MULTI-CRITERIA DECISION ANALYSIS

IN WIND POWER PROJECT DEVELOPMENT:

CASE STUDY IN LATVIA

Thesis project in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE WITH A MAJOR IN WIND POWER
PROJECT MANAGEMENT

UPPSALA
UNIVERSITET

Uppsala University
Department of Earth Sciences, Campus Gotland

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Approved by:

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ABSTRACT

Wind Power Project Development is a complicated, capital and resource-inclusive process, where a wide variety of factors have to be considered and several stakeholders have a significant say in the process. Decision making in such an environment is complex and has to be approached comprehensively. In order to sustain a structured and clear decision making process, sustainable energy industry has recognized Multi-Criteria Decision Analysis (MCDA) method as a suitable set of tools to aid in the decision making process. One of the MCDA tools – PROMETHEE II, has been examined in this master thesis, to evaluate its eligibility as a decision making aid in wind power project development.

To structurally and realistically evaluate the tool, it has been applied on a case study in Ventspils region, in Latvia. The author of this thesis has a preliminary agreement with the owners of the sites to develop the project, therefore, this thesis has a strong potential for a practical implementation in future. Four scenarios have been developed for an evaluation, contributing to four variations of different amount of turbines erected, with two different hub heights, on two differently sized sites. The scenarios are assessed based on the interests of six key stakeholders. Their opinion on twelve criteria is examined.

Input data for each criterion has been generated via WindPro and MS Excel software or by authors assessment based on the researched literature. PROMETHEE II is used to extrapolate a comprehensive and clear representation of the results.

The evaluation of the MCDA method proved that MCDA tools, and PROMETHEE II in particular, can provide excellent support in decision making in wind power development. Wide variety of input data, as well as the various and often contradicting interests by different stakeholders can be taken into account, while, at the same time, a clear result that can assist in decision making, is generated.

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NOMENCLATURE

AEP	Annual Energy Production
EIA	Environment Impact Assessment
EU	European Union
FIT	Feed-in Tariff
GHG	Green House Gas Emissions
LCOE	Levelized Cost of Electricity
MCDA	Multi-Criteria Decision Analysis
NGO	Non-Government Organization
NPV	Net Present Value
O&M	Operation and Maintenance
RES-E	Electricity Production from Renewable Energy Sources
PP	Power Plant
WACC	Weighted Average Cost of Capital
WTG	Wind Turbine Generator

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1. Introduction

Wind Power Project Development is a complicated process, where several factors of importance have to be considered, and a number of different stakeholders have a significant input in decision making. On top of that, wind power development is highly capital-intensive, which requires sharp decision making in the whole process of the development. A crucial factor of the development is creating alternatives, yet, even more importantly, a comprehensive and clear method to assess the alternatives and chose the most preferred one is essential. The industry has identified the importance of having a method to aid in the decision making and the Multi-Criteria Decision Analysis (MCDA) tools are increasingly used in the sustainable energy sector to assist in reaching decision in a comprehensive, but easily presentable way (Diakoulaki & Karangelis, 2007) (Wang, et al., 2009).

This thesis aims to put the MCDA method on test and evaluate its eligibility as a decision making aid tool in wind power project development with a help of a case study in Ventspils, Latvia. Consequently, two research questions are developed:

1. *Based on an MCDA analysis, which is the preferred scenario for development of Targale Wind Farm?*
2. *Are MCDA tools eligible to help in decision making in Wind Power Project Development?*

The evaluation in this thesis is based on an actual potential project site in Ventspils region, in Latvia. There is a heavy practical implication for this study project, since the author has reached a preliminary agreement with the owner(s) of the site(s) for a wind power project development in future. As a result, this project is closely tied to the sustainable energy market situation in Latvia. The development of legislation and support schemes currently in place in Latvia are discussed in the first part of the thesis, followed by a closer examination of the MCDA tools. The MCDA tool examined in this thesis is PROMETHEE II, which is utilized by the industry because of its simplicity as well as its capacity to approximate the way human mind expresses and synthesizes preferences when multiple contradictory decision perspectives are to be considered (Diakoulaki & Karangelis, 2007).

Further, the specific case is examined, where four scenarios are developed for investigation, first two of them exploiting the smaller project site holding with three turbines with either 91 or 141 meters of hub height. The other two scenarios, Scenarios 3 and 4, examine the same turbines of 91 or 141 meters of hub height, holding seven or six turbines, respectively. The site and scenarios are chosen according to both, the practical implementation and the aim of this thesis – to examine how eligible MCDA tools are when differently sized project scenarios on the same site are compared.

Finally, the results of the analysis are presented and the ability of the MCDA tool is discussed. Conclusion serves as a reflection of the practical implication of this thesis, depicting how MCDA performed in this actual case study and how eligible MCDA methods are in decision making in Wind Power Project Development.

2. Literature Review

This section of the thesis presents a background of the topics underlying the whole project. First part of the literature review provides a detailed explanation of the current wind power market situation in Latvia. It is followed by a section dedicated to a further explanation of the support scheme for wind power development currently in place in Latvia. Finally, since MCDA is used to generate results in this thesis, an overview, of what recent literature says about using MCDA in wind power project development, is presented. The aim of this structure is provide a sufficient informational background for the reader to be able to follow further development of the thesis work.

2.1 Overview of the Latvian Wind Energy Market

In order to sufficiently present the current market situation in a particular country, it is helpful to reference the situation in the country to similar markets. For this reason, in order to provide a representative overview of the state of the wind power industry in Latvia, the current situation in Latvia is referenced to the other two Baltic States – Lithuania and Estonia. Since the market potential and the conditions after regaining independence in early 90s are historically similar for all three counties, the Baltic States are commonly referenced as a singular market. However, as illustrated further, it is not necessarily the case.

The Baltic States, being growing economies and actively adjusting to *fit* the European and Western standards, do realize the necessity of developing the wind electricity sector. This arises from the concerns of the Baltic States regarding the energy security, competitiveness, and sustainable development of energy sectors (Bobinaitė, 2015). These are factors that are important for the development of the economy as a whole, and therefore, should be approached with care. The renewable energy sector is of a significant importance to the overall sustainability of a country. Some of the more discussed contributions are mitigation of CO_2 emissions (Roos, et al., 2012) and higher independence from net energy import (Streimikiene, et al., 2007). These contributions, however, are not the only factors where renewable energy sector contributes to the sustainability of a particular country. As illustrated by (Bobinaitė & Konstantinavičiūtė, 2010), businesses, operating in the renewable energy sector, also contribute to social aspects, such as employment. More so, the renewable energy sector has a potential of adding a significant share on economic growth – particularly, through adding to countries gross domestic product (GDP) and its component – gross capital formation (Bobinaitė, et al., 2011). Bobinaitė (2011) takes this even further, stating that development of the renewable energy is valuable for macroeconomics, since the use of renewable energy mitigates a slump of real GDP during economic recession (Bobinaitė, et al., 2011). So, it is obvious that the development of the renewable energy sector has a huge potential in driving the overall economic development of a country in general. Well-structured and developed energy law can serve as a fundament for stable development of a significant sector in the country economy. Therefore, this begs the question – what is the current energy market situation in the Baltic States and, more importantly for this research – what is the current situation in Latvia?

To set the stage of explaining how successfully the Latvian policy makers have utilized the opportunity to develop such a critical sector as renewable energy sector and energy sector in general, the current situation in wind power development, and how Latvia currently compares to the other Baltic states, is presented.

Latvia is one of the Baltic States located in Northern Europe, by the Baltic Sea. With a sufficient sea border, spreading over 498 km (Central Statistical Bureau of Latvia, 2015), there is a substantial wind power potential, particularly in the coastal regions, where the wind speed averages above 8 m/s annually (See Fig. 1). However, although a key prerequisite, sufficient wind resources is not the only criteria for wind power development. The seasonality of the energy production is an important factor for the grid compliance and energy generation in the national level. Figure 2 illustrates the seasonal characteristic of the energy potential in Latvia.

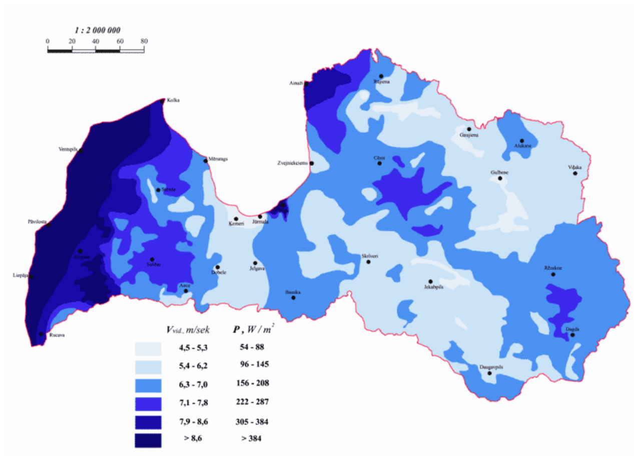

Figure 1 – The average wind speed in Latvia at 100 meters height (Wind Energy Latvia, 2016)

More so, as illustrated in Figure 2, the wind potential is generally higher in the autumn and winter months, when the demand for electricity is generally higher, ensuring energy generation in the time of the year when it is needed the most (Bobinaitė, 2015).

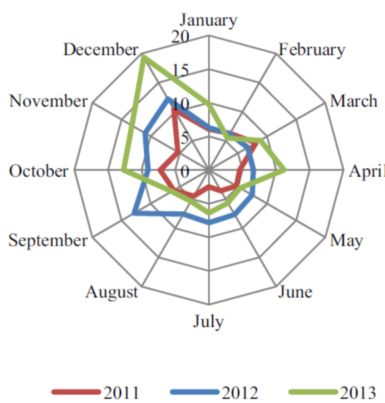

Figure 2 – Production volume of electricity produced in wind PPs in Latvia.
Adapted from (Bobinaitė, 2015)

This not only enables wind power to be a sufficient addition to the overall power generation, but also makes Latvia less dependent on electricity imports during the winter and autumn months (Bobinaitė, 2015).

However, despite the sufficient potential for wind power development in Latvia, the operational efficiency is higher in Estonia and Lithuania, when profitability is analyzed (Bobinaitė, 2015). This is a definite indicator, that there are faults in the other part of the equation of wind power development – the legislation and economical driving factors of the industry. Further indicators to an underlying problem in Latvian wind energy sector, according to research by Bobinaitė (2015) suggest that wind power development companies in Latvia demonstrate middle, but increasing probability of bankruptcy (high probability when different calculation criteria are used) (Bobinaitė, 2015). Generally, since the wind power development is very capital-intensive, it is considered that companies operating in the wind energy sector and developing wind power projects are financially sustainable and “healthy” (Bobinaitė, 2015). More specifically, the companies are able to ensure returns to investors, are liquid, and efficiently use acquired assets (Bobinaitė, 2015). In other words, companies in wind energy sector should have a strong financial and sustainable fundament to be able to effectively operate in the market. With that in mind, the results from a research by Bobinaitė (2015) which revealed that the financial sustainability of the companies in the Baltic States is moderate are rather worrying.

The development in the last decade in the RES-E sector in Latvia shows that the country has achieved the highest share of RES-E in gross inland electricity consumption within the Baltic States - 15.5% in 2013 (when electricity produced in large-scale PPs is not considered) (Bobinaitė, 2015). Large-scale PPs and hydro, in particular, are excluded in this presentation due to the fact that, as a result of three massive hydro power stations on the biggest river of Latvia, Daugava, hydro covers by far the largest share of renewable energy produced in Latvia and in the Baltic States (see Fig. 3). Since neither Lithuania nor Estonia currently have such a high share of production of hydro or any other renewable energy source, for a fair comparison, it has been excluded in this representation.

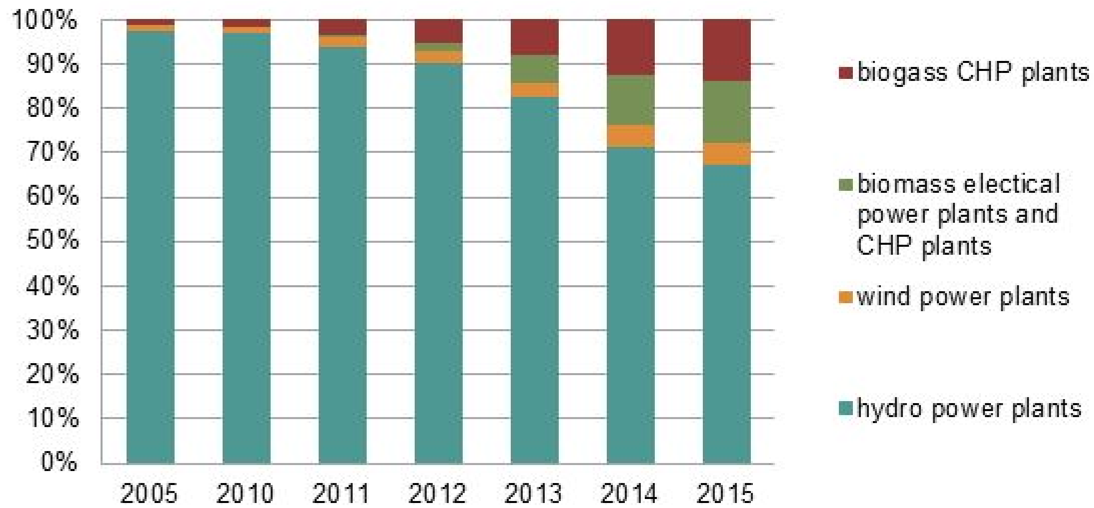

Figure 3 – Electricity Produced from Renewable Energy sources in Latvia (Central Statistical Bureau of Latvia, 2016)

Moreover, Figure 3 provide a clear illustration, indicating that growth of the renewable energy production in the last decade in Latvia is essentially linked to doubling the production of electricity using biogas and solid biomass PPs (Bobinaitė, 2015). Although production volume of wind electricity experienced significant increase of 25% in 2013 alone, the volume and share of wind electricity in Latvia remained the lowest within the Baltic States. More precisely - 120GWh of wind electricity was generated in 2013, which resulted to a modest 2.7% in gross inland electricity consumption (Bobinaitė, 2015). Limited development of wind power and increasing production of electricity using biogas and solid biomass PPs is an outcome of a not particularly effective and potentially lobbied energy production support system, which is analyzed in detail in the next section of this thesis.

Before that, though, it is important to illustrate where the Latvian RES-E industry, and wind power in particular, does stand in its development at the moment. For the Baltic States, the most significant stimulus for the development of RES-E was the announcement of the *Directive 2009/28/EC*, issued in April 23, 2009. The directive was followed by the development of *National Renewable Energy Action Plan of Latvia* (Bobinaitė, 2015). It is important to mention, that the Baltic States started developing their RES-E sectors from different bases, depending on the infrastructure which had already been created, the availability of natural and economic resources, as well as the share of RES-E required to comply with the EU regulations. As a result, the three Baltic States reached different development levels in the RES-E sector, with Latvia lagging back significantly, compared to the development of Estonia and Lithuania (see Fig. 4).

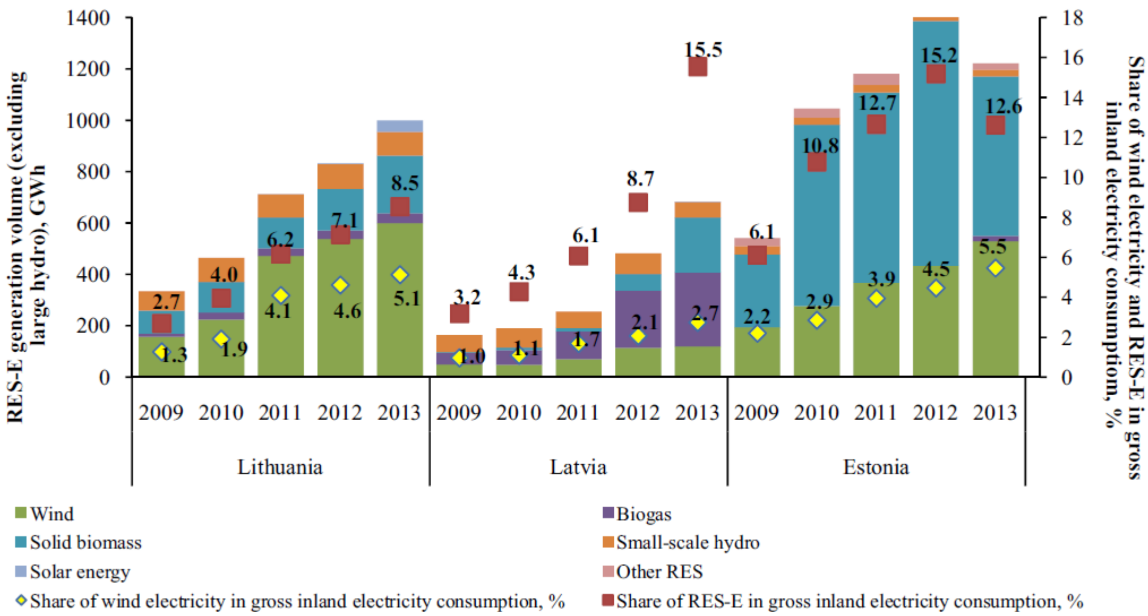

Figure 4 – Tendencies of production volume of RES-E (excluding large-scale hydro), share of wind electricity and share of RES-E in gross inland electricity consumption in the Baltic States during 2009 - 2013 (Bobinaitė, 2015)

As illustrated in Figure 4, Latvia started the development in 2009 from lower base of a development; therefore, not surprisingly, slightly higher growth rates were reached (Bobinaitė, 2015). Due to extensive development of electricity production from biogas and biomass and a low RES-E base in 2009, when a planned development was initiated due to the earlier mentioned directives and action plans, the volume of RES-E was 4.1 times higher in 2013 than in 2009 (Bobinaitė, 2015). Although enticing, these numbers do not present an accurate picture of the development. For example, in 2013, the RES-E generation in Latvia was 31.8% lower than in Lithuania and 44% lower than in Estonia (Bobinaitė, 2015). This fact also explains setting moderate interim goals for wind sector development in Latvia. As illustrated in Figure 5, in 2013, a total capacity of 67 MW of wind power had been installed in Latvia, which, compared to Lithuania and Estonia is fairly low. However, even such a low installed capacity was enough to over exceed the interim goal of RES-E set by the government based on the regulations from the EU, which was 63 MW (Bobinaitė, 2015). To once again clarify, the low interim goals are a result of the large share of hydro power generated in Latvia (Central Statistical Bureau of Latvia, 2016); therefore extra generation from RES-E is not necessary to comply with the EU regulations.

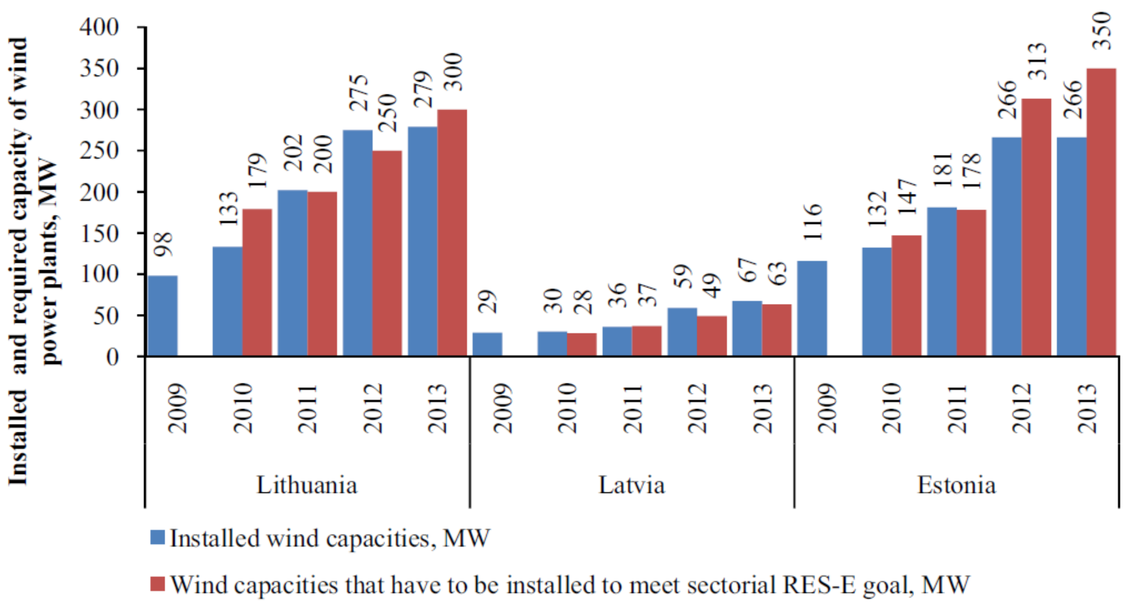

Figure 5 – Tendencies of installed wind capacities and capacities that are needed to meet sectorial RES-E goals in the Baltic States
(Bobinaitė, 2015) & (Central Statistical Bureau of Latvia, 2016)

Moreover, according to the global EU policy, the EU countries took the obligations to reach the share of RES-E in gross final consumption of energy by 20% in 2020 (Bobinaitė, 2015). Latvian government decided to take this much further, and decided to increase the share of energy from renewable sources to 40% in 2020 (European Parliament & Council, 2009). Although it might generally be considered as unreasonable, due to large share of hydro power generation, the target is achievable. Subsequently, such an ambitious target has the potential to generate a basis for the business entities of the Baltic States to successfully develop the renewable energy sector, securing the certainty and a long-term stability they need to make rational, sustainable investments in the renewable energy sector (European Parliament & Council, 2009).

To summarize, the use of RES-E is recognized to be important in the Baltic States, and the countries realize the necessity of wider production and consumption of energy from renewable sources. The main driving factors for the development are the Baltic States' concern of energy security, competitiveness and sustainability of energy sectors (Cabinet of Ministers of the Republic of Latvia, 2006). Numerous legislative acts, strategies, and legal considerations have been established in order to drive the development. To name a couple - the *Latvian Regulation on the Guidelines for the Use of Renewable Energy Sources (RES) during 2006–2013* (Cabinet of Ministers of the Republic of Latvia, 2006) was developed in 2006, followed by the *National Renewable Energy Action Plan of Latvia* (European Comission, 2009) in 2009. These legal acts also discuss wind power development, showing that wind electricity has a potential and will play an important role in fulfilling the mandatory targets (European Comission, 2009). Although this is generally a good start and it could be considered that the Baltic States have made a progress towards increasing production and consumption of wind electricity, it has been working differently in different Baltic States (Bobinaitė, 2015). The variations in development are mostly due to the discrepancies and aspects of the support systems, and are discussed in more details in the next section. The fallout, however, is that Lithuania and Estonia are the leading in terms of installed capacity and efficiency of wind farms, with Latvia lagging back considerably (Bobinaitė, 2015). Lithuania and Estonia demonstrate rapid wind electricity sector development rates, while the sector is still in early development stage in Latvia, which, solely from wind power developers perspective, seems to so far been a waste of an excellent development potential (Bobinaitė, 2015).

So, an important final note on the current status of the development in wind power sector is that, despite reasonably attractive wind resources, suggestions and regulations from the EU and actual strategies and action plans for wind power development, Latvia is significantly lagging back from its close neighbors Estonia and Lithuania, regardless of similar starting positions when the development was initiated a less than a decade ago. Large scale hydro power, which already is covering a significant part of the electricity generation in Latvia, has turned out to be a justifying factor for slower development of other renewable sources. As a result, the interim targets for wind power development were set low, limiting the drive for the development. However, those are not the only limiting factors. RES-E support systems, which, by a definition are established to drive the development of renewable energy, have not served that purpose for all renewable energy sources in Latvia. This, rather interesting phenomena, is explained in more detail in the next section of the thesis.

2.2 Support Schemes for Wind Power Development in Latvia

A well balanced and well planned support system is a crucial part of development in an early development phase of any energy sector. Transparency and coherency of the support system is essential for its successful implementation and for the security of the developers. For a better illustration on how the RES-E support system has been developed in Latvia it is necessary to look at the early versions of the wind power sector regulations. Even more so because the system is accepted and implemented by the governments and regulating authorities, decisions are meant to be long lasting (Bobinaitė, 2015). Besides, as the case study of this thesis is directly related to an actual potential development of a project in Latvia, the peculiarities of the support schemes are relevant factors for the development possibility and the sustainability of wind electricity companies and the sector as a whole (Bobinaitė, 2015).

Back in 2005, shortly after Latvia joined the European Union, a brand new *Law on Electricity Market* (Parliament of Latvia, 2005) was accepted. It set an ambitious national target for the share of 49.3% of RES-E in electricity consumption during 2006–2010 (Bobinaitė, 2015). The next advancement, based on the *Law on Energy Market*, came a year later, when, in October 31, 2006 the Cabinet of Ministers of Latvia approved the *Regulation No. 835* on the *Guidelines for the Use of RES during 2006 - 2013* (Cabinet of Ministers of the Republic of Latvia, 2006). The guidelines essentially determined the main objectives of renewable energy policy in Latvia. The main objectives as stated in the guidelines were:

- to increase the share of renewable energy in Latvian energy mix and, in a long run, to contribute to reduction of GHG emissions;
- to promote Latvian security of supply;

- to increase the share of RES-E in electricity consumption to 49.3% in 2010 electricity consumption (Bobinaitė, 2015).

Further, the first satisfactory regulations aimed to the support of wind energy came into effect only in July 24, 2007, when *Regulation No. 503* came into force (Bobinaitė, 2015) This dictated the rules for the production of electricity from renewable energy sources (Cabinet of Ministers of the Republic of Latvia, 2007). The new regulation established a clearer and more transparent feed-in tariff scheme for the promotion of wind electricity. This, as discussed earlier, is a crucial factor for wind power development. The new regulation also did set a mandatorily procured and supported volume of wind electricity for 2007–2010, expressing this volume as a percentage share of total electricity consumption in Latvia (Bobinaitė, 2015). The planned outcome of this regulation was to increase the share of wind electricity in electricity consumption from 1.48% in 2007, to 5.37% in 2010 (Bobinaitė, 2015). *Regulation No. 503* can be, however, considered as a tentative regulation, created with an intention to be adjusted when the next EU-wide policy will be published. The peculiarity of a feed-in tariff introduced in the regulation was its link with a natural gas price, which was unprecedented in the other Baltic States and most of the support systems in other EU countries (Bobinaitė, 2015). Moreover, there were several factors in this regulation, which has been heavily criticized for actually setting limitations, instead of driving the RES-E development. For example, limitations on the capacity utilization time, when PP had work at least 3000 h per year. Thus, according to Leikučs and Strīķis (Leikučs & Strīķis, 2011) such a feed-in tariff scheme was not appropriate from the perspective of producers. As a result, although installed wind power capacity and production volume were increasing, the progress was moderate (Bobinaitė, 2015).

In April 23, 2009, the *Directive 2009/28/EC* was issued by the European Union. *Directive 2009/28/EC* was developed, adjusted and implemented in all the EU countries and its main aim was the promotion of the use of energy from renewable sources, emphasizing that the increasing use of energy from renewable sources is an important factor in reducing the greenhouse gas (GHG) emissions, it would promote the security of energy supply, drive the technological developments and innovations, and finally, create new opportunities for employment and regional development (European Parliament & Council, 2009).

As a part of the *Directive 2009/28/EC*, the *National Renewable Energy Action Plan* (European Comission, 2009) was developed for Latvia. According to the *National Renewable Energy Action Plan of Latvia* (European Comission, 2009) a total of 416 MW (236 MW on-shore and 180 MW off-shore) of wind power plants (PPs) should be installed in Latvia by 2020, which would generate up to 910GWh of electricity. For a reminder, at this moment, in 2017, there is a little less than 70 MW of wind PPs installed in Latvia. This is a clue that either an extensive deployment of wind PPs is planned in the next couple of years or, which is more likely, the system has not generated the planned results. Further timeline of the following decisions might help to explain what has not gone according to the plan.

Based on the *Directive 2009/28/EC* and the *National Renewable Energy Action Plan of Latvia*, the earlier described *Regulation No. 503* was updated in March 16, 2010 and took the form of *Regulation No. 262* (Cabinet of Ministers of the Republic of Latvia, 2010). The most significant change in the refurbished *Regulation No. 262* was an updated formula for setting the feed-in tariff on wind electricity, as well as it set a mandatorily procured and supported volume of wind electricity for 2010–2020 (Bobinaitė, 2015). A feed-in tariff also became dependent upon the exchange rate, installed capacity, and a fixed certain coefficient (Bobinaitė, 2015), resulting to a very attractive compensation for electricity generated in a wind PP, ranging comfortably over 100€/MWh (Cabinet of Ministers of the Republic of Latvia, 2010), which was one of the highest in Europe. Other characteristics of the feed-in tariff dictates that it is provided for 20 years from the start of PP operation – the full amount is being awarded in first 10 years of operation, and is being reduced by 40% on years 11-20 (Bobinaitė, 2015).

In more detail, the idea of feed-in tariff scheme applied in Latvia through the *Regulation No. 262* is that wind electricity producer receives a fixed amount per 1 kWh generated regardless of the costs of generation or the price (Haas, et al., 2011). There are a number of advantages recognized for this support scheme. First of all, it allows reducing over-financing of some technologies which has a lower cost (Cinelli, 2011). Further, it has a potential to increase effectiveness of the support scheme, if set rightly (De Jonghe, et al., 2009). Additionally, from the perspective of the producers, there is technically no necessity to compete in the market (Verbruggen & Lauber, 2012). And finally, this support scheme allows exploiting different sites using different plant sizes (Held, et al., 2014).

The *Regulation No. 262* has remained unchanged and is currently in place, although with one major setback - the existing support scheme - the feed-in tariff, which also includes elements of a quota system and tenders, is under revision and closed for new installations since 2011 (Upatniece, 2017) and is yet to be reopened as for now, April 2017. Speculations are that the system will be on hold until 01.01.2020 (Upatniece, 2017). This is due to cases of corruption, lack of transparency, and unhealthy business practices, which the unusually attractive feed-in tariff has facilitated (Upatniece, 2017). Furthermore, as touched upon earlier, the *Regulation No. 262* is also criticized by actually putting restrictions for RES-E sector development, instead of driving the development (Leikučs & Strīķis, 2011). As per Leikučs & Strīķis (2011) the requirements held for RES-E producers are, once again, unrealistic. For instance, hydro PPs should be operating at least 5000 h a year, wind PPs should fully generate 3500 h, and all other PPs (including sun) – 8000 h a year, which is very close to the available potential or even over the physical possibility (as it is with 8000h/year for solar PPs) (Leikučs & Strīķis, 2011). These unreasonable regulations are compulsory in order to participate in the feed-in tariff system, making it extremely difficult for the developers to comply and participate in the RES-E sector development. As a result, after the implementation of these regulations, only solid biomass, landfill gas, and, to a very limited extent - wind PPs have been installed (Leikučs & Strīķis, 2011).

Therefore, it is safe to conclude that the support system in Latvia, although intentionally intended to drive RES-E development, does not work effectively, in some cases even setting limitations for RES-E development. According to Leikučs & Strīķis (2011) the basic barriers set by the existing system are of a structural and legislative manner, as well as the existing information asymmetry between RES-E producers and the state. Moreover, the existing legislation does not always correspond with the long-term policy developed by the Cabinet of Ministers and suggested by the EU (Leikučs & Strīķis, 2011). Therefore, the theoretically attractive feed-in tariff, which is one of the highest in the EU, has not, so far, resulted to a significant impact on promotion of RES-E production increase in Latvia (Leikučs & Strīķis, 2011). Leikučs & Strīķis (2011) have also concluded back in 2011 that, if the government will continue existing RES policy, it is very unlikely that Latvia will reach the promised goal for 2020 (Leikučs & Strīķis, 2011).

Now, six years later, in 2017, the situation has not significantly improved and the main legislative and institutional barriers, suggested by Leikučs & Strīķis (2011) and compiled in Table 1, are still valid.

Table 1 – Legislative and Institutional barriers in RES-E support system in Latvia
Own compilation from (Leikučs & Strīķis, 2011)

Legislative Barriers	Institutional Barriers
Since Latvia continues to lack a basic renewable energy law, despite improvements of energy security, adjustments of energy structure, cannot be effectively carried out.	Lack of long-term willingness in governmental level (e. g. disagreements in Ministries level – between Agricultural, Economics, Environment etc.) to fulfil goals in planning documents. Therefore, comprehensive development of important strategies and policies of energy development is problematic.
Cabinet of Ministers launches the most important regulations, but they in many ways contradict long-term planning documents. Regulations are reactionary by character (reacts to certain processes) but not counted first.	Investments in RES-E have been severely restricted by unfair governmental regulations and unpredictability.
Existing legislation practically leaves out of game local self-governments.	Barriers between research institutions and experts. Research often contains outdated or delayed information, interconnection is low, they often overlap with each other, information flow between researchers, decision makers, and investors problematic.
Frequent and short-term changes in main legislation corpus, for example, in Added value tax law.	

To summarize, at the moment, there is an existing legislation and support system in place, however, it has been heavily criticized by the researchers and industry professionals when it was issued, and is currently on hold due to cases of corruption, lack of transparency, and unhealthy business practices that was caused by the system and the attractive feed-in tariff, in particular. Also, the existing legislation is criticized by setting unrealistic requirements and actually facilitating barriers for the RES-E development instead of driving it. In February 9, 2016, *Energy Development Guidelines 2016–2020* were released, setting the goal to develop a new national support mechanism for electricity production from RES until 2018 (Upatniece, 2017). The developers and the whole energy sector can only hope that the new update will constitute more clarity and transparency in the system and the RES-E sector will be able to finally kick-start the development properly.

2.3 MCDA in Wind Power Development

2.3.1 The Background of the MCDA Tools

With the current state of the legislation and support system for RES-E presented, this section discusses the tool, which is put in test in this thesis – the Multi-Criteria Decision Analysis (MCDA). MCDA is used in this thesis to aid in the decision making when comparing the different alternatives of utilizing the project site in Latvia, Ventspils, which is used here as a reference case study.

The development of RES-E projects is a multi-disciplinary process and has to involve major decision making authorities, like governmental and non-governmental organizations, the academics, and entrepreneurs. Also, it focuses on a variety of different factors, such as national and international economy, as well as social and environmental factors (Wang, et al., 2009). As defined by the General Assembly of the United Nations, a sustainable development can be defined by reaching and satisfying the present needs without compromising the ability of future generations to meet their own needs (W.C.E.D, 1987). This is still very much true and should be more emphasized today. Hofman and Li (2009) add to the definition of sustainability, by stating that sustainability at its essence should provide a balance of social and economic activities and the environment (Hofman & Li, 2009). Wang, et al. adds that a sustainable energy sector should be able to hold a balance of energy production and consumption while ensuring minimal, or no negative impact on the environment. It is, however, also important that sustainable development gives the opportunity for a country to employ its social and economic activities (Wang, et al., 2009). This implies that sustainable energy development is a multi-disciplinary and multi-criteria sector, so an assessment method that is able to consider all the various factors and evaluates them in comparison to each other, is a crucial tool to have.

Multi-criteria decision analysis (MCDA) methods have proven to provide a significant help in decision making within the sustainable energy development sector. As per Wang, et al. (2009), with a rise of the RES-E development, variety of MCDA methods has become increasingly popular in decision-making in the sustainable energy sector. That is mainly because of the multi-dimensionality and the complexity of socio-economic and biophysical systems, that the developers have to work within (Wang, et al., 2009). Process-wise, according to Omitaomu, et al. (2012), MCDA is a process of assigning values to alternatives that are evaluated along multi-criteria (Omitaomu, et al., 2012). Anwarzai & Nagasaka (2016) and Malczewski (2006) elaborates further - the MCDA system is designed to be able to consider a number of otherwise incomparable criteria, such as technical, economic, environmental, topography, and social aspects, combined from different sources. Furthermore, the MCDA has repeatability and capability to handle possible changes in criteria or the weights (Anwarzai & Nagasaka, 2016). For these reasons, the MCDA methods has proved aid the developers and policy makers with a decision framework, that helps to come to, or at least guide to the preference (Malczewski, 2006). Since the case study analyzed in this master thesis constitutes four different possible scenarios and a number of different stakeholders, and criteria, which can influence the decision, MCDA is expected to provide a significant input to aid in making decision the decision on which would be the most attractive scenario to be developed in this particular site.

As recognized by the researchers, the most challenging problem with MCDA is to develop the weights, that are credible and justifiable (Omitaomu, et al., 2012). The weights, being a reflection of the stakeholders' perceptions, arbitrate to the preferences of the stakeholders. So, the weights are directly dependent on the perceptions of the stakeholder, which, from one hand is exactly what is needed to achieve, but from the other hand, can be biased and sensitive to the judgement of the stakeholder.

2.3.2 The Process of MCDA Analysis

There are, however, more advantages than disadvantages of using the MCDA tools and MCDA tools are recognized to be very useful in solving the energy generation and development matters (Omitaomu, et al., 2012). MCDA is widely used in the industry to assist in making decisions related to energy planning, site selection, resource allocation, energy exploitation, energy policy, building energy management, transportation energy management, and many others (Omitaomu, et al., 2012). According to Sliz-Szkliniarz & Vogt, (2011), MCDA tools have been used as a decision making aid in the selection of the best location and site layout for many wind and solar plants in the UK, Spain, the US, as well as a number of other countries.

As these decisions are usually very complex and cover large variety of factors, the MCDA tools provide a way to simplify the decision making. As put by Wang, et al., (2009), "MCDA is a form of integrated sustainability evaluation. It is an operational evaluation and decision support approach that is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, multi-interests and perspectives, and the accounting for complex and evolving biophysical and socio-economic systems" (Wang, et al., 2009).

Essentially, the MCDA is a process of assigning values to alternatives that are evaluated along multiple criteria (Omitaomu, et al., 2012). There are a number of variations of the MCDA tools, that help with handling multi-criteria decision making, but the most commonly used in renewable energy planning are:

- Analytical Hierarchy Process (AHP),
- Analytical Network Process (ANP),
- Multi-Attribute Utility Theory (MAUT),
- Technique of Order Preference Similarity to the Ideal Solution (TOPSIS),
- Elimination and Choice Translating Reality (ELECTRE) and
- Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Polatidis & Morales, 2016) (Lee, et al., 2012) (Pohekar & Ramachandran, 2004) (Sliogeriene, et al., 2013) (Lozano-Minguez, et al., 2011).

In this thesis, to assimilate and integrate various energy, social, environmental, and economic factors in a clear, analytical and transparent manner, MCDA tool PROMETHEE II has been chosen. PROMETHEE II has been widely used and recognized for assisting in renewable energy planning and provides comprehensive, comparable, and clear results (Polatidis & Morales, 2016). PROMETHEE II has gained its popularity due to an easy application for practical requirements, clear interpretation of parameters, integration of multiple criteria as well as comprehensive implementation with limited time and resources required (Polatidis, et al., 2006).

Also, MCDA tools in general are used in order to make otherwise incomparable factors comparable. MCDA method helps to homogenize the project as a whole within one area (Phua & Minowa, 2005). In addition, according to Polatidis, et al., (2006), when planning a wind power development projects and specific details of it, e.g. most effective layout or appropriate size of the project, using an integrated approach, such as MCDA, helps to increase transparency, clarify the complexity of the project, and raise the awareness of the stakeholders about the various aspects of the project.

The process of MCDA analysis usually contains of four main stages:

1. The formulation of the alternatives and the selection of criteria;
2. Weighting of the criteria;
3. The evaluation of the alternatives based on weighting of the criteria;
4. Final treatment and aggregation (Wang, et al., 2009).

Generally, as stated in the literature, it is observed that the investment cost is often considered as the most influential criterion, followed by the CO_2 emissions, because of the strong focus on the environmental protection (Wang, et al., 2009). The evaluation criteria used for this case study are described in detail in Chapter 4.

Finally, it is important to mention that MCDA can be a powerful tool for assisting in the decision making process for sustainable energy projects with one important precondition – the appropriate MCDA method has to be chosen, as well as the criteria selection, the weighting, and the aggregation methods have to be appropriate and suitable to the specific decision problems (Wang, et al., 2009). If the decision maker choses these factors wisely, using an MCDA can benefit the decision making process greatly.

3. Methodology

In order to deliver the project objectives, comprehensively analyze the four suggested scenarios, and assist in answering the research questions, a number of methods and tools have been used. For a reminder, the research questions in this thesis are:

Based on an MCDA analysis, which is the preferred scenario for development of Targale Wind Farm?

Are MCDA tools eligible to help in decision making in Wind Power Project Development?

The analysis of wind power project development alternatives require a simple, creditworthy, user-friendly, transparent, and result oriented method, with clear parameters (Polatidis, et al., 2006). Therefore, a MCDA method is used for the analysis and is supported by input data from WindPro software as well as Excel calculations. While many different MCDA tools are available, the PROMETHEE II has been chosen because of its easy application and straightforward representation of the results.

The methodological framework is designed to present the most relevant application of the MCDA method, providing the appropriate illustration of how eligible the MCDA tools are as a decision making aid in renewable energy project development. First, based on the given site for this case study, four possible scenarios are developed and the key stakeholders are identified. Site selection, as well as the development of the scenarios and identification of the stakeholders is discussed in detail in Chapter 4. Further, the main criteria used in the MCDA are determined, covering the energy potential, social, environmental and economic factors. Evaluation criteria are explained in detail in Chapter 5. The software products WindPro and Excel are used for the calculations and simulations that are required for some of the chosen criteria. Each criterion is weighted based on the preferences of each of the stakeholders. Finally, PROMETHEE II is used to compile and evaluate the criteria and provide a premise for a final decision making. A structured illustration of the process is provided in Figure 6, which is followed by a detailed explanation of the tools adapted for this analysis.

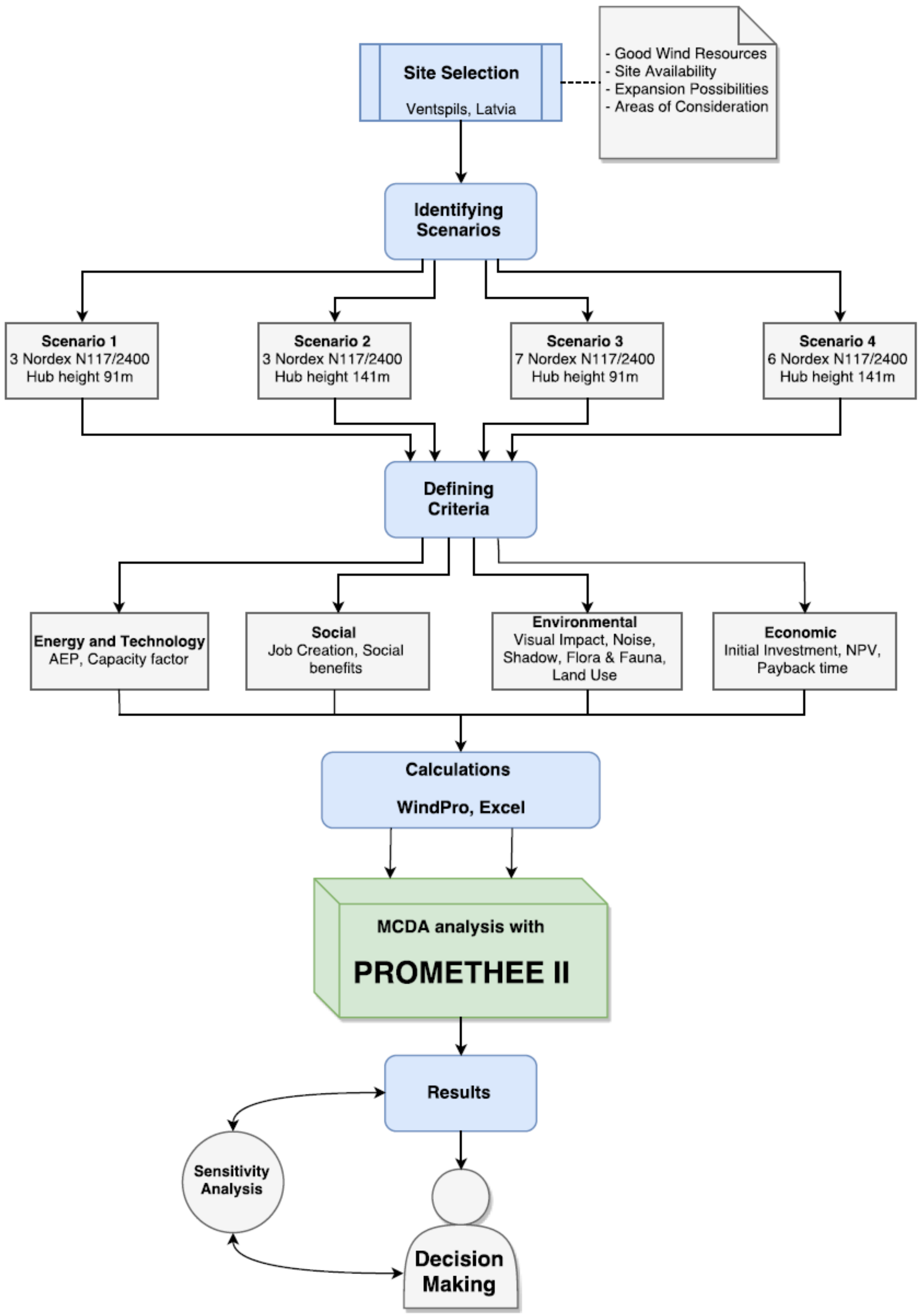

Figure 6 – The Methodological Framework Flowchart (own compilation)

3.1 WindPRO

WindPro, being one of the most popular wind power planning and design software, is used at the early stage of the analysis to essentially determine the optimal type, manufacturer, and layout of the wind farm. Furthermore, WindPro is used to calculate the annual energy production (AEP), noise immission and shadow flickering effects. The main inputs for the WindPro calculations are 20 year wind data from a met mast 50 meters from the site, which is available on the servers of EMD International and accessed through WindPro; terrain elevation and surface roughness online data, which is also accessed through WindPro, as well as the performance data of the selected wind turbines.

3.2 Microsoft Excel

Microsoft Excel is used for the financial calculations and in computing data for environmental criteria. More precisely, Excel is used for initial investment, net present value (NPV), and the payback time. The results from calculations in Excel are used in the assessment of all four different scenarios.

3.3 PROMETHEE II

As mentioned earlier, WindPro and Excel are used to only provide support for the primary tool – PROMETHEE II, which is widely applied and qualified for renewable energy planning and provides intelligibly and comprehensive results (Polatidis & Morales, 2016). There are a number of justifications for using PROMETHEE II. This tool is recognized to provide a user friendly and straightforward application for practical requirements, a clear interpretation of the parameters, at the same time allows the integration of numerous criteria (Polatidis, et al., 2006). The weighting of the criteria sets a direct influence on the decision-making results (Wang, et al., 2009), and therefore can be considered as a cornerstone of this method. As per Wang, et al., (2009), the most popular criteria weighting method is setting equal criteria weights and this method is also used here. This type of weighting is the most common because it makes the criteria understandable in theory and simple to apply in practice (Wang, et al., 2009).

In this thesis, first, the relevant criteria and stakeholders are determined, then all the necessary information and data is gathered through the supporting tools and literature, which is then applied trough PROMETHEE II on each of the four given scenarios. Based on the input information, PROMETHEE II then provides a complete outranking of the scenarios from the most preferred, to the least preferred one, based on the weighted importance of each criteria for each of the stakeholders. The most straightforward application of PROMETHEE II is to compare the scenarios in pairs along with each of the identified criterion. Maximization or minimization direction and a preference threshold are assigned to each criterion. The preference threshold is calculated for each criterion using the following formula:

$$\frac{(S_{max} - S_{min})}{n}$$

S_{max} max value in the scenario
S_{min} min value in the scenario
n number of scenarios

Furthermore, the assessment of each criterion for every stakeholder is performed and the criteria weighting is created. Determination of the criteria and appropriate weighting is a very important step when using a MCDA method (Behzadian, et al., 2010). In this case study, a number of assumptions had to be taken by the author when weighting the criteria, due to the limited scope of the thesis and the time constraint. This can be viewed as a considerable factor of limitation, however, also leaves room for further research. Interviewing the stakeholders, to understand their actual views and perceptions would add significantly to the credibility of the project and can therefore be suggested as one of the cornerstones for further research. Section 6.3 illustrates the limitations in more detail.

Finally, the net preference flow [ϕ] is calculated and compared to determine the optimal decision option (Pohekar & Ramachandran, 2004). The net preference flow is the difference between positive [ϕ+] and negative [ϕ-] flows and the sum of the positive flows [$(a,)$] is weighted as a sum of the preference of an alternative ′a′ with regard to alternative ′b′. This is done for each criterion. The sum of the negative flows [$(b,)$] is calculated by weighting sum of the preference of alternative ′b′ with regard to alternative ′a′ on each criterion. Finally, each alternative ′a′ meets (n-1) the other alternatives in a positive and negative outranking flow (Haralambopoulos and Polatidis, 2003). The equation illustrated in Figure 7 elaborates net outranking flow for each alternative and complete ranking in PROMETHEE II.

$$\emptyset(a) = \frac{1}{(n-1)} \sum_{b \neq a} [\pi(a,b) - \pi(b,a)]$$

Figure 7 – The PROMETHEE II complete ranking equation (Brans, et al., 1986)

To further elaborate on the underlying mathematical equation illustrated in Figure 7, which dictates how PROMETHEE II operates, the following section breaks down the equation in parts*.* Each separate set of calculations in PROMETHEE II is expressed as a degree of preference of one scenario over the other. This is done for all the possible pairs of scenarios. In this case *π (α,b) - π (b,α)* dictates the degree of the alternative *α* being preferred over the alternative *b.* Subsequently, each alternative *α* is facing n-1 other alternatives and the two outranking flows - the positive flow *φ+(α)* and the negative flow *φ-(α)* can be computed (Haralambopoulos & Polatidis, 2003). The positive flow calculates how much more the alternative *α* is preferred over all other respective alternatives; while the negative flow calculates how other respective alternatives are preferred over the alternative *α*. Both, positive and negative flow are considered in the equation in Figure 7, resulting to a net preference flow - *φ(α)* (Haralambopoulos & Polatidis, 2003).

To put simply, the calculation process behind PROMETHEE II pairwise compare all the different alternatives against each other, provides an index for each result, which are then put together for a final representation in an easily understandable way.

To validate and give substance to any calculations in PROMETHEE II, though, the different alternatives (or scenarios, in this analysis) must be first evaluated separately, from a viewpoint of each stakeholder. For most precise representation of the real situation, the opinion should be gathered directly from each of the stakeholfers, however, due to the limited time and resources, in this thesis an approach suggested by Behzadian, et al., (2010) has been used, where the weighting of each criterion is done by the author, by distributing 100 importance points over the 12 criteria for each stakeholder. Full overview of the distributed weights can be found in Table 2.

Table 2 – Full Weightings for each Stakeholder (own compilation)

	Direction	Developer	Legislative decision makers	Grid Operator	Local community and NGOs	Local Entrepreneurs	Investors
AEP	Max	18	12	23	5	17	15
Capacity Factor	Max	16	8	23	4	5	5
Job Creation	Max	8	13	5	14	20	2
Community Financial benefits	Max	9	13	4	19	8	6
Visual	Min	2	6	4	9	2	1
Noise	Min	2	6	4	9	2	1
Shadow	Min	2	5	4	9	2	1
Flora & Fauna	Min	3	12	8	18	3	2
Land use	Min	2	6	7	7	5	1
Initial Investment	Min	10	8	6	2	20	20
NPV	Max	15	9	6	2	10	23
Payback time	Min	13	2	6	2	6	23
Total		100	100	100	100	100	100

The distribution of the importance points is performed by taking a role of each of the different stakeholders separately and considering the varied factors of importance. This later corresponds directly to Table 11, where each criterion is quantified. This method helps to put the emphases on the criteria, that are more important for the particular stakeholder. For example, in a case of AEP, while the difference between the higher and lowest annual energy production will be of a significant importance for the *Developer* (rated 18 importance points), it will not influence the preference for the *Local Community and NGO's* as much, since the AEP has only been awarded with 5 importance points for this stakeholder.

4. Project Description

4.1 Background and Objectives

This thesis essentially has two objectives – first is to put the MCDA method to the test in order to understand how appropriate its use is when a decision has to be made about different sized projects on the same site, and understand the eligibility of the MCDA methods in wind power project development in general. Secondly, this thesis aims to develop a detailed background for a potential wind power project on a site near Ventspils in Latvia. As mentioned earlier, there is a direct potential for a practical implementation for this thesis, since the author of the thesis, at the time of the thesis creation, has a preliminary agreement with the land owner(s) of the site(s), for a wind power project development in the future. Therefore, this thesis is expected to not only deliver a theoretical contribution for the industry on the use of MCDA tools, but also to have a substantial potential for a practical implementation. This fact has influenced some aspects of the thesis, as the scenarios have been developed to fit a potential development as closely as possible, the stakeholders have been chosen based on the specific site in Latvia, and the criteria have been adjusted for the best fit for this case.

4.2 Site Selection

The site utilized in this case study is located in the Northwest of Latvia (see Fig. 8), near the coastal town Ventspils (57°23'43.1"N 21°40'59.6"E). The original site comprises 48 hectares (0.48km^2) of land, on a private property *"Ārces"* (see Fig. 9) and can be extended by adding another 65 hectares (0.65 km^2) of land in an adjacent property. This would result in a total of 113 hectares (1.3 km^2) of land available for the project on the extended site. As illustrated in Figure 1 in the Section 2.1, the west coast of Latvia is the area with the highest wind resources in the country, with an annual average wind speed of over 8.6 m/s at a height of 100m. The site is located in a logistically attractive location, with the port of Ventspils only 9.5 km away. This ice-free deep-water port is a transport, transit, and industrial center of international significance in Latvia and the whole Baltic Sea region (Freeport of Ventspils, 2014), with an easy road access for the transportation of the parts.

Figure 8 – Map of Latvia (Google Maps, 2017)

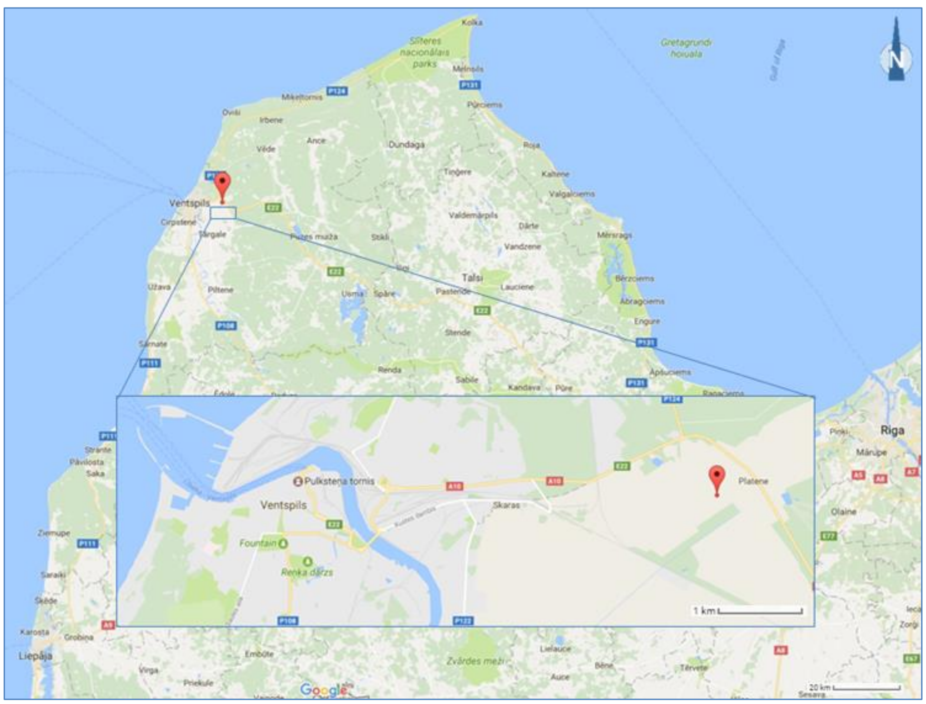

Figure 9 – Site Location: Ventspils, Latvia (Google Maps, 2017)

4.3 Turbine Selection

The turbine choice for this case study is based in the WindPro optimization tool. The optimization was run to allocate the best productivity potential of five wind turbines on the original site. Four major turbine manufacturers were chosen for the assessment – Enercon, Nordex, Siemens, and Vestas. Based on the wind resources on the particular site, the choice was narrowed down to the models designed for low and medium wind speeds. The turbine models chosen for the assessment were:

- Siemens SWT-2.3-108
- Nordex N117/2400
- Vestas V90-1.8/2.0 MW
- Enercon E-92/2.3 MW

As the capacity for the different turbines differs slightly, the main criteria for the turbine choice was output per MW installed, measured in MWh/MW. As seen in Table 3, from the turbines that were tested, the Nordex N117/2400 is the best fit for the particular site and has been chosen for further analysis for this case study.

Table 3 – Turbine comparison (own WindPro compilation)

#	WTG's	Power	Park yield	Relative	Yield/WTG	Efficiency	MWh/MW	Description	Type of calcula
1	5	11 500	45 843	100,0	9 169	95,2	3 986	Siemens 2.3 MW-101 Hub 100m	Full optimize
2	5	12 000	53 487	116,7	10 697	94,8	4 457	Nordex N117, 2.4MW - Hub 100m	Full optimize
3	5	10 000	37 163	81,1	7 433	95,7	3 716	Vestas V90 2MW, Hub 95m	Full optimize
4	5	11 500	41 298	90,1	8 260	94,8	3 591	Enercon E-92 2.3MW, Hub 98m	Full optimize

A quick sensitivity analysis, increasing the turbine capacity to 3 MW, was also performed to verify whether the chosen capacity of 2.4 MW is sufficient for this site. The analysis revealed that increasing the capacity is not feasible for this particular site, due to the limited area and possible wake effects (see Table 4).

Table 4 – Sensitivity analysis on increasing turbine capacity (own WindPro compilation)

WTG's	Power	Park yield	Relative	Yield/WTG	Efficiency	MWh/MW	Description	Type of calculation
4	9 600	43 741	95,4	10 935	96,9	4 556	Nordex N117, 2.4MW - Hub 100m	Fast layout
3	7 200	33 276	72,6	11 092	98,3	4 622	Nordex N117, 2.4MW - Hub 100m	Full optimize
4	12 000	48 377	105,5	12 094	96,4	4 031	Nordex N117, 3MW - Hub 100m	Fast layout
4	12 000	48 500	105,8	12 125	96,6	4 042	Nordex N117, 3MW - Hub 100m	Full optimize

In addition, to ensure an equal comparison of all project sites, one turbine model - Nordex N117/2400 is used in all further calculations and analyses for all four scenarios.

4.4 The Scenarios

The scenarios for this MCDA are developed based on two main criteria. Firstly, to deliver a sufficient basis for analysis of this thesis, evaluating how effective the MCDA method is when comparing differently sized projects on the same site. Assessing the eligibility of the MCDA method is the main theoretical implication for this master thesis, therefore, choosing scenarios that would serve this purpose was important. Since the actual site is limited in size, the four developed scenarios include both – the change in the amount of turbines installed, and change of the hub height of the turbines. As mentioned, the first two scenarios utilizes the original, *smaller* site, and considers turbines with two different hub heights – one lower, 91 meters, and a higher hub height of 141 meters. The second two scenarios utilize an extended site, with an adjacent property added to expand the original site. Once again, two different hub heights, 91 and 141 meters, are analyzed in the scenarios 3 and 4 respectively. The number of turbines has been selected based on the suggestions from WindPro site optimization module. All four scenarios are summarized in Table 5 and explained in detail further in this chapter.

Table 5 – Summary of the investigated scenarios (own compilation)

Scenario	Number of Turbines/Site	Turbine Model	Hub Height (m)	Rotor Diameter (m)	Total Installed Capacity (MW)
1	3 Original Site	Nordex N117/2400	91 m	117	7.2
2	3 Original Site	Nordex N117/2400	141 m	117	7.2
3	7 Extended Site	Nordex N117/2400	91 m	117	16.8
4	6 Extended Site	Nordex N117/2400	141 m	117	14.4

As there is a possibility for the project to be realized in the future, it was important to develop as realistic scenarios as possible, to evaluate the best possible alternative of the utilization of the particular project site in Latvia. Because of this practical implication, the scenarios were subjected to the rational considerations, so that the thesis work can be used for further practical implementation.

The development of the scenarios has been, once again, performed using the WindPro site optimization tool. The number of turbines is commanded by the limited area of the site(s), and the farm layout is based on the main wind direction, as well as the wind speed, accounted by the WindPro site optimization module. The main wind direction, as illustrated in the wind rose, (see Appendix B), is mainly from South-West (SW) in the particular site (Meteoblue, 2017).

4.4.1 Scenario 1

3x Nordex N117/2400 – Hub height 91m

In the first two scenarios, only the original *smaller* site is being exploited. The optimization tool in WindPro has been run with an input data of the site borders accounting for a buffer zone, the chosen wind turbines, as well as the wind and the terrain data. The site layout is suggested by a WindPro simulation - full energy optimizer, which suggests the farm layout with the highest energy production potential. As illustrated in Table 6, the full energy optimization resulted to three suggested wind turbines with a 91 meters hub height. The wind farm layout, also suggested by the optimization tool, is illustrated in Figure 10.

Table 6 – Full Energy Optimization: Scenario 1 (own WindPro compilation)

# of WTGs	Total Installed MW	MWh/MW	Efficiency	Turbine
3	7.2 MW	4'622	98,3 %	Nordex N117/2400 hub height 91m

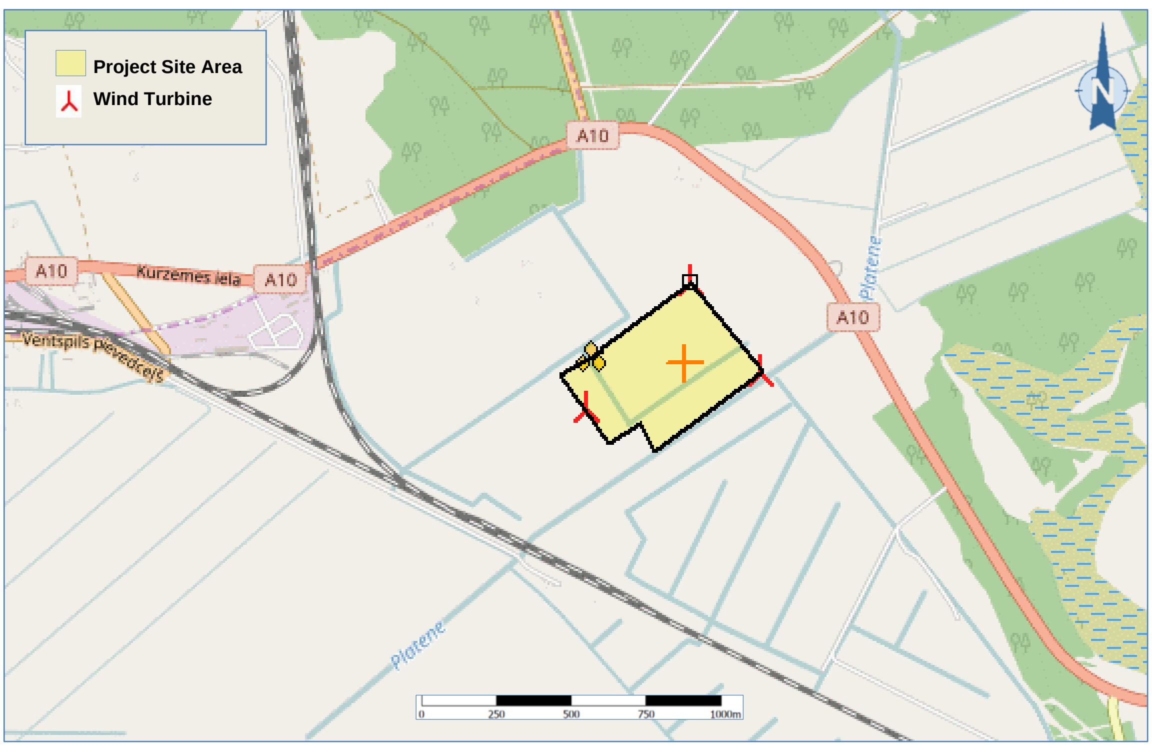

Figure 10 – Wind Farm Layout: Scenario 1 (own WindPro compilation)

4.4.2 Scenario 2

3x Nordex N117/2400 – Hub height 141m

Scenario 2, similarly as the first scenario, utilizes the original *small* project site. The same process of WindPro simulations were applied, with the only change being the increased hub height, from 91 meters to 141 meters. As seen in Table 7, the significant increase of the hub height unsurprisingly resulted in a noticeable increase of production. Also, as illustrated in Figure 11, the layout is slightly different than in scenario 1.

Table 7 – Full Energy Optimization: Scenario 2 (own WindPro compilation)

# of WTGs	Total Installed MW	MWh/MW	Efficiency	Turbine
3	7.2 MW	5'163	98,6 %	Nordex N117/2400 hub height 141m

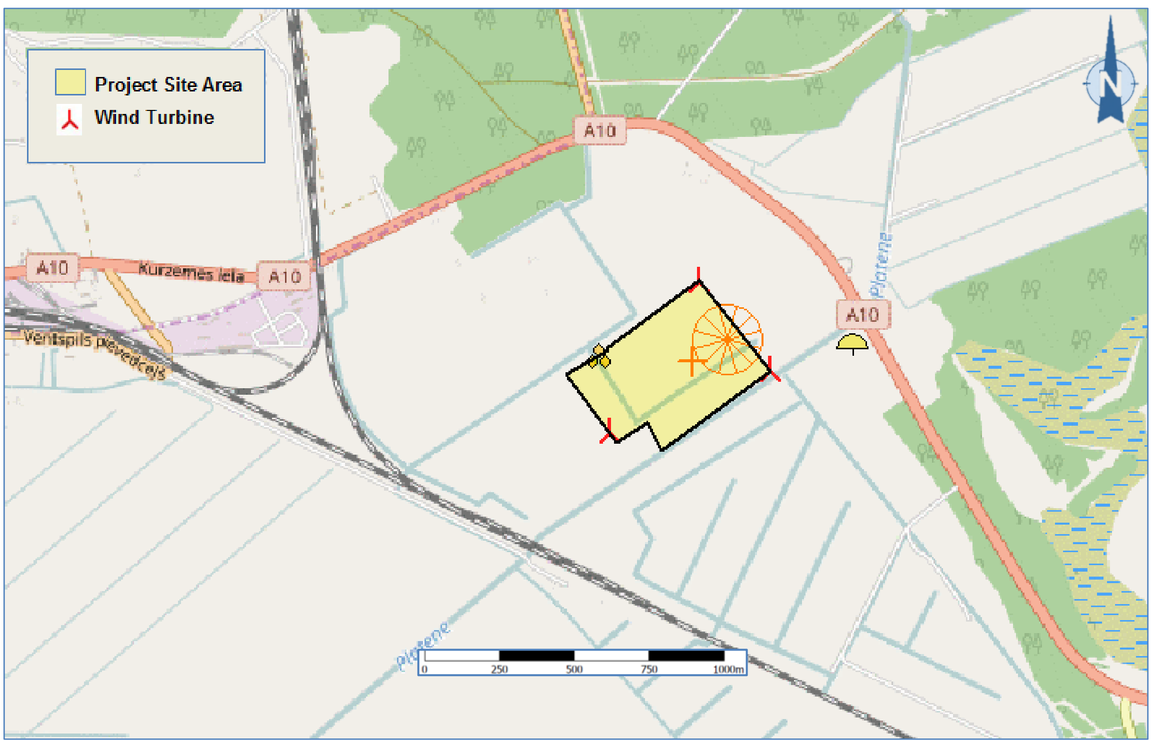

Figure 11 – Wind Farm Layout: Scenario 2 (own WindPro compilation)

4.4.3 Scenario 3

7x Nordex N117/2400 – Hub height 91m

In the scenarios 3 and 4 an adjacent property is being utilized in addition to the original project site. With the same input data of the chosen wind turbines, the same wind and terrain data, but with the updated site borders, the WindPro site optimization tool is used again. For the Scenario 3, a hub height of 91 meters is being investigated. The full energy optimization suggests locating seven wind turbines on the updated site (Table 8). The new site layout, suggested by the site optimization tool, is shown in Figure 12.

Table 8 – Full Energy Optimization: Scenario 3 (own WindPro compilation)

# of WTGs	Total Installed MW	MWh/MW	Efficiency	Turbine
7	16,8 MW	4'477	95,9 %	Nordex N117/2400 hub height 91m

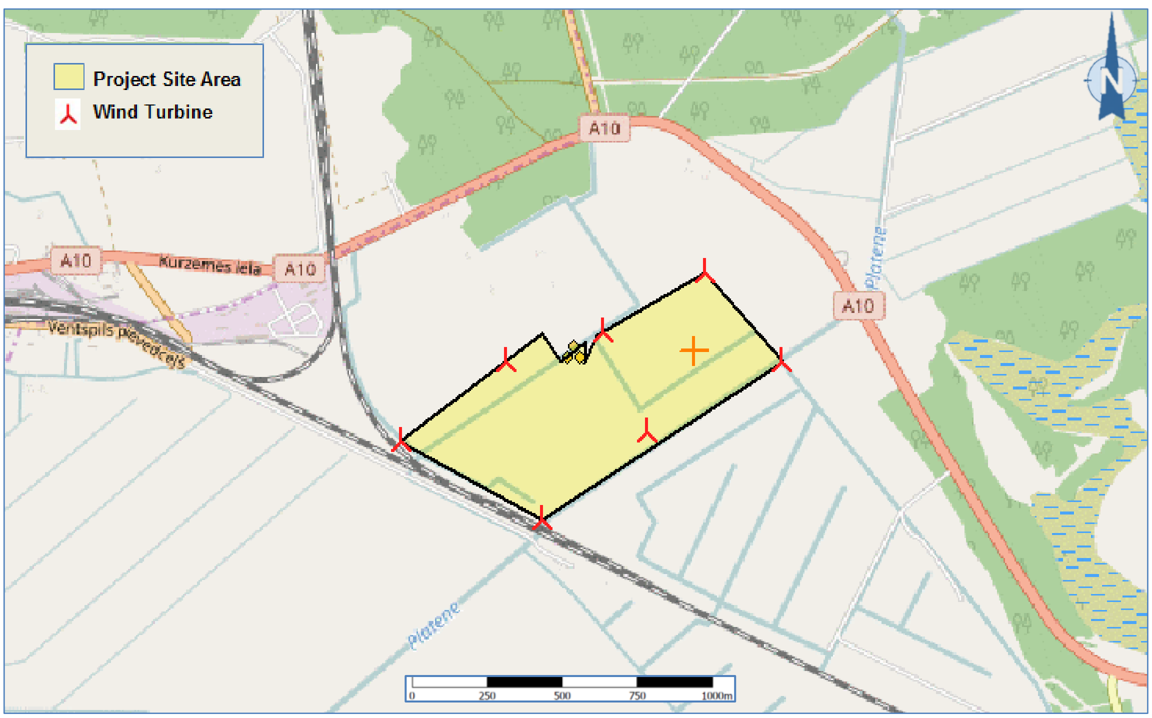

Figure 12 – Wind Farm Layout: Scenario 3 (own WindPro compilation)

4.4.4 Scenario 4

6x Nordex N117/2400 – Hub height 141m

As mentioned, the Scenario 4, similarly as the previous scenario, utilizes the extended site, but does exploit stronger winds, by using turbines with a higher hub height. When the same input data as for the previous simulations is used for turbines with 141 meters hub height in the energy optimization tool, WindPro suggests erecting six wind turbines, as illustrated in Table 9, with the site layout illustrated in Figure 13.

Table 9 – Full Energy Optimization: Scenario 4 (own WindPro compilation)

# of WTGs	Total Installed MW	MWh/MW	Efficiency	Turbine
6	14.4 MW	5'024	96,8 %	Nordex N117/2400 hub height 141m

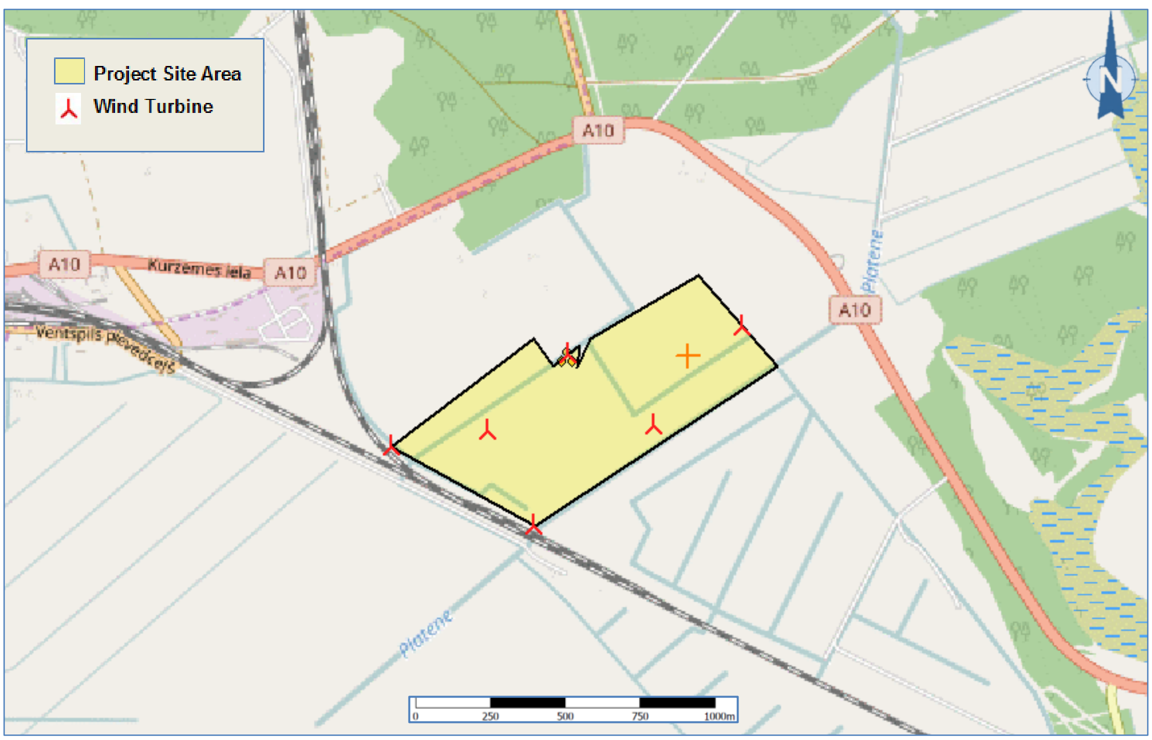

Figure 13 – Wind Farm Layout: Scenario 4 (own WindPro compilation)

4.5 Stakeholders

The stakeholders are an important part of the MCDA analysis, since the opinions of the stakeholders are what essentially define the attractiveness of one scenario over the others, or, at least, the one with the least potential conflicts. Typical stakeholders evaluated in a MCDA analysis in wind power development projects are - the investor, the regional authority, the project developer, environmental NGOs, and the local community (Polatidis & Morales, 2016). The Stakeholders should be chosen in order to represent the different types of criteria accounted for in the MCDA analysis, which usually are political, social, environmental, and economical criteria. For this case, seven stakeholders have been chosen:

- The Developer;
- Political and Legislative Decision Makers;
- National Grid Operator;
- Local Community and the Non-Governmental Organizations (NGOs);
- Local Entrepreneurs;
- The Investors.

4.5.1 Developer

The author of this thesis is also acting as the project developer for this case. The project developer is involved in the whole planning process of the project. This involves designing the wind park, managing the development, locating the potential investors, as well as informing and communicating with the local community, municipality, and the NGOs. The primary objective of the developer is the realization of the project.

4.5.2 The Political and Legislative Decision Makers

This group of stakeholders includes the National Government of Latvia and the regional municipality of Ventspils. The legislative decisions are dictated by the Sustainable Energy Law as well as the Energy Development Guidelines (Cabinet of Ministers of the Republic of Latvia, 2016) and the local legislation in Ventspils municipality. The general situation in Latvian renewable energy market is described in Sections 2.1 and 2.2 of this thesis. To summarize the findings shortly – the future of the renewable energy deployment is mostly based on the EU regulations and policies. The EU regulations have so far been the main driving force for the development of the Renewable Energy Law in Latvia, but the process and support schemes are far from being fully functional. Even more so, the current support scheme is now on hold. However, in order to comply with the EU goals, more renewable energy has to be deployed; therefore, the support system has to be fixed. The Latvian government has committed to update and reorganize the support scheme by 2018 or 2020 at latest (Upatniece, 2017). For the calculations and assumptions in this thesis, the latest version of the support system is used. Although inactive, it is the most recent and therefore most accurate guideline for the reference.

The municipality of Ventspils is considered to have a significant influence, since it is the main decision maker in the permitting process. There are no specific legislative guidelines for wind power development to be found in the documents of Ventspils municipality, the projects are evaluated on a case-by-case basis. Due to the time constraint in the creation of this thesis, no actual municipality officials have been questioned or interviewed. The perception of the municipality is derived from evaluation of previously accepted wind power development project reports. The main objective for both of these parties is to drive a renewable energy development without compromising the *well-being* in other fields.

4.5.3 Grid Operator

The Latvian National grid operator, AS “Sadales Tīkls”, is responsible for the electrical grid in Latvia, covering 99% of the territory of the country (AS "Sadales tīkls", 2016). “The company performs ensuring the operation, upgrading and planned development of distribution networks, monitoring of electricity use, activities aimed at reducing losses, electricity metering, and creation of new connections where necessary” (AS "Sadales tīkls", 2016). In addition, the mission of the grid operator contains targets, such as ensuring high quality and reliable electricity supply to customers in Latvia by ensuring sustainable and balanced development of the power grid (AS "Sadales tīkls", 2016). AS

“Sadales Tīkls” has developed the grid infrastructure in the last decade significantly and there is a 110kV substation located close by the planned site for this project.

The main concern of the grid operator is to ensure stable grid operation as well as having certainty that the energy generator is complying with the regulations when applying for connection.

4.5.4 Local Community and the NGOs

Although NGOs do not have much power in direct decision making, they can play a significant role in the project acceptance and development. According to the regulations (Cabinet of Ministers of the Republic of Latvia, 2010), for the project to be developed, the acceptance has to be received from all the parties that are influenced by the project. For this project, two main subgroups have been identified – the Latvian Ornithological Society, representing the interests of the bird population in the region; and the representatives of the local community, representing proximate dwellers of the project site. Their main concerns are the safety of the bird population, and the noise and shadow from the wind turbines.

4.5.5 Local Entrepreneurs

This group of stakeholders represents the interests of the local businesses in Ventspils region. This group of stakeholders is mainly interested in job creation, investment and the business development of the local area. For the purpose of the MCDA analysis, this group is not considered to have the same decision making background as the rest of the local population, since their decisions are mainly dictated by economic criteria.

4.5.6 Investors

Wind power development is capital-intensive, with funds generally obtained from banks or other financing institutions. Investors’ major concerns are the economic and financial factors, such as economic feasibility, income generation, and payback time of the project. Also political factors are considered, since feasibility of the project development and the overall security of the project is of a significant importance.

5. Evaluation Criteria

Sustainable energy project development is a very complex process and has a potential to involve a large number of closely entangled criteria to consider. The main advantage of Multi-Criteria Decision Analysis (MCDA) in sustainable energy decision-making is the elimination of the difficulty in comparing otherwise potentially incomparable criteria valued by different stakeholders. MCDA in its essence is a form of integrated sustainability evaluation (Wang, et al., 2009). An essential part of this method is choosing a reasonable and accurate set of criteria. As stated by Wang, et al., (2009), “developing evaluation criteria and methods that reliably measure sustainability is a prerequisite for selecting the best alternative, identifying non-sustainable energy supply system, informing design-makers of the integrated performances of the alternatives and monitoring impacts on the social environment”. The main parameters to take into account when developing and selecting the criteria are reliability, appropriateness, practicality, as well as the limitations of measurement (Wang, et al., 2009). Similarly as suggested by Wang, et al., (2009) in his and his team’s ‘Review on multi-criteria decision analysis aid in sustainable energy decision-making’, for this MCDA analysis the four main categories of criteria are:

1. Energy and Technology;
2. Social;
3. Environmental;
4. Economic.

Each of the main categories of criteria includes a number of sub-criteria that are more precise and adapted to the particular case study. For the MCDA analysis to deliver the most accurate results, it is important that all of the criteria support the following prerequisites:

1. "Completeness: all the important points of view of the problem are covered.
2. Operationality: the set of criteria can be measured and used meaningfully in the analysis.
3. Non-redundancy: two or more criteria should not measure the same thing.
4. Minimality: the dimension of the problem should be kept to a minimum" (Keeney & Raiffa, 1976).

The criteria selection is based on the nature of the case study in this thesis. The criteria are developed by the author personally. Interviews and consultations with the experts in the industry would strengthen the analysis, however, due to the limited scope and time constraint for this thesis, such extended analysis has not been performed. The following part of the thesis covers the list and descriptions of the developed criteria in each of the main groups of criteria.

5.1 Energy and Technology Criteria

5.1.1 Annual Energy Production

AEP, being one of the key indicators in wind power development is used to illustrate the production potential of each of the scenarios. The AEP is calculated using the PARK module in WindPro and is illustrated in MWh/year (with 10% reduction, which is accounted losses). This criterion has to be maximized in order to reach a higher preference. As suggested by Polatidis & Morales (2016), the AEP is presumed to be stable throughout the whole period of operation, in order to reduce the complexity of calculations.

The wind data for the calculations is accessed from online data, available in WindPro, from a met mast close by the project site and accounted for the hub heights in each of the scenarios (91 and 141 meters). Micro siting has been performed with WindPro site optimization tools, to develop most effective site layouts with the least wake losses and reach the best ratio of energy generation performance and the installation costs. For a reminder, according the optimization tool, it is most feasible to erect three turbines in Scenarios 1 & 2, seven turbines in Scenario 3, and six turbines in Scenario 4.

5.1.2 Capacity Factor

Since the installed capacity differs in some of the scenarios, a capacity factor criteria has been introduced in order to effectively compare the different scenarios. The capacity factor indicates the ratio between the maximum installed capacity and the actual annual average power generated. The capacity factor for all the scenarios is, once again, derived from the reports generated by PARK model in WindPro.

5.2 Socio-Beneficial Criteria

5.2.1 Job Creation

As for other types of industrial development and business development in general, wind power project development is expected to bring new jobs in the local area. New job creation is often considered as one of the main criteria to raise social acceptance for an energy development project and is recognized by both- the local community and the officials in the municipality. To best illustrate the job creation potential in both stages of the project – the erection phase and the operation phase, job creation potential is expressed in *person years* in this study. Maximizing the figure is expected to raise the attractiveness of the project. Temporary jobs constitute mainly to the erection phase, and the permanent jobs – in the phase of operation, mainly in O&M.

The calculations of the potential of job creation is based on the study 'Calculating Global Energy Sector Jobs: 2015 Methodology' by Rutovitz, et al., (2015). Based on the estimations in the study on global average values for onshore wind power development, wind power projects deliver 3.2 person years/MW in contruction and 0.3 person years/MW in O&M, for the entire project lifetime, which in this case would be 20 years, accounting for 6 person years/MW in O&M (Rutovitz, et al., 2015). For a reminder, these figures are averaged globally, therefore might not accuraterly display the actual situation in Latvia. However, since no actual estimations are made spcifically for Latvia, these figures are used as a reference.

5.2.2 Community Financial Benefits

Community benefits are a powerful tool to raise the acceptance by one of the key stakeholders in wind power project development – the local community. Not matter how well planned and executed, literally no large scale project development is possible without jeopardizing the interests of the local community. Changes often come hard and financial benefits are a way to make that transition easier. As shared in overview of the wind power development in Latvia in the introduction of this thesis, the industry is still in an early development stage. After an overview of the available information about the developed projects in Latvia, there was no evidence of financial community benefit scheme, therefore, once again, an educated judgement by the author is applied to allocate the scope of financial benefits.

According to the available literature, in Sweden, for example, the amount paid for a community usually lies between 0.2-0.5% of the gross revenue (Wizelius, 2010), some sources suggest allocating up to 1% of the revenues for the community, as well as 1-3% for the land lease (Liljenfeldt, 2013). In any of the cases, the community benefit is directly tied to the revenues, which means, the more money the project generates, the more funds can be allocated for the community. Therefore, for a higher preference, this criterion is expected to be maximized. For the calculations in this analysis, 1% of revenue is considered for community benefits in all four scenarios. Land lease is considered to account for 1.5% from the revenues in all four Scenarios.

5.3 Environmental Criteria and Public Acceptance

5.3.1 Visual Impact

Wind turbines, being considerably large and, more importantly, high structures, have a potential of leaving quite of a visual impact on the surroundings. There is an ongoing discussion of whether the wind turbines actually improve or hurt the landscape, but there is no discussion about the fact, that the wind turbines can be very well seen standing tall. In this case study though, it is important to point out that there are a number of wind turbines in the area already (see map in Fig. 14), which means that the local community has been exposed to the wind turbines for a number of years already.

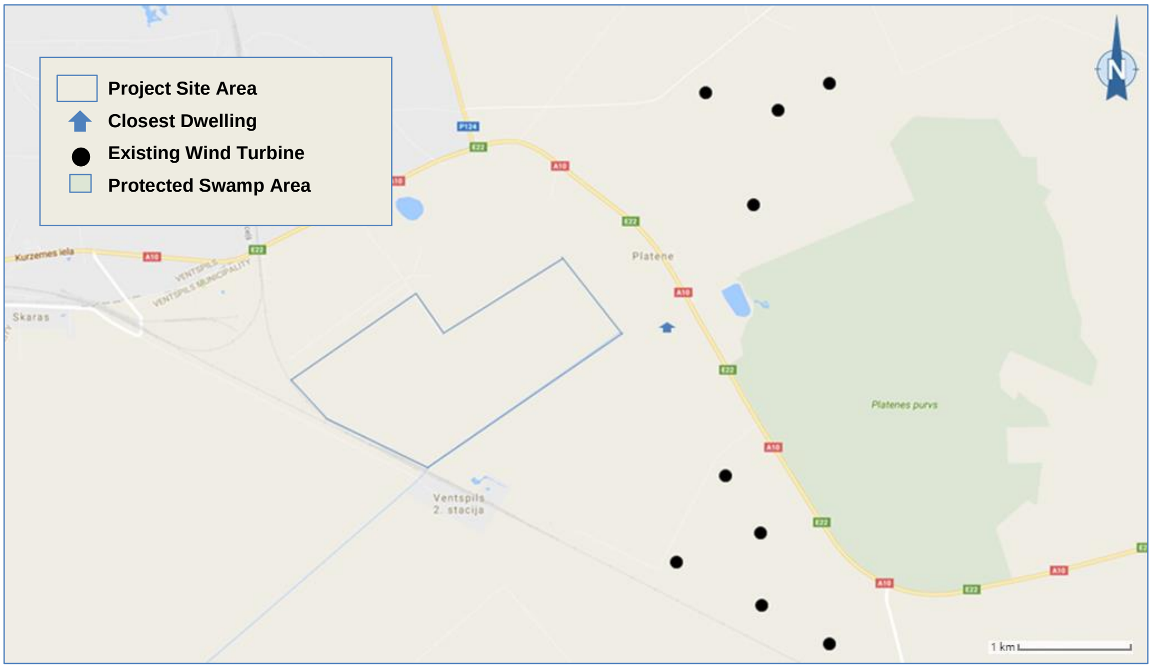

Figure 14 – Site Area Illustration (own creation based on (Google Maps, 2017))

For the scope of this study, it was therefore, decided by the author to base the evaluation of the visual impact solely based on the planned turbine count in each of the scenarios. For an increased preference for the particular scenario, this criterion is aimed to be minimized.

5.3.2 Noise Immission

Noise from the wind turbines is another factor of the debate, often brought up in the discussions for or against wind turbines. Noise from a wind turbine, which is mainly generated by aerodynamic forces acting on the rotating blades, as well as the mechanical movement of the gearbox and the generator in the nacelle, has to be accounted for. According to the most recent mapping openly available in Google Maps (Fig. 14), there is one inhabited house near by the site area (Google Maps, 2017). Although the residents of the house are family members of the potential project group (if the development project from this case is being realized), the health, comfort, and well-being of the residents is highly valued. Therefore, noise immission simulations from the turbines in each of the four scenarios, to a respect to the resident building, have been performed, using the DECIBEL module from WindPro. Full calculations and noise maps can be found in Appendix B. The noise emissions must comply with the government regulations, which dictate that the acceptable noise levels are 55 dB(A) during the daytime, 50 dB(A), during evening, and 45 dB(A) during night time, unless agreed differently (Cabinet of Ministers of the Republic of Latvia, 2014). The sound immission level in the residence must be minimized for a higher preference.

5.3.3 Shadow Flickering

The flickering effect of the shadow from the spinning wind turbine blades has a potential to disturb the local residents, therefore should also be accounted for. However, a shadow flicker does occur only for a limited time of a day, for limited number of months in the year, when the sun is in a particular range of angle in respect to the immission point. The immission point in this case is the nearest dwelling, illustrated in Fig. 14 and discussed in the section 5.3.1. The potential for shadow is calculated using the SHADOW module in WindPro and has been accounted for the expected h/year of shadow over the property. The full results from simulations, including total annual hours of shadow and the full yearly calendar can be found in Appendix C. The unit used for calculations for this criterion is total hours of shadow potential per year and is intended to be minimized for a higher preference.

5.3.4 Flora and Fauna

Wind power developers have to always account for the impact from their development activities on the surrounding environment. Once again, since the wind turbines are large objects with a considerable footprint, the impact has to be assessed and transparently communicated. Impact on flora and fauna generally include the effects on birds and bats, possible impact on mammal population, the potential of tree removal, impact on wetlands and earths hydration, and a number of other factors. For an assessment of this case study, an Environment Impact Assessment (EIA) from a wind power project developed in a close proximity to project site in 2011 (SIA "Vides Eksperti", 2011) is used for a reference.

In the referenced EIA, four major factors of consideration have been identified:

1. Protected Natural Reserves – a protected swamp area is located across the main road, about 1.5 km from the site (see Fig. 14). Project development has no direct influence on this protected area.
2. Protected Biotopes in the surroundings – a number of protected species are expected to grow in the area, as well as in the wetlands close by. However, in the case of the project, developed in 2011, the environment experts concluded that no protected species are to be found on the exact site. No updated evaluations have been done on the exact site for this project, but, for the simplicity of this analysis, this conclusion is taken as a reference. In all scenarios, approximately 0.06 km^2 of trees and bushes, currently covering a part of the original project site, will have to be cut. Although removal of these trees and bushes has been already previously planned by the land owners, the removal is accounted for in the analysis.
3. The Bird Population in the area – three ornithologists, who were assisting in the creation of the EIA, concluded that this area has a potential to be used by cranes, when travelling to and from breading areas. The average flying height was approximately 140 meters. It will therefore result to a lower preference for the scenarios with higher hub height – Scenario 2 and 4.
4. The Bat Population in the area – the most active bat population is identified in areas in a maximum of 5 km proximity inland from the coastline. The site area in this case is about 9 km inland from the coast of Baltic Sea, which means no influence in the areas most actively used by bats. Some influence is still expected though, and is accounted for in the weighting of the criteria (adapted from EIA by (SIA "Vides Eksperti", 2011)).

A numeric scale from 0-10 is used in the assessment of this criterion, with 0 corresponding to no impact at all, and 10 corresponding to a severe impact. See Table 10 for a detailed explanation of the developed impact assessment scale.

Table 10 – The description of qualitative scale (own compilation)

Scale	Impact	Description
0-2	Negligible	No or negligible impact on the migratory birds and bats, the protected areas and wetlands, as well as the protected species. Full support from the local community. No or minimal tree removal.
3-5	Medium	Some, but manageable impact on migratory birds and bats, the protected areas and wetlands, as well as the protected species. Mostly favorable local community. Moderate tree removal.
6-8	High	Impact on migratory birds and bats, the protected areas and wetlands, as well as the protected species in a level that can jeopardize the project development. Split or limited support from the community. Extensive tree removal in the project site.
9-10	Severe	Serious impact on migratory birds and bats, the protected areas and wetlands, as well as the protected species, which result to an immediate halt of project development. Strongly oppositional local community. Extensive tree removal in and around the project site.

5.3.5 Land Use

The land use in this analysis accounts for the foundations and the roads needed for the wind turbines. The impact in this criterion is measured in m^2 and it should be minimized for an increased acceptance.

The land, potentially utilized by the development of this project is calculated using suggestions from the researched literature. According to the specifications for the land use requirements when erecting *Vestas V100-1.8MW* and *V112-3.0MW* turbines, which are technically similar to the *Nordex* turbine used in this analysis, the optimal road width for the road should be 6 meters (Vestas Wind Systems A/S, 2010). The total land needed for the foundations is calculated according to specifications for *Nordex N117/3000,* which dictates to allocate 346.4 m^2 of land per turbine (Nordex Energy GmbH, 2013).

5.4 Economic Criteria

This group of criteria is crucial for the realization of the project. Financial feasibility and potential of profit is the only way to attract investors and realize the project. To draw a comprehensive picture of the financial stability of each of the scenarios, three key criteria are evaluated – initial investment, net present value (NPV), and payback time.

The calculations of these criteria are based on AEP of the whole project lifetime (20 years) and the feed-in tariff, based on the support scheme currently used in Latvia (Cabinet of Ministers of the Republic of Latvia, 2010). Based on the feed in tariff regulations, the feed in tariff for projects under 10MW of total installed capacity can account for 115.8 EUR/MWh (scenarios 1 and 2), and 114 EUR/MWh for projects with installed capacity from 10 to 20 MW (scenarios 3 and 4). This tariff is reduced by 40% in years 11-20 of the project lifetime (Attachment 8 at (Cabinet of Ministers of the Republic of Latvia, 2010)).

Other financial figures used in the calculations are weighted average cost of capital (WACC), which is 9.3% for Latvia (DIA-CORE.eu, 2016), the debt/equity ratio, which is presumed to be 70:30 in this case, with 6% of cost of debt, and 11% of cost of equity.

5.4.1 Initial Investment

This criterion accounts for all the costs, which are planned to be needed for the project development. These costs include the turbine purchase price, transportation, bird-detection system, construction of the roads and surrounding infrastructure, the installation of foundations and cabling, decommissioning costs, as well as the planning and permitting costs (the EIA), and the price for grid connection. Paired with the NPV, the initial investment indicates the feasibility of the project and directly affects the preference of the investors.

An appropriate evaluation of this scenario would call for a more sophisticated analysis, since, generalizing the evaluation to the approach where the least expensive project is preferred, does not display the full scope of the interests of the investors, to whom as high return/invested EUR as possible would be a dominant precondition. However, since gathering the investors is generally a complex process, as well as for the simplicity of the evaluation, it is presumed that lower investment would help to more easily attract the necessary investment. Therefore, this criterion is aimed to be minimized for a higher preference of a particular scenario. All calculations have been performed in Excel and detailed spreadsheets can be provided upon a request.

5.4.2 Net Present Value

NPV is a way to present the total value of a time series of cash flows and is often used to asses a feasibility for a long-term energy projects, accounting for excess or shortfall of cash flows (Wang, et al., 2009). The NPV is calculated using Excel and accounts for the initial investment costs, the capital costs (WACC), the annual revenues (AEP*Feed-in Tariff), the annual O&M costs (service, insurance, land lease, community fund, administration), for the whole project lifetime of 20 years. This criterion is aimed to be maximized for an increased preference.

5.4.3 Payback Period

The payback period illustrates the expected time for the project to generate enough income to completely cover the initial investment. This is an easily understandable figure, which illustrates the *health* of the project and, although it does not consider time value of the money, is used by the investors to evaluate the attractiveness of the proposed project (Wang, et al., 2009). Lower payback period results to higher preference, so minimization direction is applied for this criterion.

5.5 Summary of the Criteria

All aforementioned criteria are calculated for each scenario separately based on the methods presented in each section in Chapter 5. Results are compiled in Table 11.

Table 11 – Overview of the criteria (own compilation)

Criterion	Dir.	Unit	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Preference Threshold
AEP	Max	[MWh/y]	30 212,3	33 635,4	68 313	65 474,7	9 525,10
Capacity Factor	Max	[%]	47,9	53,3	46,4	51,9	1,73
Job Creation	Max	[person years]	66,24	79,49	154,56	158,97	23,18
Community Financial Benefits	Max	[EUR/year]	Fund: 26 396 + Lease: 39 594 = Total: 65 990	Fund: 29 403 + Lease: 44 104 = Total: 73 507	Fund: 58 757 + Lease: 88 136 = Total: 146 893	Fund: 57 205 + Lease: 85 808 = Total: 143013	20 211,75
Visual Impact	Min	[# of turbines]	3	3	7	6	1
Noise Immission	Min	[dBA]	39,2	39,4	57,2	53,8	4,5
Shadow Flickering	Min	[h/year]	20:17	20:10	22:41	23:39	0,87
Flora and Fauna	Min	[qualitative]	3	4	6	6	0,75
Land Use	Min	[m^2]	10 039,2	10 039,2	15 024,8	13 478,4	1 246,40
Initial Investment	Min	[EUR]	11 855 376	14 031 540	25 974 848	26 721 012	3 716 409
NPV	Max	[EUR]	9 617 652	9 887 210	21 748 705	19 814 355	3 032 763,3
Payback Time	Min	[years]	4,93	5,24	4,86	5,13	1

6. Results and Discussion

6.1 The Results of the MCDA analysis

For this case study, the aim of the MCDA method was to assist in the decision making in the choosing the most feasibly scenario of project development from four options. For a reminder, the four scenarios to choose from are:

1. Three Nordex N117-2400 turbines on the original site (hub height 91m)
2. Three Nordex N117-2400 turbines on the original site (hub height 141m)
3. Seven Nordex N117-2400 turbines on the extended site (hub height 91m)
4. Six Nordex N117-2400 turbines on the extended site (hub height 141m).

Detailed overview of the preference by each stakeholder is to be found in Figure 16, however, as illustrated in Figure 15, which represents the aggregate preference, based on the input criteria and weightings, the Scenario 4, which suggests erecting six turbines with a hub height of 141 meters on the extended site, is seen as the most preferred. Scenario 4 is closely followed by Scenarios 3 and 2, with a slight advantage to Scenario 3. According to the MCDA analysis, it can be concluded, that Scenario 4 would be the most preferable choice in the given case.

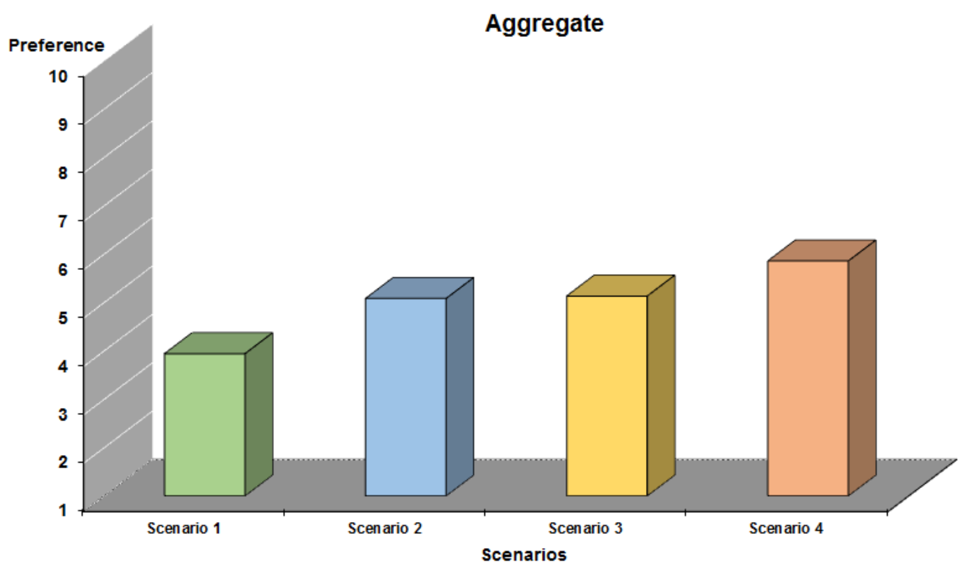

Figure 15 – MCDA Analysis: Aggregate Results (own compilation)

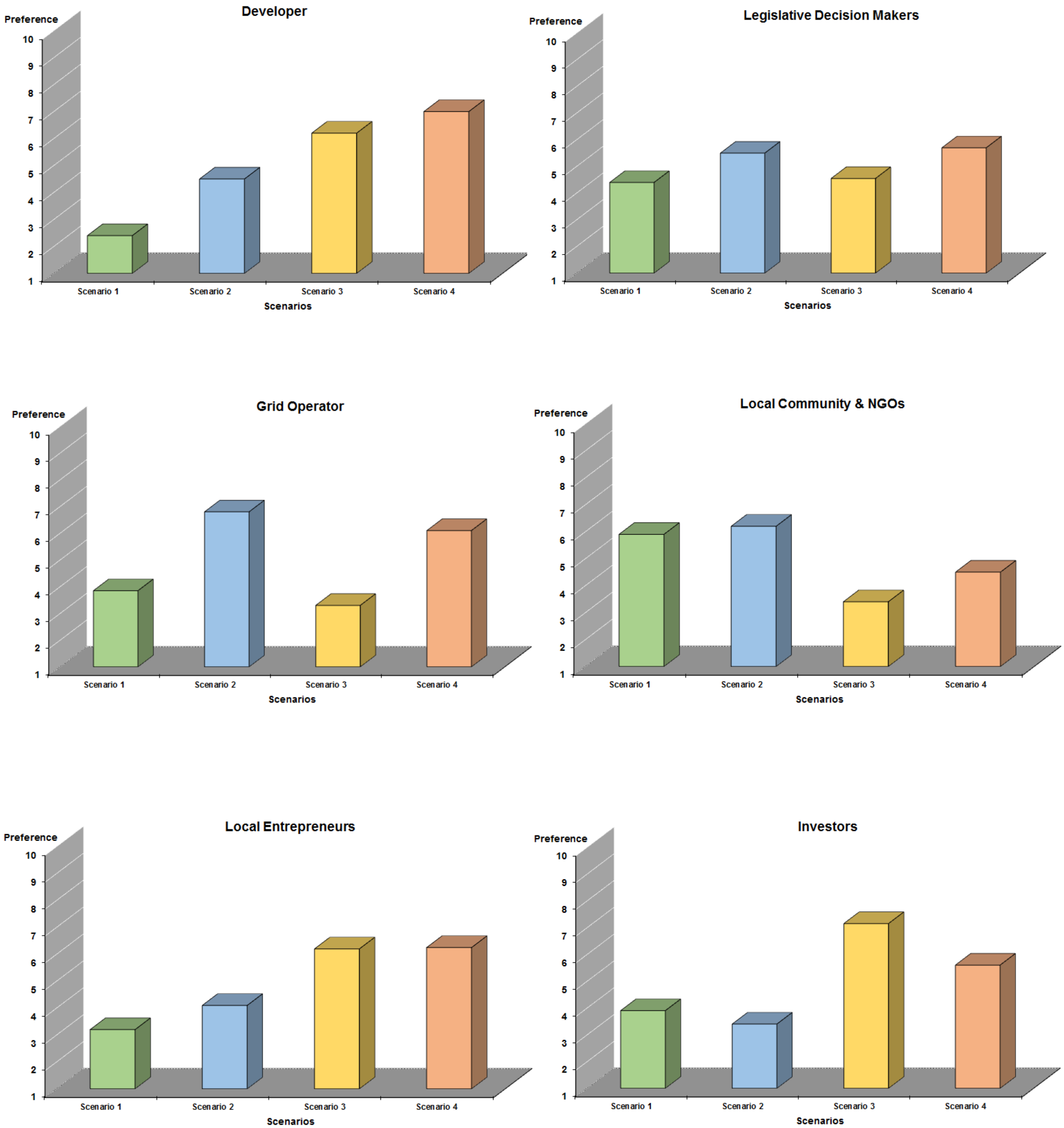

Figure 16 – MCDA Analysis: Results per Scenario (own compilation)

6.2 Eligibility of MCDA in Wind Power Development

The main objective of the MCDA method is, essentially, to accumulate all the input data and provide a clear and comprehensive overview of the analyzed subject. Wind Power Project Development is a multi-disciplinary industry, involving wide range of factors of importance and a number of stakeholders with a significant say in the decision making. Therefore, deriving a decision, that would satisfy all parties, or at least jeopardize as little interests as possible, becomes very complicated.

As illustrated in this case study, using a MCDA method is an effective tool to compile all the different factors and criteria and present the result in a comprehensive, but clear and straightforward way. It is very important to choose the appropriate stakeholders and weights, as well as weighting the criteria as accurate as possible. Doing that, will deliver credible result and effectively assist in the decision-making. It is also important to note that MCDA method is a decision making aid, and the result should not be taken for granted – the result is a structured suggestion to assist in the decision making process.

6.3 Assumptions & Limitations

As mentioned in number occasions throughout the thesis, several assumptions had to be made in the process of conducting this MCDA analysis. First of all, the criteria weighting was done based on the judgment of the author of the thesis. Interviewing the stakeholders to more accurately weigh the criteria would result to a more comprehensive analysis, however, due to the time constraint and limited scope of this master thesis, such augmentation was not performed. Furthermore, a number of assumptions were made based on data representing a global average of the particular criteria, which might not necessarily be accurate for this actual case.

However, the major limitation for this thesis is directly related to the country where the site is located, as the feed-in tariff, which is the base of all the financial calculations, is currently on hold in Latvia. Calculations will have to be updated when the new support system for wind power development in Latvia will be introduced in 2018 or 2020.

7. Conclusion

When working on a wind power development project, the developers will face a number of considerations and will have to deal with various stakeholders in the process. To assist in the decision making in such a complex environment, wind power, and sustainable energy industry in general, has recognized tools, which can make the decision making more coherent. Multi-Criteria Decision analysis is a set of tools, that provide an operational evaluation and decision making support with an approach that is suitable for addressing complex problems (Wang, et al., 2009). MCDA tools help to deal with the high uncertainty, conflicting objectives, different forms of data and information, as well as multi interests and perspectives by diverse, and often contrasting stakeholders (Wang, et al., 2009). One of the MCDA tools – PROMETHEE II has been put to test in this master thesis.

To assist in the evaluation of PROMETHEE II, a case study in Latvia has been used as a reference. The potential site is located in North West of Latvia, in Ventspils region, about 10 km from the coast of Baltic Sea. The site in question consists of two adjacent properties – the original site area covering 0.48km^2 of land, which can be extended by adding the other property, covering 0.65 km^2. The author of this thesis has a preliminary agreement with the owner of the smaller site to develop the project on his private land, as well as a provisional rental or a buyout agreement with the owner of the adjacent property. This small, but significant detail influenced the process thoroughly, and this practical implication dictated the development of scenarios, choice of criteria and stakeholders, as well as the weighting and evaluation of the criteria.

In order to evaluate the potential of the project site and, at the same time, test the eligibility of MCDA method as a decision making assistant in wind power project development, four potential development scenarios were developed:

1. Erecting three Nordex N117/2400 wind turbines with a hub height of 91 meters on the initial site;
2. Erecting three Nordex N117/2400 wind turbines with a hub height of 141 meters on the initial site;

3. Erecting seven Nordex N117/2400 turbines with a hub height of 91 meters on the extended site;
4. Erecting six Nordex N117/2400 turbines with a hub height of 141 meters on the extended site.

The MCDA analysis assisted in choosing the most preferable of the four scenarios, considering the interests of six different stakeholders - the developer, the political and legislative decision makers, the national grid operator, the local community and the NGOs, the local entrepreneurs, and the investors. Their preference was assessed based on 12 criteria from four groups of criteria - Energy and Technology, Social, Environmental, and Economic. After weighting each criterion according to the preferences of each of the stakeholders, and running the PROMETHEE II module, the Scenario 4, which suggests erecting six Nordex N117/2400 turbines with a hub height of 141 meters on the extended site, proved to be the most preferred.

As suggested in the researched literature, MCDA tools are recognized by the renewable energy industry as being a helpful tool to assist in decision making when dealing with wind power projects. This thesis aimed to assess the eligibility of the MCDA tool PROMETHEE II on a specific case, with a definite site and differently sized projects planned on it. PROMETHEE II delivered a comprehensive, clear and straightforward outcome, which makes the presentation of the results simplified and easily presentable. It is important to note that, MCDA tools are intended to aid in the decision making and not to make the decision for the developers or decision makers; thus, a clear representation of the results is the exact preferred process outcome. Therefore, it can be concluded, that MCDA method is indeed a powerful tool to compile a wide range of input data and generate an apprehensible, transparent and clear representation of the results.

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APPENDIX A. Wind Rose - Targale, Latvia

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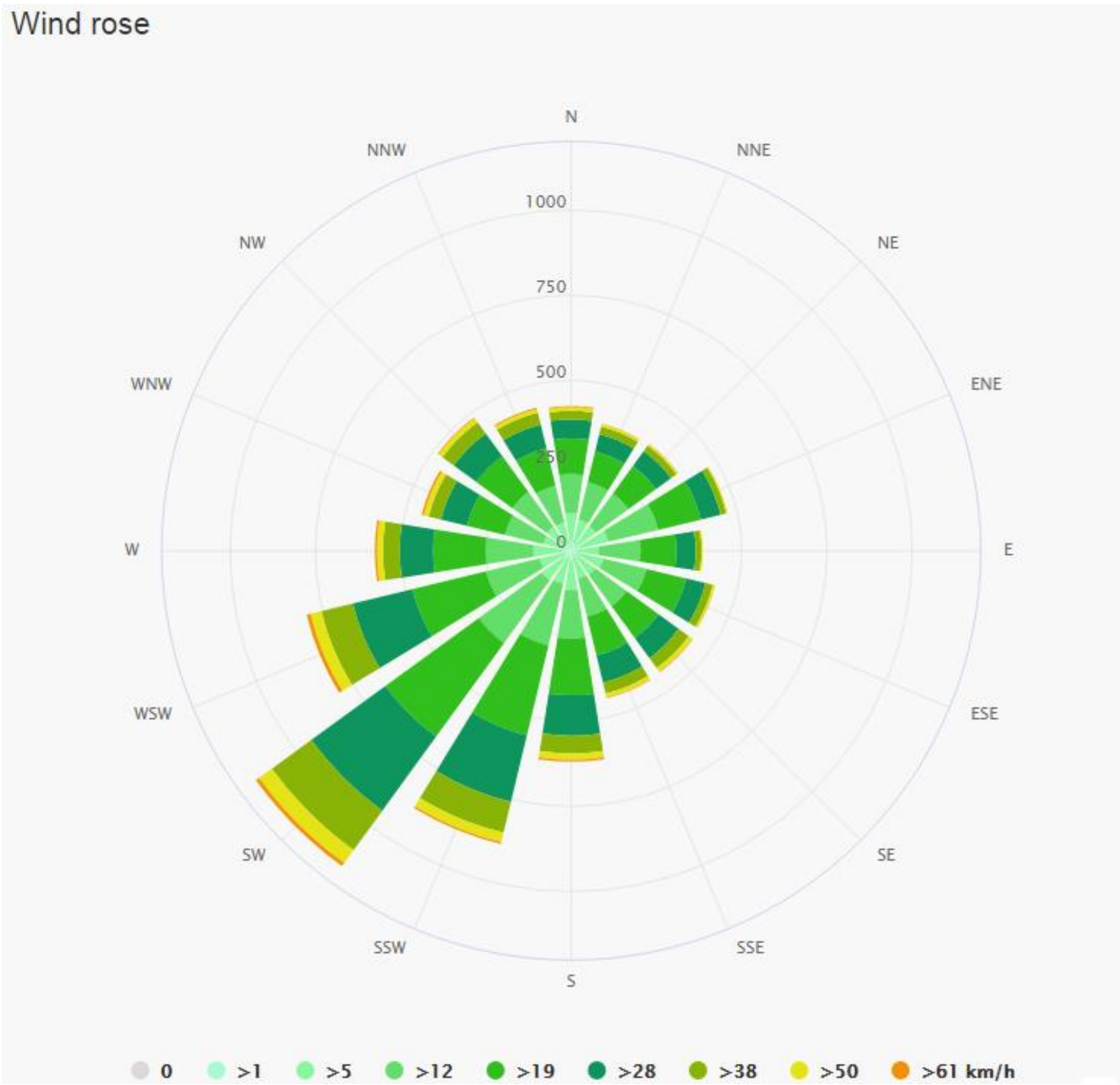

(Meteoblue, 2017)

APPENDIX B. Noise Maps and Calculations – Targale Wind Farm

[Click here, to return to in text reference]

Project:
Targale Andis Antans

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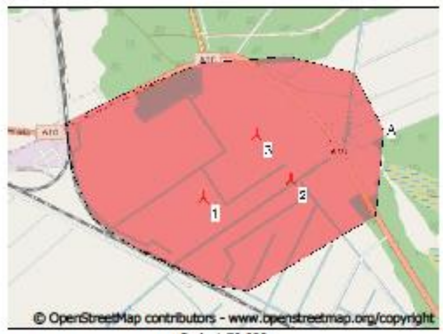
GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-26 14:38/3.0.654

DECIBEL - Main Result

Calculation: Scenario 1 - 3 Nordex N117-2400 - 91m

Noise calculation model:
ISO 9613-2 General
Wind speed:
8,0 m/s
Ground attenuation:
None
Meteorological coefficient, C0:
0,0 dB
Type of demand in calculation:
1: WTG noise is compared to demand (DK, DE, SE, NL etc.)
Noise values in calculation:
All noise values are mean values (Lwa) (Normal)
Pure tones:
Pure and Impulse tone penalty are added to WTG source noise
Height above ground level, when no value in NSA object:
0,0 m Don't allow override of model height with height from NSA object
Deviation from "official" noise demands. Negative is more restrictive, positive is less restrictive.:
0,0 dB(A)



Scale 1:50 000
New WTG   Noise sensitive area

WTGs

	Easting	Northing	Z [m]	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Noise data Creator	Name	Wind speed [m/s]	Status	LwA,ref [dB(A)]	Pure tones
1	900 773	6 380 614	6,0	NORDEX N117 2400 117.0 !O! ...	No	NORDEX	N117-2 400	2 400	117,0	100,0	EMD	Level 0 - Calculated - - 09-2011	8,0	From other hub height	105,0	No f
2	901 648	6 380 889	10,3	NORDEX N117 2400 117.0 !O! ...	No	NORDEX	N117-2 400	2 400	117,0	100,0	EMD	Level 0 - Calculated - - 09-2011	8,0	From other hub height	105,0	No f
3	901 248	6 381 314	7,0	NORDEX N117 2400 117.0 !O! ...	No	NORDEX	N117-2 400	2 400	117,0	100,0	EMD	Level 0 - Calculated - - 09-2011	8,0	From other hub height	105,0	No f

f) From other hub height

Calculation Results

Sound Level

Noise sensitive area No.	Name	Easting	Northing	Z [m]	Imission height [m]	Demands Noise [dB(A)]	Sound Level From WTGs [dB(A)]	Distance to noise demand [m]	Demands fulfilled ? Noise
A	Noise sensitive area: (1)	902 026	6 380 233	6,0	0,0	44,0	39,2	331	Yes

Distances (m)

WTG	A
1	763
2	751
3	770

windPRO 3.0.654 by EMD International A/S, Tel. +45 96 35 44 44, www.emd.dk, windpro@emd.dk   2017-04-26 14:43 / 1   windPRO

Project:
Targale Andis Antans

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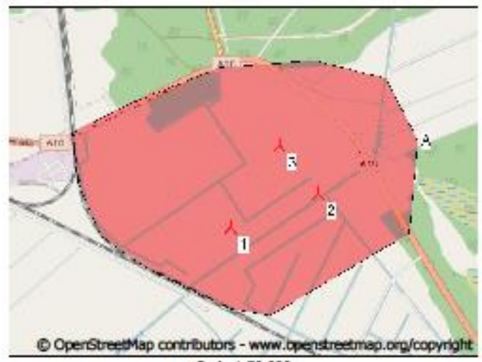
-
GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-26 16:52/3.0.654

DECIBEL - Main Result

Calculation: 3 Nordex N117/2400 - 140m

Noise calculation model:
ISO 9613-2 General
Wind speed:
8,0 m/s
Ground attenuation:
None
Meteorological coefficient, C0:
0,0 dB
Type of demand in calculation:
1: WTG noise is compared to demand (DK, DE, SE, NL etc.)
Noise values in calculation:
All noise values are mean values (Lwa) (Normal)
Pure tones:
Pure and Impulse tone penalty are added to WTG source noise
Height above ground level, when no value in NSA object:
0,0 m Don't allow override of model height with height from NSA object
Deviation from "official" noise demands. Negative is more restrictive, positive is less restrictive.:
0,0 dB(A)



Scale 1:50 000
New WTG   Noise sensitive area

WTGs

	Easting	Northing	Z [m]	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Noise data Creator	Name	Wind speed [m/s]	Status	LwA,ref [dB(A)]	Pure tones
1	900 868	6 380 499	6,0	NORDEX N117 2400 117.0 !O! ...	No	NORDEX	N117-2 400	2 400	117,0	150,0	EMD	Level 0 - Calculated - - 09-2011	8,0	From other hub height	105,0	No f
2	901 658	6 380 894	10,1	NORDEX N117 2400 117.0 !O! ...	No	NORDEX	N117-2 400	2 400	117,0	150,0	EMD	Level 0 - Calculated - - 09-2011	8,0	From other hub height	105,0	No f
3	901 248	6 381 314	7,0	NORDEX N117 2400 117.0 !O! ...	No	NORDEX	N117-2 400	2 400	117,0	150,0	EMD	Level 0 - Calculated - - 09-2011	8,0	From other hub height	105,0	No f

f) From other hub height

Calculation Results

Sound Level

Noise sensitive area No.	Name	Easting	Northing	Z [m]	Imission height [m]	Demands Noise [dB(A)]	Sound Level From WTGs [dB(A)]	Distance to noise demand [m]	Demands fulfilled ? Noise
A	Noise sensitive area: (1)	900 653	6 379 844	6,0	0,0	44,0	39,4	293	Yes

Distances (m)

WTG	A
1	687
2	749
3	770

windPRO 3.0.654 by EMD International A/S, Tel. +45 96 35 44 44, www.emd.dk, windpro@emd.dk   2017-04-26 16:53 / 1   windPRO

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Targale Andis Antans

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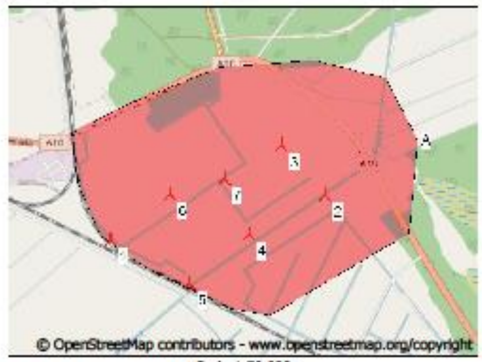
GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-27 12:09/3.0.654

DECIBEL - Main Result

Calculation: Scenario 3 - 7 Nordex N117-2400 - 91m

Noise calculation model:
ISO 9613-2 General
Wind speed:
8,0 m/s
Ground attenuation:
None
Meteorological coefficient, C0:
0,0 dB
Type of demand in calculation:
1: WTG noise is compared to demand (DK, DE, SE, NL etc.)
Noise values in calculation:
All noise values are mean values (Lwa) (Normal)
Pure tones:
Pure and Impulse tone penalty are added to WTG source noise
Height above ground level, when no value in NSA object:
0,0 m Don't allow override of model height with height from NSA object
Deviation from "official" noise demands. Negative is more restrictive, positive is less restrictive.:
0,0 dB(A)



Scale 1:50 000
New WTG   Noise sensitive area

WTGs

					WTG type						Noise data				
	Easting	Northing	Z [m]	Row data/Description	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Creator	Name	Wind speed [m/s]	LwA,ref [dB(A)]	Pure tones
1	899 759	6 380 276	5,0	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	91,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
2	901 724	6 380 891	7,8	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	91,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
3	901 269	6 381 316	7,4	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	91,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
4	901 049	6 380 451	12,7	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	91,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
5	900 539	6 379 936	9,7	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	91,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
6	900 274	6 380 751	5,5	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	91,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
7	900 764	6 380 951	6,0	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	91,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No

Calculation Results

Sound Level

Noise sensitive area						Demands	Sound Level		Demands fulfilled ?
No.	Name	Easting	Northing	Z [m]	Imission height [m]	Noise [dB(A)]	From WTGs [dB(A)]	Distance to noise demand [m]	Noise
A	Noise sensitive area: (1)	899 750	6 380 248	6,0	0,0	44,0	57,2	-417	**No**

Distances (m)

WTG	A
1	29
2	708
3	772
4	704
5	48
6	693
7	985

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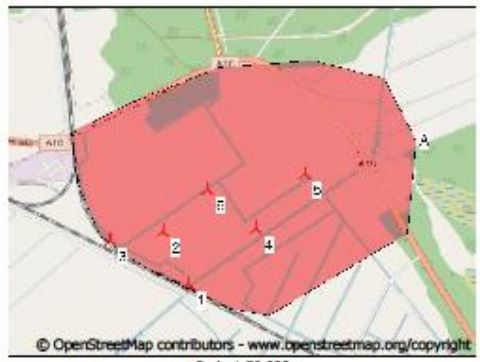
Calculated:
2017-04-27 11:34/3.0.654

DECIBEL - Main Result

Calculation: Scenario 4 - 6 Nordex N117-2400 - 141m Hub height

Noise calculation model:
ISO 9613-2 General
Wind speed:
8,0 m/s
Ground attenuation:
None
Meteorological coefficient, C0:
0,0 dB
Type of demand in calculation:
1: WTG noise is compared to demand (DK, DE, SE, NL etc.)
Noise values in calculation:
All noise values are mean values (Lwa) (Normal)
Pure tones:
Pure and Impulse tone penalty are added to WTG source noise
Height above ground level, when no value in NSA object:
0,0 m Don't allow override of model height with height from NSA object
Deviation from "official" noise demands. Negative is more restrictive, positive is less restrictive.:
0,0 dB(A)



Scale 1:50 000
New WTG   Noise sensitive area

WTGs

	Easting	Northing	Z [m]	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Noise data Creator	Name	Wind speed [m/s]	LwA,ref [dB(A)]	Pure tones
1	900 539	6 379 936	9,7	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	141,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
2	900 249	6 380 406	5,6	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	141,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
3	899 759	6 380 276	5,0	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	141,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
4	901 114	6 380 516	12,4	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	141,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
5	901 524	6 381 076	8,2	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	141,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No
6	900 629	6 380 841	4,4	NORDEX N117 2400 117....	No	NORDEX	N117-2 400	2 400	117,0	141,0	EMD	Level 0 - Calculated - - 09-2011	8,0	105,0	No

Calculation Results

Sound Level

Noise sensitive area No.	Name	Easting	Northing	Z [m]	Imission height [m]	Demands Noise [dB(A)]	Sound Level From WTGs [dB(A)]	Distance to noise demand [m]	Demands fulfilled ? Noise
A	Noise sensitive area: (1)	899 750	6 380 248	6,0	0,0	44,0	53,8	-416	No

Distances (m)

WTG	A
1	48
2	380
3	29
4	767
5	975
6	926

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APPENDIX C. Shadow Maps and Calculations – Targale Wind Farm

[Click here, to return to in text reference]

Project:
Targale Andis Antans

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GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-26 17:12/3.0.654

SHADOW - Main Result

Calculation: Scenario 1 - 3 Nordex N117-2400 - 91m

Assumptions for shadow calculations

Maximum distance for influence
Calculate only when more than 20 % of sun is covered by the blade
Please look in WTG table

Minimum sun height over horizon for influence	3 °
Day step for calculation	1 days
Time step for calculation	1 minutes

Sunshine probability S (Average daily sunshine hours) [VISBY AEROL OG. STN.]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1,88	2,10	3,74	7,42	11,12	10,06	9,30	7,35	5,38	3,30	1,17	1,10

Operational hours are calculated from WTGs in calculation and wind distribution:
EmdConwx_N57.380_E021.680 (3)

Operational time

N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
614	448	606	588	642	469	499	1 001	1 475	874	765	638	8 620

Idle start wind speed: Cut in wind speed from power curve

A ZVI (Zones of Visual Influence) calculation is performed before flicker calculation so non visible WTG do not contribute to calculated flicker values. A WTG will be visible if it is visible from any part of the receiver window. The ZVI calculation is based on the following assumptions:
Height contours used: Elevation Grid Data Object: Targale Andis Antans_EMD(
Obstacles used in calculation
Eye height: 1,5 m
Grid resolution: 10,0 m

All coordinates are in
Swedish UTM 33-SWEREF99 (SE)

Scale 1:20 000
New WTG Shadow receptor

WTGs

	Easting	Northing	Z [m]	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Shadow data Calculation distance [m]	RPM [RPM]
1	900 868	6 380 499	6,0	NORDEX N117 2400 117.0 !O! hub: 15...	No	NORDEX	N117-2 400	2 400	117,0	150,0	1 485	11,8
2	901 658	6 380 894	10,1	NORDEX N117 2400 117.0 !O! hub: 15...	No	NORDEX	N117-2 400	2 400	117,0	150,0	1 485	11,8
3	901 248	6 381 314	7,0	NORDEX N117 2400 117.0 !O! hub: 15...	No	NORDEX	N117-2 400	2 400	117,0	150,0	1 485	11,8

Shadow receptor-Input

No.	Easting	Northing	Z [m]	Width [m]	Height [m]	Height a.g.l. [m]	Degrees from south cw [°]	Slope of window [°]	Direction mode
A	902 066	6 381 045	7,8	1,0	1,0	1,0	0,0	90,0	Fixed direction

Calculation Results

Shadow receptor

	Shadow, worst case			Shadow, expected values
No.	Shadow hours per year [h/year]	Shadow days per year [days/year]	Max shadow hours per day [h/day]	Shadow hours per year [h/year]
A	67:28	106	0:59	20:17

Total amount of flickering on the shadow receptors caused by each WTG

No.	Name	Worst case [h/year]	Expected [h/year]
1	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (127)	7:01	1:31
2	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (128)	60:27	18:45
3	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (129)	0:00	0:00

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2017-04-26 17:12 / 1 windPRO

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Targale Andis Antans

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GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-26 17:04/3.0.654

SHADOW - Main Result

Calculation: 3 Nordex N117/2400 - 140m

Assumptions for shadow calculations

Maximum distance for influence
Calculate only when more than 20 % of sun is covered by the blade
Please look in WTG table

Minimum sun height over horizon for influence	3 °
Day step for calculation	1 days
Time step for calculation	1 minutes

Sunshine probability S (Average daily sunshine hours) [VISBY AEROL OG. STN.]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1,88	2,10	3,74	7,42	11,12	10,06	9,30	7,35	5,38	3,30	1,17	1,10

Operational hours are calculated from WTGs in calculation and wind distribution:
EmdConwx_N57.380_E021.680 (3)

Operational time

N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
608	450	594	553	644	464	465	950	1 491	898	750	660	8 528

Idle start wind speed: Cut in wind speed from power curve

A ZVI (Zones of Visual Influence) calculation is performed before flicker calculation so non visible WTG do not contribute to calculated flicker values. A WTG will be visible if it is visible from any part of the receiver window. The ZVI calculation is based on the following assumptions:
Height contours used: Elevation Grid Data Object: Targale Andis Antans_EMD(
Obstacles used in calculation
Eye height: 1,5 m
Grid resolution: 10,0 m

All coordinates are in
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Scale 1:20 000
New WTG   Shadow receptor

WTGs

					WTG type						Shadow data	
	Easting	Northing	Z	Row data/Description	Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Calculation distance	RPM
			[m]					[kW]	[m]	[m]	[m]	[RPM]
1	900 868	6 380 499	6,0	NORDEX N117 2400 117.0 !O! hub: 15...	No	NORDEX	N117-2 400	2 400	117,0	150,0	1 485	11,8
2	901 658	6 380 894	10,1	NORDEX N117 2400 117.0 !O! hub: 15...	No	NORDEX	N117-2 400	2 400	117,0	150,0	1 485	11,8
3	901 248	6 381 314	7,0	NORDEX N117 2400 117.0 !O! hub: 15...	No	NORDEX	N117-2 400	2 400	117,0	150,0	1 485	11,8

Shadow receptor-Input

No.	Easting	Northing	Z	Width	Height	Height a.g.l.	Degrees from south cw	Slope of window	Direction mode
			[m]	[m]	[m]	[m]	[°]	[°]	
A	902 066	6 381 045	7,8	1,0	1,0	1,0	0,0	90,0	Fixed direction

Calculation Results

Shadow receptor

	Shadow, worst case			Shadow, expected values
No.	Shadow hours per year	Shadow days per year	Max shadow hours per day	Shadow hours per year
	[h/year]	[days/year]	[h/day]	[h/year]
A	67:28	106	0:59	20:10

Total amount of flickering on the shadow receptors caused by each WTG

No.	Name	Worst case [h/year]	Expected [h/year]
1	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (127)	7:01	1:30
2	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (128)	60:27	18:38
3	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (129)	0:00	0:00

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GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-27 12:10/3.0.654

SHADOW - Main Result

Calculation: Scenario 3 - 7 Nordex N117-2400 - 91m

Assumptions for shadow calculations

Maximum distance for influence
Calculate only when more than 20 % of sun is covered by the blade
Please look in WTG table

Minimum sun height over horizon for influence	3 °
Day step for calculation	1 days
Time step for calculation	1 minutes

Sunshine probability S (Average daily sunshine hours) [VISBY AEROL OG. STN.]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1,88	2,10	3,74	7,42	11,12	10,06	9,30	7,35	5,38	3,30	1,17	1,10

Operational hours are calculated from WTGs in calculation and wind distribution:
EmdConwx_N57.380_E021.680 (3)

Operational time

N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
604	441	597	578	632	462	491	985	1 451	860	753	628	8 482

Idle start wind speed: Cut in wind speed from power curve

A ZVI (Zones of Visual Influence) calculation is performed before flicker calculation so non visible WTG do not contribute to calculated flicker values. A WTG will be visible if it is visible from any part of the receiver window. The ZVI calculation is based on the following assumptions:
Height contours used: Elevation Grid Data Object: Targale Andis Antans_EMD(
Obstacles used in calculation
Eye height: 1,5 m
Grid resolution: 10,0 m

Scale 1:40 000
New WTG   Shadow receptor

All coordinates are in
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WTGs

					WTG type						Shadow data	
	Easting	Northing	Z	Row data/Description	Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Calculation distance	RPM
			[m]					[kW]	[m]	[m]	[m]	[RPM]
1	899 759	6 380 276	5,0	NORDEX N117 2400 117.0 !O! hub: 91...	No	NORDEX	N117-2 400	2 400	117,0	91,0	1 489	11,8
2	901 724	6 380 891	7,8	NORDEX N117 2400 117.0 !O! hub: 91...	No	NORDEX	N117-2 400	2 400	117,0	91,0	1 489	11,8
3	901 269	6 381 316	7,4	NORDEX N117 2400 117.0 !O! hub: 91...	No	NORDEX	N117-2 400	2 400	117,0	91,0	1 489	11,8
4	901 049	6 380 451	12,7	NORDEX N117 2400 117.0 !O! hub: 91...	No	NORDEX	N117-2 400	2 400	117,0	91,0	1 489	11,8
5	900 539	6 379 936	9,7	NORDEX N117 2400 117.0 !O! hub: 91...	No	NORDEX	N117-2 400	2 400	117,0	91,0	1 489	11,8
6	900 274	6 380 751	5,5	NORDEX N117 2400 117.0 !O! hub: 91...	No	NORDEX	N117-2 400	2 400	117,0	91,0	1 489	11,8
7	900 764	6 380 951	6,0	NORDEX N117 2400 117.0 !O! hub: 91...	No	NORDEX	N117-2 400	2 400	117,0	91,0	1 489	11,8

Shadow receptor-Input

No.	Easting	Northing	Z	Width	Height	Height a.g.l.	Degrees from south cw	Slope of window	Direction mode
			[m]	[m]	[m]	[m]	[°]	[°]	
A	902 066	6 381 045	7,8	1,0	1,0	1,0	0,0	90,0	Fixed direction

Calculation Results

Shadow receptor

	Shadow, worst case			Shadow, expected values
No.	Shadow hours per year [h/year]	Shadow days per year [days/year]	Max shadow hours per day [h/day]	Shadow hours per year [h/year]
A	89:53	114	1:17	22:41

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Calculated:
2017-04-27 11:35/3.0.654

SHADOW - Main Result

Calculation: Scenario 4 - 6 Nordex N117-2400 - 141m Hub height

Assumptions for shadow calculations

Maximum distance for influence
Calculate only when more than 20 % of sun is covered by the blade
Please look in WTG table

Minimum sun height over horizon for influence	3 °
Day step for calculation	1 days
Time step for calculation	1 minutes

Sunshine probability S (Average daily sunshine hours) [VISBY AEROL OG. STN.]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1,88	2,10	3,74	7,42	11,12	10,06	9,30	7,35	5,38	3,30	1,17	1,10

Operational hours are calculated from WTGs in calculation and wind distribution:
EmdConwx_N57.380_E021.680 (3)

Operational time

N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	Sum
606	448	592	551	641	462	463	947	1 486	895	748	658	8 497

Idle start wind speed: Cut in wind speed from power curve

A ZVI (Zones of Visual Influence) calculation is performed before flicker calculation so non visible WTG do not contribute to calculated flicker values. A WTG will be visible if it is visible from any part of the receiver window. The ZVI calculation is based on the following assumptions:
Height contours used: Elevation Grid Data Object: Targale Andis Antans_EMD(
Obstacles used in calculation
Eye height: 1,5 m
Grid resolution: 10,0 m

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All coordinates are in
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Scale 1:40 000
New WTG   Shadow receptor

WTGs

	Easting	Northing	Z [m]	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Shadow data Calculation distance [m]	RPM [RPM]
1	900 539	6 379 936	9,7	NORDEX N117 2400 117.0 !O! hub: 14...	No	NORDEX	N117-2 400	2 400	117,0	141,0	1 486	11,8
2	900 249	6 380 406	5,6	NORDEX N117 2400 117.0 !O! hub: 14...	No	NORDEX	N117-2 400	2 400	117,0	141,0	1 486	11,8
3	899 759	6 380 276	5,0	NORDEX N117 2400 117.0 !O! hub: 14...	No	NORDEX	N117-2 400	2 400	117,0	141,0	1 486	11,8
4	901 114	6 380 516	12,4	NORDEX N117 2400 117.0 !O! hub: 14...	No	NORDEX	N117-2 400	2 400	117,0	141,0	1 486	11,8
5	901 524	6 381 076	8,2	NORDEX N117 2400 117.0 !O! hub: 14...	No	NORDEX	N117-2 400	2 400	117,0	141,0	1 486	11,8
6	900 629	6 380 841	4,4	NORDEX N117 2400 117.0 !O! hub: 14...	No	NORDEX	N117-2 400	2 400	117,0	141,0	1 486	11,8

Shadow receptor-Input

No.	Easting	Northing	Z [m]	Width [m]	Height [m]	Height a.g.l. [m]	Degrees from south cw [°]	Slope of window [°]	Direction mode
A	902 066	6 381 045	7,8	1,0	1,0	1,0	0,0	90,0	Fixed direction

Calculation Results

Shadow receptor

No.	Shadow, worst case: Shadow hours per year [h/year]	Shadow days per year [days/year]	Max shadow hours per day [h/day]	Shadow, expected values: Shadow hours per year [h/year]
A	16:12	57	0:25	3:39

Total amount of flickering on the shadow receptors caused by each WTG

No.	Name	Worst case [h/year]	Expected [h/year]
1	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (159)	0:00	0:00
2	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (160)	0:00	0:00

To be continued on next page...

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APPENDIX D. Full Production Calculations – Targale Wind Farm

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Targale Andis Antans

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Calculated:
2017-04-26 13:42/3.0.654

PARK - Main Result

Calculation: Scenario 1 - 3 Nordex N117/2400 - 91m

Wake Model N.O. Jensen (RISØ/EMD)

Calculation Settings

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,248 kg/m³ to 1,249 kg/m³
Air density relative to standard	101,9 % to 102,0 %
Hub altitude above sea level (asl)	106,0 m to 110,3 m
Annual mean temperature at hub alt.	5,8 °C to 5,8 °C
Pressure at WTGs	999,7 hPa to 1 000,2 hPa

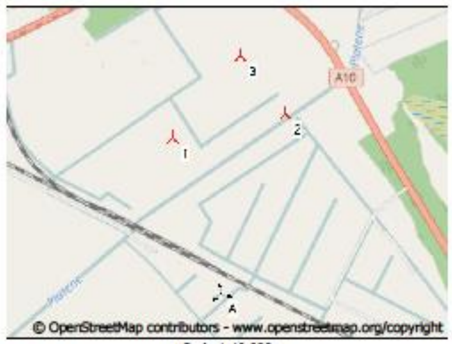
Wake Model Parameters

From angle [°]	To angle [°]	Terrain type	Wake decay constant
-180,0	180,0	Open farmland	0,075

Displacement heights from objects

Wake calculation settings

Angle [°] start	end	step	Wind speed [m/s] start	end	step
0,5	360,0	1,0	0,5	30,5	1,0



Scale 1:40 000
New WTG   Meteorological Data

Key results for height 91,0 m above ground level

Terrain Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]
A	901 268	6 379 424	EmdConwx_N57.380_E021.680 (3)	100,0	WEIBULL	4 151	7,7

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results*) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	33 569,2	30 212,3	34 148,9	98,3	47,9	10 070,8	4 196	7,7

**) Based on Result-10,0%*

Calculated Annual Energy for each of 3 new WTGs with total 7,2 MW rated power

Links	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Displacement height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-10,0% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
1 A	No	NORDEX	N117-2 400	2 400	117,0	100,0	0,0	EMD	Level 0 - calculated - - 01-2011	11 270,9	10 144	99,01	7,71
2 A	No	NORDEX	N117-2 400	2 400	117,0	100,0	0,0	EMD	Level 0 - calculated - - 01-2011	11 161,6	10 045	98,07	7,71
3 A	No	NORDEX	N117-2 400	2 400	117,0	100,0	0,0	EMD	Level 0 - calculated - - 01-2011	11 136,7	10 023	97,83	7,71

WTG siting

Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Z [m]	Row data/Description
1 New	900 773	6 380 614	6,0	NORDEX N117 2400 117.0 !O! hub: 100,0 m (TOT: 158,5 m) (109)
2 New	901 648	6 380 889	10,3	NORDEX N117 2400 117.0 !O! hub: 100,0 m (TOT: 158,5 m) (110)
3 New	901 248	6 381 314	7,0	NORDEX N117 2400 117.0 !O! hub: 100,0 m (TOT: 158,5 m) (111)

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Project:
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GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-26 16:32/3.0.654

PARK - Main Result

Wake Model N.O. Jensen (RISØ/EMD)

Calculation Settings

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,242 kg/m³ to 1,243 kg/m³
Air density relative to standard	101,4 % to 101,4 %
Hub altitude above sea level (asl)	156,0 m to 160,1 m
Annual mean temperature at hub alt.	5,5 °C to 5,5 °C
Pressure at WTGs	993,6 hPa to 994,1 hPa

Wake Model Parameters
Wake decay constant 0,075 Open farmland

Displacement heights from objects

Wake calculation settings

Angle [°]			Wind speed [m/s]		
start	end	step	start	end	step
0,5	360,0	1,0	0,5	30,5	1,0

Scale 1:40 000
New WTG   Meteorological Data

Key results for height 141,0 m above ground level

Terrain Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]
A	901 268	6 379 424	EmdConwx_N57.380_E021.680 (3)	150,0	WEIBULL	5 444	8,4

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results*) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	37 372,7	33 635,4	37 909,6	98,6	53,3	11 211,8	4 672	8,4

*) Based on Result-10,0%

Calculated Annual Energy for each of 3 new WTGs with total 7,2 MW rated power

Links	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Displacement height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-10,0% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
1 A	No	NORDEX	N117-2 400	2 400	117,0	150,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 542,4	11 288	99,25	8,44
2 A	No	NORDEX	N117-2 400	2 400	117,0	150,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 391,6	11 152	98,07	8,44
3 A	No	NORDEX	N117-2 400	2 400	117,0	150,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 438,7	11 195	98,43	8,44

WTG siting

Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Z [m]	Row data/Description
1 New	900 868	6 380 499	6,0	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (127)
2 New	901 658	6 380 894	10,1	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (128)
3 New	901 248	6 381 314	7,0	NORDEX N117 2400 117.0 !O! hub: 150,0 m (TOT: 208,5 m) (129)

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GPGJ75J / maria.klemm@geo.uu.se
Calculated:
2017-04-27 12:08/3.0.654

PARK - Main Result

Calculation: Scenario 3 - 7 Nordex N117-2400 - 91m

Wake Model N.O. Jensen (RISØ/EMD)

Calculation Settings

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,249 kg/m³ to 1,250 kg/m³
Air density relative to standard	102,0 % to 102,1 %
Hub altitude above sea level (asl)	96,0 m to 103,7 m
Annual mean temperature at hub alt.	5,9 °C to 5,9 °C
Pressure at WTGs	1 000,5 hPa to 1 001,4 hPa

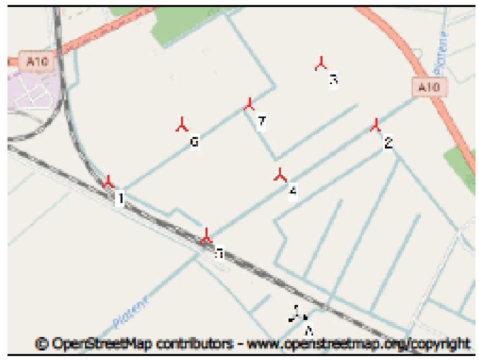
Wake Model Parameters

From angle [°]	To angle [°]	Terrain type	Wake decay constant
-180,0	180,0	Open farmland	0,075

Displacement heights from objects

Wake calculation settings

Angle [°] start	end	step	Wind speed [m/s] start	end	step
0,5	360,0	1,0	0,5	30,5	1,0



Scale 1:40 000
New WTG   Meteorological Data

Key results for height 91,0 m above ground level

Terrain Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]
A	901 268	6 379 424	EmdConwx_N57.380_E021.680 (3)	100,0	WEIBULL	4 151	7,7

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results*) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	75 903,3	68 313,0	79 139,8	95,9	46,4	9 759,0	4 066	7,7

*) Based on Result-10,0%

Calculated Annual Energy for each of 7 new WTGs with total 16,8 MW rated power

Links	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Displacement height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-10,0% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
1 A	No	NORDEX	N117-2 400	2 400	117,0	91,0	0,0	EMD	Level 0 - calculated - - 01-2011	11 045,6	9 941	97,69	7,71
2 A	No	NORDEX	N117-2 400	2 400	117,0	91,0	0,0	EMD	Level 0 - calculated - - 01-2011	10 875,3	9 788	96,19	7,71
3 A	No	NORDEX	N117-2 400	2 400	117,0	91,0	0,0	EMD	Level 0 - calculated - - 01-2011	10 755,4	9 680	95,13	7,71
4 A	No	NORDEX	N117-2 400	2 400	117,0	91,0	0,0	EMD	Level 0 - calculated - - 01-2011	10 766,9	9 690	95,26	7,71
5 A	No	NORDEX	N117-2 400	2 400	117,0	91,0	0,0	EMD	Level 0 - calculated - - 01-2011	11 008,1	9 907	97,38	7,71
6 A	No	NORDEX	N117-2 400	2 400	117,0	91,0	0,0	EMD	Level 0 - calculated - - 01-2011	10 781,8	9 704	95,36	7,71
7 A	No	NORDEX	N117-2 400	2 400	117,0	91,0	0,0	EMD	Level 0 - calculated - - 01-2011	10 670,1	9 603	94,37	7,71

WTG siting

Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Z [m]	Row data/Description
1 New	899 759	6 380 276	5,0	NORDEX N117 2400 117.0 !O! hub: 91,0 m (TOT: 149,5 m) (173)
2 New	901 724	6 380 891	7,8	NORDEX N117 2400 117.0 !O! hub: 91,0 m (TOT: 149,5 m) (174)
3 New	901 269	6 381 316	7,4	NORDEX N117 2400 117.0 !O! hub: 91,0 m (TOT: 149,5 m) (175)
4 New	901 049	6 380 451	12,7	NORDEX N117 2400 117.0 !O! hub: 91,0 m (TOT: 149,5 m) (176)
5 New	900 539	6 379 936	9,7	NORDEX N117 2400 117.0 !O! hub: 91,0 m (TOT: 149,5 m) (177)
6 New	900 274	6 380 751	5,5	NORDEX N117 2400 117.0 !O! hub: 91,0 m (TOT: 149,5 m) (178)
7 New	900 764	6 380 951	6,0	NORDEX N117 2400 117.0 !O! hub: 91,0 m (TOT: 149,5 m) (179)

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Calculated:
2017-04-27 11:32/3.0.654

PARK - Main Result

Calculation: Scenario 4 - 6 Nordex N117-2400 - 141m Hub height

Wake Model N.O. Jensen (RISØ/EMD)

Calculation Settings

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,243 kg/m³ to 1,244 kg/m³
Air density relative to standard	101,5 % to 101,6 %
Hub altitude above sea level (asl)	145,4 m to 153,4 m
Annual mean temperature at hub alt.	5,5 °C to 5,6 °C
Pressure at WTGs	994,4 hPa to 995,4 hPa

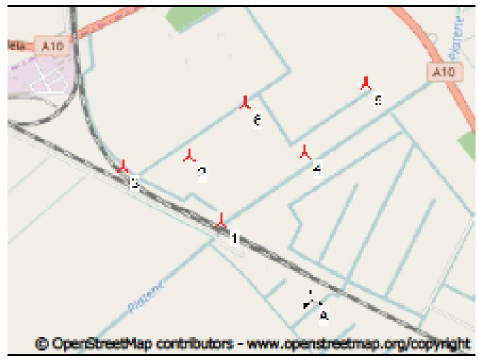
Wake Model Parameters

From angle [°]	To angle [°]	Terrain type	Wake decay constant
-180,0	180,0	Open farmland	0,075

Displacement heights from objects

Wake calculation settings

Angle [°] start	end	step	Wind speed [m/s] start	end	step
0,5	360,0	1,0	0,5	30,5	1,0



Scale 1:40 000
New WTG   Meteorological Data

Key results for height 141,0 m above ground level

Terrain Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]
A	901 268	6 379 424	EmdConwx_N57.380_E021.680 (3)	150,0	WEIBULL	5 444	8,4

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	72 749,7	65 474,7	75 137,5	96,8	51,9	10 912,5	4 547	8,4

¤) Based on Result-10,0%

Calculated Annual Energy for each of 6 new WTGs with total 14,4 MW rated power

Links	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Displacement height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-10,0% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
1 A	No	NORDEX	N117-2 400	2 400	117,0	141,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 190,4	10 971	97,35	8,44
2 A	No	NORDEX	N117-2 400	2 400	117,0	141,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 040,0	10 836	96,14	8,44
3 A	No	NORDEX	N117-2 400	2 400	117,0	141,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 253,0	11 028	97,84	8,44
4 A	No	NORDEX	N117-2 400	2 400	117,0	141,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 077,6	10 870	96,46	8,44
5 A	No	NORDEX	N117-2 400	2 400	117,0	141,0	0,0	EMD	Level 0 - calculated - - 01-2011	12 198,5	10 979	97,41	8,44
6 A	No	NORDEX	N117-2 400	2 400	117,0	141,0	0,0	EMD	Level 0 - calculated - - 01-2011	11 990,3	10 791	95,74	8,44

WTG siting

Swedish UTM 33-SWEREF99 (SE)

	Easting	Northing	Z [m]	Row data/Description
1 New	900 539	6 379 936	9,7	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (159)
2 New	900 249	6 380 406	5,6	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (160)
3 New	899 759	6 380 276	5,0	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (161)
4 New	901 114	6 380 516	12,4	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (162)
5 New	901 524	6 381 076	8,2	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (163)
6 New	900 629	6 380 841	4,4	NORDEX N117 2400 117.0 !O! hub: 141,0 m (TOT: 199,5 m) (164)

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