Feasibility of onshore wind energy in the province of North-Holland

An economic and geographic assessment of onshore wind energy in the province of North-Holland with a capitalization on synergies and a visualization in a 3D environment

Michel Paardekooper

Geodan BV Amsterdam

VU University Amsterdam

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Michel Paardekooper

Student number 2105543
Research Project (AM_1103)
Master Earth Sciences & Economics
VU University Amsterdam
Geodan BV Amsterdam
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Supervisor Geodan BV Amsterdam
Azarakhsh Rafiee
Researcher & Developer at Geodan BV Amsterdam

Supervisors VU University Amsterdam

VU Supervisor: Vasco Diogo - PhD Researcher
Department: Spatial Economics - Spinlab
Faculty: FEWEB –Economics and Business Administration

Second Assessor: Eric Koomen - Associate Professor
Department: Spatial Economics - Spinlab
Faculty: FEWEB –Economics and Business Administration

Summary

One of the aims of the Dutch national government is to stimulate renewable energy in order to create a green and diversified energy system. The province of North-Holland is obliged by the Dutch government to install 105.5 MW extra of onshore wind energy before 2020, outside national wind park Wieringermeer. In this research the feasibility of onshore wind energy in the province of North-Holland is identified. The aim was to implement the geographic and economic constraints in a spatially explicit way. This report provides a general method for the province of North-Holland, which can be easily applied to other provinces or the whole of the Netherlands, assuming that each province has the requisite data available.

Onshore wind energy is inexhaustible and decreases the dependence of foreign imported energy, such as fossil fuels. This increases the energy security of a country, because it is locally produced energy. Wind energy also provides jobs during construction, maintenance and monitoring. The negative impacts of onshore wind energy are construction nuisance, noise, landscape depreciation, shadow flicker of the rotor blades and killing of birds and bats. The zoning regulations and distance requirements, imposed by the national government, limit the suitability of wind turbines and a general prohibition applies around urban areas, radar systems and natural areas. The even more stringent regulations of the province of North-Holland make that 6.6% of the province, excluding Wieringermeer, is suitable for onshore wind energy.

The average wind speed in the province of North-Holland at 100 meters altitude is at most locations between 8 and 10 m/s, which is high compared to the rest of the Netherlands. This gives a high wind energy potential. Another spatially important factor is the distance to national grid transformers, as those function as connection points to the national grid and new transformer stations are costly. The costs for new transmission lines are estimated at € 4,000,000 per kilometre and have a large impact on the economic performance of the wind turbine. Except for two small areas, a transformer station is available within 10 kilometres, but in a large part of the province even within 5 kilometres.

The economic analysis shows that onshore wind energy is a profitable investment in all suitable locations in the province of North-Holland. The net present value, which is determined over a period of 20 years, ranges between € 250,000 and € 6,000,000 per turbine. The sensitivity analysis reveals that areas with a relatively high net present value are less sensitive to changes in costs and benefits than areas with a relatively low net present value. The largest change on the profitability is caused by the energy sales price, as a 50% drop in sales price results in a negative net present value in the whole province. Other major factors are the average wind speed and the subsidies. Even with no subsidies at all, a few areas still have a positive net present value. A wind park of 18 wind turbines with an installed capacity of 54 MW has at some very profitable locations an annual rate of return on the investment of 6.3% for a period of 20 years, whereas for example Dutch national government bonds of this duration have an annual rate of return of 2.74%. One should take into account that a wind farm is considered as a more risky investment and that the outlined economic situation is valid for 2014. For example, changes in the subsidy system are announced for 2015.

The intermittent variability of wind turbines stresses the capacity value of the wind farm, limits energy output forecasting and results in hours with zero output. Synergies with other types of renewable energy sources could resolve or decrease this intermittent variability and result in cost-efficiencies by sharing transmission lines, access roads, surveillance and monitoring.

Geothermal electrical energy production is not cost-effective in the province of North-Holland, because of low underground layer temperatures. Co-electrical generation between wind energy and solar photovoltaics reduces the intermittent variability of wind energy by 32.5%, if the solar field has an installed capacity of 44% of that of the wind farm. Solar fields also have an intermittent variability, but relatively the output is higher in summer than in winter, while wind energy output is higher in winter. The statistical analysis shows that wind energy and solar power complement each other in terms of energy generation, based on monthly and hourly data of wind speeds and solar radiation, which reveal a negative correlation between them. However, the results from the monthly data lack statistical significance, except for the month June. Also at the hourly level wind and solar power are complements, but to a lesser extent and not in the early afternoon. At nights with good winds, wind energy backs up the solar field, reducing the hours of zero output.

This research has been visualized in a 3D environment that is able to support policy makers, wind park developers and the local population in utilizing the benefits and mitigating the negative impacts of onshore wind energy, as the 3D tool shows the economic performance, suitability, average wind speed, distance to transformers and the impact on the landscape, which could be either positive or negative. Therefore, it is applicable as a communication tool to support feasibility discussions of onshore wind energy in the province of North-Holland.

The presented method of how to assess the feasibility of onshore wind energy in a spatially explicit way includes an geographical and economic assessment, while taking all spatial factors into account. The highly adaptable design of the models gives a high flexibility in producing new suitability and economic maps. This research has shown that this method is applicable in the province of North-Holland and that intermittent variability of wind energy could be decreased by adding a solar field.

Preface

This research has been done in the context of a research project for my master Earth Sciences & Economics at the VU University Amsterdam. For this research I have done an internship at Geodan BV Amsterdam from April until December 2014. To be able to participate in a dynamic business environment has been a very valuable and instructive experience. This research would not have been possible without the cooperation of Geodan BV. I really had a great time during my internship there. I especially want to thank Henk Scholten, CEO of Geodan BV, who has been willing to give me this great opportunity. I am grateful for his support and very inspiring meetings during my internship. Special thanks goes to my VU supervisor Vasco Diogo, who has been of great value throughout this research with his comments and sharp ideas. I really enjoyed the collaboration, which has enhanced the quality of this research. My colleagues at Geodan have given me a warm welcome and I soon felt a member of the DIT-team. I want to thank the DIT-team for their great help and support. My gratitude goes out to Azarakhsh Rafiee for her wonderful support and it was great working with her at Geodan. At last I want to thank Eric Koomen for being my second assessor.

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1. Introduction and method

The outline of this report is described in this section. First, an introduction into the subject and the content of the report is given. Thereafter the objectives of the report and the research questions are clarified. This section ends with a description of the method and the reading guide.

1.1 Introduction

One of the aims of the Dutch national government is to stimulate renewable energy in order to create a green and diversified energy system, which is agreed upon in *Het Energieakkoord voor Duurzame Groei* (SER, 2013). That is why 11 national wind parks have been designated in the most suitable areas (Rijksoverheid, 2013). One of these wind parks is located in the province of North-Holland with a total installed capacity of 580 MW in 2018. In *Het Energieakkoord voor Duurzame Groei* is decided that another 105.5 MW has to be installed elsewhere in the province of North-Holland before 2020. Geodan offered their expertise to support the province in visualizing the impact of wind turbines on the landscape. My internship aimed at providing input for this visualization tool. This visualization tool can be used a communication tool in discussions with local stakeholders in order to find the most suitable locations.

1.2 Objectives

This research focusses on the spatial factors concerning onshore wind turbines. The suitability of wind turbines in a densely populated country, like the Netherlands, is limited because of zoning restrictions and regulations. The impacts of wind turbines on the landscape and nature prohibit wind turbines in certain areas. Also wind speed patterns vary through the province posing geographical constraints on the economic feasibility of wind turbines. The economic performance of a wind turbine is further influenced by the distance towards national grid transformers, which constraints the economic feasibility in remote areas because of high costs for new energy infrastructure. In this report a fictive wind park of 18 wind turbines with a total installed capacity of 54 MW is examined and in this case a connection can be made to an existing transformer station. Synergies can be found with other renewable energy sources which enhances the combined energy system. The suitability of these synergies are also spatial dependent. The public acceptance of wind turbines of people in the direct surroundings or in case of a high valued landscape is an issue for policy makers. A 3D tool is able to support policy makers in finding the best suitable locations in order to minimize the negative effects of wind turbines.

This research addresses these constraints by taking all the spatial factors into account. Maps showing these spatial factors, such as suitability and profitability of onshore wind turbines in the province of North-Holland, are input for the 3D visualization tool that can be used to identify optimal locations and create support of the public by visualizing the impacts of wind turbines in the landscape.

1.3 Research questions

The aim of this report is to identify all the spatial factors of onshore wind turbines taking into account geographic and economic constraints. The following research question is leading:

How to assess the feasibility of onshore wind energy in a spatially explicit way?

In order to answer the main research question several sub-questions are set up. These sub-questions structure the report and are dealt with separately in each chapter.

- *What are the positive and negative impacts of onshore wind energy?*

- *Which spatial factors set the opportunities and constraints for the implementation of onshore wind energy?*

- *What are the economic costs and benefits of onshore wind turbines and how to determine the return of investment of onshore wind turbines in a spatially-explicit way?*

- *How to combine onshore wind energy with other renewable energy sources to decrease intermittent variability?*

- *How to visualize landscape impacts of onshore wind energy in 3D?*

1.4 Method

Chapter 2 is compiled through a literature survey to identify impacts and benefits. A spatial analysis has been done in chapter 3 to determine the spatial factors that play a role by the implementation of onshore wind energy. Chapter 4 is an economic assessment of an onshore wind turbine park, including a net present value and a sensitivity analysis. Synergies with other renewable energies are identified in chapter 5 through a literature survey. These synergies consist of cost reduction and a more stable and reliable energy system. The last chapter comprehends a tool to visualize onshore wind energy in a 3D environment that is created with CityEngine.

1.5 Reading guide

This report is structured as follows. Chapter 2 is about the impact of onshore wind turbines on the landscape, local residents and nature. Also possible benefits of wind turbines are identified. Chapter 3 deals with all the spatial factors that give the framework for finding the most suitable locations in the province of North-Holland. Geographic and technical constraints are taken into account as well as zoning regulations and the distance to the existing energy infrastructure. This chapter ends with combining all the spatial factors into a suitability map. Chapter 4 describes a cost-benefit analysis of onshore wind turbines in the province of North-Holland. In this economic assessment also the average wind speed and the distance to the nearest national grid transformer is taken into account. This chapter proceeds with a net present value analysis and ends with a sensitivity analysis. In chapter 5 different synergies that are a valuable asset for onshore wind energy are identified with an emphasis on solar photovoltaics. Chapter 6 shows how wind parks and their landscape impacts can be visualized in a 3D tool. This report ends with a discussion and a conclusion section.

2. Impacts and benefits

In this chapter negative and positive effects of onshore wind energy are identified. Negative impacts limit the feasibility of onshore wind energy, while benefits of wind turbines could provide all kinds of advantages at a regional and national level.

2.1 Impacts

Onshore wind energy turbines require precious land space and have an impact on the surroundings. These effects are explored in this section. The regulations and zoning restrictions that result from these effects are described in chapter 3.

2.1.1 Land use

Wind turbine parks require valuable and scarce space in the Netherlands. Most of the research concerning land use requirements for modern wind turbines is conducted in the United States. Denholm, Hand, Jackson & Ong (2009) have compared different studies and show that the average direct impact area is about one hectare per 3 MW turbine. The direct impact area is defined as the access roads, the wind turbines itself, power lines in the park and the substation. In the Netherlands the power lines in the wind turbine park are mostly underground and also the roads are smaller compared to the United States. It is common in the United States that a new transformer station is built, because usually the wind park is very large. It is very likely that the land use impact of a wind turbine is very small in the Netherlands, because 80% of the land use impact consists of the access road. This road could be an existing road, which could be used for all kind of purposes, for example by local farmers, because wind turbines are often placed on agricultural lands.

The indirect or temporary land impact is almost two or three times higher (Denholm et al., 2009). This impact is defined as the area used during the construction of the wind turbines by cranes, stages, etc.. For grasslands it usually takes two or three years to completely recover from this temporary impact, while agricultural areas restore faster (Arnett et al., 2007).

2.1.2 Noise

A negative effect of a wind turbine is the generated noise. Van den Berg, Pedersen, Bouma & Bakker (2008) have examined the experience of people in the Netherlands living within 2.5 kilometres of a wind turbine. Below 30 Decibel (dB) 25% of the people noticed the sound, but this increased to more than 80% above 35 dB. Also the amount of people annoyed by the noise raised with higher noise rates, but this depends of course also on the amount of background sounds. In quiet areas the noise of wind turbines are experienced sooner as annoying than in areas with a lot of background noise. The annoyance increased when the wind was blowing in the direction of their home. The noise was characterized as a swishing or rustling sound.

Above 45 dB almost no-one experienced the sound as annoying, because people living this close to a wind turbine almost always have economic interest from them, for example farmers. So to increase acceptance of wind turbines, people should be economically involved (Van den Berg, Pedersen, Bouma & Bakker, 2008). Several other studies performed in different countries show similar results (National Wind Watch, 2013). Some studies contradict about the impacts of noise and the quality of life. Some say noise does not have an impact on the quality of life (Mroczek, Kurpas & Karakiewicz, 2012), while others argue that the impact of noise is large (McBride, Shepherd, Welch & Dirks, 2014).

Annoyance from noise raises stress and causes sleep disturbances (Bakker et al., 2012). This is not because they hear the noise at night directly, but it works psychologically by knowing that the noise is there. Technological advancement decreases the noise emitted by wind turbines, but the increase in the size of the wind turbine has vanished this effect.

2.1.3 Landscape

Wind turbines have an impact on the landscape that could either be positive or negative depending on the land use. As seen in the previous section noise annoys people. The visibility of wind turbines enhances even the annoyance of people if it is experienced in combination with noise (Van den Berg, Pedersen, Bouma & Bakker, 2008). Visibility and noise strengthen each other. Wind turbines are by some people seen as disturbing in the landscape. Annoyance is most of the time induced by changes in the landscape that people have experienced during their youth (RVO, 2014a). In that respect any change is seen as a bad change. In most land use types wind turbines are seen as a disturbing factor. The disturbance could be reduced by clustering wind turbines and set the rotation synchronously. Also colouring the lower part of the hub of the wind turbine greenish reduces the negative impact, because the turbine blends in better with the landscape.

In certain land use types, such as industrial areas or ports, wind turbines could enhance the quality of the landscape. In these man-made areas the industrial character is resembled by the wind turbines. This could be seen as a positive landscape development. Wind turbines could also improve sustainability image of areas and it can be seen as innovative. Also wind turbines in a line alignment along infrastructure could strengthen the structure of the landscape. Thus land use and landscape type are important factors when investigating new wind turbine locations.

2.1.4 Shadow flicker

Wind turbines generate long moving shadows with their blades. These shadows rotate with the sun and are longest at sunset and sundown in winter. The rotating blades also create shadow flicker, which is the alternation between shadow and no shadow. Modern wind turbines have 20 to 30 revolutions per minute, which matches with 1.5 Hertz. Annoyance occurs mainly at higher frequencies between 2.5 and 14 Hertz (RVO, 2014b). If wind turbines are located within twelve times the rotor diameter of vulnerable objects, such as schools and hospitals, and if calculations show that on more than seventeen days per year, at least twenty minutes per day, shadow flicker could occur, the wind turbine should be shut down via the software of the wind turbine. It depends on the cloudiness of the day, the wind speed and wind direction whether shadow flicker could occur or not (RVO, 2014b). The shadow flicker is usually bright enough to pass through closed eyelids and to affect the illumination in houses (Harding, Harding & Wilkins, 2008). This disturbs the residents and causes stress, annoyance and sleep disturbance. Shadow flicker has to be taken into account by appointing wind turbine locations.

2.1.5 Birds and bats

Birds and bats could experience three types of disturbances caused by wind turbines (Aarts & Bruinzeel, 2009). The first one is direct impact of flying into a wind turbine, which predominantly occurs during bad weather conditions and at night. Secondly, birds and bats avoid areas with wind turbines and thus lose a part of their habitat. At last, wind parks could be a barrier obstructing their migration routes. Birds and bats have to fly around the wind parks which burns valuable energy. In figure 1 the areas with the highest risk of disturbing birds are shown (Aarts & Bruinzeel, 2009). This map is commissioned by the Dutch National Bird Watch Organization (Vogelbescherming Nederland). It is a bird density map showing bird rich areas (in dark blue) and Natura-2000 and highly valuable bird areas (in purple). These areas should remain wind turbine free according to the Dutch National Bird Watch Organization. In chapter 3 the bird rich areas and the Natura-2000 areas are taken into account as unsuitable areas for wind turbines.

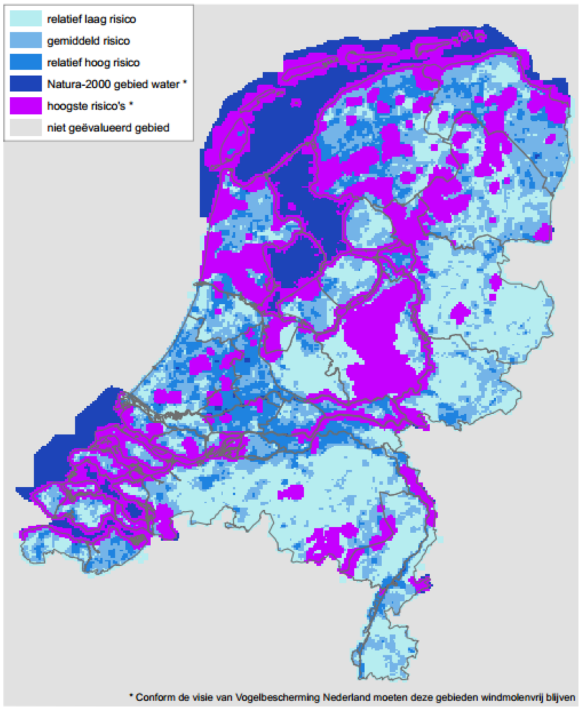


Figure 1 National risk map of the disturbance of birds. The dark blue areas are bird-rich areas in which there is a high chance that birds will experience any form of disturbance. The purple areas are Natura-2000 bird areas and areas best suitable for birds. These areas should remain free of wind turbines according to the Dutch Bird Watch. Source: Aarts & Bruinzeel (2009).

The amount of birds killed by one average sized wind turbine is between 20 and 40 birds per year (Winkelman, Kistenkas & Epe, 2008). In total 60,000 – 100,000 birds are killed by wind turbines every year in the Netherlands. It is not known if larger turbines kill more birds. Cars travelling on highways kill 2 – 8 million birds per year and power transmission lines 1 – 2 million birds per year. Studies in the Netherlands showing the effect of wind turbines on bats are not very common. There is little data, but one study showed that the effect is very small despite a large activity of bats around wind turbines (Limpens et al., 2013). The estimation is that four bats per year per turbine are killed. This suggests that bats can live close to wind turbines. Furthermore, bat activity can be predicted by temperature, wind speed and night time. When bat activity is high and energy loss is low, the wind turbines can be shut down. This reduces bat deaths by 80-90% with an energy loss of less than 1%.

In the USA most wind turbine farms have reported less than four deaths of birds per MW (NWCC, 2010). Bat deaths in the USA vary strongly from 1 per MW up to 40 per MW on the Buffalo Mountain. According to the National Wind Coordinating Committee (2010) in the USA the death of birds and bats do not pose a threat on the species population. A study in Flanders however, found a substantial part of the population of some species are killed by wind turbines (Everaert, 2008). The chance a bird flies into a wind turbine has been estimated by several studies to be around 0.01-0.02%. This depends however, strongly on the type of birds in the surroundings.

2.2 Benefits

Onshore wind energy also provides benefits. This ranges from boosting the local economy to multifunctional land use.

2.2.1 General benefits

Wind energy is inexhaustible and could be part of a stable and reliable energy system when combined with other forms of renewable energy. Wind energy is a clean form of energy and does not pollute water or air. Because wind energy is produced locally it can provide more jobs and economic benefits than imported energy (Union of Concerned Scientists, n.d.). Wind energy could also provide an alternative far off-grid energy supply instead of conventional diesel generators in remote areas, where it is not economically feasible to connect to the national power grid. This is however not so relevant for a dense and small country like the Netherlands.

Another benefit is an increased energy security. This means that a country is less dependent on imported energy. Locally produced wind energy decreases the dependence on imported fossil fuels from unstable or politically undesirable countries. This dependence is a major political concern, so an increase in energy security is a benefit.

2.2.2 CO2 savings

A decrease in the use of fossil fuels results in less CO_2 emissions. The EU aims at 20% renewable energy and 20% CO_2 reduction in 2020. The Dutch targets are 14% renewable energy and a 16% reduction of CO_2 in 2020 (Rijksoverheid, 2014). Also the Netherlands have to adhere to the Kyoto Protocol of reducing CO_2 emissions. If these obligations will not be met, there will be consequences for the Netherlands. Lower CO_2 emissions has been made monetary by taking the CO_2 market price. The current CO_2 market price fluctuates around € 6 per ton (price of 8 august 2014) (www.pointcarbon.com, 2014).

The lifecycle emissions of a wind turbine are estimated at 11 grams of CO_2 per kiloWatthour (kWh), which are solely emissions from production and infrastructure construction (IPCC, 2014). This comes down to 11 ton of CO_2 per GigaWatthour (GWh). The energy payback time of a wind turbine is between 3.4 and 8.5 months. The lifecycle emissions for coal and gas are respectively 820 and 490 grams of CO_2 per kWh (IPCC, 2014). A typical 3 MW turbine generates between 6 and 10.2 GWh per year, depending on the location (see table 2). The annual lifecycle CO_2 emissions are thus between 66 and 112.2 ton CO_2 per turbine. If the same amount of electricity had to be generated with coal or gas the amount of emitted CO_2 would be between 2940 and 8364 tons of CO_2. Every year a single wind turbine saves between 2874 and 8251.8 tons of CO_2. A CO_2 market price of € 6 per ton results in a potential revenue of between € 17,244 and € 51,131 per turbine per year. The lifetime of the reference wind turbine is set at 20 years. This potential revenue could thus be substantial, but is also dependent on the development of the CO_2 price. The current CO_2 price is very low as it was € 20 per ton in 2008. A rising CO_2 price will result in a higher potential revenue.

2.2.3 Multifunctional land use

Onshore wind energy consumes valuable land space and thus should be combined in a smart way with other land uses. Zoning restrictions limit the construction of wind turbines in built-up and natural areas (see section 3.1). As is described in the next chapter wind turbines are mainly possible along roads, waterways and railroads, in industrial and in agricultural areas. Synergies could arise from landscape valuation perspectives. Wind turbines placed along infrastructure, such as highways, railroads, waterways and dikes, accentuate this corridor and enhance the landscape type. In industrial and port areas wind turbines fit in the landscape because it is a man-made industrial-looking object, as is described in section 2.1.3. For industrial businesses it could be profitable to be part of a wind park project in order to get cheap electricity or to build their own wind turbine for energy supply. For farmers this is much more common and has already been proven profitable. In a wind park the space between wind turbines is very suitable for livestock grazing and crops. This gives farmers a strong position for making use of that land or to allow wind parks on their land. It could give them a substantial financial benefit.

3. Spatial Factors

The spatial factors that play a role on the implementation of onshore wind energy turbines are identified in this chapter. These spatial factors determine the potential of and the constraints for onshore wind energy. In the first section the spatial factors related to land use and zoning regulations are discussed. Next the interference of wind turbines with radar systems is taken into account. Thereafter the distance to the high-tension power grid is considered. A very important spatial factor is the wind potential. This potential is calculated taking technical and geographical constraints into account. At last a suitability map for onshore wind energy is given for the province of North-Holland. Throughout this report a 3 MW wind turbine with a hub height of 100 meters and a rotor diameter of 100 meters is used as a reference, because this type of wind turbine is usually installed in new wind parks.

3.1 Land use

The first spatial factor is land use. Onshore wind energy is excluded by law from several land uses or is only allowed outside a specified distance. In this section eight different forms of land use are identified. The regulations discussed below are mandatory for getting a permit for building a wind turbine, unless stated otherwise. Most of the regulations can be found in Faasen, Franck & Taris (2013) from the Ministry of Economic Affairs, unless referenced otherwise.

3.1.1 Built-up areas

This category embraces commercial and residential areas and is defined into vulnerable objects and limited vulnerable objects (Faasen, Franck & Taris, 2013). Vulnerable objects are resident homes, schools, hospitals, elderly homes, recreational areas intended for more than 50 people on consecutive days, and commercial buildings larger than 1500 square meters. Limited vulnerable objects are sport parks, shops, swimming pools, small commercial buildings, hotels, restaurants, objects with a high infrastructural value such as power plants, and resident homes with a density of maximum two buildings per hectare.

Near vulnerable objects wind turbines are not allowed within the maximum of the hub height of the turbine plus a half of the rotor diameter, which is for the reference turbine a buffer of 150 meters. Wind turbines are also not allowed within the maximal throwing distance by nominal revolutions per minute. If a rotor blade breaks off when the blades are spinning with a nominal speed by high wind speeds, the distance the rotor blade travels before it hits the ground is calculated. This distance depends on the hub height, rotor diameter and the revolutions per minute, and is called the maximal throwing distance.

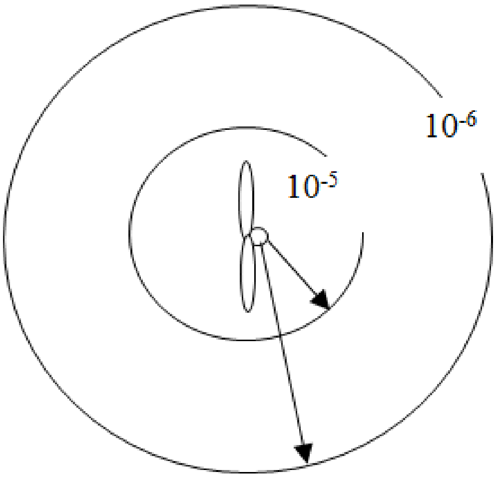


Figure 2 The inner ring has a risk of death of 10^{-5}/year and the outer ring a risk of 10^{-6}/year. The inner contour is equal to a half of the rotor diameter and the outer contour is equal to the maximum throwing distance. This is equal to the *Plaatsgebonden Risico* for limited vulnerable objects and vulnerable objects. Source: Faasen, Franck & Taris, 2013.

The reference wind turbine has a maximal throwing distance of 198 meters, which is determined by a special formula (Faasen, Franck & Taris, 2013). The risk zone of this particular wind turbine has thus a radius of 198 meters. The vulnerable objects have to be outside the risk zone, in which the risk of death is $10^{-6}/\text{year}$ (see figure 2). This means that the chance a person dies as a result of a wind turbine is once per 1,000,000 year.

Limited vulnerable objects only have to be at least a half of the rotor diameter away from wind turbines, which is 50 meters. The risk of death in this zone is $10^{-5}/\text{year}$. These risks of death (*Plaatsgebonden Risico*) is the chance that a person, that stays uninterrupted and unprotected at a certain location, dies as a result of an unusual event.

Another risk factor (*Groepsrisico voor Inrichtingen*) has to be determined if dangerous substances are stored within the maximal throwing distance by overspeed, which is 588 meters. Within this distance is the so-called influence area of the wind turbine. Overspeed is two times the nominal revolutions per minute. This risk factor states that an incident with 10 deaths or more is allowed no more than $10^{-5}/\text{year}$ and an incident with more than 100 deaths $10^{-6}/\text{year}$. This risk factor is a guideline and deviation is allowed if it is well argued (Faasen, Franck & Taris, 2013). If the risk is too high, it is not allowed to build the wind turbine.

The opportunities for onshore wind energy in built-up areas are very limited. The risk zone of a wind turbine is around 400 meters in diameter. This limits the suitability for wind turbines in built-up commercial or residential areas substantially. However, if the building density is only two residential homes per hectare, these homes - for example farms - are seen as limited vulnerable objects and thus the risk zone is 100 meters in diameter. This distinction between urban and rural areas is important for the suitability map later in this chapter.

3.1.2 Heavy industry

This type of land use does not have a minimum distance requirement. The minimum distance a turbine has to be placed from a heavy industry facility with chemical compounds is determined by calculating the $10^{-6}/\text{year}$ and $10^{-5}/\text{year}$ contours of figure 2. These contours depend on the layout of the industrial area, because every industrial area is different. Also the risk factor *Groepsrisico voor Inrichtingen* is required, which is described in the section about built-up areas (Faasen, Franck & Taris, 2013). Above these threshold values wind turbines are not allowed.

3.1.3 Nature and agriculture

Agricultural areas are usually large open areas, which are usually suitable for onshore wind energy. In practice many wind turbines are placed on agricultural grounds. Farmers generate an additional and reliable income when allowing wind turbines on their ground. The average rent is € 8000 per installed MW per year (John Dekker A&O, 2013). Farmers have to take into account that income from agricultural activities will be lower, because wind turbines require space. In recent years wind turbine development takes place in forests in Germany, Ireland and Sweden for example (RVO, 2014c). The reason behind this is that the visual impact of wind turbines in forests is less than in open areas. There is little known about the impact of trees on the wind speed patterns at 100 meters height. Some studies suggest that turbulence differs and could cause a higher wear rate (John Dekker A&O, 2013). However, most studies agree upon that modern wind turbines are so high that wind disturbance caused by the trees is likely to have a minimal impact on the profitability (Tindal & Landberg, 2008).

The manager of the forest receives a land rent for the wind turbine, but also some trees have to be cut down. This results in a loss of the wood sales revenues. For a single wind turbine around 1650 m^2 of forest needs to be cut for construction and around 1000 m^2 is permanently lost. Especially in forest areas, bird and bat movement has to be closely monitored in order to be able to take preventive measures. Natura 2000, national parks and UNESCO heritages are excluded from wind turbine development (Provinciale Ruimtelijke Verordening Noord-Holland, 2014). Other natural areas, such as wetlands and heath, are most of the time prohibited from wind turbine construction, because of the negative visual impact and consequences for wildlife. So wind turbines are possible in certain natural areas but this strongly depends on provincial and local regulations. Agricultural areas outside UNESCO heritages provide in general suitable locations for wind turbines.

3.1.4 Zoning regulations of the province of North-Holland

The legislation described in the previous sections is determined by the national government. Provinces are allowed to set stricter demands. The province of North Holland states for example that a distance of four times the hub height of a wind turbine with a minimum of 300 meters from vulnerable objects is required (Provinciale Ruimtelijke Verordening Noord-Holland, 2014). In case of a wind turbine with a hub height of a 100 meters, this comes down to a distance of 400 meters. This is twice as much as the regulation set by the national government (Faasen, Franck & Taris, 2013).

The requirements of the province intend to prevent the spreading of wind turbines and a degradation of the landscape. Wind turbines have to be placed in a line formation with a minimum of six wind turbines (Provinciale Ruimtelijke Verordening Noord-Holland, 2014). Building a new wind turbine includes the demolition of two old wind turbines, if there are old wind turbines present in the area. In order to fulfil the extra 105,5 MW onshore wind energy commitment around 50 new wind turbines of 3 MW have to be built (Bond & Talsma, 2014). The total number of wind turbines in North-Holland may even decrease but the total installed capacity will increase.

The province has also assigned several areas where wind turbines are not allowed. These areas are considered of high importance for the cultural and historic values of the landscape. Examples of these areas are monumental dikes such as the *Westfriese Omringdijk* and former defense systems such as the *Stelling Den Helder*. A list of all these areas is shown in the Appendix I, table 11, which is the input for the suitability map later in this chapter. Also natural areas are on this list. Important areas for meadow birds, national landscapes and parks and areas where noise above 40 dB is forbidden are legally protected. UNESCO heritages and geological important areas also pose constraints on onshore wind energy. In some areas wind turbines are allowed in exceptional cases, because sometimes the negative impacts are limited and the common interest is high (Provinciale Ruimtelijke Verordening Noord-Holland, 2014). This is indicated in table 11 in Appendix I as an area where extra research is required. These areas are not marked suitable in the suitability map, but could become suitable after extra research.

3.2 Infrastructure

In this section the regulations concerning infrastructure, such as roads, pipe lines and transmission lines are identified. Also the relation between radar systems and wind turbines is discussed.

3.2.1 Roads

The national highways are owned by the Dutch infrastructure organization Rijkswaterstaat and the reference turbine has to be placed at least 50 meters from the highway (Staatscourant, 2002). The following risk factors always have to be calculated if a wind turbine is placed within the influence area, regardless of the distance requirement. Wind turbines are prohibited if the stated threshold levels are exceeded. The chance a regular passing traveller of a wind turbine dies as a result of the wind turbine is set at $10^{-6}/\mathrm{year}$ *(Individueel Passanten Risico).* Also a societal risk applies in this situation (Maatschappelijk Risico). This risk is a measure for the expected number of deaths of travellers by the wind turbine and a measure for the societal perception. Rijkswaterstaat states that no more than $2 * 10^{-3}/\mathrm{year}$ travellers are allowed to die. Highways that are transport routes for dangerous substances are subject to a risk factor *(Groepsrisico voor transportroutes)* that calculates the chance that a deadly incident happens. These regulations state that an incident with 10 deaths or more is allowed $10^{-5}/\mathrm{year}$ per kilometre of transport route and an incident with 100 deaths or more $10^{-7}/\mathrm{year}$ (Faasen, Franck & Taris, 2013). A wind turbine is allowed if this risk factor does not increase by more than 10 percent. For roads owned by the province or municipalities the relevant local regulations apply and many situations are unique.

3.2.2 Waterways

Along waterways owned by Rijkswaterstaat turbines have to be placed at least 50 meters from the edge of the waterway (Staatscourant, 2002). Radar equipment and skippers experience no interference from wind turbines at this distance. All three risk factors described for highways also apply to waterways and have to be always determined. For all other waterways local regulations apply.

3.2.3 Railroads

The reference turbine is allowed at least 7.85 meters plus a half of the rotor diameter, 50 meters, away from the middle of the railroad tracks. Also for railroads the same three risk factors apply and need to be calculated. For the high-speed line, instead of an *Individueel Passanten Risico* of $10^{-6}/\mathrm{year}$ a risk factor of $10^{-7}/\mathrm{year}$ is the standard.

3.2.4 Pipe lines

Pipe lines are divided into harmless substances and dangerous substances. Harmless substances, like water pipes and sewers pose no restriction on wind energy turbines. Dangerous substances, for example gas and petrochemical pipe lines have minimum distance requirements and are divided into above ground and underground pipe lines. The national gas transporter GasUnie advises that dangerous above ground pipe lines have to be at least the maximum throwing distance by overspeed away from wind turbines, which is 598 meters. The maximum throwing distance by nominal revolutions per minute applies to dangerous underground pipe lines, which is 198 meters. The chance of failure of the pipeline is not allowed to increase by more than 10 percent. These guidelines are advisory and not obligatory for granting the permit for the construction of wind turbines, but GasUnie will protest against wind turbines within the advised distances.

3.2.5 High voltage transmission lines

The Dutch power grid supplier TenneT has a delivery obligation with respect to the transportation of electricity. TenneT advises to provide a minimum distance of at least the maximum throwing distance by nominal revolutions per minute, which is 198 meters. These guidelines are advisory and not obligatory for granting the permit for the construction of wind turbines, but TenneT will protest against wind turbines within the advised distances.

3.2.6 Dikes

Wind turbines are not allowed on the so-called core zone of waterworks with a flood defense function, whether it is a dike, dune or dam. Wind turbines are allowed in the direct surroundings of a primary water barrier provided that it has no negative consequences for the functioning of the primary water barrier.

3.2.7 Radar systems

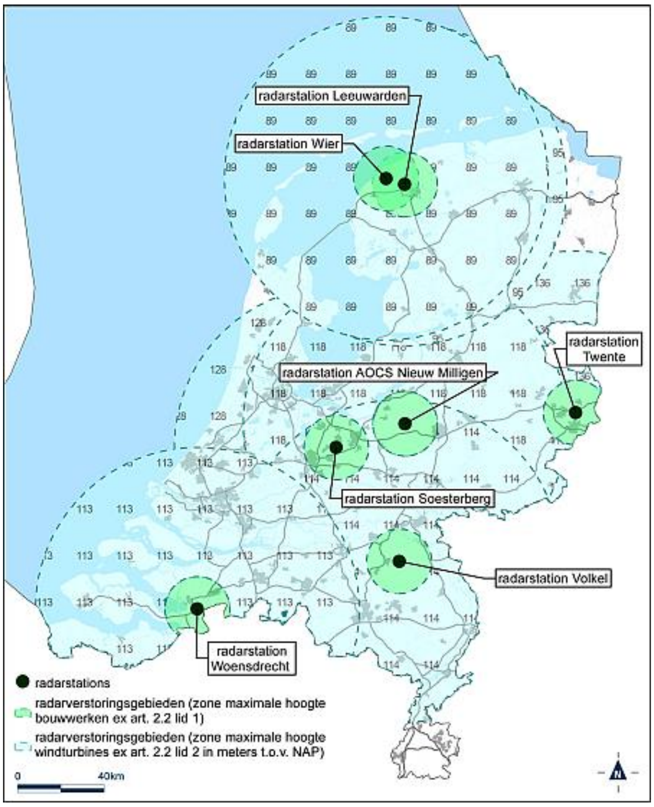


Figure 3 Defense radars in the Netherlands. The numbers represent the maximum allowed building height without an official review. Source: RVO, 2014d.

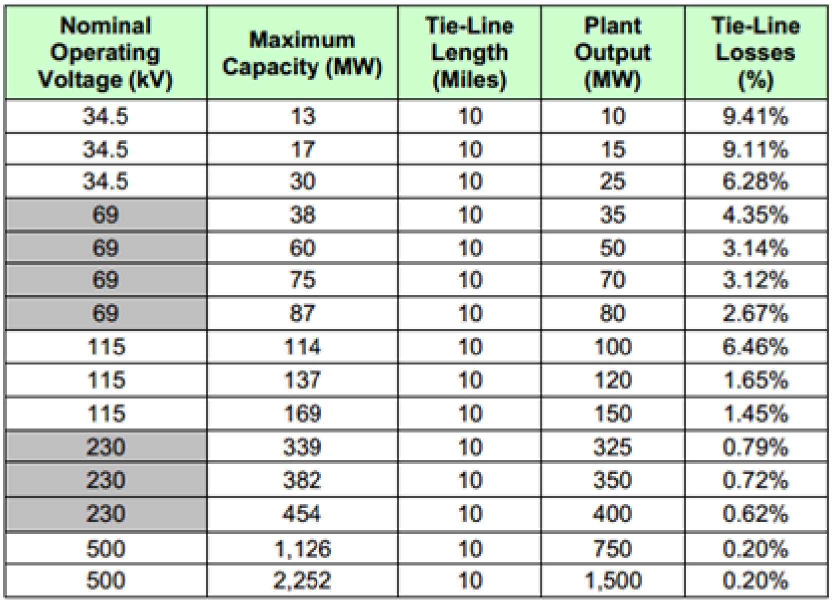
Onshore wind turbines could disturb defense and flight radars. In the province of North-Holland the navy in Den Helder and international airport Schiphol use radars. The flight zone of Schiphol should remain free from wind turbines. The radar systems of the navy in Den Helder are used to detect enemy aircraft and guard the Dutch airspace. Radar systems can be disturbed by nearby construction of all kinds of buildings (Van Gent, 2014). Therefore a building construction limit applies in in parts of this region. Wind turbines can even blind radars, because wind turbines reflect the radar energy and cause distortions. Radar systems need to detect aircraft many times per second to be able to follow the aircraft. The fast rotating blades of the wind turbine distort the detections. A wind turbine can be seen as an aircraft on the radar. Wind turbines are thus not allowed close to radar systems (RVO, 2014d). In figure 3 all defensive radars in the Netherlands are shown. The numbers represent the maximum building height that is allowed without an official review by air traffic control Netherlands. Buildings higher than the maximum allowed height are tested on interference with the radars. If the defensive radars are not disturbed the building is allowed.

3.2.8 Distance to transformer station

The current energy infrastructure is one of the determinative factors in evaluating onshore wind energy locations. The construction of new energy infrastructure is costly, consumes valuable space and has an impact on the landscape (Royal Haskoning DHV, 2013). In this section this spatial factor is highlighted. In section 4.4.1 the costs of new energy infrastructure are specified.

The policy of the province of North-Holland focusses on the concentration of wind turbines in wind parks, as is described in section 3.1.4. That is why in this analysis the approximately 50 new wind turbines are split up into three wind parks of equal size, 18 wind turbines per wind turbine park with a total installed capacity of 54 MW. This splitting up has another reason. The electricity generated by a wind park is congregated at one location, at which it is transformed into a certain operating voltage. This voltage has a limit to the maximum capacity that is installed in the wind park (see table 1). This table represents the voltages of the grid of the USA. In table 1 the 69 kV is twice as high as 34.5 kV, but the maximum capacity is three times as high. Based on the relationship between maximum capacity and voltage, an installed capacity of 54 MW is assumed to be in this analysis as almost the maximum possible on a 50 kV operating voltage.

Table 1 Relation between plant output, maximum capacity, nominal operating voltage and transmission line losses. Source: Rhyne & Klein, 2014.



Nominal Operating Voltage (kV)	Maximum Capacity (MW)	Tie-Line Length (Miles)	Plant Output (MW)	Tie-Line Losses (%)
34.5	13	10	10	9.41%
34.5	17	10	15	9.11%
34.5	30	10	25	6.28%
69	38	10	35	4.35%
69	60	10	50	3.14%
69	75	10	70	3.12%
69	87	10	80	2.67%
115	114	10	100	6.46%
115	137	10	120	1.65%
115	169	10	150	1.45%
230	339	10	325	0.79%
230	382	10	350	0.72%
230	454	10	400	0.62%
500	1,126	10	750	0.20%
500	2,252	10	1,500	0.20%

From the location where the electricity of the wind park is congregated, it is transported via underground cables to the nearest transformer station of 50 kV, where a connection can be made to the national power grid. In the province of North-Holland this voltage is either 50 kV or 150 kV. Obviously the abundance of 50 kV transformer stations is much higher, because 50 kV is medium voltage and is used for inner-city transportation. 150 kV is high voltage and is the regional power grid. (Royal Haskoning DHV, 2013).

All the 150 kV transformer stations are shown in figure 4. Most of the 50 kV transformer stations are also given, but some are left out. Some of these are located in the middle of cities or at such a close proximity of each other that these transformer stations will not be used by the wind parks, because other stations are closer. A complete list of all the used transformer stations with GPS coordinates is given in Appendix II. In figure 4 the Euclidean distance to the nearest transformer station, either 50 kV or 150 kV, is calculated using ArcGIS software from ESRI. The distance is in almost all of the province lower than 10 kilometres, except in the north eastern part of the province and on the isle of Texel. A large part of the province has a transformer station within five kilometres, which is seen as the maximum distance by Royal Haskoning DHV (2013). Figure 4 is input for the net present value analysis in section 4.4.

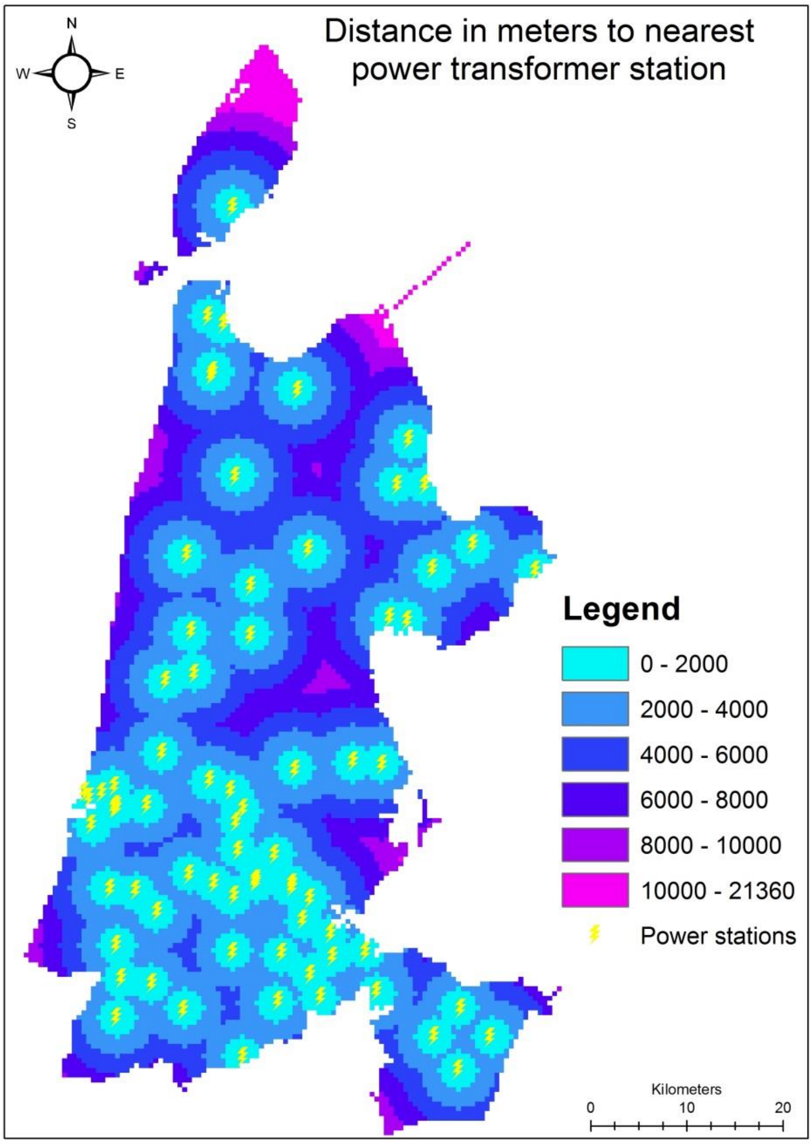


Figure 4 Distance in meters to nearest power transformer station. All 150 kV transformer stations are shown and most of the 50 kV stations. Source of transformer stations: www.hoogspanningsnet.com, 2014.

3.3 Local wind patterns

Onshore wind energy locations are naturally restricted by local wind patterns. Several different potentials connected to onshore wind energy can be distinguished (Hoogwijk, De Vries & Turkenburg, 2004). The geographical potential, technical potential and wind energy potential are discussed in this section. The economic potential is forwarded to the next chapter.

3.3.1 Wind speed

The average wind speed is a spatial factor that determines the economic potential and thus the profitability of the wind turbine. The average wind speed per year at an altitude of 100 meters is shown in figure 5**.** The highest wind speeds are recorded in the western and northern parts of the Netherlands. The wind speed at an altitude of 100 meters is relevant, because this the hub height of the reference turbine. The resolution of the data is 10 by 10 square kilometres (SenterNovem, 2005). This data set is a long-term average of the wind speeds at 10 meters height. The data is extrapolated to 100 meters (SenterNovem, 2005). In the province of North-Holland windy areas are found along the coastlines of the North Sea and the IJsselmeer. Amsterdam and Haarlem stand out as areas with lower average wind speeds, because of many (tall) buildings that disturb the wind pattern. Wind turbines have grown in height in the recent years to be able to catch undisturbed winds at higher altitudes.

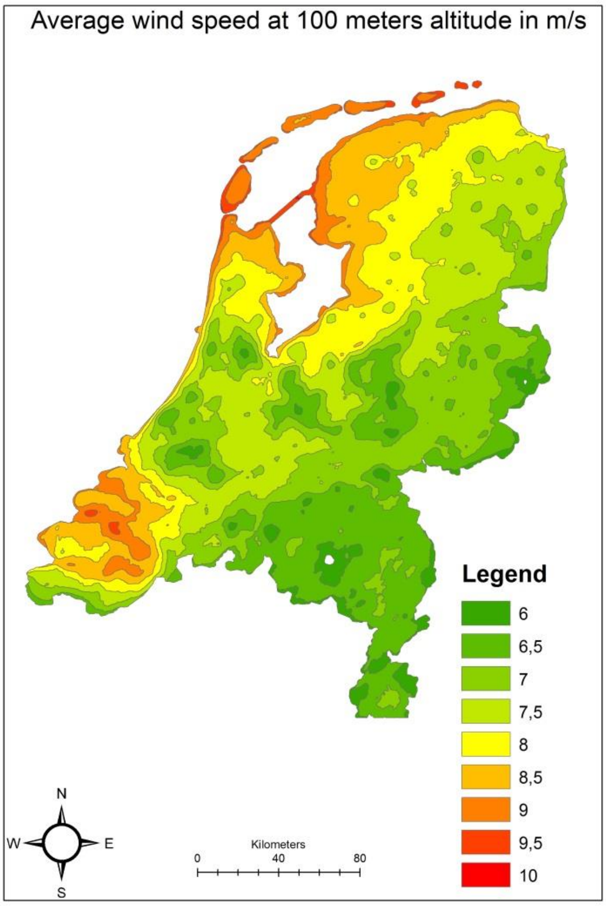


Figure 5 Average wind speed in m/s at 100 meters altitude in the Netherlands.
Source: SenterNovem, 2005.

3.3.2 Power curve

The classes in figure 5 are divided by 0.5 m/s. This seems small, but an increase of the average wind speed by 0.5 m/s results in an increase in energy yield of 30%. At a wind speed of 10 m/s the reference turbine of 3 MW utilizes its full potential (RVO, 2014e). Until a wind speed of 25 m/s the wind turbine generates the maximum power that is technically possible (see figure 6). Wind speeds higher than 25 m/s cause such a high rotation of the blades that the wind turbine is shut down for safety purposes. The optimal wind speed window is thus between 10 and 25 m/s.

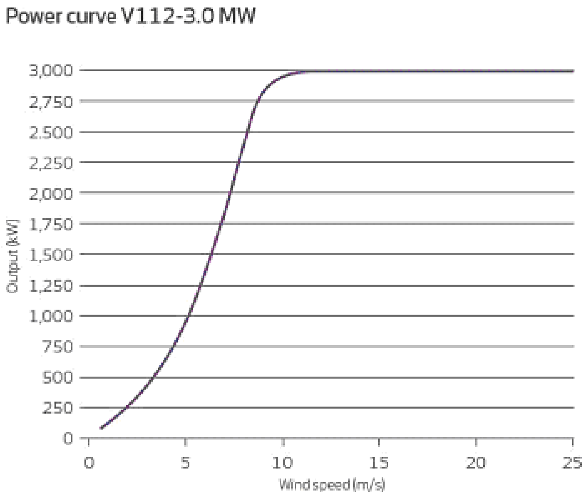


Figure 6 The power curve of a standard 3MW wind turbine with a hub height and a rotor diameter of 100 meters. Source: RVO, 2014e.

3.3.3 Wind energy potential

The wind energy potential is the maximum potential that could be generated in an area, based on the average wind speed and the characteristics of the reference turbine. The following formula calculates the wind energy potential using these inputs plus some other factors (Twidell & Weir, 2006):

$$Wind\ energy\ potential\ (kW) = 0.5 * \ \rho * c_p * v^3 * A$$

where:
ρ is the density of air (1.2 $\mathrm{kg/m^3}$)
$\mathrm{c_p}$ is the capacity factor of the wind turbine
v is the wind speed
A is the surface of the rotor blades, which is determined as follows:

$$A = \frac{(\pi * diameter\ rotor\ blade^2)}{4}$$

The diameter of the rotor blades of the reference turbine is 100 meters. The rotor surface is important because the rotors catch the wind. A higher rotor surface means that more wind can be intercepted (Ten Klooster & Van De Bilt, 2009). The wind speed is taken from figure 5. The capacity factor of a wind turbine is determined by the Law of Betz, which states that maximum 59.3% of the kinetic energy of the wind can be extracted. This is because the air must have kinetic energy to leave the region of the turbine. The capacity factor is dependent on the wind speed and varies usually between 0.35 and 0.45 (Twidell and Weir, 2006). In this analysis a capacity factor of 0.40 is used.

The GWh potential is calculated by multiplying the wind energy potential from the equation above by the amount of hours in a year, divided by 1,000,000,000 to convert to GWh. This is possible because the wind speed data set is a long-term average. The data set includes periods of time with wind speeds below 10 m/s, at which the wind turbine does not utilizes its full potential (see figure 6). Below 3 m/s the wind turbine has zero output because of the low wind speed. The downtime of the wind turbine for maintenance is not taken into account.

The following formula calculates the amount of GWh/year:

$$GWh/year = \frac{(Wind\ energy\ potential * 8760)}{1{,}000{,}000{,}000}$$

Figure 7 displays the wind energy potential in GWh/year. The highest potential is found on the isle of Texel and along the coastline. For example the potential in the northern part of the province is between 10 and 14 GWh/year.

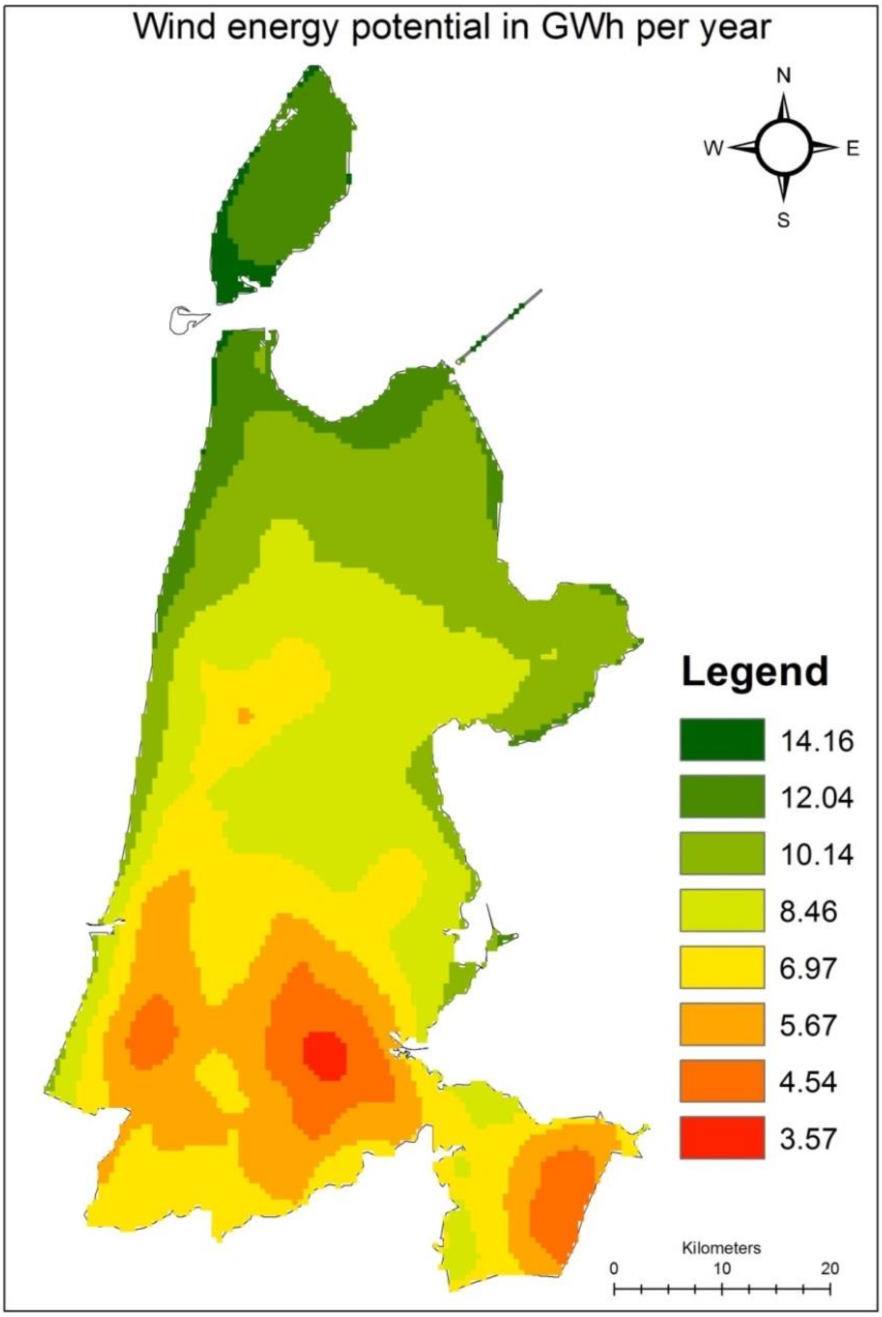


Figure 7 Onshore wind energy potential in GWh/year for the province of North-Holland.

3.4 Suitability map

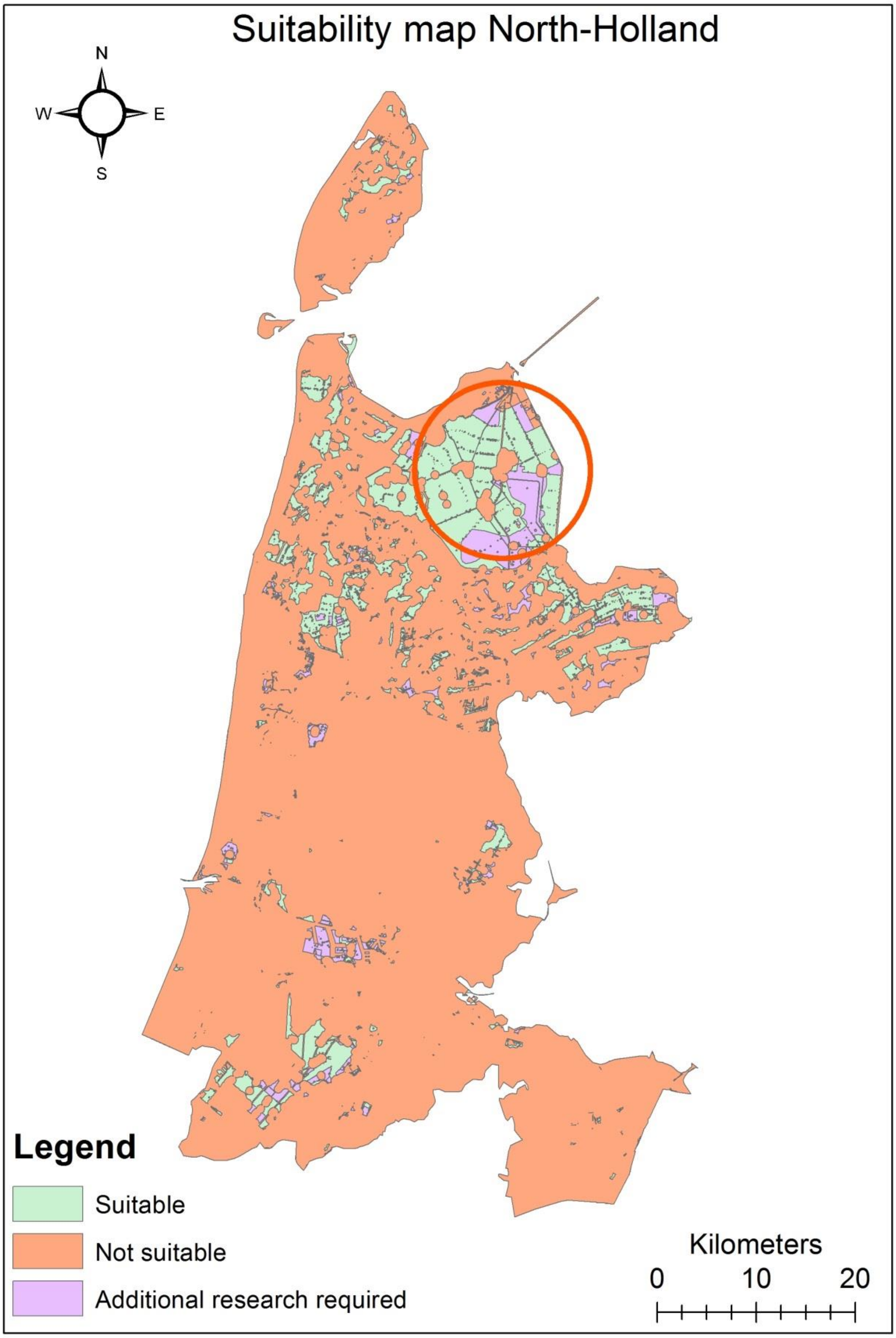


Figure 8 The suitability map for onshore wind energy in the province of North-Holland.
The red circle represents wind park Wieringermeer. The map is based on the data in Appendix I.

In this section all the previously discussed constraints, regulations and wind energy potential are combined into a map showing suitable and unsuitable areas for onshore wind energy (see figure 8). This map is constructed using FME software from Safe Software and PostgreSQL software from the Global Development Group (see Appendix III & IV for complete workflow and script). All the used data is summarized in Appendix I. Regulations state that countryside homes and urban areas have different buffer zones, as described before in section 3.1.1. Therefore, the density per hectare at the building level needed to be calculated in order to distinguish between urban and rural areas. The shapefile polygons from the *Basisregistratie Adressen en Gebouwen* (BAG) from Kadaster, Netherlands (2014a) are used. These shapefile BAG polygons depict all the buildings in the Netherlands. Around every single residential building a buffer with a surface of one hectare is computed using a script in PostgreSQL. If more than one other BAG polygon lies (partly) inside this buffer, the building is denoted as urban area. This way residential buildings with a density of maximum two buildings per hectare are separated from areas with a higher building density. Using this method two different buffers could be applied.

The buffers around highways, railroads and waterways are computed by the regulations described in section 3.2. Also nature areas, provincial monuments, fly zones, radar systems, water barrier systems, and geological monuments are excluded from wind turbines (see appendix I). Industrial areas, silence areas and geologically interesting areas are possible locations for onshore wind energy, but in these areas additional research is required. In these areas the risk factors must be calculated and be below certain standards, or the permit for wind turbine construction will be denied. Also the negative impacts on the landscape value must be avoided. The additional research areas are purple in figure 8**.** All buffers were joined, dissolved and clipped using FME.

The suitability map in figure 8 has a strong resemblance with the designated search areas determined by the province of North-Holland (Kadaster, 2014b). This validates the method used to construct figure 8. The large area in the north eastern part of the province is reserved for wind park Wieringermeer, which is one of the eleven large onshore wind energy development parks, shown as the red circle in figures 8 and 9**.** The extra 105.5 MW needs to be located outside this area. In the province of North-Holland 6.6% of the land outside Wieringermeer is suitable for onshore wind energy development. Figure 9 shows the potential on those suitable locations without the wind park Wieringermeer. This shows that the high potential suitable areas are around this wind park Wieringermeer in the north of the province and also on the isle of Texel.

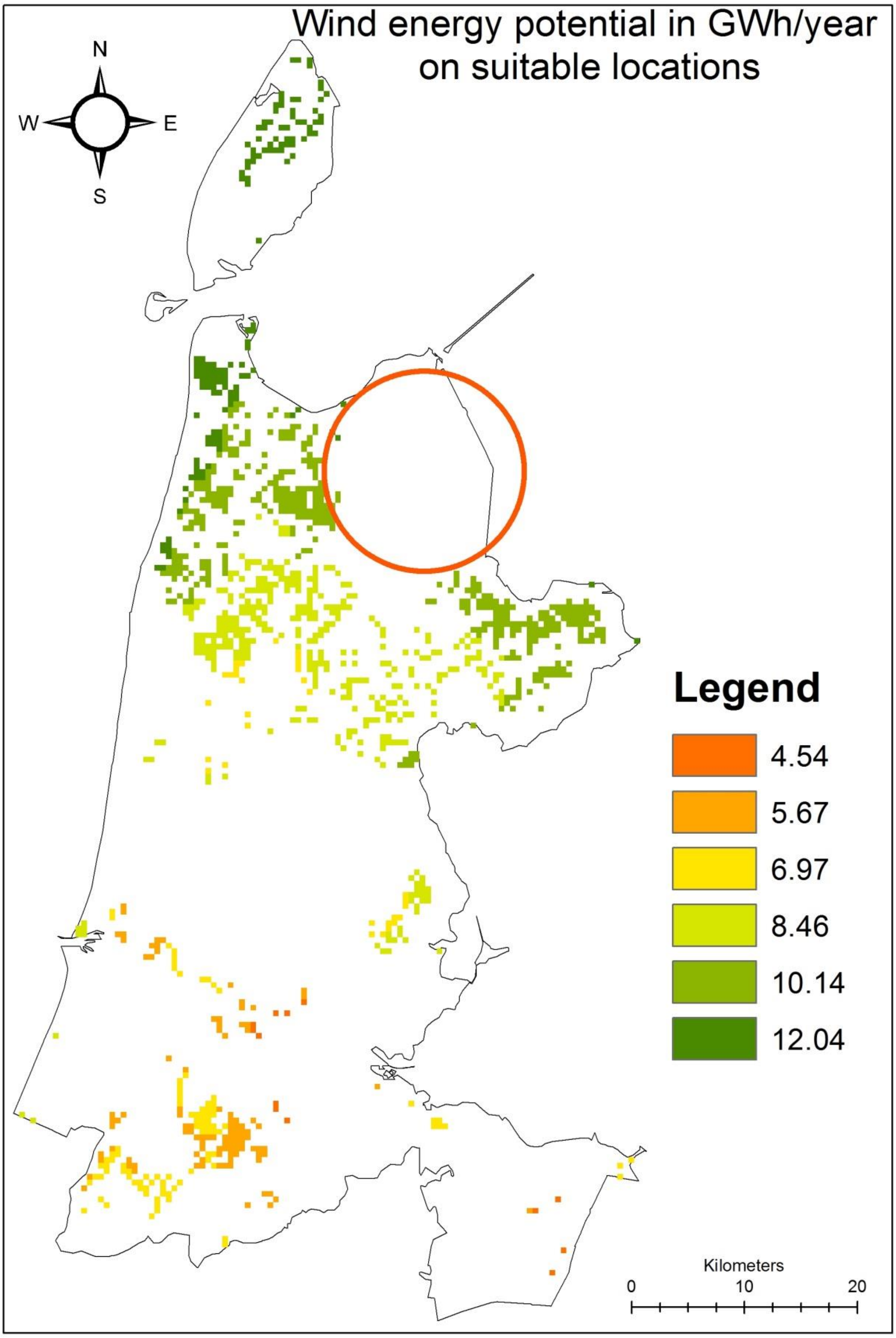


Figure 9 Potential in GWh/year on suitable locations in the province of North-Holland. The red circle represents wind park Wieringermeer and is left out as a suitable location.

4. Economic Factors

In this chapter the economic factors of wind turbine parks are highlighted. The detailed costs and benefits are given for a wind park of 18 turbines with an installed capacity of 54 MW, which is about one-third of the task of the province of North-Holland. A wind park of 54 MW provides electricity for around 40,000 households (Rijksoverheid, 2013). First the costs are specified. Thereafter the benefits are highlighted and as a summary a total economic overview is given. Furthermore, a net present value analysis, including the transmission line costs, shows where wind turbines are a profitable investment. This chapter concludes with a sensitivity analysis underpinning what happens if costs and benefits change.

4.1 Costs

In this part all costs of the wind turbine park are specified. Both the initial investment costs and the yearly variable costs are taken into account. An overview of the costs is given in section 4.3.

4.1.1 Investment

The investment costs are the building costs of a wind turbine park. These consist of the wind turbines itself and the foundation, the energy infrastructure at the wind park, and construction preparation and roads. The investment costs are estimated at 1350 €/kW (Lensink et al., 2012). For a 54 MW wind park this comes down to € 72,900,000. 70% of these costs are needed for the wind turbines itself and its foundation (RVO, 2014f). 30% of these costs are for roads and energy infrastructure (cables, transformers etc.) at the wind park itself. The costs for the transmission lines are dealt with separately in section 4.4.1 and are not included in the investment costs, because of their spatial dependence.

The investment costs are however, without development costs, local taxes, costs for citizen participation and legal procedures. These costs are not generic and are not eligible for subsidies (Lensink et al., 2012). Necessary permits and construction fees have to be paid to the local government. Because every municipality uses different rates, the average for the province North-Holland is taken (www.bouwleges.nl, 2014). The average construction fee is 3.3% of the building costs, but usually this rate decreases when the building costs increase. For simplicity, in this case 3.3% is taken and all necessary permit costs are included in this percentage. The building fees are in this case thus € 2,405,700.

The development costs are estimated at € 20,000 per MW (Fryslânfoardewyn, n.d.). The total costs for the wind park of 54 MW are € 1,080,000. The development of a wind park takes 5 – 10 years and many cost are inevitable, for example environment research costs. These costs contain a lot of risks, because it is uncertain whether the wind park will be built or not. Monitoring costs can also be obligatory. The costs for monitoring the sound nuisance and effects on birds and bats after completion of the wind park are determined at € 50,000 per year for a period of three years. (Ten Klooster & Van De Bilt, 2009).

The total investment costs for the wind park, including these non-generic costs, are € 76,535,700. This translates to € 1417/kW. This is close to the value of € 1430/kW, which is advised by a research company (Rademaekers & Van Gorp, 2009). This research company has included all the non-generic costs in the investment costs.

4.1.2 Financing

On average 80% of the investment costs are financed with loaned money. The other 20% is equity, which is often (partly) generated by participation of citizens. The economic life cycle of a wind turbine is determined at 15 years (Ten Klooster & Van De Bilt, 2009). The technical life cycle is more than 20 years. The annuity financing method is often applied, which involves that the amount to be paid each year is the same. With this financing method the repayment increases every year and the interest payment decreases every year. A contract lasts 15 years, which is the economic lifetime of a wind turbine. The average interest rate is 5%, which includes an interest discount (Ten Klooster & Van De Bilt, 2009). This discount, which is supported by the Dutch government, is applicable because a wind turbine park is a 'green' and environmentally friendly project (RVO, 2014g). Another legislation is the *Energie InvesteringsAftrek* (EIA). Up to 44% of the investment costs can be subtracted from the fiscal profit (Lensink, 2013). This reduces the tax payment on average by 10%. The condition is that the company has to make (enough) profit to able to subtract the investment costs in order to benefit from the tax reduction. However, since 2014 projects that request subsidies are no longer able to make use of the EIA legislation (RVO, 2014h). Because (almost) no project is profitable without subsidies the EIA legislation is not taken into account.

The financing costs consist of repayment and interest. The annuity financing method works according to the following formula:

$$a = \frac{i}{1-(1+i)^{-n}} B_0$$

Where:
A is the yearly repayment
i is the interest rate
n is the number of years
B_0 is the investment

So:

$$a = \frac{0.05}{1-(1+0.05)^{-15}} * 76{,}535{,}700 = € \, 7{,}373{,}624/year$$

In this case 100% of the investment costs are taken, because it is almost always the case that 80% is provided by the bank and 20% by other investment parties, which can also be citizens. Every year € 7,373,624 has to be paid as interest and repayment for 15 years consecutively. After 15 years a total sum of € 110,604,360 is paid, with € 76,535,700 as repayment and€ 34,068,660 as interest.

4.1.3 Land rent

Another cost factor is the acquisition of land for wind turbine construction. Land can be reclaimed in two different ways: either from the national government or from the local government and private parties. Local governments and private parties are both treated as private parties in this case.

4.1.3.1 RVOB

The Dutch national government gives out building rights for wind turbines on state-owned land (RVOB, 2014). The initiator of the wind turbine park must acquire all permits before a request can be submitted to the relevant government agency, the *Rijksvastgoed- en ontwikkelingsbedrijf (RVOB).* If there is a lot of interest in the desired land, also for other purposes than wind turbine parks, or in case of large wind parks, which is the case in this situation, the RVOB organizes a public tender. Because it is very difficult to determine the value of the land the RVOB uses information from the subsidy regulation, ECN (Dutch Energy Research Centre) and market parties. The value of the land is set at € 5.30 per MWh by the RVOB. The lease is valid for 15 or 20 years. After this period a new contract has to be agreed upon.

Because the total land rent is dependent on the amount of generated MWh, the land rent is spatially different. The first column in table 2 shows the average wind speed of figure 5. The wind potential of figure 7 is given in the second column. The costs for renting land are shown in the column *State-owned*. The costs increase with higher average wind speed and are computed by multiplying the MWh/year for the wind park by € 5.30. However, if the energy price changes the land rent also changes (Rijntalder & Vogelaar, 2013). A rising energy price results in higher revenues when selling electricity. In that case the land rent increases by 5.5% of the additional benefits. If the energy price decreases the land rent decreases by 5.5% of the lost revenues. An important aspect of the land rent is that no indexation takes place during the duration of the contract (Rijntalder & Vogelaar, 2013). No adjustment of the land rent occurs if a year has a lower or higher average wind speed.

Table 2 Total land rent costs for the wind turbine park with different average wind speeds. * No indexation.

Average wind speed at 100 meters altitude in m/s	Total MWh/year		Total land costs €/year	
	Turbine	Wind park	State-owned	Local government or private parties*
6 - 6.5	3570	64,260	340,578	675,000
6.5 – 7	4540	81,720	433,116	675,000
7 – 7.5	5670	102,060	540,918	675,000
7.5 – 8	6970	125,460	664,938	675,000
8 – 8.5	8460	152,280	807,084	675,000
8.5 – 9	10,140	182,520	967,356	675,000
9 – 9.5	12,040	216,720	1,148,616	675,000
9.5 - 10	14,160	254,880	1,350,864	675,000

4.1.3.2 Private parties

Research shows that since 2009 the average land rent for wind turbine construction is about € 12,500/MW/year (Rijntalder & Vogelaar, 2013). The wind park of 54 MW has in that case a land rent cost of €675,000/year (see table 2). An important difference with the RVOB compensation is the yearly or five-yearly indexation. In this case the land rent is yearly indexed by 2.2%, which is the long term average since 1994 (CBS, 2014). Another difference is that there is no relation with the average wind speed, which results in a single land rent price throughout the province of North-Holland.

Table 3 shows the differences between the two forms of land rent. State-owned areas with a high wind potential are much more expensive than land with the same potential on private ground. The indexation increases the costs of the wind park project during its lifetime. Despite the annual indexation private land costs are often lower over the lifetime of 20 years based on these calculations. In practice however, private parties take the RVOB land rent as a guideline and do not deviate much from this. That is why further in this analysis the RVOB land rent will be considered as the land costs.

**Table 3 Difference between total land costs. Lifetime of a wind turbine is 20 years.
Local government or private parties is yearly indexed by 2.2%.**

Average wind speed at 100 meters altitude in m/s	Total land costs by lifetime of 20 years in €	
	State-owned	Local government or private parties
6 - 6.5	6,811,560	13,648,591
6.5 – 7	8,662,320	13,648,591
7 – 7.5	10,818,360	13,648,591
7.5 – 8	13,298,760	13,648,591
8 – 8.5	16,141,680	13,648,591
8.5 – 9	19,347,120	13,648,591
9 – 9.5	22,972,320	13,648,591
9.5 - 10	27,017,280	13,648,591

4.1.4 Grid power delivery

In order to be able to deliver electricity to the grid the owner of the wind turbine park has to pay maintenance and measuring costs of the network. These costs are € 11/kW per year and are to be paid to the power grid company (Lensink et al., 2012). The total costs are € 594,000 per year for the wind turbine park of 54 MW, but are yearly indexed in the net present value analysis in section 4.4.

4.1.5 Maintenance and insurance

Yearly maintenance of the wind turbine park is obligatory. Every year the rotating parts of the wind turbine have to be checked, sometimes multiple times. Also management of the property, like cutting grass and maintaining roads is necessary. All kind of insurances are required to be covered in cases of failure of the wind turbine and breaking off of the rotor blades (Lensink et al., 2012). All these costs together are estimated at € 0,011 kWh/year (Ten Klooster & Van De Bilt, 2009). Again these costs are spatially dependent, because higher average wind speeds and thus more generated kWhs result in a faster wear of the rotating parts. The costs vary between € 706,860 and € 2,803,680 per year (see table 4). Annual indexation of 2.2% is applied in the net present value analysis in section 4.4.

Table 4 Maintenance & Insurance costs in €/year for the wind park.

Average wind speed at 100 meters altitude in m/s	Total MWh/year wind park	Maintenance & Insurance costs in €/year
6 - 6.5	64,260	706,860
6.5 – 7	81,720	898,920
7 – 7.5	102,060	1,122,660
7.5 – 8	125,460	1,380,060
8 – 8.5	152,280	1,675,080
8.5 – 9	182,520	2,007,720
9 – 9.5	216,720	2,383,920
9.5 - 10	254,880	2,803,680

4.1.6 Taxes and other costs

Wind park owners have to pay taxes, because wind turbines are seen by the government as properties. The average property tax (OZB) for the province North-Holland in 2013 is 0.0967% of the value of the wind park (www.cijfernieuws.nl, 2014). The property tax (OZB) is also obligatory for wind turbines on state-owned land (RVO, 2014i). The value of the wind park is determined as the investment costs, which is € 76,535,700. The property tax is € 74,010 per year and is annually indexed in the net present value analysis in section 4.4.

A private organization also have to pay a profit tax. This tax is called the *Vennootschapsbelasting.* This tax is paid over the profit of the company. The tariff is determined at 20% for the first € 200,000 and 25% for the rest of the profit (www.rijksoverheid.nl, 2014).

The policy of the province of North-Holland aims at demolition of at least two (small and old) wind turbines before a new one is placed with a higher installed capacity (Provinciale Ruimtelijke Verordening Noord-Holland, 2014). The demolition costs are approximately equal to the residual value of the wind turbine. If the wind turbine is not older than twelve years, reselling the wind turbine could cover the demolition costs entirely (Ten Klooster & Van De Bilt, 2009).

4.2 Benefits

The benefits of a wind turbine park contain subsidies and sales. First the sales are discussed and thereafter the subsidies. In section 4.3 an overview of the benefits is given.

4.2.1 Sales

The current energy sales price for energy producers is 4.5 €ct/kWh (RVO, 2014f). This is equal to 45 €/MWh. The total energy generation of the wind park is dependent on the average wind speed and thus also on the location (see table 5). The total revenues from electricity sales are between € 2,891,700 and € 11,469,600 per year and are yearly indexed in the net present value analysis in section 4.4.

Table 5 Energy sales revenues, which are calculated by multiplying the total MWh/year generated by the energy sales price of 45 €/MWh.

Average wind speed at 100 meters altitude in m/s	Total MWh/year wind park	Sales revenues in €/year
6 - 6.5	64,260	2,891,700
6.5 – 7	81,720	3,677,400
7 – 7.5	102,060	4,592,700
7.5 – 8	125,460	5,645,700
8 – 8.5	152,280	6,852,600
8.5 – 9	182,520	8,213,400
9 – 9.5	216,720	9,752,400
9.5 - 10	254,880	11,469,600

4.2.2 Subsidies

The cost price of generating green energy is higher than the cost price of conventional energy. The Dutch national government provides a subsidy, the SDE+, that covers this difference, until a maximum. The subsidies are determined for onshore wind energy by subtracting the cost price of fossil fuel energy from the cost price of renewable energy (RVO, 2014j). Every year the cost prices are determined by the National Energy Research Center in the Netherlands (ECN) (Lensink et al., 2012). Every year a predetermined budget for subsidies is available. In 2014 the total budget for all renewable energy sources is € 3.5 billion (RVO, 2014h). A year is divided into phases in which subsidy can be requested. With every phase the amount of subsidy per kWh increases, because the cost price for wind energy increases (see table 6). This makes that projects that require a lower subsidy, because of a lower green energy cost price for that technology, apply for subsidy first. This way the most cost efficient projects are developed first. Projects asking for more subsidy have to wait for later phases but have to take into account that in the latest phase, which has the highest subsidy, the total subsidy budget of € 3.5 billion could have already been totally consumed.

For onshore wind energy a year is divided into three phases. In table 6 the three phases are shown. Only one phase at the time is open and phase 1 and 2 last for about a month. For onshore wind energy a wind factor is applied (RVO, 2014h). This wind factor accounts for the annual variability in average wind speed. During a year with less wind the operator receives less subsidy and it is not possible to compensate this in a year with higher wind speeds because the maximum amount of subsidy per year is fixed. The annual wind speed variability can be up to 20%. Therefore subsidy is given for maximum 80% of the full load hours. The cost price for wind energy is multiplied by 1.25 (=1/80%) to account for the wind variability. The cost prices for onshore wind energy and fossil fuel energy, grey energy, are shown in table 6, which also gives the maximum subsidized amount of full load hours in the fifth column. The subsidy is thus the cost price of wind energy minus the cost price for grey energy. The full load hours are multiplied by the power (3MW) of the wind turbine to get the maximum subsidized amount of MWh/year, which is shown in the sixth column of table 6. This is then multiplied by € 54.5, which is the subsidy per MWh, in order to get the maximum subsidy per turbine per year. The last column of table 6 shows the annual subsidy for the whole wind park. The subsidies differ each year, because they are dependent on the cost price of grey energy and wind energy. The cost price for wind energy is decreasing every year, so if the cost price of grey energy remains unchanged the subsidy will be lower (Lensink et al., 2012). It is very difficult to predict the cost prices and correct for inflation. That is why in this analysis the subsidies remain the same for 15 years.

Table 6 Annual subsidy per 3 MW turbine and for the whole wind park. CP = cost price, including wind factor. Source: RVO, 2014h. The lower two rows are advised by ECN. Source: Lensink, 2013.

	CP wind energy €ct/kWh	CP grey energy €ct/kWh	Subsidy €ct/kWh	Subsidy €/MWh	Full load hours	Subsidized MWh/year per 3 MW turbine	Subsidy €/year per 3 MW turbine	Subsidy €/year wind park
Phase 1 From 1 April 09:00	8.75	5.8	2.95	29.5	2800	8400	247,800	4,460,400
Phase 2 From 12 May 17:00	10	5.8	4.2	42	2280	6840	287,280	5,171,040
Phase 3 16 June 17:00 - 18 December 17:00	11.25	5.8	5.45	54.5	1960	5880	320,460	5,768,280
Wind speed 7.5 m/s	9.6	5.8	3.8	38	2700	8100	307,800	5,540,400
Wind speed 8 m/s	8.75	5.8	2.95	29.5	3400	10,200	300,900	5,416,200

The two lowest rows are the subsidies advised by ECN (Lensink et al., 2012) based on average wind speed. ECN advises the government about the subsidies in the SDE+. However, in the SDE+ this classification is not applied and the three phases are leading. The total annual subsidies are quite similar. The subsidy acquired in phase 3 is used in this analysis, because it is the phase with the highest subsidy. It is very unlikely that before phase 3 the total subsidy budget is spent, because phase 3 already starts in June. A wind turbine is able to generate more than the subsidized 5880 MWh/year of phase 3 in especially the northern part of the province of North-Holland (see figure 7), but only to this amount is subsidized. Any extra MWh is not subsidized but can still be sold for the current energy price and thus provides a higher profit.

4.3 Net annual cash flow

This section gives an overview of the net annual cash flow, taking into account all the costs and benefits, discussed in sections 4.1 and 4.2, for a wind park of 18 turbines with an installed capacity of 54 MW (see table 7). As expected, a higher average wind speed results in a higher annual profit, despite higher costs. This overview is for the first year only. In the next years the costs and benefits have to be discounted and corrected for inflation, which is done in the net present value analysis in section 4.4. The financing costs and subsidies drop out after 15 years. The total lifetime of a wind turbine is 20 years. It is important to note that the transmission line construction costs are excluded from table 7, since they are spatially dependent. The transmission line costs are dealt with in section 4.4.1.

Table 7 Net annual cash flow for the first year in Euros, based on the analysis in sections 4.1 and 4.2.

Total generated GWh	*64.26*	*81.72*	*102.06*	*125.46*	*152.28*	*182.52*	*216.72*	*254.88*
Average wind speed in m/s	*6 - 6.5*	*6.5 - 7*	*7 - 7.5*	*7.5 - 8*	*8 - 8.5*	*8.5 - 9*	*9 - 9.5*	*9.5 - 10*
Costs								
Financing	7,373,624	7,373,624	7,373,624	7,373,624	7,373,624	7,373,624	7,373,624	7,373,624
Land rent	340,578	433,116	540,918	664,938	807,084	967,356	1,148,616	1,350,864
Maintenance & Insurance	706,860	898,920	1,122,660	1,380,060	1,675,080	2,007,720	2,383,920	2,803,680
Grid power delivery	594,000	594,000	594,000	594,000	594,000	594,000	594,000	594,000
Property tax	74,010	74,010	74,010	74,010	74,010	74,010	74,010	74,010
Total costs	**9,089,072**	**9,373,670**	**9,705,212**	**10,086,632**	**10,523,798**	**11,016,710**	**11,574,170**	**12,196,178**
Benefits								
Sales	2,891,700	3,677,400	4,592,700	5,645,700	6,852,600	8,213,400	9,752,400	11,469,600
Subsidy	5,768,280	5,768,280	5,768,280	5,768,280	5,768,280	5,768,280	5,768,280	5,768,280
Total benefits	**8,659,980**	**9,445,680**	**10,360,980**	**11,413,980**	**12,620,880**	**13,981,680**	**15,520,680**	**17,237,880**
Saldo	-429,092	72,010	655,768	1,327,348	2,097,082	2,964,970	3,946,510	5,041,702
Tax	-117,273	8003	153,942	321,837	514,271	731,243	976,628	1,250,426
Net annual cash flow	**-311,819**	**64,008**	**501,826**	**1,005,511**	**1,582,812**	**2,233,728**	**2,969,883**	**3,791,277**

Table 8 gives an overview of the total costs and benefits after the wind park has been operating for 20 consecutive years. Caution is required when interpreting these results, because transmission line costs and the discounting are excluded. Also the profit tax assumes for simplicity that every year is profitable, which overestimates the tax at lower wind speeds because some years are not profitable. This is dealt with in the net present value analysis in section 4.4. Annual inflation is taken into account.

Table 8 Net cash flow of the wind park with 18 turbines (54 MW) after 20 years. Every year is summed up. No discounting or high-tension power grid costs. All numbers are in Euros.

Total generated GWh	*1285.2*	*1634.4*	*2041.2*	*2509.2*	*3045.6*	*3650.4*	*4334.4*	*5097.6*
Average wind speed in m/s	*6 - 6.5*	*6.5 - 7*	*7 - 7.5*	*7.5 - 8*	*8 - 8.5*	*8.5 - 9*	*9 - 9.5*	*9.5 - 10*
Costs								
Financing	110,604,360	110,604,360	110,604,360	110,604,360	110,604,360	110,604,360	110,604,360	110,604,360
Land rent	6,811,560	8,662,320	10,818,360	13,298,760	16,141,680	19,347,120	22,972,320	27,017,280
Maintenance & Insurance	17,521,073	22,281,701	27,827,587	34,207,810	41,520,527	49,765,738	59,090,679	69,495,350
Grid power delivery	14,723,591	14,723,591	14,723,591	14,723,591	14,723,591	14,723,591	14,723,591	14,723,591
Property tax	1,834,500	1,834,500	1,834,500	1,834,500	1,834,500	1,834,500	1,834,500	1,834,500
Total costs	**151,495,084**	**158,106,472**	**165,808,398**	**174,669,021**	**184,824,658**	**196,275,309**	**209,225,450**	**223,675,081**
Benefits								
Sales	71,677,118	91,152,414	113,840,129	139,941,040	169,856,700	203,587,109	241,734,595	284,299,158
Subsidy	86,524,200	86,524,200	86,524,200	86,524,200	86,524,200	86,524,200	86,524,200	86,524,200
Total benefits	**158,201,318**	**177,676,614**	**200,364,329**	**226,465,240**	**256,380,900**	**290,111,309**	**328,258,795**	**370,823,358**
Saldo	6,706,234	19,570,142	34,555,931	51,796,219	71,556,242	93,836,000	119,033,345	147,148,277
Tax	1,476,559	4,692,536	8,438,983	12,749,055	17,689,061	23,259,000	29,558,336	36,587,069
Net cash flow	**5,229,676**	**14,877,607**	**26,116,948**	**39,047,164**	**53,867,182**	**70,577,000**	**89,475,009**	**110,561,208**

4.4 Net present value analysis

In this section a net present value analysis (NPV) is performed, which takes into account all costs and benefits and the costs for constructing the underground transmission lines from the wind park to the nearest grid transformer station. A net present value analysis discounts all future costs and benefits into current prices based on a discount rate. The net present value is calculated for the single reference wind turbine, on the condition that it is part of a wind park of 18 wind turbines with an installed capacity of 54 MW. Throughout this section, all the raster maps have a cell size of 500 by 500 meters. This way each cell represents one turbine because 500 meters is the recommended mutual distance.

4.4.1 Transmission line costs in the net present value model

A wind park has to be connected to the national power grid. All cables from the wind turbines in the park come at a central point (Royal Haskoning DHV, 2013). From this central point an, usually underground, high-tension cables connect the wind park with the national high-tension power grid via a transformer station. Obviously, the distance from the wind park to the nearest transformer station of the national grid determines the total costs. That is why the costs for this high-tension cables are expressed per kilometre.

The big project launched by the Dutch national government, that aims at bringing high voltage transmission lines underground in residential areas, is taken as a reference to estimate the costs (Ministry of Economic Affairs, 2014a). In this project, starting in 2017, a total of 135 kilometres of 50/110/150 kV high voltage pylons in residential areas are demolished and replaced by underground cables to decrease radiation risks (TenneT, 2014). This project costs € 440 million and the costs per kilometre are estimated at € 3.25 per kilometre. Municipalities in which this transformation takes place, use this number as a reference. Similar other projects, outside this program, report costs that vary between € 3 – 5 million (Maarssen, 2008 & Nieuwegein, 2006).

In this analysis some other factors have to be taken into account. The distance towards transformer stations, which are either 50 kV or 150 kV and are shown in figure 4, is a straight line and is the shortest distance. In reality it is usually not possible to use the shortest distance because of obstacles, such as other cables in the ground and buildings. Constructing these high-tension cables is a costly affair, so it is necessary to set up a financing construction with the bank. This includes an interest rate that has to be paid. In order to include these two factors the cost for underground cables is set in this use case at € 4 million per kilometre, which is € 4000 per meter. This number is divided by 18, because a wind park of 18 wind turbines is assumed and this way all wind turbines bear the costs equally. The underground transmission lines cost then € 222.22 per meter per turbine, because the net present value analysis is constructed per single turbine. The costs in figure 10 represent the building costs of underground transmission lines from that particular location to the nearest national grid transformer station for a single wind turbine, assuming it is part of a wind park of 18 wind turbines. It shows, as expected, circles of increasing costs further away from the transformer stations. In the south of the province large cities, such as Haarlem and Amsterdam, and the industry in Ijmuiden, make that there are more transformer stations available than in the rural upper part of the province. A full list of all the used transformer stations with GPS coordinates is available in Appendix II.

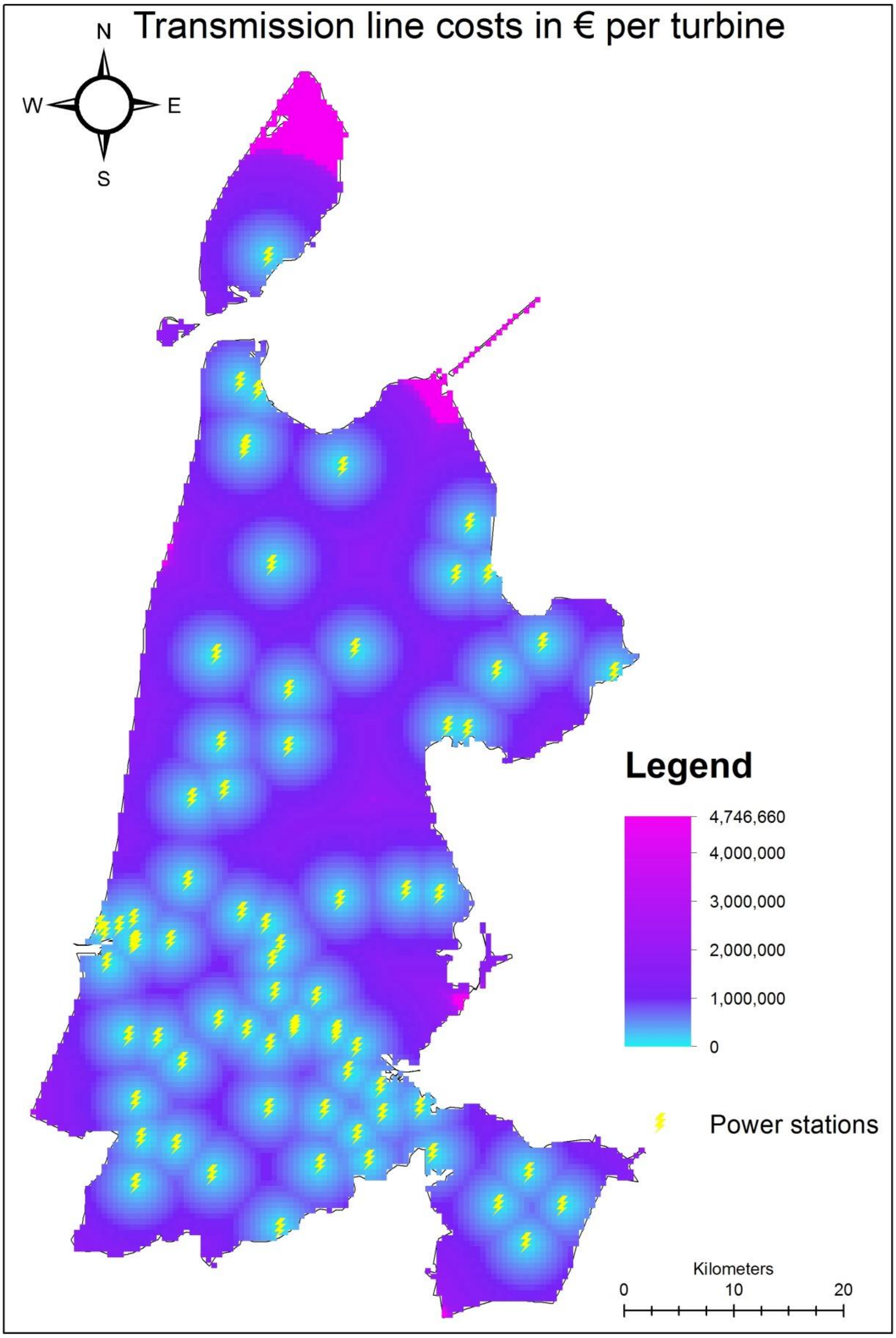


Figure 4 The costs of underground high-tension transmission lines from the wind park to the nearest national grid transformer station for a single wind turbine, assuming that this wind turbine is part of a wind park of 18 wind turbines.

4.4.2 Equation of the net present value model

The wind energy potential map in figure 7 is input for the net present value model. Certain costs and benefits are dependent on the wind energy potential. These spatial dependent factors, which are the energy sales, maintenance and insurance, and the land rent, are expressed per GWh. The other costs and benefits are expressed per turbine, because one raster cell represents one turbine (see table 9). Model Builder in ArcGIS software of ESRI is used to setup the net present value equation for twenty consecutive years, which is the average lifetime of a wind turbine. The twenty years are summed up and then the grid costs are subtracted. The reader is referred to Appendix V for the net present value model and the full equation. A net present value analysis discounts all future costs and benefits into current cash flows. Each cost and benefit is discounted back to its present day value. It is used to be able to appraise alternative investment options, taking future cash flows into account. The general net present value formula is as follows:

$$NPV(i,N) = -R_0 + \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Where:
R_0 is the initial investment
R_t is the annual net cash flow (i.e. annual gross benefits minus annual total costs) at time t
i is the discount rate
N is the lifetime of the project

The NPV equation sums up all the discounted net cash flows and subtracts the initial investment. In this analysis the initial investment is the transmission line costs, which are € 222 per meter of transmission line. These costs are not included in the financing costs, because of their spatial dependence. The investment in transmission lines have to be done before the wind turbine park is operable. The investment of the wind park itself is included in the financing costs, which are spread over 20 years, and thus are not included in the initial investment. The formula in this analysis is complex and that is why it has been split up in different parts:

$$NPV = -C_{line} * d +$$

$$\sum_{t=1}^{20} \frac{A - Con(If\ A \leq\ 0,\ then\ 0;\ If(A > 0),\ then\ Con\big(If\ \big(A \leq 200{,}000 * (1+I)\big),\ then\ A * 0.2;\ If\ A > 200{,}000,\ then\ (A - 200{,}000 * (1+I) *\ 0.25 + (40{,}000 * (1+I)))\big)}{(1.05^t)}$$

Where:
$\mathrm{C}_{\mathrm{line}}$ is the costs of installing the transmission lines (in Euro/m)
d is the Euclidian distance to the nearest power station (in m)
I is the annual inflation rate
A is the net annual cash flow without taking into account the profit tax

$$A = \ wind * \big((Sales * (1+I) - Land\ rent - (M\&I * (1+I))\big) + Subsidy - Financing - (Other\ costs * (1+I))$$

Where:
wind is the wind energy potential (figure 7)
M&I are the maintenance & insurance costs
Other costs are the grid power delivery costs and the property tax

The equation has three different conditional statements. This complication stems from the profit tax, which is 20% until € 200,000 and 25% above that (see section 4.1.6). In the equation *A* is either the profit or loss, before the profit tax. The first conditional statement says that if the net annual cash flow is zero or smaller, no profit tax has to be deducted. The second conditional statement states that if the profit is between zero and € 200,000, 20% profit tax has to be deducted. The last conditional statement is more complicated. If the profit is more than € 200,000, this amount has to be subtracted from the profit and over what remains 25% profit tax is deducted. Then, € 40,000 is added up, because over the first € 200,000 only 20% profit tax is required, which is € 40,000. That is why first € 200,000 is subtracted, 25% profit tax is determined and € 40,000 is added up again. As can be seen in the equation also the € 200,000 and € 40,000 numbers are corrected for inflation. The reasoning behind this is that because of inflation of sales, M&I and other costs, the profit will be higher as time progresses, since the sales are higher than the other costs and M&I combined. If € 200,000 is not corrected for inflation this limit is reached earlier and more profit taxes have to be paid (earlier in the 25% zone). This is not realistic because the trend since 1980 shows that profit taxes are decreasing (Van ‘t Riet, 2012). This is not only the case in the Netherlands, but in almost all developed countries in the world and is known as the *race to the bottom* (Cary, 1974). Consequently, the inflation correction also applies to € 40,000.

Table 9 shows the annual costs and benefits that are used in the equation. The costs and benefits presented in sections 4.1 and 4.2 are expressed per GWh or per turbine. The sales price is € 4.5 ct/kWh and thus the revenues per GWh are € 45,000. The land rent is € 5300 per GWh, since the land rent is determined at € 5.30 per MWh. Maintenance and insurance costs are € 11,000 per GWh, because the costs are estimated at € 0.011 per kWh. These spatial dependent costs and benefits are summed up and multiplied by the wind energy potential per turbine (see equation). This way all costs and benefits are thus expressed per turbine, while taking into account the spatial variation in wind speed.

Table 9 Annual costs and benefits in Euros per GWh or per turbine. Sales, land rent and M&I are multiplied by the wind energy potential to express them by turbine.

Sales	45,000	GWh
Land rent	5300	GWh
M&I	11,000	GWh
Subsidy	320,460	Turbine
Financing	409,646	Turbine
Other Costs	37,112	Turbine

From table 9: $A = wind * \left((45{,}000 * 1.022) - 5300 - (11{,}000 * 1.022)\right) + 320{,}460 - 409{,}646 - (37{,}112 * 1.022)$

The spatially independent costs and benefits are directly expressed per turbine. The annual subsidy per turbine is € 320,460 and the financing costs are € 409,646. The subsidy and financing costs have a duration of 15 years and from year 16 onwards they drop out of the equation (see sections 4.1.2 and 4.2.2). The other costs are the property tax and the grid power delivery costs. The investment costs are € 4,251.983 per turbine and the property tax is 0.0967% of that. The property tax is thus € 4112 per turbine. The grid power delivery costs are 11/kW and the power of the reference turbine is 3000 kW. These costs are thus € 33,000, which makes the other costs € 37,112 per turbine.

The electricity sales, maintenance and insurance, and the other costs are corrected for inflation annually by 2.2%, which is the long term average since 1994 (CBS, 2014). The discount rate is set at 5%, which consists of the recommended market capital interest rate of 2.5% and a risk factor of also 2.5% (Rijkswaterstaat, 2012). The interest rate, for repaying the loan for coverage of the investment costs, is already included in the financing costs by using the annuity method (see section 4.1.2.)

4.4.3 Outcome of the net present value model

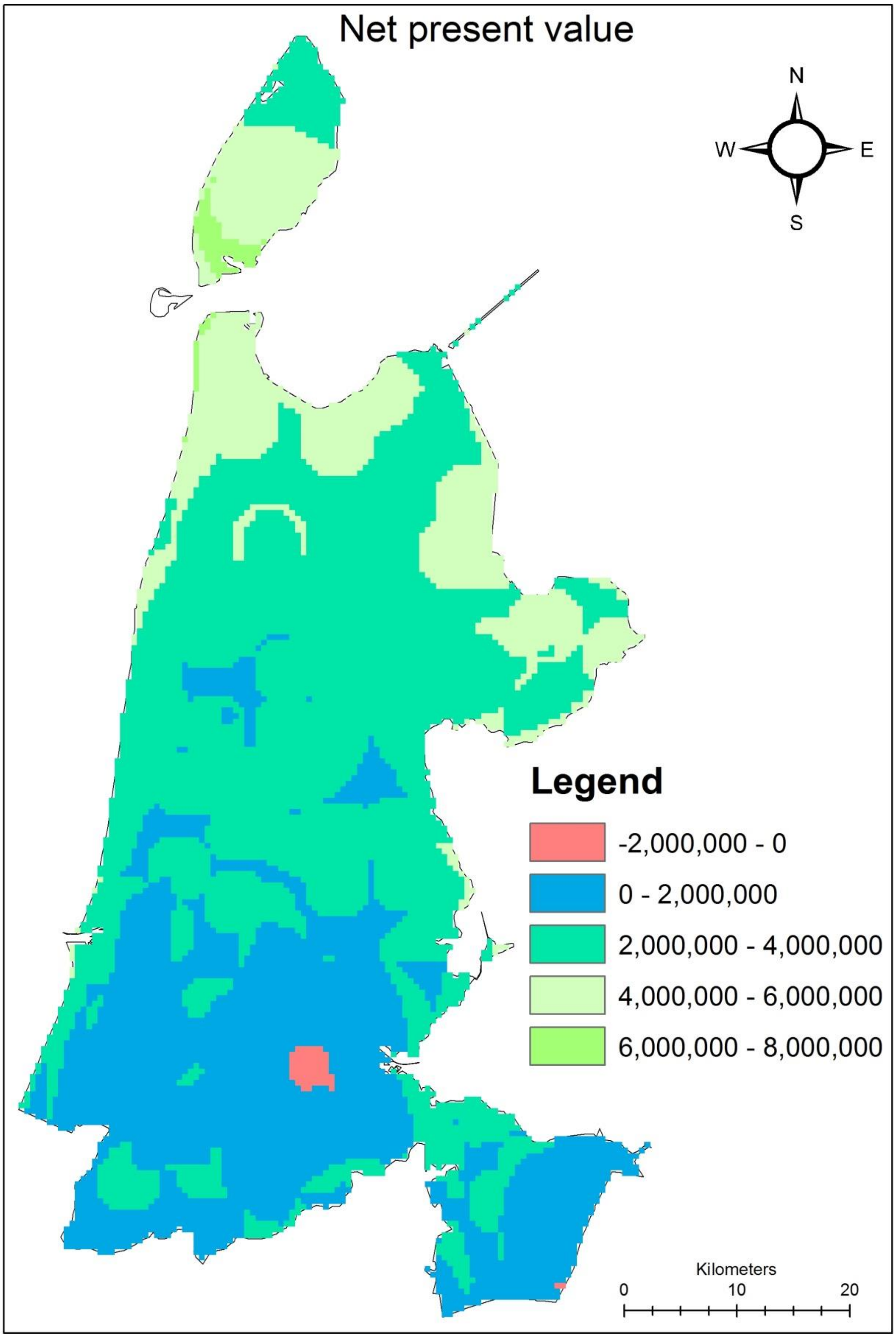


Figure 11 Net present value of a single wind turbine for the province of North-Holland in Euros.

In this section the outcome of the net present value model is presented. Figure 11 shows the net present value of a single wind turbine in the province of North-Holland. Two factors are important. The contours of figure 7, which is the wind energy potential, are visible. The other factor is the distance towards the nearest national grid transformer. Circles of increasing net present value towards the transformers are visible. The fact that both factors can be identified in figure 11 shows that both factors have an important impact on the net present value and that one factor is not very dominant over the other one. For example in the south of the province very close to the transformer stations (small greenish areas), still a relatively high net present value is reached despite of the relatively low wind energy potential.

There is only in Amsterdam and on the edge of the south east of the province a negative net present value. The city of Amsterdam stands out as an area with a low net present value, because the wind patterns are disturbed by high buildings, so average wind speed is lower. It is also the case that transformer stations within the city of Amsterdam are not included in the analysis, because wind turbines cannot be placed in urban areas and other transformer stations at the edge of the city are closer to open possible suitable areas.

Very high net present values are present in the north-east and upper north of the province, especially close to transformer stations. This is because of the high wind energy potential in the north of the province. The southern part of the isle of Texel and around the city of Den Helder are very profitable areas for onshore wind energy.

Figure 12 gives the net present value only for the suitable locations. High net present values are found south of Den Helder, on the Isle of Texel and in the area between Hoorn and Enkhuizen in the north-east of the province. It is important to remember that a single wind turbine is resembled by one raster cell in figure 11 and figure 12. Three wind parks of around 18 wind turbines need to be placed in the province of North-Holland to fulfil the target of 105,5 MW (SER, 2013). The area south of Den Helder and the area between Hoorn and Enkhuizen are suitable and profitable. The third location could be either also below Den Helder, further south than the other wind park, or in the middle of the province, or at the isle of Texel. The area in the middle of the province has a somewhat lower net present value, but could be preferred above a second large wind park near Den Helder or a wind park on the isle of Texel.

In order to calculate the net present value of the wind park with 18 wind turbines with an installed capacity of 54 MW, 18 raster cells have to be added up. As an example, this is done for the area just south of Den Helder along the North Sea in the most upper part of the province. 18 green adjacent cells have been selected in the large green block with a total net present value of € 96,290,105. The original investment was € 76,535,700 (see section 4.1.1). This allows for calculating the economic rate of return (ROR), which is the profit on the investment over time expressed as a proportion of the investment. The general formula is:

$$ROR = \frac{NPV - Initial\ investment}{Initial\ investment)}$$

Thus:

$$ROR = \frac{€\,96{,}290{,}105}{€\,76{,}535{,}700} = 126\%$$

So over a period of 20 years this investment gives a return of 126%. In order to calculate the annual rate of return, 126% has to be divided by the lifetime of the project, which is 20 years. It is assumed that the profit is not reinvested in the wind park, which is a reasonable assumption because maintenance costs are already taken into account. So the annual rate of return is:

$$\frac{126\%}{20} = 6.3\%$$

The annual economic rate of return of 6.3%, which is to be considered as a rather good investment. One should take into account that this area has one of the highest net present values possible in the model. This rate of return is compared with national government bonds of the Netherlands. This is considered as a relative riskless investment. The current stock price can be found here (www.iex.nl, 2014). A government bond with a duration of 23 years, an interest rate of 4% and a stock price of 145.75 has a rate of return according to the following formula:

$$Rate\ of\ return = \frac{interest\ rate}{stock\ price} * 100\% = \frac{4\%}{145.75} * 100\% = 2.74\%$$

This shows that the economic rate of return of the investment in the wind turbine park is much higher. However, this investment is also more risky.

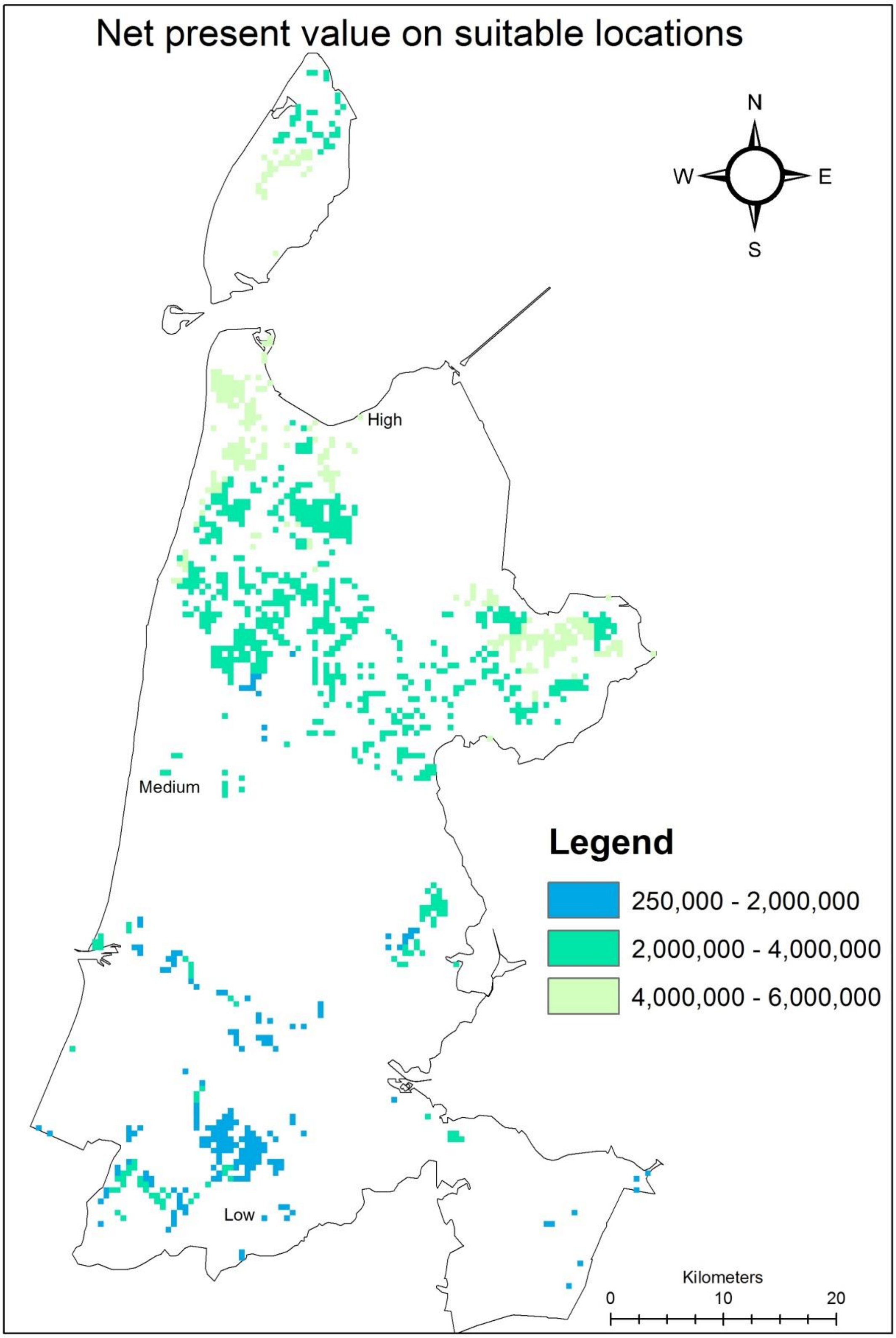


Figure 12 Net present value of a single wind turbine for the province of North-Holland in Euros on suitable locations with locations of the three raster cells used in the sensitivity analysis.

4.5 Sensitivity Analysis

This section defers the costs and benefits used in the net present value analysis to a sensitivity analysis. The costs and benefits are compiled under certain assumptions. This sensitivity analysis changes one cost or benefit and concretizes the impact on the net present value. It shows the sensitiveness of the net present value to each cost and benefit.

For this sensitivity analysis three raster cells with a relatively low, medium and high net present value have been randomly chosen from figure 12**.** The value of these raster cells are given in table 10. The sensitivity analysis is performed with five different factors. These factors are examined by increasing or decreasing them by 50%, except for the subsidies. It makes no sense that cost or benefits drop to zero, except for the subsidies. It is very likely that subsidies will not increase in the (near) future, because of declining wind turbine costs (Lensink et al., 2012). The analysis for subsidies shows the results for a decrease by 50% and 100%. Financing costs can be seen as the investment costs. Other costs here consist not only of the property tax and grid power delivery costs, as described in section 4.4.2, but also of the land rent and the maintenance and insurance costs. So table 10 gives the effect if all these other costs decrease or increase by 50%.

Table 10 The effect of a change of one of the factors on the net present value.

	Net present value								
	Low (€ 1,158,512)			*Medium (€ 2,854,187)*			*High (€ 5,171,823)*		
	0%	*50%*	*150%*	*0%*	*50%*	*150%*	*0%*	*50%*	*150%*
Financing	-	217%	-250%	-	86%	-97%	-	48%	-50%
Other costs	-	108%	-117%	-	62%	-66%	-	44%	-46%
Energy price	-	-258%	233%	-	-152%	141%	-	-117%	112%
Wind speed	-	-167%	150%	-	-100%	93%	-	-77%	73%
Subsidies	-392%	-192%	-	-155%	-72%	-	-81%	-40%	-

A first conclusion that can be drawn from table 10 is that if the net present value is low the effect of a change of one of the factors is very high. For example, a decrease in the sales price for electricity by 50% results in a negative net present value change of 258%. If the original net present value is high, this effect is only 117%. Thus a small change of the factors at a low original net present value results in a relatively high change of the net present value. Areas with an high net present value are more robust to a change, which is good for the predictability of future profitability.

One should also take notice of the fact that a decrease by 258% does not imply that an increase in energy price by 50% results in positive effect of 258%. This effect is only 233%. The negative effect is always larger than, or equal to, the positive effect and this holds for all costs and benefits. This is caused by the profit tax. A positive effect results in a higher net present value and thus a higher profit tax have to be paid, which is a cost and thus lowers the positive effect. It also applies for the subsidies. The negative effect of no subsidies is more than double the effect of a decrease in subsidies by 50%.

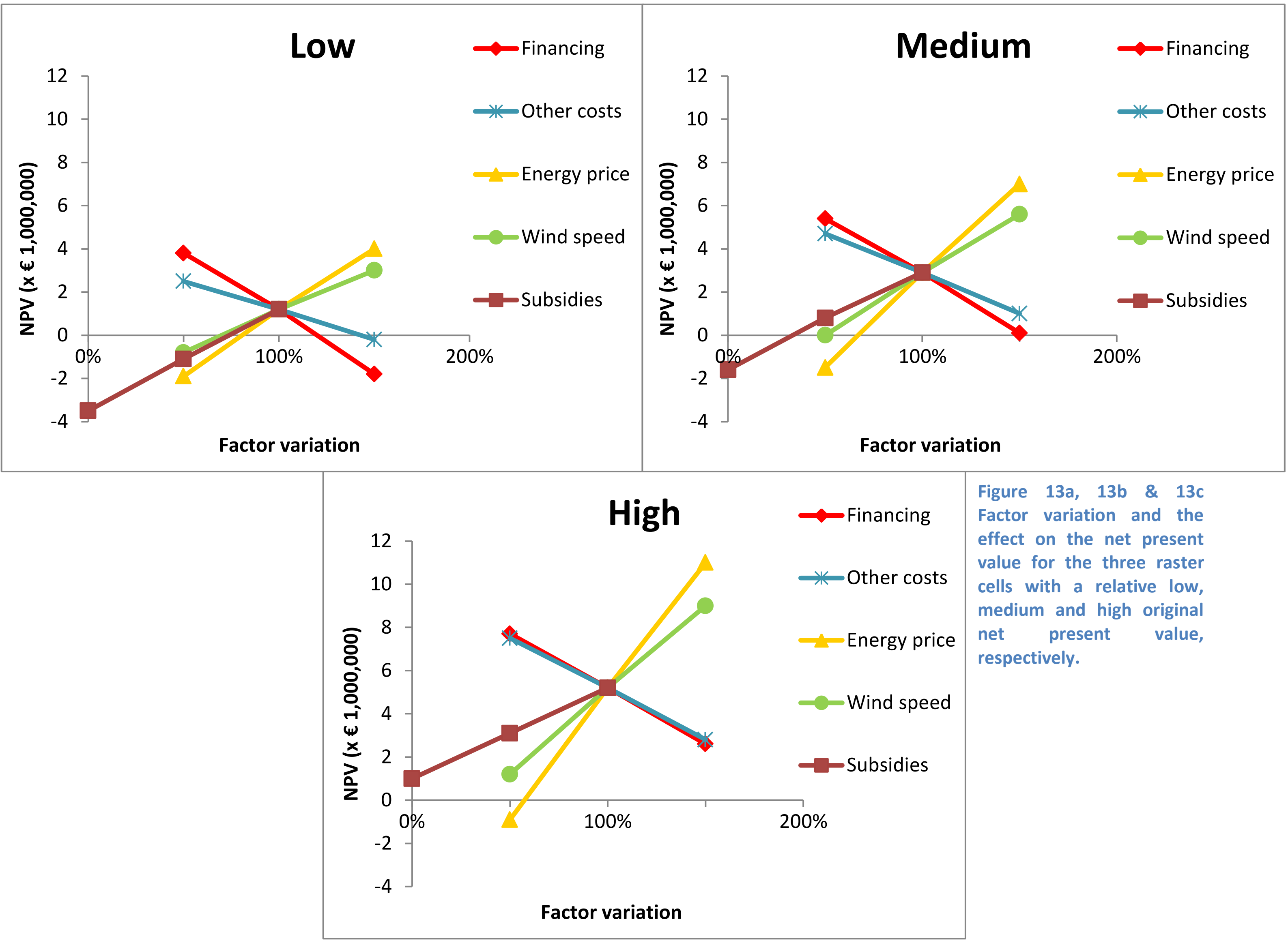


Figure 13a, 13b & 13c Factor variation and the effect on the net present value for the three raster cells with a relative low, medium and high original net present value, respectively.

The effects of the sensitivity analysis on the net present value for the whole province of North-Holland are given in ten different figures in Appendix VI. The effects are also made visible in the graphs of figure 13. The energy sales price is a major factor that determines the profitability. A decrease by 50% leads in all cases to a negative present value and even the whole province has a negative present value (see Appendix VI). As can be seen in table 10, the energy price has the largest influence on the net present value. The negative effect of less subsidies, relative to the negative effect of a lower energy sales price, is higher at a low original net present value than at a high original net present value. At a high net present value the effect of a 50% decrease in energy sales price is almost three times as large as a the effect of a decrease in subsidies by 50%. At a low net present value the energy sales price effect is only about 50% larger than the subsidy decrease effect. This means that areas with a low net present value are more dependent on subsidies for their profitability, because these areas have lower average wind speeds and thus have a lower income from energy sales.

The average wind speed is the second largest factor. It is related to the sales revenues, land rent and maintenance and insurance costs (see section 4.4.2). Because the sales revenues are higher than the land rent and maintenance and insurance costs combined, an increase in wind speed leads to an increase in net present value. It is common that the wind speed per year deviates up to 20% from the average (RVO, 2014h). Such a deviation has a large effect on the profitability of that year. Financing and other costs have a negative effect on the net present value. Their effects are the smallest, but still substantial. For example in the medium raster cell, if the financing cost, which is the investment, decreases by 50%, the net present value increases by 86% (see table 6). The other costs factor plays a smaller role. However, with a high net present value the effects of financing and other costs are almost similar. This is because of the dependence on the wind speed of some of other cost, such as land rent and maintenance and insurance. At higher wind speeds the other cost factor increases while the financing costs remain the same. Overall, the cost factors have a large negative effect, but the positive impact of the benefits and wind speed on the net present value is greater.

5. Synergies

In this chapter synergies between onshore wind energy and other forms of renewable energies with respect to electricity production are identified. A synergy is a mutual advantage for both energy sources. Wind and solar energy are both variable throughout the day, week, month and year. This is called intermittent variability. If they complement each other in terms of energy production the intermittent variability of the output is decreased. A hybrid solar-wind energy farm, for example, could be more predictable in terms of output, which results in better forecasting of the amount of produced energy. Also the amount of hours with zero output are reduced. These advantages lead to a higher capacity value of the farm (Stoutenburg, n.d.). A hybrid energy farm could lead to cost efficiencies, for example by sharing the same grid.

This chapter starts with describing the study area. In section 5.2 the synergies with geothermal energy combined with wind energy are identified. In section 5.3 the complementariness in energy production of wind energy and solar photovoltaics (PV) is explored. At last the optimal size and the costs of the solar field are determined.

5.1 Study area

In this analysis a study area in the province of North-Holland has been chosen based on the land use, wind speed, solar radiation and proximity of national grid transformers. It is evident that the study area requires a high average wind speed, a high solar potential, a close proximity to transformers and a large suitable area. The chosen study area is shown in figure 14 and 15. The region is called West-Friesland and has two larger cities, Hoorn and Enkhuizen. The land use is denoted by figure 14 (CBS, 2010). Between the cities is abundant open space, which are mostly meadows. Figure 15 shows the erage wind speed and geothermal potential (TNO, 2014).

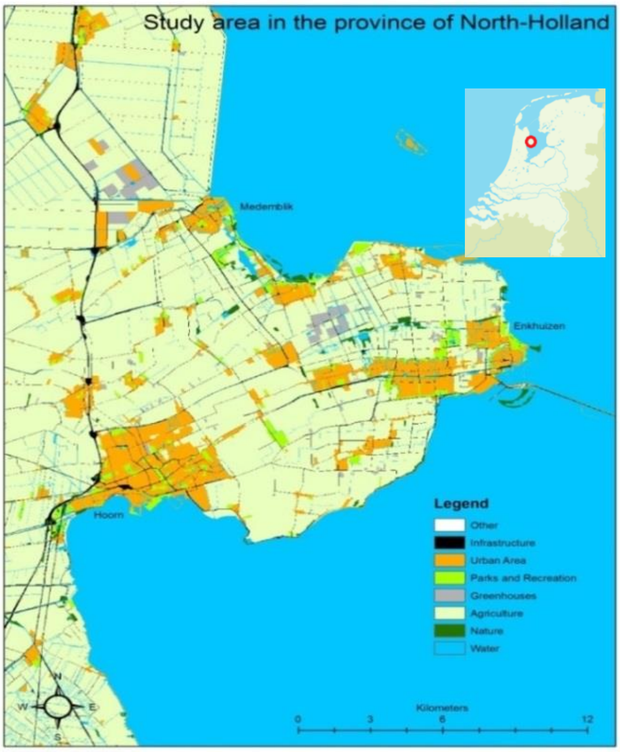


Figure 14 Land use in the study area. Source: CBS, 2010.

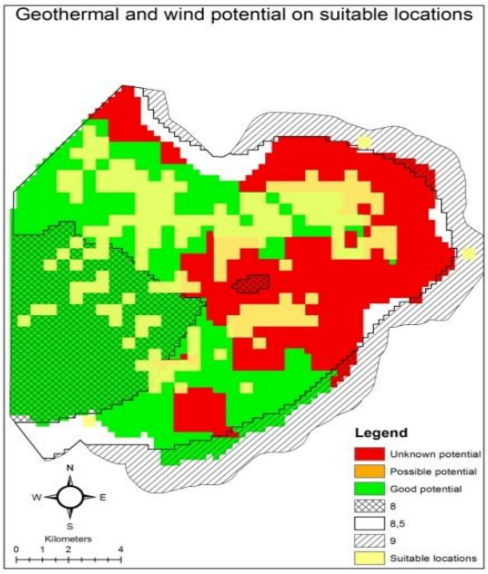


Figure 15 Geothermal and wind potential in the study area on suitable locations. Sources: SenterNovem, 2005 & TNO, 2014.

5.2 Geothermal energy

There is a geothermal potential present in the province of North-Holland, but this potential is only suitable for heat production. The required temperature for electricity generation from geothermal energy is more than 100 C°. The rock formation with the highest geothermal potential is the Slochteren Formation of the Rotliegendes reservoir (Kramers et al., 2010). This formation consists of highly permeable and porous sandstones, which are sealed by salt layers. The thickness varies from 30 meters in the southeast of the province to 300 meters in the northwest (Rijsdijk & Smakman, 2008). In the northwest this formation lies at 4000 meters depth, while in the southeast it is closer to the surface at 1500 meters depth. The temperature is at only a few places above the 100 C°, but those places occur at great depth (below 3000 meters). At a temperature just above 100 C° geothermal energy for electricity production has a very low efficiency. Combined with the great depth makes that this renewable energy source is not cost-efficient in the province in North-Holland and thus cannot provide a synergy for onshore wind energy.

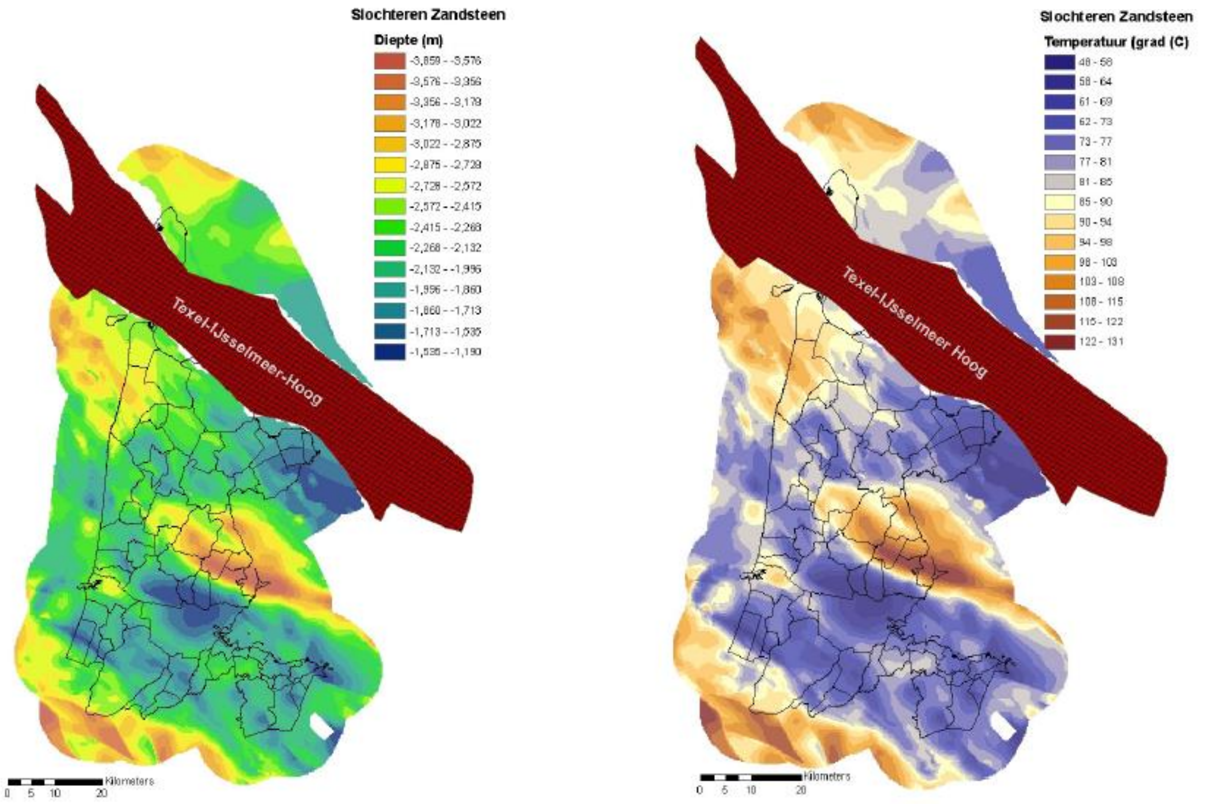


Figure 16a & 16b Depth and temperature of the Slochteren Formation. Source: Rijsdijk & Smakman, 2008.

5.3 Solar photovoltaics

In this section the possible synergy of combining wind energy and solar photovoltaics is explored. Wind and solar energy are both variable renewable energy sources and thus have to be back-fired by an energy source with a stable base load, such as nuclear, geothermal or fossil fuel energy. The reasoning behind the combination of wind and solar power is that variable renewable energy sources could decrease the variability of the output of the total energy farm by generating electricity at different moments. For example wind energy is stronger in winter and also present at night, while solar energy generation is absent during the night and stronger in summer. This complementariness of wind and solar power is explored for the study area. First the relative generated output per month and per hour are given for wind and solar energy. Thereafter the output of the solar field is determined. The correlation is used as measure for complementariness. In order to decrease the variability in the combined output of wind and solar power, the optimal size of the solar field is determined. At last the costs of the solar field are calculated.

5.3.1 Relative output

In the study area is an official KNMI weather station called Berkhout. The measurements from this weather station are acquired, containing a consecutive time series for a fourteen year period (2000 – 2013) (KNMI, 2014). This data set has a record for every hour of the average wind speed in 0.1 m/s and the solar radiation in ($\mathrm{J/cm^2}$). Every day has thus 24 records for wind speed and 24 records for solar radiation. The records show the value over the last hour, so 12:00 represents the average wind speed or the total solar radiation between 11:00 and 12:00. With this data set the correlation between wind speed and solar radiation is determined. This is done per hour and per month using SPSS software. In order to calculate the correlation per month, every record per month for the wind speed and radiation is summed up. The summing up of the values for average wind speed makes them completely meaningless, but it is useful for the statistical analysis. The full SPSS output with the mean and standard deviation is located in Appendix VII.

Figure 17 shows very clearly that solar PV systems have a much larger variation in hourly and monthly output than wind turbines. In May, June and July solar PV systems produce almost half of the annual output. Obviously, during the day between 09:00 and 15:00 most of the output is generated. A second thing that stands out is that wind speed is relatively low during the summer months, while radiation is high, which indicates signs of complementariness. The hourly variation shows that during the day wind speed is relatively high, but solar radiation is also high. It is important to take into account that from 22:00 until 03:00 the output from solar PV systems is zero.

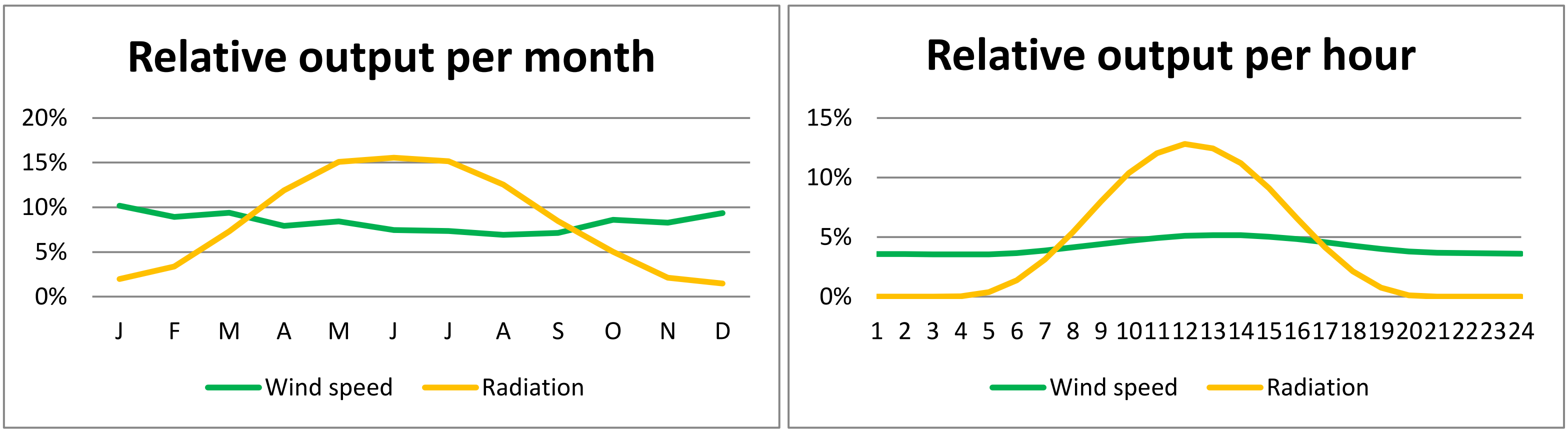


Figure 17 Relative output per month and per hour. Data source: KNMI, 2014.

5.3.2 Solar fields

Wind turbines are sometimes combined with solar PV panels in fields (NFU, 2013). A recent study suggested that shadow losses from wind turbines on solar PV panels are small and in the range of 1-2% (www.pv-magazine.com). In the UK, where multiple of these solar fields exist, typically two hectares are required per MW of power (NFU, 2013). In this analysis the size of the solar field is set at 50 MW as a starting point, which is close to the installed capacity of the wind park (54 MW). For 50 MW around 100 hectares of space is needed. A single solar panel of 300 Wp has a surface area of 2 m^2 (www.comparemysolar.nl). In the study area a total of 166,667 solar panels are placed in the field in order to have an installed power capacity of 50 MW. The total solar panel area is thus 333,333 m^2, which is 33% of the size of the field. The remainder is left empty to avoid shadow losses from the panels itself. This space is often used for some small cattle to graze or for installing bee hives or for environmental measures (NFU, 2014).

The efficiency of solar panels is on average 16% (Twidell & Weir, 2006). The data set from the KNMI indicates that the annual radiation in the study area is 1042 $\mathrm{kWh/m^2}$ (KNMI, 2014). It is likely that the radiation is higher at the solar panels itself because the tilting, orientation and active sunwards rotation of the solar panels is not taken into account in this analysis. With this information the expected electricity generated output can be calculated by using the formula (www.photovoltaic-software.com):

$$E = A * r * H * PR$$

Where:

E is the energy output (in kWh)
A is the total surface area of the solar panel (in m^2)
r is the efficiency of the solar panel
H is the annual radiation (in kWh/m^2)
PR is the performance ratio

The performance ratio is a correction measure for losses, such as converting to electricity via inverters, temperature losses, snow, shadings, weak radiation and cable losses. This ratio is usually set at 0.75 (www.photovoltaic-software.com). The annual generated electricity is:

$$E = 333{,}333 * 0.16 * 1042 * 0.75 = 41{,}679{,}958\ \mathrm{kWh} = 41.68\ \mathrm{GWh}$$

Compared to the energy output of the wind turbines the efficiency of the solar panels is much lower than the wind turbines. Figure 15 shows that the average wind speed in the study area is 8.5 m/s. According to table 7 in section 4.3 the energy output is then around 150 GWh per year. The installed capacity of the solar panels and wind turbines is about the same, but the generated electricity of the solar panels is only 27.8% of the electricity generated by the wind turbines.

5.3.3 Correlation

In this section various statistical methods are used to identify the correlation and the nature of the relationship between wind speed and solar radiation. The data contains monthly and hourly records.

5.3.3.1 Monthly correlation

In order to identify complementariness between wind and solar power, the bivariate Pearson correlation is calculated. This correlation method assumes a linear relationship between wind speed and solar radiation. A strong negative correlation indicates a high complementariness. A negative correlation states that one factor is low, while the other is high. The correlation per month is shown in figure 18. However, only the month June is statistically significant. The month June has a strong negative linear relationship between solar radiation and wind speed of -0.631. The negative relationship is caused by the relative low average wind speed in June and obviously the high solar radiation, because of the long days. This indicates that in this month the solar PV systems are a valuable addition to the wind farm. All months, except for February and May, have a negative correlation. So in those months wind speed is relatively high when solar radiation is relatively low and vice versa. However, those months lack statistical significance.

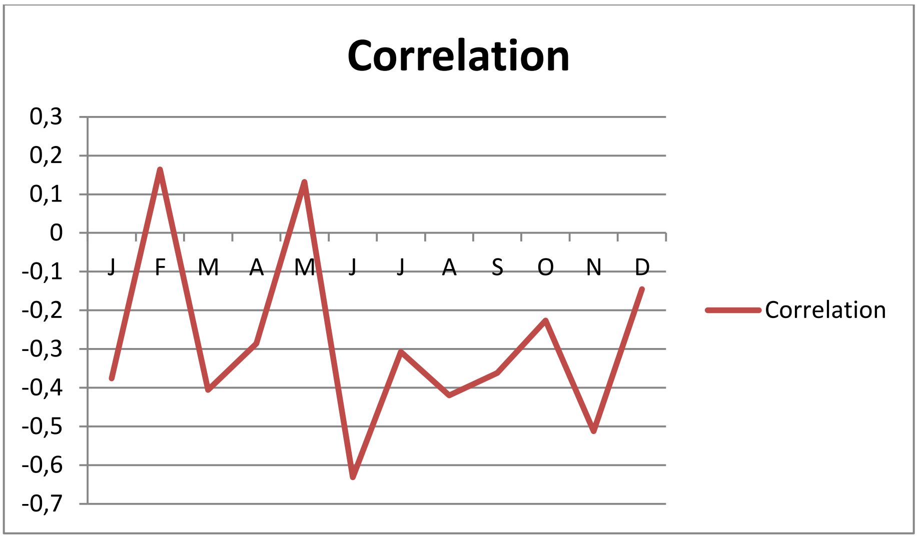


Figure 18 Monthly correlation between wind speed and solar radiation in the study area. Data source: KNMI, 2014.

In order to improve the statistical significance also two other correlation methods are used. The Kendall's tau and Spearman's rho are calculated and given in Appendix VII-3. These correlation methods assume a rank correlation relationship instead of a linear relation. This rank correlation looks at the similarity of the orderings of the data when ranked by each of the quantities. The statistical significance did not change that much, however. Still only June is significant. This lack of statistical significance is a motivation to explore the relation between wind speed and solar radiation more thoroughly. In Appendix VII-1 scatterplots are given of the monthly data. Linear, exponential and logarithmic fit lines are added. As can be seen in figure 32 of Appendix VII-1, the R-squared is of the same magnitude in all of the graphs and is particularly low. None of the trend lines fit the data very well. Based on this evidence, only a linear relationship is considered. Additionally, also the correlation of the natural logarithm of wind speed and radiation is calculated. Again, only June is statistically significant and thus this output is left out of the report.

5.3.3.2 Hourly correlation

Figure 19 shows the results of the same analysis for the hourly data. Again not all hours are significant. The hours 14:00, 15:00, 18:00 and 21:00 lack significance. Also, the correlation for the hours between 22:00 and 03:00 could not be calculated because the solar radiation is zero at night. The other hours show a weak negative correlation, because solar radiation is low between 04:00 and 09:00. During the day the negative correlation transforms into a weak positive correlation, because in the afternoon wind speed is highest, but also solar radiation is highest. The highest average wind speed is between 12:00 and 13:00 and the peak for solar radiation is between 11:00 and 12:00 (KNMI, 2014). So only in the early afternoon there is positive correlation. During the other parts of the day a weak negative correlation exists, indicating that at the hourly level wind and solar power complement each other as co-electricity producers. Also the wind farm backs up the solar field at nights with a strong enough wind, because the solar field has then no electricity production.

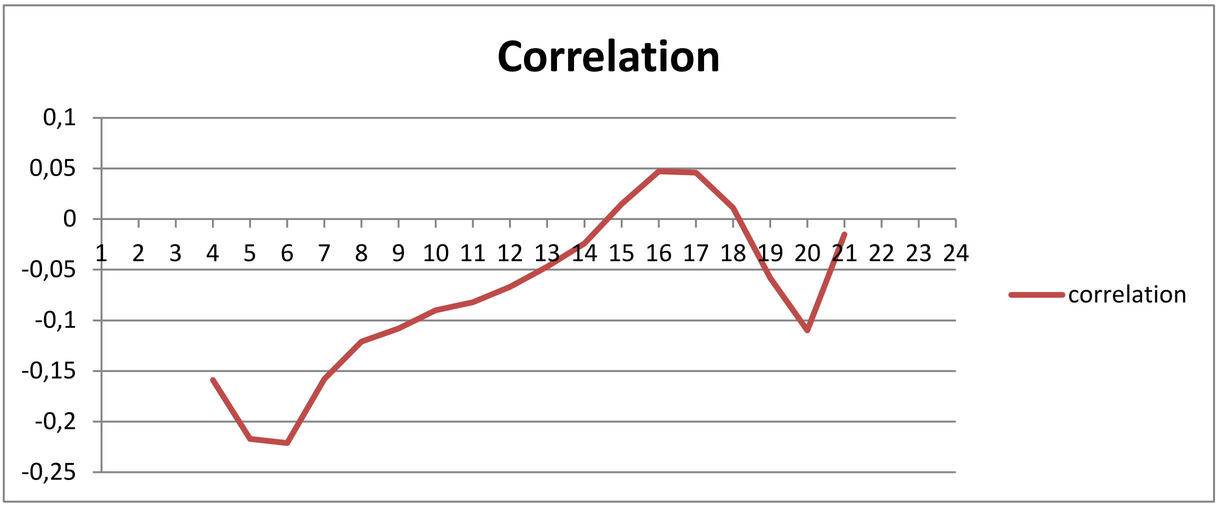


Figure 19 Monthly correlation between wind speed and solar radiation in West-Friesland. Data source: KNMI, 2014.

5.3.4 Size of the solar field

In this section the size of the solar PV field of 50 MW is optimized in order to decrease the excess supply of energy. The monthly data is used, because hourly data is too variable and hourly variations can be corrected rapidly by, for example, gas-fired power plants. The aim is to minimize the variation of the combined output. This is done by minimizing the difference between the smallest and largest combined output value. In figure 20 the monthly output is given in GWh for the wind farm, solar field and combined. It shows that November has the lowest and May the highest output.

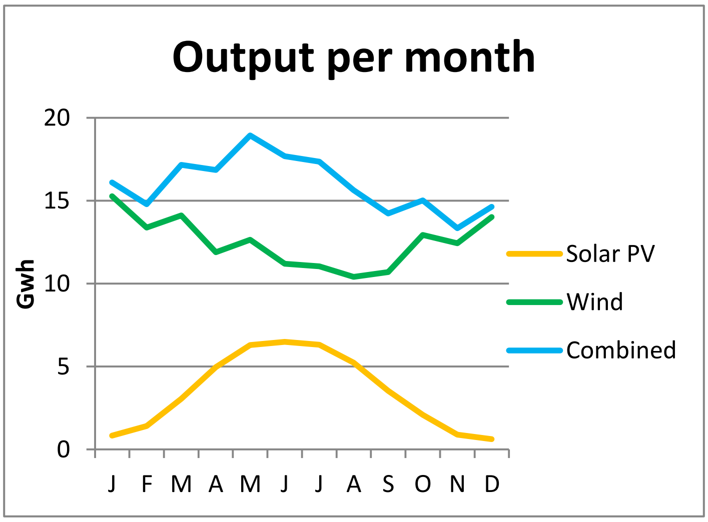


Figure 10 Output per month for the wind farm, solar field and combined output. Data source: KNMI, 2014.

In figure 21 the size of the solar field is adjusted to minimize the difference between the lowest and the highest combined output. At 100% the solar field has an installed capacity of 50 MW. If the solar field does not exist the output is fully generated by the wind farm. In that case January has the highest output, because it has the highest average wind speed. August has then the lowest output. June has the highest and December the lowest solar radiation. As the size of the solar field increases, the difference between the lowest and the highest output per month decreases (blue line). This is because in January solar radiation is very low, so the output in January does not increase that much. In August solar radiation is relatively high, so the output in August rapidly increases. This decreases the difference between the highest and lowest output.

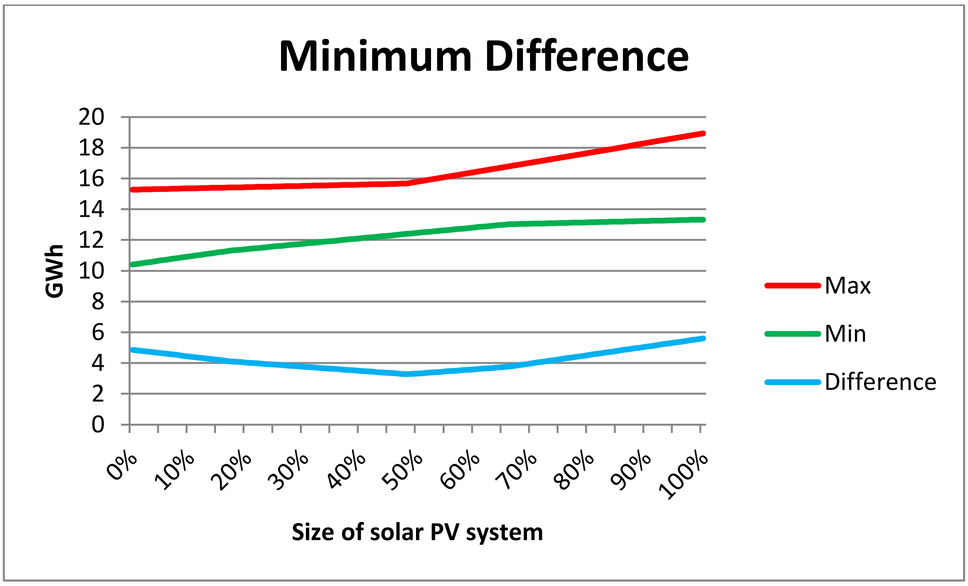


Figure 21 Minimum difference between the lowest and highest output per month at various solar PV system sizes. 100% is the original size of the solar field of 50 MW. The red line represents the month with the highest output. The green line represents the month with the lowest output. The blue line is the difference between the lowest and highest output. Data source: KNMI, 2014.

At a size of the solar field of 17% the month with the lowest output shifts from August to September, because the solar radiation is higher in August. The average wind speed of September is comparable with August, but the output of the solar field is higher in August. At a size of 66% onwards November is the month with the lowest output, because of the very low solar radiation. The month with the highest output is January, but at a size of 49% onwards May has the highest output. This is because solar radiation is very high in May. The rapid increase of output in May is the cause that from 49% onwards the difference increases again. This is clearly visible in the red line, which has a breakpoint at 48%, causing the blue line to increase. Thus at a size of the solar field of 48% of the original 50 MW, the difference between the lowest and highest output is smallest. Therefore the optimal size of the solar field is 48% of 50 MW, which is 24 MW. The solar field of 24 MW is 44% of the size of the wind park of 54 MW. The solar field provides then a synergy for the wind farm by decreasing the variation in monthly output. The difference between the lowest and highest monthly output with only the wind farm is 4.86 GWh. By adding a solar field of 24 MW this decrease to 3.28 GWh. This is a decrease in difference by 32.5%.

5.3.5 Costs of the solar field

Solar fields and wind turbines could also share the same grid and other energy infrastructure. This could reduce the investment costs. Suppose the hybrid solar-wind energy farm is located 2.5 km from the nearest national grid transformer, the construction costs for power grid lines are $€\,4000 * €\,2500 = €\,10{,}000{,}000$ (see section 4.4.1). The wind farm of 18 wind turbines has an investment cost of € 76,535,700 excluding transmission lines (see section 4.1.1). Total investment is thus € 86,535,700, of which the transmission lines account for 11.6% of the investment costs if only the wind farm is built, which is a substantial amount.

The costs for a solar field range from € 1500/kW (NFU, 2014) to € 2000/kW (www.innovativesolarfarms.com), compared to € 1150/kW for wind turbines. The costs for the optimal sized solar field of 24 MW ranges between € 36,000,000 and € 48,000,000. The total investment is therefore between € 46,000,000 and € 58,000,000, if only the solar field is built. The transmission lines costs account then for 17.2% - 21,7% of the total investment costs. These transmission lines only have to be built once and are used more efficiently if both the wind energy farm and the solar field use the same transmission lines. By combining wind and solar the total investment is € 76,535,700 plus € 42,000,000, which is the mean of the investment costs for the solar field. Instead of double costs for the transmission lines, which would bring the total investment costs to € 138,535,700, the transmission line costs only have to be taken into account once, which gives a total investment cost of € 128,535,700. This saving of € 10,000,000 is a saving of 7.2%. This shows that cost-reduction synergies arise by using hybrid power plants instead of two separate energy farms. During the lifetime of the hybrid power plant, one could imagine that costs are further reduced by sharing of surveillance, monitoring, maintenance, insurances, access roads and more.

6. 3D Visualization

The output of this report can be incorporated in 3D visualization tools to inform decision making processes. Spatial factors often have a 3D component, such as noise, visibility impacts and shadows. In this section screenshots are given of a 3D visualization created with CityEngine software from ESRI. It presents a way of how such an analysis can be visualized in 3D to use as a communication tool. It supports policy makers in understanding the visual impacts of wind turbines in the landscape. The 3D tool can also be used for modelling other spatial factors, such as noise and shadow modelling. The 3D environment can be opened in the browser and different layers can be turned on and off. It is freely accessible via this link:

http://www.arcgis.com/home/item.html?id=212e36e60feb40a4882b4d7951992038

6.1 data

In the province of North-Holland a small area is chosen with a high average wind speed with already some wind turbines in place. The area is located between Petten and Burgerbrug in the municipality of Schagen in the north western part of the province. Figure 22 shows the area in a 3D environment. The size of the area is around 2 by 2 kilometres. The building footprints of the BAG data are used to reconstruct the locations of the buildings (Kadaster, 2014a). The roads and waterways are Top10NL data and the trees originate from the national tree register. Also already existing wind turbines are placed. As a background an aerial picture is used, with a coarse (2x2 meters) resolution because of software constraints. To include elevation, data from the Actueel Hoogtebestand Nederland is used. The building characteristics such as building height and type of roof are added, which are based on the real world. The buildings are randomly textured. Using all these realistic data results in a very good representation of the real world. All this data is open data for research purposes, except for the trees and the building characteristics.

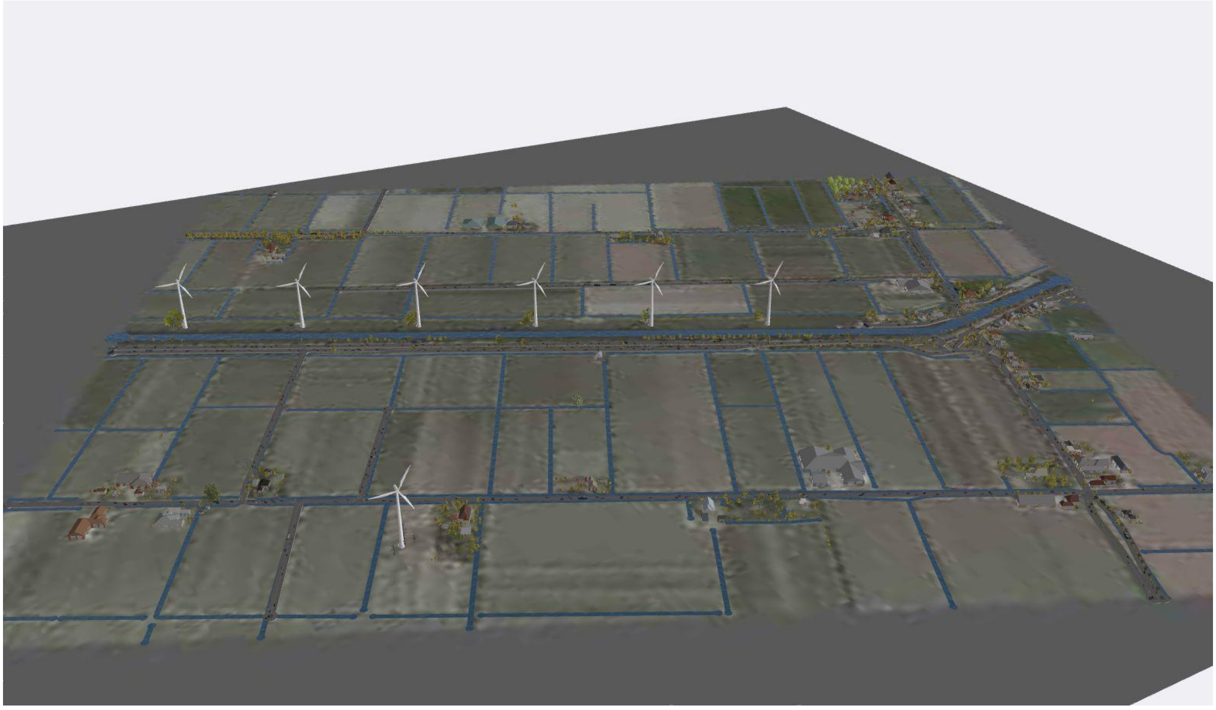
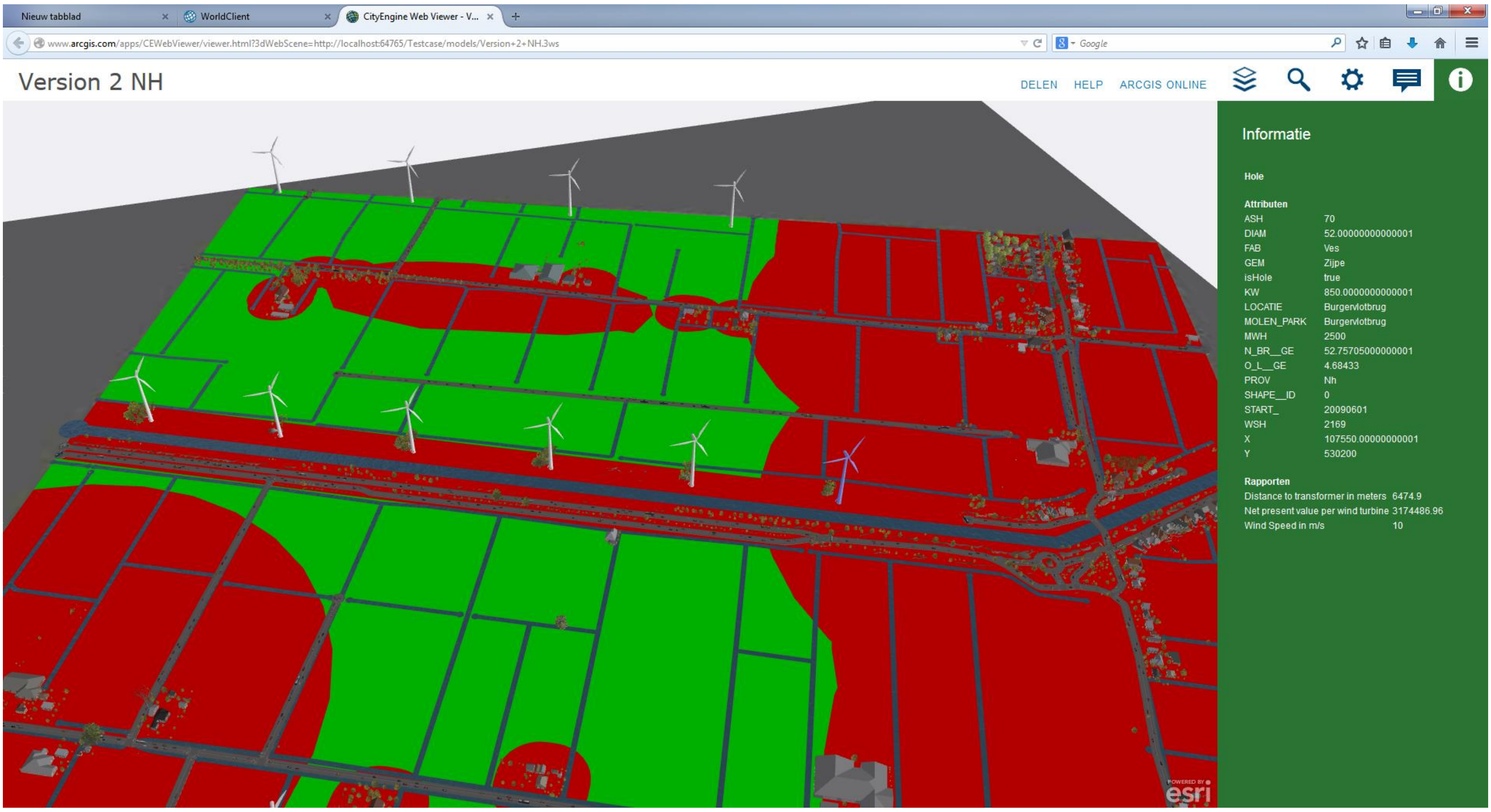


Figure 22 3D visualization of the area created with CityEngine from ESRI.

6.2 Communication tool

This 3D environment is very suitable to use as a communication tool. It visualizes the effect on the landscape if a wind turbine is added. In figure 23 the suitability map, that is constructed in section 3.4, is used as the background layer. This shows immediately which locations are suitable for new wind turbines. Figure 23 shows unsuitable locations around the already existing wind turbines, urban areas and farms. On the meadows plenty of space is suitable. As an example four wind turbines are added on the edge of the area. Residents and policy makers immediately see the effects on the landscape and whether these suitable locations are desirable or not. A disadvantage of this 3D environment is that it does not support a drag and drop method of wind turbines. New wind turbines have to be added beforehand before the 3D environment is published. The wind turbines can be made invisible, so from multiple wind farm configurations the most desired one can be chosen by hiding the other ones.



Informatie

Hole

Attributen

ASH	70
DIAM	52.00000000000001
FAB	Ves
GEM	Zijpe
isHole	true
KW	850.0000000000001
LOCATIE	Burgervlotbrug
MOLEN_PARK	Burgervlotbrug
MWH	2500
N_BR__GE	52.75705000000001
O_L__GE	4.68433
PROV	Nh
SHAPE__ID	0
START_	20090601
WSH	2169
X	107550.00000000001
Y	530200

Rapporten

Distance to transformer in meters	6474.9
Net present value per wind turbine	3174486.96
Wind Speed in m/s	10

Figure 5 3D visualization of suitable and unsuitable areas.

As an extra feature all buildings and the six existing wind turbines report in the green box the average wind speed at 100 meters altitude (see figure 5), the profitability in terms of the net present value (see section 4.4), and the distance to the nearest national grid transformer (see figure 4), if on that particular location a wind turbine is placed. Unfortunately, the screenshot makes the reports slightly unreadable in figure 23. The average wind speed at the most right selected wind turbine (the blue wind turbine in figure 23) is 10 m/s. The distance to a transformer is 6475 meters and the net present value is almost € 3,200,000. With this information in combination with the suitability map, the most desirable locations can be identified by policy makers in consultation with local residents.

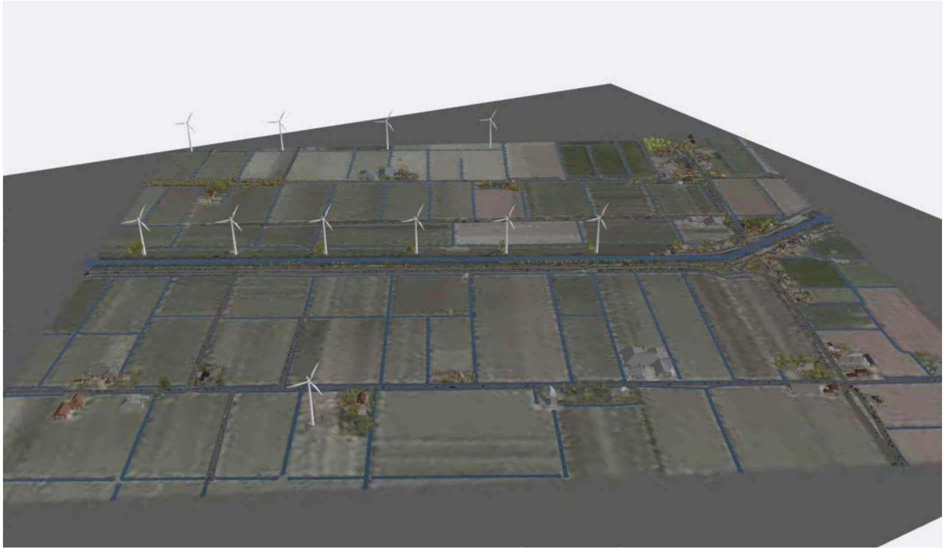


Figure 24 New wind turbines are added in the 3D visualization tool

Figure 24 shows how the area looks like with the aerial picture and the new wind turbines. In figure 25 multiple views from urban areas towards the wind turbines are given. This indicates the visibility of the wind turbines from the houses. Visibility of wind turbines is sometimes seen as a disturbance. As an extra feature also a morning and an evening screenshot of the same location is given, because visibility changes during the day.

Figure 25a, 25b, 25c & 25d Day and night visualization of the created area.
The bottom figures show the visibility of wind turbines from other perspectives.

7. Discussion and conclusion

This chapter contains a discussion of the results and assumptions. Also recommendations for further research and at last the conclusions of this report are given.

7.1 Discussion

This report presents a method how to assess the feasibility of onshore wind energy in a spatially explicit way. It provides a general method for the province of North-Holland, which can be easily applied to other provinces or the whole of the Netherlands, assuming that each province has the requisite data available. Data limitations of provincial zoning regulations could be an issue, because it restricts the correctness of the suitability map. All the other data used are available and accessible, sometimes at a cost.

Throughout the report several assumptions have been made, which are either supported by the literature or necessary, because of lack time or missing data. However, these assumptions do not decrease the usefulness of the results from a general point of view. The results should be used as a broad overview of the feasibility aspects in a geographical and economic sense. It could serve as a first step in selecting locations for onshore wind energy. Case-specific research is always required to validate the economic and geographic feasibility at a specific location.

In the economic assessment one should take into account that the outlined economic situation is valid for 2014. For example, changes in the subsidy system are announced for 2015 (Ministry of Economic Affairs, 2014b). The subsidy for wind energy will become totally dependent on the average wind speed at the location of the new wind turbine. Wind energy on dikes will also be possible and treated as a separate category. This shows that the models presented should be updated when new developments occur in order to prevent outdating. The fully automated generation process of the models is easy to update, because it is designed for quick adaptation of new zoning regulations and economic developments. This way new suitability and economic maps are produced rapidly. In order to validate the economic model, the outcomes should be compared with the economic performance in reality. This can be done by comparing the outcomes with estimates of sector businesses for case-specific locations. Also the real costs and benefits during the first year can be used. It is more difficult to validate the net present value, as this is computed over a period of 20 years.

The identification of synergies focussed mainly on solar photovoltaics and its complementariness with respect to wind energy generation and the resulting cost-efficiencies. As a measure of complementariness the correlation between wind speed and solar radiation is calculated, assuming that a strong negative correlation indicates a high degree of complementariness in energy generation. This method may seem to be a bit too simplistic, but is used in the literature to identify this type of synergy, because it is a fast and easy way with often realistic results (Fusco, Nolan & Ringwood, 2010). The records of weather station Berkhout show that wind and solar power complement each other at the monthly level in terms of energy generation. Unfortunately, the results should be interpreted with the notion of a lack of statistical significance, except for the month June. Also at the hourly level wind and solar power are complements, but to a lesser extent and not in the early afternoon. During nights with good winds wind energy backs up the solar field. A hybrid solar-wind farm reduces the amount of hours with zero output.

The applied statistical methods did not reveal the true character of the relationship between wind speed and solar radiation. This relationship is very interesting to explore in a future research, because more interacting factors could be involved. It is for example possible that this relationship is dependent on the geographic location of the weather station, as the solar radiation and wind speed pattern differ throughout the province of the North-Holland and the Netherlands. It is interesting to include more weather stations to compare the results. Another point for further research is the identification of synergies or complementariness between wind power and different storage options of wind electricity, and between wind power and other renewable energy sources, such as biomass and wave energy, the latter especially in the case of offshore wind energy. The storage of wind electricity could occur at peak production during high winds and relatively low demand of electricity. This peak could be entrapped by using it for charging electric cars, district heating or hydrogen energy storage, in order to prevent overloading of the grid network and maintaining grid stability.

The content of the research is visualized in a realistic as possible 3D environment. This proves the applicability of the method in the province of North-Holland. However, technical limitations restrict the size of the area visualized in 3D, but multiple areas could be visualized separately. The 3D tool is able to support policy makers, wind park developers and the local population in utilizing the benefits and mitigating the negative impacts of onshore wind energy, as the 3D tool shows the economic performance, suitability, average wind speed, distance to transformers and the impact on the landscape, which could be either positive or negative. Again, it is easy to update this 3D tool with new content, if this content is available. Realistic models of noise and shadow flicker are very complex and were not available during this research, but are definitively a necessary part of a feasibility analysis of onshore wind energy. It would be very valuable if these models could be added to the 3D tool. This would strongly enhance the communication capabilities and usefulness of this 3D environment for policy makers, wind park developers and local residents.

7.2 Conclusion

In this research the feasibility of onshore wind energy in the province of North-Holland is identified. The aim was to implement the geographic and economic constraints in a spatially explicit way. Wind energy is inexhaustible and decreases the dependence of foreign imported energy, such as fossil fuels. This increases the energy security of a country, because it is locally produced energy. Wind energy also provides jobs during construction, maintenance and monitoring.

The negative impacts of onshore wind energy are construction nuisance, noise, landscape depreciation, shadow flicker of the rotor blades and killing of birds and bats. That is why zoning regulations exist, which limit the suitability of wind turbines. Along infrastructure certain distance requirements have to be met. Also radar systems and built-up areas are subject to limitations. Natural areas are cleared from wind energy development, but agricultural lands usually are suitable locations. The province of North-Holland has set more stringent regulations such as greater distances from built-up areas and excluding geologically important landscapes. The result is that 6.6% of the province of North-Holland, excluding Wieringermeer, is suitable for onshore wind energy.

A very important spatial factor is the average wind speed at 100 meters altitude, because this determines for a large part the feasibility of wind energy. The average wind speed in the province of North-Holland is at most locations between 8 and 10 m/s, which is high compared to the rest of the Netherlands. This gives a high wind energy potential. Another spatially important factor, from an economic point of view, is the distance to national grid transformers, as those function as connection points to the national grid. Except for two small areas, a transformer station is available within 10 kilometres, but in a large part of the province even within 5 kilometres.

The economic analysis shows that onshore wind energy is a profitable investment in all suitable locations in the province of North-Holland. The net present value, which is determined over a period of 20 years, ranges between € 250,000 and € 6,000,000 per turbine. The costs for new transmission lines are estimated at € 4,000,000 per kilometre and have a large impact on the net present value of the wind turbine. The sensitivity analysis indicates that areas with a relatively high net present value are less sensitive to changes in costs and benefits than areas with a relatively low net present value. The largest change on the profitability is caused by the energy sales price, as a 50% drop in sales price results in a negative net present value in the whole province. Other major factors are the average wind speed and the subsidies. Even with no subsidies at all, a few areas still have a positive net present value. A wind park of 18 wind turbines with an installed capacity of 54 MW has at some very profitable locations an annual rate of return on the investment of 6.3% for a period of 20 years, whereas for example Dutch national government bonds of this duration have an annual rate of return of 2.74%.

The intermittent variability of wind turbines stresses the capacity value of the wind farm, limits energy output forecasting and results in hours with zero output. The temperature of the Slochteren Formation of the Rotliegendes reservoir, which is the layer with the highest geothermal potential, is too low for cost-effective geothermal electricity production in the province of North-Holland, making it impossible to combine geothermal and wind energy. Solar fields also have an intermittent variability, but relatively the output is higher in summer than in winter, while wind energy output is higher in winter.

The statistical analysis gives a strong negative correlation between wind speed and solar radiation, except for February and May, indicating that wind and solar power complement each other in terms of energy production. It should be noted that only June is statistically significant. The hourly data shows a weak complementariness between wind and solar power from 04:00 until 14:00 and in the early evening. During the afternoon the correlation is positive. At nights with good winds, wind energy backs up the solar field, reducing the hours of zero output. In order to decrease the variation between the months with the lowest and highest output of the wind farm during a year, the size of the solar field has to be 44% of that of the wind farm. This gives a more equal output between the months, as the variation has decreased by 32.5% from 4.86 GWh to 3.28 GWh. The wind and solar farm could also experience cost-efficiencies by sharing transmission lines, access roads, surveillance and monitoring, which lowers costs.

This research has been visualized in a 3D environment that can be used in discussions among policy makers, wind park developers and local residents to address the landscape impacts of wind turbines. The tool also shows suitable areas, net present value, average wind speed and distance to transformers. Therefore, it is applicable as a communication tool to support feasibility discussions of onshore wind turbines in the province of North-Holland.

The presented method of how to assess the feasibility of onshore wind energy in a spatially explicit way includes an geographical and economic assessment, while taking all spatial factors into account. The highly adaptable design of the models gives a high flexibility in producing new suitability and economic maps. This research has shown that this method is applicable in the province of North-Holland and that intermittent variability of wind energy could be decreased by adding a solar field.

References

Aarts, B., Bruinzeel, L. (2009). *De nationale windmolenrisicokaart voor vogels*. SOVON Vogelonderzoek Nederland. Vogelbescherming Nederland.

Arnett, E.B., Inkley, D.B., Johnson, D.H., Larkin, R.P., Manes, S., Manville, A.M., Mason, R., Morrison, M., Strickland, M.D., Tresher, R. (2007). *Impacts of Wind Energy Facilities on Wildlife and Wildlife Habitat.* Wildlife Society Technical Review 07-2. The Wildlife Society, Bethesda, Maryland, USA.

Bakker, R.H., Pedersen, E., Berg, van den, G.P., Stewart, R.E., Lok, W., Bouma, J. (2012). *Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress*. Science of the Total Environment, Vol. 425, 42-51.

Bond, J., Talsma, T. (2014). *Nieuwe opgave wind op land*. Provincie Noord-Holland. Haarlem.

Cary, W. (1974). *Federalism and Corporate Law: Reflections Upon Delaware*. The Yale Law Journal. Vol. 83, No. 4, pp. 663-705.

CBS (2010). *Dataset Bodemgebruik Nederland*. Centraal Bureau voor de Statistiek. Heerlen/The Hague. Downloaded at 11-09-2014 at: <http://geoplaza.vu.nl/cdm/singleitem/collection/gpz/id/233/rec/7>

CBS (2014). *Consumentenprijzen; inflatie van 1963*. Centraal Bureau voor de Statistiek. Heerlen/The Hague.

Denholm, P., Hand, M., Jackson, M., Ong, S. (2009). *Land-Use Requirements of Modern Wind Power Plants in the United States*. Technical Report NREL/TP-6A2-45834. National Renewable Energy Laboratory, Golden, Colorado, USA.

Everaert, J. (2008). *Effecten van wind turbines op de fauna van Vlaanderen – Onderzoeksresultaten, discussie en aanbevelingen*. Instituut van Natuur- en Bosonderzoek, rapportnr. INBO.R.2008.44., Brussel.

Faasen, C.J., Franck, P.A.L., Taris, A.M.H.W. (2013). *Handboek Risicozonering Windturbines.* DNV KEMA. Agentschap NL, ministry of Economic Affairs, The Hague.

Fryslânfoardewyn (n.d.). *Model van kosten en baten van een windpark met 5 turbines van 3 MW*. Leeuwarden.

Fusco, F., Nolan, G., Ringwood, G.V. (2010). *Variability reduction through optimal combination of wind/wave resources – An Irish case study.* National University of Ireland, Maynooth. Energy, Vol. 35, pp. 314-325.

Gent, O. van (2014). *Toelichting bij de nieuwe radarhinder toetsingsmethode*. TNO. The Hague.

Harding, G., Harding, P., Wilkins, A., (2008). *Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them*. Epilepsia, Vol. 49, Issue 6, 1095-1098.

Hoogwijk, M., Vries, B., de, Turkenburg, W. (2004). *Assessment of the global and regional geographical, technical and economic potential of onshore wind energy.* Elsevier Energy Economics. No. 26, pp. 889-919.

IPCC (2014). *Annex III: Technology-specific cost and performance parameters. Intergovernmental panel of climate change*. Working Group III – mitigation of climate change.

John Dekker A&O (2013). *Windturbines in het Robbenoordbos*. Online researched at 27-10-2014 at: <http://www.rvo.nl/sites/default/files/2014/07/eindrapport%20Pilot%20windturbines%20in%20het%20Robbenoordbos%2013%2003%202013%20en%20bijlage.pdf>

Kadaster (2014a). *Basisregistratie Adressen en Gebouwen (BAG)*. Open data Kadaster, Netherlands. http://www.kadaster.nl/bag. Downloaded as shapefiles at 27-06-2014 at: <http://geoplaza.vu.nl/cdm/singleitem/collection/gpz/id/238#>

Kadaster (2014b). *Wind op Land - Potentiegebieden binnen randvoorwaarden herstructurering PRVS art. 32. lid 4. incl. overige ruimtelijke randvoorwaarden (niet limitatief).* Provincie Noord-Holland. Haarlem.

Klooster, M., ten, Bilt, S., van de (2009). *Kosten en baten windpark op land*. Pondera Consult. Hengelo. Agentschap NL, ministry of Economic Affairs. The Hague.

KNMI (2014). *Klimatologie: Uurgegevens van het weer in Nederland – Download.* De Bilt, Netherlands. Downloaded at 11-11-2014 at: <http://www.knmi.nl/klimatologie/uurgegevens/select_uur.cgi?language=nl>

Kramers, L., Vis, G.J., Pluymaekers, M.P.D., Van Wees, J.D.A.M., Mijnlieff, M.H. (2010). *Inventarisatie aardwarmtepotentie Nederlandse ondergrond: geologische onzekerheden en te nemen maatregelen*. Delft: TNO bouw en ondergrond.

Lensink, S.M., Wassenaar, J.A., Mozaffarian, M., Luxembourg, S.L., Faasen, C.J. (2012). *Basisbedragen in de SDE+ 2013 Eindadvies*. ECN-E—12-038. Energy Research Center Netherlands (ECN), Petten.

Lensink, S.M. (2013). *Conceptadvies SDE+ 2014*. Energy Research Center Netherlands (ECN), Petten.

Limpens, H.J.G.A., Boonman, M., Korner-Nievergelt, F., Jansen, E.A., Valk, van der, M., La Haye, M.J.J., Dirksen, S., Vreugdenhil, S.J. (2013). *Wind turbines and bats in the Netherlands – measuring and predicting*. Report 2013.12, Zoogdiervereniging & Bureau Waardenburg.

Maarssen (2008). *Voorstel college van Maarssen aan gemeenteraad: Hoogspanningsmasten niet ondergronds brengen*. Municipality of Maarssen press release.

McBride, D., Shepherd, D., Welch, D., Dirks, K. (2014). *Longitudinal study of the impact of wind turbine proximity on health related quality of life*. University of Otago, Dunedin, New Zealand.

Ministry of Economic Affairs (2014a). *Voortgang programma “Uitkoop en Verkabeling”*. Dutch Minister of Economic Affairs, H.G.J. Kamp, 03-07-2014. The Hague. NO. 00000001003214369000.

Ministry of Economic Affairs (2014b). *Kamerbrief SDE+ 2015*. Dutch Minister of Economic Affairs, H.G.J. Kamp, 11-11-2014. The Hague. NO. 00000001003214369000.

Mroczek, B., Kurpas, D., Karakiewicz, B. (2012). *Influence of distances between places of residence and wind farms on the quality of life in nearby areas*. Annals of Agricultural and Environmental Medicine 2012, Vol 19, No 4, 692-696.

National Farmers Union (NFU) (2013). *Solar photovoltaic electricity in agriculture – on your roofs and in your fields*. United Kingdom.

National Wind Coordinating Collaborative (NWCC) (2010). *Wind Turbine Interactions with Birds, Bats and their Habitats – A Summary of Research Results and Priority Questions*. United States Department of Energy. Online researched at 27-08-2014 at: <http://www1.eere.energy.gov/wind/pdfs/birds_and_bats_fact_sheet.pdf>

National Wind Watch (2013). *Studies of Health Effects of Industrial Wind Turbine noise, 2003-2012*. Online researched at 27-06-2014 at: <https://www.wind-watch.org/documents/studies-of-health-effects-of-industrial-wind-turbine-noise/>

Nieuwgein (2006). *Verkenningenstudie Hoogspanningslijn Nieuwegein*. Municipality of Nieuwegein. VHP architects, Rotterdam.

Provinciale Ruimtelijke Verordening Noord-Holland (2014). Online researched at 27-06-2014 at: <http://decentrale.regelgeving.overheid.nl/cvdr/XHTMLoutput/Actueel/Noord-Holland/323343.html>

Rademaekers, K., Gorp, N., van (2009). *Contra-expertise op ECN/KEMA-advies wind op land*. Ecorys, Rotterdam.

Rhyne, I., Klein, J. (2014). *Estimated Cost of New Renewable and Fossil Generation in California*. California Energy Commission. CEC-200-2014-003-SD.

Riet, M., van 't (2012). *Fiscale prikkels en vennootschapsvorming*. CPB achtergronddocument behorend bij CPB Policy Brief 2012/02: 'De fiscale behandeling van zelfstandigen: Een kritische blik'. Centraal Plan Bureau, The Hague.

Rijksdienst voor Ondernemend Nederland (RVO) (2014a). *Landschappelijke beleving windenergie.* Zwolle. Online researched at 26-11-2014 at: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/ruimtelijke-ontwikkeling/landschappelijke-beleving>

Rijksdienst voor Ondernemend Nederland (RVO) (2014b). *Slagschaduw.* Zwolle. Online researched at 14-06-2014 at: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/milieu-en-omgeving/slagschaduw>

Rijksdienst voor Ondernemend Nederland (RVO) (2014c). *Windmolens in bos en natuur.* Zwolle. Online researched at 26-11-2014 at: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/ruimtelijke-ontwikkeling/bos-en-natuur>

Rijksdienst voor Ondernemend Nederland (RVO) (2014d). *Radar*. Zwolle. Online researched at 01-06-2014 at: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie opwekken/windenergie-op-land/milieu-en-omgeving/radar>

Rijksdienst voor Ondernemend Nederland (RVO) (2014e). *Opbrengst*. Zwolle. Online researched at 20-05-2014 at: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/techniek/opbrengst>

Rijksdienst voor Ondernemend Nederland (RVO) (2014f). *Kosten en baten.* Zwolle. Online researched at 13-06-2014 at: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/financien/kosten-en-baten>

Rijksdienst voor Ondernemend Nederland (RVO) (2014g). *Regeling groenprojecten.* Zwolle. Online researched at 13-06-2014 at: <http://www.rvo.nl/subsidies-regelingen/regeling-groenprojecten>

Rijksdienst voor Ondernemend Nederland (RVO) (2014h). *SDE+ 2014 - Zo vraagt u subsidie aan voor de productie van duurzame energie.* Zwolle.

Rijksdienst voor Ondernemend Nederland (RVO) (2014i). *WOZ en planschade.* Zwolle. Online researched at 14-06-2014 at: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/financien/woz>

Rijksdienst voor Ondernemend Nederland (RVO) (2014j). *Aanvragen Stimulering Duurzame Energieproductie (SDE).* Zwolle. Online researched at 20-06-2014 at: <http://www.rvo.nl/subsidies-regelingen/aanvragen-stimulering-duurzame-energieproductie-sde>

Rijksoverheid (2013). *Windenergiegebieden op Land*. The Hague, Netherlands.

Rijkswaterstaat (2012). *Discontovoet bij LCC en MKBA*. Ministry of Infrastructure and Environment. The Hague, Netherlands. Online researched at 20-06-2014 at: <http://www.rijkswaterstaat.nl/zakelijk/see/nieuwsbrieven/december_2012/discontovoet_bij_lcc_en_mkba.aspx>

Rijntalder, H., Vogelaar, B. (2013). *Grondvergoedingen bij windenergieprojecten*. Pondera Consult. Hengelo.

Rijsdijk, V., Smakman, G.J.J. (2008). *Geothermie in Noord-Holland: Inventarisatie van locaties voor toepassing geothermische energie*. Grontmij. De Bilt, Netherlands.

Royal Haskoning DHV (2013). *Plan-MER Structuurvisie Windenergie op Land*. Ministry of Infrastructure & Environment. The Hague.

RVOB (2014). *Windturbines*. Rijksvastgoed- en Ontwikkelingsbedrijf (RVOB). Zwolle. Online researched at 13-06-2014 at: <http://www.rvob.nl/producten_en_diensten/windturbines>

SenterNovem (2005). *Windkaart van Nederland op 100 m hoogte***.** Arnhem.

Sociaal-Economische Raad (SER) (2013). *Energieakkoord voor duurzame groei*. 6 september 2013. The Hague.

Staatscourant (2002). *Beleidsregel voor het plaatsen van windturbines op, in of over rijkswaterstaatswerken.* Staatscourant, No. 123, pp. 13.

Stoutenburg, E. (n.d.). *Combining offshore wind and wave energy farms to facilitate grid integration of variable renewables*. Stanford University.

TenneT (2014). *Wonen nabij hoogspanning*. Online researched at 13-09-2014 at: <http://www.tennet.eu/nl/nl/net-projecten/hoogspanning-en-omgeving/wonen-nabij-hoogspanning.html>

Tindal, A., Landberg, L. (2008). Wind Power in Forests. Garrad Hassan, Malmö, Sweden.

TNO (2011). *Quick Urban Energy Scan*. Delft: TNO bouw en ondergrond.

TNO (2014). *ThermoGIS Basic*. Delft. Downloaded at 15-10-2014 at: <http://www.thermogis.nl/basic.html>

Twidell, J., Weir, T. (2006). *Renewable energy sources*. Abingdon: Taylor & Francis.

Union of Concerned Scientists (n.d.). *Benefits of Renewable Energy Use*. Online researched at 13-07-2014 at: <http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/public-benefits-of-renewable.html>

Van den Berg, F., Pedersen, E., Bouma, J., Bakker, R. (2008). *WINDFARMperception – Visual and acoustic impact of wind turbine farms on residents*. FP&-2005-Science-and-Society-20, Specific Support Action, Project no. 044628.

Winkelman, J.E., Kistenkas, F.H., Epe, M.J. (2008). *Ecologische en natuurbeschermingsrechtelijke aspecten van turbines op land*. Alterra, Wageningen.

www.bouwleges.nl (2014). *Analyse Legestarieven.* CalcSoft BV. The Hague. Online researched at 15-06-2014 at: <http://www.bouwleges.nl/Analyse/analyses.aspx>

www.cijfernieuws.nl (2014). *OZB-tarieven Noord-Holland 2014*. Leiden. Online researched at 26-07-2014 at: <http://www.cijfernieuws.nl/ozb-tarieven/noord-holland/ozb-tarieven-2014/>

www.comparemysolar.nl. *Afmetingen zonnepanelen – Hoeveel zonnepanelen passen op mijn dak?* Online researched at 11-07-2014 at: <http://www.comparemysolar.nl/afmetingen-zonnepanelen>

www.hoogspanningsnet.com (2014). *De netkaart van de Benelux in Google Earth*. Online researched at 27-06-2014 at: <http://www.hoogspanningsnet.com/google-earth/standaardnetkaart/>

www.iex.nl (2014). *Obligatie NL 4.00% 2037/01/15.* Online researched at 26-11-2014 at: <http://www.iex.nl/Obligatie-Koers/207585/NL-400-2037-01-15.aspx>

www.innovativesolarfarms.com (2014). *Solar Farm Cost Per Acre*. Online researched at 26-11-2014 at: <http://innovativesolarfarms.com/solar-farm-cost-per-acre>

www.photovoltaic-software.com (2014). *How to calculate the annual solar energy output of a photovoltaic system.* Online researched at 27-06-2014 at: <http://photovoltaic-software.com/PV-solar-energy-calculation.php>

www.pointcarbon.com (2014). Online researched at 27-06-2014 at: <https://www.pointcarbon.com/>

www.pv-magazine.com. *Wind-solar hybrid plants up to twice as efficient*. Online researched at 06-08-2014 at: <http://www.pv-magazine.com/news/details/beitrag/wind-solar-hybrid-plants-up-to-twice-as-efficient_100010997/#axzz3KdtKTpbO>

www.rijksoverheid.nl (2014). *Europa 2020*. Online researched at 14-08-2014 at: <http://www.rijksoverheid.nl/onderwerpen/europese-unie/europa-2020>

www.rijksoverheid.nl (2014). *Belastingen voor ondernemers – vennootschapsbelasting*. Online researched at 26-07-2014 at: <http://www.rijksoverheid.nl/onderwerpen/belastingen-voor-ondernemers/vennootschapsbelasting>

Appendix

The appendix contains additional information and data that is used for this research.

Appendix I Data description suitability map

Legislation: wind turbine allowance, if not allowed then permission is required by the authorities and an additional independent research has to be conducted. All data is open data from the province of North-Holland, except the BAG data. BAG data is open data from the Kadaster, Netherlands (Kadaster, 2104a). All data is in RD New projection.

Table 11 List of data used in the suitability map.

Name	Data format	Description	Legislation
BAG data	Shapefile polygon	*Basisregistraties Adressen en Gebouwen.* All buildings in province of North-Holland	Buildings per hectare: ≤2 buffer 50 meters >2 buffer 400 meters
DPDATA_WKK_PROVINCIALE_MONUMENTEN	Shapefile polygon	Provincial monuments	Not allowed
DPDATA_aardkundige_monumenten	Shapefile polygon	Geological monuments	Not allowed
DPDATA_aardkundige_waarden	Shapefile polygon	Geological interesting areas	Additional research required
DPDATA_WKK_NATIONAAL_LANDSCHAP	Shapefile polygon	National important landscapes	Not allowed
DPDATA_stiltegebieden	Shapefile polygon	Areas where the sound level has to below 40 decibel	Additional research required
DPDATA_WKK_UNESCO	Shapefile polygon	Landscapes on the UNESCO heritage list	Not allowed
STRUCTUURVISIE_lands_noorderijdijk	Shapefile polygon	Monumental dike: *Noorderijdijk*	Not allowed
STRUCTUURVISIE_lands_zuiderijdijk	Shapefile polygon	Monumental dike: *Zuiderijdijk*	Not allowed
STRUCTUURVISIE_lands_hondsbossche	Shapefile polygon	Flood defense system	Not allowed
STRUCTUURVISIE_lands_westfriesomring	Shapefile polygon	Monumental dike: *Westfriese Omringdijk*	Not allowed
STRUCTUURVISIE_lands_stelling_dh	Shapefile polygon	Protected area: *Stelling Den Helder*	Not allowed
STRUCTUURVISIE_lands_wierdijk	Shapefile polygon	Monumental dike: *Wierdijk*	Not allowed
STRUCTUURVISIE_recr_zuiderzeeplaats	Shapefile points	Recreational areas close to the *IJsselmeer*	Buffer 50 meters
STRUCTUURVISIE_recr_stelling	Shapefile polygon	Recreational areas *Stelling van Amsterdam*	Not allowed within and buffer 50 meters around
STRUCTUURVISIE_recr_stelling_fort	Shapefile points	Recreational areas with fortresses of the *Stelling van Amsterdam*	Buffer 50 meters

STRUCTUURVISIE_recr_rijksbuffer	Shapefile polygon	Large recreational areas intended to limit development and to preserve green areas	Not allowed within and buffer 50 meters around
STRUCTUURVISIE_recr_linie_fort	Shapefile points	Recreational area	Buffer 50 meters
STRUCTUURVISIE_recr_linie	Shapefile polygon	Large recreational area between Utrecht and Amsterdam	Not allowed within and buffer 50 meters around
STRUCTUURVISIE_nat_weidevogel	Shapefile polygon	Natural areas for meadow birds	Not allowed
STRUCTUURVISIE_nat_ehs	Shapefile polygon	Natural areas	Not allowed
STRUCTUURVISIE_nat_nat_park	Shapefile polygon	National park	Not allowed
STRUCTUURVISIE_nat_eco_verb	Shapefile polygon	Natural areas	Not allowed
STRUCTUURVISIE_nat_natura2000	Shapefile polygon	Natural areas	Not allowed
STRUCTUURVISIE_sign_mvkk_naderingsfunnel	Shapefile polygon	Radar system navy *Den Helder*	Not allowed
DPDATA_risico_aanvliegroutes	Shapefile line	Fly zone international airport *Schiphol*	Not allowed
STRUCTUURVISIE_sign_mvkk_radar	Shapefile polygon	Radar system navy *Den Helder*	Not allowed
STRUCTUURVISIE_water_prim	Shapefile polygon	Important waterways	Buffer 50 meters
DPDATA_vaarroutes_staande_mast	Shapefile polygon	Important waterways	Buffer 50 meters
STRUCTUURVISIE_tot_waterstructuur	Shapefile polygon	Water bodies on land	Not allowed
STRUCTUURVISIE_verk_weg_rijk	Shapefile line	National highways	Buffer 50 meters
STRUCTUURVISIE_verk_spoor	Shapefile line	National railroads	Buffer 57.85 meters

Appendix II Transformer stations

The complete list of included transformer station with their name, location and power voltages.

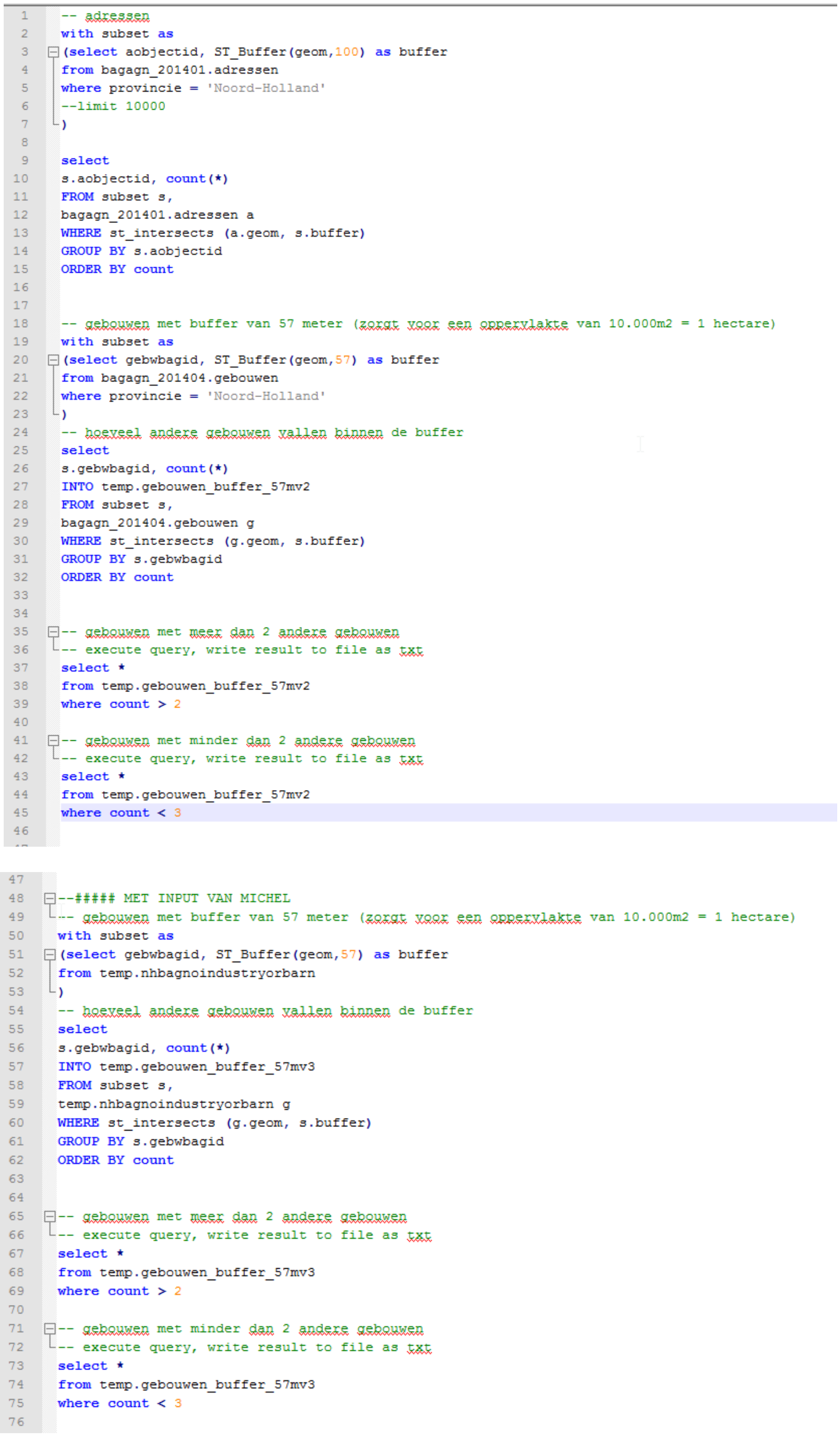
Table 12 The complete list of included transformer stations.

Name	Latitude	Longitude	Power
Wijdewormer	52°30'28,57"N	4°54'23,36"E	50/150kV
Gasunie Balcton Bogzand	52°52'34,89"N	4°46'24,29"E	150kV
Anna Paulowna	52°52'49,17"N	4°46'31,06"E	50/150kV
ECW Wieringermeer	52°46'28,86"N	5°03'39,41"E	150kV
Westwoud	52°41'47,12"N	5°06'58,15"E	50/150kV
Oterleek	52°37'59,88"N	4°50'10,45"E	50/150kV
TAQA Boekelermeer	52°35'49,24"N	4°45'01,62"E	150kV
Beverwijk	52°28'25,53"N	4°40'46,90"E	150kV
Velsen	52°28'14,85"N	4°37'51,28"E	150kV
Nuon Velsen	52°28'17,39"N	4°38'02,73"E	150kV
Velsen IJM1	52°28'24,21"N	4°37'53,89"E	150kV
TATA Zeestraat	52°29'27,49"N	4°37'47,56"E	50/150kV
TATA HVS23	52°29'05,79"N	4°36'38,32"E	50/150kV
TATA HVS20	52°28'48,99"N	4°35'29,43"E	50/150kV
NoordZeeWind	52°29'06,78"N	4°35'05,09"E	150kV
Waarderpolder	52°23'38,03"N	4°39'51,28"E	150kV
Vijfhuizen	52°22'27,29"N	4°41'50,59"E	50/150kV
Haarlemmermeer	52°18'41,55"N	4°38'35,41"E	150kV
Nieuwe Meer	52°20'12,33"N	4°48'47,85"E	50/150kV
Amstelveen	52°17'29,36"N	4°52'58,12"E	50/150kV
Bijlmer Noord	52°18'58,49"N	4°55'55,28"E	150kV
Bijlmer Zuid	52°17'42,98"N	4°56'52,64"E	150kV
Zorgvlied	52°20'11,19"N	4°53'17,23"E	50/150kV
Venserweg	52°19'59,83"N	4°57'56,09"E	150kV
s-Graveland	52°15'33,30"N	5°07'16,64"E	50/150kV
Diemen	52°20'16,60"N	5°00'57,01"E	150kV
Watergraafsmeer	52°21'17,63"N	4°57'46,10"E	150kV
Hoogte Kadijk	52°22'03,20"N	4°55'10,18"E	50/150kV
Oostzaan	52°25'42,86"N	4°52'34,53"E	150kV
Hemweg HW7	52°24'18,65"N	4°50'50,70"E	150kV
Hemweg	52°24'09,83"N	4°50'51,25"E	50/150kV
Papaverweg	52°23'53,66"N	4°54'11,91"E	50/150kV
Klaproosweg	52°24'05,40"N	4°54'11,84"E	150kV
Texel	53°03'02,55"N	4°48'13,29"E	50kV
De Schooten	52°55'52,85"N	4°46'00,47"E	50kV
NAM Anna Paulowna	52°55'29,57"N	4°47'29,09"E	50kV
Ulkesluis	52°51'46,36"N	4°54'23,23"E	50kV
Schagen	52°46'54,99"N	4°48'41,05"E	50kV
Warmerhuizen	52°42'30,78"N	4°44'15,99"E	50kV
Heerhugowaard	52°40'46,06"N	4°50'10,88"E	50kV

Hoogwoud	52°42'50,96"N	4°55'29,84"E	50kV
ECN	52°49'01,62"N	5°04'43,39"E	50kV
Medemblik	52°46'03,82"N	5°06'15,15"E	50kV
Wervershoof	52°43'10,26"N	5°10'42,07"E	50kV
Enkhuizen	52°41'42,55"N	5°16'29,23"E	50kV
Holenweg	52°38'53,96"N	5°04'38,68"E	50kV
Geldelozeweg	52°39'02,49"N	5°03'02,47"E	50kV
Heiloo	52°35'25,43"N	4°42'24,15"E	50kV
Alkmaar	52°38'11,78"N	4°44'42,56"E	50kV
Edam	52°30'46,94"N	5°02'23,93"E	50kV
WKK Purmerend	52°30'57,91"N	4°59'43,70"E	50kV
Uitgeest	52°31'21,58"N	4°42'09,00"E	50kV
Krommenie	52°29'50,89"N	4°46'32,00"E	50kV
Wormerveer	52°29'17,48"N	4°48'27,50"E	50kV
Zaandijk	52°28'15,69"N	4°49'38,61"E	50kV
Zaandam Noord	52°27'31,21"N	4°49'00,10"E	50kV
Zaandam West	52°25'55,14"N	4°49'13,56"E	50kV
Ruigoord	52°24'31,49"N	4°44'42,60"E	50kV
Basisweg	52°23'23,02"N	4°48'52,29"E	50kV
AVI	52°24'03,54"N	4°47'00,69"E	50kV
Vliegenbos	52°23'14,93"N	4°55'50,74"E	50kV
Weesp	52°18'03,39"N	5°01'59,80"E	50kV
Jonkerweg	52°13'41,80"N	5°09'29,98"E	50kV
Naarden	52°17'07,20"N	5°09'42,16"E	50kV
Crailoo	52°15'29,51"N	5°12'22,50"E	50kV
Uithoorn	52°14'20,40"N	4°49'46,81"E	50kV
Hoofddorp	52°18'25,15"N	4°41'24,04"E	50kV
Rozenburg NH	52°16'55,75"N	4°44'17,72"E	50kV
Nieuw-Vennep	52°16'28,83"N	4°38'11,20"E	50kV
Heemstede	52°20'32,22"N	4°38'06,63"E	50kV
Ijmuiden	52°27'17,99"N	4°35'42,23"E	50kV
Overveen	52°23'42,30"N	4°37'29,59"E	50kV

Appendix III PostgreSQL script

This PostgreSQL script constructs a buffer, with a surface area of one hectare, around each residential building (BAG polygon). Then it counts the amount of buildings within the buffer around each building, including itself. It separates the data set into two CSV files: one file with residential buildings that have a count of one or two buildings; and a file with a count of more than two buildings. These CSV files are input for the FME workflow in **appendix III.**

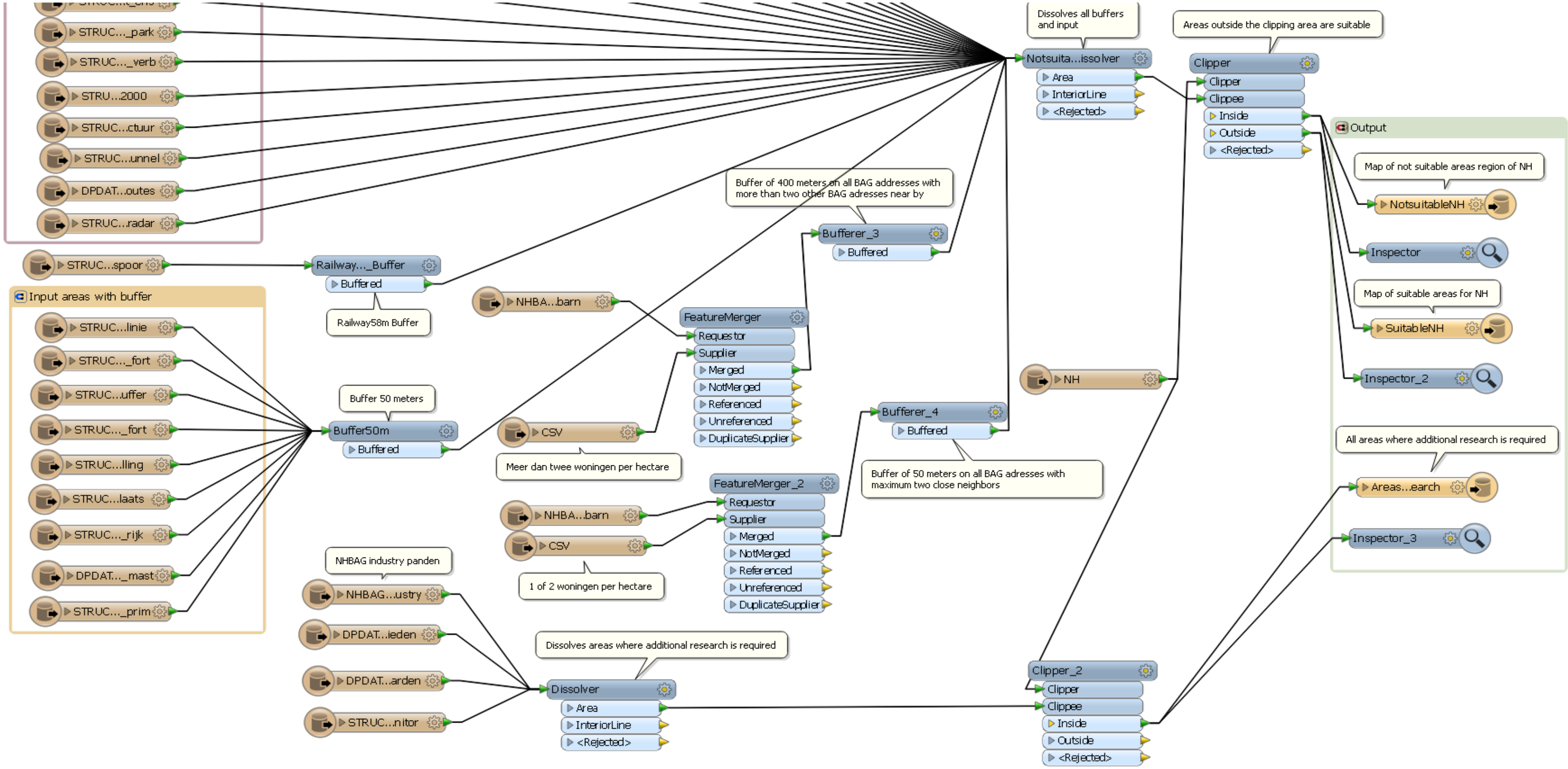


```
-- adressen
with subset as
(select aobjectid, ST_Buffer(geom,100) as buffer
from bagagn_201401.adressen
where provincie = 'Noord-Holland'
--limit 10000
)

select
s.aobjectid, count(*)
FROM subset s,
bagagn_201401.adressen a
WHERE st_intersects (a.geom, s.buffer)
GROUP BY s.aobjectid
ORDER BY count


-- gebouwen met buffer van 57 meter (zorgt voor een oppervlakte van 10.000m2 = 1 hectare)
with subset as
(select gebwbagid, ST_Buffer(geom,57) as buffer
from bagagn_201404.gebouwen
where provincie = 'Noord-Holland'
)
-- hoeveel andere gebouwen vallen binnen de buffer
select
s.gebwbagid, count(*)
INTO temp.gebouwen_buffer_57mv2
FROM subset s,
bagagn_201404.gebouwen g
WHERE st_intersects (g.geom, s.buffer)
GROUP BY s.gebwbagid
ORDER BY count


-- gebouwen met meer dan 2 andere gebouwen
-- execute query, write result to file as txt
select *
from temp.gebouwen_buffer_57mv2
where count > 2

-- gebouwen met minder dan 2 andere gebouwen
-- execute query, write result to file as txt
select *
from temp.gebouwen_buffer_57mv2
where count < 3


--##### MET INPUT VAN MICHEL
-- gebouwen met buffer van 57 meter (zorgt voor een oppervlakte van 10.000m2 = 1 hectare)
with subset as
(select gebwbagid, ST_Buffer(geom,57) as buffer
from temp.nhbagnoindustryorbarn
)
-- hoeveel andere gebouwen vallen binnen de buffer
select
s.gebwbagid, count(*)
INTO temp.gebouwen_buffer_57mv3
FROM subset s,
temp.nhbagnoindustryorbarn g
WHERE st_intersects (g.geom, s.buffer)
GROUP BY s.gebwbagid
ORDER BY count


-- gebouwen met meer dan 2 andere gebouwen
-- execute query, write result to file as txt
select *
from temp.gebouwen_buffer_57mv3
where count > 2

-- gebouwen met minder dan 2 andere gebouwen
-- execute query, write result to file as txt
select *
from temp.gebouwen_buffer_57mv3
where count < 3

```

Figure 26 PostgreSQL script.

Appendix IV FME workflow

This is the FME workflow that has **appendix I and appendix II** as input data. There are three different output files: unsuitable areas, suitable areas and areas where extra research is required. It constructs buffers around all the input data according to the regulations stated in **appendix I**. It dissolves the buffers into one large shapefile for the unsuitable areas and one large shapefile the areas with extra research. The suitable areas are extracted from these two shapefiles.



Dissolves all buffers and input

Areas outside the clipping area are suitable

Buffer of 400 meters on all BAG addresses with more than two other BAG adresses near by

Railway58m Buffer

Buffer 50 meters

Meer dan twee woningen per hectare

Map of not suitable areas region of NH

Map of suitable areas for NH

All areas where additional research is required

Buffer of 50 meters on all BAG adresses with maximum two close neighbors

1 of 2 woningen per hectare

NHBAG industry panden

Dissolves areas where additional research is required

Figure 27 FME workflow for the suitability map.

Appendix V ArcGIS model net present value

This is the model that is used for the net present value analysis in ArcGIS model builder. The blue balloons are the input data, which are all the costs and benefits specified in **chapter 4** and the transmission line costs**.** The yellow balloons are the equations, which are shown below the figure. These raster calculators compute the net present value for each year (the green balloons). All these years are summed up in Raster Calculator (21) and the transmission line costs are subtracted. The net present value map is the green balloon on the right.

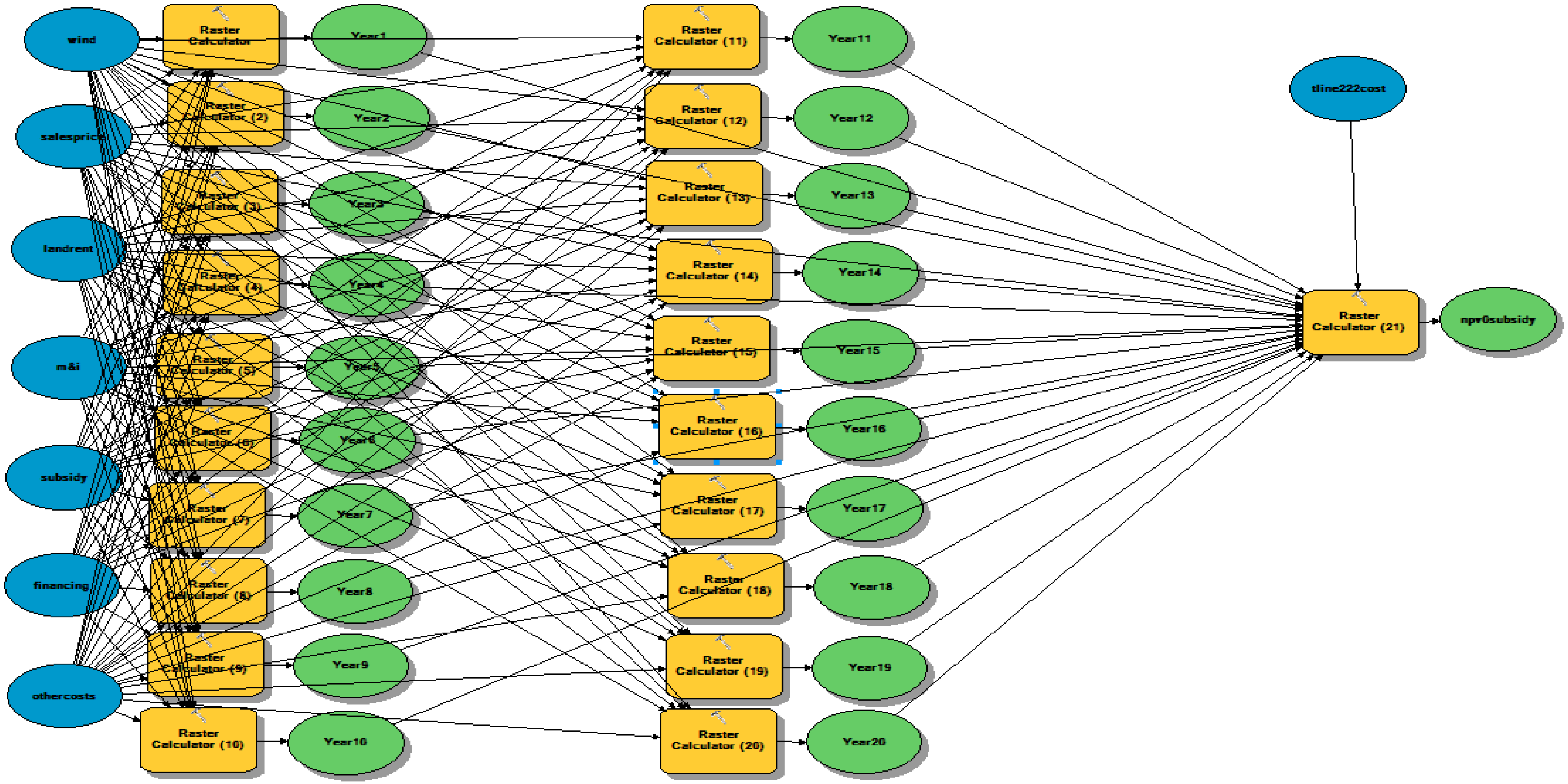


Figure 28 ArcGIS model of the net present value analysis.

This is the equation of Raster Calculator (10) from the figure above. It shows how the equation looks like for year 10. The equations for years 1 till 15 look similar.

("%wind%" * ("%salesprice%" * Power(1.022, 10) - "%landrent%" - "%m&i%" * Power(1.022, 10)) + "%subsidy%" - "%financing%" - "%othercosts%" * Power(1.022, 10)) - (Con (("%wind%" * ("%salesprice%" * Power(1.022, 10) - "%landrent%" - "%m&i%" * Power(1.022, 10)) + "%subsidy%" - "%financing%" - "%othercosts%" * Power(1.022, 10)) <= 0, 0, Con ((("%wind%" * ("%salesprice%" * Power(1.022, 10) - "%landrent%" - "%m&i%" * Power(1.022, 10)) + "%subsidy%" - "%financing%" - "%othercosts%" * Power(1.022, 10)) >0) & (("%wind%" * ("%salesprice%" * Power(1.022, 10) - "%landrent%" - "%m&i%" * Power(1.022, 10)) + "%subsidy%" - "%financing%" - "%othercosts%" * Power(1.022, 10)) <= 200000 * Power(1.022, 10)), (("%wind%" * ("%salesprice%" * Power(1.022, 10) - "%landrent%" - "%m&i%" * Power(1.022, 10)) + "%subsidy%" - "%financing%" - "%othercosts%" * Power(1.022, 10)) * 0.2), Con (("%wind%" * ("%salesprice%" * Power(1.022, 10) - "%landrent%" - "%m&i%" * Power(1.022, 10)) + "%subsidy%" - "%financing%" - "%othercosts%" * Power(1.022, 10)) > 200000 * Power(1.022, 10), ((("%wind%" * ("%salesprice%" * Power(1.022, 10) - "%landrent%" - "%m&i%" * Power(1.022, 10)) + "%subsidy%" - "%financing%" - "%othercosts%" * Power(1.022, 10)) - 200000 * Power(1.022, 10)) * 0.25 + 40000 * Power(1.022, 10)))))) / Power(1.05, 10)

This is the equation of Raster Calculator (16) from the figure above. In the years 16 till 20 the subsidies and financing costs drop out from the equation.

("%wind%" * ("%salesprice%" * Power(1.022, 16) - "%landrent%" - "%m&i%" * Power(1.022, 16)) - "%othercosts%" * Power(1.022, 16)) - (Con (("%wind%" * ("%salesprice%" * Power(1.022, 16) - "%landrent%" - "%m&i%" * Power(1.022, 16)) - "%othercosts%" * Power(1.022, 16)) <= 0, 0, Con ((("%wind%" * ("%salesprice%" * Power(1.022, 16) - "%landrent%" - "%m&i%" * Power(1.022, 16)) - "%othercosts%" * Power(1.022, 16)) >0) & (("%wind%" * ("%salesprice%" * Power(1.022, 16) - "%landrent%" - "%m&i%" * Power(1.022, 16)) - "%othercosts%" * Power(1.022, 16)) <= 200000 * Power(1.022, 16)), (("%wind%" * ("%salesprice%" * Power(1.022, 16) - "%landrent%" - "%m&i%" * Power(1.022, 16)) - "%othercosts%" * Power(1.022, 16)) * 0.2), Con (("%wind%" * ("%salesprice%" * Power(1.022, 16) - "%landrent%" - "%m&i%" * Power(1.022, 16)) - "%othercosts%" * Power(1.022, 16)) > 200000 * Power(1.022, 16), ((("%wind%" * ("%salesprice%" * Power(1.022, 16) - "%landrent%" - "%m&i%" * Power(1.022, 16)) - "%othercosts%" * Power(1.022, 16)) - 200000 * Power(1.022, 16)) * 0.25 + 40000 * Power(1.022, 16)))))) / Power(1.05, 16)

This is the equation of Raster Calculator (21) from the figure above. The equation above is performed for twenty years. All the years are summed up and the grid costs are subtracted.

("%Year1%" + "%Year2%" + "%Year3%" + "%Year4%" + "%Year5%" + "%Year6%" + "%Year7%" + "%Year8%" + "%Year9%" + "%Year10%" + "%Year11%" + "%Year12%" + "%Year13%" + "%Year14%" + "%Year15%" + "%Year16%" + "%Year17%" + "%Year18%" + "%Year19%" + "%Year20%") - "%tline222cost%"

Appendix VI Sensitivity analysis

The ten maps below show the net present value if one of the factors is changed. The net present value is per wind turbine, which is part of a wind park of 18 turbines. The first two maps give the net present value if the subsidies decrease by 50% and 100%.

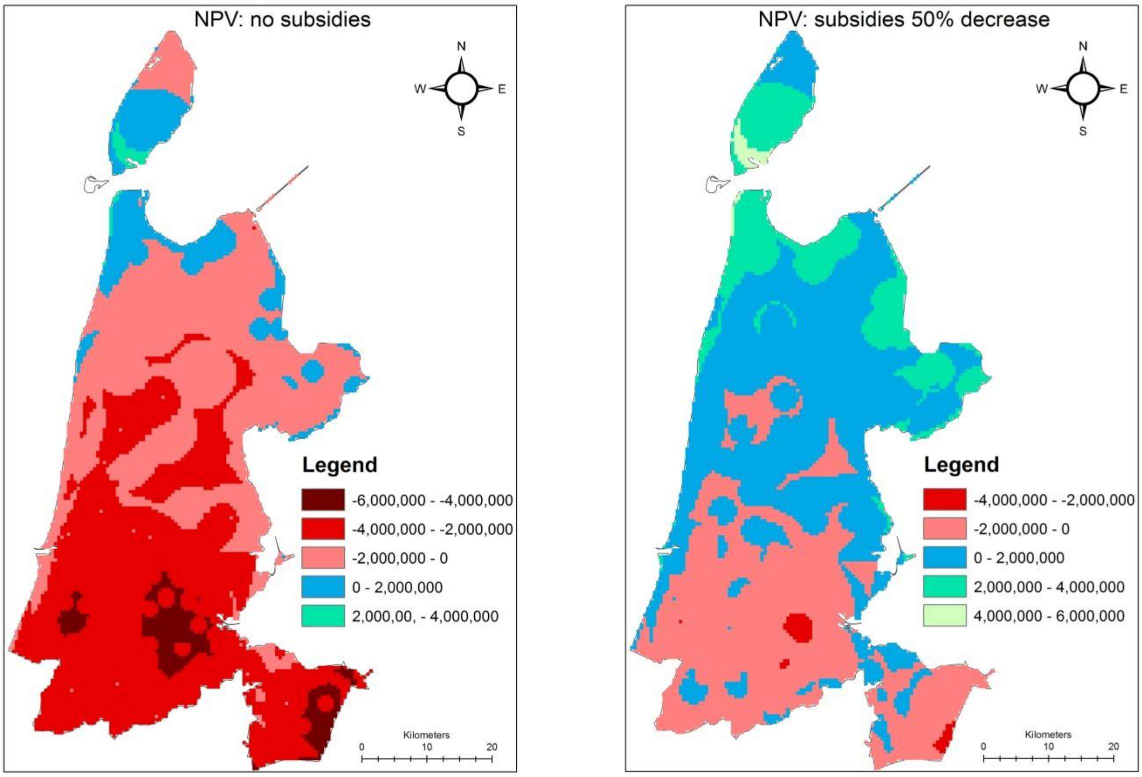


Figure 29a & 29b Effect of no subsidies and a decrease in subsidies by 50%.

These four maps have also a negative impact on the net present value: Investment costs increase by 50%; Other costs plus the maintenance and insurance costs and land rent combined increase by 50%; Energy sales price declines by 50%; And the average wind speed goes down by 50%.

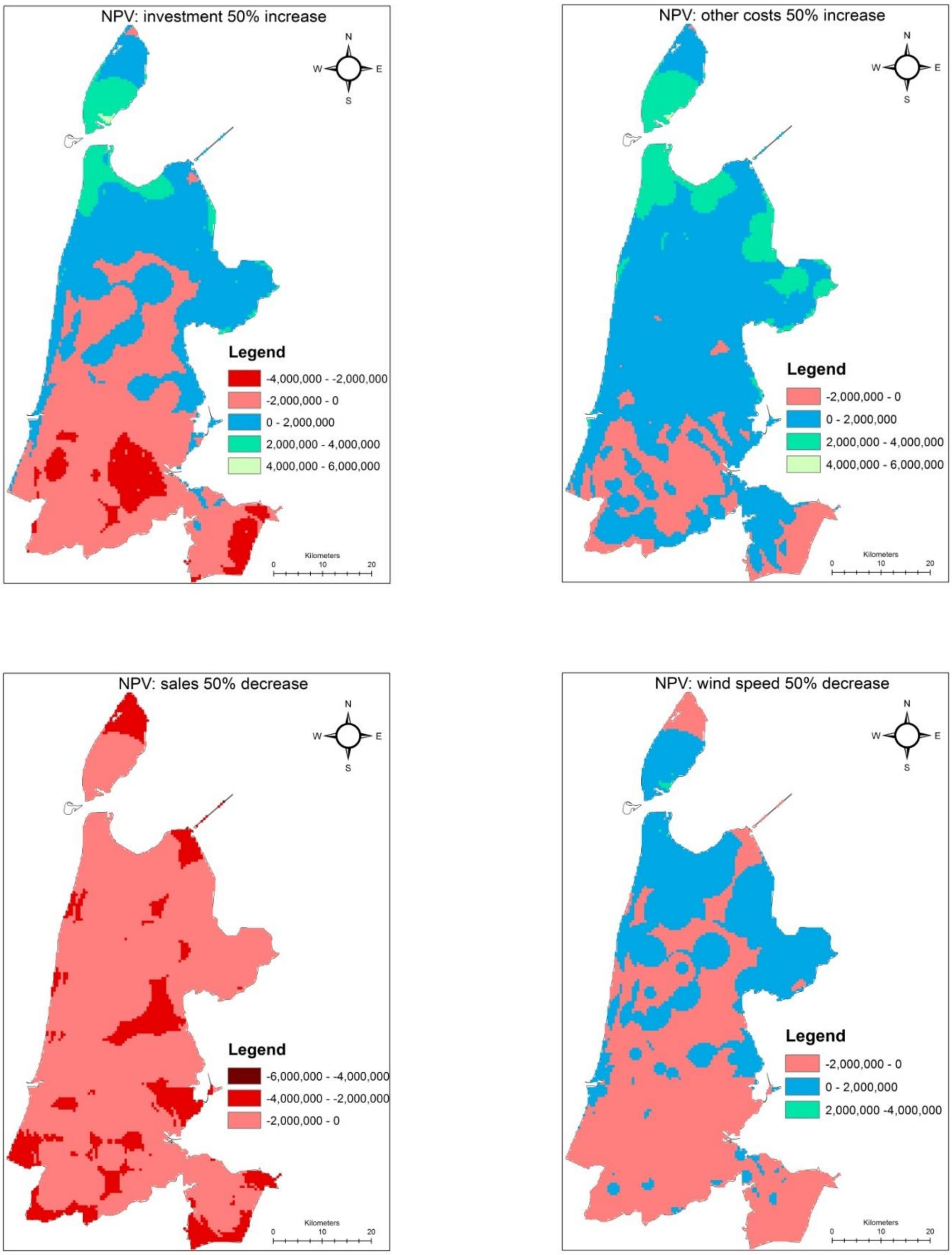


Figure 30a, 30b, 30c & 30d Effect of a decrease in investment costs by 50%, other costs by 50%, sales by 50% and wind speed by 50%.

These four maps have a positive effect on the net present value: Investment costs decrease by 50%; Other costs plus the maintenance and insurance costs and land rent combined decrease by 50%; Energy sales price rises by 50%; And the average wind speed moves up by 50%.

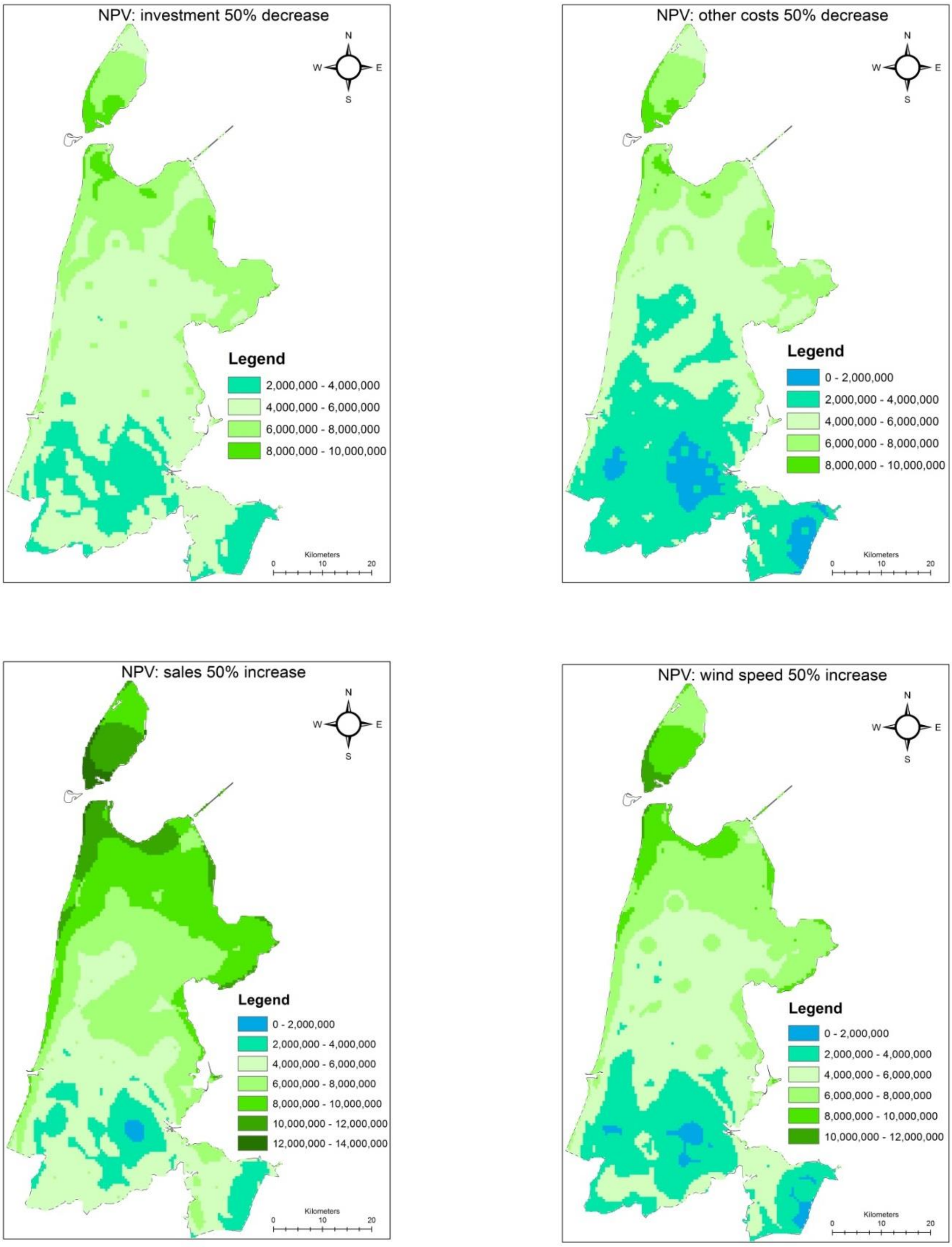


Figure 31a, 31b, 31c & 31d Effect of an increase in investment costs by 50%, other costs by 50%, sales by 50% and wind speed by 50%.

Appendix VII KNMI Data

This is the output of the SPSS software with the KNMI data set. The data set is downloadable **from XXX**. In SPSS the mean, standard deviation and correlation are calculated. First the outcome per month is given and after that the outcome per hour.

VII-1 Scatterplots monthly data

It is reasonable to assume that in summer solar radiation is high and in winter average wind speed is high. This suggests a non-linear relationship for the monthly data. That is why this three scatterplots are given. However, it shows that the relationship between radiation and wind speed is equally described by a linear, exponential or natural logarithm regression.

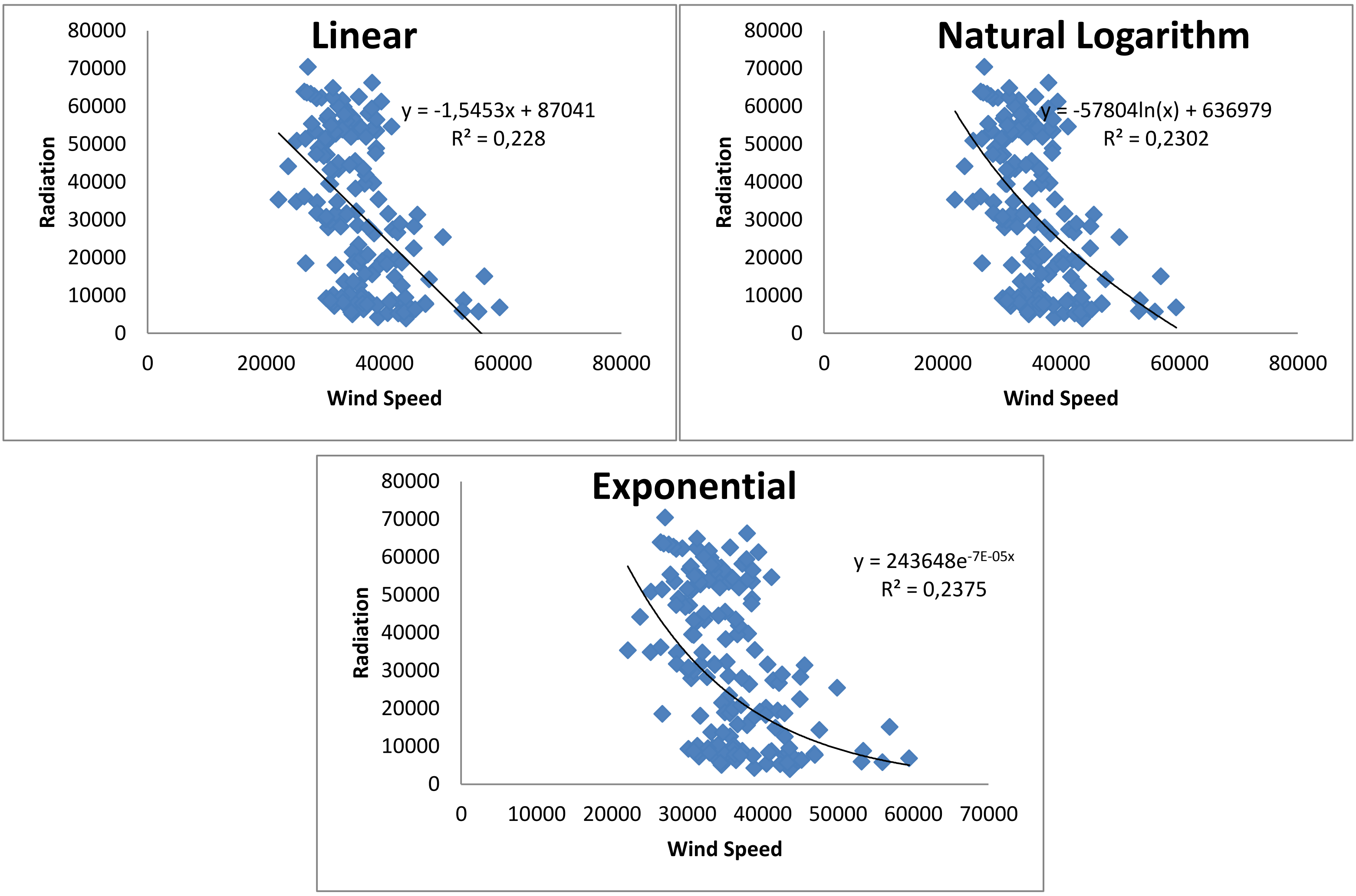


Figure 32a, 32b & 32c Scatterplots of monthly data with different trend lines.

VII-2 Descriptive statistics

The following tables show the mean, standard deviation and sample size per month and per hour respectively. The mean wind speed is meaningless, because of the summing up of average wind speeds. Please note Dutch notation: Commas are dots in English.

Table 13 Descriptive statistics per month. Data source: KNMI, 2014.

Month		Mean	Std. Deviation	N
January	Wind speed	43729,29	8118,16	14
	Radiation	7572,43	1004,37	14
February	Wind speed	38291,43	7151,28	14
	Radiation	12889,36	2694,48	14
March	Wind speed	40391,43	5473,29	14
	Radiation	27890,86	3561,43	14
April	Wind speed	34047,14	3327,02	14
	Radiation	45360,79	5529,83	14
May	Wind speed	36205,00	2887,75	14
	Radiation	57405,64	3909,44	14
June	Wind speed	32080,71	3375,25	14
	Radiation	59197,86	4183,74	14
July	Wind speed	31620,00	3408,02	14
	Radiation	57657,14	6269,82	14
August	Wind speed	29798,57	3351,88	14
	Radiation	47722,29	4700,57	14
September	Wind speed	30642,86	4345,83	14
	Radiation	32215,64	2924,65	14
October	Wind speed	37004,29	4406,05	14
	Radiation	19072,50	1990,29	14
November	Wind speed	35607,86	4775,03	14
	Radiation	8141,64	782,67	14
December	Wind speed	40107,14	5634,65	14
	Radiation	5628,43	839,07	14

Table 14 Descriptive statistics per hour. Data source: KNMI, 2014.

Hours		Mean	Std. Deviation	N		Hours		Mean	Std. Deviation	N
1	Wind speed	42,24	26,03	5114		13	Wind speed	60,67	27,202	5114
	Radiation	0	0	5114			Radiation	129,63	90,19	5114
2	Wind speed	42,09	25,975	5114		14	Wind speed	60,58	27,05	5114
	Radiation	0	0	5114			Radiation	116,85	85,772	5114
3	Wind speed	41,89	26,011	5114		15	Wind speed	59,18	26,541	5114
	Radiation	0	0	5114			Radiation	94,93	78,267	5114
4	Wind speed	41,62	25,966	5114		16	Wind speed	56,83	25,867	5114
	Radiation	0,27	0,829	5114			Radiation	68,7	66,631	5114
5	Wind speed	41,92	25,912	5114		17	Wind speed	53,64	25,532	5114
	Radiation	3,97	7,893	5114			Radiation	43,05	49,616	5114
6	Wind speed	43,05	26,093	5114		18	Wind speed	50,3	25,325	5114
	Radiation	14,34	22,007	5114			Radiation	22,12	30,662	5114
7	Wind speed	45,54	25,946	5114		19	Wind speed	47,18	25,32	5114
	Radiation	32,52	40,127	5114			Radiation	7,95	13,869	5114
8	Wind speed	48,58	25,928	5114		20	Wind speed	44,58	25,934	5114
	Radiation	56,43	57,982	5114			Radiation	1,19	2,794	5114
9	Wind speed	51,8	26,33	5114		21	Wind speed	43,38	26,406	5114
	Radiation	83,23	71,696	5114			Radiation	0	0,024	5114
10	Wind speed	54,97	26,765	5114		22	Wind speed	42,89	26,438	5114
	Radiation	108,04	81,426	5114			Radiation	0	0	5114
11	Wind speed	57,78	27,051	5114		23	Wind speed	42,72	26,198	5114
	Radiation	125,5	87,745	5114			Radiation	0	0	5114
12	Wind speed	59,93	27,114	5114		24	Wind speed	42,5	26,201	5114
	Radiation	133,61	90,884	5114			Radiation	0	0	5114

VII-3 Correlation

The tables below give the Pearson, Kendall’s Tau and Spearman’s Rho correlation and their significance per month and per hour respectively. Please note Dutch notation: Commas are dots in English.

Table 15 Pearson, Kendall’s tau and Spearman’s rho correlation for the monthly data. Data source: KNMI, 2014.

January	Pearson Correlation	-0,286	July	Pearson Correlation	-0,286
	Sig. (2-tailed)	0,322		Sig. (2-tailed)	0,322
	Kendall’s tau_b	-0,209		Kendall’s tau_b	-0,231
	Sig. (2-tailed)	0,298		Sig. (2-tailed)	0,250
	Spearman’s rho	-0,305		Spearman’s rho	-0,345
	Sig. (2-tailed)	0,288		Sig. (2-tailed)	-0,227
February	Pearson Correlation	-0,286	August	Pearson Correlation	-0,286
	Sig. (2-tailed)	0,322		Sig. (2-tailed)	0,322
	Kendall’s tau_b	0,077		Kendall’s tau_b	-0,319
	Sig. (2-tailed)	0,702		Sig. (2-tailed)	0,112
	Spearman’s rho	0,138		Spearman’s rho	-0,495
	Sig. (2-tailed)	0,637		Sig. (2-tailed)	0,072
March	Pearson Correlation	-0,286	September	Pearson Correlation	-0,286
	Sig. (2-tailed)	0,322		Sig. (2-tailed)	0,322
	Kendall’s tau_b	-0,253		Kendall’s tau_b	-0,297
	Sig. (2-tailed)	0,208		Sig. (2-tailed)	0,139
	Spearman’s rho	-0,376		Spearman’s rho	-0,376
	Sig. (2-tailed)	0,185		Sig. (2-tailed)	0,185
April	Pearson Correlation	-0,286	October	Pearson Correlation	-0,286
	Sig. (2-tailed)	0,322		Sig. (2-tailed)	0,322
	Kendall’s tau_b	-0,077		Kendall’s tau_b	-0,143
	Sig. (2-tailed)	0,702		Sig. (2-tailed)	0,477
	Spearman’s rho	-0,108		Spearman’s rho	-0,187
	Sig. (2-tailed)	0,714		Sig. (2-tailed)	0,523
May	Pearson Correlation	-0,286	November	Pearson Correlation	-0,286
	Sig. (2-tailed)	0,322		Sig. (2-tailed)	0,322
	Kendall’s tau_b	0,121		Kendall’s tau_b	-0,363
	Sig. (2-tailed)	0,547		Sig. (2-tailed)	0,071
	Spearman’s rho	0,143		Spearman’s rho	-0,451
	Sig. (2-tailed)	0,626		Sig. (2-tailed)	0,106
June	Pearson Correlation	-0,286*	December	Pearson Correlation	-0,286
	Sig. (2-tailed)	0,322		Sig. (2-tailed)	0,322
	Kendall’s tau_b	-0,560**		Kendall’s tau_b	-0,143
	Sig. (2-tailed)	0,005		Sig. (2-tailed)	0,477
	Spearman’s rho	-0,675**		Spearman’s rho	-0,169
	Sig. (2-tailed)	0,008		Sig. (2-tailed)	0,563

* Correlation significant at the 0.05 level

** Correlation significant at the 0.01 level

Table 16 Pearson, Kendall's tau and Spearman's rho correlation for the hourly data. Data source: KNMI, 2014.

1	Pearson Correlation	NA	13	Pearson Correlation	-0,047**
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,001
	Kendall's tau_b	NA		Kendall's tau_b	-0,019
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,050
	Spearman's rho	NA		Spearman's rho	-0,027
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,051
2	Pearson Correlation	NA	14	Pearson Correlation	-0,024
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,080
	Kendall's tau_b	NA		Kendall's tau_b	-0,002
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,810
	Spearman's rho	NA		Spearman's rho	-0,003
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,805
3	Pearson Correlation	NA	15	Pearson Correlation	0,015
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,277
	Kendall's tau_b	NA		Kendall's tau_b	0,026**
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,009
	Spearman's rho	NA		Spearman's rho	0,035**
	Sig. (2-tailed)	NA		Sig. (2-tailed)	0,011
4	Pearson Correlation	-0,159**	16	Pearson Correlation	0,047**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,001
	Kendall's tau_b	-0,150**		Kendall's tau_b	0,054**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
	Spearman's rho	-0,177**		Spearman's rho	0,075**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
5	Pearson Correlation	-0,217**	17	Pearson Correlation	0,046**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,001
	Kendall's tau_b	-0,202**		Kendall's tau_b	0,058**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
	Spearman's rho	-0,251**		Spearman's rho	0,078**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
6	Pearson Correlation	-0,221**	18	Pearson Correlation	0,011
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,418
	Kendall's tau_b	-0,205**		Kendall's tau_b	0,020
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,054
	Spearman's rho	-0,268**		Spearman's rho	0,024
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,080

7	Pearson Correlation	-0,158**	19	Pearson Correlation	-0,058**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
	Kendall’s tau_b	-0,128**		Kendall’s tau_b	-0,048**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
	Spearman’s rho	-0,175**		Spearman’s rho	-0,064**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
8	Pearson Correlation	-0,121**	20	Pearson Correlation	-0,110**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
	Kendall’s tau_b	-0,081**		Kendall’s tau_b	-0,095**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
	Spearman’s rho	-0,114**		Spearman’s rho	-0,115**
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,000
9	Pearson Correlation	-0,108**	21	Pearson Correlation	-0,015
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,273
	Kendall’s tau_b	-0,068**		Kendall’s tau_b	-0,015
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,224
	Spearman’s rho	-0,096**		Spearman’s rho	-0,017
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	0,224
10	Pearson Correlation	-0,090**	22	Pearson Correlation	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA
	Kendall’s tau_b	-0,052**		Kendall’s tau_b	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA
	Spearman’s rho	-0,073**		Spearman’s rho	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA
11	Pearson Correlation	-0,082**	23	Pearson Correlation	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA
	Kendall’s tau_b	-0,044**		Kendall’s tau_b	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA
	Spearman’s rho	-0,062**		Spearman’s rho	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA
12	Pearson Correlation	-0,067**	24	Pearson Correlation	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA
	Kendall’s tau_b	-0,033**		Kendall’s tau_b	NA
	Sig. (2-tailed)	0,001		Sig. (2-tailed)	NA
	Spearman’s rho	-0,047**		Spearman’s rho	NA
	Sig. (2-tailed)	0,000		Sig. (2-tailed)	NA

* Correlation significant at the 0.05 level

** Correlation significant at the 0.01 level