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Wind Turbines along highways

Feasibility study of the implementation of small scale wind turbines along the Prins Bernardweg Zaandam to Bolswarderbaan highway in the Netherlands

Keywords: Wind power, small scale wind turbines, traffic turbulence, onshore wind market, wind power development, economics of wind, technological evolution, future prospects, Social Cost-Benefit Analysis

Master Thesis

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Abstract

The Netherlands has the goal to have 14% of the total energy production in 2020 generated in a sustainable way. In order to achieve this goal, onshore wind turbines need to have a combined capacity of 6000 MW and the offshore capacity needs to be increased to 4450 MW. The onshore wind industry is however quite saturated. Experts forecast that the onshore energy target will not be achieved due to the lack of space and heavy conflicts with local residents. Even if the target can be achieved, there is little to no space left for more large wind farms. Fully dedicating and shifting the wind energy development to the offshore sector is not without risk. Social cost benefit analyses show a wide array of different outcomes for the construction of large offshore wind farms. The net results range from losses of 5 billion euros to profits of 12 billion Euros. The Dutch government has decided to continue research and development of Dutch offshore wind projects.

However, instead of completely focusing on the offshore sector, new potential onshore wind solutions could be investigated as well. The small wind turbine industry is also part of the onshore wind sector and has been well developed over the past decades. Over millions of small- and micro turbines are part of the onshore wind industry across the world. Small wind turbines are integrated into buildings or used as wind batteries. One new potential application could be to use the space along highways to install small wind turbines. Both the natural wind as the turbulence created by traffic could feed the generators to provide electricity to the grid or local applications such as street lighting or electric charging stations in the future.

The report investigates the feasibility of this new concept by using the Prins Bernardweg Zaandam to Bolswarderbaan highway in the Netherlands as a virtual case study. The case study analyzes how and if the concept can be constructed and explores the impact of possible implementation. A combined technical-, stakeholder-and social cost benefit approach comprise the most essential components to make a careful assessment and recommendations. Multiple experts and stakeholders participated in interviews to provide expertise and validate information used in the analyses.

The technical analysis showed that using the conventional vertical axis wind turbines from Windside grant accurate, reliable data to be used in the study and no inescapable technolocial barriers to turn up. An important unknown factor remains how the windside turbines affect the air resistance for ongoing traffic. Even though experts indicated that the effect is most likely in the favor of the traffic participants, if the project turns out to increase fuel usage the project cannot be launched. This was the main outcome from the stakeholder analysis, where both representatives from Rijkswaterstaat as the ANWB indicate a no go when drivers face additional travelling costs by driving on a highway filled with wind turbines. When this is not the case, the stakeholder analysis showed that there are no stakeholders who are likely to seriously threaten or influence the project in a negative way. All critical stakeholders can be convinced to support the project or stay neutral. These outcomes would have paved the way for the concept of wind turbines along the highway, if it was not for the social cost benefit analysis showing excessive negative social costs. Even in a best case scenario the net value of the project over

the course of time touches a negative amount of over 700 million euros, with costs of over 3600 euro per Mwh.

The preceeding answers the research question: *To what extent can the concept of converting traffic turbulence and regular wind to useful energy be implemented in the Netherlands?* The answer is that the concept can be fully implemented, but at as for now excessive costs. It should not be implemented yet on a medium- or large scale. Implementing the concept on a small scale could be worthwhile to investigate several matters. First, the effect of traffic passing wind turbines should be investigated. This knowledge can be used to inspire highly customized wind turbines which could potentially be cheaper and more efficient. The research is also needed to replace the assumptions made by the report with empirical evidence. Secondly, the potential reduction of both noise pollution and blinding effects by a row of wind turbines need to be researched. When these effects are substantially positive the use of wind turbines along highways might yet become interesting again. Third, the complete potential of wind capacity along all the highways in the Netherlands needs to be mapped. This provides an indication of the extra capacity that could be installed onshore using this method. In the future this capacity could be called upon when other options turn out to have a more negative net value, or the net value of this concept changes to an acceptable value. The last recommendation is to expand the concept to researching the installment of wind turbines along railroads. The electrical infrastructure is in place and trains come and go when it is not winter time in the Netherlands.

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Chapter 1: Introduction and defining research Problem

1.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) has prepared various climate change reports in the past (Source). These reports provide a scientific framework that points to human activity leading up to the warming of the earth by burning fossil fuels. This eventually led to the Kyoto protocol on the reduction of greenhouse gas emissions (Bohringer, 2003). However, the scientific framework the IPCC delivered has not gone unchallenged. The link between the observed warming of the Earth's surface and increasing concentration of greenhouse gases in the atmosphere is questioned and topic of debate (Harvey, 2000; Gray, 2002). The IPCC claims that the increase in the mean surface temperature of the earth cannot be explained by the natural variability of the atmosphere-ocean system alone.

Skeptics on the IPCC's view state several counter arguments. Urbanization and land-use change could have a stronger impact on the climate than the greenhouse gas emissions(Hansen et al, 2000; Degaetano & Allen, 2002); (Kalney & Cal, 2003). Some scientific studies state that increased CO2 levels in geological times are not linked at all with the increased mean temperature (Viezer, 2000; Shaviv & Viezer, 2003). These arguments, among others, create a strongly dissenting view of the global warming science (Khandekar et al, 2005).

Besides the controversy concerning global warming, the IPCC reports did have considerable impact. Figure 1 shows the capacity growth of wind power installed globally. Since 1996, the release of the first IPCC report, the wind capacity started growing annually. To diminish the effects of climate change, the burning of fossil fuels had to be reduced. Renewable energy sources like wind power started to gain interest, resulting in a remarkable development rate of installed global wind power capacity.

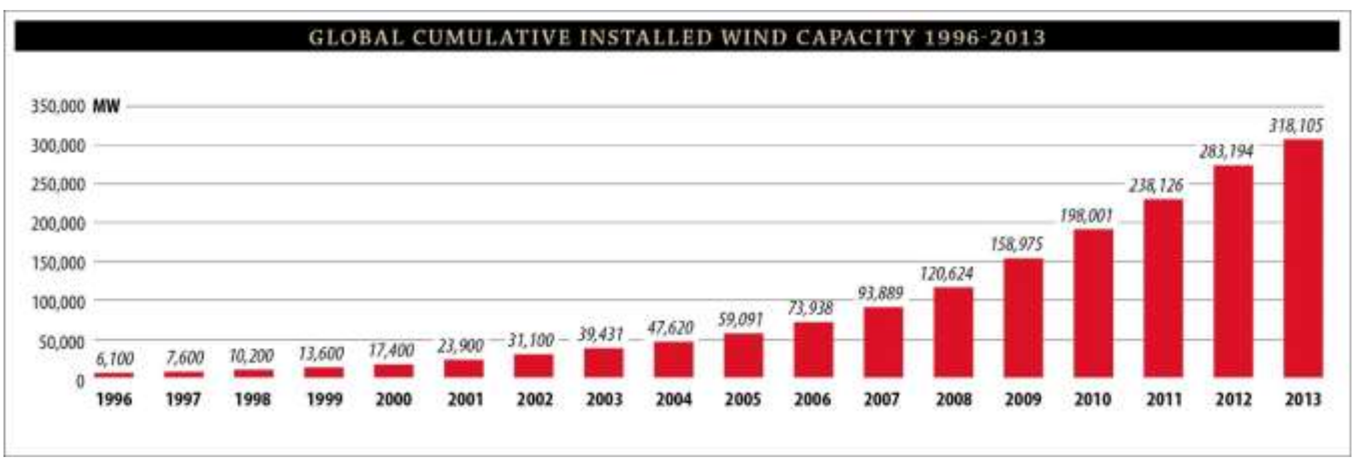
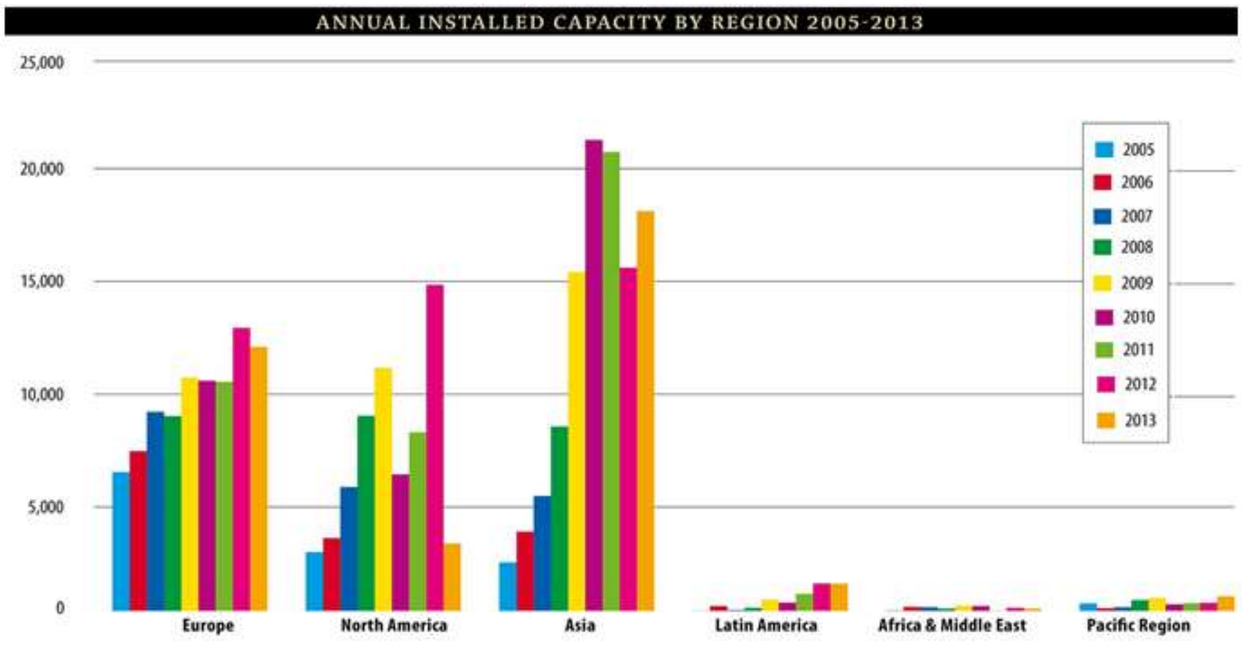


Figure 1: Global cumulative installed wind capacity (GWEC, 2014)

During 2009, a total of almost 158 GW worth of electricity capacity was installed throughout the world (GWEC, 2014). This resembles sufficient power to currently provide electricity for over 5 and half years to all households in the Netherlands (CBS, 2014); (Rijksoverheid, 2014). However, this was only 3.2% of the total electricity installed capacity in the world (EIA, 2014). While China aims at doubling its cumulative capacity each year and India shows a large steady growth, (Mabel & Fernandez, 2008), European countries have been facing serious challenges with regard to growing wind power capacity. Figure 2 shows the annual growth of Europe remaining more or less the same over the last years, while North America (besides 2013) and Asia show significant growth patterns. The European growth also includes offshore wind capacity growth, which amounted to approximately 12% in 2012 (GWEC, 2014).



Figuur 2: Annual installed capacity (GWEC, 2014)

One of the reasons that Europe is struggling with increasing their growth of installed wind capacity is because the local wind potential in many European countries, including the Netherlands, has considerably been exploited already (Kaldellis & Zafirakis, 2011). The focus of European countries has therefore shifted to offshore operations. By 2020, the Netherlands wants to increase offshore capacity from 220 MW to 4450 MW (Rijksoverheid, 2014) while Germany and the United Kingdom aspire to increase their off shore wind energy contribution together by 33 GW by 2015 already (WE, 2010).

While the money, R&D and policy making of the European countries are focused on developing off shore wind markets, the development of the industry of small scale wind turbines (WTs) is not cast in the spotlights. However, the range of applications is of very special interest. Small WTs can for example be integrated into several structures, used for mini wind farms or simply as single turbine installations (Knoll & Klink, 2009 – Kaldellis, 2010). The scientific journal

Refocus even describes small wind turbines as ‘‘the unsung heroes of wind industry’’ (Refocus, 2002; Refocus, 2009) where millions of small scale wind turbines make significant contributions to supplying electricity in off-grid and grid connected areas.

This research report focuses on these unsung heroes, particularly one new potential application: utilizing both natural wind flows and wind flows created by traffic on highways. The electricity output could possibly be used for road lighting, traffic lights or possible electric car charging stations in the future. Small wind turbines could be a great asset in developing the onshore wind energy source of renewable energy. Whether CO2 emissions are indeed linked to global warming or not, increasing the share of renewable energy will save scarce fossil fuels for the future and increase the independency on foreign electricity (gas) imports.

Figuur 3:Possible design of small wind turbines: E-Turbine: design by Pedro Gomes (Ecofriend, 2014)

1.2 Defining the research problem

The Netherlands has managed to plan another 1200 onshore windmills, providing 57% of the required generation capacity to meet the 2020 energy targets (NFR, 2013). However, the onshore wind energy market in Europe seems to be getting saturated. The contribution of wind power of the Dutch onshore market towards the whole electricity production is significantly higher compared to other large European wind energy producers, accounting for the population density and the geographical area available (Kaldellis et al, 2011). According to Gerard van Bussel, professor of wind energy at TU Delft, the Netherlands will never achieve to install this amount of wind capacity by 2020 (Bussel, 2013). At least a quarter of projected locations will not be built upon due to heavy conflicts with inhabitants, nature and recreation (Zuidervaart, 2013).

The lack of space and heavy conflicts are growing disadvantages for installing new onshore wind capacity. Therefore new investments are focused on offshore wind, as the sea providers bigger suitable free areas where offshore wind farms can be installed, leading to greater

installations compared to onshore sites. Another advantage of offshore wind is the better quality of the wind resource in the sea (Lopez et al, 2013).
There might be more space available on the sea, accompanied with a higher grade of wind quality, but the disadvantages of offshore wind are still quite substantial. The cost of the permitting, the engineering process and of the construction- and operation phases are very high due to the costs of the sea operations and strengthening existing electrical infrastructures (Lopez et al, 2013). A second disadvantage is the necessity of a more developed offshore wind farms technology, this is essential for the wind turbine generators which will be subjected to high loads and must to adapt themselves to the marine environment (Esteban, 2009). A third disadvantage is the high cost and complexity of wind resource evaluation offshore compared to onshore (Lopez et al, 2013).

Even though the shift to offshore wind energy is a very costly one, the Netherlands is still focusing to increase offshore wind energy capacity dramatically, from 220 to 4450 MW by 2020 (Rijksoverheid, 2014). A social cost benefit analysis (SCBA) showing the negative net result of 5 billion Euros to achieve this goal has not changed policy maker's thoughts (CPB, 2014). This could have to do with other SCBA which was more positive, with net results ranging between -2.1 billion to +12 billion Euros (Tieben & Hof, 2014). Due to the wide range of outcomes and uncertainty about what SCBA withholds the most accurate answers, it is worthwhile to seek for new cost effective onshore solutions. The onshore market may not be as saturated as it seems. This would also profit inland European countries, as they do not have the ability to build offshore wind parks. Millions of small- and micro-turbines are part of the onshore wind industry. These turbines have been installed on a huge scale over the past decades, making significant contributions to supplying electricity in off-grid and grid connected areas. The small wind turbine industry can thus be considered very important, yet there is little research and media attention being paid to, compared to the gigawatt scale wind projects either on- or offshore. In the Netherlands, the use of small scale wind turbines is minimal. The growth of the use of photovoltaic solar panels on roofs is far greater. However, small scale wind turbines have a growing array of both on-grid and off-grid applications, such as building integration (Knol & Klink, 2009), mini wind farms, wind-batteries and wind-based hybrid systems (CWEA, 2010). This report investigates one potential new application: capturing traffic turbulence generated on highways and turning this into useful power. Other applications to use the space along highways could be to install photovoltaic sound screens (Schepper et al, 2012), or extract heat out of the roads (Ooms, 2014).

1.3 Knowledge gaps

The concept of capturing traffic turbulence has only recently started to being developed and experimented with inside a few States of the USA (TGR, 2014). There are no publications or any other reports published related to these experiments on scientific libraries as Scopus, ScienceDirect or on Google Scholar. Research is necessary to optimize any small wind turbines for the application near highways. The Green Roadway project, initiator on using wind turbines along highways in the United States, suggests the use of nano wind turbines. These nano wind turbines are an inch in length or less, that could be attached to guardrails, road signs or noise-barrier walls (Fein et al, 2014). However, no research confirms that nano wind turbines would be a better solution compared to e.g. small wind turbines as Windside produces (Windside, 2014).

Additionally, it remains to be seen whether the wind power project would be cost-competitive with other sources of power generation. The Green Roadway system suggests that each 10 miles could generate power for up to 2000 homes, including solar components. The associated cost estimates would be $ 2.6 million for solar and $ 4.2 million for wind components (Fein et al, 2014). However, it is unknown what these estimates are built upon and how well they represent any other highway in the USA, let alone in the Netherlands. Another knowledge gap worth mentioning is whether these wind turbines will be socially accepted. Wind turbines could possibly be such a distraction on the roads that it could create dangerous situations, or could potentially have other negative influences on drivers, like having them drive slower. Furthermore, the large amount of smaller turbines could possibly increase noise and scenery pollution.

1.4 Scientific relevance

As mentioned, the concept of wind turbines along highways has been barely developed anywhere. In the United States there is some research being done, but no scientific publications or empirical results have been published. This results in an inadequate amount of general knowledge regarding the concept, a lack of knowledge about the applicability in the United States itself and no specific knowledge about the feasibility of the concept in Europe or the Netherlands at all. Scientific libraries Scopus and ScienceDirect hardly contain literature regarding experiments or simulations of wind turbines stationed along highways. The literature that does refer to wind turbines along highways describe the idea of how this could be designed and propose various applications for the generated electricity (Megahed, 2013). There are no feasibility studies available on any type of wind turbine project along the highway. The main line of research for small wind turbines focuses on the urban environment, for which the highways are not yet included in terms of empirical research (Grieser et al, 2015);(Sunderland et al, 2013);(Walker, 2011). This report will be one of the first to research the feasibility of wind turbines along highways and adds scientific value by providing empirical research. It is unknown how this concept works out in reality and this report makes a first step into providing insight on this matter. The methods that are used to reach this goal are not new or used in a different way.

1.5 Social relevance

The global population is still growing every year and fossil fuels are running out on a rapid pace (Buhaug & Urdal, 2013); (Shafiee & Topal, 2009). It is evident that solutions are required to solve the growing energy problem. The concept of turning traffic turbulence into electric power by small wind turbines could be such a crucial solution. The development could be beneficial to the whole world, a global breakthrough in generating energy with wind as the sustainable source. Not every country has access to the ocean for off shore wind parks, but every country has highways

On a national scale, the Netherlands still remains to be one of the most fossil fuel dependent economies in Europe due to the extensive use of natural gas (World Bank, 2013). More 'homegrown' wind energy generation decreases the negative outlook of this situation, while also lowering the dependency on foreign gas imports. In 2009, the people in the Netherlands consumed a total of almost 26 GW (CIA WORLD, 2013). Installing wind turbines along the whole Dutch highway network could potentially create over 35 GW in the future according to claims of the GreenRoadway Project (Fein et al, 2014). This would mean that the whole Dutch society could ideally be supported by this energy concept. However, ideally is the key word here and the claims of Fein et al are questionable to say the least (Fein et al, 2014). Nevertheless, if only a fraction of the 35 GW can be generated in a cost effective manner and implemented in other countries too, the global energy problem can be diminished tremendously.

However, there are also potential downsides for society to this new concept. Would the smaller wind turbines add to noise- and scenery pollution? How economically and technically efficient is this concept in comparison to building large offshore wind parks? Could the global society see pollution levels decrease dramatically through implementation of this concept, or are critics on wind energy right thinking wind turbines can even increase CO_2 emissions (Udo, 2009)? It is relevant to find answers to these questions in order to determine fully how beneficial this concept would be to society when implemented.

Figure 4: Wind turbine highway lights (TAK, 2010)

1.6 Problem statement, research objective and deliverable

In the previous sections the reasons behind the project proposal have been discussed, together with corresponding problems and knowledge gaps. Combining the problem and the knowledge gap, the following problem statement is made to summarize the issue at hand: *There is no qualitative nor quantitative assessment done on the feasibility of small wind turbines installed along highways anywhere in the world that indicates at what social costs and benefits electricity can be fed into the grid.*

Research objective and deliverable

The research objective logically follows from the problem statement. The research will try to provide both a qualitative and quantitative exploratory assessment on the implementation of the turbulence capture and conversion by small wind turbines concept in the Netherlands. The main deliverable is a recommendation report on the feasibility of the concept in the Netherlands. A virtual case study will be carried out to visualize the research and challenges.

1.7 Reading guide

This report consists out of 7 chapters. In chapter 1 the research problem has been introduced and defined, together with background info and the objective of this exploratory research report. Chapter 2 digs deeper into the research to be done by formulating the main research questions and sub questions. After that the research methods to answer these questions are posed and explained, consisting out of three main analyses. Chapter 3 and 4 contain the first two analyses to be done; the technical- and stakeholder analysis. Chapter 5 and 6 deal with the social cost benefit analysis, where in chapter 5 the foundation of the analysis is laid out by defining and describing the relevant effects and assumptions of the social cost benefit analysis. Chapter 6 proceeds to show and interpret the results of the social cost benefit analysis and takes a closer look at them by performing several sensitivity analyses, concluding with a recommendation based on the social cost benefit analysis. Chapter 7 finalizes this report with an overall conclusion and recommendations.

Chapter 2. Research questions, methods and challenges

2.1 Research questions

To achieve the research objective, the explorative feasibility report is structured into answering the main research question and sub questions. The main research question is as follows: *To what extent can the concept of converting traffic turbulence and regular wind to useful energy be implemented in the Netherlands?*

There are many different frameworks on how to perform a feasibility study. In this report, the infrastructure and investment feasibility study model of Professor Phillip Thomas from California State University is used to provide the research sub questions for answering the main research question. The reason behind using Thomas' model is because it offers a specific, readily understandable methodology on performing a feasibility study in the infrastructure domain (Thomas, 2014). The model is applicable for assessing the feasibility of installing thousands of wind turbines along the highway and uses 12 different steps to undertake. Appendix III shows the relevant steps that are taken in this exploratory report. Due to limited resources for this research report, not all 12 steps are included. The most relevant steps for this feasibility study are followed, resulting in the following sub questions:

1. What technological options are available and most feasible to use?
2. What relevant actors are involved, what is their range of powers and how are they influenced?
3. What are the (social) costs and benefits of the concept?

2.2 Research Methods, challenges and data collection

A feasibility study comprises of a range of interrelated and often interdependent sub studies (Thomas, 2014). The study links and integrates the sub-studies into one coherent whole. In this report three sub studies are performed to evaluate the concept of wind turbines along highways. The sub studies will be carried out by means of an exploratory virtual case study; according to Yin (2003) an exploratory case study should be considered when you want to cover contextual conditions because you believe they are relevant to the study. The study of the feasibility of wind turbines along highways needs to cover contextual conditions. One simple example is that the average wind speed differs throughout the Netherlands, resulting in different outputs for wind turbines. The same goes for electrical grid connections, highway speed limits and the way highways are structured (double lanes, median or not). Trying to explain the presumed causal links in real-life interventions by the use of surveys or experimental strategies only is too complex (Baxter & Jack, 2008). Therefore a virtual case study is carried out which entails the crucial aspects involved in implementing the concept. This case study focuses on implementing wind turbines along the Prins Bernardweg Zaandam to Bolswarderbaan highway. This strip is 110 kilometers long. There are three main reasons why for this case study this piece of highway has been chosen.

First of all, a large part of this highway runs along the water from which the wind turbines could benefit due to increased wind speeds. Secondly, nearly the whole highway entails the legally maximum speed allowance in the Netherlands of 130 km/hour. Last reason to choose this highway is that the whole highway has a free middle strip separating the lanes, including rails as well. This means that the small wind turbines could be placed in the middle strip as the design, or micro turbines could be placed on the rails which is another alternative to consider.

Methods for answering sub questions

In order to give a plausible answer to the research sub questions, an individual analysis is done for each question. The first two analyses to be done are the technical analysis and stakeholder analysis. The third analysis is a social cost and benefit analysis (SCBA). The technical analysis is necessary to display what technical options are available for the project. The key finding will be what specific wind turbine is most suitable to be used in the exploratory study

The technical analysis provides input data for the SCBA and therefore needs to be performed first. Within the technical analysis two methods are used to gather insight. First, interviews with experts combined with literature research on wind turbines and its characteristics in different environements will provide the rough design requirements set for the wind turbine used in this study. The interviews and literature research is then also used as a method to select potential concepts that are could be used to for this exploratory study. To make a decision between the selected concepts, a multi-criteria decision analysis (MCDA) is carried out.
The second analysis to be carried out is the stakeholder analysis. The stakeholder analysis needs to be performed simultaneously with the technical analysis, as they are linked and need data input from each other. For example, the technical analysis shows that wind turbines could be placed in between the median or next to the sides of the highway. However, stakeholder Rijkswaterstaat only allows wind turbines to be placed when guardrails are in front of them to protect the drivers. This demarcates the technical analysis to only look for wind turbines that are small enough to fit next to the road including new guardrails or still in the median. Another example is that the wind turbines cannot be distracting traffic, or stakeholder Rijkswaterstaat will not allow any wind turbines to be installed.

The last analysis to be done is the SCBA. The reason for incorporating the social aspect is twofold. First, the highway wind turbine project creates substantial benefits for society (e.g. CO_2 reduction, potential fuel reduction) that would not be taken into account in a cost benefit analysis (CBA). Secondly, the project is highly innovative and expected to not be economically feasible for investors without subsidies. Exploring the benefits for society gives an indication for the government on how beneficial subsidizing the highway wind turbine project would be. The SCBA will also show stakeholders, like drivers and environmental groups, that their interests are taken into account. While carrying out the SCBA, the technical- and stakeholder analysis are both revised when needed. Figure 5 shows how the analyses are linked and what data is used to perform them. This is explained further in the next sections.

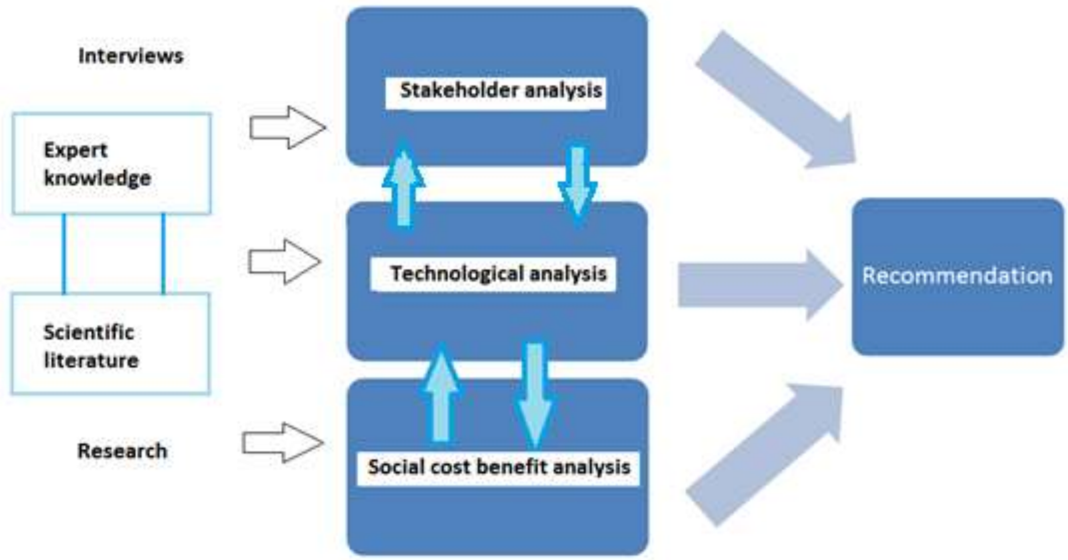


Figure 5: Interaction between analyses and data used

2.3 The technological analysis

This analysis determines the type of wind turbine used in the explorative study. The key findings are the necessary requirements for the specific highway wind turbine and the choice between two different identified wind turbine concepts.

Challenges

Among the challenges in the technical analysis, the biggest one concerns the reliability and accuracy of the retrieved data. There are no custom made wind turbines on the market for along highways and no scientific publications on testing this matter. Therefore assumptions need to be made, translating performances of wind turbines placed elsewhere to performances along highways. Additionally, the stated characteristics of wind turbines by producers need to be taken with caution as they are not an objective third party.

Data gathering

The data used for the analysis is based upon literature reviews and six interviews with experts and wind turbine producers. The interviews are conducted to obtain direct insight in different stakeholders perspectives and to gain specific technical knowledge. Appendix I shows the selection of respondents, method used and questions asked.

The literature reviews concern information about the use of small wind turbines used in different places and for different applications. The scientific library Science direct offers relevant literature, for example the journal Refocus on small wind turbines and their characteristics and outputs (Refocus, 2009). Also technical patents of existing and projected small wind turbines are reviewed (Bahari, 2009; Fein et al, 2011). Next to literature research, experts and producers are interviewed. Appendix I shows the interviews of the approached experts and producers, including their descriptions and interview methods that are chosen.

2.4 The Stakeholder analysis

The stakeholder analysis is used to explore the institutional and process design options to implement the wind turbine along highways concept. The analysis focuses on identifying the actor's powers, interests and attitude towards the project.

Challenges

The main challenge in the stakeholder analysis is to find the right experts who have the time and interest to be interviewed. Another challenge at hand is to find out the true viewpoints of the stakeholders during the interview, as not every actor might be as willing to display their interests, attitude and power.

Data gathering

Most of the data for this analysis is based upon interviews with representatives of the involved actors. Additionally, literature research is performed to support any statements made by the interviewees (Rijkswaterstaat, 2014; Windside, 2014) and is also used to form the characteristics of actors that refused or whom from it is not possible to conduct an interview. Appendix I shows the interview set ups and who have been approached.

2.5 The social cost benefit analysis

The social cost benefit analysis (SCBA) is used to estimate the costs and benefits of the implementation of the specific wind turbine along highways concept.

Challenges

The SCBA faces the same challenges as the technical analysis and stakeholder analysis does. In addition, there are many effects that need to be estimated that involve a high degree of uncertainty. There is no scientific consensus on all relevant effects and accurately estimating the data over a long period of time seems to be the biggest challenge to be dealt with.

Data gathering

The data gathered for the SCBA is mainly based on literature research, especially from the literature other SCBA's regarding wind energy projects have used (Blom et al, 2012; Decisio, 2014). Also a literature review comparing several SCBA's done in the Netherlands regarding wind energy is consulted (Ecofys, 2014). SCBA's from a while back, like from de Vries et al. (de Vries et al, 2005), and are carefully looked at to learn from. Next to literature research, interviews with experts are conducted to accumulate knowledge. The interviews are displayed in appendix I.

Chapter 3 Technological Analysis

3.1 Introduction

Wind power turbines can generate power that can be delivered via interconnection to existing grid systems or can be used to power individual homes, businesses, and utilities. Most wind power systems that are used to generate amounts in the megawatt range are large-structure wind turbines, of which the majority is at least over 30 meters high. In the past, also smaller wind turbines have mostly been placed high up from the ground (Merritt et al, 2011).
As of now large wind installations cloud the landscape of the planet, often being placed in remote fields, off-shore or on private property away from public infrastructure. Smaller wind turbines are now typically used in isolated areas, but are also adapted to a micro-level for use to power compartments of single homes, businesses and power government utilities, like light stands and other street lighting (Wood, 2014). Smaller wind energy gathering systems can also be interconnected to a grid system for the purpose of selling the power that is generated by the system to a public or private utility.

Advantages of small wind turbines

Large turbines have faced concerns raised by environmental parties (SNM & PM, 2009) the ministry of defense (ANP, 2012) and local residents (NLVOW, 2014). The noise and size of turbines disrupts scenic and habitat conditions and birds are caught in the turbine blades. The defense department is concerned over possible interference of large turbines with radar signals and tracking. Additionally, existing conventional uses of wind turbines have limitations in distribution and deployment, while large turbine systems that are placed far away from existing infrastructure also incur a large expense in the transportation or building of infrastructure to carry the power generated by the turbines (Fein et al, 2011).

Smaller wind turbines generate less noise and the smaller size minimizes any disruption to habitat conditions and the military defense radar signals (DOD, 2006). Building new grid infrastructure to carry power is a less costly endeavor when small wind turbines can be placed closer to existing grids and interconnections. Especially, since a large turbine system represents a major, volatile investment for one single turbine. Additionally, if wind currents change, then the large turbine would be viewed as more of a poor investment because it will not generate enough power to be profitable, while small wind turbines are easier to reinstall elsewhere. The decommissioning of large wind turbine is another environmental issue to be contended and quite costly (WEU, 2009). During the life cycle for large wind turbines, intensive labor maintenance and monitoring are required.

Why small wind turbines along the highway?

The micro-level use of wind turbines, together with the option of delivering to a grid system, inspire the potential application of placing wind turbines along highways. Converting both natural wind and the turbulence created by traffic to useful energy, the power could possibly be used to directly feed electrical utilities like lighting and traffic lights. In the future, electric car charging stations could be green fed by wind turbines which are boosted by cars themselves. For what other reasons would a highway be fit to install wind turbines near?

First, private highways and municipalities have existing maintenance crews as well as existing relationships with contracted infrastructure building providers who can be trained to install the wind generation systems along specified parts of roadways. Second, the wind power generation systems can be small and noiseless, small enough to fit large numbers of wind turbines in the median between opposite sides of a divided highway with existing median according to Wim Stevenhagen. Wim Stevenhagen is an expert on small noiseless wind turbines and wind energy (Interview with Stevenhagen, 2014).

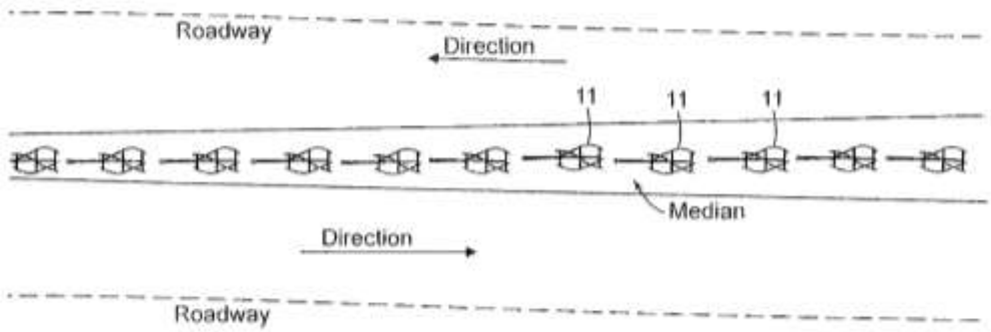
Third, the energy generated by the devices may be distributed directly to homes or businesses along the highway route, used to power up electrical vehicle charging stations or provide electricity in areas that are insufficiently covered by power stations. Fourth, the power coverage in remote areas can be improved and the energy production is clean. The infrastructures can also benefit the wind power generator companies and the roadway owners via lease or easement revenue (Interview with Harald Versteeg, 2014). Harald Versteeg works for Rijkswaterstaat as the program manager sustainability and has worked for over 6 years at Rijkswaterstaat.

Virtual case study

To explore the realization of wind turbines along the highway, a virtual case study is carried out. The study focuses on implementing wind turbines along the Prins Bernardweg Zaandam to Bolswarderbaan highway. This highway stretches over 110 kilometers long and drivers can take on the maximum speed of 130 km/hour over the whole strip. Additionally, the whole highway is divided in two by a free middle strip, suitable to install wind turbines. A considerable part of the highway also has free space on the sides of the highway, however, for the main analysis of the project only the middle strip is focused on. Only filling the middle strip with wind turbines is the cheapest option available, since the Dutch law determines guardrails need to be built in between the road and a placed object (WBR, 2014).

Figuur 6:Google image of A7 (Google, 2014)

Figuur 7:Google image of A7 (Google, 2014)



Figuur 8:Conventional helix shaped turbines in median. Edited from Fein et al (Fein et al, 2011).

3.2 Wind turbine requirements

As of right now there are no customized wind turbines on the market for the use along highways. Therefore, one concept needs to be used that is on the market but currently used in different areas or one that is under development suitable to use along the highway. The first step towards selecting a suitable concept is defining the requirements the wind turbine concept needs to fulfill.

Required characteristics

The wind turbines are placed along the highway and their aim is to convert natural wind currents and traffic turbulence to power. The type of wind turbine needed should have certain characteristics to optimize this conversion and be cost effective. A list of characteristics is founded through literature research and interviews with experts. (Interview with Zaaijer, 2014; Interview with Stevenhagen, 2014; Fein et all, 2011; Refocus, 2009; Bahari, 2009; Rijkswaterstaat, 2014;Windside 2014; Burton et al, 2011;Hau & Renouard, 2013). Michiel Zaaijer works at the TU Delft at the wind energy community and research group. He is specialized in offshore wind farms but has great knowledge and experience with onshore wind turbines as well.
The list of required characteristics is shown below. The characteristics are explained as well.

- Small wind turbine: The wind turbine, including the generator, needs to be small. This feature is required as the turbines need to be placed in the middle strip, so the base of the turbine cannot be too large. Also the length of the torque arm cannot be too long, as it would distract and possibly endanger drivers in case of a breakdown.
- No need to be directed to wind currents: The wind turbine needs to work with the natural wind and the traffic turbulence that comes from any direction. The wind turbine must therefore automatically turn towards the wind direction.
- Withstand harsh weather conditions: The wind turbine must be able to stand snow, frost, heat, humidity and storms.
- Minimum undesired sound output: Even though the traffic makes a lot of noise, the wind turbines should not produce any volume themselves in such way that it could be distracting drivers.

- Minimum need of maintenance and long lifespan: Since the wind turbines are built along the highway, it is very important that daily traffic is left undisturbed.
- Safe to people, animals and nature: Obviously the turbines need to be safe.
- Cost effective: Naturally the turbines should not be too expensive.
- Producer- and product experience: The wind turbine should preferably be produced by a manufacturer with a vast amount of experience. As for the product, it would be beneficial if the product has been around for some time and been developed over a period of time.

3.3 Identifying wind turbine concept alternatives

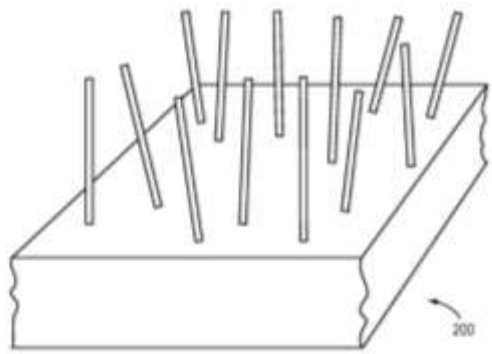
A multi-criteria decision analysis (MCDA) is carried out to make a decision between any concepts that are used further in this exploratory study. An essential goal of MCDA is to be helpful in decision processes and identifying preferred alternatives (Stewart, 2014). Within the multi-criteria context, the decision-making problems are realized in the following paradigm: first the decision maker considers a set of alternatives and then seeks to take an optimal decision considering all the factors that are relevant to the analysis (Zopounidis & Doumpos, 2003). The first issue that now needs to be addressed is identifying a set of alternatives. For this exploratory study, the choice is made to have a discrete set of two alternatives. The reason that two concepts are chosen is because there is no such thing yet as a customized wind turbine specifically developed for along highways. In order to explore whether it would be worth to develop such turbine, two concepts are selected. One concept is based on the only wind turbine currently being developed specifically for areas like highways. The other concept entails the use of conventional small wind turbines and placing these along highways.

3.3.1 Concept A: Nano wind turbines on energy gathering sheets

The concept of capturing wind by vehicles driving along highways is not completely new. In 2006, Mark Oberholzer proposed an idea to install wind turbines near highways (Inhabitat, 2007). In 2007, de Jong et al (TM, 2008) from the Netherlands proposed to research the concept in the Netherlands, showing its high potential. Joe et al (2007) from Arizona State University also posed the same idea in 2007 for the Phoenix highway system. It took until 2009 when the idea got more commercialized in the form of the Green Roadway Project. The last several years the initiators of this project have been gathering patents for their idea, including specific wind turbines, system and method for creating a networked infrastructure roadway distribution platform (GRW, 2014). The State of Massachusetts has been trying her own take on the Green highway concept, installing a utility scale wind turbine on land adjacent to the Massachusetts Turnpike's Bland ford Rest area. The wind turbine is big enough to power 400 households (Vestel, 2009).

The Green Roadway project aims to turn hundreds of miles of highway into potential power plants by placing both solar and wind energy gathering devices along the highway (GR, 2014). The wind gathering device that will be used for this purpose is under development, while the Green Roadway Company (GRC) is securing all their patents for corresponding methods and inventions.

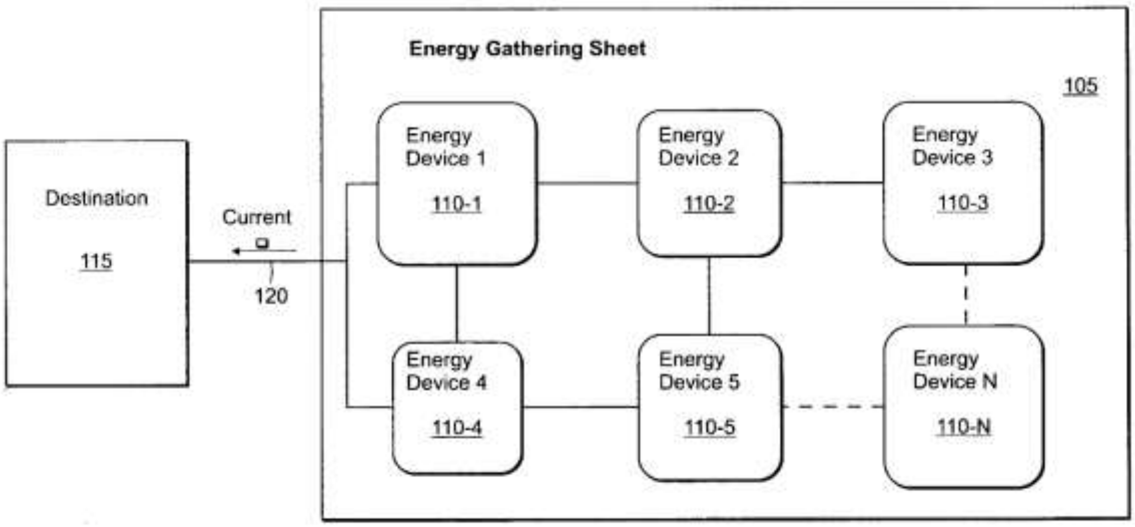
The GRC wants to fabricate wind energy gathering devices ranging from 18th of an inch to 1/8th of an inch. The tiny wind turbines are ‘helix shaped’, which is a very important feature. As the wind blows the long helical blade scoops catch wind from all directions, forcing it through the turbine (Helix Wind, 2014). This offers the option of using cross-wind, wind coming from passing vehicles on both sides of the highways. The nano wind turbines would be deployed on large strips of installable sheets and could be rolled out in the median lane Figures 9 and 10 show an individual nano wire wind turbine and an array of these turbines installed on a sheet.



Figuur 9: Nano wind t

Figuur 10: : Array of nano wind turbines on sheet (Fein et al, 2011).

The installable sheets contain a series of tiny power generating wind turbines. The turbines can serve a variety of uses by generating-small or large amounts of energy based on the number and size of the turbines that are deployed in a given installation. The micro turbines can be manufactured using existing nanotechnology practices and are wired together to efficiently distribute the total electricity gathered by all of the turbines on an installation sheet. The sheet is used as the infrastructure to transfer that electricity to an organized distribution system or desired destination point (Fein et al, 2011).



Figuur 11:Energy gathering sheet (Fein et al, 2011).

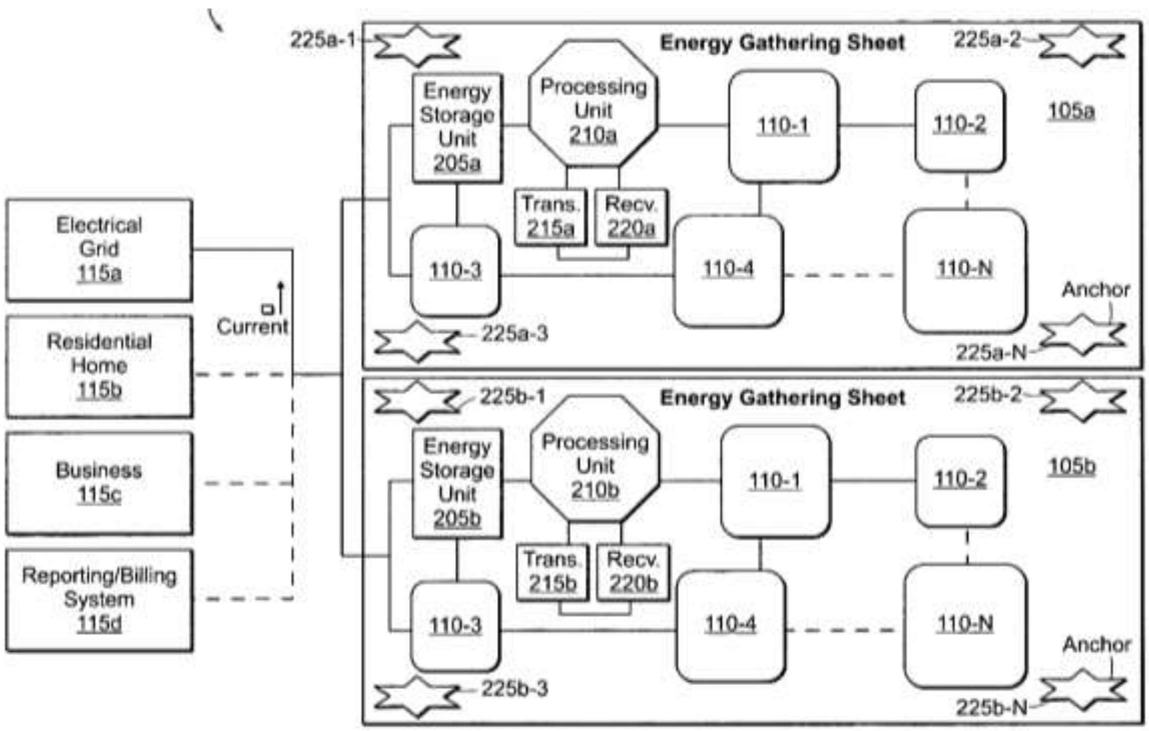


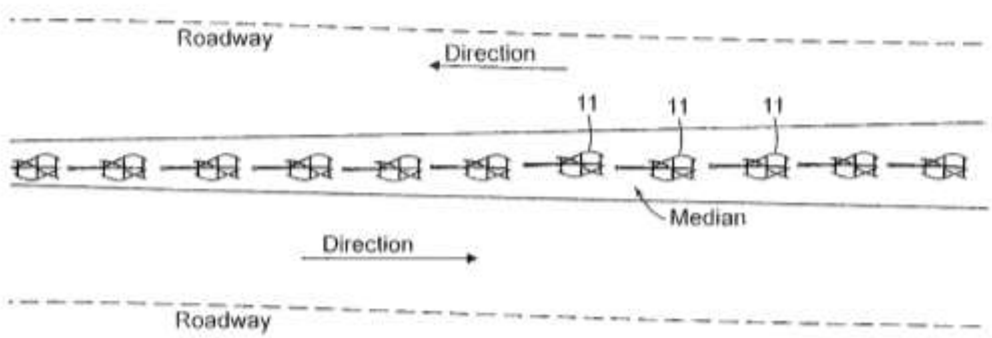
Figure 12: Detailed energy gathering sheet (Fein et al, 2011)

Output and costs

The inventors of this concept claim to be able to turn one hundred miles of highway into a potential power plant of 46 MW (GR, 2014). This would include solar panels as well. The fabrication of the nano turbines and sheets can be automized, as well as the installation of the turbines on the sheets. Simply rolling them out in the median would require little time and cost to install. There is no projected price estimated or published.

3.3.2 Concept B: Conventional small wind turbines

Finland-based Oy Windside Production Ltd. (Windside) is a specialized manufacturer of robust, rugged, and reliable vertical axis wind turbine (VAWT) systems (Windside, 2014). Windside was founded in 1982, therefore having a lot of experience in the use and engineering of vertical-axis wind turbine systems. The vertical axis or 'helix shape' wind turbines are not dependent on single direction wind. The median could be filled with these conventional small wind turbines and capture wind from both sides of the highway. Figure 13 shows the concept of conventional helix style wind turbines placed in a row in the median of a roadway. The specific model focused on is the WS 4B model, shown in figure 14.



Figuur 13:Row of helix style wind turbines in median (Edited from Fein et al, 2011).

Figuur 14: WS 4 turbine (Windside, 2014)

Output and cost: The specifications of the WS 4B model and the price list are shown in figure 15 and figure 16 respectively.

Windside Turbine Model	Height m	Diameter Ø	Swept Area m²	Weight Kg *	Wind endurance class m/s	Power Production at average wind speed of 5 m/s Annually in kWh **	Power Production at average wind speed of 7,5 m/s Annually in kWh **	Power Production at average wind speed of 10 m/s Annually in kWh **
WS-4B	4	1	4	1200	40	2000,00	5200,00	11180,00

* Turbines weight may change by +- 2 kg due to change in materials for certains applications.
* * esimated power production when the turbine is installed according to Windside instructions.

Figuur 15: WS 4B specifications (Windside, 2009)

Price List februari 2013

Windside Turbines

Ex works, VAT, handling fee, transport and insurance	WS-4B EUR
Windside wind turbine	44.450
Charging controller **WGU-25**/12,24V **or**	975 safety switch 63A: 195
Charging controller **WGU-50** /12,24V	3.100 safety switch 63A : 195
Fastening cylinder/plate	2.495 / 2.130
Lubrication syst.	Manual/automatic
Art colour/extra colour	3.700

Figuur 16:Price list (Windside, 2013)

Potential vehicle fuel use reduction

Setting up rows of vertical axis conventional turbines can potentially influence the resistance for passing traffic. Vehicles could either burn through extra fuel, or reap the benefits of the turbulence created by traffic from both sides of the highway. Wind experts lean towards a potential benefit, as the ongoing traffic from both sides can provide a wake effect, which pulls the vehicles forwards on each side (Interview with Zaaijer, 2014;Interview with Stevenhagen, 2014;Interview with Raemsdonk, 2014). Gandert van Raemsdonk completed his PhD research at TU Delft on the topic of fundamental knowledge in bluff body aerodynamics. Due to his specialty in the aerodynamic design of road transport vehicles he can provide reliable insights and estimations on the effect of wind turbines on passing vehicles or vice versa. Figure 17 illustrates the wake or tornado effect.

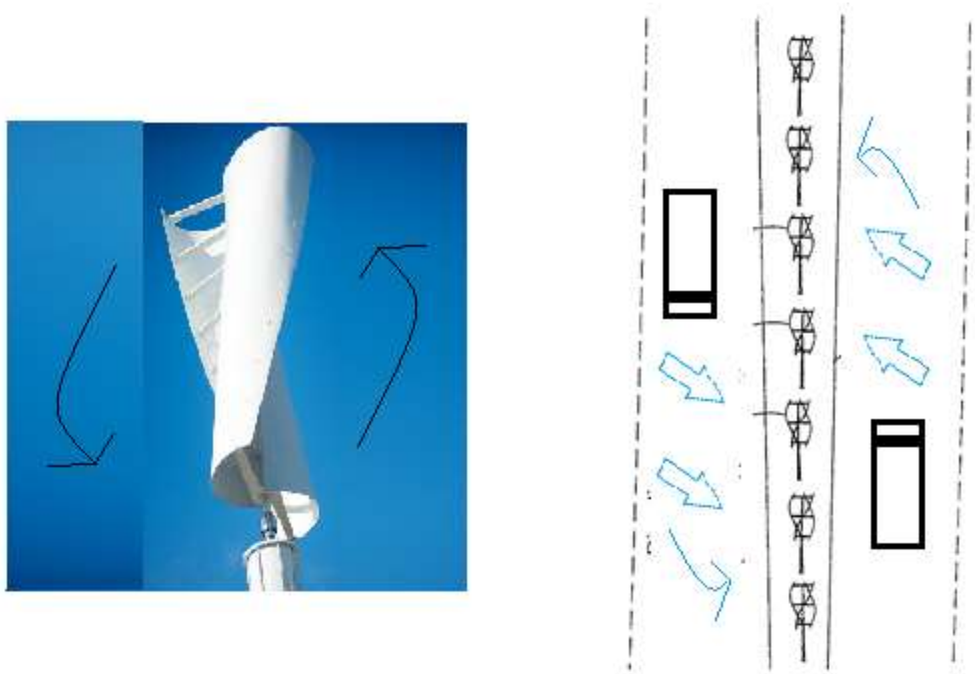


Figure 17: Illustration of potential wake effect (Author, 2014).

3.4 Final selection of wind turbine concept

The set of alternatives is identified and now a preferred alternative needs to be selected. Due to the limited resources for this exploratory study, only one alternative can be researched. In order to select one of the two concepts, the alternatives need to be compared by the decision factors or 'criteria'. These are derived from existing requirements of small wind turbines (Boyle, 2004) (Interview with Zaaijer). The scoring of the concepts on the criteria is based on interviews with experts (Interview with Zaaijer, 2014); (Interview with Happee, 2014) and research (Fein et al, 2011;Windside, 2014;Herbert et al, 2014). The scores range from 1 being very unsatisfactory to 5 (very satisfactory). Riender Happee works in the section planning and design of transport systems at civil engineering at the TU Delft.

Criteria and scores

Shown below are the different criteria and their corresponding scores. The criteria are defined and the scores are explained.

<u>Available Research knowledge</u>: Amount of relevant research knowledge available with regard to the selected wind turbine concept, such as scientific publications, scientific articles and empirical research. This exploratory study needs to be a reliable indicator on whether to pursue research on the topic of wind turbines along highways. This criterion is therefore considered crucial and the scoring is multiplied by the weight of 3.

Concept A: The theory of how the nano turbines can be produced and installed on sheets is there, but there are no official publications on a working end product. This means that there is also no empirical data available on whether the theoretical calculations of the claimed output are accurate. The claims made by the inventors of this new product regarding the potential output seem to be exaggerated (Interview with Zaaijer, 2014). The theory provided is plausible, but due to the high uncertainty concerning whether the end product acts according to theory this concept receives a score of 2: unsatisfactory

Concept B: There is sufficient research knowledge available on vertical axis wind turbines, including empirical results. Empirical results on placing the turbines along the highway still need to be published. However, these kind of wind turbines have been on the market for over a decade (Windside, 2014). The output of the wind turbines is not expected to be that much lower when installed along the highway (Interview with Zaaijer, 2014; Interview with Stevenhagen, 2014). In the best scenario, the output could even increase due to the traffic turbulence. The research knowledge is there and the wind turbines have been well developed and produced, therefore this concept receives a score of 4: satisfactory

Expert opinion on requirements: The degree of confidence the interviewed experts have in the selected wind turbine to fulfill the set of requirements. This criterion is considered as crucial as the available research knowledge for the same reason, therefore the scoring is also multiplied by the weight of 3 on this decision factor.

Concept A: The absence of any test results is alarming and should make one very wary if the system works out in the open, including whether the nano turbines can withstand heavy to extreme weather conditions (Interview with Zaaijer, 2014). The patent describes the concept's technical abilities (Fein et al, 2009), but anyone can submit any patent. This does not mean that it can actually be made like that (Interview with Happee, 2014). The concept scores 2 on this criterion: unsatisfactory.

Concept B: The windside turbines have proven to be very reliable. They have fulfilled the set requirements for decades and can endure extreme weather. The windside turbines are the best shot to gain insights on the highway wind turbine concept (Interview with Zaaijer, 2014). When the wind turbines are optimized for the purpose of generating energy along highways, this criteria could be fulfilled in a fully satisfactory way. As of right now the concept scores 4: satisfactory.

Investment and operational cost: The cost of fixed capital costs and variable costs over the lifetime of the concept, including maintenance. The investment and operational cost do not form the most important criterion, mainly because the study is exploratory and a reliable insight in the range of costs is also valuable. Therefore a weight of 2 is allocated to this criterion.

Concept A: Building high technology grade production facilities for the nano turbines will be a costly endeavor. However, when the facilities are there the turbines should easily be installed and the sheets of nano turbines automatically produced fast. It is unknown how long one sheet with turbines lasts, but minimal maintenance is expected. Research and development cost will be high as the technology is only just being researched, but a substantial learning curve is still there. The concept scores 3: indifferent. Higher investments and research because the technology is completely new is not a reason to give a low rate in this case.

Concept B: The technology has been developed quite well, the question remains how much more efficient a conventional turbine can be optimized or reformed to work best along highways. The investment cost of the turbines is very high and it is unsure how much this can be lowered by a more automated production. The concept scores 2.5: slightly unsatisfactory.

Potential profit: The amount of profits that can be expected from developing and utilizing the selected wind turbine concept. For the same reason given at the investment and operational cost criterion, the potential profit criterion is allocated a weight of 2.

Concept A: The new highly optimized nano wind turbines will take time to develop, but the main question remains whether the output comes close to what is projected by the inventors. However, if the nano turbines and sheets can indeed be easily produced in factories, simply ' rolled ' out as installation and withstanding the environmental conditions, this concept could be very profitable and revolutionary. Therefore this concept is awarded a score of 4: satisfactory

Concept B: The wind turbines that will be used have been developed and will not get less costly easily. It seems that the significant economic potential lies in optimizing the turbines themselves for higher efficiency and output. It is unknown to what extent this concept can generate more output. This concept scores 3: indifferent

Criteria scores and weights

Criteria Score (1-5)	Nano wind turbine sheets	Conventional WS-4B turbines	Weight (1-3)
Available research knowledge	2	4	3
Expert opinion on requirements	2	4	3
Investment and operational cost	3	2.5	2
Potential profit	4	3	2
Total score	26	35	

Figure 18: Criteria score outcomes (Author, 2014

3.6 Conclusion Technical Analysis

The technical analysis has shown two different concepts to convert traffic and natural wind into useful energy along highways. The use of conventional wind turbines is reliable and technically possible without doubt, but as of this moment still costly and it is unknown how much room is left to get these costs down. The concept of using nano-turbines on installable sheets sounds promising, but the lack of any publications and distrust of wind energy experts that have been interviewed makes this concept not suitable enough to be used in this exploratory study. The conventional wind turbine concept is used, which entails that there are no technical barriers to be expected, but mere obstacles for which the means already exist to come by.

Chapter 4 Stakeholder Analysis

4.1 Introduction

A stakeholder can be described as any party with an interest in the project process or outcome (Pearson, 2010). Other terms sometimes used in a similar way to stakeholders are “actors”, which stresses that stakeholders are active and interact with each other (Hawkins, 2014). Stakeholders can make demands or ask for certain types of compensation increasing the project costs, or they can influence crucial decisions which impact or lock in the whole project. System engineers can use a stakeholder analysis to understand the problems stakeholders can bring. Identifying the people and organizations relevant to the problem at hand and determining their needs, wants and desires with respect to the problem is critical (Parnell et al, 2011). A great example of how important managing stakeholders is can be derived from the construction of the Berlin Brandenburg Airport. The project team refused to budge from its original, legally correct approach and ignored the possibility of stakeholder resistance (Stromeyer, 2014). Among other reasons, ignoring critical stakeholders led to a spent budget of twice the original budget and no end in sight to all the additional costs (Stromeyer, 2014). Opposition can therefore result in costly delays, while often involving stakeholders in an early stage can avoid many problems.

To prevent such project crisis as the Berlin Brandenburg project team endured, it is important to get a complete overview of the different stakeholders, regarding their power, attitude and interests towards the wind turbine project. Obtaining this knowledge will make it to come up with strategies to positively influence these stakeholders in order to get support for the project. Hillson and Simson have developed the ATOM methodology to assess stakeholders and include them into risk managing a project (Hillson & Simon, 2007). This methodology is used to analyze the stakeholders for the wind turbines along the highway project.

Reading guide

In this chapter the stakeholders of the project are analyzed. This analysis has the purpose of indicating whether the project is viable based on the wishes and potential actions of the stakeholders involved with the project. First, the stakeholders will be identified and mapped according to similar characteristics. After the stakeholder identification and mapping, their attitude, power and interests are discussed. Based on these three criteria, the stakeholders will be divided into different types and mapped as being critical, non-critical, supportive, neutral or opposing. Then the inter-relations between the stakeholders will be presented to investigate the way the different stakeholders can influence both each other and the project. Combining these inter-relations with the critical stakeholder table, provides insight in how even at first sight non-critical actors can have their possibilities of influencing the project through an indirect way. In the last paragraph of this chapter, a possible strategy and engagement plan to approach the different stakeholders is laid out.

4.2 Stakeholder identification

This section will start by mapping the different stakeholders according to the environment they are in and according to the level of involvedness in the project (direct or indirect). The mapping of the stakeholders in these different groups will increase both the overview and the understanding of certain views and interests of the stakeholders and is based upon literature research and the conducted interviews shown in appendix I.

Stakeholder mapping

The key stakeholders that were identified in this project can be divided into the following four groups, as illustrated in figure 19 (Maylor, 2010)

1. Governmental environment: having public/non-profit interests, mostly consistent with each other
2. Market environment: having private/profit interests, with every stakeholders maximizing its own utility
3. Civil environment: mostly non-profit, acting out of interests based on norms, values and the maximization of well-being.
4. Direct project environment: having direct interests in the project both profit based as value based.

Figuur 19:Stakeholder map (Author, 2014)

Within these four groups of stakeholders a distinction can be made according to Maylor's description (Maylor, 2010) between internal- and external stakeholders. The internal stakeholders are working directly on the project being able to make decisions about the project's final outcome; they include Rijkswaterstaat, the project´s main shareholders and initiators (project organization) and the municipalities Sudwest Fyrsland, Hollandse Kroon and

Zaanstad. The external stakeholders do not have any direct influence on the project´s outcome and they include the remaining stakeholders.

4.3 Defining the types of different stakeholders

In order to identify what stakeholders could be threatening or supporting the project their attitude, power and interests need to be examined. The stakeholder analysis technique used for this is the interview technique, alternatives are focus groups and surveys (Parnell et al, 2011). Using the focus group technique requires several experts coming together on one day for a period of 6 to 8 hours, which is hard to accomplish on a short term. Surveys are considered too short and not suitable enough to gather knowledge out of open questions. The possibility of having a dialogue with the expert or stakeholder during an interview is key to identifying the stakeholder's position in the project.

Now that the stakeholders have been identified, it is important to discover what attitude, power and interest these stakeholders have towards the project in order to know how to approach them from the perspective of the project management. These characteristics are defined below and rated for every stakeholder on the basis of interviews with representatives and literature research.

Attitude: The extent to which a stakeholder is supportive or resistant towards a project (0-2)
Power: The degree to which the stakeholders can influence the project (0-2)
Interest: The extent to which a stakeholder worries about the project succeeding or failing (0-2)
After defining these characteristics for each stakeholder, it becomes clear what type of stakeholder each of them is. Hillson and Simon (2007) have developed a model using eight cubes with at each end displaying an extreme.

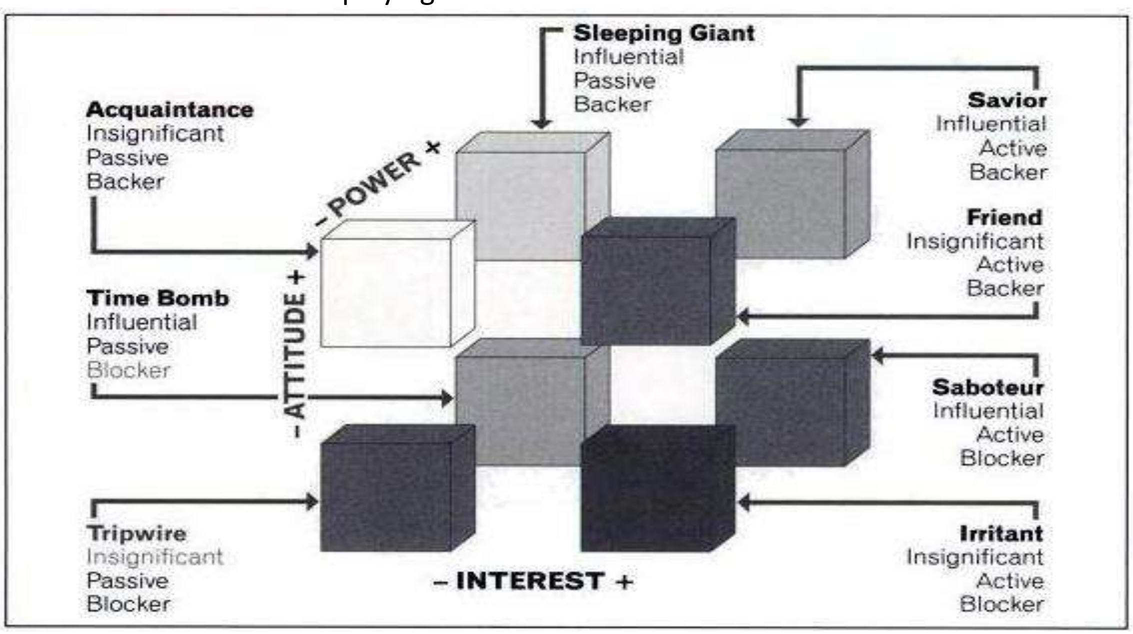


Figure 20: Stakeholder mapping cube (Hillson and Simon, 2007)

This report adapts the model of Hillson and Simon by allowing a third option, rather than working with extremes only. This is done in order to display the stakeholders' perspectives on a more accurate scale because it offers room to not have to pick an extreme. If a stakeholder is in doubt whether he is supportive or against, the more reliable option is to pick neutral. Figure 21 shows the labels of the different scores. For each stakeholder is explained who it is and how they score on these three characteristics.

0	1	2
Negative Attitude	Neutral attitude	Positive attitude
No interest	Low interest	High interest
High power	Low power	No power

Figure 21: Labels of the different scores (Author, 2014)

Rijkswaterstaat: Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and Environment. Its role is the practical execution of the public works and water management, including the construction and maintenance of waterways and roads (Rijkswaterstaat, 2014). Without the consent of Rijkswaterstaat, nothing can be built along their highways (Interview with Versteeg, 2014). This means that Rijkswaterstaat has high power (2) on the project outcome. Rijkswaterstaat has a postive attitude towards the project (2) (Interview with Versteeg, 2014), but their interest is still neutral (1) until also advantages for Rijkswaterstaat are shown (Interview with Versteeg, 2014). Rijkswaterstaat can also directly be used to sell the generated power to, offering customizable contracts for a long time period to secure some risk for the project investor (Interview with Versteeg, 2014).

Project organization: The project organization tries to establish the wind turbine project. Of course its attitude and interest are both positive (2), and the power towards the project is big too (2) as the project organization is the initiator of the project.

Municipalities: Rijkswaterstaat has to give permission to build along the highway, but also the municipalities of the area need to grant a building permit. In the case of the selected highway, the municipalities are Sudwest Fryslan,Hollandse Kroon and Zaandstad. Usually the municipalities always grants such building permit when Rijkswaterstaat has given permission (Interview with Versteeg, 2014). When the municipality decides not to grant a building permit the project cannot initiate, therefore the municipality yields high power (2). The attitude is considered positive (2), as sustainable energy projects can make a municipality look good. However, the interest towards the project is considered to be neutral (1). There are many sustainable project proposals out there today, so the municipalities do not seem to have a preference to this particular project.

Ministry of I&M and Ministry of Economic Affairs: The Ministry of Infrastructure and Environment is ultimately responsible for the contruction and maintenance of waterways and roads. However, they have delegated this matter to Rijkswaterstaat. The Ministry of Economic affairs might also get involved when the project would be implemented on a huge scale, as this ministry takes the most important decisions regarding wind energy. Both ministries have the power to stop project from launching (2), their attitude (1) and interest are considered neutral and low (0) respectively.

Political parties: Political parties could use the wind turbine project as a way to promote sustainable energy generation. It could be an opportunity to be the first country in Europe to have ‘green’ highways. Political parties have the power to make such projects happen, regardless of costs. Of course other political parties can block the project if costs are deemed to be too excessive. Political parties have high power (2), a positive attitude and high interest.

Companies for electric driving: The electricity generated by wind turbines along highway could potentially be used to charge local charging points for electric driving. Since electric driving has recently been introduced and is still in the early stages of being used, the companies do not have a significant market share to have any power (0). However, they are considered to be highly interested (2) in such wind turbine project as it could make charging stations more affordable due to subsidies and a positive attitude (2).

Other project investors: It is likely that the space along the highways can be used for different ways of energy generation. Another possibility besides wind turbines are solar panels. These panels can be placed on sound barriers, be sound barriers themselves or be installed just as solar panels alone (TU Eindhoven, 2014);(Verheijen & Bevelander, 2014). Other project investors could have high power if their product is considered better than the wind turbine project. As of right now also the solar panels along the highway is just being researched, making the competitors have low power (1) for now. Their attitude towards the wind turbine project is considered neutral (1), as there is still plenty of space available along highways (1). Competitors have a high interest in other competitors, this case is considered to not be any different (2).

Windside: As the producer of the turbines that have been selected, windside is a powerful stakeholder (2). They are not easily to replace as they own the best developed and most efficient conventional wind turbine. Their attitude and interest in the project are positive and high, as this could be their opportunity to enter a new market firstand reap the benefits. Also the order of thousands of wind turbines would be very profitable.

Media: The media’s goal is to cover the news. They indirectly yield high power (2) as they can potentially influence civilians and the image of the project. Their attitude is considered neutral (1), as the media’s main goal is to cover the news. However, their attitude could potentially shift quickly to a negative or positive one, depending on the journalists and what would benefit the media best. The interest in the project is considered to be high (2), since it involves the safety of drivers and the topic of sustainable energy generation.

Local residents: Local residents usually are opposted to wind turbines placed nearby, due to scenery and noise pollution. When united, they can exert high power to delay or even prevent wind turbine projects (2) (BLW, 2014, Volkskrant, 2014). Their attitude is considered neutral, until proven that the wind turbines do not cause harm (1), while their interest in the project is high because of this matter (2).

ANWB: The Royal Dutch Touring club is a traveler's association in the Netherlands, supporting all modes of transport. This association lobbies for their members and aims to safeguarding the traveler's needs and interests. The ANWB has a convenant with Rijkswaterstaat, but only yields low power (1). Only fully backed by all members responding in large surveys, it could influence decisions of Rijkswaterstaat (Interview with de Bakker, 2014). Arjen de Bakker is the program manager of sustainability at the ANWB. The attitude of the ANWB towards the wind turbine project is considered positive (2), but their interest in the project is low (1). This could be improved by realizing features that benefit traveler's (Interview with de Bakker, 2014).

Environmental groups: Environmental groups can take part in the project process when they suspect harm to the environment, for example when the project can potentially harm natural habitats or animals such as birds. Their attitude would be on guard, neutral and leaning to oppose a wind turbine project until proven that there is hardly any to no damage to the environment (1). Environmental groups can have significant power today (2) with deep pockets to engage in legal battles to drag out projects and make them less interesting. However, the environmental groups are not likely to be interested in this project (0), as small wind turbines along highways do not seem to pose a threat to the environment.

Other energy generating companies: Companies that have powerplants that need to be shut off temporarately froom time to time will probably not be happy to hear about this project. However, the scale of the described project in this report in means of capacity is so low that energy companies are not threatened. Their interest and attitude are considered neutral (1), while their power is considered high (2) because of their deep pockets and lobbying power at the government.

4.4 Identifying stakeholder engagement strategies

Each stakeholder has been identified as a certain type of stakeholder. The ones that have a high degree of power are critical stakeholders to the project, as they can directly influence the results (Hillson and Simon, 2008). It is very important to keep or try get the critical stakeholders in a position that they will provide support to the project or minimize their influence and potential damage. Figure 22 summarizes the critical stakeholders and their perceived base attitude towards the project. Base attitude is considered the attitude of the stakeholder without any intervention from the project management.

	Supportive	Neutral	Opposing
Critical Stakeholders	Rijkswaterstaat Project organization Windside Political parties	Media Municipality Ministry of I & M Ministry of EA Environmental groups	

		Local residents	
Non critical Stakeholders	Companies electric driving ANWB	Other project investors Other energy companies	

Figure 22: Critical and non-critical stakeholders (Author, 2014)

It is important to sway the critical actors into all being supportive and keep the supportive actors that way, since they can directly influence the project with their powers. Figure 23 shows, based on research and interviews with experts and stakeholders, what potentially can be done to get and keep the neutral stakeholders on the supportive side. Also strategies to keep supportive stakeholders on the supportive side and opposing stakeholders to the neutral side are laid out.

Stakeholder	**Interest of stakeholder in project**	**Engagement tactics**	**Best case result**	**Worst case result**
Rijkswaterstaat	-Safety of drivers -Possible rent or electricity (Interview with de Bakker, 2014	-Guardrail to protect drivers -Offer electricity or rent to Rijkswaterstaat	-Wind turbines can be installed	-Rijkswaterstaat does not grant permission to build turbines
Windside	-Selling and developing reliable wind turbines (Interview with Stegenman, 2014)	-Close cooperation -Fulfill payments	-Reliable Wind turbines produced and succesfully used	-Windside does not deliver wind turbines
Media	-Covering news	-Convince that project is sustainable and no noise/horizon pollution - Ensure that the project is safe for traffic participants -Make them part of the process early on and update them (O'Leary, 2008) -Potential fuel reduction due to wind	-Media coverage is positive and helps create a sustainable and positive image of the project	-Media coverage is negative and potentially fuels and strengthens any opposition

		turbines		
Municipality	-Generating sustainable energy within area	-Offer opportunity to share sustainability image -Do everything according to legal standards	-Grants building permit	-Refuses to grant building permit
Ministry of I & M and Ministry of EA	-No interest unless Rijkswaterstaat has issues with the project	-Notify of project start and developments	-Does not intervene with project	-Intervenes with project and does not allow construction
Environmental groups	-No interest unless a threat to environment becomes clear	-Make them part of the process early on and update them (O'Leary, 2008) -Potential fuel reduction due to wind turbines	-Provide support or stay out of process	-Try to sabotage wind turbine project
Local residents	-Do not want to be harmed by wind turbine project	-Make them part of the process early on and update them (O'Leary, 2008) -Convince that project is sustainable and no noise/horizon pollution	- Provide support or stay out of process	-Try to sabotage wind turbine project
Companies electric driving	-Potentially connect electric charging stations with wind turbine project	-Share knowledge and look for business opportunities	-Co operation between companies and wind turbine project	-Do not work together with wind turbine project
Other project investors	-Wind turbine project might take the space that is needed	-Make an effort to co-operate. E.g for wind turbine project location is very important. Try to allocate less suitable space for wind turbines to solar panels	- Co operation between other investors so both are in a win-win situation	-Try to sabotage wind turbine project
ANWB	- Protect interests and rights of drivers	-Seek blinding reduction of disturbing vehicle neon-headlights by	-ANWB and its members supportive of wind turbine	-ANWB and members lobbying to Rijkswaterstaat to not grant permission

		wind turbine wall (Interview with de Bakker, 2014-Offer help for electric driving in the future -Potential fuel reduction due to wind turbines	project	for the project

Figure 23: Stakeholder engagement strategies

4.5 Conclusion stakeholder analysis

The most important finding of the stakeholder analysis is that every critical actor is supportive or can be swayed into being supportive without struggling through any major expected problems. This can be done by the project management of the wind turbine project, following the engagement tactics shown in figure 23. These tactics are directions and should be investigated more, as also other potential options that have not been listed due to the limited resources of this study. Examples of tactics are convincing local residents that the wind turbine project is not harmful to them, on the contrary, it might benefit them even due to a potential fuel reduction. Potential competitors could be approached to rationally divide geographical areas best suitable for wind turbines and e.g solar panels. The best case scenario is much more likely to happen than the worst case scenario, according to interviews with relevant stakeholders. Further research should focus on a more detailed strategy and engagement plan, including potential backup strategies in case relationships with stakeholders grow sour.

Chapter 5 The social cost benefit analysis

A social cost benefit analysis (SCBA) is an economic evaluation of a project that includes social effects and, if possible, translates these effects into monetary values. This SCBA is based on the methodology of the Algemene Leidraad Maatschappelijke Kosten Baten Analyse (ALMKBA) (CPB, 2013). The first step of this methodology is describing the problem situation. Appendix III shows this first step, including an explanation on what a SCBA is. Figure 24 shows the other steps that are taken.

Step 1	Problem analysis	Appendix III
Step 2	Determine reference alternative	Section 5.1
Step 3	Determine project alternative	Section 5.1
Step 4	Determine cost	Section 5.2
Step 5	Determine benefits	Section 5.2
Step 6	Comparison and results	Section 6.1
Step 7	Sensitivity analysis	Section 6.2
Step 8	Interpretation of SCBA	Section 6.3

Figure 24: Steps taken in the SCBA based on ALMKBA (CPB, 2013).

5.1 Reference- and project alternative, overview of social costs and benefits

The second and third step entail providing a description of the reference- and project alternative. This needs to be done first in order to compare the social costs and benefits later between the current situation and the situation in which the wind turbine project is carried out. Also these alternatives provide a demarcation to help identify the most important costs, benefits and effects.

Reference alternative: Current policies followed

According to the ALMKBA (2013), the reference alternative describes the likely development without the project alternative being carried out. In this SCBA the reference alternative assumes that there are no other developments along highways that could replace the wind turbine project. Even though solar panels along highways could potentially be a good alternative, the development of this technology for placing them along highways is as little developed as for windturbines. It has to be researched extensively what the effects and likelihood of placing solar panels along highways are. Without this research, any projections would not be considered reliable enough to include in this report as of right now.
The Prins Bernardweg Zaandam to Bolswarderbaan highway therefore stays the way it is and is only used for the purpose of providing a way for vehicles to travel to their destinations. The Dutch energy policy will keep focusing on reaching the 2020 sustainability targets by aiming for 6000 MW on shore wind energy capacity and increase offshore capacity from 220 MW to 4450 MW (Rijksoverheid, 2014). Conventional power plants are still built and repowered when needed.

Project alternative: Wind turbines along the highway
The project alternative entails using the median of the Prins Bernardweg Zaandam to Bolswarderbaan highway to install 50,000 WS 4B wind turbines. The projected annual output of approximately 200 gWh will not change the Dutch energy policy on reaching the 2020 sustainability targets. Conventional power plants are still built and repowered when needed, but the new 200 gWh could potentially replace a small power plant. The wind turbines are installed in the median of the highway, where all turbines are ready to generate power after 1 year. The wind turbine project will end in 2090 and it is assumed that the wind turbines have no value anymore at this point as they would be outdated.

Overview of the social costs and benefits
During the last decade several SCBA's have been carried out that were focusing on wind energy projects in the Netherlands. Based on these studies, interviews with experts and other scientific literature the costs and benefits for the wind turbine along the highway project are identified and shown in figure 25, including effects (Interview with Stevenhagen, 2014;Versteeg, 2014; Interview with de Bakker, 2014; CPB, 2005; Decisio, 2010; CE Delft, 2012; VNG, 2013; Decisio,

2014).

5.2. Social costs

Figure 25 shows the investment costs, operational costs, reserve capacity costs, balancing power costs and overcapacity costs as the main negative factors. Each of these cost factors is delineated and the data input for the SCBA is explained.

5.2.1 Investment costs

The investment costs consist out of multiple components; buying and installing wind turbines, cost due to lower travelling speed and establishing a connection to the electrical grid.

Figuur 25:Overview of social costs and benfits highway wind turbine project (Author, 2014).

Buying wind turbines

The wind turbines that will be used to fill the median of the Prins Bernardweg Zaandam to Bolswarderbaan highway are the Windside 4B turbines (WS 4).

- **Amount of turbines**: The WS-4B has a diameter of 1 meter (Windside, 2014). It has been assumed that 3 meters between each turbine should suffice in order to not negatively affect each other's production (Zaayer, 2014). However, engineer Wim Stevenhagen believes that due to the large amount of turbines placed next to each other, a distance of the width of one wind turbine would be sufficient (Stevenhagen, 2014). Wim Stevenhagen is specialist in the specific WS 4 turbines. To be safe, 1.1 meter is used as the space in between each turbine. Since the selected highway is 110 kilometers long, approximately fifty thousand wind turbines could be placed and this amount is used in the analysis.
- **Cost:** The cost of one WS-4B wind turbine amounts to 53.785 Euros (Windside, 2013). This amount excludes the handling fee, transport, insurance, fastening, and potential art color (Windside, 2013). To compensate for this exclusion, the final purchase cost of one turbine is estimated to be 55.000 Euros.

Installing wind turbines

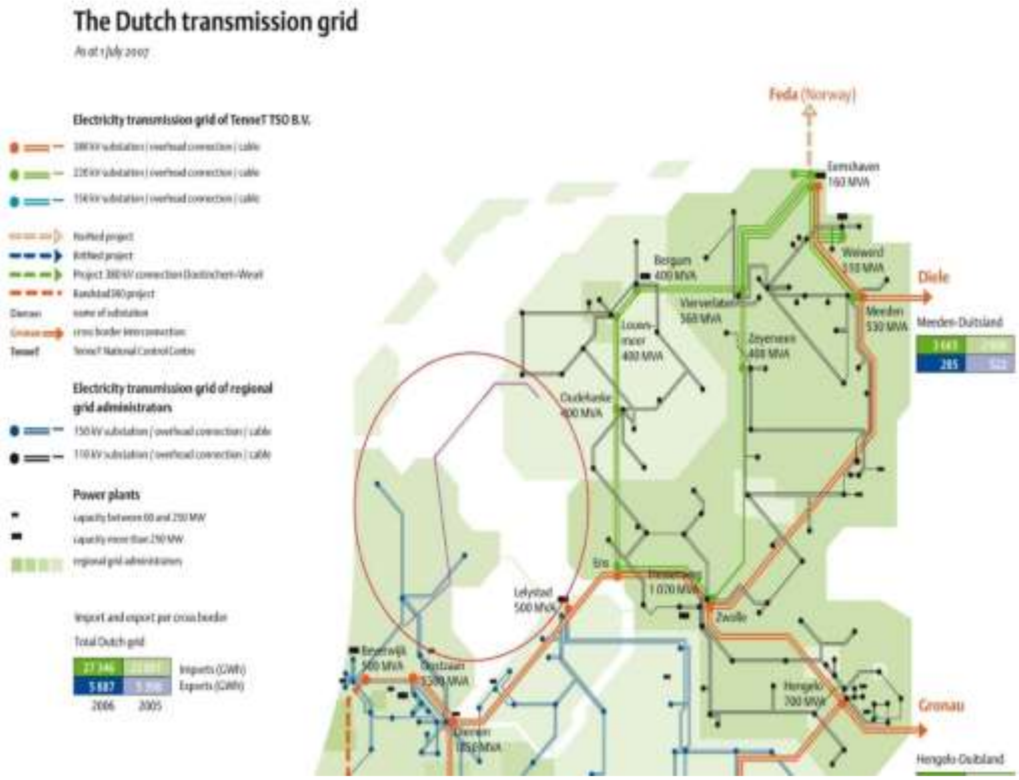
The ALMKBA points out that costs are determined by the resources the investors will spend to implement the project. These resources are not spent in the reference alternative (CPB, 2013). The largest amount of costs involved with installing the wind turbines consist out of wages for the workers involved.

- **Time to install turbines:** There are 7 people needed to install one WS 4 turbine. Currently the approximate time this can be done amounts to 30 minutes. It is assumed that due to learning effects the time to install one turbine can be lowered by 10 minutes, which means one turbine is installed in 20 minutes (Stevenhagen, 2014).
- **Cost to install turbines:** For the installment of the turbines no experts are required. It is assumed that a road worker between 0 and 5 years of working experience receives an average salary of 1850 euros gross income per month (Loonwijzer, 2014) and works 40 hours a week. It is assumed that the road worker works 160 hours a month to compensate for vacation- and sick time. This means that one crew of 7 workers can install 24 turbines a day for the cost of 647.5 Euros.
- **Total time limit to install turbines:** The total amount of fifty thousand wind turbines should be installed within a year, leading to approximately 9 crews of 7 people working for one year.

Establishing a connection to the electrical grid

The wind turbines need to be connected to the grid in order to transport the generated energy. Electricity distribution company Nuon has already installed transmission cables underneath a large part of the project's highway (Van Baal, 2008). The fact that there are already transmission lines installed, offers the possibility of less costs involved by placing additional ones if needed.

Figure 26 shows that there are transmission distribution substations relatively close to the selected highway. The purple line within the red circle shows the selected highway, -the blue and black lines show substations connections. The WS turbines do not necessarily need to be connected to high voltage transmission lines, local cables are also suitable connection points (Interview with Versteeg, 2014).



Figuur 26:Dutch transmission grid as of 1 July 2007 (Tennet, 2014).

Arjan de Bakker, program manager of sustainability at the ANWB, indicates that there are plans to install new transmission cables along many highways to provide support for enabling Wi-Fi connections (Interview with de Bakker, 2014). This could possibly be combined with the wind turbine project if those cables are necessary too for this matter. As for now it is unknown what connections and cables still need to be installed. Therefore this effect is considered a cost of unknown value.

5.2.2 Operational cost

<u>Maintenance</u>

To keep the wind turbines operational maintenance is required. The maintenance consists out of refreshing the oil of the turbines and replacing the ball bearings (Interview with Stevenhagen, 2014). The oil needs to be refreshed about 3 to 4 times a year, but with the automatic lubrication system in place the only thing that needs to be done is add lubrication oil every few years. Every 20 to 40 years, the ball-bearing of the turbines need to be replaced, depending on the location and the intensity of the wind. It is assumed that for this project the ball-bearing will be replaced every 25 years. Mick Sagrillo has over 33 years of experience in the small wind industry and estimates that 1% of the cost of the wind turbine system should be saved for maintenance (DWEA, 2013). For this particular project 0.25% is assumed to be enough. The oil is automatically refreshed and the turbine and generator hardly wear down (Interview with Stevenhagen, 2014).

5.2.3 Security of delivery

Wind energy is a variable energy source. This results in uncertainty regarding the security of delivering electricity. This uncertainty causes different kinds of costs to be made.

Reserve capacity costs

The uncertain supply of wind energy results into needing additional reserve capacity to maintain the security of electricity supply at all times. When there is insufficient balancing capacity available, the reserve capacity is used. Since the wind turbine project will add a new variable energy source, extra reserve capacity needs to be arranged. Technical University Delft has researched that when adding new wind energy capacity in the Netherlands, 1% of this capacity should be added as reserved capacity (IEA Wind, 2013). Since 2014, TSO TenneT has to buy primary reserve capacity through auctions. Currently 101 MW reserve capacity is needed per week. TenneT buys 105 MW, 70 MW through an international auction, paying 2582 to 3774 Euros per MW (Energeia, 2014). The other 35 MW is bought through a national auction, where prices per MW range between 3000 to 20000 Euros (VEMW, 2014). Based on this data, it is assumed that 1 MW reserve capacity costs 5400 Euros per MW per week. The 50.000 wind turbines combined would approximately form a capacity of nearly 23 MW.

Balancing power costs

Balancing power is the capacity that is used continuously in order to maintain the balance between the supply and demand of electricity. The cost of balancing amounts to 1.30 Euros per MWh (ECN, 2013).

Profile effect

Wind turbines produce energy when the wind is blowing, not necessarily when the demand is high. This leads to a lower average market price for wind energy. When the share of wind energy increases in the total electricity supply, this effect will be amplified. Other SCBA of wind projects take this effect together with reserve capacity costs into account by cutting a part of the electricity profits (CE Delft, 2012; CPB, 2013). This study assumes the option of signing 1 on 1 contracts with Rijkswaterstaat (Versteeg, 2014) for a fixed market price for electricity for a longer period of time. It is important to note that this is not a subsidy, but a business agreement.

Over capacity costs

At this moment there is an overcapacity of electricity supply available in the Netherlands (Zeilmaker, 2013). This results in extra costs because power plants are not turned down to 'balance', but completely shut down for some time. Electricity company Nuon lost half a billion

Euros due to temporarily shutting down her gas power plants, also Essent had to cancel the production of 3 Gigawatt (Zeilmaker, 2013). The majority of overcapacity in the Netherlands is caused by the very low prices of coal due to the shale gas revolution in the United States. However, new wind energy capacity could also cause extra costs before the market is balanced again. It is unknown what the share of new wind energy capacity would be in the costly unbalance. Therefore the over capacity effect is allocated as an unknown cost in the SCBA.

5.3 Benefits

Figure 27 shows positive benefit factors. Each of these cost factors is delineated and the data input for the SCBA is explained.

Figure 27: Overview of social costs and benefits highway wind turbine project (Author, 2014).

5.3.1 Exploitation profits

The profits from selling the electricity that is generated depends on the selling price and output of the wind turbines capacity. Empirical data shows the different estimated power production of the WS 4B wind turbines at different average wind speeds. Figure 28 shows these data.

WindsideDataSheet2009

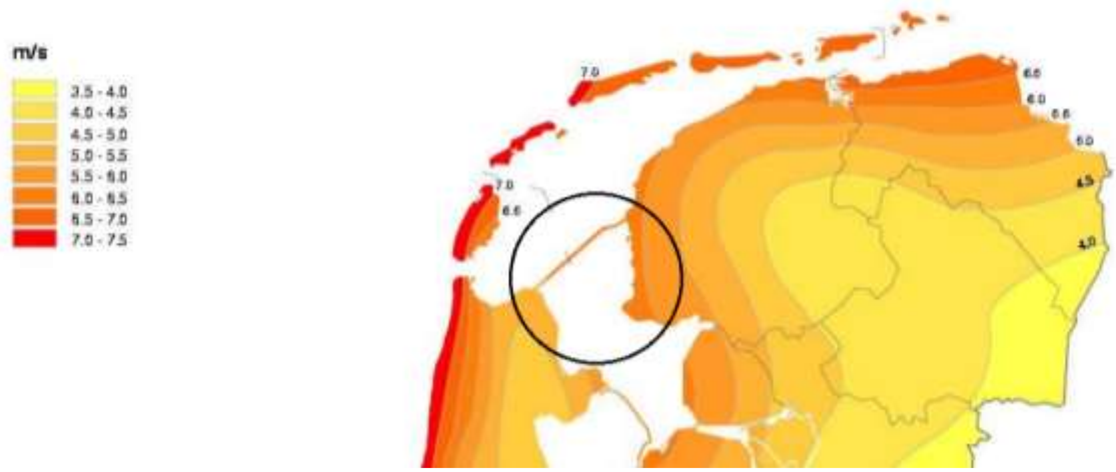
Windside Turbine Model	Height m	Diameter Ø	Swept Area m²	Weight Kg *	Wind endurance class m/s	Power Production at average wind speed of 5 m/s Annually in kWh **	Power Production at average wind speed of 7,5 m/s Annually in kWh **	Power Production at average wind speed of 10 m/s Annually in kWh **
WS-4B	4	1	4	1200	40	2000,00	5200,00	11180,00

* Turbines weight may change by +- 2 kg due to change in materials for certains applications.
** esimated power production when the turbine is installed according to Windside instructions.

Figuur 28:WS 4B characteristics (Windside, 2009)

Electricity profits

- **Average wind speed:** Figure 29 shows the average wind speed per year, measured on a height of 10 meters. The wind turbines however, will only be on a height of around 5 to 6 meters. It is assumed that the turbulence created by traffic will at least compensate for the lower wind speed. The average wind speed on the wind turbines for about 3 quarters of the turbines lies between 6.5 and 7.0. The other quarter is driven by an average wind speed that lies between 5.0 and 5.5. The SCBA will take the average of these ranges.



Figuur 29:Average windspeed at the selected highway, 1971-2000 (Edited from KNMI, 2014)

- **Annual power production at average wind speed:** Based on figures 29 it is assumed that 37500 wind turbines are driven by an average wind speed of 6.75 and 12500 wind turbines by 5.25. The corresponding outputs are estimated to be 4560 kWh and 2425 kWh respectively. This would mean an annual estimated output of 201.3 gWh. An average Dutch household consumes 3400 kWh a year (De Decker, 2009), meaning the wind turbine project could potentially generate power for around sixty thousand homes.

- **Electricity profits:** The Energy research Centre of the Netherlands (ECN) has performed a study estimating the prices for which electricity can be sold. ECN expects the price of electricity to rise to 60 euros per MWh in 2023, remaining steady and slightly dropping to 59 euros per MWh in 2030 (ECN, 2014). The SCBA of Decisio on offshore wind then assumes the price to rise to 74 euros in 2040 (Decisio, 2014).

5.3.2 Potential vehicle fuel use reduction

Driving along a long row of wind turbines makes one wonder whether the turbines cause resistance for the passing traffic. If this were the case, vehicles would burn through extra fuel compared to the situation of no wind turbines. However, the wind turbines rotate around a vertical axis and are placed in the median. Driving along this highway could potentially save fuel rather than costing more fuel. Wind experts Zaaijer, Van Raemsdonk and Stevenhagen all feel that if there is any effect, it would lean more to fuel reduction than to extra fuel consumption

(Interview with Zaaijer, 2014; Interview with Van Raemsdonk, 2014; Interview with Stevenhagen, 2014). Due to the high degree of uncertainty and lack of specific studies, this effect is included in the SCBA has a benefit with unknown value.

5.3.3 Higher road safety

In the United Kingdom many drivers use xenon headlights or rear lights on their vehicles. A poll among over thirteen thousand drivers showed that over 90% of the respondents think that xenon lighting is dangerous (Bagott, 2011). A study from Kansas University indicated that especially older people suffer from high intensity discharge headlamps that cause a blinding glare (Mainster & Timberlake, 2003). So while improving a drivers own safety, the use of these lamps decreases the safety of drivers confronted by the lights on another lane.

Arjan de Bakker, program manager at the ANWB, has noticed a high rate of criticism on the increasing amount of people driving with Xenon headlights in the Netherlands (de Bakker, 2014). Building a wall of wind turbines could diminish the blinding effect drastically for drivers on the other side of the highway. This means less dangerous situations due to blinding and less frustration for drivers, increasing their comfort of driving. The SCBA takes this effect into account by including it as a benefit of which the value is still to be determined.

5.3.4 Higher job availability

Producing and installing thousands of wind turbines along the highway requires some extensive manpower. After the turbines are installed, they also need to be maintained. This would mean that new jobs are created. Even though the production of the wind turbines will most likely not be carried out in the Netherlands, assembling, installing and maintaining the turbines would be done by Dutch workers. In order to create social benefits, the created jobs need to be additional jobs. If workers redistribute themselves to new jobs there is no additional job availability, thus no social benefits.

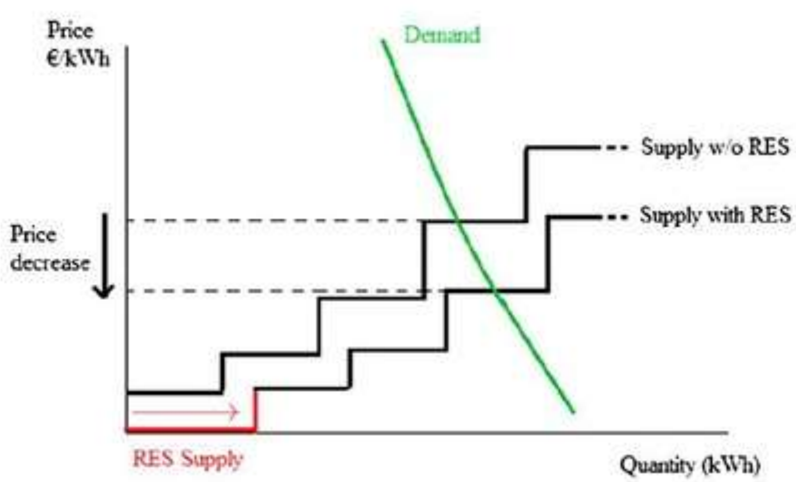
The Algemene Leidraad Maatschappelijke Kosten Baten Analyse states that unless a project provides direct effects on the job market, there are no social benefits unless the project leads to agglomeration effects (CPB, 2013). The Social cost benefit studies of CPB and Decisio on building offshore wind parks concluded in line with the Algemene Leidraad; building new offshore wind parks does not lead to additional jobs. However, there are SCBA's that provide counter arguments against the Leidraad and included higher job availability as a social benefit in their studies (VNG, 2013; CE Delft, 2013; CE Delft, 2012). The common agreement among the studies is that a high majority of workers do redistribute themselves to new jobs, but not all of them. This leads to a limited amount of additional jobs, resulting in some social benefits. An international study on the investments of offshore wind parks in the United Kingdom also concludes that a limited amount of additional jobs would be created (CE, 2012). All studies do agree that any effect on job availability would be larger on the short term rather than the long term. In case of the highway wind turbine project, the SCBA does include job availability effect as a benefit, but its value has yet to be determined.

5.3.5 First mover advantage

Building wind turbines for highways and installing them there is completely new. Nowhere in the world has a highway been used yet to place a row of hundreds to thousands of wind turbines. Therefore, the Netherlands could benefit from a 'first mover advantage'. If a specific wind turbine could be developed here and used everywhere else, together with exporting knowledge being ahead of competition, the Dutch economy could benefit from its first mover advantage and learning effects. However, the extent of these benefits are quite uncertain. Also the period of time the benefits last is uncertain, due to the leaking away of knowledge and the uncertain potential of the wind turbine development. These reasons make it hard to allocate an accurate value to this effect. Therefore the first mover advantage and learning effects are put as a benefit of which the value is still to be determined.

5.3.6 Effects on the market price

The electricity market price is determined by the marginal cost- and average cost function. The technology that can produce according to the lowest marginal costs will be used first, this is called the 'merit order'. As explained before, after assembling and installing the wind turbines, maintenance and operating costs are very low. This means that the marginal costs are almost zero and that wind turbines are first in the merit order. With many new wind turbines producing electricity, the overall marginal cost function stretches out, leading to lower costs and prices on the short term. Figure 30 illustrates the theoretical effect a large increase of renewable energy supplies would have on the market price. A study on wind energy in the Netherlands confirms that the use of wind energy does lower the electricity price, but this effect is small (Mulder & Scholtens, 2013). Also this effect is a redistributive effect, consumers pay less and suppliers pay more.



Figuur 30: Effect on market price when RES supply increases (Syntropolis, 2015)

5.3.7 Avoided spending on conventional power plant investments

When investments are made in sustainable energy generation, less investments need to be made in conventional energy generation. When wind turbines can replace the power plants running on conventional energy fuels like gas- and coal power plants, these investment- and operating costs are prevented. The highway wind turbine project could generate 201 gWh a year which is not enough to replace any coal fired power plant in the Netherlands (WSS, 2014). However, a gas-fired power plant could be replaced. The Algemene Leidraad Maatschappelijke Kosten Baten Analyse describes that when a new renewable energy source is large enough to influence prices, it will replace conventional capacity (CPB, 2013).

The study of CPB from 2005 includes the avoided investments effect and uses a value of 550 euro/kW prevented investment costs for a new gas-fired power plant (CPB, 2005). A more recent study of Fraunhofer shows investment costs for a new gas power plant ranging between 75 and 98 euros per MWh (Fraunhofer, 2013). The average of this value is used in the SCBA. Since several plants have been built years ago, 2020 will be taken as the year of replacement, with the lifetime of a gas-fired power plant of 20 years.

5.3.8 Avoided costs by not importing electricity

In May and June 2012, electricity imports in the Netherlands were higher than ever (CBS, 2012). While the electricity price in the Netherlands remained stable, countries like Norway and Germany had a supply surplus of cheap sustainable energy. In Norway a surplus of hydro-powered electricity was available as a result of the large volumes of precipitation there. In Germany, hefty subsidies for solar powered electricity in Germany resulted in a surplus of solar generated electricity. Therefore it was cheaper to import electricity elsewhere than to produce electricity from natural gas in the Netherlands.

If the Netherlands produces more sustainable electricity herself, less electricity would need to be imported. Since the electricity derived from wind energy will barely influence the electricity price in the Netherlands, it would still be cheaper to import electricity. In the future this might change again. For now the avoided import costs are noted as an unknown benefit.

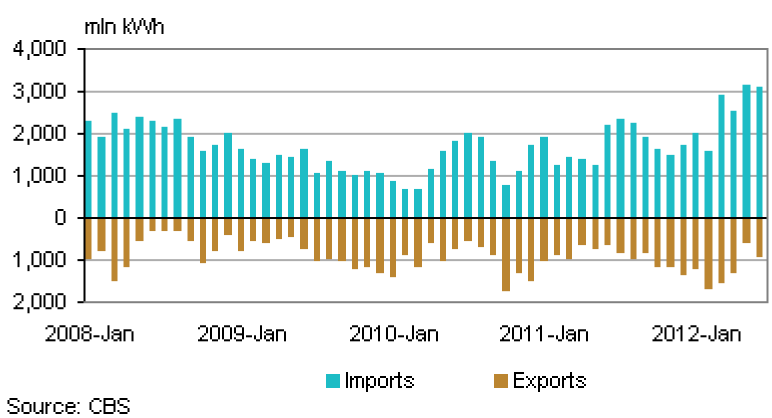


Figure 31: Imports and exports of electricity (CBS, 2012)

5.3.9 Avoided costs by reduced CO_2 emission damage

It has been topic of discussion whether investments in wind energy truly reduce CO_2 emissions on a European scale. The SCBA of Decisio on offshore wind parks (CPB, 2014), brought up lots of questions, as they gave the CO_2 reduction benefits (avoided damage to the environment by the reduction of CO_2) the value 0. This means that they argued that investments in wind energy do not cut down CO_2 emissions on a European level. This is against the ALMKBA methodology, which classifies the reduction of CO_2 by renewable energy as an important social benefit (CPB, 2013). Also TKI Wind op Zee argues that there is a net CO_2 reduction benefit (Ecofys, 2014) when investments in wind energy are made. This classification turns out to be crucial to the resulting net value of the SCBA. The SCBA of 2014 by Decisio has a negative net value of 5 billion Euros (CPB, 2014). However, when the CO_2 reduction benefits are included, scenario's seem to exist that range from -2.1 billion Euros to a positive net value of 12 billion Euros (Tieben & Hof, 2014). It is important to consider the arguments for each side to decide in what way this effect is included in this report.

The current policy to combat CO_2 emissions in Europe is the EU-Emission Trading System (EU-ETS) (EC, 2014). The system sets a CO_2 emission cap, meaning that no more CO_2 emissions can be made than the amount set as the cap. In the CO_2 rights trade market, CO_2 emission certificates can be bought and sold. The total emission value of the certificates resembles the CO_2 emission cap amount. In the EU-ETS conventional power plant owners need to buy CO_2 rights in accordance with their CO_2 emission. In a proper functioning system, there should be no more CO_2 emissions than the cap prescribes. This way over time, the cap can be lowered and therefore CO_2 emissions will be reduced.

The discussion on whether CO_2 reduction takes place strongly depends on the EU-ETS policy and what is done with this system in the future. As policy making around this topic is uncertain, several possible scenario's need to be discussed.

1. EU- ETS works as it was intended. The ETS has a cap and CO_2 emission allowances can be bought and sold on the market. There are no flaws.
2. EU-ETS is not effective. The cap is not working and CO_2 prices are zero or close to zero
3. Alternative policies that do not include a cap

Arguments of SCBA of Decisio

The SCBA of Decisio, which gave the CO_2 reduction benefits a value of 0, is based on the first scenario. When the ETS is working well, a local reduction of CO_2 does not offer CO_2 benefits. The sustainable energy that is produced by e.g. off shore wind parks makes the CO_2 price drop, offering room somewhere else to emit CO_2. The only costs saved are the avoided purchases of CO_2 allowances. The cost of purchased CO_2 emission allowances are therefore equal to the marginal cost to reduce CO_2. This means that the avoided purchases of allowances are benefits that are internalized in the price of electricity (CPB, 2005). The recent SCBA of CPB (CPB, 2014) uses these benefits which are considerably lower than benefits to CO_2 reduction.

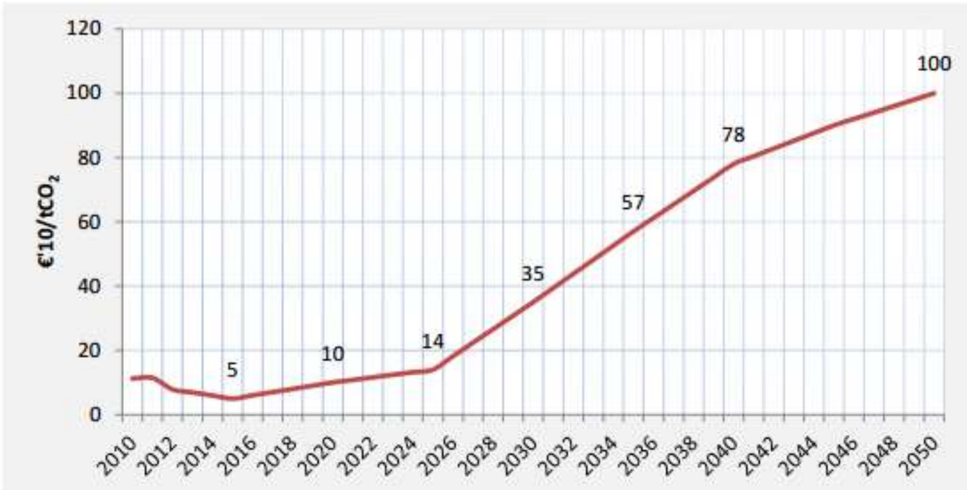


Figure 32: Projection of the ETS price (European Commission, 2013)

Counter arguments against SCBA of Decisio

Opponents like TKI Wind op Zee argue that the EU-ETS is currently not working as intended. The cap of the ETS has not been reached for years and there is an abundance of CO_2 allowances (TKI, 2014) resulting in a low CO_2 price. This means that the CO_2 reduction by wind energy is not emitted anywhere else. This provides CO_2 benefits through the actual reduction of CO_2. By reducing CO_2, damage is prevented to the environment. These prevented CO_2 emission damage costs replace avoided costs of purchasing CO_2 rights. The prices of the CO_2 rights turn very low to zero because the EU-ETS is not functioning. Since the prevented CO_2 emission damage costs are much higher than the avoided costs of purchasing CO_2 rights, a positive net value emerges in the majority of scenarios.

Choice made for this report

The crucial consideration seems to be whether the EU can get the EU-ETS to work or decides to choose an alternative solution. In the latter case there also will be CO_2 benefits because a reduction in some place will not create an advantage to pollute somewhere else, if that solution functions correctly. There is no way to tell whether the EU-ETS get pursued or replaced, the policy process is highly uncertain and there has not been any projections published on what is most likely to happen. This report assumes that the EU-ETS will not be replaced for quite some time, but will keep failing nevertheless. This argument is supported by the fact that the EU-ETS system has been failing for years and is unlikely to be reformed on the short term (Economist, 2013). The system cannot be changed unless significant numbers of MEPs change their minds, as they have been voting against reform of the EU-ETS (Economist, 2013). Even if reforms were negotiable, all 27 EU governments would need to approve which would take several years itself. Therefore in this SCBA the main scenario used is a replacement of the failing EU-ETS. This means that over the whole time horizon it is assumed that investments in renewable energy do cause a reduction of CO_2 emissions, following the reasoning of TKI Wind op Zee (2014) and the Algemene Leidraad Maatschappelijke Kosten Baten Analyse (2013).

CO_2 emission damage costs

The emission of CO_2 has many damaging effects, of which the main effects are summarized in figure 33 (CE Delft, 2010).

Damaging effects of CO_2 emissions
Effects on human health
Effects on productivity of ecosystems
Effects on materials and buildings
Effects on the resilience of the ecosystem

Figure 33: damaging effects of CO_2 emissions (CE Delft, 2010).

There have been several studies on how these damaging effects can be monetized. Figure 34 shows the study estimations of CE Delft. The costs depend on the possibility of damages to the global climate due to CO_2 emissions.

Damage		2010	2020	2030	2040	2050
Low	Euro / ton CO_2	7	17	22	22	20
Middle	Euro / ton CO_2	25	40	55	70	85
High	Euro / ton CO_2	45	70	100	135	180

Figure 34: cost of CO_2 emissions (CE Delft, 2010)

Reduction of CO_2

In order to determine how much CO_2 reduction takes place due to the wind energy project, a CO_2 emission factor of 0.57 kg / kWh is used (Harmelink et al, 2012). This value is derived from what the Dutch electricity mix would emit, combining gas- and coal fired power plants and nuclear power plants. It is assumed that this CO_2 emission factor lowers over time due to replacement of conventional plants with more efficient ones. This value then amounts to 0.35 kg/kWh.

5.3.10 Security of supply

The production of more wind generated electricity leads to a higher degree of diversification of energy sources. This results in being less dependent on fossil fuels, with natural gas in particular. More diversification could be beneficial for the security of supply. When the gas market is disturbed, there are alternative options to fall back to instead of importing gas. The SCBA of CPB reflected this benefit in the sensitivity analysis by lowering the discount rate of the exploitation profits by 0.8% (CPB, 2013). This SCBA also includes this percentage in the sensitivity analysis as there is no scientific consensus on the validity of including this effect in this manner (CPB, 2013).

5.3.11 Prevention of NOx, SO2 and PM10

The production of electricity in conventional power plants using coal, gas and biomass involve the emission of Carbon oxides (CO_2), nitric oxides (NO_x), sulphur oxides (SO_2) and particulate matter (PM_{10}). Wind turbines do not produce any of these emissions. In the Netherlands there are norms for how much NO_x and SO_2 can be emitted on a national level. For PM_{10} there are norms on the concentration in the air. The prevention costs are used for NO_x and SO_2, 9.4 and 5,4 Euro per kg respectively. For PM_{10} the damage cost of 44,3 Euro per kg is used (RIGO, 2012). The SCBA of CPB also used these values (CPB, 2013). It is assumed that the prevented emissions amount to 205 kg/gWh SO_2 (Essent, 2013) and 4,91 kg / gWh PM_{10} (Essent, 2012).

NO_x

The Dutch Emissions Authority has set performance standards for companies that participate in the NO_x emission trade (DEA, 2013). The electricity sector is also included in this scheme and needs to perform in line with the standards. The electricity sector performs slightly above the current standards. Figure 35 shows the performance standard rates of the last 5 years.

	2005 (jun-	2006	2007	2008	2009	2010	2011	2012	2013
psr verbranding (g/GJ)	68	63	58	52	46	40	39	38	37

Figure 35: Performance rate standards Knox emission (DEA, 2013).

It is assumed that in the future the sector will be performing according to the performance standards, which will be tightened over the course of time by the DEA. These performance standards are used to determine how much NO_x is emitted by the electrical sector, so an estimation can be made on how much NO_x emission is prevented by the wind turbine project.

5.4 Effects with value zero and net zero effects

There are several effects that have been identified which are valued to not influence the balance of the SCBA. These effects are important, as in the future they could be valued differently.

Costs due to increase travelling time: During the installation of the wind turbines, the maximum speed on part of the highway will most likely be only 50 kilometers an hour instead of 130 kilometers an hour. This means that travelers will take longer to reach their destinations, which can be monetized into social costs.

- **Loss of travelling time:** Since there are 9 crews working a day, 216 wind turbines are installed on a daily basis. This means that a length of the highway of 216 x 2.2 is used. Drivers should lower their speeds well in advance, it is assumed that a traffic sign is placed approximately 1 kilometer before the roadworks. This means that drivers are slowed for about 2 kilometers in total, when the distance covered to get back to the maximum speed is also included. It is assumed that the average speed during the 2 kilometers amounts to 80 kilometers an hour. The difference of 50 kilometers an hour over this distance results in a loss of 35 seconds for the driver.
- **Amount of drivers and value of loss of time:** In 2009, 9500 drivers used the Afsluitdijk on a daily basis (Berto, 2011). It is assumed that approximately 8000 drivers use the Afsluitdijk during the 8 hours that work is in progress. Furthermore, it is also assumed that the remaining part of the selected highway for the wind turbine project is used by the 8000 drivers and that these drivers are all living in the area or travelling for work. The travel time loss per hour for these group of travelers is valued at 9.55 Euros per hour (Rijkswaterstaat, 2011). This results in a total loss of approximately 740 Euros during the installation of the wind turbines. This amount is so small that this effect is included in the SCBA with a value of zero.

Effects on scenery and nature

Main reasons behind resistance to wind parks are the potential noise and scenery pollution they can cause. Highways do not have much of a scenery value in the Netherlands, so placing wind turbines in the median is not considered scenery pollution. Harald Versteeg from Rijkswaterstaat also indicated that he expects no problems regarding scenery pollution. This effect is therefore rated zero.

Sound

In the case of the highway wind turbine project, there is no noise pollution coming from the wind turbines. The output of the turbines ranges from 0-5 dB (Windside, 2014). This is practically soundless already and the noise from highway traffic far exceeds this value. Wim

Stevenhagen (Interview with Stevenhagen, 2014) has indicated that the turbines can even be used to reduce sound by forming a sound barrier. According to the specialist, empirical results show a reduction of up to 15%. However, since the empirical results are not published and the turbines in this specific case are placed in the median, this potential benefit has been given the value zero.

Subsidies

Potential subsidies have no effect on the results of a SCBA. The costs of the government are profits of the companies investing in the wind turbine project, so the balance would be zero. Sometimes it is important to compare different alternatives on the subsidy that is needed to be profitable, but since the reference alternative contains no subsidies these will not be used in the SCBA. During the sensitivity analysis the effect of subsidies is investigated for a business case perspective.

Excess burden of taxes

When the government grants subsidies to help financing project, an effect called the 'excess burden of taxes' emerges due to taxing disturbances and additional administrative costs. Since the SCBA does not include subsidies granted by the government, the analysis will rate this effect zero

5.5 Additional assumptions for parameters and effects

In order to complete the analysis, there are still some parameters and effects left to discuss.

Time horizon

The time horizon chosen for the SCBA ranges from 2015 until 2090. The reason behind this range is that the WS 4B turbines have a very technical life expectancy. As long as the ball bearings are replaced every 25 years, the turbines could be functioning as new for over 150 years (Interview with Stevenhagen, 2014). This assumption would require estimating a rest value of the turbine. However, these high life expectancies sound questionable and there is no empirical evidence that shows the validity of this claim. Therefore it is assumed that the wind turbines will either be replaced by better products or have worn out after 75 years.

Discount rate

The Algemene Leidraad Maatschappelijke Kosten Baten Analyse prescribes using a discount rate of 5.5%. This value will be used for all costs and benefits, except for the irreversible climate change effects CO_2, NO_x and SO_2. These will be discounted by 4% according to the ALMKBA (CPB, 2013).

Estimation electricity price

It is assumed that after 2040 the electricity price will increase with 1 Euro per year per MWh. When the price of 100 euros is reached in 2067, the price stays fixed at this amount.

Estimation CO_2 emission damage costs

The middle path of the CO_2 emissions is assumed to increase at exactly the same rate as it has over the previous decades, with 15 Euro per ton CO_2 every decade,. The low price path is considered to grow slightly from 20 to 23. The high damage price path is expected to keep growing at the same intervals as it is expected to 2050.

Damage		2050	2060	2070	2080	2090
Low	Euro / ton CO_2	20	21	22	23	23
Middle	Euro / ton CO_2	85	100	115	130	145
High	Euro / ton CO_2	180	235	300	375	455

Figure 36: Assumed CO_2 damage price paths (Author, 2014)

Estimation NO_x, SO_2 and PM_{10} emission damage costs

The NO_x, SO_2 and PM_{10} emission damage or prevention costs are assumed to grow in the future, just like the CO_2 emission damage costs will grow in the middle price path. It is assumed that the costs grow with 15% per decade.

6. Results of the Social Cost Benefit Analysis

In this chapter, the first results of the SCBA are shown in 6.1. The results are then interpreted and discussed in 6.2, followed by sensitivity analyses in section 6.3. After these sensitivity analyses are performed and interpreted, the final results of the SCBA are shown and discussed. In section 6.4. The chapter concludes with lining up the most important observations and conclusions that can be drawn by the SCBA and offers a recommendation based on the SCBA perspective.

6.1 First results of the SCBA

The results of the SCBA of the wind turbine project are shown in figure 37. These results are based on the main values for the factors described in chapter 5. Figure 37 shows that launching the wind turbine project would cost the society approximately 2,3 billion Euros. The main costs result from the initial purchase of the wind turbines. The main benefits are derived from the avoided damage by CO_2 emissions, followed by the annual electricity profits. The cost for this project currently amounts to 11,500 euro per MWh. In comparison, offshore wind projects currently price 200 euro per MWh (OWW, 2014). The SCBA by Decisio on offshore wind projects costs ranging from 355 euro per MWh to 200 euro per MWh (CPB, 2013). Onshore wind costs are currently in the range of 50-65 euros per MWh (IEA, 2012). The wind turbine purchase price would have to be reduced to approximately 8,000 Euros per windturbine in order to achieve the cost of 200 euro per MWh. Since the current price amounts to 53,000 Euros, it is highly unlikely that a cost reduction of 85% can be achieved this way. Studies suggest that the life cost of energy for onshore wind energy can be reduced by 0-40% by 2030 (IEA, 2012). However, these studies assume the cost of 50-65 euros per MWh in base year 2011 and include larger wind turbine installations than the small windside turbines used in this exploratory study.

Direct Installation of all wind turbines in 2015	Total costs in millions
Wind turbine purchases	**2689**
Worker costs to install turbines	**1,3**
Yearly maintenance fees	**120**
Reserve capacity cost	**115,3**
Balancing cost	**4,7**
Connection to grid costs	**?**
Increased travelling time costs	**0**
Sum	**2.930,60**
	Total benefits in millions
Annual Electricity profits	**241,6**
Avoided investment cost	**14**
Avoided CO_2 emission damage costs	**311**
Annual avoided NO_x output cost	**23,8**
Annual avoided SO_2 output costs	**7,6**

Annual avoided PM_{10} output costs	**1,5**
Avoided costs by not importing electricity	**+**
First mover advantage	**+**
Higher job availability	**+**
Higher road safety	**+**
Vehicle fuel use reduction	**+**
Potential sound pollution reduction	**0**
Sum	**599,5**
Total balance costs and benefits	**-2.331,10**

Figure 37: Results SCBA wind turbine project

6.1 Interpretation of first SCBA results

The SCBA results show that it seems paramount to spread the installation of the wind turbines over more than just one year. At the cost side, the wind turbine purchases amount to over 90% of the total costs. Spreading these costs out over several years will cut expenditures greatly. Another reason why spreading out the installation of the turbines is because the avoided CO_2 emission benefits have a larger growth in the future. Also the electricity price is expected to stay stable for the first 15 years before growing, raising the annual electricity profits benefits later in time. The avoided CO_2 emission- and annual electricity profits benefits are the biggest contributors to the total benefits. Due to these reasons, it is considered worthwhile to spread the installation of the wind turbines over 20 years. The reduction from spreading out the costs should outweigh the loss of benefits. The extra time also enables research and development to reduce the wind turbine price and possibly increase their efficiency. The most important reason however is to spread out the initial purchase costs of the wind turbines.

Spreading the installation

In order to find out what difference this altered alternative makes, the analysis is run again with the same input values as before. The only difference is that the wind turbines are now installed over the first 20 years. Figure 38 shows that spreading the installation would reduce the costs by almost a billion Euros, to still a negative net value of approximately 1,4 billion Euros, or 690 euro per MWh. This calculation does not include a potential wind turbine price reduction and increased efficiency of the wind turbines installed in the future. This, among other scenarios, are taken into account in the sensitivity analyses.

	All wind turbines from start	Spread installation	Difference
	Total costs in millions	Total costs in millions	Costs saved
Wind turbine purchases	**2689**	**1695,3**	993,7
Worker costs to install turbines	**1,3**	**0,9**	0,4
Yearly maintenance fees	**120**	**74,9**	45,1
Reserve capacity cost	**115,3**	**71,9**	43,4
Balancing cost	**4,7**	**2,9**	1,8
Sum	**2.930,60**	**1.845,80**	1084,8
	Total benefits in millions	Total benefits in millions	Benefits lost
Annual Electricity profits	**241,6**	**164,7**	76,9
Avoided investment cost	**14**	**14**	**0**
Avoided CO_2 emission damage costs	**311**	**249,2**	61,8
Annual avoided NO_x output cost	**23,8**	**18,2**	5,6
Annual avoided SO_2 output costs	**7,6**	**5,8**	1,8
Annual avoided PM_{10} output costs	**1,5**	**1,1**	0,4
Sum	**599,5**	**453**	146,5
Total balance costs and benefits	**-2.331,10**	**-1.392,80**	-938,3

Figure 38: Results SCBA comparison between installing all the turbines right away vs. a spread installation

6.2 Sensitivity analyses

The interpretation and analyses in section 6.1 have brought up the possibility that a spread installation should be investigated. Results so far show that a spread installation is preferred over a direct installation. In this section, the two alternatives are investigated further. The sensitivity analyses that are following will first investigate the effects individually, before being worked out in three different scenarios.

6.2.1 Different electricity price paths:

The price path used for electricity profits has been relatively low compared to the KBA Structuurvisie 6000 MW Windenergie op land (WOL) (CPB, 2013). The current price path used and the price paths used in the WOL are shown in figure 39. Even the lowest price path used in WOL is higher than the currently used price path. It is assumed that during the time period between 2040 and 2090 the electricity price keeps rising, slightly faster than before due to resources getting scarcer.

Price path (in Euro / MWh)	**2015**	**2020**	**2040**
Currently used	54	60	74
Low price path WOL	63	71	83
Middle price path WOL	63	74	98
High price path WOL	63	84	104

Figure 39: Different potential electricity price paths (ECN, 2014; CPB, 2013)

Direct Installation	**Current price path**	**Low WOL**	**Middle WOL**	**High WOL**
	Total benefits in millions	**Total benefits in millions**	**Total benefits in millions**	**Total benefits in millions**
Annual Electricity profits	**241,6**	**286,9**	**325,5**	**345,3**
Benefits gained	**-2.331,10**	**45,2**	**83,9**	**103,6**

Figure 40: Results for different price paths for electricity profits for direct installation.

Spread Installation	**Current price path**	**Low WOL**	**Middle WOL**	**High WOL**
	Total benefits in millions	**Total benefits in millions**	**Total benefits in millions**	**Total benefits in millions**
Annual Electricity profits	**164,7**	**191,5**	**222**	**235,8**
Benefits gained	**-1.392,80**	**26,9**	**57,3**	**71,2**

Figure 41: Results for different price paths for electricity profits for a spread installation.

Figure 40 shows the results for the different price paths for electricity profits for a direct installation. Changing to the low price path of WOL results in a 19% increase in benefits, to the middle path in 35% more profits and changing to the high WOL path results in 43% more profits. The maximum amount of benefits gained is if the electricity price path follows the high WOL, resulting in 104 million more positive benefits. For a spread installation the max benefits amount to 71 million Euros.

Main conclusion

The main conclusion that can be drawn from this analysis is that the annual electricity profits factor is quite sensitive to the price path chosen and is therefore an important factor to be dealt with. It is also worthy to note that even in the best case scenario, the spread installation has only 33 million Euros worth of less benefits. The main reason for the latter is that the price paths really start growing being further into the future. By 2035, also the spread alternative has installed all the wind turbines to benefit from the stronger growth in the future. This means that choosing a spread installation is more risk aversive, minimizing loss while sacrificing not that much profit.

6.2.2 Different CO_2 emission damage price paths

For the initial SCBA, the middle path of the expected CO_2 emission damage was chosen. This is the most likely path to happen, but there are also two other scenarios possible. The damage done by CO_2 emissions can also be lower than expected, or higher (CE Delft, 2010).

Direct Installation	Low CO_2 emission damage path	Middle CO_2 emission damage path	High CO_2 emission damage path
	Total costs in millions	Total costs in millions	Total costs in millions
Wind turbine purchases	2689	2689	2689
Worker costs to install turbines	1,3	1,3	1,3
Yearly maintenance fees	120	120	120
Reserve capacity cost	115,3	115,3	115,3
Balancing cost	4,7	4,7	4,7
Sum	2.930,60	2.930,60	2.930,60
	Total benefits in millions	Total benefits in millions	Total benefits in millions
Annual Electricity profits	241,6	241,6	241,6
Avoided investment cost	14	14	14
Avoided CO_2 emission damage costs	92,4	311	653,4
Annual avoided NO_x output cost	23,8	23,8	23,8
Annual avoided SO_2 output costs	7,6	7,6	7,6
Annual avoided PM_{10} output costs	1,5	1,5	1,5
Sum	381	599,5	942
Difference middle path	-218,5	-	341,5
Total balance costs and benefits	-2.549,70	-2.331,10	-1.988,60

Figure 42: Results of SCBA at different CO2 emission damage price paths for direct installation

Figure 42 shows results for the different CO_2 emission damage price paths. Following the higher price path, the direct installation will yield around 342 million Euros worth more of benefits compared to the middle price path. Following the lower price path results in additional costs worth 218 of million Euros. The choice of price path changes the net benefits dramatically.

Spread Installation	Low CO_2 emission	Middle CO_2 emission	High CO_2 emission

	damage path	damage path	damage path
	Total costs in millions	Total costs in millions	Total costs in millions
Wind turbine purchases	1695,3	1695,3	1695,3
Worker costs to install turbines	0,9	0,9	0,9
Yearly maintenance fees	74,9	74,9	74,9
Reserve capacity cost	71,9	71,9	71,9
Balancing cost	2,9	2,9	2,9
Sum	1.845,80	1.845,80	1.845,80
	Total benefits in millions	Total benefits in millions	Total benefits in millions
Annual Electricity profits	164,7	164,7	164,7
Avoided investment cost	14	14	14
Avoided CO_2 emission damage costs	67,3	249,2	543,8
Annual avoided NO_x output cost	18,2	18,2	18,2
Annual avoided SO_2 output costs	5,8	5,8	5,8
Annual avoided PM_{10} output costs	1,1	1,1	1,1
Sum	271,1	453	747,6
Difference middle path	-181,9	-	294,6
Total balance costs and benefits	-1.574,70	-1.392,80	-1.098,20

Figure 43: Results of SCBA at different CO^2 emission damage price paths for spread installation

Spreading out the installation of the wind turbines while the electricity price follows the higher price path raises the benefits by 295 million Euros, while the lower price path increases the costs by 182 million Euros.

Main conclusion

The analysis results show that the choice of the CO_2 emission price path has a heavier impact than the electricity price path due to the larger values and variation. The choice that has to be made depends on the risk adversity of the decision maker. Choosing the spread installation would yield 48 million less potential benefits compared to direct installation, but losses are 37 million Euros less in case of the low CO_2 emission damage path.

6.2.3 Higher output for the turbines

A higher electricity output means higher electricity profits. There are two occasions that the wind turbine output could be higher than considered in the main analysis. First, the effect of the traffic turbulence could potentially be bigger or smaller than so far expected and increase or decrease the wind speed. A decrease in this situation would mean that the positive effects that were expected do not happen. Figure 44 shows the results when the output increases or decreases by 5 and 10% due to the traffic turbulence effect. It must be noted that increasing the output will increase the costs of reserve capacity and balancing.

Direct installation	Current	-10%	-5%	5%	10%
Higher/lower output	Total benefits in millions	Total benefits in millions	Total benefits in millions	Total benefits in millions	Total benefits in millions
Reserve capacity cost	115,3	103,8	109,5	121,1	126,8
Balancing cost	4,7	3,8	4,2	5,2	5,7
Annual Electricity profits	241,6	217,5	229,6	253,7	265,8
Avoided investment cost	14	12,6	13,3	14,7	15,4
Avoided CO_2 emission damage costs	311	279,9	295,4	326,5	342,1
Annual avoided NO_x output cost	23,8	21,5	22,7	25	26,2
Annual avoided SO_2 output costs	7,6	6,8	7,2	8	8,3
Annual avoided PM_{10} output costs	1,5	1,3	1,4	1,6	1,6
Total Benefits gained	-2.331,10	-47,5	-23,6	23,7	47,4

Figure 44: Results of SCBA with different level of generated electricity output for direct installation

Spread Installation	Current	-10%	-5%	5%	10%
Total benefits in	Total benefits	Total benefits	Total benefits	Total benefits	Total benefits

millions	in millions	in millions	in millions	in millions	in millions
Reserve capacity cost	71,9	64,7	68,3	75,5	79,1
Balancing cost	2,9	2,6	2,8	3,1	3,2
Annual Electricity profits	164,7	148,2	156,4	172,9	181,1
Avoided investment cost	14	12,6	13,3	14,7	15,4
Avoided C_{O2} emission damage costs	249,2	224,3	236,8	261,7	274,1
Annual avoided NO_x output cost	18,2	16,4	17,3	19,1	20
Annual avoided SO_2 output costs	5,8	5,2	5,5	6,1	6,4
Annual avoided PM_{10} output costs	1,1	1	1,1	1,2	1,3
Total benefits gained	-1.392,80	-37,8	-18,9	18,9	37,8

Figure 45: Results of SCBA with different level of generated electricity output for spread installation

Customized wind turbine
The spread alternative offers time to research and develop a truly customized wind turbine. To take this possibility into account, an additional 10% output is added to the wind turbines installed from 2025 onwards. The new wind turbine would be developed within 10 years. Figure 46 shows the additional benefits for only the 10% extra output from 2025 onwards.

Spread Installation	Current	10%
	Total benefits in millions	Total benefits in millions
Reserve capacity cost	71,9	74,5
Balancing cost	2,9	3
Annual Electricity profits	164,7	171,1
Avoided investment cost	14	14,7
Avoided CO_2 emission damage costs	249,2	260,1
Annual avoided NO_x output cost	18,2	19
Annual avoided SO_2 output costs	5,8	6
Annual avoided PM_{10} output costs	1,1	1,2

Benefits customized turbine	-1.392,8	16,4

Figure 46: additional benefits for only the 10% extra output from 2025 onwards

Main conclusion

The results of the SCBA's in this section show that altering just the output value of produced electricity creates a linear range of gained or lost benefits. The direct installation results change by 24 million for every 5% gained or lost, while a spread installation either gains or loses 19 million euros. However, a spread installation is considered to have half of the installed wind turbines work more efficiently. An increase in output of the spread installation would therefore be more beneficial than the direct installation, by almost 12 million Euros per 10% addition of output. It must be noted that these results can change drastically in combination with other effects, such as a high electricity price path and CO_2 emission damage costs price path.

6.2.4 Lower purchase price for wind turbines

The production process of the turbines could be improved over time (Versteeg, 2014), which should make the turbines considerably cheaper to purchase. However, making the turbines more efficient could also potentially reduce this effect. This analysis considers the possibility of reducing the purchase costs by 10%, 15% and 20%. The wind turbines installed from 2025 onwards could be purchased cheaper. It is assumed that the maintenance costs is not influenced because the maintenance only consists out of refreshing the oil and replacing the ball bearings. This will not change unless a whole different type of wind turbine would be developed.

Spread installation	Current	10%	15%	20%
	Total costs in millions	Total costs in millions	Total costs in millions	Total costs in millions
Wind turbine purchases	1695,3	1632,7	1601,4	1570,1
Worker costs to install turbines	0,9	0,9	0,9	0,9
Yearly maintenance fees	74,9	74,9	74,9	74,9
Reserve capacity cost	71,9	71,9	71,9	71,9
Balancing cost	2,9	2,9	2,9	2,9
Sum	1.845,80	1.783,20	1.751,90	1.720,60
Cost reduction	-1.392,80	62,6	93,9	125,2

Figure 47: Results of a purchase price change after 10 years.

Main conclusion

The potential reduction in purchase costs generates a considerable amount of benefits. The sooner the wind turbines can be bought cheaper, the greater this effect will be.

6.2.5 Benefits due to security of supply

Adding wind power to the energy supply leads to a diversification in energy sources. The production of more wind generated electricity leads to a higher degree of diversification of energy sources, resulting in being less dependent on fossil fuels and thus benefiting the security of supply (ECR, 2011). The SCBA of CPB reflected this benefit in the sensitivity analysis by lowering the discount rate of the exploitation profits by 0.8% (CPB, 2013). Tieben en Hof (2014) lower the discount rate by 0.4% to investigate this effect. The argumentation behind lowering the discount rate is because the diversification is considered to lower the investment risk against disappointing macro-economic results. However, there is no scientific consensus on the validity of including this effect in this manner (CPB, 2013).

Spread Installation	Current price path -0,4 %	Low WOL -0,4 %	Middle WOL -0,4 %	High WOL -0,4 %
Securty of supply benefits	19,1	21,4	25,2	26,7

Spread Installation	Current price path -0,8 %	Low WOL -0,8 %	Middle WOL -0,8 %	High WOL -0,8 %
Securty of supply benefits	41,3	46,4	54,6	57,8

Figure 48: Security of supply benefits spread installation

Direct installation	Current price path -0,4 %	Low WOL -0,4 %	Middle WOL -0,4 %	High WOL -0,4 %
Securty of supply benefits	20,9	23,7	27,7	29,4

Direct Installation	Current price path -0,8 %	Low WOL -0,8 %	Middle WOL -0,8 %	High WOL -0,8 %
Securty of supply benefits	45,0	51,0	59,7	63,3

Figure 49: Security of supply benefits direct installation

6.2.6 Best, worst and expected scenario results

In the previous sections effects on the main scenarios have been investigated individually. In this section all the effects are taken into account. By investigating the best, worst and most likely scenario, the range of net present values can be estimated. For the best case scenario, all effects are assumed to have the value that maximizes the benefits. The worst case scenario works exactly the opposite way. The neutral case scenario finds values that lay in the middle between both extremes.

Direct Installation

Best case scenario

- High electricity price path WOL
- High CO_2 emission damage path
- +10% output due to positive traffic turbulence results
- 0,8% security of supply discount

Worst case scenario

- Current electricity price path
- Low CO_2 emission damage path
- -10% output due to negative traffic turbulence results
- 0% security of supply discount

Neutral case scenario

- Low WOL price path
- Current CO_2 emission damage path
- 0% more output by traffic turbulence
- 0,4% security of supply discount.

Spread installation

Best case scenario

- High electricity price path WOL
- High CO_2 emission damage path
- +20% output, 10% by positive traffic turbulence and 10% by more efficient turbines from 2025 onwards
- -20% purchase costs from 2025 onwards
- 0,8% security of supply discount

Worst case scenario

- Current electricity price path
- Low CO_2 emission damage path
- -10% output due to negative traffic turbulence results, +0% from new turbines)
- 0% less purchase costs
- 0 security of supply discount

Neutral case scenario

- Low WOL price path
- Current CO_2 emission damage path
- +5% output due to more efficient turbines from 2025 onwards
- -10% purchase cost (spread only)
- 0,4% security of supply discount

Direct installation	Base scenario	Best case scenario	Worst case scenario	Neutral scenario
	Total costs in millions	Total costs in millions	Total costs in millions	Total costs in millions
Wind turbine purchases	2689	2689	2689	2689
Worker costs to install turbines	1,3	1,3	1,3	1,3
Yearly maintenance fees	120	120	120	120
Reserve capacity cost	115,3	115,3	103,8	115,3
Balancing cost	4,7	5,1	4,2	4,7
Sum	2.930,60	2.931,10	2.918,60	2.930,60
	Total benefits in millions	Total benefits in millions	Total benefits in millions	Total benefits in millions
Annual Electricity profits	241,6	449,4	217,5	310,6
Avoided investment cost	14	15,4	12,6	14
Avoided CO_2 emission damage costs	311	718,8	83,2	311
Annual avoided NO_x output costs	23,8	26,2	21,5	23,8
Annual avoided SO_2 output costs	7,6	8,3	6,8	7,6
Annual avoided PM_{10} output costs	1,5	1,6	1,3	1,5
Sum	599,5	1.219,80	342,9	668,5
Difference with base scenario		608,3	-244,7	68,9
Total balance costs and benefits	-2.331,10	-1.722,80	-2.575,80	-2.262,20
Benefit cost ratio	0,2	0,4	0,1	0,2

Figure 50: Final scenario SCBA results for the direct installation of all wind turbines

Spread installation	Base scenario	Best case scenario	Worst case scenario	Neutral scenario

	Total costs in millions	Total costs in millions	Total costs in millions	Total costs in millions
Wind turbine purchases	1695,3	1570,1	1695,3	1632,7
Worker costs to install turbines	0,9	0,9	0,9	0,9
Yearly maintenance fees	74,9	74,9	74,9	74,9
Reserve capacity cost	71,9	81,7	64,7	74,9
Balancing cost	2,9	3,3	2,6	3
Sum	1.845,80	1.730,80	1.838,30	1.786,20
	Total benefits in millions	Total benefits in millions	Total benefits in millions	Total benefits in millions
Annual Electricity profits	164,7	334,9	148,2	217,1
Avoided investment cost	14	16,1	12,6	14,3
Avoided CO_2 emission damage costs	249,2	622,5	60,6	254,6
Annual avoided NO_x output cost	18,2	20,8	16,4	18,6
Annual avoided SO_2 output costs	5,8	6,6	5,2	5,9
Annual avoided PM_{10} output costs	1,1	1,3	1	1,2
Sum	453	1.002,20	244	511,8
Difference with base scenario		664.2	-201,5	118,4
Total balance costs and benefits	-1.392,80	-729	-1.594,30	-1.274,40
Benefit cost ratio	0,25	0,6	0,15	0,3

Figure 51: Final scenario SCBA results for the spread installation of all wind turbines

6.2.7 Final interpretation and conclusion SCBA results

The main SCBA scenario showed that installing all the wind turbines in 2015 yields a negative net value of around 2.3 billion Euros. The largest factor that plays a role in the negative value is the total purchase costs of all the wind turbines, amounting to over 90% of the costs. This is the main reason why installing all the wind turbines at one time is not a good idea. Spreading out the installment over 20 years would reduce costs by over 900 million Euros. Installing the wind turbines over time would also grant time for R&D to improve the efficiency of the wind turbines for additional output and the production process to lower the initial wind turbine purchase price. Even though extra output increases reserve capacity- and balancing costs, the additional gains by avoided CO_2 emission damage and electricity profits outweigh these costs substantially.

Combining all the effects into one scenario shows that neither concept comes close to a net constant value (NCV) of zero. In the worst case, a direct installation would cost society almost

2.6 billion Euros, while in the best case scenario 1.7 billion euros would be lost. The spread installation concept does considerably better, with a worst case of -1,6 billion euros and a best case of -0,7 billion euros. Even though there still are positive effects of which its values has not yet been determined, it is highly unlikely to impossible that these will get the NCV even near zero. From an investor perspective the situation seems even direr. Without receiving any subsidies, the best case scenario would mean a loss to the investor of 1,4 billion Euros. The investor would need a subsidy equal to the electricity price for the first 20 years to break even in the best case scenario. It can therefore be concluded that both from the perspective of the society and investors that the conventional wind turbine project along highways, under the conditions described in this report, is not worth it of being launched.

7 Overall conclusion, recommendations and self-reflection

In this concluding chapter the overall conclusion is drawn and translated into recommendations regarding the concept of installing wind turbines along highways. The report will be finalized with a critical self-reflection of the author.

7.1 Overall conclusion

The research objective of this explorative feasibility report was to answer to what extent the concept of converting traffic turbulence and regular wind into useful energy could be implemented in the Netherlands. This research question was attempted to be answered by performing a virtual case study. The case study focuses on the implementation of small scale wind turbines along the Prins Bernardweg Zaandam to Bolswarderbaan highway in the Netherlands. In order to do investigate the feasibility, the technical, stakeholder- and social costs and benefits perspectives have been analyzed.

The technical analysis showed two potential concepts of generating energy through wind along the highway; the use of nano wind turbines on installable sheets and the use of conventional Windside turbines. After comparing these two concepts through the use of a multi criteria decision analysis, the conventional windside turbine was considered the most fitting choice to be used in this exploratory study. The analysis showed that it is technologically feasible to successfully build the project using conventional wind turbines along highways. However, just because the project is technologically feasible does not mean that it cannot fail. Stakeholders to the project might exert such influence on the project that success is not an option. Therefore, a stakeholder analysis has been carried out to identify the relevant stakeholders, together with their attitudes, interest and power. The stakeholder analysis shows that there are quite some critical stakeholders that need to be satisfied, or else the project is not even allowed to be launched. Fortunately for the virtual project management, most stakeholders are supportive or easily swayed to be supportive. The only slight threat could be posed by competitors that would want to use the space along highways for other purposes, like placing solar energy generators. Fortunately again, there is plenty of space available and entering in early engagement with potential competitors could turn them into partners.

The final analysis that has been carried out is the social cost benefit analysis. In this analysis it has been investigated whether the society would benefit from pursuing the wind turbine along the highway project. The social costs and benefits effects have been identified, explained and monetized where possible. This time the virtual project management would be unfortunate. The SCBA and its sensitivity- and scenario analyses show that under no condition the society would achieve a net benefit on the project. Not even in the best case scenario the final values come close to an NCV of zero, with costs of over 3600 euro/MWh and a cost benefit ratio of 0.6. These high costs need to be reduced drastically before large scale investments become interesting to pursue. This answers the research question set in this report: *To what extent can the concept of converting traffic turbulence and regular wind to useful energy be implemented in the Netherlands?* The concept could possibly be worth setting up a pilot project in order to see what learning curve this innovation has and to maybe develop a customized wind turbine. As of right now, the costs are too excessive to start any medium- to large scale project.

7.2 Reflection on the outcomes of the report

Before describing any recommendations, it is important to interpret the outcomes of the exploratory study and discuss what they really mean.

Cost benefit ratio
First of all, the cost benefit ratio of the best case scenario of the wind turbine project along highways amounts to 0.6. This ratio is higher than the ratio of the SCBA on the offshore wind project by Decisio (CPB, 2013), which ranged from 0.35 to 0.55. The Dutch government agreed to further research and develop the offshore wind project, despite this cost benefit ratio and the corresponding negative net value of 5 billion euros. One could argue to also invest and research the highway wind turbine project, as the cost benefit ratio seems higher in a best case scenario. However, the SCBA on the offshore wind project assumed that there is no CO_2 reduction taking place, the CO_2 emissions will simply be relocated elsewhere. This assumption is crucial, as calculating on the basis of CO_2 reduction leads to a range of net values from -1 billion euros to +12 billion euros (Tieben en Hof, 2014). The conclusion that can be drawn from this is that if this report assumed that no CO_2 reduction were to take place, the cost benefit ratio and net value would drop dramatically. Another reason why the Dutch government agrees to develop the offshore wind project is because it provides 21.5 Twh capacity, against for now projected costs of around 225 Euro/Mwh. The highway wind turbine project covering 110 kilometres of highway would only provide 200 Gwh capacity, for projected costs of around 3600 Euro/Mwh.

Best case scenario
Another very important thing to note is that for the virtual case study, one of the most suitable piece of highway has been selected. The highway allows the maximum driving speed and runs through the area of the highest average wind speed in the Netherlands. When the capacity of the highway wind turbine project is increased, less suitable highways are used. The lower average wind speed results in less generated electricity, decreasing profits and social benefits.

Included effects
This report has included all effects that have been included in the offshore wind project CBA's and onshore CBA of 2013 (CE Delft, 2014;CPB,2013), except for unique project specific effects such as fishery, oil shipping and marine wildlife. On the other hand, unique effects as potential fuel reduction due to wind turbines and a higher degree of road safety have been included. Not all the effects have been quantified yet, but it is to be expected that the net results of the unknown effects will be positive.

Assumptions regarding input data
The input data for the SCBA comes from a variety of sources. Data has been retrieved from other SCBA's,research reports and experts. The technical data regarding the windside turbine used for this exploratory study comes directly from the producer. Also the expert interviewed has an interest in selling windside turbines. Therefore the data related to the windside turbine needs to be taken with caution. Very extensive sensitivity analyses have been carried out to show what differences could be expected in case variables change. Another important assumption is that the average wind speed that is used matches the average wind speed close to the wind turbines to be placed along the highway. The wind speed data comes from measurements at a height that is larger than the wind turbines reach. This means that the wind speed closer to the ground is actually lower, resulting in a lower wind speed driving the wind

turbines. This report has assumed the wind speed to be the same, with the turbulence from passing traffic compensating for a lower wind speed. It could however be the case that there is no compensation and that the net result is a lower wind speed for the wind turbines than used in this study, which results in a more negative outcome. A third note regarding the data is that it is assumed that after 2090, the wind turbines are not of any value anymore. This is not necessarily true, as the materials that are left of 50,000 wind turbines could possibly be (re) used in different ways.

Conclusion reflection on the SCBA outcomes of the report
This report has investigated the potential of placing wind turbines along highways in the Netherlands. It can be expected that empirical results turn out lower, due to the assumptions made regarding the data input and the sources of some of the data input. Regardless, there are still several positive benefits of unknown value that can compensate for this. The most important matter effect to determine is the influence of the passing traffic on the wind turbine production.

7.3 Recommendations

The project as described does not seem suitable yet to be invested in, but that does not mean that further research on this matter is a waste of time, money and effort. There are still several things to explore that are worthwhile. First of all, the report has used the concept of conventional wind turbines and careful assumptions have been made to translate these turbines in the environment of highways. Yet, the careful assumptions need to be validated or replaced with empirical data. Therefore the effect of traffic passing wind turbines should be investigated and is essential. The knowledge could be used to develop a new customized wind turbine which could change the outcome considerably. The purchase price and output are the most crucial factors to gain benefits, when the price is reduced and output is increased respectively. The research is also necessary to determine whether vehicles passing wind turbines use less fuel.

In order to research this matter a pilot project should be initiated, consisting out of a row of wind turbines along a highway. With several conventional wind turbines placed in a row along the highway, empirical results can be obtained to validate the current research and stimulate customized wind turbine development. The research itself is also valuable, since the population keeps growing leading to urbanization. Wind turbines could very well have to deal with passing objects in the future. There might be a first mover advantage for obtaining this knowledge first with corresponding technological developments. There are also several other undetermined effects that should be investigated. Potentially positive effects are noise reduction and Neon-head and rear light blinding reduction by the wind turbines. When these effects are substantially positive the use of wind turbines along highways might yet become interesting again.

The second recommendation is to map the potential of wind capacity along all the suitable highways in the Netherlands. This provides an indication of the extra capacity that could be installed onshore using wind turbines along highways. In the future this capacity could be called upon when other options turn out to have a more negative net value, or the net value of this concept has changed into an acceptable value. Currently over 2500 kilometers of highway stretch out over the Netherlands. If 2000 kilometers could be used to place wind turbines in the middle lane over 300 MW capacity could be installed, accounting for the different average wind speed in other parts of the Netherlands If it is possible to place wind turbines on both sides of the highway as well, the capacity could potentially triple. This would make up for approximately 20% of the planned offshore wind capacity of 2020. The turbines could also be placed on suitable roadways, but also this needs to be researched. The last recommendation is to use the application of wind turbines along highways and translate it into wind turbines along railroads. The Netherlands has over 6800 kilometers of railroad laid out. Small wind turbines could possibly be placed along both sides of the railroad and directly feed the surrounding grid.

7.3 Self reflection

One of the most important characteristics of a (good) scientist is having the ability to critically look at oneself to seek for improvement. As I have the ambition of becoming a good scientist, I can look back and be proud, while still having a lot of room for improvement.
I have been too much of a lone wolf during my period of research. I have almost been doing everything without asking much help. While being independent can be a good feature, knowing when to ask for help or guidance is a strength as well. Since this has been my first social cost benefit analysis, I should have contacted my supervisors sooner to ask for feedback.
Not only should I have asked for feedback more often, I should also have been less sloppy. I found myself looking around for documents I made, interviews I worked out and other data I had stored. I need to learn how to manage everything more carefully. The prime example is working out the social cost benefit analysis in excel. For quite some time I edited the values in only a few tabs. After finding out an error later while calculating a different scenario, I had to go back to the base scenario and recreate the scenario which had an error all over again. This happened several times and has been a good lesson for me and for everyone.

Things I feel I have improved upon

While there are still many things for me to improve upon, I have learnt quite a lot during the completion of this research report. I have conducted several interviews, which went better the more experience I gained conducting nterviews. There is a lot of theory available on interviews, but you cannot learn how to conduct an interview unless you actually conduct a real interview. The experts who agree on sharing their knowledge mostly have a tight schedule which gives limited time to gather the information that is needed. I have learnt to be persistent in making appointments and improved my skills on how to set up an interview and guide the conversations. Also staying patient and polite are important characteristics, which were tested quite frequently.
The social cost benefit analysis was completely new for me. I have learnt what a social cost benefit analysis is, how it is done and how it can be interpreted. The first thing I learnt was that a social cost benefit analysis is not the Holy Grail in decision making. Projects with a high negative value can still be accepted and vice versa. By no means do I think I am now an expert in social cost benefit analyses, but I hope I can say I am not a layman anymore.

References

AD. Defensie toetst invloed windmolens rond radars, 2012. Retrieved from http://www.ad.nl/ad/nl/5596/Planet/article/detail/3241384/2012/04/16/Defensie-toetst-invloed-windmolens-rond-radars.dhtml Last accessed on 6th June, 2014

Allianz. Road Energy Systems Heat From Street. 2014. Retrieved http://knowledge.allianz.com/environment/energy/?341/road-energy-systems-heat-from-street Accessed on May 24th 2014

Archinect. Highway Wind, 2007. Retrieved from http://archinect.com/article Accessed on April 16 2014

Baal, M. (2008). Afsluitdijk als electricitetiscentrale. Technisch weekblad. Retrieved from http://www.technischweekblad.nl/afsluitdijk-als-elektriciteitscentrale.77839.lynkx Last accessed on 5th June, 2014

Baggott, J. Autoblog readers condemn dangerous HID headlights, 2011. *Cars AOL*. Retrieved from http://cars.aol.co.uk/2011/02/24/autoblog-readers-condemn-dangerous-hid-headlights Last accessed on 24th March, 2014

Baxter, P. & Jack S. (2008). Qualitative case study methodology: study design and implementation for novice researchers. *The qualitative report,* 13 (4) 544-559

Berto. Een kijk op de afsluitdijk. Infoyo, 2011. Retrieved from http://wetenschap.infoyo.nl/onderzoek/24342-een-kijk-op-de-afsluitdijk.html Last accessed on 7th June, 2014

BLW. Geen windmolens tussen woonwijken. Buren van de Lage Weide, 2014. Retrieved from http://burenvanlageweide.nl/ Last accessed on 15th June, 2014

Buhaug, H. & Urdal, H. (2013). An urbanization bomb? Population growth and social disorder in cities. *Global Environmental Change, 23 (1) 1-10*

Burton, T, Jenkins N, Sharpe ,D & Bossanyi E, (2011). Wind energy handbook. Retrieved from http://books.google.nl/books?hl=en&lr=&id=qVjtDxyN-joC&oi=fnd&pg=PR5&dq=small+wind+turbine+requirements&ots=Q6lTD6rqgK&sig=4kE5nFUQjAS6IQBv93cE3n3n4qE#v=onepage&q=small%20wind%20turbine%20requirements&f=false Last accessed on 28th June, 2014

CBS. Aantal inwoners per periode, 2014. Centraal Bureau voor de Statistiek. Retrieved from http://www.cbs.nl/nl-NL/menu/cijfers/default.htm. Accessed on April 5 2014

CBS. Electricity imports at record level, (2012). Retrieved from http://www.cbs.nl/en-GB/menu/themas/industrie-energie/publicaties/artikelen/archief/2012/2012-3659-wm.html. Last accessed on 29th April, 2014

CE Delft (2010) Handboek Schaduwprijzen: Waardering en weging van e missies en milieueffecten. S.M. (Sander) de Bruyn, M.H. (Marisa) Korteland, A.Z. (Agnieszka) Ma rkowska, M.D. (Marc) Davidson, F.L. (Femke) de Jong, M. (Mar t) Bles, M.N. (Maartje) Sevenster Delft, CE Delft, maart 2010

CE Delft (2012) MKBA windenergie Flevoland. G.E.A. (Geert) Warringa , M.J. (Martijn) Blom, M. (Mart) Bles ,Delft, CE Delft, februari 2012

CE Delft (2013) MKBA windenergie Lage Weide. G.E.A. (Geert) Warring a, M.J. (Martijn) Blom, M.J. (Marnix) Koopman, Delft, CE Delft, april 2013

Chittibabu, P., Murty T.S. & Khandekar, M.L. (2005). The Global warming debate: A review of the state of science. *Pure appl. Geophys*, (165) 1557-1586.

CPB (2005) Windenergie op de Noordzee; een maatschappelijke ko sten-batenanalyse. Annemiek Verrips, Hage de Vries, Ad Seebregts en Mark Lijesen. Centraal Plan bureau. September 2005 ISBN 90-5833-232-2

CPB (2013) KBA Structuurvisie 6000 MW Windenergie op land. KBA Structuurvisie 6000 MW Windenergie op land. CPB Notitie, 14 juni 2 013, Den Haag

CPB (2013). KBA Structuurvisie 6000 MW Windenergie op land. Den Haag

CPB en PBL (2013) Algemene leidraad voor Maatschappelijke Kosten Bate n Analyse. Gerbert Romijn, Gusta Renes, CPB/PBL Den Haag, 2013

CPB. Algemene Leidraad Maatschappelijke Kosten Baten Analyse, 2013.

CWEA. Small wind turbine Purchasing guide of grid, Residential, farm & small Business applications, 2010. Canadian Wind Energy Association. Retrieved from http://www.canwea.ca/images/uploads/File/SmallwindturbinesFINAL.pdf. Accessed on April 1 2014

Decisio (2010) Maatschappelijke Kosteneffectiviteit van ruimtelijle opties voor offshore Windenergie. Niels Hoefsloot, Menno de Pater en Gerwin van der Meulen. Decisio, Amsterdam, 2010

Decisio (2014). MKBA Windenergie binnen de 12 mijlszone Amsterdam, 2010

Decisio. MKEA Windenergie op zee. 2014. Retrieved from http://www.decisio.nl/wp-content/uploads/2013/10/MKEA-Windenergie-op-zee.pdf Accessed May 10th

Dias L, Mousseau V, 2014. Applying MCDA: Challenges and case studies. *Journal of Multi-Criteria Decision Analysis*, 21(1-2)

DWEA. Board team members. Distributed Wind Energy Association, 2014. Retrieved from http://distributedwind.org/our-staff/mick-sagrillo/ Last accessed on 8th June, 2014

E. De Schepper, S. Van Passel, J. Manca, T. Thewys (2012). Combining photovoltaic and sound barriers – A feasibility study. Renewable Energy. DOI 10.1016/j.renene.2012.03.022. Available online 6 April 2012

EC. The EU Emissions Trading System. European Commission, 2014. Retrieved from http://ec.europa.eu/clima/policies/ets/index_en.htm Last accessed on 5th June, 2014

ECN (2013, b) Profiel- en onbalanskosten van windenergie in 2012. F.D.J. Nieuwenhout, A.J. Brand, S.M. Lensink. 28 maart, 2013.

ECN (2013,a) Kosten van het inpassen van grote hoeveelheden zon en wind in de Nederlandse elektriciteitsvoorziening. Nieuwenhout, F.D.J.. Pet ten, 8 mei 2013

ECN. Berekening van de CO2- emissies, het primair fossiel energiegebruik en het rendement van elektriciteit in Nederland, 2012. Retrieved from http://english.rvo.nl/sites/default/files/2014/08/Notitie-Energie-CO2-effecten-elektriciteit-Sept-2012.pdf Last accessed on 9th September, 2014

ECN. Update Referentieraming 2013c. ECN april 2013

Ecofriend. Future Perfect innovatie ideas for renewable energy generation on highways. 2014. Retrieved from http://www.photius.com/rankings/energy/electricity_installed_generating_capacity_2013_0.html Accessed May 10th

EIA. Total Electricity Installed Capacity, 2014. U.S Energy Information Administration. Retrieved from http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=7&cid=ww,&syid=2007&eyid=2011&unit=MK Accessed on April 3 2014

Energeia. Nederlands reservevermogen wordt flink duurder aangeboden dan international, 2014. Retrieved from http://www.energeia.nl/preview/2041-nederlands-reservevermogen-wordt-flink-duurder-aangeboden-dan-internationaal.html. Last accessed on 29th November, 2014

Enervisa. Wijziging CO2-uitstoot van electriciteitsproductie, 2014. Retrieved from http://www.enervisa.nl/news/30/57/Wijziging-CO2-uitstoot-van-elektriciteitsproductie Last accessed on 25th July, 2014

Essent. Productie en emissieoverzicht 2012. Essent, 2012. Retrieved from https://www.essent.nl/content/Images/105708_Essent%20Productie-%20en%20emissieoverzicht%202012.pdf Last accessed on 28th November, 2014

Essent. Productie en emissieoverzicht 2013. Essent, 2013. Retrieved from https://www.essent.nl/content/Images/118290_ESS-ESS14024-RAP-Emissieoverzicht%202013.pdf Last accessed on 8th April, 2014

Esteban, D. M., Diez, J.J., Lopez J. S. & Negro, V. (2011). Why offshore wind energy? Retrieved from http://oa.upm.es/6735/2/INVE_MEM_2010_74444.pdf Last accessed on 20th June, 2014

Eurostat. Energy statistics-infrastructure. 2014. Retrieved from http://www.europa.eu/portal/page/portal/energy/data/database Accessed on March 27 2014

Eurostat. Energy Statistics-supply, transformation, consumption. 2010. Retrieved from http://www.epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database Accessed on March 27 2014

EWEA. Wind Energy Statistics and Targets, 2014. European Wind Energy Association. Retrieved from http://www.ewea.org/uploads/pics/EWEA_Wind_energy_factsheet.png Accessed on March 30 2014

Firoz A, Golde S. An Aerodynamic Study of a Micro Scale Vertical Axis Wind Turbine, Procedia Engineering 2013; 56:568-572

Fraunhofer. Levelized cost of electricity renwable energy technologies, 2013. Retrieved from http://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf Last accessed on 27th September, 2014

Gall, M. D., Gall, J. P., & Borg, W. R. (2003). Educational research: An introduction (7th ed.). Boston, MA: A & B Publications

Gardner P, Garrad A, Hansen LF, Jamieson P, Morgan C, Murray F, et al. Wind energy the facts part I & technology. Garrad Hassan and Partners-UK; 2009.

GWEC. Global Wind Energy Outlook, 2012. Global Wind Energy Council. Retrieved from http://www.gwec.net/index.php?id=181&L=0%B4. Accessed on April 4 2014

Hammons TJ. Integrating renewable energy sources into European grids. Electricity Power Energy Systems, 2008; 30:462-75.

Harmelink et al (2012), Harmelink, M., Bosselaar, L., Gerdes, J., Segers, R., Verdonk, M., Berekening van de CO2-emissies, het primair fossiel energiegebruik en het rendement van elektriciteit in Nederland, Agentschap.nl, CBS, ECN, PBL, 2012

Hau, E & Renouard H, (2013). Wind turbines: Fundamentals, technologies, application, economics Retrieved from http://books.google.nl/books?hl=en&lr=&id=KeNEAAAAQBAJ&oi=fnd&pg=PR2&dq=small+wind+turbine+requirements&ots=Bb3VFZnbo1&sig=uts-WAXMfxDenHzU_xgunp58LqA#v=onepage&q=small%20wind%20turbine%20requirements&f=false Last accessed on 20th July, 2014

Helix wind. About small wind, 2014. Retrieved http://www.helixwind.com/en/aboutSmallWind.php last accessed on 20th June, 2014

Herbert, J. G. M., Iniyan, S. & Amutha, D. (2014). A review of technical issues on the development of wind farms. *Renewable and sustainable energy reviews,* 2014 (32) 619-641

Hillson& Simon. Practical Project Risk Management – The ATOM Methodology. Management Concepts, 2007.

ICRA. Stakeholders – key concepts. International centre for development oriented research in agriculture, 2014. Retrieved from http://www.icra-edu.org/objects/anglolearn/Stakeholders-Key_Concepts.pdf Last accessed on 19th June, 2014

IEA. Design and operation of power systems with large amounts of wind power, 2013. Retrieved from http://www.ieawind.org/task_25/PDF/T75.pdf Last accessed on 22th July, 2014

Ijsselmeervereniging. Friesland gooit kansen in het water, 2014. Retrieved from http://www.ijsselmeervereniging.nl/nieuws/2014/2014-11-17_friesland_gooit_kansen_in_het_water.htm Last accessed on 5th September, 2014

Inhabitat. Highway Wind Power. 2007. Retrieved from http://inhabitat.com/highway-wind-power/. Accessed on April 15 2014

Kaldellis J. K & Zafirakis, D., 2011. The wind energy (r)evolution: A short review of a long history.

Kaldellis JK. Stand-alone and hybrid wind energy systems: technology, energy storage, and applications. 1st ed. Cambridge: Woodhead Publishing; 2010.

Knoll A, Klink L. Residential- and commercial-scale distributed wind energy in North Dakota, USA. Renewable Energy 2009

Loonwijzer. Grondwerker wegenbouw, 2014. Retrieved from http://www.loonwijzer.nl/home/salaris/salarischeck?job-id=9312060000000 Last accessed on 15th March, 2014

LTM. Small windmills put to the test. Low-Tech Magazine, 2014. Retrieved from http://www.lowtechmagazine.com/2009/04/small-windmills-test-results.html Last accessed on 8th June, 2014

Mabel C, Fernandez E. Growth and future trends of wind energy in India. Renewable Sustainable Energy Review 2008; 12:1745-57

Mainster, M. A., & Timberlake, G. T. (2003). Why HID headlights bother older drivers. *The British Journal of Ophthalmology*, *87*(1), 113–117.

Matiss, A (2011). Energy security and diversification of energy supplies. Retrieved from http://ecrgroup.eu/wp-content/uploads/2011/07/Anrijs-Matiss_Energy.pdf Last accessed on 27th September 2014

Maylor, H. (2010). Project management. Financial Times Prentice Hall.

McNamara, C. (2009). General guidelines for conducting interviews. Retrieved from http://managementhelp.org/businessresearch/interviews.htm Last accessed on 13th June, 2014

Moesgaard R, Chandler H, Barons P & Bakema G, 2008. Wind energy the facts Part III The economics of wind power. Risø DTU National Laboratory, Technical University of Denmark

Mulder, M & Scholtens, (2013). De invloed van wind en zon op stroomprijzen. *ESB,* Jaargang 98 (4664-4665) .

Müller G, Jentsch MF, Stoddart E. Vertical axis resistance type wind turbines for use in buildings. Renewable Energy, 2009; 34:1407-12.

Natuur en Milieu. Geconcentreerde windkracht in de Lage Landen. De proinvicale milieufederaties, 2009. Retrieved from http://nmfgroningen.nl/friksbeheer/wp-content/uploads/2013/10/PDF-Wind-2009-Geconcentreerde-Windkracht-in-de-Lage-Landen-NMFs.pdf Last accessed on 16th June, 2014

New York Times. Harvesting Clean Energy Along the Road, 2009. Retrieved from http://green.blogs.nytimes.com/2009/07/23/harvesting-clean-energy-along-the-road/?_php=true&_type=blogs&_r=0 Accessed on April 13 2014.

NLVOW. Geluid en Overlast. Nederlandse vereniging omwonenden windturbines, 2014. Retrieved fromhttp://nlvow.nl/geluid-overlast/ Last accessed on 17th June, 2014

NRF. European renewable energy incentive guide – The Netherlands, 2013. Norton Rose Fulbright. Retrieved from http://www.nortonrosefulbright.com/knowledge/publications/66148/european-renewable-energy-incentive-guide-the-netherlands. Accessed on March 29 2014

OOMS. Energie uit Asfalt. 2014. Retrieved http://www.ooms.nl/nl/3/73/energie_uit_asfalt.aspx Accessed on May 12th 2014

OPC. Solar Green Point A4 – 8000 zonnepanelen langs de snelweg. One Planet Crowd, 2014/ Retrieved from http://www.oneplanetcrowd.com/nl/project/53245 Last accessed on 21st June, 2014

Overheid. Wet en Regelgeving, Wet beheerrijkswaterstaatswerken, 2014. Retrieved from http://wetten.overheid.nl/BWBR0008331/geldigheidsdatum_02-10-2014. Last accessed on March 18th 2014.

Parnell, S. G, Driscoll, P, J. Dale & Henderson L, (2011). Decision making in systems engineering and management. Second edition.

RAE. The cost of generating electricity, Royal Academy of Engineering. 2004. Retrieved from http://www.raeng.org.uk/news/publications/list/reports/Cost_Generation_Commentary. Accessed on March 30 2014

Refocus. Small wind turbines: the unsung heroes of the wind industry. Refocus 2002;3:30.

Rengers, M. Steeds meer weerstand tegen windmolens. Volkskrant, 2014. Retrieved from http://www.volkskrant.nl/politiek/steeds-meer-weerstand-tegen-windmolens~a3640525/ Last accessed on 5th June, 2014

REW. Wind Energy 2014 Outlook: Major Markets Recover, Battling Policy and Grid Concerns, 2014. Renewable Energy World. Retrieved from http://www.renewableenergyworld.com/rea/news/article/2014/02/wind-energy-2014-outlook-major-markets-recover-battling-policy-and-grid-concerns. Accessed on March 30 2014

Rijkswaterstaat. Opwekken van zonnestroom met geluidsschermen langs de snelweg, 2013. Retrieved from http://www.rijkswaterstaat.nl/images/Rapport%20Opwekken%20van%20zonnestroom%20met%20geluidsschermen%20langs%20de%20snelweg%2018.10.2013_tcm174-356694.pdf. Last accessed on 4th June, 2014

ROV. Wind Energie, 2014. Rijksoverheid. Retrieved from http://www.rijksoverheid.nl/onderwerpen/duurzame-energie/windenergie. Accessed on April 3 2014

Sagrillo, M. (2002). Wind Operation and maintenance costs. *Windletter,* 21(12). Retrieved from http://www.renewwisconsin.org/wind/Toolbox-Homeowners/Operation%20and%20maintenance%20costs.pdf Last accessed on 28th July, 2014

Shafiee, S. & Topal, E. (2009). When will fossil fuel reserves be diminished? *Energy Policy, 37 (1) 181-189*

Stromeyer, H.(2012). Reset rules: managing projects in crisis. Retrieved from https://www.iapm.net/.../meist-sind-projektkrisen-se.pdf Last accessed on th June, 2014

Technische Universiteit Eindhoven. TM messenger, 2008. Retrieved from http://w3.tm.tue.nl/fileadmin/tm/Faculteit/facultair_materiaal/TM_Messenger_2008_03.pdf . Accessed on April 14 2014

TU Eindhoven. Zonnestroom langs de snelweg, 2014. Retrieved from http://www.cursor.tue.nl/nieuwsartikel/artikel/zonnestroom-langs-de-snelweg/ Last accessed on 20th June, 2014

VEMW. VEMW zet vraagtekens bij veiling primair reservevermogen, 2014. Retrieved from http://www.vemw.nl/nl/Nieuws/VEMW%20zet%20vraagtekens%20bij%20veiling%20primair%20reservevermogen.aspx. Last accessed on 18th May, 2014

Vestel, L. Harvesting clean energy along the road. Green blogs New York Times, 2009. Retrieved from http://green.blogs.nytimes.com//2009/07/23/harvesting-clean-energy-along-the-road/?_r=0 . Last accessed on 19th June, 2014

WEF. Wind energy the facts, offshore developments. Wind Energy Facts. 2010. Retrieved http://www.wind-energy-the-facts.org/en/part-3-economics-of-wind-power/chapter-2-offshore-developments/ Accessed on March 30th 2014

WEU. Offshore decommissioning market is emerging, but is wind industry prepared? Wind energy Update, 2014. Retrieved from http://social.windenergyupdate.com/operations-maintenance/offshore-decommissioning-market-emerging-wind-industry-prepared Last accessed on 24th June, 2014

Windside. Windside company, 2014. Retrieved from http://www.windside.com/company. Last accessed on 9th June, 2014

Wood, D. (2011). Small wind turbines*. Advances in wind energy conversion technology, Enviromental science and engineering*, 2011 195-211.

World Bank. World development indicators*, 2014.* Retrieved from http://data.worldb1nk.org/data-catalog/world-development-indicators Last accessed on 1st June, 2014

WSS. Steenkool info. Wij stoppen steenkool, 2014. Retrieved from http://www.wijstoppensteenkool.nl/?page_id=4691 Last accessed on 4th June, 2014

Zeilmaker, R. (2012). Ook Essent zet centrales stil dankzij overcapaciteit en marktverstoring overhead, climategate. Retrieved http://climategate.nl/2013/08/21/ook-essent-zet-centrales-stil-dankzij-overcapaciteit-stroomproductie-en-marktverstoring-overheid/ Last accessed on 2nd April, 2014

Zeilmaker, R. Forse overcpaciteit stroomproductie Nederland nekt Nuon: iedere windmolen één teveel. Climategate, 2013. Retrieved from http://climategate.nl/2013/07/27/forse-overcapaciteit-stroomproductie-nederland-nekt-nuon-iedere-windmolen-een-teveel/ Last accessed on 24th June, 2014

Zopounidis C, Dompuos M., 2002. Multi-criteria decision Aid in Financial Decision Making: Methodologies and literature review. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/mcda.333/pdf Last accessed on 5th June, 2014

Zuidervaart, B (2013). Windmolens: veel verzet, weinig ruimte. *Trouw.* Retrieved from http://www.trouw.nl/tr/nl/4332/Groen/article/detail/3446475/2013/05/24/Windmolens-veel-verzet-weinig-ruimte.dhtml Last accessed on 18th June, 2014

Appendix I Interviews

Interview technique used

The interview technique that is used for the interviews is the general interview guide approach. This technique is more structured than the informal conversational interview but still leaves quite a bit of flexibility in its composition (Gall, Gall, & Borg, 2003). The structure in the interview is needed as specific topics and questions need to be discussed. The strength of the general interview guide approach is to ensure that the same general areas of information are collected from each interviewee; this provides more focus than the conversational approach (McNamara, 2009). This technique has also been used during telephone interviews. Telephone interviews enable a researcher to gather information rapidly. Like personal interviews, they allow for some personal contact between the interviewer and the respondent (Valenzuela & shrivastava, 2004). By sending a pre-determined list of topics and open ended questions the interview is structured while still informal and flexible to receive as much relevant information as possible.

Selection of respondents, interview questions and results

The respondents that have been selected have not all participated in an interview. Yet the questions to be asked are still written down in case the respondent does participate in the future. The questions and answers have been written down as accurately as possible while conducting the interviews. The respondents that have participated in interviews have granted permission to use the information and quotes they provided. This was verified by email.

No response

<u>Gene Fein (Green highway Project US)</u>

Gene Fein is the CEO and Co-Founder of Genedics Clean Energy. This company is now focusing on the Green Roadway project. This project combines the use of wind turbines and solar panels along highways to generate sustainable energy. His knowledge about both the technical as economic aspects of this project would be very valuable to this research report. Unfortunately Gene Fein nor any of the employees at Genedics Clean Energy responded to any attempt of communication.

The questions to be asked are both open and closed questions

- What type of wind turbine(s) do you use?
- Do you place these turbines on the rails or on empty land in the middle of the two highways?
- Could you please give me any output specifications of the wind turbines? (electricity produced on certain range of wind speeds)
- Wind turbine technicalities (maintenance when? How, costs involved)

- What parties challenge you on this project? Who are supporting you?
- How much time does it take to install the rows of turbines? (With how much manpower per turbine, etcetera)
  What are the safety specifications?
- How much innovation is still there to be gained / what is the potential of the turbines in the coming years?
- According to you, what are other really important things I ought to know about the project, not only focusing on the wind turbines only but also on the actors and other things involved?

Personal interviews

Arjan de Bakker (ANWB)

Arjan de Bakker had been program manager on sustainable mobility at the ANWB from 2006 to 2009, before specializing in socially responsible entrepreneurship. His official function now is program manager sustainability and affordability. From this function his goals are to help make mobility on the roads cleaner, more friendly to the environment, more quiet, more comfortable and also cheaper if possible as well. He still works closely with the department of sustainable mobility at the ANWB as well. Arjan de Bakker is considered to be capable of providing the perspective from stakeholder ANWB and also his experience will be valuable to the project research.

Guiding questions for the interview and answers. Arjan de Bakker preferred to talk about each question individually.

- Do you expect the ANWB to support or oppose such project as the wind turbine project? Why? How could this be influenced?

  This depends on how the members of the ANWB (participants in traffic) have to deal with the project. When there is no concern for the safety of any of the drivers due to the wind turbines, there would be no objections to be expected. Research by TNO must be very clear on the matter of safety. The attitude of the ANWB would be neutral, but when elements of increased sustainable mobility can be added the ANWB would b really positive. When the generated electricity can be used to charge electrical vehicles or street lighting for example.

- What would be the most heard objections against this project?

Mainly the safety for traffic and whether the project has positive effects for the mobility of drivers. Horizon pollution would normally be one as well, but the way this project is set up this negative aspect does not seem to apply.

- What support could the ANWB offer?

  The ANWB could provide data on how its members perception is towards the project. Also the ANWB can help lobbying and sustain cooperation with Rijkswaterstaat

- What kind of limits does the ANWB see regarding the financial features of the project?

  The ANWB would not like to see large expenditures of the ministry on infrastructure, as this would increase taxes for drivers in the form of road taxes, fuel taxes, vehicle taxes etcetera. The ANWB wants to have these taxes lowered or have the ministry keep the taxes stable while increasing expenditures on infrastructure to increase its quality.

- What kind of direct or indirect influence can the ANWB exert on the decision whether this project can be launched or not?

  The ANWB has a covenant with Rijkswaterstaat. Therefore the ANWB could bring the project up in meetings to support it. When hectares of unused ground is not used for any purpose, there should be something done with it from the socially responsible entrepreneurship perspective. Electric driving and sustainable generation of electricity are hot topics at the government. On the A15 highway a project will be launched to make this highway a sustainable highway. Many electric cars would need to drive here and charge their cars with electricity generated in a sustainable way around the A15.

- Would the ANWB invest in a project like the wind turbine project?

  No. There is no funds availalbe. Only funds available is for upgrading the ANWB assortiment.

- What should the ANWB know exactly before this project is supported, next to safety for drivers and the financial aspect?

  These were the main issues, besides horizon pollution which does not seem to be applicable. Another point on which the project could help though is to reduce the blinding effect of xenon headlights on vehicles. There is growing concern and growing frustration among drivers because of getting blinded by vehicles driving on the other lane. By building a row of wind turbines this effect might get reduced and increase the mobility of drivers.

- From your experience and your position within the ANWB, how do you think other stakeholders will view this project? How do you think Rijkswaterstaat would react? And the municipalities?

  I would not be surpised to hear positive replies. In the past these entities had taken in a more active role in such projects, but now due to the lack of funds only pilot projects could possibly be set up.

- What procedure would start at the ANWB when this project is suggested?

  If the project is going to be done on huge scale, the ANWB will look carefully into the reports on the effects on the safety of the traffic participants. The members are asked their opinion on the project. When the members say no, the design could be adapted to still be made to work. When it is a hell no, this will be forwarded to Rijkswaterstaat which will take this no into account and probably not launch the project either

Michiel Zaaijer (Wind energy research group)

Michiel Zaaijer received his M.Sc. in Applied Physical Engineering from Delft University of Technology in 1993. In 1999 he joined the wind energy community. Even though his main focus is offshore wind darms, Michiel Zaaijer has the physical background and knowledge due to the wind energy group to analyze onshore wind structures and projects. He is involved in the initiation of projects and contributed to proposals and management of WE@Sea, PhD@Sea, Upwind and Innwind. Where Innwind focuses on onshore wind turbines. Michiel Zaaijer is considered capable to accurately judge and estimate the technical challenges of the wind turbine concepts. Additionally, other non-technology related questions are written down as guiding questions in case these can be answered too with Michiel Zaaijers knowledge and experience.

Guiding questions asked

- What type of wind turbine(s) would you suggest for this application?
- Does the output suggested sound plausible to you? What would be best ways to verify or improve this estimate?
- Would you be able to say anything about the potential of innovation in the coming years?
- From your experience, what stakeholders would really challenge this project and/or support this project?
- What comparisons/differences can be drawn looking at your off-shore experience and projects? (Many/More actors? Different actors? The procedures?
- Can you say anything about the economics involved? What is needed to create an environment to build and invest in these projects?

- What are your expectations on the CO2 emission price in the future and its current and future role regarding wind energy?
- What is your general expectation of the electricity price in the future?
- Can you tell anything about the subsidies for renewable energy sources? And expectations?
- Would you know of other certain experts that I should contact?
- What aspects would you suggest I am missing, focus on better or check whether I have taken it into account properly?

Relevant answers to the wind turbine project in bullet points

- Looking at the two different wind turbine concepts proposed, the nano turbines installed on sheets concept need to be looked at very cautiously. There are no publications so whether the claims are accurate cannot be determined by any evidence. Also the potential output the claims seem to make are substantially high and it is to be seen whether the nano turbines can withstand weather conditions and other requirements set. The project could be revolutionary, but Michiel Zaayer really thinks the conventional wind turbine concept would be the right and fitting approach for the exploratory study. There is too little empirical data available on the nano wind turbine concept
- The conventional wind turbine concept could focus on three lanes at a time if need be. As long as the wind turbines keep sufficient distance from each other to not negatively influence each other by disturbing the turbulence.
- When the topic of potential fuel increase/reduction of the vehicles is discussed, Michiel Zaayer leans towards thinking there are potential benefits. Yet, these benefits are not expected to be large.
- The conventional wind turbines are expected to have a similar output when placed along the highway. If the output would be lower, it is not expected to be that much lower.
- The procedures of constructing wind turbines onshore and offshore are similar. However, offshore wind farms have additional procedures due to building in the ocean.
- Sander Martens has a company in the Netherlands focusing on small wind applications. It would be worthwhile to contact him and ask more specific questions. (Unfortunately Sander Marens has been abroad and too busy to make an appointment since he has been back. He has not responded to the last two emails I sent him).

Riender Happee (Programme manager Automotive and TU Delft mobility project)

Riender Happee works in the section planning and design of transport systems at Civil Engineering at TU Delft and specializes in 'haptic feedback'. How do people react in the car? How do they look, what do they feel? Riender Happee is in charge of the TU Delft mobility project: *'Standardized Self-diagnostic Sensing Systems for Highly Automated Driving'*. He is the programme manager of Automotive and researches the abilities of vehicles to be driving by themselves, automated. Riender Happee could potentially judge whether drivers would be distracted by the wind turbines. Also his knowledge of the variety of stakeholders involved in implementing something new in the transport sector could be worthwhile.

Guiding questions

- What type of wind turbine(s) would you suggest for this application?
- Do you think drivers could be distracted from wind turbines along highways?
- What would be the effect of wind turbines on the resistance of vehicles and the fuel use?
- From your experience, what stakeholders would really challenge this project and/or support this project?
- Do you have any suggestions on who to contact for the effect wind turbines could have on the fuel use of vehicles?

Relevant answers to the project, in bullet points.

- The nano wind turbine concept provides claims of high outputs without empirical evidence. Just because patents are filed and accepted, does not mean what these patents say is true. ‘’I can file a patent saying 1+1 = 3 and it will get accepted’’.
- Rijkswaterstaat and the ANWB would be the key stakeholders.
- Gandert van Raemdonck should be contacted regarding the effects the wind turbines potentially have on vehicles and their fuel use.
- It might be a good idea to customize the turbines in such way that they harmonize with the vehicles so both the wind turbines and the traffic participants profit. When trucks are driving in a row, the truck in the back receives less air resistance and also pushes the trucks in the front forwards.

Intervies conducted by telephone

Gandert Van Raemdonck (Expert in aerodynamic design of road transport vehicles)

In September 2012 Ephicas (which Gandert van Raemdonck co-founded in 2008) was acquired by WABCO. This acquisition introduced WABCO into the field of aerodynamics for commercial vehicles. Within WABCO, Gandert van Raemsdonck is responsible for the R&D of the aerodynamic WABCO's OptiFlow solutions. WABCO is a leading global supplier of technologies and control systems for the safety and efficiency of commercial vehicles.
During his PhD research at TU Delft he gained a lot of fundamental knowledge in bluff body aerodynamics. Additionally, he succesfully developed several aerodynamic drag reduction devices for the trailer with the aid of numerical simulations, wind tunnel experiments and full-scale road testing. Specialties: Aerodynamic design of road transport vehicles. Due to this

specialty Gandert van Raemdonck could potentially give a fair judgement on the effects wind turbines have on the resistance of vehicles and whether there are benefits or costs to be expected regarding the fuel use.

Guiding questions

- What is the probable effect of wind turbines on the resistance of vehicles?
- How should this be tested?

Relevant answers to the project, in bullet points.

- The wind turbines gather energy out of the stream of air, creating a wake. This should create lower pressure for the vehicles, thus the fuel usage should lower. However, the wind turbines also create air vortices, which could have a negative effect on the vehicle. The wake effect yet should be stronger than the negative effect, resulting in a fuel reduction.
- The only way to research this problem is to install a row of wind turbines and test facilities. The research needs to be designed, mapped and included in numeric simulations. This is perfectly doable.
- Gandert van Raemsdonck does personally not believe in the concept of small wind turbines due to the low efficiency. The pressure displacement by vehicles is not that large, trucks do have good pressure displacement.

Wim Stevenhagen (Expert on energy and windside turbines)

Wim Stevenhagen has been the owner and director of SET, Stevenhagen Energie & Tractie, for over 22 years. This company is specialized in generating electricity in a sustainable way. Wim Stevenhagen himself is specialized in soundless windturbines for local energy production, in particular the windside wind turbines. Wim Stevenhagen is therefore considered to be an invalualbe asset when he could give crucial information e.g about the prices, output, efficiency, survivability of the windside turbines that are used in this research report. All the questions asked are based on the windside 4 (WS4) turbines

Guiding questions

- How long do WS turbines last before they have to be replaced?
- What maintenance is needed for the turbines? When and how frequently?
- What are the outputs of the turbines by given windspeed, based on empirical data?
- What is the volume of the wind turbines regarding noise pollution?
- How many people are needed to install the WS turbine? How long does it take?
- What does the WS 4 turbine cost to purchase?
- What do you think the influence is of wind turbines on the air resistance towards traffic?

- Would WS 4 turbines fit easily in middle lanes of most highways?
- How well would the WS 4 turbine fulfill the techniqual requirements set in this report?
- What other feastures can the WS 4 wind turbine provide to benefit the environment or society?

Relevant answers to the project, in bullet points.

- The WS 4 turbines last 20 to 40 years, depending on the location.
- Every few years the oil needs to be refilled of the automatic lubrication system and every 20-40 years the ball-bearings need to replaced. That is all the maintenance that is needed. When the ball-bearings are replaced the turbine is 'as good as new', since the turbine itself does not wear.
- The table shown on the Windside website is based on empirical data and the results for these turbines placed along the highway should be similar. The price list shown in chapter 5 shows the correct purchase prices of the windside turbines.
- Installing a WS 4 turbine should take 20-30 mins, depending on the experience of the crew. A crew of 7 people is needed to install one of these turbines.
- The WS 4 turbine seems to be most suitable for this project. Windside turbines of the type L and C are city turbines. These turbines are too fragile to be placed along the highway, as the maximum speed they can endure is 20 m/s. They are absolutely not suitable for this project.
- Wim Stevenhagen believes a row of the vertical axis wind turbines would lead to less resistance towards traffic, creating a fuel use benefit, yet small.
- A barrier of Windside turbines could potentially reduce sound outputs of the environment by 15%. There is no empirical data published yet but research is on its way.
- The WS 4 turbines could fit in most middle lanes of the highway and would not bother or distract traffic participants.

Harald Versteeg (Rijkswaterstaat)

Since 2009 Harald Versteeg has been the program manager sustainability at Rijkswaterstaat. There he is safeguarding all the activities regarding sustainability and the cohesion between these activities. Harald Versteeg focuses on cooperation and has many meetings with other departments in the ministry, partners, contractors and other parties outside Rijkswaterstaat. He also has a lot of knowledge about the strategic planning and innovation department within Rijkswaterstaat. Therefore Harald Versteeg qualifies to represent the perspective of Rijkswaterstaat on this project and his information and experience to be very valuable.

Guiding questions for the interview

- Do you expect RWS to be in support of the project or opposing the project? Why? How could this be influenced?
- What major issues would the RWS have with the project?
- What support could the RWS provide the project?
- What 'power' does the RWS have to block or support the project?
- What financial capabilities/budgets does RWS roughly have for such projects?
- Does RWS decide whether the project can take off or is it the government (ministries)
- Would RWS allow other parties to invest in the project / wind turbines, if so, who would be the most likely candidates?
- What does RWS need to know to decide for a yes or no to support or start the project
- Verwacht je dat Rijkswaterstaat een dergelijk project steunt of tegenwerkt? Waarom? Hoe zou dit beinvloed kunnen worden?

Relevant information out of interview in bullet points

- If anyone has a plan, we would like to cooperate but not put any money into it in most cases. We would allow to make land available for sustainable energy generation if this can be done in a safe way. When objects are placed in any lane, a guardrail needs to be placed in front of the object. The project initiave would have to pay for this if there is no guardrail present. If any advertisement is to be placed on wind turbines, rent should be paid for this.
- When an electricity cable is laid along highways would be the perfect time to install wind turbines or solar panels. Rijkswaterstaat might help investing a very small amount in first test locations and calculations.
- The installment of the wind turbines and the wind turbines located along the highway must uphold the law for placing objects along the highway, Wet Beheer Rijkswaterstaat. As long as the objects are not dangerous for traffic, the object is allowed to be placed. The ministry of Infrastructure and the Environment have the end decision on this matter, but when Rijkswaterstaat approves the Ministry usually approves as well. Then the municipality needs to grant a construction permit. This procedure is a regular construction permit procedure. When Rijkswaterstaat approves and no one files a complaint, the municipality will most often grant the permit
- Recently Rijkswaterstaat works closer together with municipalities and provinces to initiate many programs on the local generation of electricity. The idea of small wind turbines has been put forward before, but no one has ever provided a proper business case. Rijkswaterstaat can buy electricity for around the price of 5 to 7 cents. For Rijkswaterstaat many ways of generating sustainable energy is therefore not interesting doing themselves. Only local generation of energy is an exception sometimes.
- People see Rijkswaterstaat as a very tough entity to work with and that Rijkswaterstaat would be reluctant to cooperate. This is not the case. Rijkswaterstaat does not take the initiative herself but has worked with parties to install over hundreds of wind turbines already. Rijkswaterstaat just cannot grant permission when there is an expansion planned in the future or the safety for drivers cannot be guaranteed.

- Rijkswaterstaat offers the possibility to make 1 on 1 long term contracts to buy electricity from a project party. Rijkswaterstaat has a willing attitude to come to find a fair price, but this price will not stray far from the market price.

Appendix II Use of Thomas' model

To assess the feasibility of the wind turbine along the highway project Thomas' model (Thomas, 2014) has been used. Since this research report is exploratory, not all elements are incorporated in this study. The following elements of this model have been used and translated into research questions

1) Legal Study

2) Market Study

3) Environmental protection

4) Social Economic Effects

5) Options Analysis on different hypothesis and scenarios

The stakeholder analysis contains research on whether placing the wind turbines is legal or not and what legal requirements need to be fulfilled. The analysis also includes a market study, scanning for companies that could offer support or would oppose the project. The social cost benefit analysis contains the social economic effects, with sensitivity analyses to account for different hypothesis and scenarios

Appendix III Background- and additional information on the social cost benefit analysis

Background

As previously described in this report, the use of wind energy is a crucial way to support the quest for reaching a sustainable energy supply. The local wind potential in the Netherlands, however, has drastically been exploited already. Alternative options are off shore wind parks and onshore micro wind turbines. Latter alternative has not been researched as extensively as off shore options, and even off shore alternatives are still infested with high uncertainty and high investment costs. With the deadline of the 2020 European energy goal rapidply appearing, every country needs to generate 14% of their energy consumption in a sustainable way, using micro wind turbines might provide additional support to reach the sustainable energy target. Possible locations for these micro turbines could be along highways. Perhaps this innovation could be a crucial solution to shift away from fossil fuel economies.

Problem statement

Realizing a chain of micro turbines along highways would be a very complex project. After securing what technological options are most feasible, including installment, (new) grid connections and maintenance, the project is yet only just beginning. Highway drivers on the road along which the turbines are installed will interact with the turbines, which could be both positive or negative. A party such as the ANWB, protecting the rights of Dutch drivers, will need to consent to whether the project does not cause any safety issues on the roads. Competitors might want to use the area for a different alternative of generating energy, like solar energy generation. All kinds of different actors need to be taken into account. The project cannot even take off, if Rijkswaterstaat cannot guarantee the safety of drivers or has no confidence in the proposed business case. Therefore a social cost benefit analysis could be the solution.

What is a social cost benefit analysis

The analysis can be used to support decision making, by providing valuable insights and comparisons between different project alternatives for a complex (multi actor) problem. The SCBA enables comparisons between effects as accessibility and nature, which are hard to compare directly. This means that purely economically evaluated projects that are not considered profitable to earn back investment costs, could actually be profitable if other benefical social effects are included in the evaluation. Of course, this also works the other way around. Internalizing negative effects like CO-2 emissions and habitat damage could mean a project cannot be justified from a social perspective (Decisio, 2014).

In case there are multiple actors who are supporting and opposing a project proposal, the social cost benefit analysis can provide an objective overview to analyze the statements of the involved actors. This way decision making can be supported by the SCBA, which offers the opportunity to compare project alternatives, provide an integral consideration of all the different relevant effects and provides balancing of costs and benefits between different actors involved. Also the uncertainties and risks of a project are mapped and accounted for in a SCBA.

SCBA for micro wind turbines along highway project

As explained in the previous paragraphs, the highway wind turbine project can only be started up when the involved actors feel confident about the project. The actor analysis in chapter x has shown that all critical actors are supportive or can be made supportive. The last step is to show the critical actor Rijkswaterstaat that a positive business case excists (or not). By only taking pure economic aspects into account, the business plan will most likely be negative since this innovation is completely new. However, by including effects such as reduced CO-2 emissions and fossil fuel independency, the business plan might yet be worthy to execute.

The main question for the SCBA is as follows:

What are the differences in the social costs and benefits of the realization of the micro wind turbine project along the Prins Bernardweg Zaandam to Bolswarderbaan highway?

Problem situation

The need for sustainable energy production

The majority of scientist and the public agrees that rising greenhouse gas emissions from the extensive use of fossil fuels results in increasing effects of climate change. In the mean time, the fossiul fuel energy sources are depleting rapidly, leading to increasing energy prices as well. It is clear that a more sustainable energy production is necessary to engage the use of fossil fuels. However, there is no clear pathway yet on how to realize a complete package of measures to gain significant changes.

Wind power as one of the solutions

What is clear however, is that it is very important to keep developing alternative renewable energy sources like wind power. Asia and North America have been expanding their share of wind power considerably, while European countries are challenged to keep up with their expanding rate. Even though European focus lies on off shore wind developments, a success in micro turbines along highways would create new on shore potential. This development could be beneficial to the whole world.

Challenges

The technical analysis has shown that the project can be carried out without major difficulties. The materials and concept chosen make that it is highly certain construction and implemention will not endure any delays. The challenge of gathering support of critical actors is one that can be tackled quite effectively. The stakeholder analysis pointed out that all crucial actors are supportive or can be quite easily swayed into supporting the project. The main remaining challenge is to perform the SCBA with data was accurate as possible. There has not been any pilot testing yet to obtain accurate output results. Also, the windside turbines are determined to be suitable for the highway project, but not yet specifically optimized for this task. This means that there are still quite some uncertainties at play, however, these are uncertainties that eventually can be measured during experiments. These challenges therefore should not pose too many difficulties. This SCBA will be an indicator on whether it is worth to further pursue the project and getting the really accurate data by means of pilot projects and wind tunnel experiments.