TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

School of Engineering

Department of Materials and Environmental Technology

HIIUMAA WIND PARK FEASIBILITY ANALYSIS

MASTER THESIS

Student: Gökhan Temel

Student code: 177339KAYM

Supervisor: Eduard Latõšov, Associate Professor (TalTech)

Tallinn, 2019

(*On the reverse side of title page*)

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

"......." 2019

Author: Gökhan Temel ....

/signature /

Thesis is in accordance with terms and requirements

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Supervisor: Eduard Latõšov ……………………..

/signature/

Accepted for defence

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Chairman of theses defence commission: ....

/name and signature/

Department of Materials and Environmental Technology

THESIS TASK

Student: Gökhan Temel, 177339KAYM

Study programme: KAYM09, Materials and Processes for Sustainable Energetics

Main speciality: Processes for Sustainable Energetics

Supervisor: Assoc. Prof. Eduard Latõšov, Lecturer at Tallinn University of Technology, +372 620390

Thesis topic:

(in English) Hiiumaa Wind Park Feasibility Analysis

(in Estonian) Hiiumaa tuulepargi ehitamise otstarbekuse analüüs

Thesis main objectives:

1. Provide a theoretical background reference for wind parks, cost structures and procedures for establishment of offshore facilities.
2. Analysing the Hiiumaa Wind Park project financials' feasibility from the investor viewpoint.
3. Determining the critical issues about the first Estonian offshore wind park project in the context of electricity pricing and greenhouse gas emission reduction.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Review of available literary references related to offshore wind energy and parks	18.01.2019
2.	Data collection	22.03.2019
3.	Results, data analysis and final calculations	29.03.2019

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Student: Gökhan Temel .... ".......".....................201….a

/signature/

Supervisor: Eduard Latõšov .... ".......".......................201….a

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PREFACE

The topic of thesis project is thoroughly discussed with Associate Professor Eduard Latõšov in the very beginning. I would like to thank my supervisor and professor, Associate Professor Eduard Latõšov who has provided support, advice and recommendations during the complete process of my thesis.

Tallinn University of Technology choice was quite extraordinary for me because I quit my full time job in Turkey. Then I settled in Tallinn to study Materials and Processes for Sustainable Energetics master program as well. Whole period since I began to live in Estonia, contributed a lot on my research and adaptation skills. Taltech provided various facilities for me to utilize. Right now I changed my mind on conducting academic studies in the future so that the thesis project is my final job in my student life. Hope it will be like a masterpiece for me to hand them to my prospective kids. I love my family who always respect my choices and ask for help during this time.

In overall, thesis project should be practical in my opinion. If an offshore wind park project will be evaluated from the investor stand point, then this work should be checked. From that point of view, related literature information, Estonia procedures for wind parks, support mechanisms, cost structures and calculations are clearly written. Then the final results and conclusions are shared in terms of project feasibility evaluation for Hiiumaa Wind Park which will be the first Estonian offshore wind farm.

Keywords: Offshore, wind energy, Hiiumaa, Estonia, wind park, NPV, IRR

List of abbreviations and symbols

IEA: International Energy Agency

UN: United Nations

REN21: Renewable Energy

Network for 21^{st} Century

WTG: Wind Turbine Generator

GHG: Greenhouse Gas

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INTRODUCTION

Wind energy industry is growing globally. Most of the countries organizing support mechasims for investors in order to improve national capacities. Wind turbines are developing as well. Wind turbine manufacturers spend huge budgets on research in order to produce bigger machines. Therefore, global wind energy installed capacity has tremendously rised from 7.5 GW in 1997 to 564 GW by 2018. Offshore wind energy projects are also installed with an increasing trend. 5 GW global capacity is expected to 75 GW by 2020.

Environmental sustainability is one of the most important issues for the countries. Greenhouse gas emission rates must be reduced in order to provide healthy environments for next generations. In this point, fossil fuels are not the right choice. Considering the side effects and limited availability of fossil fuels, future strategies and nations must rely on renewables like wind energy. Therefore, planning and policies must be clearly determined for new renewable energy projects.

Estonia is one of the Baltic countries in Europe. There is no offshore wind park yet in Estonia. Regarding the secure and sustainable energy strategy, first offshore wind park will play a key role in offshore wind industry development. Accordingly, the project must be feasible and profitable. There are many projects are being planned for the future, but none of them are realized. This results from the drawbacks on national procedures and policies related to maritime spatial plannings. The shareholders here like investors, government and project developers should collaborate in order to build more wind parks which will create additional value by new jobs and energy outputs.

The objective of this study is to examine the offshore wind industry, wind energy potential of Estonia and effects of Hiiumaa Wind Park over Estonia country energy strategy. Firstly, we examined theoretical background for wind parks, cost structures and procedures for establishment of offshore facilities, Then we analysed the Hiiumaa Wind Park project financials' feasibility from the investor viewpoint. The critical issues about the first Estonian offshore wind park project in the context of electricity pricing and greenhouse gas emission reduction are determined as well. The thesis based on calculations for net present value and internal rate of return for investors. Related literature review is added in order to understand the possible outcomes of Hiiumaa Wind Park Project as first offshore wind energy project in Estonia.

1. LITERATURE REVIEW

1.1 Wind Energy

Renewable energy usage was almost zero in 1971. Fossil fuels constitutes 91 % of global production according to the report published by World Energy Council in 2016. However the issues including economical fluctuations, environmental damage and global warming effect of fossil fuels, made people looking for new sources. Renewable share in total refers to 14% by 2015.(Figure 1.1). Wind energy is one type of renewable by 1.44% globally which expected to increase in the future. Technology developments create 170 meters long towers, 5 MW onshore and 8 MW offshore capacity of wind turbines [2,3]. Although wind energy investment values are quite intense, government supports for establishing infrastructure are widely available all over the world.

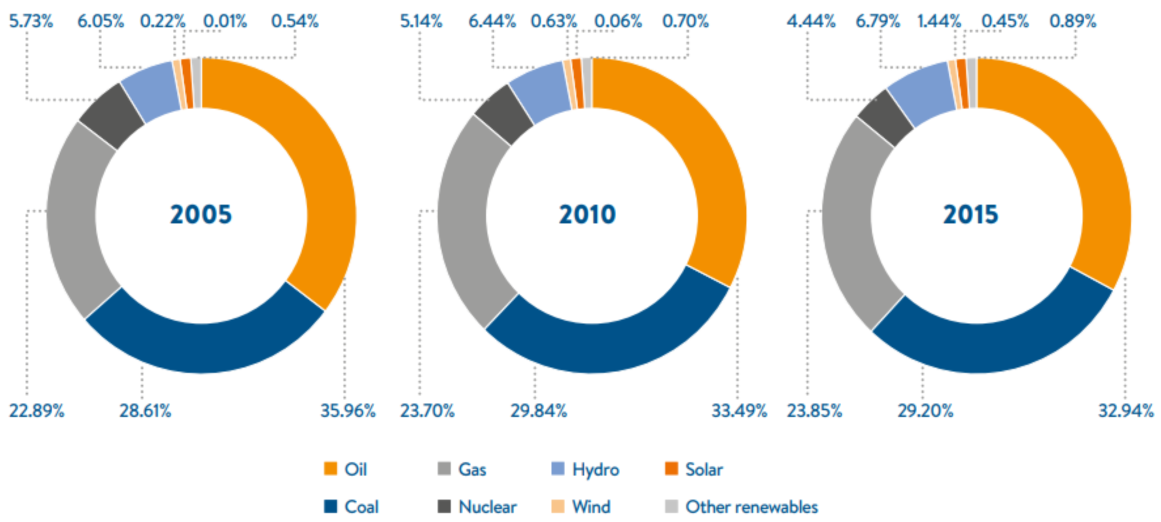

Figure 1.1 2005, 2010 and 2015 Energy Source Usage [2]

Main reason of winds on earth is different temperature distribution which is caused by geographical latitudes, heights and seasons. Coastal areas have higher wind potential with regards to greater temperature difference. Mountains, hills and coastal areas should be considered as windy places.

One of essential forces that plays role in wind occurence is pressure gradient. Gradient is defined as change in specific distance. Hence pressure gradient is the pressure change in specific area. Different pressure values among locations apply force on airflows. This force is defined as pressure gradient force. Pressure gradient force determines the winds' velocity and direction as flowing from high pressure areas to low pressure areas. The bigger pressure gradient force the faster winds flow.

Furthermore, coriolis force also effects wind characteristics. As the earth rotates the coriolis force is created which always force the things to tend right on the northern hemispehere [4].

Sun is the cause of winds on earth. Wind occurs due to different temperatures on earth heated by different sunlight distribution. The best way to utilize wind power is to determine wind energy potential correctly. Wind energy is the function of wind velocity, air density, rotor height and swipe area. The most effective item in the function is wind velocity because its value is calculated as cube power. Main wind characteristics are speed and direction. Wind speed is measured as km/h or m/s [5].

Wind turbines convert the kinetic energy in the air to electricity. Firstly, wind blows throught the blades. Then the blades begin to rotate because of their design and shapes. Rotating blades maket he generator work which is directly connected to blades by shaft. Wind power amount is determined by the capacity of turbine and the dimensions of the blades [1].

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power generation capacity. Obviously, sites with steady high wind produce more energy over the year [6].

1.2 Estonia Wind Power

Considering the development of wind industry in Estonia between 2012-2016, two datasets showing the installed capacity and electricity generation are shown below (Figure 1.2 and 1.3). On the wind energy installed capacity side, total capacity has increased from 266 MW to 310 MW by 16.5% as of 2016. Meantime electricity generation has reached 594 GWh in 2016 by 36.8 % increase comparing to 2012.

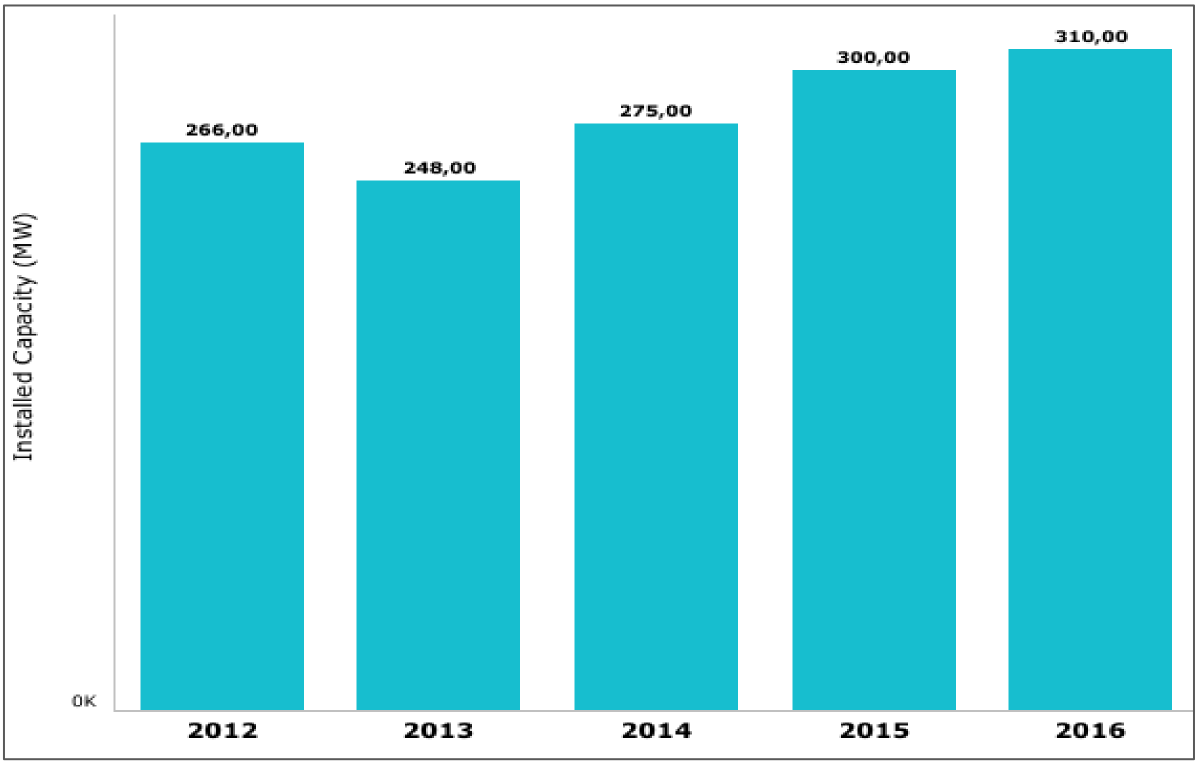

Figure 1.2 Installed Capacity of Wind Energy in Estonia [1]

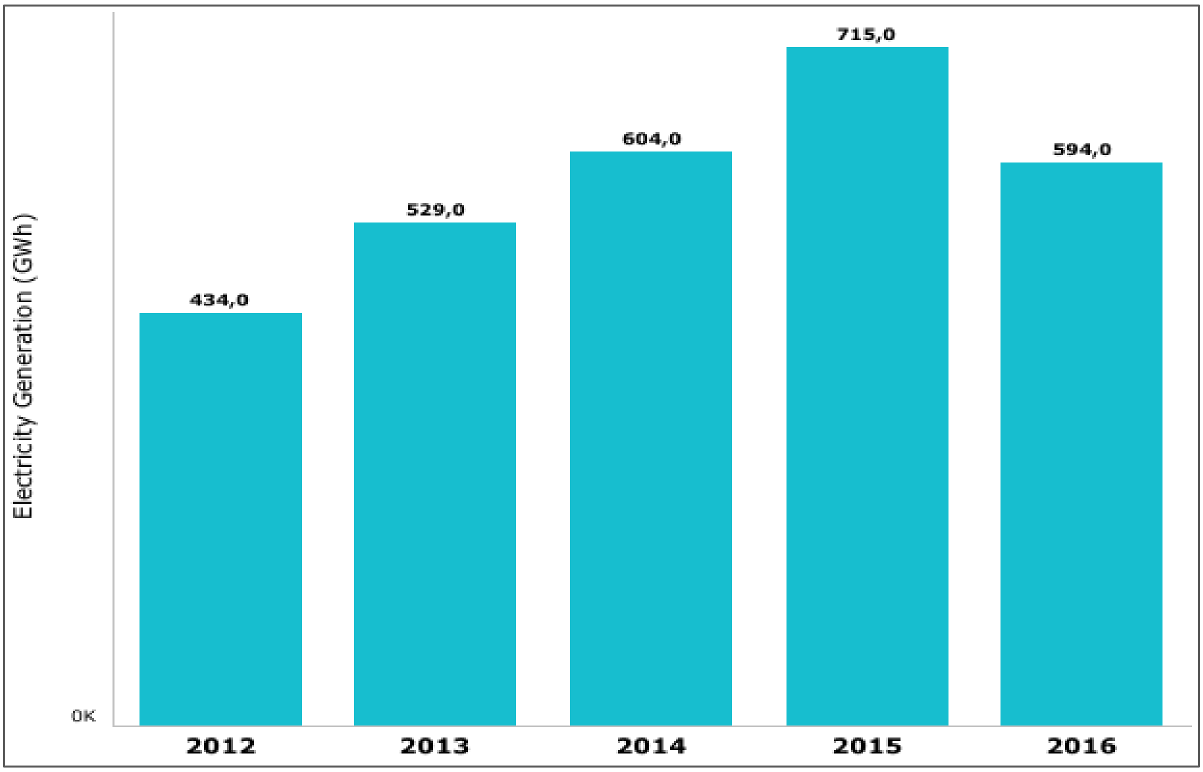

Figure 1.3 Electricity Generation from Wind Energy in Estonia [1]

The EU 2020 renewable energy target for Estonia is 25%. In 2016 the share of the renewable energy in Estonia's gross final energy consumption was 16%. Today Estonia is expected to have a surplus of renewable energy up to 2020 as the share of RES reached 25% already in 2011. From the wind energy perspective, although onshore wind energy installations are increasing, there is no offshore wind farm yet in Estonia.

Estonia has excellent wind. It's coastline is more than 2500 km long and mostly underpopulated. Average wind speed in the Gulf of Finland, Liivi Bay and west of Saaremaa and Hiiumaa islands is 9.01 – 9.25 m/s, further distant from the shore even more than 9.25 m/s. Accordingly, Baltic Sea has many advantages regarding offshore wind energy load hours (Figure 1.4). Due to low waves in Baltic Sea, the cost of construction and maintenance in the Baltic Sea is 1/3 cheaper due to higher accessibility (Figure 1.5). Higher accessibility means higher availability. Higher availability means higher production as well. Whereas the trend is to move away from shore (the average distance to shore of new installations in 2014 was 32.9 km) the Estonian offshore wind farms are closer to the shore. Due to less extreme wind conditions, it is possible to use larger rotors, thus gain higher productivity at all [7].

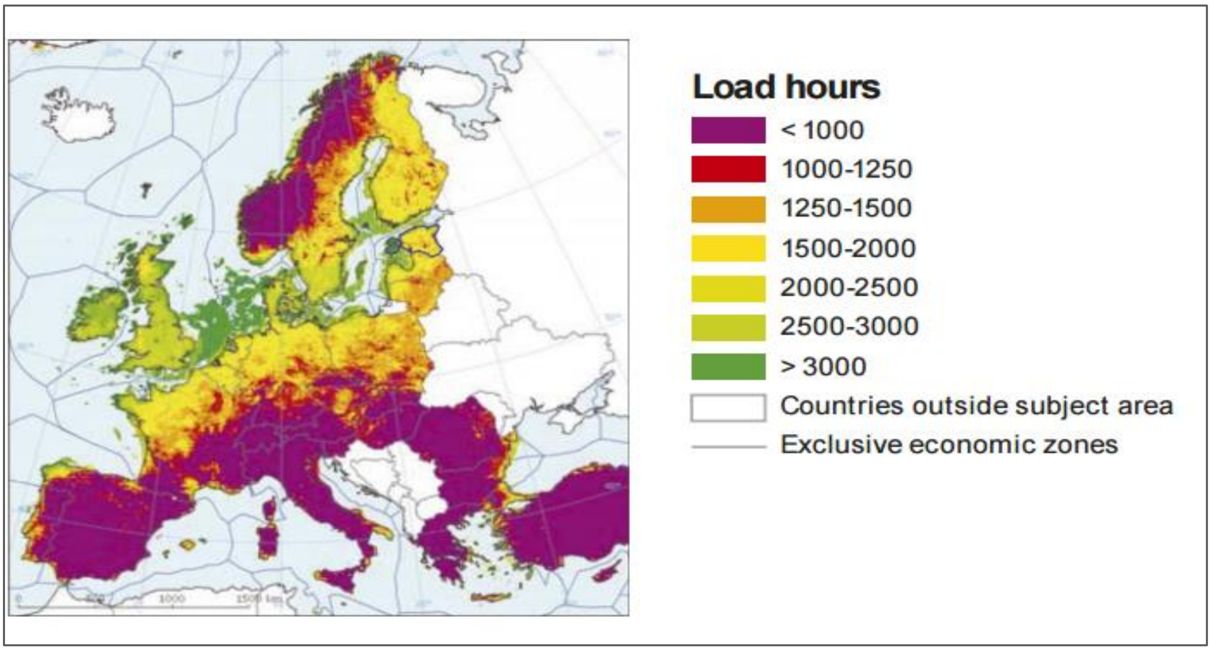

Figure1.4 Wind load hours in Europe [7]

According to the recently launched WindEurope analysis on wind energy scenarios for 2030, the Baltic Sea, where 1.5 GW of offshore wind is grid-connected today, will represent the second largest basin for offshore wind, with potentially 9 GW installed by 2030. On 28 September 2017,WindEurope signed the Baltic Sea Declaration on Offshore Wind in Tallinn. The document, co-signed by wind energy associations from Estonia, Denmark, Finland, Germany, Latvia, Lithuania, Poland and Sweden, asks governments to enhance their regional cooperation with a view to supporting offshore wind deployment in the region [7].

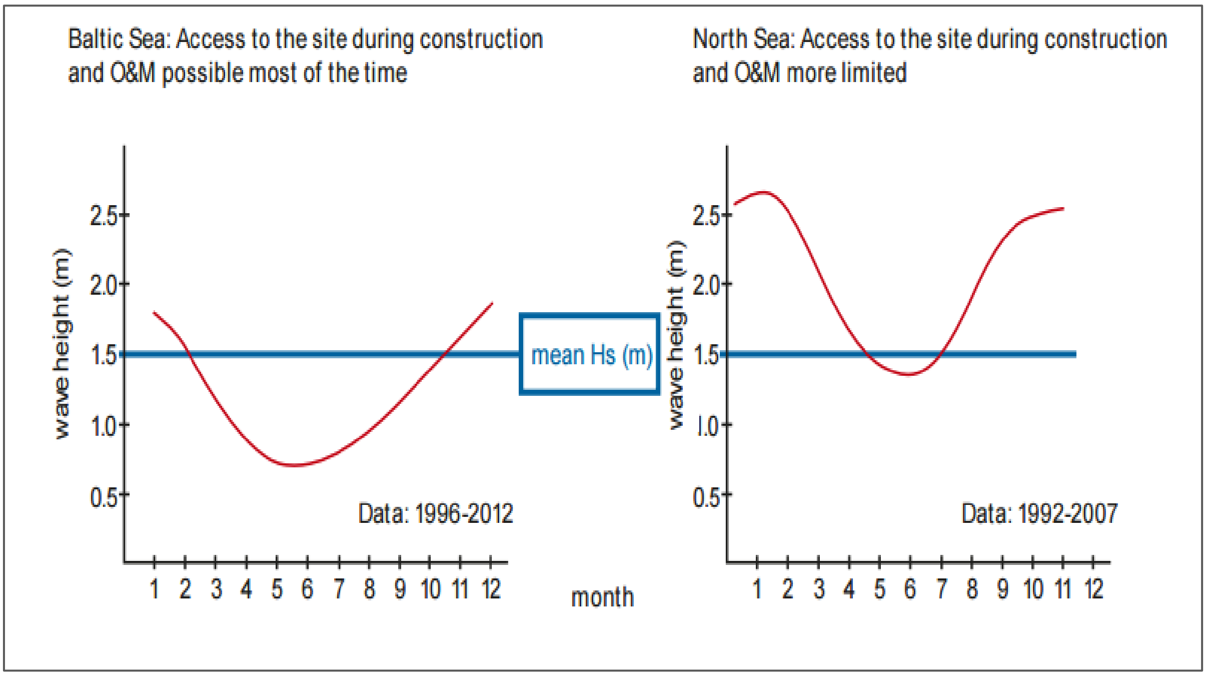

Figure 1.5 Wave lengths in Baltic Sea vs. North Sea [7]

1.3 Renewable Support Scheme in Estonia

The support mechanism in Estonia aims to improve the efficiency and security of energy supply for renewables like the rest of the Europe. Electricity Market Act is the reference regulation for subsidies. Rate of the premiums at the moment is 53.70 EUR/MWh for renewables (except biomass). Wind-powered plants may apply for support until 600 GWh production limit has been reached per calendar year. Investment support has been given out by the Environmental Investment Centre (investments for the application of wind energy in electricity generation and for extended use of renewable energy sources for the generation of energy and reconstruction of district heating). There are no tax exemptions or compensations for connection costs currently in force in Estonia for RES capacities [9].

1.4 Policy Instruments for Wind Park Planning in Estonia

Regarding the procedures of wind park authorization in Estonia, wide range of documents are needed. There are in total 8 laws and regulations determining wind park development procedures in Estonia:

- Planning Act,

- List of objects of significant spatial impact,
- Aviation Act,
- Environmental Impact Assessment and Environmental Management Act,
- Specified list of operations, for the initiation of the Environmental Impact Assessment,
- Water Act,
- Electricity Act,
- Building Act.

A wind park planning in Estonia can take place based on three types of planning documents: county plan, comprehensive plan and detailed plan. A comprehensive plan is a spatial plan of a city or rural area to determine the development of the territory. With the county plan, the land usage of the whole county territory or a part thereof is determined. The detailed plan is prepared to mark the construction works and land use for a part of the territory of a local authority. Most of these documents are compiled by local authorities thereby assigning small governmental entities the full responsibility for spatial planning. The comprehensive plan needs an approval from the Ministry of Defence and the Ministry of Internal Affairs. Detailed plans for wind parks need to be approved by the Aviation Office, the Ministry of Defence, Police and Border Guard and also by the Ministry of Internal Affairs. Furthermore all wind parks must apply for appropriate construction permits, whereas the construction permits for onshore wind farms are granted by local authorities. For offshore wind farms the permits are granted only by the national Technical Surveillance Authority. A location selection process for a wind park must be initiated for wind farms with more than 5 wind mills or/and for a wind farm with a total capacity over 7.5 MW [10,11].

Creation of wind park may have a significant negative impact on seabed fauna on soft seabed, seabed dwelling places (shoals), fishing (trawling, in close proximity) ,birds, sea mammals, fish ecosystem, migration of water birds and noise disturbance to nearby sites. In order to proceed further, any wind farm developer must publish EIA report and get approval from government. The EIA process in Estonia is being regulated by the Environmental Impact Assessment and Environmental Management System Act (22.02.2005). In 2015, the Act (and the whole the impact assessment system) was revised. One of the main changes was bigger involvement/lead role of the decision maker in the impact assessment procedure. Despite the fact that the overall procedures for Environmental Impact Assessment are well in line with national and European legal frames, much needs to be done to give better technical guidance to developers and implementing competent authorities to take decisions that are environmentally sound. This guidance must address the specific ecological features of the Baltic Sea, especially its Northern parts which are less investigated, but more vulnerable; they must address more than the marine biology [12].

Spatial planning is a key element of the regulatory framework. Increased activity within Europe's marine waters has led to increased spatial demands and therefore growing competition between sea users. Spatial planning provides stability and clarity for investors as well as helping reduce project costs. Although a few European countries currently have defined dedicated offshore areas, most countries use existing marine planning laws, which can delay projects considerably. Among the objectives of maritime spatial plans are some directly relevant to planning the locations of offshore wind farms, application of an ecosystem-based approach, contribution to the preservation, protection and improvement of the environment, as well as contribution to the sustainable development of energy sectors at sea.

The overall MSP process in the Baltic Sea has just started. At the moment, only two Baltic Sea countries possess maritime spatial plans. Germany has an approved maritime spatial plan since longer time (adopted in 2009). In Lithuania, the plan was adopted in 2015. In Estonia, two first pilot maritime spatial plans have been developed in Pärnu and Hiiu Counties, but they are not yet in force. On 23 July 2014, the Directive 2014/89/EU of establishing a framework for maritime spatial planning was adopted, thus establishing an overall legal EU framework for compulsory spatial planning of marine areas. The Directive obliges Member States to set up maritime spatial plans which identify the spatial and temporal distribution of relevant existing and future activities and uses in their marine waters. The plans for all marine waters of the Member States shall be established by 2021 [13].

The Strategic Environmental Assessment (SEA) procedure can be summarized as an environmental report is prepared in which the likely significant effects on the environment and the reasonable alternatives of the proposed plan or programme are identified. An SEA is mandatory for plans/programmes which are prepared for agriculture, forestry, fisheries, energy, industry, transport, waste/ water management, telecommunications, tourism, town & country planning or land use and which set the framework for future development consent of projects listed in the EIA Directive [14].

1.5 Wind Park Development Stages

Offshore wind farms consist of arrays of turbines linked together. The energy produced by the farm is collected within this array of turbines and transported to shore to a grid connection point where the electricity is transferred to the integrated public grid. A typical layout is shown below (Figure 1.6).

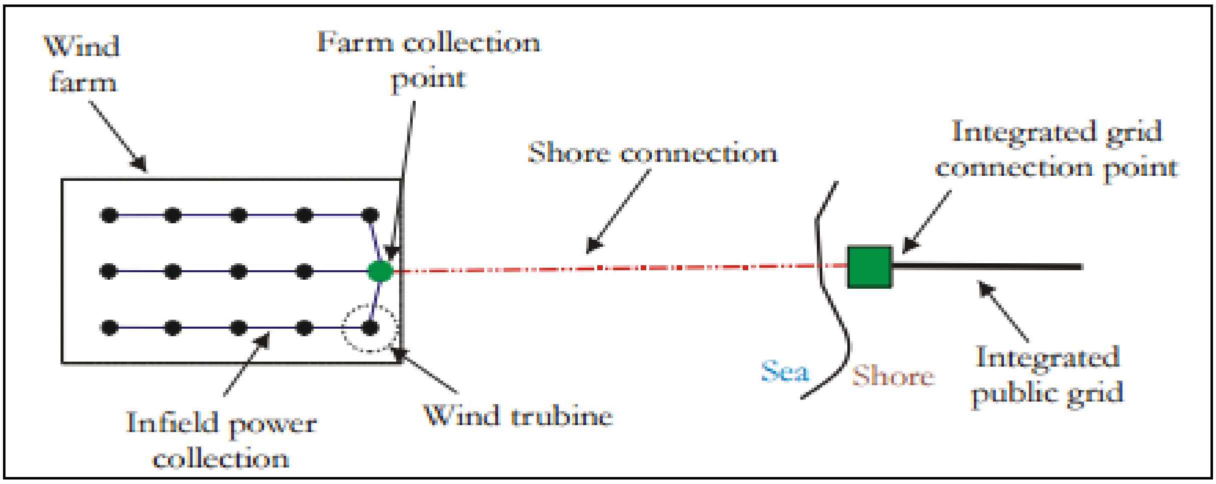

Figure 1.6 Typical Layout of an offshore wind farm [15]

Project developers initiate the wind farm development, ordering the first surveys and conducting the preliminary wind farm design. Wind turbine manufacturers are responsible for the design and manufacturing of that component. Nonetheless, they can act further in the farm life cycle, and may install, operate and maintain the wind farm. Then, engineering companies, contractors and manufacturers of other components are active from the wind farm design & manufacturing to the decommissioning. Beyond these private actors, governments and other public actors are crucial to offshore wind, leading the planning process for offshore wind farms and providing support mechanisms to offshore wind.

The planning may involve defining the maritime spatial planning with the allowed wind farm locations and obtaining the environmental or other necessary permits. There is currently a convergence towards this model with governments planning and pre-permitting offshore sites, and then using competitive auctions to allocate them, supporting offshore wind with premiums paid on top of wholesale power market prices [15]. In overall, wind farm development stages are shown on Figure 1.7.

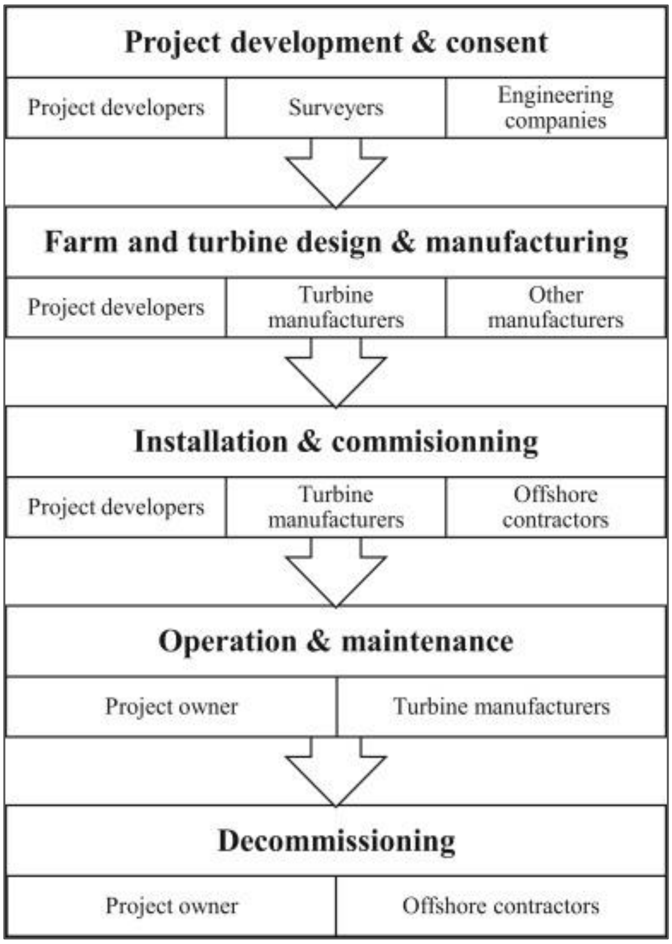

Figure 1.7 Wind farm development steps life cycle [15]

Nelja Energia began to plan the Hiiumaa offshore wind farm project in 2006. Then,Environmental Impact Assessment (EIA) process has been progressed with collaboration of ministry. The range of plans for the wind park have capacity between 700 and 1100 MW. The average distance is 12 km from the Hiiumaa island. 100-160 wind turbines will be installed. The number of wind turbines can be also changed according to updates for the project. The final locations of the turbines will be decided after National Maritime Spatial Plan and Environmental Impact Assessment (EIA). After establishing the wind park with expected capacities, the Hiiumaa Offshore Wind Farm will expectedly produce 3-5 TWh per year with an annual turnover of 170 – 250 mln Euros.

The investment will be between 1.7 – 2.5 billion Euros and half of that goes for the turbine technology, and two quarters go to the substructure and grid connection. The Hiiumaa wind farm is planned to connect with Estonian transmission grid through Kanapeeksi substation in Hiiumaa island. (Figure 1.8) [16].

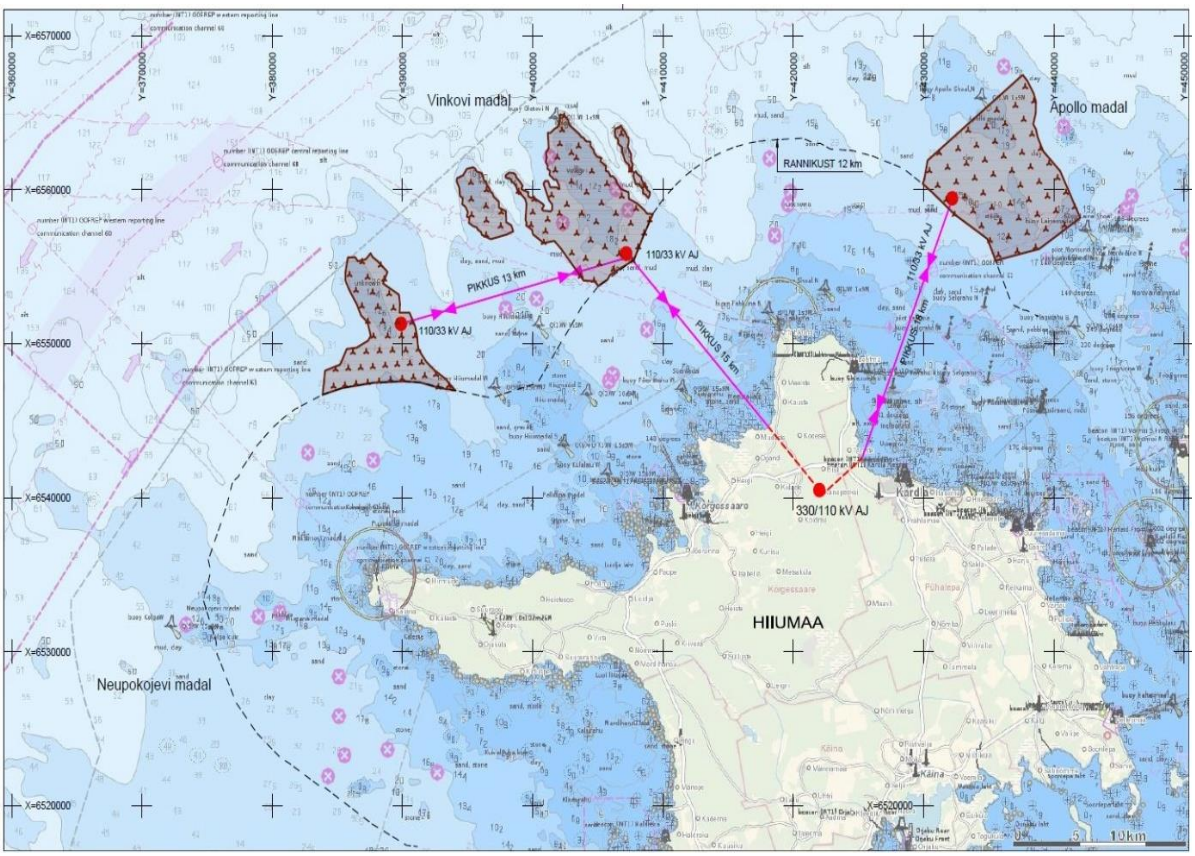

Figure 1.8 Hiiumaa offshore wind farms' transmission plan [16]

1.6 Current Status of Hiiumaa Wind Farm

Nelja Energia submitted its application to the Ministry of Environment for the special use of water in 2006. On the basis of the application the Ministry of Environment initiated the Environmental Impact Assessment (EIA) on 05.05.2006. In addition, Nelja Energia submitted its application for superficies licence to the Estonian Government in 2010. Both water special use permit and superficies licence application proceedings have been suspended until the approval of EIA report.

The Ministry of Environment published the Environmental Impact Assessment report on the 10th of February, 2017. In October 2012 the Government of Estonia initiated maritime spatial planning at the area around Hiiu Island. The preparation of the plan and strategic environmental assessment (SEA) was delegated to the governor of Hiiu county, who established the Maritime Spatial Plan (MSP) on 20.06.2016. Hiiumaa Offshore Wind Farm is planned in the MSP areas marked PT 1, PT 2, PT 3, PT 4 & PT 5.(Figure 1.9) [16].

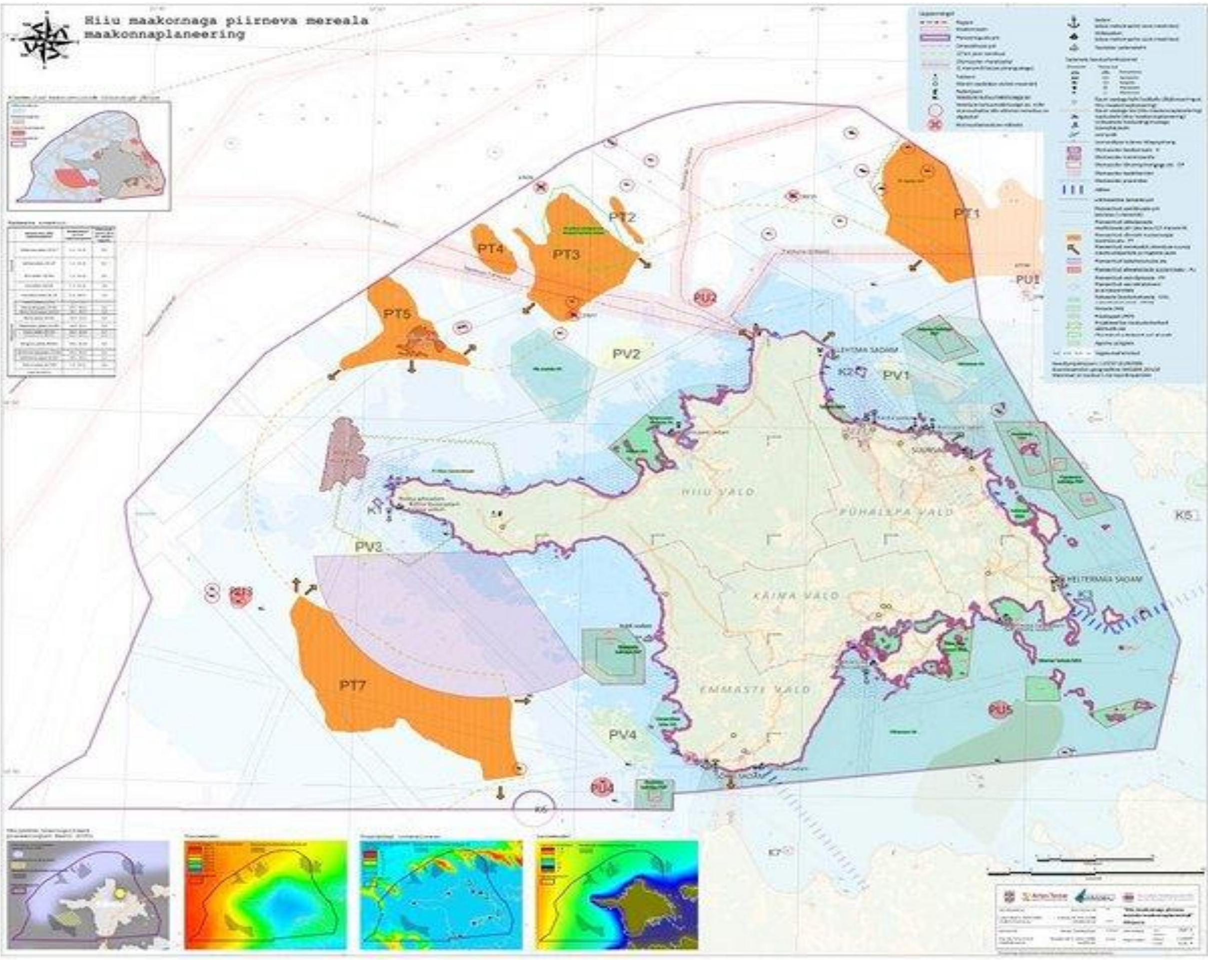

Figure 1.9 Maritime Spatial Planning of Hiiumaa Offshore Wind Farm [16]

The Supreme Court of Estonia rejected the plan Of Hiiumaa Wind Park due to insufficient environmental impact assessment report. This report shows the wind park’s effects on einvormental fauna in the sea. The effects of foundations, cablings and links must be clearly understood on marine species. Besides the relevant surveys are not appropriate to show the impact of offshore wind project site. Therefore, the establishment of the planned construction area, is not legally eligible for now [17]. This situation indicates the country wise importance of Maritime Spatial Planning (MSP). If the Estonia MSP would be ready, then it would be quickly approved by government officials.

1.6.1. History of Hiiumaa Wind Farm

On 11 October 2012, the Government of Estonia initiated maritime spatial planning in the marine area around Hiiu island in Estonia. The draft plan included the development of areas for offshore wind farms, and the area north of Hiiuma was deemed most preferable. Several island residents were not satisfied with these designations. After the MSP was adopted on 20June 2016, opponents of the plan filed an appeal at the administrative court because of the visual impact of the turbines and the potential impact they could have on nature around the island. The governor, however, endorsed the maritime spatial plan, determining the areas selected as suitable for offshore wind farming. The plan contains several images of what the offshore wind farms would look like from different vantage points on the island (Figure 1.10).

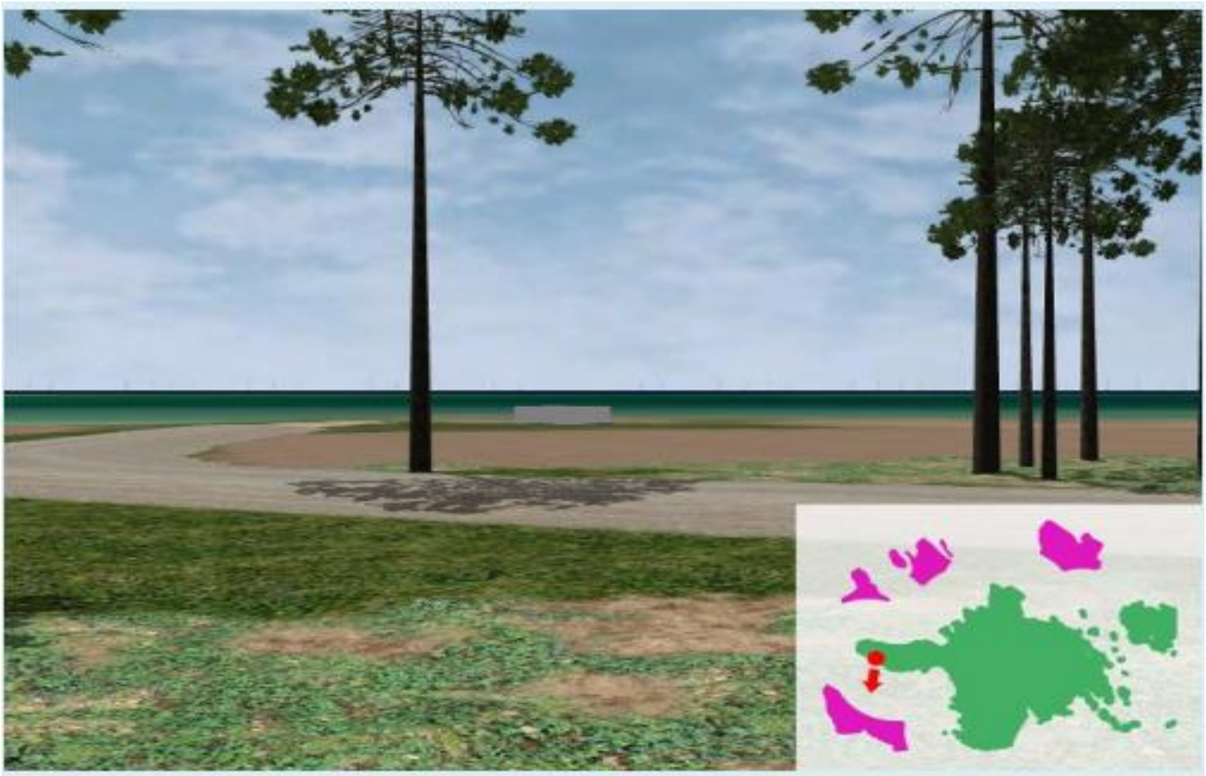

Figure 1.10 One visualisation of the potential view on the offshore wind farms from Hiiu Island [18]

Once the plan was endorsed, Hiiu municipal council began to implement it. In 2017 it approved a cooperation agreement with Nelja Energia and Hiiumaa Offshore Tuulepark to build a wind farm of 100 to 160 wind turbines with an aggregate capacity of 700 to 1100 megawatts. The company, financed by investors from other EU countries, committed itself to contributing to the development of the island, its economy and energy security.

The most important aspect was that the wind farm would only have a minimal visual footprint and that no turbines would be put up closer than 12 kilometres from the island and on Neupokoyev Bank. The visual footprint would additionally be kept under control by using only submerged and underground cables. Regardless of whether the wind farm was connected to the grid via Hiiumaa or by a link to mainland Estonia, the developer was committed to establishing a loop connection with Hiiumaa. However, a group of protesters did not stop after the first ruling of the administrative court and after the plan of the developers was put forward. The opponents filed a complaint at the appellate court in Tallinn. The case came before the court on 30 October 2017, providing the opponents with an opportunity for presenting their arguments. At that time the court ruled that the offshore wind farm development could not be blocked. In addition, the appellate court decided that some of the opponents did not have the right to challenge the spatial plan [18].

Figure 1.11 Protest in Tallinn against the new offshore wind turbines [18]

Nevertheless, the protest of the local inhabitants had its effect on the agreement between the offshore wind farm developers and the government. The new agreement foresaw that a maintenance operation centre of the wind farm should be set up on Hiiumaa and that the training of technicians would take place in Hiiumaa. The service centre was expected to create 30 new jobs directly as well as 20 indirect jobs. Also, the developer and the municipality were to set up a non-profit association aimed at promoting the economic and social wellbeing of the municipality, spreading the positive effects generated by the wind farm through supporting local not-for-profit initiatives.

The wind farm would donate to the non-profit at least 0.2 percent of its revenue from the sale of electricity, but not less than 0.32 Euros per each megawatt-hour of electricity produced. In addition, it would be possible for the residents of Hiiu municipality to invest in the wind farm by buying preference shares or bonds bearing a fixed annual interest of 15 percent.

However, even this new agreement was not supported by all stakeholders. A group of protesters filed a complaint to the Estonian (highest) National Court. Eventually, on 8 August 2018, the National Court determined that the offshore wind farm designations should be removed from the Hiiu MSP. This means that the MSP is still valid, however without the offshore wind farm designations. Therefore, it is currently unclear whether the proposed offshore wind farms will ever be built around the island [18].

1.7 Future Offshore Wind Projects in Estonia

There are many offshore wind projects planned to be established in Estonia. Baltic Blue Energy, Eesti Energia and Saare Wind Energy companies are also interested in building new offshore wind energy parks in the future. All of the future projects' locations are marked on the map with blue dots which are shown on Figure 1.12 [19].

Figure 1. 12 Offshore Wind Projects in Estonia with blue dots [19]

The integration of wind power in the power system is now an issue in order to optimize the utilization of the resource and in order to continue the high rate of installation of wind generating capacity, which is necessary in order to achieve the goals of sustainability and security of supply. The wind power production is decentralized in the regions with high average wind speeds. Because it's unpredictable in the short term, the wind power is beneficial only in particular situations when there is a good correlation between the production and the consumption, or between the production and the specific needs of the grid. [21]

Concerning the variability of electricity supply generated at wind parks the existing power grid needs to be investigated for its acceptable minimum and maximum capacities. Usually wind farms are located at peripheries where there is sparse population, no industry and therefore no strong power networks either. Grid failures may exist in cases where the energy production from a wind farm exceeds the maximum capacity of the network or if there is no backup generator to keep the grid at its minimum level in case of low wind speeds. In Estonia currently when the wind park capacity is up to ¼ of the energy system's total capacity no significant effects on the power transmission can be detected. Until now the maximum output of the wind parks has stayed below 30 MW installed capacity and no effects on the power network have been noted. Estonian wind resource however makes it possible to construct wind farms with capacities up to 90-100 MW. This would significantly disturb the electricity network. In order to overcome possible problems from power transmission investments into the power network are needed or wind farms with larger capacities cannot be installed [10].

2. COST ANALYSIS

Energy projects require huge investments. Project developers aim to get maximum profit or benefit from the targets. Moreover, energy investment return periods may be longer rather than the other options for investors. Therefore, cost analysis must be conducted elaborately in order to understand the energy project investment outcomes. Four main sections should be evaluated in costing strategy:

- Capital Costs: Target project's establishment costs including construction, transportation and installation costs along with interest rates, credits, payback periods.
- Resource Costs: Processing of the resource according to the type of energy which will be harvested.
- Operation Costs: Facility maintenance, process and repair costs.
- External Costs: Indirect costs which may be related to environment or industrial changes.

On the other hand, cost analysis is efficient where the country of operations has a stable economic and industrial indicators. Otherwise fluctuations in the regulations or pricings would cause unexpected issues on financing [23,24].

Regarding wind energy, costs per MWh or kWh is considered expensive unit prices, but meantime there is unlimited source and low operating costs. Moreover the unit prices would vary on the either location and capital costs. Wind speed and applicable credits' interest rates have certain financial effects on the location. Furthermore, government support regulations have essential impacts on budget. Wind energy project specific costs may be classified as below:

- Capital costs (Construction and connection to grid),
- Operation and maintenance costs,
- Capacity factor,
- Turbine lifetime.

Especially capital costs and capacity factor are critical in terms of profit position of the project.

The power generated by a wind turbine depends on both the design characteristics of the turbine and the properties of the wind resource. These parameters determine the capacity factor which is ratio of average power output to rated power of the turbine [22]. Firstly, periodical precise wind measurements are done by devices in the site. Then average wind speeds are acquired. Estimation of wind turbine output according to average wind speed is divided by maximum output value. The resulting value is expressed by percentage. Generally, capacity factors are in a range between 20%-45% which directly effects capital costs at all. One of the main items that effect capacity factor is the geographical characteristics of the site. Turbulence rates deviate the the capacity factor and turbine lifetime if the geographical conditions of the site cover such climate. [23,24]

Latest developments in the turbine industry provide lower costs for the higher, lighter and more efficient wind turbine types. 4 MW wind turbines are widely in use nowadays comparing to 200 kW wind turbines in 1990. The most preferred turbines types have 2-3 MW output power in the sites.

The efficiency of electricity production depends on the swipe area of airfoils. New designs of airfoils and increasing height of towers have contributed to efficiency as well as output power. Current wind turbines are able to harvest much more energy in the same site rather than the older versions.

Operation costs play a key role after the completion of construction. Periodical maintenance, repair, spare parts costs along with insurances refer to operation costs. Insurance and periodical maintenance costs are determined based on the wind turbine type and lifetime. However, spare parts and repair costs are very hard to estimate before the project start. Operation costs take approximately 10-15% of the unit electriciy cost of the site. As long as the turbine gets older, the operation costs can lead up to 35% range. Consequently, manufacturers constantly researching for new designs which need less frequent repairs.

Wind turbine version and capacity have also major ratio of operation costs. The comparison of opearation costs for 55kW and 150kW capacity wind turbines are shown in Table 1.1. 55kW capacity of wind turbine operation cost is 3.5 c€/kWh while 150 kW wind turbine operation cost at the same aged site is 2 c€ is less. If the turbines are at the same age, the higher capacity one has lower operation costs [23,24].

Table 2.1 Operation costs comparison of wind turbines[23]

	3 Years Old Wind Park		5 Years Old Wind Park	
Operation Costs	55kW (c€/kWh	150kW (c€/kWh)	55kW (c€/kWh	150kW (c€/kWh)
Repair	1,1	0,3	2,6	0,5
Maintenance	0,9	0,4	0,7	0,6
Insurance	0,5	0,4	0,7	0,4
Service	0,2	0,3	0,3	0,2
Other	0,7	0,2	0,1	0,2

Table 2.2 Cost breakdown of operations [23]

Costs	Ratio %
Turbine	74-82
Construction	1-6
Electrical connection	1-9
Grid connection	2-9
Procedures	5-10
Landscape	1-3
Financial	1-5
Road links	1-5

Cost breakdown of operational costs of wind turbine is shown in Table 1.2. The biggest ratio belongs to turbine purchasing costs while electrical and grid connections have significant effect on the costs. Construction, landscape, electrical and grid connection costs compose almost 80% of total operating costs [23].

2.1 Cost Evolution of Wind Energy

Offshore wind is a relatively new technology. First offshore wind farm is the Vindeby site at Baltic Sea belonging to Denmark. 5 MW capacity installation of Vindeby is completed in 1991. Then offshore wind parks and researches drastically attracted people as a trending industry. Worlwide wind power capacity has reached 19 GW by the end of 2017. In 2000 global offshore wind industry capacity was 35 MW. In that sense offshore wind industry has an enormous increase in terms of capacity as well. Located in the Irish Sea, the Walney Extension Offshore Wind Farm has a total capacity of 659MW by 87 turbines and is capable of powering nearly 600.000 homes in the United Kingdom (Figure 2.1) [25].

Significant progress has been achieved through design developments on airfoils of wind turbines in last 20 years. Wind power unit costs change depend on the country basis. For instance, comparison has been done for 95 kW wind turbine in 1985 versus 1000 kW wind turbine in 2000. While 95 kW wind turbine has 8.8 c € / kWh electricity production cost, 1000 kW has 4.1 c € / kWh. In 15 years between 1985 and 2000, the production costs has already decreased about 50%. Considering current industry trends, wind energy installed capacity is being doubled almost by every 3 years. As long as turbine technology develops and capacity increases, accordingly the costs would be lower [23].

Generally wind energy parks are established on top of the hills which do not contain forests or biological ecosystem. Nevertheless, wind sites can be utilised for raising livestock and farming. One typical wind turbine cover an area about 100 m^2. Each turbine has a distance to the subsequent one from 50 up to 400 m. according to airfoil length and wind speeds.

Figure 2.1 The largest offshore wind farm on the planet, Walney Extension, is situated in the Irish Sea [25].

The empty areas among the wind turbines in a wind park are convenient for other purposes like farming or raising cattles. There are many examples about that situation. Meanwhile offshore wind turbines do not occupy any installation region with regards to their position in the sea. Issues come through road availability, construction and offshore installation topics in terms of expenses [24].

2.2 Offshore Wind Turbines Installation

Offshore wind energy has advantages and disadvantages comparing to onshore wind energy. Although offshore wind turbine overall installation costs are significantly higher, wind speed and consistency over the sea is much greater than the land. Consequently offshore wind projects provide much more profit in the long term. The advantages of offshore wind turbines may be listed as follows [26]:

- Higher wind speed all over the sea providing more electricity,
- Constant wind on the sea because no obstacle blocking wind speed unlike on the land,
- Locations for offshore wind parks in the sea are much applicable in terms of regulations, renting or purchasing expenses,

- Offshore wind parks do not create noise pollution due to absorption by the sea. Moreover offshore sites are far away from habitat areas,
- Sea transportation costs are occasionally much cheaper than land transportation.

On the other hand, offshore wind turbines' disadvantages are:

- Subsea wind turbine foundations' dimensions due to depth of sea ,
- Construction conditions are extremely harder,
- Maintenance periods are more frequent because of the corrosive effect of seawater on turbine foundations,
- Cabling and transmission connections are quite complex,
- Decommissioning challenges,
- Effects on naval traffic [26].

Offshore wind turbine types are different than the onshore wind turbines due to their foundation types applicable for seabed. Foundation costs of offshore wind turbines are 25% of total installation costs regarding the materials used in manufacturing. Analysing the offshore seabed has some critical points as listed below [27]:

- Buoyancy of water changes the forces applied on foundation,
- Wave force and glacier effects especially in seas near North Pole,
- Underwater currents impact on fatigue characteristics around the foundation,
- Need for strong base on the seabed.

In order to achieve safety requirements of offshore wind parks, all of the above mentioned points must be fully analysed. Offshore wind turbine selection process is made upon the sea depth criteria. Foundation type of wind turbines are determined according to the sea depth [27]. The height and consequently the depth of installation are determining factors in choosing the farm location. Turbines installed on land generally have a tower height equal to the rotor diameter to overcome wind shear from ground obstacles. However, the offshore tower height can be 70% of the rotor diameter due to the low shear effect of water. The most favourable water depth for an offshore wind farm is 2 to 30 m. Depths less than 2 m are not accessible by ship, and those greater than 30 m make the foundation too expensive. In this range, three possible foundation designs are shown in Fig.2.2. They are: monopile for 5 to 20 m depths, gravity for 2 to 10 m depths, and tripod or jacket for 15 to 30 m depths [6].

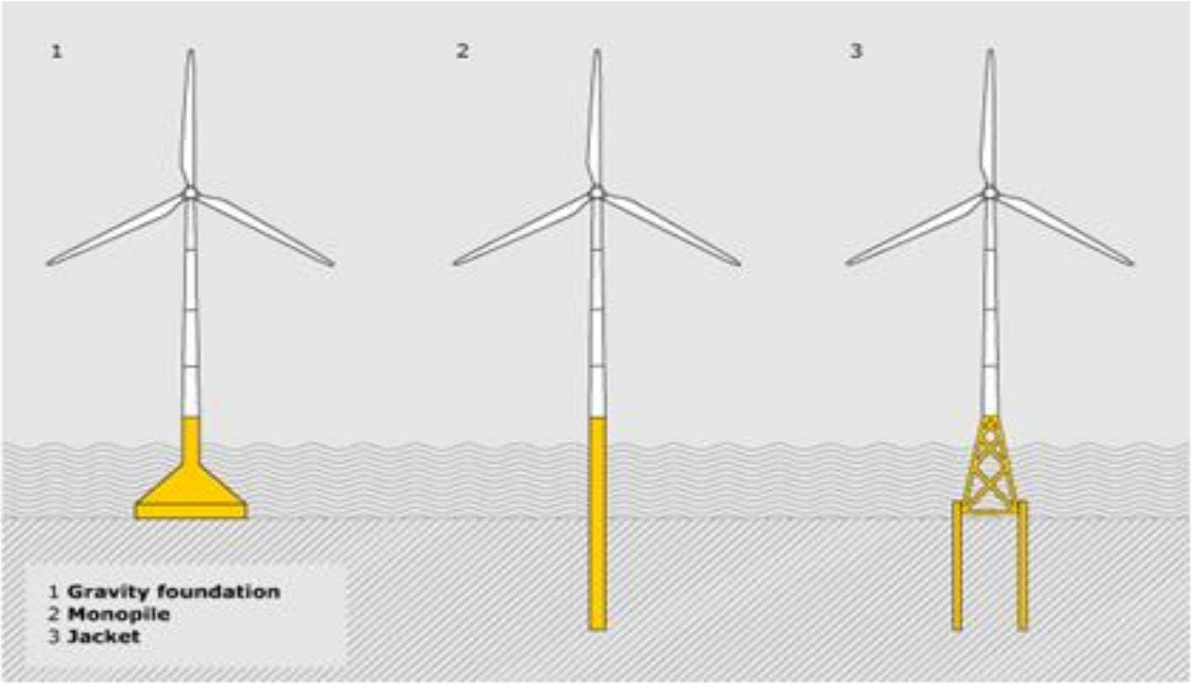

Figure 2.2 Foundation types for offshore wind farms

2.3 Wind Turbine Location Selection

Key essential of improving efficiency of wind turbines is selection of the location. In order to increase the power output, turbulence areas must be avoided. Turbulence not only decrease the lifetime of wind systems but also puts additional costs with regards to maintenance. Wind energy costs should be clearly determined before the installation of wind turbines. Such kind of analysis require huge amount of wind data related to characteristics of location. These analysis include [28]:

1) Energy Resource Analysis
    - Forecast of wind turbine output,
    - Wind systems' start requirements,
    - Overall required energy for beginning.
2) Economic Analysis
    - Wind turbine costs,
    - Operating costs,
    - Environmental conditions.
3) Location and System Selection
    - Wind speed data in selected region,
    - Calculations for power output,
    - Storage type,
    - Cost comparison versus other options.

2.4 Wind Energy Feasibility Analysis Programs

There are many investment analysis, optimization and project management computer programs for wind energy as well. Although there are many programs, WindSim and RETScreen programs are investigated with regards to present a brief overview.

WindSim is a CFD wind simulation program by non-linear modelling. The program is developed by Vector AS which is a Norwegian company in collaboration with Norwegian Meteorology Institute since 1998. The aim of the cooperation was to investigate wind conditions on rough shoreline of Norway. The first version of the program is released in 2003, then the first Windows operating system based version is released in 2005. There are more than 200 licensed users worldwide. WindSim program explores efficiency of wind farm, estimation of productivity and optimization of turbines mapping. Program is known with skills regarding the solutions for complex climates and landscapes. However, WindSim needs other complementary programs because of digital requirements [29].

RETScreen is a feasibility analysis program designed for evaluation of renewable energy projects. Energy output, project costs and lifetime, greenhouse gas emissions can be examined at all. The advantages of the program are easy to use and practical interface. Renewable energy investment risk analysis, solar radiation and wind speed applications can be executed in the program.

RETScreen program has two fundamental sections including conventional and renewable energy Technologies. Basic sections refers to conventional Technologies, recommended section refers to renewable energy Technologies. In order to make an economical comparison, the systems are assumed on a stable output based on the data inputs. Investment return analysis is also possible via RETScreen. Conventional and renewable energy comparisons also provide greenhouse gas reductions and convertions in the program.

After that greenhouse gas emission section can be used which is optional. That section provides the amount of reduction in greenhouse gases. Subsequently, financial analysis can be done Therefore, cash flow rates and financial sustainability of the project can be determined as overall view. Risk analysis section is the last one which offers also sensitivity analysis where the effect of change in parameters could be observed. Main renewable energy sources in the RETScreen program are; wind energy, hydro, photovoltaics, biomass and geothermal. [30]

2.5 Support Mechanisms for Wind Energy

Wind energy support mechanisms are widely available in all over the world. Depending on the country or location support mechanisms' effects is considered. Feasibility studies before the investment includes risk analysis and payback period. Support mechanisms lower the risks of the projects, increase the market reliability and investment trends. Subsequently, wind energy installed capacity has a correlation with suitable support mechanisms as well. In summarize, there are two types of support mechanisms. First one is fixed price, secondly quote systems [31].

The prices are set by the governments in fixed price mechanisms which provide advantage by regulating higher prices than the market for a certain period. Therefore fixed price mechanism reduce risks and financing drawbacks. Fixed price systems contain different methods such as Investment Subsidies, Fixed Feed-in Tariffs, Fixed Premium Systems and Tax Credits. Investment subsidies are financial supports given by governments. Governments can apply conditions like local production of some parts in regarding country. Constant price per every MWh supplied to grid is called Fixed Feed-in Tariff. Some countries specifies a certain payment period like 20 years which is almost equal to average wind turbine lifetime. Payment level remains independent from the market price, offering a guaranteed payment for a specific period of time in fixed feed in tariff. Feed in premiums apply a payment level which is based on a premium offered above the market price for electricity; this premium can either be constant, or it can vary based on a sliding scale [31,32].

2.6 Feasibility Analysis

In order to understand the project finance, we applied an overall approach for calculations. Internal Rate of Return (IRR) and Net Present Value (NPV) calculations are executed. Since the capacity and annual power output of the project is not clarified yet we determined the cases according to the limits. For instance the capacity is planned between 700 MW and 1100 MW. Moreover the annual power output is estimated at between 3 TWh and 5 TWh. Accordingly the scenarios consist of three options are:

- 700 MW capacity - 3 TWh annual production – 1.700.000 Euro initial investment,
- 900 MW capacity - 4 TWh annual production – 2.100.000 Euro initial investment,
- 1100 MW capacity - 5 TWh annual production – 2.500.000 Euro initial investment.

Net Present Value (NPV), is a method analysing an investment's or project's profit margins. For instance, if the NPV is positive, then the project or investment is profitable. Furthermore, in the NPV positive case, the gain from the project is bigger than the initial investment. If the NPV is negative, that means the project or investment is not feasible which refers to economical losses. NPV can be calculated automatically by formula on Excel. Required data for calculation of NPV on Excel are:

- Initial investment,
- Fix costs,
- Discount rate,
- Project lifetime.

Internal Rate of Return (IRR), is another method for evaluation of investments or projects. IRR is the discount rate which makes an investment project's NPV zero. Moreover, IRR is the measure of the profitability of the project. From the investor point of view, IRR is compared with the expected profit ratio. The approach for decision making can be effected by the risk analysis of the investment. In summary, if the IRR of the project is higher than the expected discount rate, then the investment can be accepted. Otherwise, the project can be rejected. IRR is also automatically calculated on Excel by formulas. The required data for calculation of IRR on Excel is as same as NPV [33].

3. RESULTS

One of the goals in thesis is to evaluate the project feasibility by three main scenarios which covering overall characteristics of project. Three main scenarios are based on capacity, power output and initial investment. If the real life case would slightly differ from the values rather than the chosen ones here, still the acquired results will be useful in a broad manner.

3.1 Financial

Total investment amount is considered as 1.7-2.5 billion Euro according to the official website. Therefore regarding the capacities, the investment amount is allocated to capacities in average. For instance, 1.7 billion Euro investment belongs to 700MW, while 2.5 billion Euro initial investment belongs to 1100 MW capacity. We assumed that the operation and maintenance costs as 55.000 MW/year [35]. Currently the premium amount in Estonia is 53.7 €/MWh but there is a limit which is up to 600 GWh. Considering the project's total power output there would be full or none premium at all so that we examined a long scale for prices. Nordpool market prices vary in a range between 35 and 55 €/MWh. Taking into account both premium and market prices, investor's lower limit for electricity sales price is 30 €/MWh. Meantime upper limit is 110 €/MWh. Project lifetime is 20 years. Discount rate is taken as 8% which is the average in Nordics [36].

First of all, 700 MW capacity with 3 TWh power output by 1.7 billion Euro investment scenario calculations are shown in Table 3.1. In that scenario, as the NPV and IRR values clearly highlight that electricity prices must be 80 €/MWh in order to get profit from that investment. If the electricity prices are lower than 80 €/MWh, then the project will cause huge losses. When we take a look at 110 € / MWh range, the IRR is almost double than the today's value which is quite attractive investment opportunity. Linear relation about electricity related incomes are shown in Figure 3.1.

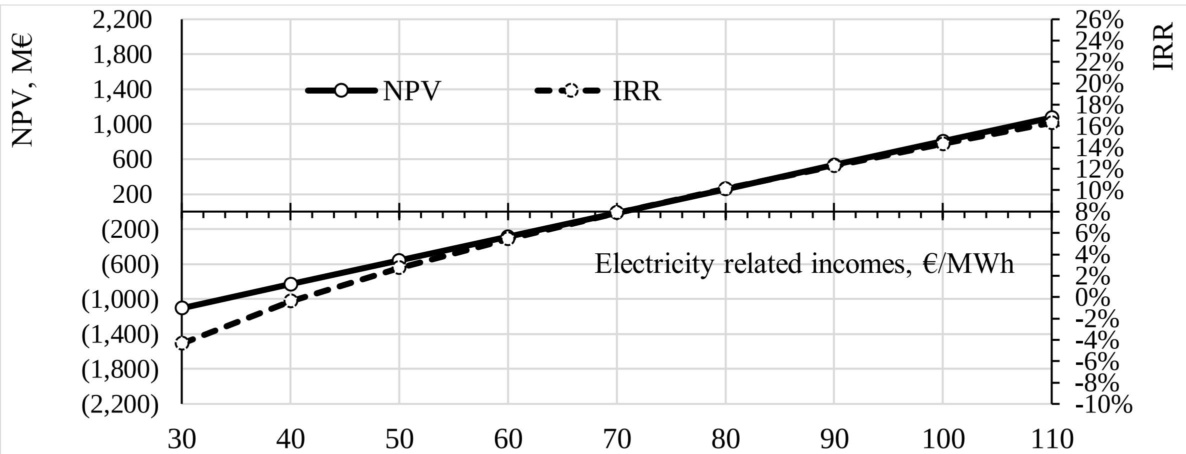

Figure 3.1 Electricity income values for 700MW capacity wind park with 3 TWh annual production

Secondly, Table 3.2 shows the data of 900 MW capacity with 4 TWh power output by 2.1 billion Euro investment. In that case minimum electricity price should be 70€/MWh to have a sustainable financials during lifetime of project. Lower than 70€/MWh means loss. If the electricity prices realize like 90 €/MWh, then the revenue is almost 878 million Euros at all. Electricity related incomes naturally increase with uprising electricity prices along with NPV and IRR which is shown in Figure 3.2.

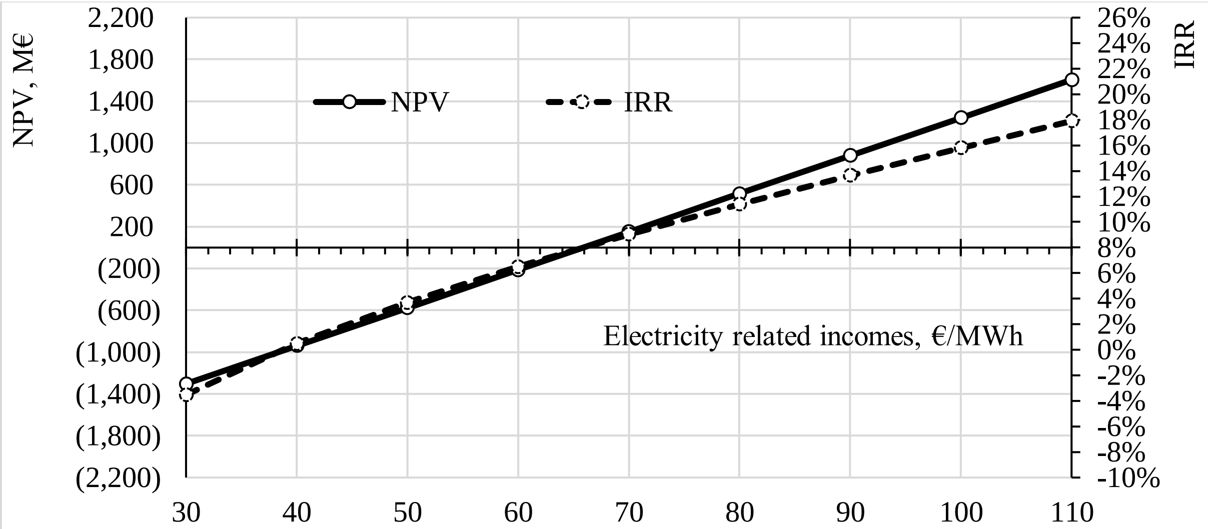

Figure 3.2 Electricity income values for 900MW capacity wind park with 4 TWh annual production

Finally, the most expensive scenario is shown by Figure 3.3. If the installed capacity of wind park is 1100 MW by 2.5 billion Euro initial investment with 5 TWh annual production, then the acceptable electricity price is 70 € / MWh. Below that range project fails financially. However if the electricity prices reach 110 € / MWh, then that risky investment create enormous profit by 17.9 % IRR. The relevant calculations are shown in Table 3.3.

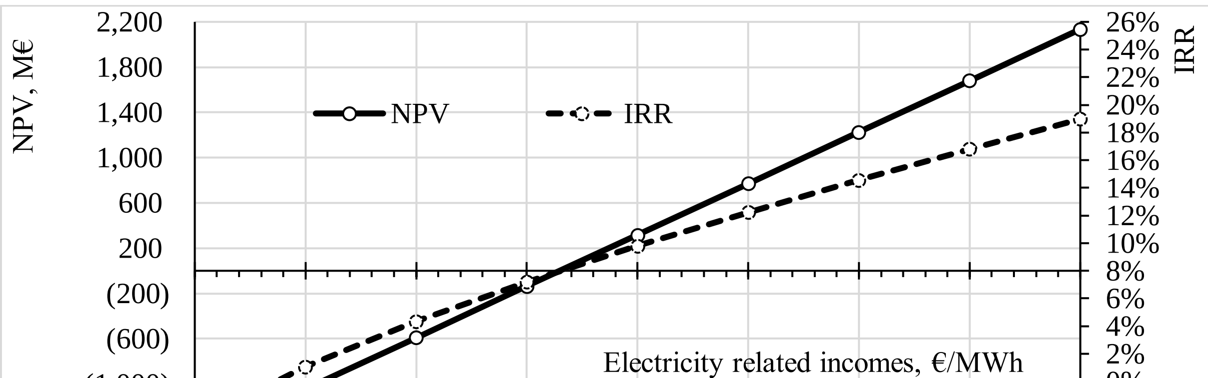

Figure 3.3 Electricity income values for 1100MW capacity wind park with 5 TWh annual production

3.2 Environmental

The Greenhouse Gas (GHG) emission factor is taken into account as 1086 tonnes CO_2 per MWh. 2017 Estonia total electricity production is 12 060 GWh according to official government unit for statistics [37]. Consequently the base CO_2 emission level is estimated as 13.097.160 tonnes by multiplying the total electricity production by GHG emission factor. All the values are shown in Table 3.1.

Table 3.1 Base levels for GHG emission rates

Title	Value	Unit
Electricity Generation	12060	GWh
Average electricity CO2 emission factor in Estonia	1,086	tCO_2/MWh
Base CO_2 emission level	13097160	tCO_2

Moreover, the positive effects of Hiiumaa Wind Park on GHG emission reduction along with power output range between 3-5 TWh are shown in Table 3.2.

Table 3.2 Wind park position effect on CO2 emission rates

Electricity production, TWh	3	4	5
CO_2 emission reduction, tCO_2	3.258.000	4.344.000	5.430.000
CO_2 emission reduction, %	25%	33%	41%

From the environmental point of view, greenhouse gas emission reduction effect is significantly essential to realize the project. If the project is established by the minimum capacity by 3 TWh annual production, Estonia's whole CO_2 emission level will be reduced by 25%. Accordingly 4 TWh and 5 TWh scenarios, will reduce 33% and 41% respectively. Considering the sustainability of future generations' energy needs, this amount of greenhouse gas emission reduction is extremely necessary.

4. CONCLUSIONS

Electricity prices must be minimum 70 €/MWh in all scenarios which is breakeven point for investors. None of the investors would prefer such return with that amount of money. They would like to gain much more return in long range. Besides premium rates are not guaranteed because of Estonia's total premium payment is worth 600 GWh. One option can be to guarantee a special allowance for Hiiumaa wind park project with regards to its strategic importance which is the first offshore wind park in Estonia. If that advantage is realized, then the electricity price expectations could be analysed closer. Afterwards, if the price expectations are 100 €/MWh or above, then the feasibility analysis shows the huge profit with a guaranteed payment. On the contrary, if electricity prices remain below 70 €/MWh, the project will be complete financial loss which is undesirable.

Regarding the selection of capacity for the wind park, 700 MW capacity can be recommended. From the investor point of view, whatever the calculations show, reality matters. First coming to the market is usually risky. In order to minimize that risk, 700 MW would be wise choice rather than 900 MW or 1100 MW as an investment suggestion. Capacities higher than 700 MW, bring more profit but create much more loss if the electricity prices are unexpectedly low. In any case, if there is price stability, there would be capacity addition in the upcoming years. For instance, 700 MW capacity wind park could be improved to 900 MW after 5 years by addition of several wind turbines if the business is going well.

Hiiumaa Wind Park will reduce Estonia' s national greenhouse gas emission level by 25% at least. It would be 33% or even 41% if the capacity is increased. Greenhouse gas emission reduction should be supported also from the government side for the sustainable environment for new generations. The reduction of the gas emission of Hiiumaa Wind Park is equal to case which almost 600 000 cars or trucks are not used in the traffic. That is very promising with regards to European Union environmental criterias.

Moreover, maritime spatial planning for the coastal areas of Estonia must be clearly identified by government. There are many shortcomings about the procedures of maritime spatial planning where the maps show available locations for wind parks. This availability is provided by fundamental researches for sea ecosystem, fish and ship traffic. Lack of sea planning, put delays or obstacles on project development. If sea locations would be ready and approved by the government, the investors would be more willing to establish wind farms.

SUMMARY

The aim of thesis project is to understand if the Hiiumaa Wind Park is financially feasible or not. In order to make the right decision from the investor viewpoint, each scenario is investigated according to all possible electricity prices. Therefore the investor can make forecasts about the future of the Hiiumaa Wind Park. After the calculations are done in Microsoft Excel program, the scenarios belonging to each capacity are examined. Key findings show that project's total capacity has significant effect on the decision. Not only the electricity related incomes and power production are analysed, but also greenhouse gas emission reduction values are calculated to realize the positive effect of the project on environmental basis.

First Estonian offshore project, Hiiumaa Wind Park planning is based on a capacity between 700 MW and 1100 MW along with 3-5 TWh annual production by 1.7-2.5 billion Euro investment. First of all, the investment amount is allocated according to capacities. For instance 700 MW capacity goes with 3 TWh annual power output by 1.7 billion Euro investment. Then NPV values are calculated to see if the project is profitable or not during 20 years of lifetime. Up to date Nordpool electricity market prices and Estonia premium for renewables are taken into account. Therefore the electricity price range is determined as 30 to 110 Euro per MWh. For example, 1100 MW capacity with 5 TWh annual production scenario creates 1.2 billion Euro NPV if the electricity is priced 90 €/MWh in average. In order to visualize the revenue increase, the graphs are also added which highlight the linear trend between electricity prices and NPV with IRR.

Moreover, CO_2 emission levels are calculated due to project's possible scenarios. In any case, significant positive effect will be gained. Investors always pay attention for the financials in the first place. Environmental effects are not taken into consideration as much as financials. Nevertheless, Estonia government can take that as an opportunity to offer various extra support or opportunities to attract investors while getting benefits for environment in terms of CO_2 reduction.

Another point is that current premium amounts for renewables are not able to cover huge investments like Hiiumaa. Furthermore, offshore wind energy parks are considered as quite strategic in terms of energy management policies of countries. Due to limitless and powerful wind sources off the coast, the energy production provide great impact for meeting consumption. Especially Baltic Sea has tremendous advantages in offshore wind industry which Estonia would get benefits as well.

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APPENDICES

Appendice 1. 700 MW Wind Park NPV and IRR Calculation

	3000000	MWh	or 3 TWh	700	MW				
Year	30	40	50	60	70	80	90	100	110
0	-€ 1.700.000.000	-€ 1.700.000.000	-€ 1.700.000.000	-€ 1.700.000.000	-€ 1.700.000.000	-€ 1.700.000.000	-€ 1.700.000.000	-€ 1.700.000.000	-€ 1.700.000.000
1	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
2	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
3	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
4	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
5	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
6	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
7	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
8	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
9	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
10	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
11	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
12	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
13	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
14	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
15	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
16	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
17	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
18	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
19	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
20	€ 51.500.000	€ 81.500.000	€ 111.500.000	€ 141.500.000	€ 171.500.000	€ 201.500.000	€ 231.500.000	€ 261.500.000	€ 291.500.000
NPV	-€ 1.105.893.897	-€ 833.167.580	-€ 560.441.263	-€ 287.714.946	-€ 14.988.629	€ 257.737.688	€ 530.464.004	€ 803.190.321	€ 1.075.916.638
IRR	-4,4%	-0,4%	2,7%	5,4%	7,9%	10,1%	12,3%	14,3%	16,3%

Appendice 2. 900 MW Wind Park NPV and IRR Calculation

	4000000	MWh	or 4 TWh	900	MW				
Year	30	40	50	60	70	80	90	100	110
0	-€ 2.100.000.000	-€ 2.100.000.000	-€ 2.100.000.000	-€ 2.100.000.000	-€ 2.100.000.000	-€ 2.100.000.000	-€ 2.100.000.000	-€ 2.100.000.000	-€ 2.100.000.000
1	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
2	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
3	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
4	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
5	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
6	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
7	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
8	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
9	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
10	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
11	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
12	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
13	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
14	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
15	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
16	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
17	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
18	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
19	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
20	€ 70.500.000	€ 110.500.000	€ 150.500.000	€ 190.500.000	€ 230.500.000	€ 270.500.000	€ 310.500.000	€ 350.500.000	€ 390.500.000
NPV	-€ 1.303.537.600	-€ 939.902.511	-€ 576.267.421	-€ 212.632.332	€ 151.002.757	€ 514.637.846	€ 878.272.935	€ 1.241.908.024	€ 1.605.543.114
IRR	-3,5%	0,5%	3,7%	6,5%	9,0%	11,4%	13,6%	15,8%	17,9%

Appendice 3. 1100 MW Wind Park NPV and IRR Calculation

	5000000	MWh	or 5 TWh	1100	MW				
Year	30	40	50	60	70	80	90	100	110
0	-€ 2.500.000.000	-€ 2.500.000.000	-€ 2.500.000.000	-€ 2.500.000.000	-€ 2.500.000.000	-€ 2.500.000.000	-€ 2.500.000.000	-€ 2.500.000.000	-€ 2.500.000.000
1	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
2	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
3	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
4	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
5	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
6	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
7	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
8	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
9	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
10	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
11	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
12	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
13	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
14	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
15	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
16	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
17	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
18	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
19	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
20	€ 89.500.000	€ 139.500.000	€ 189.500.000	€ 239.500.000	€ 289.500.000	€ 339.500.000	€ 389.500.000	€ 439.500.000	€ 489.500.000
NPV	-€ 1.501.181.303	-€ 1.046.637.441	-€ 592.093.580	-€ 137.549.718	€ 316.994.143	€ 771.538.004	€ 1.226.081.866	€ 1.680.625.727	€ 2.135.169.589
IRR	-3,0%	1,1%	4,3%	7,2%	9,8%	12,2%	14,6%	16,8%	19,0%