744	96.059	88.943	82.355	76.255	70.606
Subsidies 122,2 €/MWh + Market Price = 177,4 €/MWh		453.541	419.946	388.839	360.036	333.366	308.673	285.808	264.637	245.034	226.884
90 €/MWh		230.081	213.038	197.258	182.646	169.117	156.589	144.990	134.250	124.306	115.098
105 €/MWh		268.428	248.545	230.134	213.087	197.303	182.688	169.155	156.625	145.023	134.281
Total disc. Revenue	Market price:	1.496.614	Subsidies+MP:	4.809.170	FiT 90€:	2.439.689	FiT 105€:	2.846.304			
NPV with:	Market price 55,21 €	-2.124.516	Subs. 178 €	1.188.040	FiT 90 €	-1.181.441	FiT 105 €	-774.826			
IRR with:	Market price 55,21 €	-13%	Subs. 178 €	5%	FiT 90 €	-6%	FiT 105 €	-4%			
LCOE in €/MWh	65,58										

London Array Wind Farm, NPV, IRR, LCoE, 2023-2032

In k €	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Wind turbine										
Installed cost										
Transmission	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522
Variability										
O&M	82.829	82.829	82.829	82.829	82.829	82.829	82.829	82.829	82.829	82.829
Total expenses	88.351	88.351	88.351	88.351	88.351	88.351	88.351	88.351	88.351	88.351
Discounted total costs 8%	37.892	35.085	32.487	30.080	27.852	25.789	23.879	22.110	20.472	18.956
Total disc. expenses										

Revenue in k € with a discount rate of 8%										
Annual MWh production	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975	2.760.975
Market price 55,21 €/MWh	65.376	60.533	56.049	51.898	48.053	44.494	41.198	38.146	35.321	32.704
Subsidies 122,2 €/MWh + Market Price = 177,4 €/MWh	210.077	194.516	180.107	166.766	154.413	142.975	132.384	122.578	113.498	105.091
90 €/MWh	106.572	98.678	91.368	84.600	78.334	72.531	67.159	62.184	57.578	53.313
105 €/MWh	124.334	115.124	106.597	98.700	91.389	84.620	78.352	72.548	67.174	62.198
Total disc. Revenue										

London Array Wind Farm, NPV, IRR, LCoE, OFTO Data, 2012-2022

In k €	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Wind turbine	693.000										
Installed cost	1.512.000										
Transmission	510.780	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522	5.522
Variability	35.893										
O&M		89.871	89.871	89.871	89.871	89.871	89.871	89.871	89.871	89.871	89.871
Total costs	2.751.673	95.393	95.393	95.393	95.393	95.393	95.393	95.393	95.393	95.393	95.393
Discounted total costs 8%	2.751.673	88.327	81.784	75.726	70.117	64.923	60.114	55.661	51.538	47.720	44.185
Total disc. Cost	3.688.260										

Revenue in k € with a discount rate of 8%

Annual MWh production		2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705
Market Price 55,21 €/MWh		153.142	141.798	131.294	121.569	112.564	104.226	96.505	89.357	82.738	76.609
OFTO 28 €/MWh		83.707	77.507	71.765	66.449	61.527	56.970	52.750	48.842	45.224	41.874
Total disc. Revenue	Market Price 55,21€	1.623.851	OFTO 28€	887.597							
NPV with:	Market price: 55,21 €	-2.064.409	OFTO 28€	-2.800.663							
IRR with:	Market price: 55,21 €	-13%	OFTO 28€	N/A							
LCOE in €/MWh	61,56										

London Array Wind Farm, NPV, IRR, LCoE, OFTO Data, 2023-2032

In k €	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Wind turbine										
Installed cost										
Transmission	5.522	5.522	5.522	5.522	5.522	5.523	5.524	5.525	5.526	5.527
Variability										
O&M	89.871	89.871	89.871	89.871	89.871	89.871	89.871	89.871	89.871	89.871
Total costs	95.393	95.393	95.393	95.393	95.393	95.394	95.395	95.396	95.397	95.398
Discounted total costs 8%	40.912	37.882	35.076	32.478	30.072	27.845	25.782	23.873	22.105	20.467
Total disc. Cost										
Annual MWh production	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705	2.995.705
Market Price 55,21 €/MWh	70.934	65.680	60.815	56.310	52.139	48.277	44.701	41.389	38.324	35.485
OFTO 28 €/MWh	38.773	35.901	33.241	30.779	28.499	26.388	24.433	22.623	20.948	19.396
Total disc. Revenue										
NPV with:										
IRR with:										
LCOE in €/MWh										

Questions for thesis interviews

Introduction

Present yourself and your company

What is your / your company's role in renewable energy?

Revenue

What is the most efficient pricing system for electricity from clean energy?

Should it be government-lead or subject to free market rules?

Are sustainable energy projects, especially wind power, profitable enough, even without feed-in-tariffs?

Costs

Why are costs in renewable energy higher than other energies?

What is the typical cost of:

-1 onshore wind turbine in € OR €/kW

-1 offshore wind turbine in € OR €/kW

-1solar panel in € OR €/kW

Where do you see most potential for reducing the costs?

Some people suggest that renewable energy should be integrated better into the energy system. Where do you see the main challenges to do so?

Do you think a suitable renewable energy mix is possible, without relying on fossil fuels or nuclear power at all?Sustainability

How sustainable is the production/manufactuting process of a wind mill?

What happens with the material if and when a windmill is taken apart?

Co2 emissions are often part of the LCOE (Levelized Cost Of Energy) calculations, which is an advantage for renewable energies; do you think it is enough for sustainability calculations?

Have you heard of SCOE (Society's Cost Of Energy)? If yes, what do you think of it?

Conclusion

What do you think the potential of renewable energy is?

Can you imagine a future where energy is only produced through renewable energies?

What would your recommendations to investors that are thinking about investing in renewable energies but are not convinced of the profitability compared to other sources of energy be?

Extra Questions

What do you think of the wind farm London Array?

Do you have any further comments on wind power or renewable energies in general?

Thank you for your time.

Interview with Patrik Holm, CTO & founder of Mervento and Chairman of the Board of the Swedish-speaking Association for Wind Power, 13.03.2015, Helsinki.

Introduction

Present yourself and your company: Patrik Holm

What is your / your company's role in renewable energy? Developer and provider of advanced direct drive multi-megawatt wind turbine power plant solutions for both nearshore and offshore applications. (Mervento website)

The long interview was used as a source of argumentation but direct citations have been retrieved from Powerpoint presentations shared by Patrik Holm to the author. As these presentations are too long they are not added to the appendices, but can be required from the author.

Furthermore the recording file of the conducted interview got broken and therefore the author is not able to transcribe the interview (only short notes can be found in this transcript).

Revenue

What is the most efficient pricing system for electricity from clean energy?

Should it be government-lead or subject to free market rules?

Are sustainable energy projects, especially wind power, profitable enough, even without feed-in-tariffs?

Costs

Why are costs in renewable energy higher than other energies?

What is the typical cost of:

-1 onshore wind turbine in € OR €/kW

-1 offshore wind turbine in € OR €/kW

-1 solar panel in € OR €/kW 435 euro per kilowatt (weber)

Where do you see most potential for reducing the costs?

Some people suggest that renewable energy should be integrated better into the energy system. Where do you see the main challenges to do so?

Do you think a suitable renewable energy mix is possible, without relying on fossil fuels or nuclear power at all?

Sustainability

How sustainable is the production/manufacturing process of a windmill?

What happens with the material if and when a windmill is taken apart?

Patrik: Recycling rate of 93,7% for 125 meters rotor blade wind turbines and 91,7% for 90 meters (amount of steal makes the difference)

Co2 emissions are often part of the LCOE (Levelized Cost Of Energy) calculations, which is an advantage for renewable energies; do you think it is enough for sustainability calculations?

Have you heard of SCOE (Society's Cost Of Energy)? If yes, what do you think of it?

Conclusion

What do you think the potential of renewable energy is?

Can you imagine a future where energy is only produced through renewable energies?

Patrik: Yes but not any time soon.

What would your recommendations to investors that are thinking about investing in renewable energies, but are not convinced of the profitability compared to other sources of energy, be?

Extra Questions

What do you think of the wind farm London Array?

Do you have any further comments on wind power or renewable energies in general?

Typical profitability analyses:

IRR/NPV

Pay-back time

Cash flow

Energy industry specific calculation: LCoE

Thank you for your time.

Interview with Alexander Kuhn and Christian von Olnhausen, youmex AG, 10.02.15, Frankfurt-am-Main.

Introduction

Present yourself and your company:

Youmex (email):

- We are a group of financial specialists covering a broad range of financial services

- We simplifie, accelerate and optimize transactions for all classes of capital, i.e. from debt, mezzanine and equity capital all the way to IPOs and the issue of small and mid-cap bonds.

- We focus on bank-alternative or bank-complementary corporate and project financing within the business areas corporate finance, capital markets, clean energy, infrastructure and real estate.

What is your / your company's role in renewable energy?

Youmex (email):

- We structure and arrange bridge, short-term and long-term financing of wind and solar parks as well as biogas, biomass and hydro power throughout Europe for project developers, investors and utilities.

– We also market and place wind and solar power plants – directly or in the form of investments in project companies

Revenue

What is the most efficient pricing system for electricity from clean energy?

Youmex: Aus unserer Sicht haben sich bisher drei Modelle etabliert.

1. Einmal der klassische Feed in Tarif (FiT) über eine bestimmte Frist, meistens über 20 Jahre, also über eine staatlich garantierte Einspeisevergütung (FiT). In den letzten Jahren haben sich die FiT-Levels immer mehr an den Marktpreisen genährt. Beispielsweise im Wind Bereich ist man derzeit bei rund 9 Cent. Wenn man sich die Börsenpreise anguckt Marktpreise ansieht ist da immer noch eine große Differenz, aber auf

dem Preisniveau hat sich das mittlerweile etabliert. Es wird demnächst auch von keiner weiteren Veränderung ausgegangen.

2. Das nächste das kommt sind die Auktionsmodelle, bisher gab es dort noch keine Erfahrung in den klassischen Märkten wie Deutschland, Frankreich, Italien oder UK. Ausschreibungen gibt es bereits in mehreren Ländern.
3. Das dritte Modell ist ein so genanntes Quoten System über Zertifikate, die gewisse Energie Versorger abnehmen müssen um ihre Quote zu erfüllen. Das bedeutet, dass die Energie Versorger eine bestimmte Menge an Zertifikaten einkaufen müssen, z.B. UK und Polen. In Polen wechselt allerdings zum Ende des Jahres das System zu Auktionsmodellen. Die Klimaziele werden von der EU festgelegt bis 2020, aber das wurde auch nochmal im letzten Jahr geändert.

Das effizienteste Modell ist eine Kombination aus dem Basispreis für die Stromabnahmen und Subventionen für den Strom von Zertifikaten oder einen Aufschlag. So kann man steuern, dass es rentabel genug ist im Wind- und Solarbereich und es trotzdem nicht zu einer Überforderung kommt. Der Marktpreis ist darin enthalten und dann werden zusätzlich Verträge abgeschlossen. UK ist da ein ganz guter Markt für, mit verschiedenen Energie Versorgern und Abnehmern. Das effizienteste Modell ist also ein Quotenmodell, z.B. ROCs (Renewable Obligation Certificates), oder einen festen FiT.

Das Problem mit FiT war schon immer die Diskrepanz zwischen Marktpreisen und staatlichen Vergütungspreisen. Daher ist so ein Zertifikaten-Modell, mit dem sich an der Börse ein Strompreis bilden kann, effizienter. Polen hat aufgrund verschiedener Gründe einen sehr niedrigeren Strompreis durch das Quotensystem, aber UK hat gezeigt, dass so ein Quotensystem auch gut funktionieren kann. Dazu hat UK mittlerweile Deutschland überholt, an im letzten Jahr dazu installierter Kapazität. Mit dem System müssen die Investoren mit flexiblen Marktpreisen umgehen können und gucken wie sie das Risiko abgesichert bekommen. Da gibt es auch Möglichkeiten, wie ein so genanntes PPA (Power Purchase Agreement). In dem Fall, nimmt ein Stromversorger den Strom ab und mit seiner Bonität sichert er einen gewissen Mindestpreis zu. Aber es wird komplexer. Denn am einfachsten für einen Investor ist es, mit einer festen Einspeisevergütung über 20 Jahre. Darüber werden dann die Cash Flows ausgerechnet. Mit dem Auktionssystem / Zertifikaten Modell muss man vorne herein investieren (für den Windpark oder Solarpark) und weiß nicht, was hinten heraus kommt.

Mit dem Zertifikaten-Modell sind es also zwei Komponenten: die eine festgesetzte subventionierte und dann die schwankende Marktpreis-Komponente. Mittlerweile können Investoren das relativ gut vorhersehen. Dazu sind auch noch die Zinsen herunter gegangen und damit hat man ein bisschen mehr Spielraum oder eine gewisse Marge. Bei so einem Auktionssystem ist es relativ teuer mit vorne einzusteigen, um bei dieser Auktion mitzumachen zu können. Danach wird der Zuschlag gegeben und dann kann eigentlich erst mit dem Bau und mit der Finanzierung gestartet werden. Kritik daran ist, dass es die größeren Energie-Konzerne fördert, da kleinere oder mittelständige Unternehmen bei diesen Auktionen nicht leicht mitmachen können. Wenn sie mitmachen können, kann es auch sein, dass sie einen schlechten Zuschlag bekommen und deswegen ihren Windpark dann nicht mehr geregelt bekommen oder es ist nicht mehr kostendeckend. Es kostet relativ viel Kapital um so ein Projekt baufertig zu bekommen und um bei so einer Auktion mitmachen zu können. Das ist gut, denn es werden die Projekte gefördert, die am günstigsten gebaut werden können. Aber es drängt dann kleinere Unternehmen aus dem Markt. Es war in der Energieindustrie vorher so und durch die neuen Energien hatte sich das grundlegend geändert, dass kleinere Unternehmen mitwirken konnten.

Youmex (email):

There are four main categories of pricing systems:

1. *Price Based Incentives: FiTs (and net metering)*

2. *Quantity Based Incentived or Quota Obligations: Renewable Portfolio Standards/Renewable Energy Certificates, and Competitive Procurement (auctions)*

3. *Fiscal and Financial Incentives: Tax credits, government subsidies and loan guarantees*

4. *Voluntary measures*

Should it be government-lead or subject to free market rules? Are sustainable energy projects, especially wind power, profitable enough, even without feed-in-tariffs?

Youmex: Es muss geregelt werden, denn der Strompreis ist kein freier Markt. Jetzt mit dem System ist man darauf angewiesen, Strom in das Netz einzuspeisen und das Stromnetz gehört jemanden. Die Person, der das Stromnetz gehört, muss nicht für den Strom zahlen, denn es macht wahrscheinlich sein eigenes Geschäft kaputt.

Die FiT-Levels waren sehr hoch, denn man wollte die Technik in Gang setzen und sie wirtschaftlich machen, dadurch gibt es jetzt ganz viele Produzenten die beispielsweise Solarmodule herstellen. Aufgrund der technischen Entwicklung gehen die Preise herunter. Dadurch haben sich die pro-Kilowatt oder pro-Megawatt-Kosten stark reduziert. Damit kann Strom durch erneuerbare Energien günstiger produziert werden. In Windkraft kommt es weniger von der Kostenreduzierung her, da der technische Fortschritt niedriger ist als bei Solaranlagen. Aber auch da werden die Windkraft-Rotoren immer größer und länger und drehen sich schneller oder mehr und deshalb ist die

Technologie effizienter und es wird mehr Strom erzeugt. Auch bei schwächerem Wind, weil sie eine größere Fläche haben, die den Wind auffangen. Das sehen wir auch aktuell hier in Deutschland, wo neuere Windparks deutlich mehr Ertrag erzielen. In Solar hat auch eine Entwicklung stattgefunden: im Moment werden für 7,5 Cent pro Kilowatt-Stunde Anlagen gebaut. Und damit hat man auch eine Grid Parity erreicht, vielleicht nicht jetzt bei den aktuellen Strompreisen aber bei normalen Strompreisen auf jeden Fall.

Costs

Why are costs in renewable energy higher than other energies?

Youmex: Es gibt diese Anschlusskosten. Es gibt diese Hochspannungsleitungen, die über längere Strecken gehen. Da muss ein Transformer gebaut werden und so ein Spannwerk kostet eventuell 12 Millionen. Es ist viel Kapital, das eingesetzt werden muss. Man kann aber nicht sagen wie hoch die Anschlusskosten sind, denn die sind von Projekt zu Projekt unterschiedlich; es kommt auch auf die verschiedenen Energieversorger an. Es geht allerdings nicht nur um Kosten, es geht auch darum, wenn das Netz überlastet ist, dann kann einfach kein weiteres Projekt mehr angeschlossen werden. Das Problem ist auch, dass die Spannung anders ist und meistens ist das Netz so gebaut, dass es um Stromverteilung geht und nicht um Stromeinspeisung. Dann muss das Netz geändert werden. Als die Infrastruktur vor 20–30 Jahren errichtet wurde, hat keiner daran gedacht, dass da auch Strom hereingehen könnte, sondern nur dass der Strom verteilt wird. In Deutschland haben wir zum Beispiel den Strom aus windstarken Staaten, wie den Nordbundesländern, nach Süden zu schaffen. Es ist schon lange eine Diskussion eine Nord-Süd-Spannung zu errichten. So ein Projekt, das durch mehrere Länder geht, ist kompliziert und bisher ist nicht viel daran gemacht worden. So eine große Spannungsleitung sieht auch nicht gut aus und es will sie keiner in der Nähe haben.

Deutschland hat eine ganz gute Ausgangssituation. Andere Länder haben da noch ältere Leitungen, das steigert natürlich auch die Projektkosten. Und wiederum auch die Erzeugungskosten.

Onshore ist schon seit 30 Jahren etabliert, im offshore-Bereich ist noch alles sehr neu. Den Offshore-Bereich muss man auch noch mal differenzieren: zum Beispiel in den UK machen die das relativ intelligent, weil, sie bauen Nearshore-Projekte, die nah an der Küste sind. Dadurch ist es technisch noch beherrschbar. Mit onshore-Windmühlen muss man immer gucken, wo man sie rechtlich bauen kann. Das ist dann einfacher mit offshore-Wind-Parks. In Deutschland werden die meisten Projekte 20 km vor der Küste gebaut, das sind andere Tiefen und es kostet mehr. Es gibt offshore-Wind-Parks, die bis zu 100 km von der Küste entfernt gebaut werden, damit man sie von der

Küste aus nicht sieht. In Deutschland sind es also Tiefen von 20–30 m und in den UK sind es ungefähr 10–15 m und dadurch ist es viel leichter dort.

Dadurch dass offshore eine neuere Technologie ist, sind Wartungskosten höher. Zum Beispiel wenn irgendwo eine Schraube abfällt, ist es ein großer Aufwand im Vergleich zu onshore-Windparks. Es müssen auch erst mal Mitarbeiter ausgebildet werden, es ist also viel wartungsintensiver. Windmühlen-Rotoren sind rotierende Teile und da kann immer mal was kaputt gehen. Es ist bei onshore schnell behoben aber auf hoher See ist es komplexer. Offshore-Windmühlen sind meistens auch im Salzwasser, was extrem aggressiv ist, weil es auch in der Luft ist und sich zwangsläufig auf die Technik auswirkt.

Was wir jetzt beobachten, weil wir immer die Projekte nach den Ertragskennzahlen rechnen ist, dass da auch die Herstellungskosten, die laufenden Kosten, aber auch die Finanzierungsmöglichkeiten einfließen und da gibt es wieder das langfristiges Risiko. Es ist also einfacher einen onshore-Park günstiger und länger finanziert zu bekommen als einen offshore-Park. Der Kapitalgeber rechnet natürlich mit ein, dass das Risiko höher ist und dadurch gibt es auch einen höheren Zinssatz. Dem gegenüber steht ein höherer Betrag, da auf der See höhere Windgeschwindigkeiten sind. Was wir jetzt auch beobachten ist, dass Windanlagen effizienter werden, durch höhere Türme und breitere Rotoren und dadurch können heutzutage onshore-Wind-Anlagen genauso viel Ertrag produzieren wie auch offshore-Anlagen vor fünf Jahren. Allerdings sind sie günstiger im Betrieb und auch leichter zu finanzieren. Deshalb sind sie flexibler und dadurch gibt es im onshore-Bereich mehr mittelständige Betreiber und im Kontrast dazu ist der Offshore-Bereich ein Konzerngeschäft. Von den Erzeugungskosten ist der offshore-Bereich die teuerste Variante.

Es gibt zwar schon Deutsche offshore-Wind-Parks aber die wurden noch mit dem alten Vergütungslevel finanziert, der damals 0,19 € war. Mittlerweile sind es nur noch 9 Cent im Onshore-Bereich jedenfalls. Es ist also fast das Doppelte an Förderung und dementsprechend kosten die offshore-Parks auch mehr und deshalb ist wahrscheinlich offshore nicht die intelligenteste Energiequelle. Onshore ist auf jeden Fall besser, denn in den letzten Jahren sind viele große Fortschritte entwickelt worden, was die Ausbeute und Effizienz angeht. Die Windkraft-Branche (Developer und Investoren) ist relativ konservativ, es steckt zum Beispiel viel institutionelles Geld in der Industrie und die Projektfinanzierung wird konservativ gerechnet.

What is the typical cost of:

-1 onshore wind turbine in € OR €/kW:

youmex (email):

Costs vary depending on the scale and manufacturer: - between € 1.5 m - € 2.5 m

-1 offshore wind turbine in € OR €/kW

-1solar panel in € OR €/kW

youmex (email):

– Costs vary depending on the type (thin-film modules or monocrystalline solar modules), origin (country) and efficiency
– Between 450 €/kWp – 620 €/kWp

Where do you see most potential for reducing the costs?

youmex (email):

Solar power: elimination of import duties (within the EU the module prices stagnate slightly above the 50 Cent/Wp mark; outside the EU projects are realized in the lower 40 Cent/Wp area)

Some people suggest that renewable energy should be integrated better into the energy system. Where do you see the main challenges to do so?

youmex (email):

Requires large initial investments to build infrastructure
Prospecting: developers must find publicly acceptable sites with good resources and with access to transmission lines. Potential wind sites can require several years of monitoring to determine whether they are suitable.
Permissions: renewables often involve new types of issues and ecosystem impacts. And standards are still in the process of development.
Marketing: Public education will be a critical part of a fully functioning market if renewables are to succeed.

Sustainability

How sustainable is the production/manufacturing process of a wind mill?

What happens with the material if and when a windmill is taken apart?

youmex (email):

Often dismantled windmills are sold to the former CIS states but the scrap can also flows melted back into the cycle of steel production. Generator and gearbox often end up as a spare part depot and are exploited. Concrete rubble is transformed into road metal. Rotor blades based on fiber optics are shredded and burned in a special cement plant. Thus, the high calorific value is used for the energy-intensive cement production. The ash is added to the cement as an additive.

But there are only few windmill in practice which are recycled because There is no stable market for used windmills so far, even for old models with less than 1MW

Co2 emissions are often part of the LCOE (Levelized Cost Of Energy) calculations, which is an advantage for renewable energies; do you think it is enough for sustainability calculations?

Have you heard of SCOE (Society's Cost Of Energy)? If yes, what do you think of it?

Conclusion

What do you think the potential of renewable energy is?

Can you imagine a future where energy is only produced through renewable energies?

Youmex: Es entstehen immer mehr Projekte, aber große Projekte werden nicht mehr so begünstigt. Das Geld ist im Moment da: die Investoren suchen zur Zeit nach Investments, auch immer mehr im Ausland und in Entwicklungsländern.

Technisch ist es möglich, wenn man die Netzte sehr intelligent betreibt. Das kann nicht im engeren Umkreis gemacht werden, denn es gibt selten Standorte, wo beides, Solar- und Windkraft vorhanden sind. Aber man kann es jetzt schon über das Netz steuern und das machen schon viele. Gerade Stadtwerke sind da in der Forschungsphase und haben erfolgreiche Projekte. Es wird also in kleineren Volumen schon gemacht, aber großvolumig muss da noch eine Entwicklung stattfinden. Biogasprojekte werden in Deutschland kaum mehr gefördert und so viel Kapazität gibt es auch nicht.

Das Problem, wenn wir zum Beispiel 70 % unseres Stroms aus Windkraft und Solarkraft bekommen, ist das, wenn mal weder Wind weht noch die Sonne scheint, man 70 % der Energie aus anderen Energiequellen erzeugen muss. Es gibt also zwei Seiten: einmal muss mehr Strom erzeugt werden und einmal muss weniger Strom verbraucht werden. Deshalb muss eine Entwicklung in der Effizienz unseres Stromverbrauchs stattfinden, zum Beispiel energieeffiziente Häuser.

Wichtig ist die Speicherung von Energie. Es kann jetzt als Backup zum Beispiel Speicherkraft benutzt werden. Gäbe es allerdings leistungsstarke Batterien, die den überschüssigen Strom aufnehmen können, würde man sie (Backup-Energien) brauchen.

Youmex (email): At the moment one disadvantage with renewable energy is that it is difficult to generate the quantities of electricity that are as large as those produced by traditional fossil fuel generators. This may mean that we need to reduce the amount of energy we use or simply build more energy facilities. It also indicates that at the present situation the best solution to our energy problems may be to have a balance of many different power sources.

What would your recommendations to investors that are thinking about investing in renewable energies but are not convinced of the profitability compared to other sources of energy be?

Youmex (email):

Returns are higher than i.e. returns of standard cash savings accounts (although the risk is higher in RE investments)
Wind and sun are pretty much constant therefore the blow of the wind and daylight from the sun is pretty much predictable
Low risk of technology failing
Inflation-beating
Impact on local communities
Impact on energy security
Impact on the planet
Transparency of your investment

Extra Questions

What do you think of the wind farm London Array?

Do you have any further comments on wind power or renewable energies in general?

Thank you for your time.

Interview with Anders Stenberg, WPD Oy, 09.03.15, Helsinki.

Introduction

Present yourself and your company: Anders Stenberg, WPD Oy, a Germany-based company, with around 1000 employees over Europe, of which 10 are in Finland.

What is your / your company's role in renewable energy? Implementing onshore & offshore wind power projects (488MW wind turbines were connected to the grid in Finland in the end of 2013, 33 MW of wind power are to be connected to the grid by the end of 2014) (WDP website)

Revenue

What is the most efficient pricing system for electricity from clean energy?

Stenberg: I know the Feed-in-Tariff system well, because we have it in Finland and I'm also in charge, for WPD, of the application for the FiTs, so I'm all the time in contact with the energy authorities and dealing with their "satu" program. When you do an application, you fill in all the information via Satu and then the energy authority looks at it, and if they accept it then it's okay, but if some information is missing then they send it back to the developer and we update it and so on. But there are several phases in the application; I think it's up to nine phases. So you start more or less when you know you have a project and then you have to announce it to the authority, that you will build this. […]

But FiT as a whole, as a system, I think it's a really good, let's say way of financing clean energy, especially wind energy, also solar, but because wind energy is fluctuating so much. But if you have a FiT then you have a certain level and you can count on that and make the profitability calculations on that and you know exactly what it will lead to, in a bigger perspective. So that's a positive side. It's easier to talk to the banks, because the banks want to have some calculations and figures and so on, so if you have a FiT, then it's good to put those [FiT] papers on the table and say that you are following this.

In Sweden, they have this certificate system, but that price also weights the same as the electricity price, so at the moment they are quite low, both of them, which is not good of course, from the financing perspective. So this [FiT] gives certainty but there are also problems with it, especially now when they have this high level of the FiT, which has lead to this so-called "Gold Rush". A lot of projects are really in a hurry to get done, finalized and accepted in the FiT so they can take the FiT.

[…] In Finland it's only FiTs at the moment, but it's a question mark what happens in the future.

Author: So if you apply for a FiT but you don't get it, what happens then? How do you sell your energy?

Stenberg: Well, you can sell on the market. But everyone wants the FiT.

Author: How much higher is [the price level] to the electricity prices?

Stenberg: It's 105€/MWh, that's the higher FiT but by the end of this year [2015], it will go down to 83,5€/MWh. But if you are going to apply for the FiT, well the energy authorities have guidelines of what should be followed, technically, economically, and everything, So every developer should follow these guidelines and plan in the way that it will be accepted for the FiT.

This is the situation at the moment [shows a file]. 2500 MW will be accepted in the FiT system in Finland, so at the moment these are in the system, so it's 836 MW and these are in the process of getting accepted, so at the moment it's a little bit over 1000 MW, currently. The goal is a political target set by the "20-20 goals", but it's not limited in time, so when the amount is reached then it's reached. I think the Finnish wind power association has estimated that it will be reached in 2017 or 2018, something like that. But these are the biggest question marks, what happens after these 2500 MW? And it's hard to plan and nobody knows what the system will look like. This system is, I would say, finished then. I can't see that they will continue it in this way, so some changes will come. What are the changes and what does it mean money wise, that's a big question. But this is also a question that now almost half of it [the 2500 MW] is used but that also means that we have almost come to the point that it's a question mark whether you can start in the green field anymore. Can you start a project and go into the Fit? Because time-wise it will not manage to be built and there are so many projects out there. So a lot of these projects will not manage to get in anyway. […]

All this [showing on the map] should be built in the very near future, so here you get a rough estimation of the amount: about 500 MW should be built in the next year, so if you compare that to the FiT level, which is 2500 MW, it goes quite fast. Preparing for construction is 200 MW more, so if you take also applying for permits, so take the first three levels, then you almost have the FiT filled. You have like 400/500 MW, which will not be in the FiT, so that's the big issue. Politically, I think it would be a disaster if the FiT of 2500 MW will be reached and nothing else happens, because then they would kill off the projects and lose quite a lot of information and experience because then they would be are not going forward and the people that work with the project will of course move to other companies and maybe in other segments of the business and so on. So if the wind power should be continued in Finland, if the politicians agree on that, they have to find a solution to that, so we can continue the building of the wind power.

Stenberg (email):

Feed-in is a good way, but in Finland the decision came too early as the regulation of the rules and laws regarding the planning of wind farms were not on place at the time, for example how to define and measure turbine noise emissions. Also the higher tariff until 2015 has developed a gold-rush type of project planning; it is not necessarily the best projects that are in the FiT but the fastest ones.

Should it be government-lead or subject to free market rules?

Stenberg (email):

In my point of view, the big target should be that it would follow the free market rules, but as we are not there yet a government-lead is good. This is more predictable and easier to plan and calculate for project developers, banks and the government itself.

Are sustainable energy projects, especially wind power, profitable enough, even without feed-in-tariffs?

Stenberg: It is difficult in that way because it might be profitable, if you have a really good wind, for example in the Åland islands, it might be profitable, but then on the other hand the risks are too high so banks will never give you the financial support to build it. But if you have a FiT, then the banks can see that you will manage this. But let's say in Åland, there are six turbines, which are on the island, on the very southern part of Åland. [...]

This is the situation in Åland, because if you look at the wind speed, the average wind speed is, on a random dot on the wind map, is 9m/s and if you have that kind of wind then it might be possible to get profitable wind power project, without FiT. But well Åland is then a different topic because they are not in the FiT system at the moment, so they have been struggling quite a lotto get in to the FiT, so that's the reason why there are no projects going further there at the moment. They are part of Finland, but it's a political issue, because they have their own kind of government and they have their own tax system and this kind of thing. […] But they have more or less 3-4 projects ready to go so as soon as they have financing on FiT base, so it will be interesting to see if they are able to build in time and so on.

So that's the situation with Åland, where wind speeds are more than 9m/s on an annual average. But if you go inside of Finland, inland, then it's like 6m/s and then you have quite a difficult situation so then no bank would finance that kind of project without FiT system at the moment. The risks are too high, but actually the electricity price is too low to go on that. But also the lifetime of a wind project is 20-30 years, so what is the electricity price let's say in 15, 20 years? It's almost like guessing the gas price; it is really difficult to make a calculation, without any like levels to go on. In that way I would say that FiT is a great way from the financing perspective.

But I’m not that familiar with the FiT in Germany but at least in Finland the situation was that 2011 the FiT level was fixed, 2500 MW and euro level 83,5€/MWh with the higher FiT then until 2015. But then afterwards when everyone started projects and the project development got really fast, then a lot of other problems came. One big issue is the noise, the noise levels have been discussed for years, many many years: should it be 40 decibels, should it be 45 should it be 35 decibels? Should it be for summer cottages, should it be for all houses, how should it be taken into account into this project development?

Author: That’s why maybe sometimes offshore is better because it is off the coast.

Stenberg: Yes, in that sense yes, but then the offshore have higher cost and there are other problems on that side. But if we look at the FiT so we have the noise problems, and also environmental problems, everything is not decided yet how it should be, let’s say eagles in Finland, which could be a project killer, if somewhere an eagle would build a nest then it could be that the projects has to be killed and so on. These things in my opinion should have been sorted out before you put the level / the goal of the FiT. How much should we build in 2020, because if you put that one then we should have 2500 MW but then we can’t build any because we have the decibel’s, we have the military defence, we have so many no-areas in Finland, so it’s actually really difficult to build. If you take Finland and you take a dot, and you tke within a couple of kilometers, you will find one summer cottage, it’s so interesting because there is a lot of space but the summer cottages are all over the country. That has been more or less what all the developers have been doing, this kind of mapping: taking out the no-areas and then they look at the projects. […]

Stenberg (email):

Depending on the site and the project. But as the electricity price is low at the moment and the risks therefor are high, the financing of a project without FIT is really difficult. The FIT gives the project security for the different parties in the process.

Costs

Why are costs in renewable energy higher than other energies?

Stenberg: This is an interesting question about costs in renewable energy are higher than other energies, because in my opinion that might not be true.

Author: Yeah I realized that at my first interview, but why is there not more of clean energy power plants then?

Stenberg: Well you can divide that into many things but one is that other energies get also money but not in a FiT form, but they get tax reduces, other kind of sources of money and another thing is…

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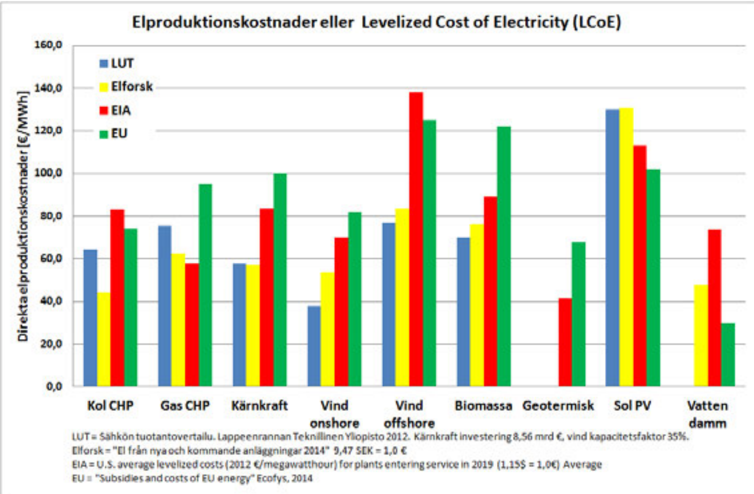


Typical cost of:

	Onshore	Near shore	Offshore	Offshore
Wind speed class	III	II	II	I
Annual atverage wind speed	6,5 – 7,5 m/s	7,5 – 8,5 m/s	7,5 – 8,5 m/s	8,5 – 10,0 m/s
Capacity factor	30 – 40 %	35 – 45 %	45 – 55 %	45 – 60 %
Rotor diameters	90 – 120 m	100 – 120 m	100 – 120 m	115 – 170 m
Nominal turbine power	1,5 – 3,0 MW	3,0 – 4,0 MW	3,0 – 4,0 MW	5,0 – 7,0 MW
Wind power plant cost	1,2 – 1,8 M€/MW	1,4 – 2,0 M€/MW	2,0 – 3,0 M€/MW	3,0 – 4,5 M€/MW

Vindkraftföreningen rf

Where do you see most potential for reducing the costs?

Stenberg (email):

- Planning! There are a lot of things that can go wrong in a wind project, so in order to minimizing the risks the planning should be done with care. Layouting, wind measurements, economical calculations, choosing the right turbine type for the site, good co-operation with authorities and the local people, soil studies etc.

- But on the other hand, there are also such things that cannot be planned, eg. changing of regulations and rules, unexpected nature observations and so on.

Some people suggest that renewable energy should be integrated better into the energy system. Where do you see the main challenges to do so?

Stenberg (email):

The electricity produced by wind energy is fed into the grid and sold on the electricity market, as all other sources of electricity.

Do you think a suitable renewable energy mix is possible, without relying on fossil fuels or nuclear power at all?

Stenberg (email):

Technically yes, but as this is a political question the realization can be difficult and will need time. Opinions are already that Sweden could do this. [Vindögat 2-2013, sid 16] Nuclear seems not to be as cheap as earlier assumed, and the existing nuclear in Sweden is going to its end. It might be cheaper to invest in wind and renewables compared to nuclear and fossils.

Sustainability

How sustainable is the production/manufacturing process of a windmill?

Stenberg (Email):

-The amount of energy used to build a wind turbine is produced again within 6-10 months.

What happens with the material if and when a windmill is taken apart?

Stenberg (email):

-The material in a wind turbine is worth money and is therefore mostly recycled or sold.

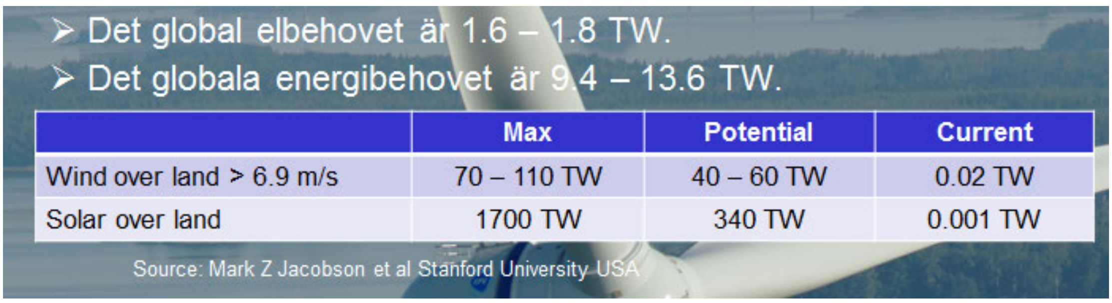
Conclusion

What do you think the potential of renewable energy is?

Can you imagine a future where energy is only produced through renewable energies?

Stenberg (emai):

The potential of renewable energy is huge and we can definitely produce the energy needed with only renewables. The figures below demonstrate this, as the current used is only a fraction of the potential.



- Det global elbehovet är 1.6 – 1.8 TW.
- Det globala energibehovet är 9.4 – 13.6 TW.

	Max	Potential	Current
Wind over land > 6.9 m/s	70 – 110 TW	40 – 60 TW	0.02 TW
Solar over land	1700 TW	340 TW	0.001 TW

Source: Mark Z Jacobson et al Stanford University USA

-

Interview with Erkka Rinne, VTT Technical Research Centre of Finland, 10.03.15, Espoo.

Introduction

Present yourself and your company: Erkka Rinne, VTT Technical Research Centre of Finland

What is your / your company's role in renewable energy? Smart energy and integration system in the wind power team. Basically we do a bit more long-term research on energy systems and also some contract research.

Revenue

What is the most efficient pricing system for electricity from clean energy?

Rinne: There are Feed-in-Tariffs right now in Finland, but I do not think it is the best system. In my opinion, if you are actually heading for the clean, which is maybe less CO2, you probably should stress the meaning of less CO2 in your pricing system, so that would mean a better CO2 trading system.

It might be that that could be a better option, because it is more flexible. We have seen that, because the FiTs were decided a few years ago, it is pretty good but it is still quite inflexible. Because those prices and the quotas were set already few years back and now the technology has advanced, so now actually they are making much more energy with less investments and that is costing a lot of money for the taxpayers.

For example, we made a quick calculation with my colleague this morning: if you did not have the FiTs, then probably the electricity prices would be a bit higher. What do you think? If you introduce a FiT would the prices go up or down?

Author: But the FiTs are higher than the actual prices, right?

Rinne: But how do you think it would affect the actual price?

Author: I do not know, I have not thought about it…

Rinne: Basically it will lower the prices, because there is more capacity with a very low cost in the market and they can offer cheap electricity but their costs are still covered by the FiT. So basically a FiT will lower the market price for electricity.

Author: It is pretty low right now.

Rinne: It is pretty low right now. But if we would not have introduced the FiT then prices would probably be a bit higher and then the wind power producers would actually also make profit. I mean it is pretty complicated but by doing a quick pre-calculation, you could figure out that “was the FiT really helpful?” Because if it was not there, then the prices would be higher and the producers would…

Author: But do you think they would be as many wind power plants as there is?

Rinne: Probably not.

Author: Because what I have heard so far is that the FiT basically just gives you, well it takes away the volatility of the prices so basically, there is investments just because it is backed-up by the government and therefore banks even invest in it, otherwise they would not, because it is too risky.

Rinne: That is definitely true. Even in Finland we have seen a lot of new instalments just because of the (FiT) policy.

Author: Yes, so I just think that if there was no FiTs maybe it would affect the price but it would also affect the fact that there just would not be that much wind power, or solar power for that matter.

Rinne: Basically that is right yes. But there is still a connection between the tariff being there and the price, which goes down, because of the tariff.

But you will probably know that the emission trading system is not really functioning very well because the prices are so low. […] I think the price is way too low for a real effect, and that is because of many things. For example there were too many allowances given free and so on and so on. But I think if that would be really functioning that would probably be the best thing to cut CO2 prices because that is what it is for. And because it is market based, it is basically more flexible to the change of technology because it is trying to find the optimum, always the best technology will be chosen, or the worst technology generating most CO2 will be thrown out of the market.

But anyway, the FiT is there but there is a deadline. It (the current system) will end some day and then something new will probably be installed. But as a definitive answer, I do not know. It depends what we want (and) what the definition of “clean” (energy) is. If you think clean is less CO2, then the CO2 emission trading would be the best. And if you want wind power then, wind power FiT is what you want.

Should it be government-lead or subject to free market rules?

Rinne: I think we still need some government lead stuff. Nothing really happens if there is just the free market. The free market needs some constraints from governments.

Are sustainable energy projects, especially wind power, profitable enough, even without feed-in-tariffs?

Rinne: I think that they are starting to be. Especially wind turbines, their rotor diameter is growing by the year, the towers are getting higher and higher, so they are producing more and more energy and the capacity factor is increasing, it's around 35%, the highest by today. So it's getting better and better. So I think so, but then again, it depends on the technology. It's going forward everyday or at least every year, so I think it will be.

Costs

Why are costs in renewable energy higher than other energies?

Rinne: I was able to get a number for onshore wind turbines from my colleague, he said something like EUR 1,2 million / MW, roughly. And that would be for one turbine but you do not usually build one turbine, you build a park, you built a farm, say 10 or 15 turbines, so that might be something less. The cost is for the whole thing (including transportation, support structure etc.). And of course the transportation (cost) is much less if you build a whole site.

But to answer why it is more expensive, basically it is so new. Coal power plants were invented something like 200 years ago. […]

Of course it is (more expensive than other energy sources). If something has been there for 200 years, then of course it is cheaper: in the economy and the society, the way things are built, everything is built on fossil fuels. Say we have this kind of gas/petrol station network over the whole country, but we only have a handful of natural gas stations. There is one in Helsinki and on in Tampere I think. You need this kind of infrastructure for the economy to run. I was trying to find information on how the fossil fuel subsidies are. […] And in addition to that, I think the way things are built, for instance the petrol station network, they are there and it would be a huge cost to install electric vehicle loading stations every 200 km.

I think it applies to any technology that over time they get cheaper and cheaper. Those renewable technologies are now getting cheaper and cheaper. I do not think we have reached their minimum cost yet. But we will get there.

What is the typical cost of:

-1 onshore wind turbine in € OR €/kW 1,2million MW

-1 offshore wind turbine in € OR €/kW

-1solar panel in € OR €/kW

Where do you see most potential for reducing the costs?

Rinne: Probably not the implementation, because it needs work and human resource are expensive, especially in Finland. So probably the material and how it is used and probably the power electronics and so on. For example if you think of solar panels, they are getting cheaper. I think it has a lot to do with the materials and the efficiency.

It also has something to do with the easiness of access and of how you can out up thing, for example in Germany, they set it up so that you can put up your own solar panel and you can feed power into the grid and get some revenue. That (system) kind of exploded in Germany and now they are producing lots of solar power.

[…]

If the subsidies are getting lower, [the clean energy companies] will probably figure out something new and make their costs lower and it's kind of a cat-and-mouse game between the subsidies and the costs.

Some people suggest that renewable energy should be integrated better into the energy system. Where do you see the main challenges to do so?

Rinne: Basically, that is what I do with my colleagues. We model energy systems and power markets, taken into account the increased variability and uncertainty that for example wind and solar power bring, because you really cannot predict them with 100% accuracy. So you have to have some kind of increased flexibility in the system. There are several options in increasing that. Of course there has been variability before, you cannot forecast load exactly. Producers have to guess how much they will be load on a given hour in beforehand because they have to commit their plans on certain generation levels. If you introduce something like 10 or 20% wind power, then they will be this additional component of variability, coming from the wind forecasts. Also forecasting is getting better and better, but still you need to have some kind of increased flexibility in the power system. That could be something like storages or more flexible thermal units that can go to a lower minimum load and they can go up and down, so adjust their output level more easily, or some kind of demand flexibility, demand-side management or demand response, or similar. I think tackling this kind of flexibility issues would… Now the main challenge is on the power system level. It should be figured out which kind of investments would be the best to accompany large amounts of variable generation, be it wind or solar power.

Natural gas turbines are quite cheap to build and they can be brought online very quickly and they also have a flexible output level. They are the clean end of the fossil fuels. And then there is also another thing with gas would be to store excess electricity as gas. It's called power to gas. Say you had excess electricity because of high wind, or solar power, and you did not have enough demand, you can use that electricity to produce natural gas or methane, from coal and hydrogen. That is not the quite thorough definition, but you are using the storage capacity of the gas network itself, if you pump the gas into the network and then you can use that gas again to produce electricity when it is needed.

I cannot say if it is the best (solution), but I think it is very important in the future. We are currently making a proposal for a EU project. In the project we do a modelling system, which includes power, heat and gas as the main energy carriers. If you think of that, it is one of the most important ones. One of the good things is that it can be distributed by (only one same) network, all three of them.

And you can also store electricity as heat of course, maybe to produce again some electricity or to serve someone that wants just heat.

Do you think a suitable renewable energy mix is possible, without relying on fossil fuels or nuclear power at all?

Rinne: Just wind is not good. If you could store the wind power somehow, that is a very big question right now, because energy storage is not very cheap, not yet. But if somebody would somehow invent how to store energy cheaply that would be the end of my work. Solar and batteries would be the answer for Southern Europe and wind and batteries would be the answer for Northern Europe.

But because the battery technology is not yet there, probably we need something else to back-up the variable generation. The main thing here is that the whole mix has to be optimized: what kind of components is there. For example there is the wind and solar power that give us less CO2 and then some flexibility measures, as what I said earlier, this demand side or thermal generation. And maybe some of the base loads. I wouldn't say nuclear is totally useless but at least from an investment point of view it's very interesting still.

[…] Somehow it's getting too complicated, the investments are huge units compared to wind power, which is very flexible to build u because you can build smaller units.

Bottom line, the mix needs to be optimized, it's not just adding wind power to the generation mix. We should optimize and look at how many components we have in the energy mix.

Sustainability

How sustainable is the production/manufacturing process of a windmill?

What happens with the material if and when a windmill is taken apart?

Rinne: That is a very interesting question. I was able to find a report by Vestas. You might be interested into looking into that. I just went through the conclusion (of the report) and they said that the lifetime costs are hardly noticeable compared to other energy generation technologies in Europe. The report was form 2006, so it's quite old already. […]

Also I have heard that in Finland They have bought old wind turbines from Germany and re-erected them. So it's also possible t sell the wind turbine as an old wind turbine. […] So by the end of the lifetime you can probably quite easily recycle the metal and etc. And there is not kind of accumulating waste such as ashes, or nuclear waste or anything. There is not that issue at least. […]

I just had a discussion with my colleagues about this water use of different technologies. I think wind was one of the only technologies that do not rely on any water use. For example hydropower, that's also renewable but then you need a lot of water and in some places in the world that might be an issue. I think that the water issue has to be considered in the future and also, say developing countries, of which unfortunately many are in areas that lack water. If you want to put some kind of renewable energies in those places you have to think of how much water it uses.

Co2 emissions are often part of the LCOE (Levelized Cost Of Energy) calculations, which is an advantage for renewable energies; do you think it is enough for sustainability calculations?

Rinne: You can define sustainable as in renewable, or is it clean (as in no carbon dioxide emissions) or everything. And then also CO2 is never a local problem; it is a global problem, i.e. global warming.

But there is also local pollution, say sulphur oxide or nitrogen oxide, which affect things that are nearby. I mean also fossil fuels have more of those; nuclear power is somewhere in the grey area, it doesn't emit anything but of course there's the risk of a meltdown, which is also local, or at least not global. It's kind of in between. But then there's also the nuclear waste and what is the locality of that?

I would say that there are other sustainability factors that should be in (the calculations) to count the true cost of something, say fossil fuels. Even if we had a proper working CO2 trading scheme, how would you price the local pollution. I think they are some policies on that, but there are in the form of limits and so on. There are some legislations on those (emissions). And it is actually working much better than for CO2 because those emissions have decreased heavily in the last 10 or 20 years. For example acid rain used to be an issue in Europe in the 80ies or 90ies, but not anymore.

But still I think more factors should be calculated in the costs, in order to account the true costs.

Have you heard of SCOE (Society's Cost Of Energy)? If yes, what do you think of it?

Rinne: No. I think it sounds interesting; I need to look it up. Also in the project that we are preparing for the EU, there is - also societal and environmental issues of new technologies. […] I think that employment is also an important thing to notice about these new technologies. As you said, wind power is more local also in that sense. Say fossil fuels, that do not actually exist in Finland, which means we have to import everything.

Conclusion

What do you think the potential of renewable energy is?

Rinne: Huge. If you look at some numbers, for example how much energy is coming from the sun each day on the planet, it's more than we need in a thousand years or similar. Of course the problem is how to tap into those sources. (To store the energy) is one of the main challenges? And also it might be one of the corner points of what happens here in the energy system. So if there was a way to store energy or electricity cheaply then that would probably change a lot of things.

Can you imagine a future where energy is only produced through renewable energies?

Rinne: Yes but it would probably require a way to store the energy. We would also need some kind of total system redesign. i.e. how do the markets operate, how are things organized. For example the markets that we are running now in the Nordic countries, the power markets function like this that the bids for the day are placed on the previous day. And after that they open a so called intra day market where you can also sell or buy electricity for a given hour, until one hour before that given hour. And then on a third level you can sell or buy balancing power on the so-called balancing market. But the point is that this kind of system, you have to know your production almost 36 hours before, that might not be optimal for renewable energies because of the forecasting and so on. Maybe the market design should be something else; I don't really know how it should be but that is something I would really like to find out.

Also, the electricity transmission system is also built on this completely one-way system, where we have this kind of transmission network, where there are distribution networks and so this is high voltage and this is low voltage distribution level.

Old technologies used to be centralized technologies so they would be connected to the central transmission network, but these new technologies they are more distributed in their nature. So it might be that the distribution grid has to be redesigned. Because the system was designed to be one way from the high voltage generation to the demand in the distribution network. It's not really functioning perfectly with the distributed generation. So that's also something that is obviously very hard to change because of the huge investments in the transmission grid.

It's not a huge problem but if somebody would design the network from scratch it would probably be something different.

[…] Probably the array will link into something, which is called the North Sea grid, which is something that might someday connect Norway, Denmark, Netherlands, and Germany. So it is something that would connect all these undersea high voltage currents, so then also the future wind farms will be inter connected. There are different views on how the grid should be organised. Should it be this or this kind of mesh or something like that. Because the seawater here is quite shallow so it is quite a good place for wind and this type of cabling. For a few years already I've seen several different plans how it should be.

Transmission is something that is also very important for the renewables, because always when you increase your area you can easily transfer power in, which also smoothens all the variations of wind and solar and also demand. If you think of one single turbine, production will of course vary a lot. But if you increase the geographical area and the wind farm then its less variable. The wind speed varies also.

Extra Questions

What do you think of the wind farm London Array?

Rinne: I have heard, but as I said it will need to develop a sea grid, sometime in the future. The North Sea grid is not there yet but it will probably be somehow linked. So in that case the London Array energy could be also used somewhere else than UK.

Do you have any further comments on wind power or renewable energies in general?

Rinne: Renewables are not that capital intensive (i.e. compared to nuclear).

FiT money usually goes to the big companies, because they have gained so much market share.

It’s interesting to see what the next 10 or 15 years will bring. As I said earlier, the technology is getting better and better and cheaper and cheaper, probably they will be some big changes. I don’t know when but they will be. Sometimes it feels like it’s only a step ahead but then sometimes it feels it’s only in the 22nd century. Of course it will need also other technologies and innovations, say batteries, to complement the renewables.

Thank you for your time.