The potential of PV panels near road infrastructure in the Netherlands

Author:

P.M. Jochems (Paul)

Student ID: 0748558

Graduation program:

Construction Management and Engineering

University:

Eindhoven University of Technology

Graduation committee:

Prof. dr. ir. B. de Vries (Bauke)	(TU/e)
ing. J. Dijkstra (Jan)	(TU/e)
ir. J. van de Sande (Job)	(Ballast Nedam)

Eindhoven, 25-04-2013

Table of contents

Preface

This master thesis comprises a study to the potential of PV panels near road infrastructure in the Netherlands and is my final product in order to finish the master Construction Management and Engineering at the Eindhoven University of Technology. The genesis of this subject is a result of my interest in the topics renewable energy and infrastructure. Fortunately, Ballast Nedam was willing to support me with my thesis. Ballast Nedam is actively involved in markets related to both infrastructure and renewable energy.

I would like to thank my supervisors at the university, Bauke de Vries and Jan Dijkstra. Furthermore, I would like to thank my colleagues at Ballast Nedam, especially Job van de Sande for his guidance and input.

Nieuwegein, April 18, 2012

Paul Jochems

1. Introduction

In this introduction the problems are explained that led to this master thesis about PV panels near road infrastructure in the Netherlands. The aggregation of these problems was the motivation for the main research question and associated sub questions. The relevance and objective of this study will also be addressed. At the end of this chapter, the structure of this report is clarified.

1.1. Problem

The problem that led to this research consist of two components. The first component is related to energy, and the second component is related to road infrastructure. Both are explained further on in this section and it will become clear why they are merged together into the subject of this thesis.

As most people know, energy is a hot topic nowadays. Not just only in the Netherlands but throughout the world. The demand for energy increases every year. In order to comply to this increasing demand in the future, renewable energy is necessary. The need for new energy sources isn't only because of an increase in demand, but also due to adverse consequences of energy from fossil fuels(D'haeseleer, 2005). In addition to that, energy from fossil fuels is finite and energy from nuclear sources is controversial due to recent developments.

Since most of the energy that is currently consumed throughout the world comes from fossil fuels like coal, gas and oil, the level of CO_2 in the atmosphere is risen. Increasing levels of CO_2 are responsible for a higher average temperature on earth, and thus a higher sea-level due to melting pole-ice and glaciers. There might be no consensus among scientists whether or not the higher average temperature and sea-level is mainly caused by human actions, but one thing is evident, and that is that the sources of fossil fuels are depleting. The fact that there might be not enough energy for the children of our children should be important enough to make a transition towards renewable energy sources. Currently, there are already multiple techniques available which can be considered as renewable energy or energy from sustainable sources. Examples are energy from wind, energy from solar radiation, earth heath, tidal energy, waterpower, biomass and biogas.

However, the share of energy from renewable sources is still very low in the Netherlands. In this regard, the Netherlands is one of the worst performing countries in Europe(see Figure 4). This is especially the case for energy from solar radiation by using photovoltaic(PV) panels. PV panels are often installed on buildings and rooftops, thus there are often limitations regarding available space, orientation and tilt of existing buildings. Another option is to install PV panels in an open field configuration, called PV parks. But since space is scarce in the Netherlands, PV panels along the roadside could be an interesting option. That's called multiple use of space.

The second component of the problem is related to road infrastructure. Not only the demand for energy will increase the coming years, the demand for road infrastructure will increase too. As stated in the document 'Verkenning mobiliteit en bereikbaarheid 2011-2015'(Kennisinstituut voor Mobiliteitsbeleid, 2010), even with limited economic growth, mobility will increase in all transport modes in the medium term, with the exception of regional public transport. In 2015, the number of kilometers travelled by car is expected to be 14% higher than in 2010 with average economic growth. Not just only the factor economic growth is responsible for this increase in kilometers travelled by car, factors as population and behavior towards car-use are also important.

Recent forecasts from the 'Centraal Bureau voor de Statistiek(CBS)' and the 'Planbureau voor de Leefomgeving(PBL)' show that the population in the Netherlands will grow with approximately 1 million people until 2040. According to the CBS/PBL-forecasts(2009), the population will continue to

grow until 2038, from that point it will gradually decrease. However, it is expected this decrease will proceed very slowly. So the Netherlands will still have a higher population in 2050 than it has in 2010, namely 17.3 million(Kennisinstituut voor Mobiliteit, 2010). As expected with forecasts, there are many uncertainties. In this case it's no different. For the year 2040 this result in a bandwidth of approximately 4 million people. The conservative scenario result in a population of almost 16 million, while the other scenario result in a population of almost 20 million. Furthermore, the development of the population in the Netherlands won't be equally distributed over the country. In the central regions of the country the population will grow, while in the peripheral regions the population declines. The declination in the peripheral regions is especially a result of the aging population in these areas.
Economic development is also a factor which influences the amount of traffic. Based on an average economic growth rate of 1,75% per year, the congestion levels on the main motorway network will return to pre-crisis levels in 2014. Consequently, in 2015 there will be 16% more congestion than in 2010(Kennisinstituur voor Mobiliteitsbeleid, 2010).

Also the development of the ownership of cars is important. From the year 2000 the number of cars owned by individuals has increased with 22%. This increase is significantly greater than the increase in individuals who are older than 18, which was between 2000 and 2011 approximately 6%. Furthermore, the number of households increased in the same period with 10%.
Based on this it is not possible to concluded whether more people own a car, or whether more people own multiple cars. But it is possible to conclude that the behavior towards car-use by people changed and that more cars are present on the roads.

The report 'Verklaring mobiliteit en bereikbaarheid 1985-2008'(Kennisinstituut voor Mobiliteitsbeleid, 2010) shows that the major part of the increase in traveled kilometers is caused by changing behavior, see Figure 1. This behavior has more influence than an increase of population. People drive more kilometers to get from their home to work and they also use the car more often in their spare time.

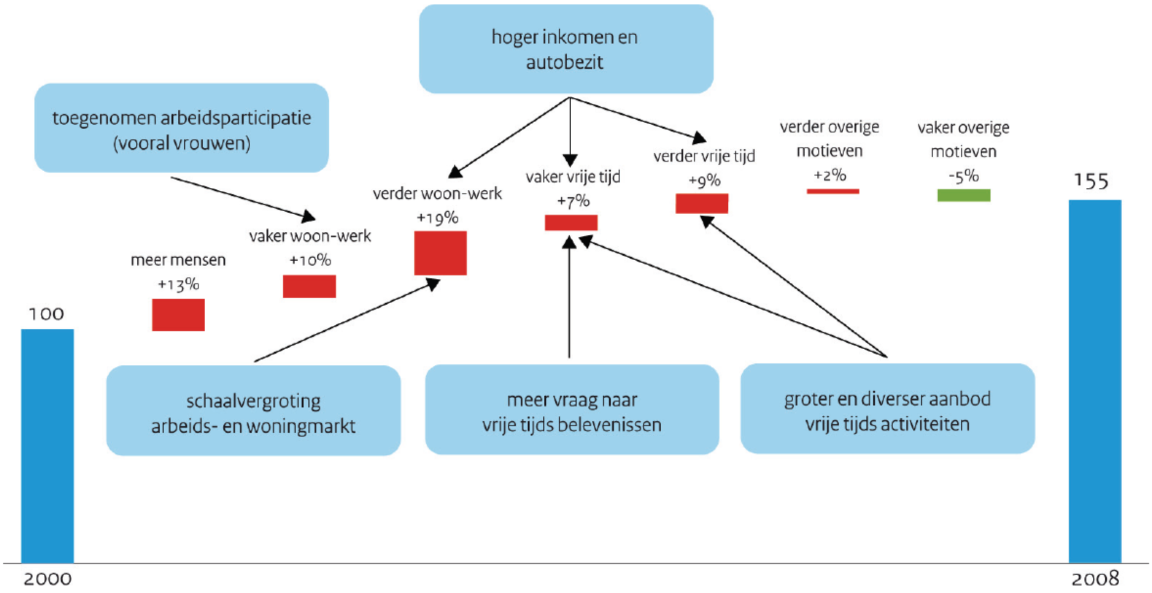


Figure 1: Explanation for increased car-use(Kennisinstituut voor Mobiliteitsbeleid, 2010).

Although the public realizes the importance of sufficient infrastructure, not that many are aware of the costs. Especially of the expenses to keep the infrastructure in good condition. When focusing just on road infrastructure, the costs for maintenance and construction of new roads are displayed in Table 1. Even though these numbers are not very recent(2006), they give a good picture of the ratio between the construction costs and the maintenance costs. Maintenance costs weigh heavily on the total costs of road infrastructure.

	Total
Maintenance costs	630
Construction costs	1.578

Table 1: Infrastructure costs 'Rijkswegennet'(milion €, pricelevel 2006). Source: CE Delft, 2008.

The numbers stated above about the demand for road infrastructure would suggest high priority will be given to investments for construction of new infrastructure and expenses for maintenance in order to keep up with these trends. However, this is not the case. Due to the economic situation, budget cuts seem necessary and they are already taken by policy makers. In total, € 6.4 billion will be saved in the years between 2014 and 2028 on infrastructure in general, of which € 3.43 billion is for the account of road infrastructure(Schultz van Haegen and Mansveld, 2013). This means a significant decrease in investments done by the government in infrastructure. Since the government is the biggest client in the construction industry in the Netherlands, this decrease in investments done by the government obviously result in financial difficulties for the construction industry as a whole.

When the two problems described above are putting next to each other, opportunities may arise. Summarized, the problems are that more energy should be generated with PV panels but space is scarce in the Netherlands, and the infrastructural sector is facing significant budget cuts even though it is obvious investments are necessary. In the best scenario, revenues from the generated electricity by using PV panels are used to finance (partly) road construction or road maintenance. Currently, examples of functions the road shoulder posses nowadays are:

- Vegetation;
- Lighting;
- Road signs;
- Separation of traffic lanes;
- Mitigation of noise nuisance.

One function should be added to the list of functions of the shoulder and that should be energy generation.

1.2. Research questions

Research question

Could PV panels bring added value to the main road infrastructure in the Netherlands, and what will be the potential?

Sub questions

1. What is the current situation concerning PV panels near road infrastructure?
2. What are important criteria or preconditions to make PV panels successful near main road infrastructure?
3. What are the opportunities and/or limitations in case of DBFM(O) contracts?
4. Are changes in policy or regulation necessary to stimulate the use of PV panels near road infrastructure?
5. Which road types or road sections would offer the highest potential?
6. Can it result in an interesting revenue model or competitive advantage for Ballast Nedam?

1.3. Research relevance and objective

The findings could contribute in fostering the application of PV panels near the main road infrastructure in the Netherlands. In this way, road infrastructure can contribute in the ongoing transition towards energy from renewable sources.

The main objective is to demonstrate the potential the main road infrastructure currently possesses to produce electricity and therefore to generate revenue. This is attempted by identifying important criteria or preconditions to make PV panels near roads successful, and identifying issues that result in limitations. In order to be able to demonstrate the potential, the most important goal of this thesis is the development of a financial model, which allows decision makers to assess large scale PV projects. Furthermore, an additional goal is to concretize this potential by applying the financial model to a case study and present an advice to Ballast Nedam what strategy to follow or what their opportunities are in order to set them apart from other competitors. Based on the case study will be determined which road types offer high potential.

1.4. Reading guide

In order to build a sufficient financial model and be able to answer the research questions, extensive background knowledge is essential. This knowledge is provided in chapter 2-4. The energy market is discussed in chapter two. Chapter three is about photovoltaic systems, i.a. how can electricity be generated with PV panels and how does the development of photovoltaic systems proceeds. In chapter four, the issues are discussed that are relevant when installing photovoltaic panels near road infrastructure. Since chapters 2-4 are intended as background information and comprehension of the subject, specific information about the financial model will be explained in chapter 5. With the use of the financial model and with the knowledge gained in chapters 2-4, a case study is elaborated in chapter 6. The final chapter consists the conclusion and recommendations for further research.

2. Energy market

The energy market worldwide is constantly changing, and so is the energy market in the Netherlands. At this moment, this change is significant and everyone can notice it in their everyday life. People may hear about the raising fuel and electricity prices or people may be confronted with an increasing number of PV panels or windmills in their environment. The energy market in the Netherlands consists of multiple components and is influenced by multiple factors such as regulation, taxes, EU-agreements, subsidies etc. How does the energy mix in the Netherlands, regarding electricity, looks like and what tools are used to encourage renewable energy in the Netherlands. The above stated issues are discussed in this chapter.

2.1. Actors

The energy branch in the Netherlands has significantly changed as a result of the liberalization recent years. The production, trade and selling of energy have become commercial activities. This liberalization was commissioned by the European Union, started in 1998 and was completed in 2004. Despite the liberalization, the branch isn’t completely free to enter and the government does have an important role in the energy branch.

The role of the government is to regulate and control, and this task is executed by the Netherlands Competition Authority(Nederlandse Mededingingautoriteit(NMa)). This executive body is part of the Ministry of Economic Affairs. The mission of the NMa is: ‘Making markets work’. If a market works well, businesses constantly do their best to raise the quality of their products and services, by keeping prices low, and by offering new products and services. Businesses that outperform their competitors will sell the most products and services. Competition thus result in consumers having more options, and getting value for their money. And as independent authority, the NMa oversees competition(Annual report 2011, NMa).

In some industries, competition is not always feasible. This is also the case for energy grids. In this market there is room for just one grid operator. Building multiple grids next to one another would not be very efficient. Such providers are therefore called ‘natural monopolists’(Annual report 2011, NMa). The investments necessary to build a grid are simply too enormous that make competition impossible and if it was possible, it would be a waste of valuable resources for which in the end the consumer has to pay for. The NMa determines for these ‘natural monopolists’ maximum price levels. By doing so, they are able to protect the consumers.
At other levels in the energy branch, competition is possible. In fact, competition was the most important reason for the European Union to impose the directives for the liberalization of the energy branch. This competition is present among for instance producers and suppliers of energy. Consumers are free to choose the supplier they like.

Since the liberalization of the Dutch energy market the composition of the market has changed, and so are the parties involved. These parties are listed below;

- Producers;
    - Electricity is mainly generated in large power plants. Large power plants in the Netherlands are owned by for instance NUON, EON, Delta, Essent. Some of these producers produce also renewable energy, such as energy from solar radiation or wind. Furthermore, a significant amount of electricity is imported from other countries, this is especially the case for energy from sustainable resources.
- National grid operator(Tennet);
    - In the Netherlands there is one party responsible for operation of the national grid. They are responsible for the 110 kV-, 150 kV-, 220kV- and 380 kV-grid. For instance the large energy lines above the ground throughout the country are managed by them.

- Regional grid operators;
  - Regional grid operators take care of the transportation of electricity in the region, lower than 110 kV. This includes the realization, maintenance and operation of the grid in order to keep it safe and reliable. Since the liberalization grid operators are independent and the number of grid operators has reduced. The three largest grid operators in the Netherlands are Liander, Enexis and Stedin. One cannot choose a regional grid operator they like, because in every city or region there is only one single grid operator.
- Program-responsible parties;
  - Any party who has one or more connecting points to a grid bears programme responsibility for these connecting points. This means that the party concerned (referred to as the Programme‐Responsible Party or PRP) is supposed to draw up programmes relating to the expected electricity supply to the grid and the expected consumption from the grid. These Energy Programmes are supplied to TenneT on a daily basis. TenneT and the other grid administrators ensure that the actual production or consumption is measured on the day after the day of operation and that the sum of each individual PRP's production or consumption is reported to TenneT. TenneT settles the differences between the volume agreed on in advance and the actual measured volume. If a PRP does not adhere to the Energy Programmes, this will result in an imbalance and will have financial consequences (imbalance settlement).(www.tennet.nl)
- Suppliers.
  - Suppliers are the end of the chain, they supply the energy to the end users(individuals and corporate clients). The end users are free to choose a supplier they like. Suppliers buy their energy from the Program-responsible parties. In the Netherlands, suppliers and Program-responsible parties are often part of the same holding, but there are exceptions.

2.2. Electricity price in the Netherlands

The energy rates in the Netherlands are considered as the lowest in Europe, exclusive of taxes. However, the taxes that are inherent to the energy rates are high. So in the end, the rates that have to be paid are relatively high compared with other countries. The different components of the electricity price and the development of the fares are discussed below.

Energy price development

The costs of energy for households have risen steadily over the previous 15 years. In a 15 year period, the energy costs rose more than three times as fast as the prices of other goods and services, see Figure 2. The energy prices are in January 2012 almost 120% higher than 15 years ago. Thus the average annual increase in the energy price is more than 5%. On the other hand, the 'Consumentenprijsindex'(CPI), which is an index that represent the price development of goods and services, rose with 35% in the previous 15 years. This is a substantial difference.

In the price development of energy in Figure 2 can be observed there is a gradual increase until 2009. From that moment, the price dropped enormously. This decrease in price was a result of the worldwide financial crisis. The energy price depends for an important part on the price that has to be paid for crude oil. Due to the crisis the demand for oil decreased substantially. Consequently the oil price dropped, and thus thereafter the energy price too.

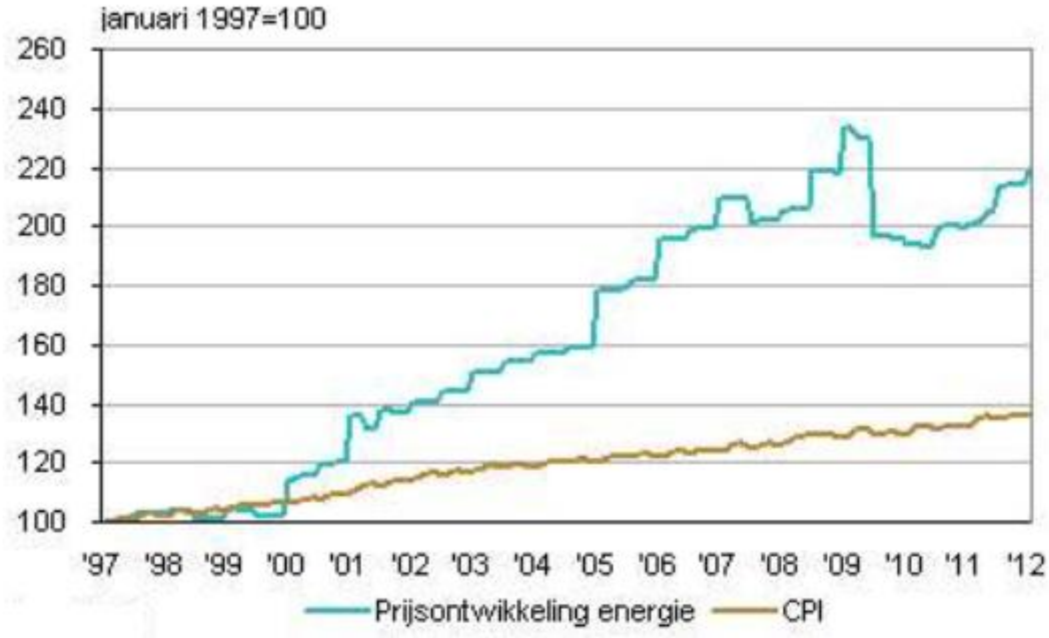


Figure 2: Price development energy and CPI(source: CBS)

In 2010 the energy price started to increase with the same pace it did before the crisis and is at the moment about as high as before the price drop in 2009. It is expected the rise of the energy costs will continue in the future, due to worldwide developments.
Cheap and conventional sources of energy like gas and oil become more and more scarce. The sources which are easy to mine become depleted so it is inevitable the focus shifts towards sources which are more difficult to mine. Therefore more efforts and investments are necessary. Furthermore, another reason for the increasing energy prices are the emerging economies. Examples are China, India and Brazil. They are responsible for a growing demand for oil. Also a lack of spare production capacity and political uncertainties in essential oil producing countries have impact on the energy price.

Composition electricity price
The price of electricity consist of multiple components, including energy tax and VAT. Taxes have an important share in the total electricity price. The size of this share is dependable on the type of energy consumer. For an average household, this share varies between 40% and 45%. Another important share of the price goes to costs for the grid/network. And obviously, there is a share for the electricity itself.

The price that has to be paid for electricity itself depends among others on the supplier and the contract that is agreed. However, the price for which electricity is sold at the APX-ENDEX is a good indication. The APX-ENDEX is an energy exchange for electricity and natural gas in the Netherlands, the United Kingdom and Belgium. APX-ENDEX facilitates the development of liberalized and integrated energy markets in Europe by providing an efficient, transparent and reliable electronic trading environment for electricity, gas and biomass, market data services, clearing services, and a wide range of indices(annual report 2011 APX-ENDEX). The trends of the market price of electricity for the years between 2007 and 2012 are shown in Figure 3. Apart from the year 2008, the price level remains relatively stable over the years. This is in contradiction with the trend of the general energy price shown in Figure 2. This can be explained because in Figure 2 also expenses for gas, grid costs and taxes are included.

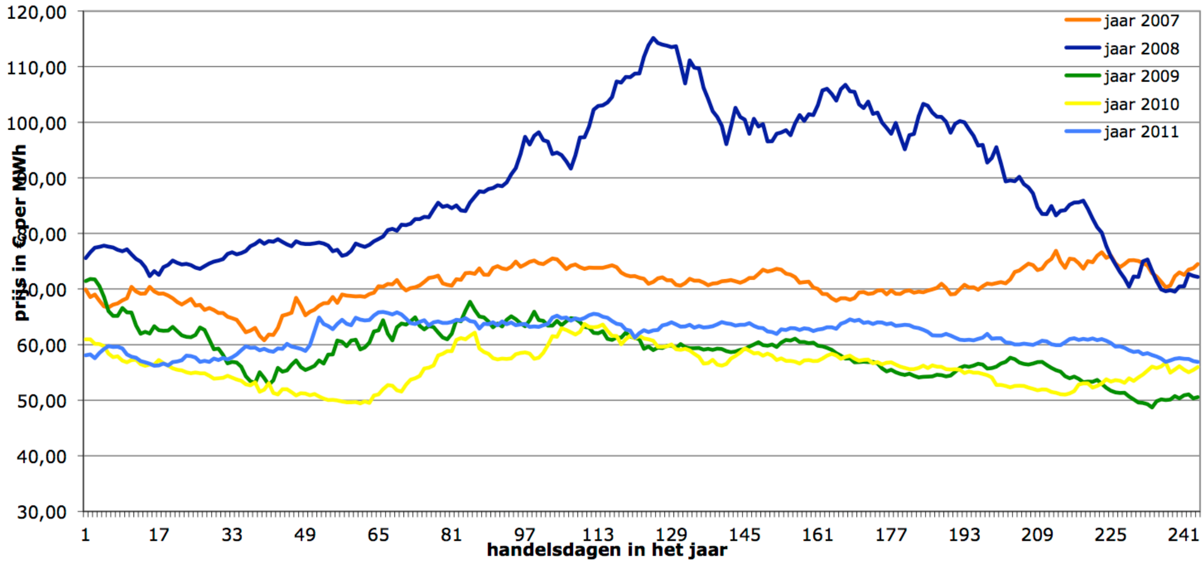


Figure 3: Historical price development electricity, 2007-2012.(source: www.zichtopenergie.nl / APX-ENDEX)

As already explained, energy tax account for a large share in the electricity price. In the Netherlands energy tax has to be paid for the consumption of electricity(per kWh) and natural gas(per m^3). The amount charged depends on the quantity which is consumed. For both energy products, the energy tax is based on a degressive principle. This means the energy tax per kWh decreases when the consumption increases. Thus the energy tax is based on a system with 4 tax levels. The fares associated with the levels are listed in Table 2. Normally, households fall under level 1 and pay relatively high energy taxes compared with the large consumers such as industrial companies. Based on the numbers in Table 2 there is no significant inclination in energy tax between 2009 and 2013. However, there is a significant increase in 2009, compared with 2008. This increase is 44%. The reason for this was to compensate a removed incentive to save energy in the amount that had to be paid to the grid operator in the previous years.

				€/kWh			
Level	**Consumption(kWh)**	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**
1	0 t/m 10.000	€ 0.1165	0.1140	0.1121	0.1140	0.1085	0.0752
2	10.001 t/m 50.000	€ 0.0424	0.0415	0.0408	0.0406	0.0398	0.0375
3	50.001 t/m 10.000.000	€ 0.0113	0.0111	0.0109	0.0108	0.0106	0.0104
4	> 10.000.000 non commercial	€ 0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
4	> 10.000.000 commercial	€ 0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

Table 2: Energy tax per kWh(source: www.essent.nl)

To keep the electricity grid safe and reliable, maintenance is necessary and thus expenses are made. Regional grid operators and the national grid operator are responsible for this task. Eventually, the energy consumers have to pay for this. That's why a part of the energy bill is intended for the grid operators.

The network costs(grid costs) will depend on which company is operating and managing the grid, each of them have set their own fares. The Netherlands Competition Authority has only set maximum fares, thus the prices slightly differ among the different grid-operators. Furthermore, a distinction is made between whether the energy consumer is a 'large consumer'(Dutch: grootverbruiker) or 'small consumer'(Dutch: kleinverbruiker). Which classification an energy consumer gets depends on the type of connection to the grid. If the connection is equal or smaller than 3 x 80 Ampere, the rate for a 'small consumer' is applied, when the connection is larger than 3 x

80 Ampere, the energy consumer can be classified as a 'large consumer'. Obviously, households are 'small consumers', but this is also often the case for small businesses. An often used rule of thumb is that when the energy consumption is less than 80.000 kWh a year, a connection of 3 x 80 Ampere is possible. To get an idea of the costs, in Appendix 1 the rates of the grid-operator Liander are enclosed for 'small consumers' and 'large consumers'. In the documents of Liander, it can be observed costs can be divided in fixed costs and variable costs. For 'small consumers', there are only fixed costs per year, dependable on the type of connection. For 'large consumers', there are besides fixed costs also variable costs, which means costs for every kWh that is consumed. Furthermore, there are costs for the national grid which have to be paid to TenneT. For 'small consumers' this contribution is discounted in the fixed costs, the 'large consumers' have to pay € 0.00111 per kWh to TenneT.

In the end, Value Added Tax(VAT) has to be paid on all components of the electricity price. Since October 1st 2012, the tax rate in the Netherlands has risen to 21%.

2.3. Energy-mix

What is the current share of renewable electricity in the Netherlands? Even more important for this thesis, what is the share of electricity from PV panels. The climate goals of the national government are an important factor for the future of renewable energy.

Current situation

The Dutch government aims to achieve a well balanced mix of energy sources. This makes the energy supply reliable and keeps the costs within boundaries. Thus energy from fossil fuels remains important the next decades. Energy from fossil fuels is still the cheapest energy source and it is necessary to maintain reliability in the energy supply. The Netherlands tries to become CO_2 neutral in 2050 and the use of (limited) fossil fuels doesn't threaten this ambition due to emissions trading, CO_2 storage and cleaner engines(Energierapport, 2011).

As already explained in the introduction of this report, the Netherlands isn't the best performing country in Europe regarding renewable energy generation. The share of energy from sustainable sources is very low compared with other countries, as can be seen in Figure 4. Only Malta, Luxembourg and the United Kingdom perform even more worse. One explanation for this low position is that in other countries energy from sustainable sources is more supported by the government than in the Netherlands. Figure 4 is based on numbers from 2011, when the goals of renewable energy production for the year 2020 were set at 14%, nowadays they are set at 16% by the Dutch national government.

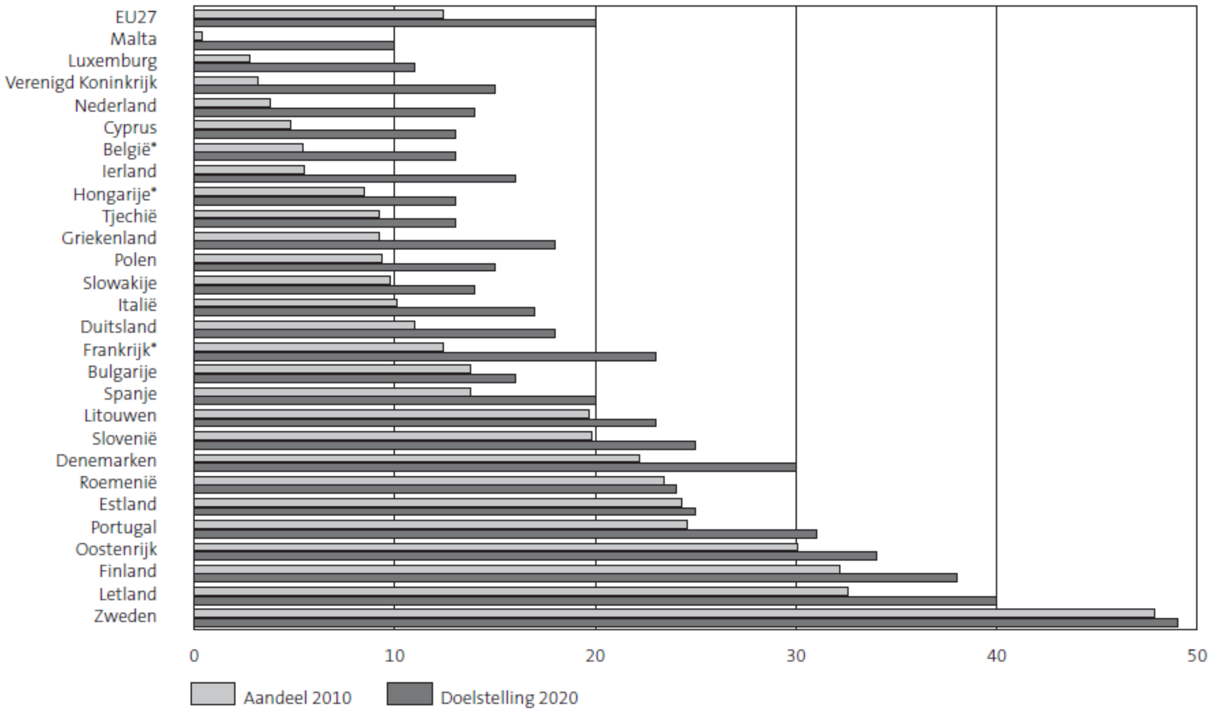


Figure 4: Comparison among EU-members regarding share of renewable energy, 2011.(source: CBS/Eurostat)

Figure 4 displays the share of renewable energy at the total energy consumption, including gas, bio-fuels, electricity, etc. For the Netherlands, this share was 4,3% in 2011, compared with 3,7% in 2010. A remark to this increase is that the total energy consumption dropped due to the economic situation. The share of renewable energy consumption at the total electricity consumption was 9.8% in 2011. Approximately 58% of the consumed renewable electricity was produced with biomass, about 39% by wind turbines. Although the increases in capacity of PV panels during recent years seems impressive(Figure 5), the share of electricity from solar power compared with the total electricity consumption from sustainable sources is just 0.8%. Regarding PV capacity, 15 countries in Europe perform a lot better than the Netherlands does(CBS).

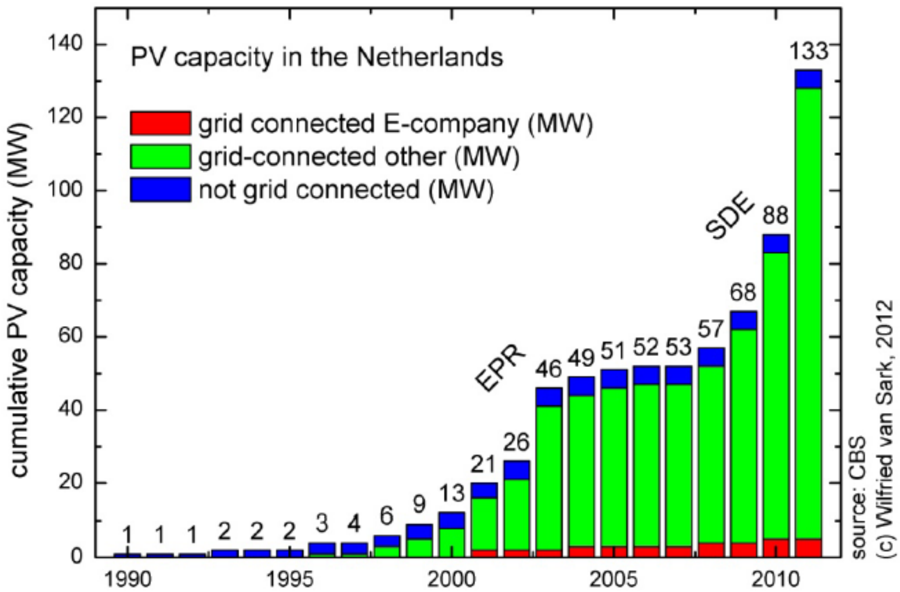


Figure 5: Cumulative installed photovoltaic capacity in the Netherlands until 2011.(source: CBS)

Climate goals

Climate change is a hot topic in Europe. That is why they want to reduce the emissions of greenhouse gasses, encourage energy saving and enlarge the share of energy from renewable energy sources. Every member state of the European Union is obliged to contribute their share in achieving the climate goals of the European Commission(EC). So the EC defined tailor made goals for every member state, including the Netherlands. The Dutch government committed herself to the European goals concerning renewable energy sources. The current government 'Rutte-Asscher' committed themselves to the following goals for 2020: 20% CO_2 reduction compared with 1990 and 16% of the total energy use should come from renewable sources. In 2010 the share of renewable energy in the total national energy consumption was 4,0%.

At lower governmental levels there is a focus at sustainability, also regarding infrastructure. For example, the province of North Brabant and the municipality of Oss are developing the 'road of the future'('weg van de toekomst'). During the development of this road, sustainability received high priority with the application of state of the art technical applications. Rijkswaterstaat(RWS), as a governmental body, doesn't state their own energy goals related to renewable energy production. This is because RWS has no ambition to produce energy by themselve at the land they own/manage. Energy production isn't a public task anymore thus commercial parties have to take the first step in this. So there are no concrete goals set regarding energy generation that can be expressed with specific numbers. Their goal is to help and support private parties with realizing installations that generate energy in a sustainable manner. By doing so, they deliver a contribution to the national government which helps them to achieve the energy goals that are stated above.

In order to achieve the climate goals which are set, the government uses subsidies and fiscal measures to stimulate renewable energy generation. The subsidies and measures which are currently in operation are covered in the next section.

2.4. Subsidies

From an economic point of view, an investment in PV systems becomes more and more viable. However, despite the continuously decreasing price for PV panels and the rapid development of new technologies, energy from solar radiation is still more expensive than energy from fossil fuels. Even in the most favorable regions, solar power is still a few years away from true "grid parity"—the point when the price of solar electricity is on par with that of conventional sources of electricity on the power grid(Lorenz et. al, 2008). This is especially applicable for the Netherlands, since grid parity is as first expected in countries in southern Europe. Until then, subsidies from the government will still play an important role in the development of this sector. Government subsidies all over the world are for a main part responsible for the rapid growth of solar power.

Over the years, multiple support measures and subsidies came available in the Netherlands, which have the purpose to encourage the use of electricity from sustainable resources. It helps solar energy to compete with energy from fossil fuels. Compared with other European countries, the Netherlands isn't very generous with subsidies and the policies in this field are also not very consistent. But based on literature, it is viable to raise criticism about the policies in all European countries. Laleman and Albrecht(2012) concluded in their paper they can safely say that European governments should critically evaluate current renewable subsidy schemes, especially for PV-systems, and raise public RD&D investments. These higher RD&D budgets could drive down production costs, which will result in a decreasing need for demand-pull measures in the longer run. Further efforts should be made to obtain more reliable and complete data on public and private RD&D expenditure and to improve our understanding on the interactions between demand-pull and supply-push policy measures, such that policy makers have the knowledge and the tools to bring new, promising technologies to the market in an effective and efficient manner(Laleman and Albrecht, 2012).

This section tries to give insight in the subsidies or support measures that are currently put in place in the Netherlands and can influence the output of the financial model. These programs are only available for businesses.

- EIA;
  - The EIA('EnergieInvesteringsAftrek') makes it possible to subtract 41.5% of the investment costs for energy saving assets from the fiscal profit, on top of the regular depreciation. The minimum investment amounts € 2.300, the maximum investment is € 118 million. Investments can be eligible for both the EIA and KIA. The combination of EIA and MIA isn't possible.
- SDE+;
  - This subsidy program is put in place in 2008 to foster the production of renewable energy. The SDE+ is only available for energy consumers with a connection larger than 3 x 80 Ampere and for installations larger than 15.000 Wp(15 kWp). Every year, new funds come available and details and conditions of the program are set. The resources which were reserved for the SDE+ 2012 are completely used. The SDE+ program will come available again at April 4th 2013, and it is possible to apply for until December 19th 2013. The money which is reserved for the program in 2013 is significantly more than it was in 2012, namely € 3,0 billion. The subsidy is based on an amount of money that is paid per kWh that is generated and the subsidy program is subdivided into 6 phases. Per phase, a different amount per kWh is determined. The amount becomes higher every phase, but when one waits with his application for a next phase, it may be possible the whole subsidy budget is already depleted. This subsidy is intended to (partly) compensate the gap between the grey electricity price and the price for electricity from solar radiation. Details about the SDE+ program 2013 are enclosed in Appendix 2.
    Figure 6 illustrates the essence of the SDE+ program. Both the costs of green(renewable) energy and the (provisory) costs of grey energy are determined before the program is put in use. The cost of green energy is different in every phase, thus the SDE-contributions changes. If the SDE subsidy is granted, the yearly contribution is paid during 15 years from installation.

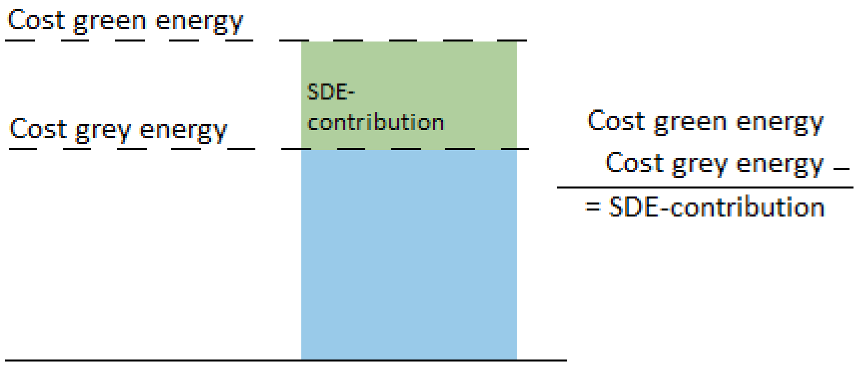


Figure 6: SDE+ subsidy.

- KIA;
  - KIA is an abbreviation for 'KleinschaligheidsInvesteringsAftrek'. Since this subsidy isn't only applicable for the investment in PV systems but also for other assets, the total of all investments should be summed. Investments between €2.300 and €306.931 are eligible for this subsidy. Dependable of the investment, it can be calculated which amount may be subtracted from the profit(before tax), see Table 3.

Investment	'KleinschaligheidInvesteringsAftrek' (KIA)
< € 2.300	0%
€ 2.301 - € 55.248	28%
€ 55.249 - € 102.311	€ 15.740
€ 102.312 - € 306.931	€ 15.470 minus 7.56% of the part of the investment that is above €102.311
> €306.931	0%

Table 3: Levels for the KIA.

- MIA/VAMIL.
    - These subsidy programs stimulate companies to invest in environmental friendly devices. But these programs are not very relevant in case of large scale energy production with PV panels. In fact, the only situations when energy production with PV panels become eligible for these programs, occur when the generated energy is used to power electric cars or when the PV panels are installed in combination with the remediation of an asbestos rooftop. Therefore, the details of this program will not be further discussed.

It is possible to combine multiple subsidies. EIA and VAMIL can be used together, EIA and MIA cannot. The MIA, VAMIL and KIA can also be used simultaneously. The SDE+ can be used in combination with all other programs. The legal status of an entity is an important aspect whether it is possible to make use of subsidies.

The above named subsidy programs are all meant for businesses, so are not available for individuals. For individuals, there is only one subsidy program available. It is in place since July 2nd 2012 and consist of a single contribution when buying PV panels. This contribution is 15% of the purchase sum of the PV panels, with a maximum of €650.

At last, there is another mechanism available in the Netherlands to foster the development of energy from solar radiation. This mechanism is called net metering(Dutch: salderen). Officially it isn't qualified as a subsidy, but it can be considered as one since consumers receive a much higher price for their self produced electricity than the market prices for renewable electricity. It is regulated by law that 'small consumers'(< 3 x 80Ampere) have the right on net metering. So this could be individuals, as well as small businesses. Net metering means that the electricity that is fed into the grid, can be subtracted from the total amount of electricity that is received from the energy supplier. More details about net metering and the regulation in this regard is explained in section 4.5.1.

Example: *When an energy consumer receives in a particular year 3.500 kWh from the energy supplier, and feeds back 1.000 kWh into the grid, then the energy supplier will charge only for (3.500-1.000=) 2.500 kWh.*

Thus, individuals receive indirect approximately €0,23 per kWh. Since approximately €0.15 per kWh are taxes, the government misses lots of income due to net metering. By law, there is a maximum amount of kWh set that can be deducted from the energy bill, which is 5.000 kWh. However, there are a few energy suppliers in the Netherlands that raised this bar, namely:

- Greenchoice;
- Atoomstroom;
- Mainenergie;
- Essent B2B.

‘Virtual’ net metering may become possible in the near future. The essence is the same as for regular net metering, except about the location of the PV system. Virtual net metering means that the electricity can be generated at another location than behind the connection to the grid. So the electricity is generated with a PV system for which you paid, located at a different location, and is transported via the grid to your house or company. This would make renewable energy from solar radiation possible for people or companies who do not have enough space at their own property. The issue virtual net metering is currently discussed at political level. There has already started a pilot in Amsterdam in order to ‘test’ virtual net metering in a residential complex.

The above mentioned subsidies are all programs from the national government. In addition to these, it is very likely there are subsidy funds available from the local governments. Obviously, this is different for every province or municipality. It could be worthwhile to do some research to subsidies from lower governmental bodies.

The Dutch government isn’t only intervening in the energy sector by stimulating energy from renewable energy sources, but subsidies go also to energy from fossil fuels. In fact, much more subsidies go to fossil fuels. The numbers for 2010 are shown in Table 4. Especially very large energy consumers(both electricity and gas) are benefiting from the subsidies on fossil fuels. The numbers in Table 4 aren’t really corresponding with the sustainability goals of the government.

	Amount(bln. €)
Fossil fuels	5.6
Renewable fuels	1.5

Table 4: Government interventions on energy in the Netherlands, 2010.(source: Ecofys, CE)

3. Photovoltaic systems

In this chapter some general issues about photovoltaic systems will be elaborated. What are the market developments for photovoltaic systems worldwide? How can electricity be generated from solar radiation and how do photovoltaic systems work? What factors are relevant for the energy production of a photovoltaic system? These are questions that will be answered in this chapter. The technique behind photovoltaic panels is briefly covered as well, as are the different types of photovoltaic systems available on the market.

3.1. PV market worldwide

Energy from solar radiation by using photovoltaic systems is becoming more and more popular. The market share of energy from solar radiation is slowly increasing every year and gains ground against energy from conventional resources such as fossil fuels and nuclear power sources. The potential of this energy source is enormous. World photovoltaic industry has an average growth rate of 49.5% over the past 5 years (Yan, Zhou, Lu, 2009). The total PV installations grew in 2011 to 70 GW, compared with a total installed capacity of 40 GW in 2010. The development of the market size over the years 1995-2010 is displayed in Figure 7.

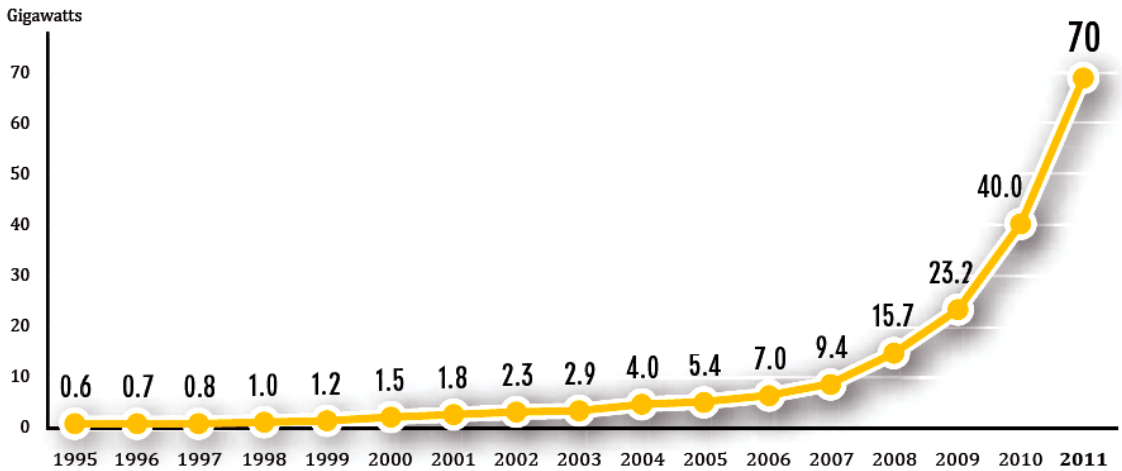


Figure 7: Total solar PV capacity worldwide, 1995-2011.(source: REN21, 2012)

The IEA(International Energy Agency) envisaged solar power accounting for 11% of global electricity production by 2050 and solar electricity contributes about 20% of the world's energy supply by 2050 and over 60% by 2100 (ISPRE, 2009). Several factors can be considered which are responsible for this transition and increasing demand, and thus increasing amount of installed PV installations. One factor is the awareness of people and governments towards energy from sustainable and renewable sources. This is due to the fact that energy from conventional resources is related to multiple disadvantages like scarcity, pollution, climate change and adverse safety issues. Another factor, which is probably the most important one for the continuous growing demand for PV installations, is the decreasing price of PV panels. The lower the price, the more people can afford the installation of PV panels and the more attractive investments become for companies. Cost reductions will be achieved through the following measures: (i) higher conversion efficiency, (ii) less material consumption, (iii) application of cheaper materials, (iv) innovations in manufacture, (v) mass production and (vi) optimized system technology(Dincer, 2010). A low PV panel price results in a shorter payback period. Also, the price of fossil fuels and electricity is showing a rising tendency(see Figure 8). Therefore the difference in price between energy from solar radiation and energy from fossil fuels is becoming smaller.

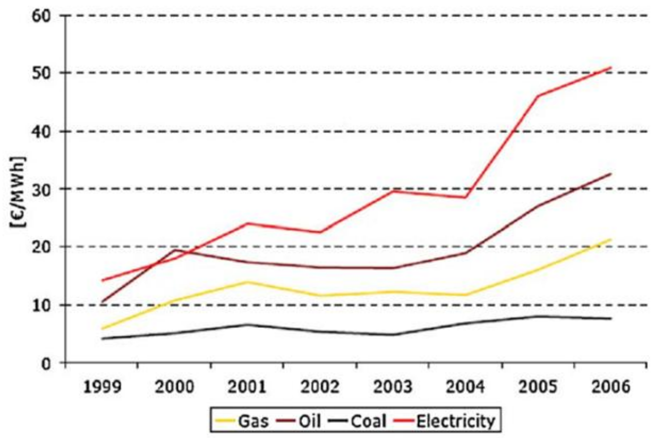


Figure 8: Price development of fossil fuels and electricity from 1999 until 2006(Suna et. el. 2007)

The European Union dominated the global PV market, thanks to Italy and Germany, which together accounted for 57% of new operating capacity in 2011(see Figure 9). The EU installed an estimated 17 GW and connected nearly 22 GW to the grid; this was less PV capacity than was installed during 2011, but far more of it began feeding power into the region's grids. With a total of 51 GW by year-end, the EU accounted for almost three-quarters of the world's total installed solar PV capacity, and had enough solar PV in operation to meet the electricity demand of more than 15 million European households. For the first time ever, solar PV accounted for more additional capacity than any other type of electricity generating technology: PV alone represented almost 47% of all new EU electric capacity that came on line in 2011(REN21, 2012).

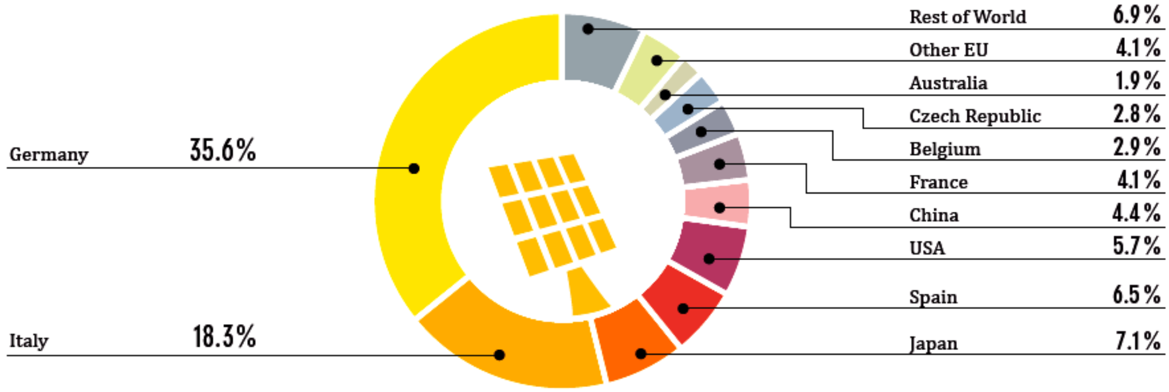


Figure 9: Top 10 countries in 2011 regarding operating capacity.(source: REN21, 2012)

3.2. Solar irradiation

The yield, the amount of produced electricity, of a photovoltaic system depends mainly on the irradiation of the photovoltaic system. The solar irradiation is not just only influenced by the tilt and orientation of the system, but also by the solar radiation.

Solar radiation

The sun supplies energy in the form of radiation, which is the basis of all life on earth. Due to the immense distance from the sun to the earth, just a small part of the solar radiation reaches the earth. This small part can be quantified at approximately 2 ppm(parts per million). This can be expressed in a number of kWh per annum. That amount of 2 ppm seems very little, but the amount of energy that is still reaching the earth's surface is about 1000 times the current global energy demand. So if mankind could only capture a small part of this energy, no other resources would be necessary to meet the global energy demand(Ecofys, 2005).

This enormous amount of energy generates annually on average 1700 kWh/m^2. In the Netherlands this amount is much lower, due to the location, and is approximately 1000 kWh/m^2/year. The impact of the location will be further elaborated later on in the section. The radiation from daylight can be directly transformed into electricity. Radiation can be divided into direct and indirect radiation. Indirect radiation could be referred to be as diffuse or scattered. Obviously, direct radiation generates more energy than diffuse. Therefore it is very important to focus the PV system optimally towards the sun because on clear days direct radiations prevails. However, on mostly cloudy days (especially during winter), solar radiation is almost entirely diffuse. In London for instance, the proportion of diffuse solar radiation measures 60%, and that of direct radiation 40% over the year(Ecofys, 2005). This shows the important contribution diffuse radiation delivers to the total production during one year. The observation which is done for the city of London is also applicable to the Netherlands, due to the more or less same climate and location at the same latitude.

The intensity of the radiation varies during the day and year, and due to weather conditions. In order to make communication much easier and to make it possible to calculate with data from solar irradiation, it is agreed the total amount of solar energy can be expressed in hours of full sun load per square meter. Internationally it is determined the radiation level in case of good weather conditions reaches 1000 W/m^2. In the Netherlands there are on average approximately 1000 hours of full sun load per year, but the exact number depends on the location. Figure 10 displays an indication of hours of full sun load per year for the Netherlands. Even in a small country as the Netherlands, there is a significant difference in hours of full sun load between the eastern and western part of the country.

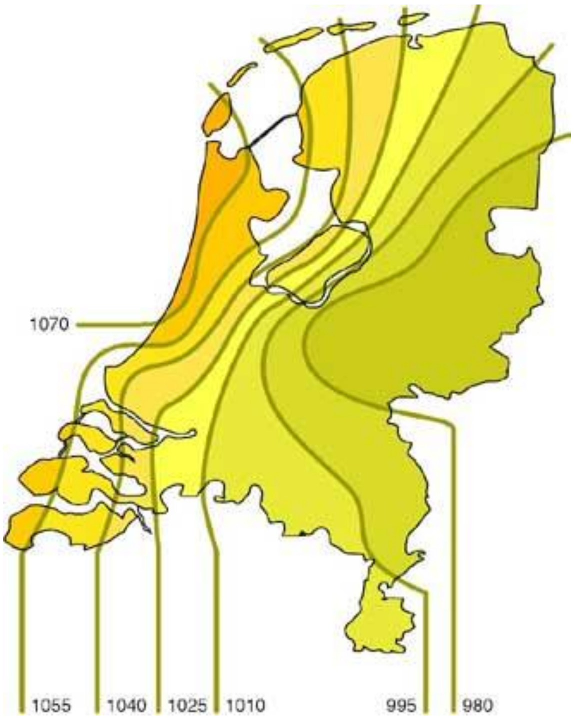


Figure 10: Hours of full sun load a year per location.

It is obvious that it is difficult to derive very accurate numbers from Figure 10 for every location in the Netherlands. This figure is based on data collected by the Royal Netherlands Meteorological Institute(Dutch: Koninklijk Nederlands Meteorologisch Instituut(KNMI)). This data is collected daily by 36 weather stations across the country and consist for instance information about temperature, wind, sunshine duration, precipitation, global radiation, etc. A map with every weather station in the Netherlands is available in Appendix 3. When it comes to photovoltaic systems, global radiation is the most important piece of information. The global radiation is measured in Joules per square cm(J/cm^2). Because the global radiation is at most stations measured since 1990, it is possible to calculate the average radiation per year over a period of 23 years. Since the unit J/cm^2 can be converted into Wh/m^2 and the radiation level in case of one hour of full sun load is 1000 W/m^2, it is easy to calculate for that specific location the total hours of full sun load per year.

Tilt and orientation

According to the location, the ideal tilt and orientation should be determined. First, the tilt or inclination of a PV panel is very important in order to achieve the highest yield possible. If a place is perpendicular to the sun's rays, the solar radiation is always higher than on a horizontal level with the same size. Ideally, since the azimuth and the elevation angle change during the day and year, the PV system should follow the track of the sun in order to keep his position perpendicular to the sun's rays all day. Technically this is possible with a tracking system, however, in very few PV systems this feature is implemented due to cost considerations.

During winter periods, the yield is maximized when the tilt of the panel is adjusted towards a more vertical position(e.g. 70°), while in the summer a more flatter position(e.g. 25°) of the panel is preferred. Furthermore, the location on earth does matter. More specific, it is important at which latitude the PV system is located. Around the equator the inclination angle of the sun is very high, while it's much lower when going North. In the UK, for instance, the optimal position of a PV panel for total annual gain faces the south with an inclination angle of approximately 30°-40°. In the US, depending on whether you are in the north of the country or in the more southern states, the optimum angle for total annual gain can range from 20°-30°(Ecofys, 2005, p13).

Secondly, the orientation or azimuth of the PV system is very relevant. Often, this depends on external factors because the system is installed on rooftops or other existing structures. In the Netherlands the ideal orientation is towards the South. When the azimuth is fixed, the efficiency can still be optimized by choosing the adequate tilt angle(see Figure 11). In case of a fixed PV system in the Netherlands oriented to the South, a panel with an inclination angle of 37° would generate the most electricity annually(source: PVGIS).

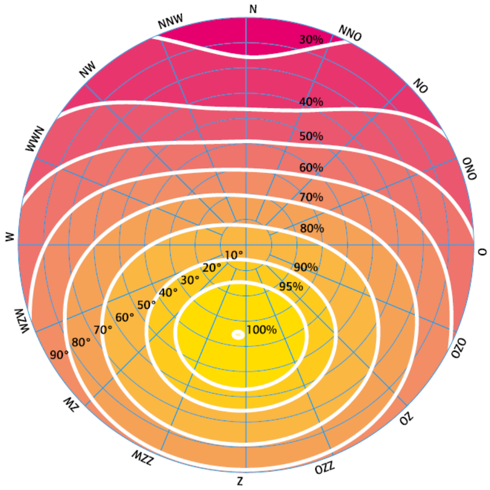


Figure 11: Irradiation diagram for the Netherlands(source: AgentschapNL).

Temperature

Past research has demonstrated that the efficiency of crystalline silicon PV modules decreases with approximately 0.4 – 0.5 % for every degree Celsius the temperature rises(Ronnelid, Karlson, Krohn, & Wennerberg, 2000). Module performance is generally rated under Standard Test Conditions (STC). PV modules are tested in a laboratory where the Standard Test Conditions are present. This means an air mass of AM 1.5, light irradiation of 1.000 Watt per m^2 and a module temperature of 25 °C. Thus, when the module temperature exceeds 25 °C, the efficiency drops. It should be noted that we are talking about module temperature and not about the temperature of the environment. Even in the Netherlands the module temperature could reach 60 °C during a sunny day. The temperature coefficient of Thin Film PV is lower compared with Crystalline Silicon PV. The temperature factor makes the panels perform best during a sunny windy day in the spring. During this period the sun is already powerful, temperatures are low, and the wind can discharge the heat. Therefore it is important to install PV panels in such a way the air is able to flow easily around it.

3.3. PV basics

The photovoltaic cell is able to convert light directly into electrical energy. In this process, semiconductor materials such as silicon, gallium arsenide, cadmium telluride or copper indium diselenide are used(Ecofys, 2005). Most solar cells are made from silicon. Silicon is one of the most abundant elements on earth, although not directly available in the state that is required for photovoltaic cells.
One cell on itself is very small and produces very little power, therefore a PV module consists of multiple individual solar cells that are connected in series in order to increase the power. In Figure 12, the basic structure of a solar cell is shown. A cell consist of two differently doped silicon layers, called a p- and n- layer. An electric field is produced at the boundary of these two layers. When sunlight falls upon the cell, the charges are setting free. Metal contacts that are attached to the front and the back make it possible to generate electricity. This photovoltaic process continues as long as there is sunlight falling on the cells. No materials are being lost during this process, that's why this method is very sustainable.

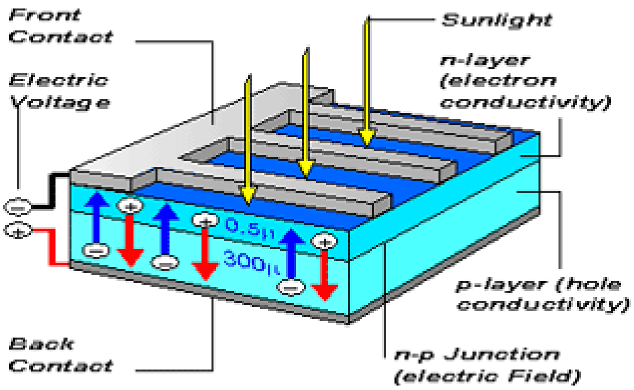


Figure 12: Structure of a crystalline solar cell(source: ECN)

At present, there are two types of photo voltaic technologies:

- Crystalline silicon cells;
- Thin layer cells(or thin-film cells).

Most of the installed solar capacity in the world uses the crystalline technology. Two different types of cell technologies are developed that are based on this concept, which are mono-crystalline and poly-crystalline. The crystalline technology is more efficient than the thin layer technology, thus mono-crystalline solar panels need less surface area. If space is very valuable, crystalline silicon cells would prevail. On the other hand, a principal advantage of thin-film solar cells is that they use far less semiconductor materials than are required to fabricate crystalline silicon solar cells. Thin-film cells are also less susceptible to damage. Since silicon is the most expensive component, the thin layer cells are less expensive. One important disadvantage of the thin-layer technology is the efficiency, which is lower.

While thin-film shipments continued to grow to 3.7 GW in 2011, cheap crystalline silicon dominated the industry from 2010 onward. Market share of thin-film PV dropped to 11%. In 2011, crystalline silicon PV prices dropped by over 40% over the course of the year, undermining the value proposition of thin-film solar cells(GTM Research, 2012). Crystalline silicon PV modules are expected to remain a dominant PV technology until at least 2020, with a forecasted market share of about 50% by that time(Energy Technology Perspectives, 2008). This is due to their proven and reliable technology, long lifetimes and abundant primary resources. Companies are starting to approach the theoretical efficiency limit, which is 31 percent, of a mono-crystalline silicon photovoltaic cell. Several now achieve efficiencies in the 20 to 23 percent range. Compared with crystalline silicon, the thin layer technology is relatively new but has been available for many years and proved recently it can reach sufficiently high efficiency level at commercial volumes. This technology has significant headroom to extend the cost gap in the long term(Lorenz et. al, 2008).

Significant steps forward may be expected in the field of photovoltaic's. Companies that use either of the current photovoltaic technologies, which generate electricity directly from light, are striving to reduce costs by making their systems more efficient. In power conversion, efficiency means the amount of electrical power generated by the solar radiation striking the surface of a photovoltaic cell in a given period of time. For each unit of power generated, more efficient systems require less raw material and a smaller solar-collection surface area, weigh less, and are cheaper to transport and install(Lorenz et al.).

The technologies explained above are the basis for multiple developments. Examples are for instance Building Integrated PV(BIPV, semi transparent) or bifacial PV.

3.4. Price development

The costs of PV systems has been going down for decades and is now approaching competitiveness. Figure 13 illustrate that remarkable price decline: over the last 20 years, PV has already shown impressive price reductions, with the price of PV modules decreasing by over 20% every time the cumulative sold volume of PV modules has doubled(learning factor). The average price of a PV module in Europe in July 2011 reached around 1.20 €/Wp; this is about 70% lower than 10 years ago(IPIA, 2011). Currently(February 2013), prices per Wp for crystalline solar panels range between €0.60-€0.65. So a significant price drop occurred since July 2011. Partly this is caused by cost reductions and increasing efficiency, but another factor is involved. Namely, there was a surplus of PV panels on the market, the production rate was too high compared with the demand. In order to sell as much as possible, manufacturers, especially from China, dropped their prices.

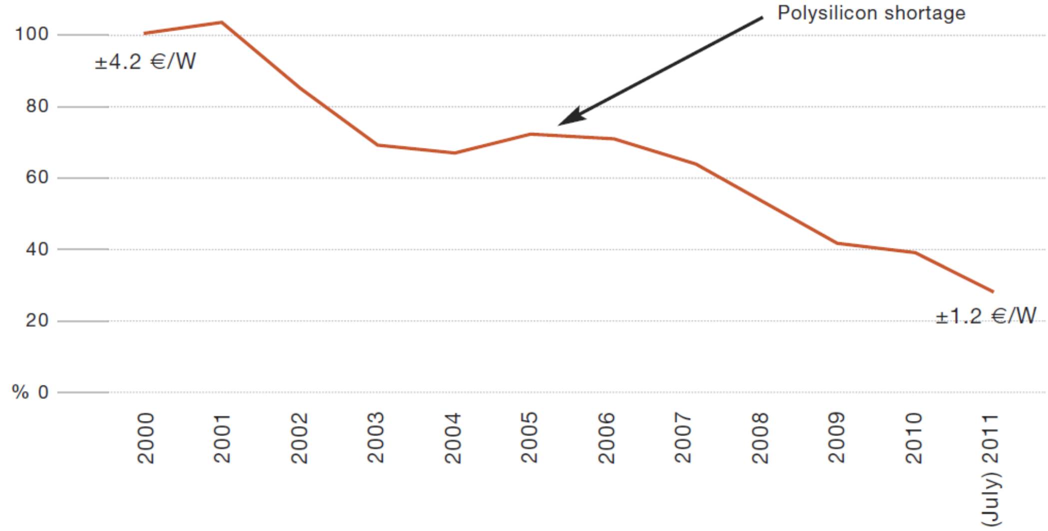


Figure 13: Evolution of the average PV module price in Europe.(source: EPIA)

Due to price drops from photovoltaic producers in China, a lot other producers in the world weren't able to compete and went bankrupt. Nowadays, a lot of the biggest photovoltaic companies are originated in China. Even more have the production facilities located in China. In Figure 14, the top 15 of the biggest manufactures worldwide are shown, accompanied with their market share and home country.

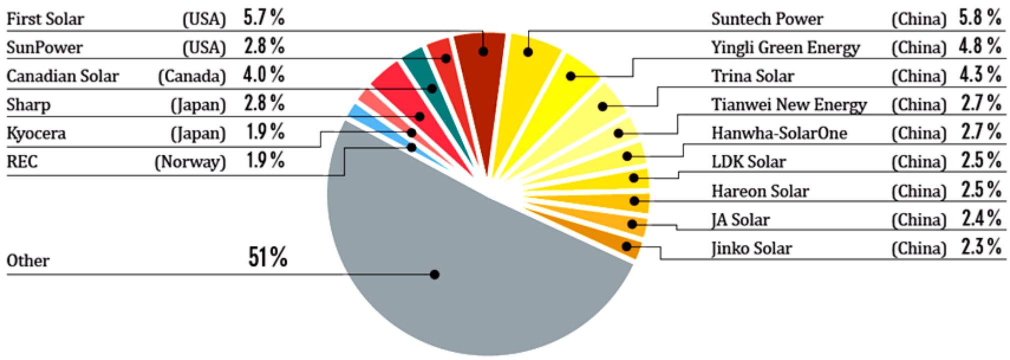


Figure 14: Market shares of top 15 solar PV module manufactures, 2011.(Source: REN21, 2012)

4. PV systems and road infrastructure

This chapter considers the most relevant issues and opportunities that are important when PV systems and road infrastructure are combined. An overview of the current situation regarding PV systems and infrastructure is given. Also topics as stakeholders, legislation and efficiency near road infrastructure will be addressed.

4.1. Potential and advantages

The Netherlands is a highly populated country, thus the road network is very compact, namely 331 km of road per 100 sq. km of land area(www.data.worldback.org). Figure 15 displays the network of main roads. Some figures(RWS):

- 3.046 km motorway;
- 1.428 km access, exit and connection roads;
- 2.749 viaducts, 13 ecoducts;
- 22 tunnels;
- 743 bridges.

Figure 15: Overview of the main road network.

From Figure 15 can be seen motorways run throughout the country. Therefore they are often located in the near vicinity of populated areas. Without further measures, it would result in noise nuisance for the environment. In the Netherlands and most of the other European countries there is strict regulation regarding noise protection in populated areas. Due to this regulation, more noise(or sound) barriers are being build these days compared with 15 years ago.

Multiple advantages arise when using the current and new to build noise barriers as a substructure for PV systems. In the paper 'PV on noise barriers'(Nordmann, Clavadetscher, 2004) the following advantages were identified:

- Double use of land resources;
  The strip of land along a rail or road infrastructure in a built up area can be utilized for noise protection and also for the placement of PV modules to produce electric energy.
- High potential;
  There is a high potential for photovoltaic noise barriers (PVNB) especially in highly populated and industrialized areas, which also have a high usage of electric energy. In recent studies the potential to produce electric energy along motorways and railways in Europe was quantified.
- Bulk prefabrication;
  Mechanical and electrical prefabrication of photovoltaic or complete photovoltaic noise barriers (PVNB) subsystem was exercised in most of the grid connected PV plants built along transport infrastructure in the past 14 years.
- Public ownership;
  A highway project, including noise protection, is usually a public project and the additional PV plant can be included in the finance plan, the planning and building process as a whole.
- Easy access.
  The transport-ways can be used for the construction and maintenance of the PVNB systems. Appropriate transport vehicles are already available for general road or rail maintenance.

About 15 years ago, a European study was carried out in order to quantify the energy potential of PVNB in Europe. The study was conducted by a partnership of 6 countries, including the Netherlands. Road and railway infrastructure was considered. From this study, data about the potential of the road network in the Netherlands can be extracted. This data is given in Table 5. The theoretical, technical and short term potential was estimated. The theoretical potential assesses the maximal possible number of PVNBs. All existing roads will be equipped with a PVNB. The technical potential includes all NB along the road, existing and planned in 1999. They are assumed to be equipped with PV under realistic boundary conditions. These conditions are related with orientation and irradiation yield factor. The short term potential considers all NB planned in 1999, which are suitable to be equipped with PV.(Goetzberger et al., 1999)

Potential	Relevant roads(km)	Power installed(MWp)	Electricity produced(GWh/y)
Theoretical(max possible)	2701	3233	2590
Technical(new and retrofit)	475.9	114.6	91.8
Short term(next 5 years)	210.1	50.6	40.5

Table 5: Potential of PVNB in the Netherlands(Goetzberger et al., 1999).

The Netherlands possesses high potential compared with other countries in the European Union. Germany and the Netherlands have 74% of the total technical potential, whereas the United Kingdom and Italy have only 9% of the existing NB which could be upgraded to PVNB. The large rail projects offer the best perspective for short-term large-scale introduction of PVNB in the Netherlands. The part East and South of Amsterdam is also one of the highest potential densities in all of Europe. Furthermore, the central-western part and the triangle with Belgium and Germany are high potential areas (Goetzberger et al., 1999).

Not only noise barriers provide opportunities when combined with PV systems. Besides there are many noise barriers which may be suitable to combine with PV systems, there is also lots of unused land near road infrastructure.

Road- and railway-infrastructure covers almost 3% of the space outside the urban areas. A large share of this space is called indirect land use because it isn't actually directly used for roads. In addition there is space that is unused due to safety, noise and emission regulations. In theory, (parts of) these areas could be used to generate electricity with PV systems(ECN, n.d.). The advantages which are stated above and related to noise barriers, are also applicable for the unused areas of land. Potential locations for PV panels, beside PVNBs, are:

- Around entrances and exits;
- Ground walls;
- Shoulders;
- Intersection of highways;
- In between roads.

4.2. Current situation

Currently there are several examples in Europe and a few in the Netherlands where PV systems and road infrastructure are combined. Most of these projects encompasses PV systems incorporated in noise barrier structures, however in a few projects other applications are applied. In this section these projects are elaborated in order to provide a clear picture about the current situation concerning PV systems and road infrastructure. Furthermore, at the end of this section an example of a PV park in the Netherlands is considered since it is expected it will provide insight and learned lessons.

Most of the projects are located in European countries. About 25 years ago, several countries saw already high potential in noise barriers combined with PV systems. So some of them started with studies and trials. The first photovoltaic noise barrier (PVNB) came into use in Europe in 1989 and is located in Switzerland in the municipality of Domat/Ems. Only a few years later other countries followed that example and build the first PVNB in their country. In Table 6, all known locations of PVNBs in the world until 2011 are shown.

Country	Road	City	Construction	Size(kWp)
Switzerland	A13	Domat/Ems	1989	100
Austria	A1	Seewalchen	1992	40
Germany	A23	Rellingen	1992	30
Germany	A620	Saarbrücken	1995	60
The Netherlands	A27	Utrecht	1995	48,5
Switzerland	A2	Giebenaach	1995	100
Switzerland	A1	Zürich	1997	10
Germany	A96	Ammersee	1997	30
Switzerland		Zürich	1997	10
Switzerland	(railroad)	Zürich	1998	9.6
The Netherlands	A9	Amstelveen	1998	205
France	A21	Foquière	1999	63
Germany	A6	Sausenheim	1999	100
Switzerland	A1	Safenwil	2001	80
Austria	A2	Gleisdorf	2001	101
Germany	A31	Emden	2003	53
Germany	A92	Freising	2003	599
Germany	(railroad)	Vaterstetten	2004	180
Germany	B31	Freiburg	2006	365
Germany		Grosbettlingen	2006	28
Switzerland	582	Melide	2007	123
Germany	A94	Tögin am Inn	2007	1.000
China	(metroline)	Shanghai	2007	8
Australia		Melbourne	2007	24

Switzerland		Münsingen	2008	12
Germany	A3	Aschaffenburg	2009	2.650
Italy	A22	Marano d'Isera	2009	730
Germany	B57	Bürstadt	2010	283
Italy		Oppeano	2010	833
Germany		Biessenhofen	2010	90

Table 6: Overview of PVNB locations.

The total installed capacity of photovoltaic noise barriers worldwide is about 8 MWp. More than half of the worldwide installed capacity is located in Germany. This isn't very surprising considering the German policy regarding renewable energy. Since Italy built two large PVNBs in 2009 and 2010, they took over the second place from Switzerland. Switzerland has got with a total of 8 more PVNBs than Italy, but the capacity of each of these installations is very low.
Another observation is that outside Europe there are just only two PVNBs. One is located in Melbourne, Australia, the other one is located in Shanghai, China. The purpose of the project in China is mostly research related. Possible designs for the PVNB are investigated, together with an economic and environmental analysis. For the first time, a PVNB has been installed along a metro line in China. The installed power is 8 kWp and the total length of the PV array is 360 m.(Gu et. al., 2012). Thus far, in Canada, despite a massive transport system and a high per capita use of vehicles, no building integrated photovoltaic projects of this type have been undertaken(Remmer, Rocha, 2005). Until now, only efforts are made regarding feasibility studies. It didn't led to trial projects in Canada.

The most interesting PVNBs that are listed in Table 6 will be briefly elaborated below.

Switzerland, Domat/Ems
This plant(Figure 16) was the first PVNB ever built. Switzerland has been the pioneer in the field of PVNBs, so it isn't surprising the first PVNB was build within Swiss borders. However, like many PVNBs, this plant hasn't really got the function of a noise barrier. It was built in 1989 in Switzerland, near the city of Domat/Ems in the shoulder of the A13. Build in 1989, this 100 kWp plant still delivers 1000 kWh/kWp per annum to the local grid(Clavadetscher, Nordmann, 2004). Due to the location of this plant it is highly visible for passing drivers and thus had quite an educational effect about the possibilities of photovoltaic cells.

Figure 16: PV system near A13, Switzerland.

It is interesting to note the glass surface of the modules has never been cleaned, but no significant degradation of the array efficiency has been observed. This is remarkable since the modules are so near a motorway. The plant operated without any major interruptions for 10 years. During the 11th and 12th years there were a series of major interruptions and some minor but important components of the inverter unit had to be replaced. The time between failure and repair appeared to be rather long. Since May 2002 the plant has been back in full operation(Nordmann, Clavadetscher, 2004)

Switzerland, Giebenach

This PVNB(Figure 17) has a noteworthy characteristic. The PV systems doesn't face towards the road, but are mounted on the other side of the barrier. In this setup, there is no extra space needed between the barrier and the road. This project has demonstrated that it would be possible to mount PV cells on noise barriers at both sides of the road, one barrier with PV cells facing the road and on the opposite barrier PV cells facing the outside. A second option, which is probably less attractive, would be to build PVNBs near roads that run from north to south.

Figure 17: PV plant near Giebenach, Switzerland.

The Netherlands, Utrecht

On the noise barrier along the A27 near Utrecht, the Netherlands, a PV system was installed in 1995. This resulted in the first photovoltaic noise barrier located in the Netherlands, with a total length of 550 meters. This was the first trail project to demonstrate it is possible to combine noise barriers and energy from solar radiation. The total installed capacity amounts 48,5 kWp and is connected to the grid. The PV panels are mounted on top of the concrete noise barrier and contribute to the blocking of noise. The following parties were involved in this project:

- Dutch government(owner);
- Remu;
- Novem;
- Holland scherm;

The behavior and performance of the system is monitored continuously from July 1995 till September 1997 in order to study whether the system meets the expectations and to learn from issues for further development. The system was in operation 92% of the time. During the monitoring period the system failed 4 times, of which 2 in the first year. The two failures during the first year of operation resulted in a loss of yield of approximately 12%. Based on this extensive monitoring during the two year period, it can be concluded the system meets the expectations during normal operation. The main conclusions that can be extracted from the monitoring results in the document 'Opbrengstgegevens van het PV-geluidsscherm langs de A27 na twee jaar systeembedrijf'(Betcke et al., 2002) are:

- A substantial amount of generated energy was required for the heating of the inverter building. The first year it was 8%, the second year it was 5%. This issue should be kept in mind in case of further designs;
- Due to emissions from traffic the accumulation of dirt occurs much faster compared with other applications(e.g. rooftops). This is proven with a reference cell in a solar simulator. The decrease in irradiation amounted 5.5% over a two year period;
- The orientation of the PV system, South-West to SouthSouth-West, resulted in a loss of irradiation of 18% compared with the ideal azimuth.


Figure 18: PVNB near Utrecht, the Netherlands.

The Netherlands, Amstelveen

This PVNB is the second one that was built in the Netherlands, and despite it has been in operation since 1998 it is still the last one being built in the Netherlands until now. The PV system has been integrated into a 1650-meter long noise barrier at the A9 near Amsterveen. This project was a demonstration project, financially supported by the European Commission and the Netherlands Agency for Energy and Environment (NOVEM). The following parties were involved in this project:

- NUON International / Duurzame Energie (co-ordinator and owner);
- Netherlands Energy Research Foundation, ECN;
- TNC Energy Consulting GmbH;
- TNC Consulting AG;
- Fraunhofer Institut für Solare Energysysteme.

Shell Solar Energy manufactured the PV-modules and also installed the entire PV system. 2160 Modules are mounted on top of the noise barrier, totally accounting for 205 kWp. Every module has its own micro-inverter and a tilt angle of 50°. At the time of construction this technology was relatively new and some technical problems were encountered. Since it is a demonstration/trail project, two types of inverters(type A and type B) were used to study the difference.

An extensive monitoring program started when the system came into operation and lasted for 2 years. The goal of this monitoring program was to learn more about the module efficiency, effect of traffic dust, DC/AC efficiency and grid interference. The main conclusions were(van der Borg, Jansen, 2001):

- The AC-modules with type A inverters perform very well and have a low failure rate;
- The AC-modules with type B inverters perform less good and have a higher failure rate. The reasons for the lower performance are the lower inverter efficiency and the occurrence of grid interference. Modifications on the PV-system to prevent the grid interference are ongoing;
- Accumulated traffic dust on the modules causes significant energy losses;
- General monitoring should be continued for the assessment of the results of the modifications and for detecting possible failures in the future;
- Annual cleaning of the modules after the winter season should be considered.

Figure 19: PVNB near Amstelveen, the Netherlands.

Germany, Freising

When this PVNB(Figure 20) came in operation in 2003, it was the world largest with a capacity of 500 kWp. It is located near Freising in Germany, next to the Munich airport. This barrier isn't only worthwhile to mention because of its size, but also because it is the first barrier with photovoltaic panels which are noise blocking on itself. The aim was to develop specially for this project a PV module which per se has a noise reduction function such that no conventional noise barrier is needed in addition to the PV array(Grottke et al., n.d.). In order to fulfill the noise blocking requirement the minimum weight of the panels had to increase. So the newly developed PV modules got a ceramic carrier plate. About two third(338 kWp) of the barrier is covered with these ceramic based modules and are located at the highest part of the barrier. The remainder part is covered with conventional PV panels, on the bottom side of the barrier. Because the panels at the lower part are not noise blocking, they are backed by a concrete wall.

Based on extensive monitoring, the performance of the PV panels with a ceramic carrier plate is more or less equal with the performance of conventional PV panels.

Figure 20: PVNB near Freising, Germany(Grottke et al., n.d.).

Italy, Marano

This noise barrier(Figure 21), build in 2009, was the first of the two currently realized high-efficiency photovoltaic noise barriers in Italy. Based on the capacity, it is one of the biggest PVNBs in Europe. The barrier runs along the edge of the hard shoulder on the southbound carriageway of the A22 at Marano, Trento. It is 1.069 meters in length and 5,6 meters in height and was designed and installed to protect the municipality of Isera and bring noise levels within the limits. In total 3.944 monocrystaline silicon panels are installed, thus the panels cover an area of 5.035 square meters.

The systems peak power reaches about 730 kWp and the production amounts approximately 690.000 kWh annually.

The design of the photovoltaic noise barrier is composed of 6 subfields. Each subfield has 657 photovoltaic panels, 19 6-kWp inverters and one 20kV sub-station. The foundation of the structure consist of prefabricated concrete which is elevated above ground level in order to minimize any potential loss due to shading from traffic. The structure which supports the photovoltaic panels consist of a framework made from aluminum profiles. As is the case in almost every PVNB, the PV panels itself do not provide enough noise blocking capacities, so aluminum sound absorbing panels are mounted on the rear of the barrier.

Figure 21: 730 kWp PVNB in Marano, Italy.

Germany, Aschaffenburg

This project proved other applications than PVNB are possible when combining PV systems with road infrastructure. Namely, in 2009, a highway is completely covered with PV panels(see Figure 22). It is the largest PV plant in the world combined with road infrastructure, the total capacity is 2.65 MWp. The PV panels are mounted on top of a 2,7 km long tunnel on the A3 highway.

Figure 22: Solar array on the tunnel near Aschaffenburg, Germany.

The Netherlands, Waalwijk

This PV installation is one of the biggest in the Netherlands and is part of a so called Eco Park, where also energy is generated from wind and biomass. It was completed in 2004. In total, 674 kWp is installed, generated by 4.212 Shell Solar SQ 160-C WP panels. The azimuth of the installation is

180°(South), with a tilt of 33°. An interesting fact is the installation is build on the slope of a former landfill site, which is expected to subside the coming years. This required an expensive dynamic support structure for the PV panels, consisting of a large beam construction supported at two points, as can be seen in Figure 23. Involved stakeholders were:

- Shell(PV);
- REMU(investor/owner);
- Artin(engineering);
- Province of North Brabant;
- Municipality of Waalwijk;
- Ecofys(feasibility studies).

This uncommon PV park required an investment of approximately €5.000.000, which results in a price of €7,40 per Watt peak. Even for that time period this was very high. Despite this high investment, Eneco(REMU) expects to achieve a return on investment for the total Eco Park, including the PV park, of 8%. The generated energy appeared higher than predicted, namely 600.000 kWh a year. This resulted in a yearly yield of 890 kWh/kWp.

Some lessons can be learned from this project. The first is security. Despite the fact the site is surrounded by water and fences, in 2005 one hundred PV panels were stolen from the property. Second, the high investment. Without the wind turbines, the PV Park was never been build. The turbines generate more revenue and of which the PV park could be partly financed from. So for future projects, fewer money has to be spend on the supporting structure.

Figure 23: PV park at the slope of a landfill site in Waalwijk, the Netherlands.

4.3. Energy demand of a road

The energy that will be generated with PV systems may be used by the road itself. When that's the case, it is important to have an idea about the energy demand of the road infrastructure. There isn't a rule of thumb to quantify the energy demand of a road per kilometer. Namely, the demand depends on multiple factors such as location, occupancy and width of the road. In Table 7 several components which consume energy are listed. This list contains the most common energy consumers, but isn't limited to these examples. There are multiple energy consumers which are specific for one part of a road, e.g. 'bermDRIP' and VeVa. Obviously, the power of a component is important regarding the yearly energy consumption. That's why energy saving components are constantly in development, such as LED lighting. But another factor which should be valued with equal importance is the operating time of a component. Lighting in tunnels are operating 24/7, in contrast to regular lighting which is operating about 12 hours a day. A recent decision made by Rijkswaterstaat illustrated the importance of operation hours on the total energy consumption. Rijkswaterstaat decided to switch of lighting at some parts of the main road network in order to save energy. This will decrease their expenses on energy costs, but it has also impact on the maintenance costs.

Component	Power(Watt/piece)	Operation hours(h/day)
Lighting	300	12
Lighting underpass	150	12
Lighting aqueduct	150	24
Pumping station	3.500-28.000	0.5
LED lights	5	24
Portals(matrix signs)	2.000	4
Gates	800	1
Camera's	250	24

Table 7: Energy components of a highway(indication).

4.4. Stakeholders

The realization of energy generation with photovoltaic along the main road network can be considered as a complex process. Therefore it is important to get a clear view of the stakeholders who could be involved in the process from the idea phase until the exploitation phase. The list of stakeholders may differ according to the situation. In this section the stakeholders that could be involved are mentioned. One of the most important stakeholder is Rijkswaterstaat, thus they are discussed more thoroughly below.

Stakeholders who might get involved:

- Municipality;
- Province;
- Utility company;
- Regional grid operator;
- National grid operator;
- Investors;
- Contractor;
- PV panel manufacturer;
- Sub-contractor(e.g. electrical installation company);
- Interest groups;
- Consultancy firm;
- Research institute(university, ECN);
- Nearby residents/companies;
- Ministry of economic affairs;
- Rijkswaterstaat(RWS).

4.4.1. Rijkswaterstaat(RWS)

Traditionally, the public sector is responsible for the main infrastructure in the Netherlands. 'Rijkswaterstaat'(RWS) is the executing organization of the 'ministerie van infrastructuur en mileu'. It is the task of RWS to manage and develop the national network of roads and waterways. Lower governmental bodies are responsible for regional and local roads. A reliable network of roads is the basis for a sufficient and safe flow of traffic. Every day, about 3 million car drivers make use of the road and travel about 165 million kilometers. Annually this results in 61.5 billion kilometers travelled by car users. This traffic should be guided in a safe manner, which is the task of RWS.

Their mission: 'Rijkswaterstaat' is the executing body commissioned by the minister of 'Infrastructuur en Milieu', who manage and develops the national networks in a sustainable way.(RWS annual report, 2011)

The mission of RWS states they aim to develop the national networks in a sustainable way. This doesn't imply they have the ambition to produce sustainable energy. Not even when the energy will be consumed within their own organization or activities. Their ambitions are related to energy saving, rather than energy production. For instance, one of their targets is to reduce the energy consumption from the objects they own with 20%. RWS doesn't want to produce electricity in a sustainable way because energy production isn't a public task anymore. They say commercial parties have to take the first step. This doesn't mean they sit back and wait until others take action. RWS will do everything in their power to create a situation in which it's possible for private parties to generate electricity at the land or objects owned by the government.

It seems that Goetzberger et al.(1999) acknowledged this and concluded that in the Netherlands the attitudes of the parties involved in the erection of PVNB(photovoltaic noise barier) are neutral to positive. Obviously, one of the parties he mentioned is Rijkswaterstaat. Beside RWS, more parties are often involved. Implementation barriers are the large number of parties involved in the erection of noise barriers, the economic feasibility and the accessibility of noise barriers in urban areas (Goetzberger et al., 1999).

RWS manages and develops the national road network, but they outsource activities such as engineering, building and maintenance to the market. They take these activities to the market in different types of contracts. During previous years, most activities were brought to the market based on traditional contracts, but the DBFM(O) contracts(public private partnership) are emerging. Although RWS expects from the market to take initiative regarding energy from sustainable sources, the opportunities for private parties may depend on choices made by RWS. Considering the attitude of RWS, which is to assist the market as good as they can in the transition towards energy from sustainable sources, this offers potential.

RWS puts a lot efforts in minimizing the nuisance due to maintenance as much as possible. Therefore, maintenance activities are taking place as much as possible behind the crash barriers. By following this approach, safety is provided for the workforce and closing lanes isn't necessary. When lanes have to be closed due to working activities, this is always scheduled during the night or weekend.

4.5. Legislation and directives

When planning a PV installation near road infrastructure, one has to deal with regulation related with either road infrastructure and electricity. Therefore it is important to gain insight in the Dutch, and sometime European legislation when planning such projects. Legislation may set boundaries to develop PV installations near road infrastructure and will definitely have influence on the financial gains. Also regulation regarding noise and the zoning plan is considered.

4.5.1. Electricity

The law states the (regional) grid operator is obliged to connect anyone to the public grid who poses a request for a connection(article 23 Elektriciteitswet). Every consumer possesses the right to be connected to the nearest connection point associated with the needed voltage level, provided that a consumer requests a connection level of no more than 10MVA. When a connection is requested of more than 10MVA, the consumer should be connected to the nearest point in grid with sufficient capacity(article 2.1.5 Tarievencode). Unless the request for a connection with a certain voltage level is from a technical viewpoint unreasonable, the applicant decides the height of the voltage level.

Grid operators have the obligation to build, expand and maintain the grid in the region they are responsible for(article 16, section 1c Elektriciteitswet). Others than the grid operators are prohibited to conduct such activities. However, there are a few exemptions to this rule:

- The first exception is that companies and people are permitted to install electricity cables when they are located within an installation. An installation can be considered as everything 'behind the connection'. Everything 'behind the connection' is the responsibility of the owner. However, in the law there is no definition stated for the term installation. The NMa did define this term:

- the combination of electrical components of the connected party, and everything that is using electricity within the dwelling or site.

Although this explanation is limited, in practice it is a decisive guideline. Based on this definition there is an installation when the appliances are owned by one owner. So when one owner has multiple dwellings or sites that are connected, it can be considered as installation and may be maintained by the owner. When another owner would connect to this, it would no longer be considered as an installation. Figure 24 shows schematically a situation when it is allowed for companies or people to build and maintain a grid;

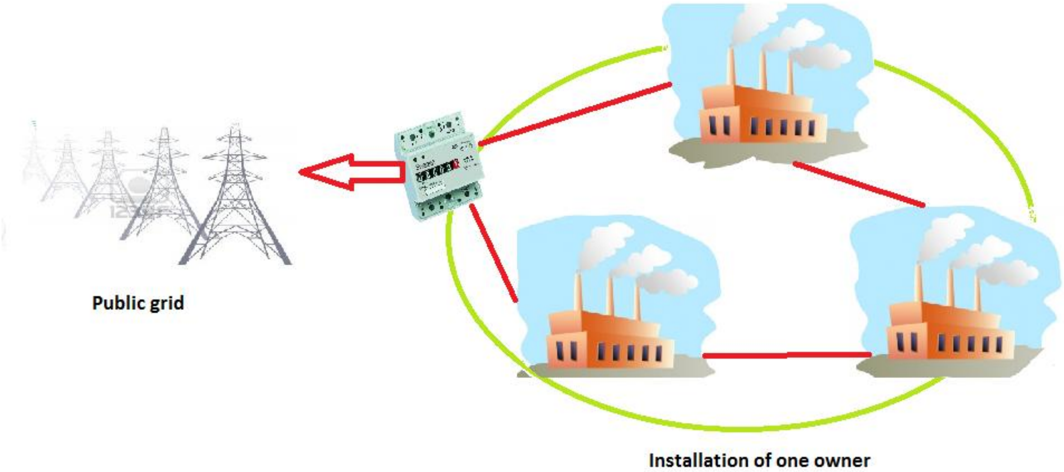


Figure 24: Illustration of a situation where one company owns multiple buildings which are interconnected, and thus can be considered as one installation.

- The second exception is the so called private grid(article 15, Elektriciteitswet). A private grid can be build and operated by private parties. However, to build and operate a private grid, exemption must be granted by the Minister of economic affairs. The Minister will be represented by the board of directors of the NMa(Dutch competition authority) and may grant permission if:
  - the business- or production-process of the users of a closed(private) grid is integrated due to specific technical or safety reasons;
  - the private grid primarily transports electricity for the owner of the system(private grid) or associated companies;
  - the applicant isn't a grid operator and isn't part of a parent group with a grid operator.

  The maximum duration from request to permission is 12 months. For this exception also the illustration of Figure 24 is applied, but then the buildings can be replaced by independent companies.

The text above explains issues related with the grid and connection, but also selling energy may be important for the opportunities of PV systems near road infrastructure. It may be possible the owner of the PV system would like to sell his self-produced electricity to others, for instance to 'small or large energy consumers'(Dutch: klein- of grootverbruikers). Selling electricity is called by law: 'supplying' (electricity).

Since the liberalization, which was completed in 2004, the market for production, trade and supply is free to enter. So in the basis everyone is allowed to produce electricity and either use this electricity them-self or to supply it to others. Vice versa, everyone is allowed to buy electricity from the party of her or his choice. An important exception to this rule is supplying to 'small consumers'. While supplying electricity to 'large consumers' is free, for supplying to 'small consumers', i.e. connection smaller than 3*80 A, a supply license is required. One has to comply with certain requirements in order to receive a license(article 95a, section 1, Elektriciteitswet). However, there are a few important exemptions when supplying to 'small consumers' is allowed without a license:

1. a license isn't required when there is a cooperation among 'small consumers', when the investment of the installation is paid proportionally by the participants and the self-produced energy is consumed by the participants. The law doesn't mention something about the location of the installation. Thus this also applies for electricity generated at another location and the electricity is transported by the public grid;
2. when there is a supply agreement with a group of electricity consumers, of which the majority of that group consist of legal entities or consumers who act in order to execute a business. This could be seen as a type of collective purchase by companies or individuals. There are a number of conditions that have to be met in this case;
3. when the 'small consumer' is the same legal entity as the producer or a daughter company;
4. total supply is less than 0.25 GWh and to no more than 15 'small consumers';
5. when the supply of energy is of inferior importance for the total company of the supplier;
6. when the supply is transported via a private grid.

When an individual Y produces electricity himself with PV panels, and one of the exemptions that is stated above is applicable for his situation, he is allowed by law to supply electricity to for instance his neighbor. This however may result some practical problems. The neighbor has already an energy supplier who charges network(grid) costs. But when individual Y is considered as a supplier, he should also charge network(grid) costs.

Given the system and regulation it is obvious 'small consumers' consume the generated energy initially themselves, and supply the excess energy to their energy supplier. The law states 'small consumers' have the right to deduct the amount of energy they feed into the grid from the amount of energy they received from the energy supplier, with a total of 5.000 kWh a year(net metering). Energy suppliers are by law obliged to accept an offer to supply energy from 'small consumers'. When the fed electricity into the grid, provided this is fed by a 'small consumer', exceeds 5.000 kWh a year, the energy supplier is obliged to pay a fair price for the energy. These rules are put in place to protect the 'small consumers' and guarantee a certain level of supply certainty.

In case of 'large consumers', other rules are applicable. As can derived from the text above, they too are allowed to self produce, consume, trade and supply electricity. However, they cannot deduct the electricity that is fed into the grid from the amount which is supplied to them. So when a 'large consumer' wants to fed electricity into the grid, he has to make sure to search for buyers. The energy supplier isn't obliged to buy the sustainable produced electricity. The price for which the fed in electricity is sold has to be negotiated.

Then there are rules for the tax on energy. These rules are not as straightforward as may be expected, especially when it comes to energy which is self produced. However, a brief description will be given. On this subject there is one main rule: tax have to be paid for the total electricity consumption. First, tax is based on the electricity that is supplied via the connection to the public grid to the consumer. Second, tax have to be paid for the electricity that is obtained differtly than via the connection to the public grid.(Wet belastingen op milieugrondslag)

There are two exemptions when no tax have to be paid:

1. when net metering is allowed, only tax have to be paid for the positive amount of supplied electricity(supplied electricity - fed in electricity);
2. the main rule states also energy tax have to be paid on energy that is self produced, because it is obtained differently than via the connection to the public grid. However, this doesn't apply when this electricity is obtained via sustainable resources. So when electricity is generated with PV panels, no tax have to be paid.

Exemption 2 only applies when the generation occurs behind the meter. When the generation takes place at a different location and the electricity is transported via the connection, energy tax have to be paid according to the law. At this moment there is no jurisprudence available about the subject of remote electricity generation. This may change in the near future since an organization(Windvogel) went to court because they think no tax should be paid in any situation when the electricity is self produced.

4.5.2. Road infrastructure

In the 'Wet beheer rijkswaterstaatwerken'(Wbr) and the thereon based stipulations, 'waterstaatswerken' means: by the national government managed roads, waterways, and when also managed by the national government, the therein located objects. Obvious examples are roads and waterways, but also flood defenses, bridges and tunnels.

In accordance with the provisions in article 2 section 1(Wet beheer rijkswaterstaatwerken), it is not allowed to make use of a 'waterstaatwerk' for other purposes than it is intended for, without permission from the Minister of Transport. This includes:

a. build or operate buildings on, in, under or over the 'waterstaatwerk';
b. keeping, storing, locating solid materials or objects on, in or under the 'waterstaatwerk'.

To obtain permission to make use of a 'waterstaatwerk', several conditions have to be met. Further on in this section few of them will be discussed. However, meeting those conditions isn't a guarantee for obtaining permission. In extraordinary and special (local) situations, Rijkswaterstaat could decide to not grant permission. This would however require extra justification and motivation from RWS.

In the basis of the Dutch law it is stated the owner of the land also owns the immovable property on it. This can be separated by agreeing the right to build(Dutch: recht van opstal). In that case, the property or object isn't owned by RWS. Furthermore, it is very likely the government demands a compensation for the use of the 'waterstaatwerk'. In practice this means ground lease have to be paid to the government. There isn't a fixed rate for ground lease, it depends on the situation and probably on the expected revenues. In case of a DBFM contract, it is expected ground lease isn't applicable since it is agreed the private party manages and maintains the infrastructure for a particular period of time.
The essence of the Wbr is to ensure a safe and adequate use of the 'waterstaatwerk'. Also secondary interests for RWS must be protected, which is provided by article 3, section 2. One could think of interests such as landscape, nature and culture.

Permission to make use of the 'waterstaatwerk' will be granted with certain limitations. One important limitation that should be considered is time. The time period for a permit is limited since it may not restrict developments in the long term. Since the lifetime of contemporary PV panels is at least 25 years, the desirable time period should equal that. It may be expected RWS would comply to such a time period, since it is known from past experience with wind turbines, the time period lays often between 10 and 20 years. Furthermore, the operation and maintenance of the PV panels should cause as few hinder as possible to the activities where RWS is responsible for.

Furthermore, there are guidelines compiled in 'Nieuwe Ontwerprichtlijn Autosnelwegen'(RWS, 2007) regarding the design of highways. Some relevant issues which are relevant when applying PV systems are elaborated below.

Maintenance of highways can be divided into road works and work at the roadside. Both of these activities may result in a discontinuity of the trace or may distract road users, thus the driving behavior is influenced. Obviously, this may result in hazardous situations for both the road users and the construction workers. Therefore, when maintenance or construction work is planned, the following goals should be taken into account:

- achieving sufficient working conditions, especially focusing on safety;
- enhance the road safety during construction or maintenance;
- reduce traffic congestion.

An important element when objects are placed in the roadside is the length of sight. The length of sight refers to the distance road users need in order to respond to discontinuities in the road, as is the case with short bends. Short bends are often present at entrances, exits or interchanges. It is important to see trough the bends in order to respond in time to situations and make adjustments. Objects like PV panels may block the line of sight(see Figure 25). To ensure a sufficient length of sight, two elements can be adjusted:

- the radius of the bend;
- displace the object further away from the road.

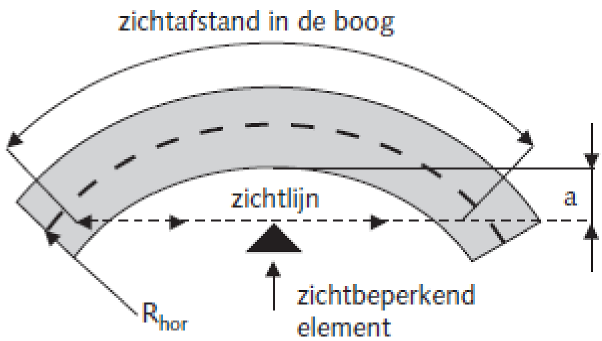


Figure 25: Essence of the length of sight in a corner(source: Nieuwe ontwerprichtlijn autosnelwegen, 2007).

Another important issue is related to the directives for the area that is free of obstacles. This obstacle free zone(Dutch: obstakelvrije zone) is put in place to reduce the risks for the road user(personal risks) and the risks for third parties. The obstacle free zone is in terms of safety preferred above blocking of the hazard zone or obstacles. A blocking construction, e.g. a crash barrier, result by itself in risk of injury in case of a collision. So there are 3 options for a roadside which is considered sufficiently safe according to the directive:

- creating an obstacle free zone;
- use of collision safe objects, and place them as far as possible away from the road;
- blocking of objects that cannot be removed or objects which are not collision safe.

The width of the obstacle free zone is wide enough to make sure a vehicle remains in the obstacle free zone when it gets of the road. The width of the obstacle free zone is therefore determined at 13 meters for a road with a design speed of 120 km/h. When the safety of third parties is considered, the width should be at least 25 meters. So for instance in case of the central shoulder in between roads, the width should be 25 meters. When a crash barrier is applied, there is no need to take an obstacle free zone into account. Thus, in that case there are more possibilities to place objects near the road.

4.5.3. Noise

In the Netherlands, regulation regarding noise nuisance along roads is determined by the 'Wet geluidhinder 1987'(law on noise nuisance). The law specifies boundary levels. Generally, when these levels are exceeded a noise barrier has to be build. The law makes a difference between situations where the emission levels were already exceeded before the law came into effect (existing situations) and situations where this started after the law came into effect (new situations)(Goetzberger et. al, 1999). So every situation is different and thus different rules are applicable.

Noise-barriers for new situations are the responsibility of the party that changes the situation. For example, if a noise barrier has to be built because traffic on an existing road has grown, the ministry of traffic has to pay for the noise barrier. If a municipality develops a new housing area near an existing road, the local municipality has to pay for the noise-barrier(Goetzberger et. al, 1999). The existing situations are covered by the same law(article 126, Wet geluidhinder 1987).

Application of plain or smooth materials(transparent or aluminum) and certain types of coating could lead in specific conditions to distractive optical reflection for the road users. Especially for East-West oriented transparent constructions there might be a danger the road users are blinded by reflecting sunlight. This phenomenon should be taken into account for situations with an orientation between NE and SE(55° - 140°) or between NW and SW(220° - 305°). It is still unknown to what extend reflection could lead to blinding. In order to assess the situation regarding reflection, 'TNO Defensie en Veiligheid' developed a model which can quantify blinding on the basis of parameters like illuminance, blinding angle, background luminance and dynamic properties. When the length of the noise barrier is shorter than 50 meter and thus time of blinding of max. 1.5 seconds, the risk of blinding by reflections is acceptable(GCW, 2012). RWS is able to simulate specific situations in order to determine the degree of potential reflections.

Currently, there is no regulation and are no guidelines specific to photo voltaic noise barriers. The regulation related to infrastructure, noise barriers and electricity is at the moment sufficient enough to prevent unwanted situations to occur.

4.5.4. Zoning plan

In a zoning plan, the desirable user-functions and possibilities to build for a certain area are determined. The stipulations in a zoning plan allow certain developments in the area and make other developments impossible. It isn't a tool to enforce certain developments such as renewable energy production in a specific area.

Installing PV panels at rooftops doesn't require a permit or adaptation of the zoning plan in the Netherlands. Installing PV panels for instance near parking lots in order to power electric cars or PV panels in an open field configuration does require a permit. Before granting a permit by the municipality, it is very likely the municipality has to change the zoning plan. This would take some time, but in general not many obstacles are expected in the process since the attitude of the governmental bodies are very positive towards energy generation with PV systems. Furthermore, impact for local residents and the environment is not expected, in contrast to wind turbines. PV systems should not impact the appearance of the environment too much. However, issues could be expected. The construction of a PV park in Ouddorp in the Netherlands suffered some delays due to the zoning plan and permits. Construction was eventually allowed, provided ground walls are realized around the PV park in order to prevent the PV panels become visible from the road.

4.6. Noise barriers

The combination of PV and noise barriers could bring multiple advantages as explained earlier in this chapter. Multiple use of space is in the Netherlands always interesting to policy makers. But the primary function of noise barriers is (still) blocking of noise. So to gain insight in the potential of photovoltaic noise barriers, it is essential having some basic knowledge about noise barriers, e.g. the design, directives and costs.

Basics

Without noise barriers, the noise is able to propagate from the source to the recipient. The source could be road traffic and the recipient could be nearby residents or offices. A noise barrier will act as an obstacle between the source and the recipients. Thus, the goal of a noise barrier is to reduce noise nuisance along road infrastructure. The level of reduction depends primarily on the position of the noise barrier in the cross profile, height and length, and distance between the recipient and road. Design and acoustics specifications have also influence.

According to the GCW(2012), sound waves could end up in three ways behind a noise barrier:

1. Transmission: the noise goes through the noise barrier;
2. Diffraction: the noise bends over the noise barrier;
3. Reflection: the noise bounces at a structure(e.g. noise barrier) on the other side of the road, and then goes over the noise barrier.

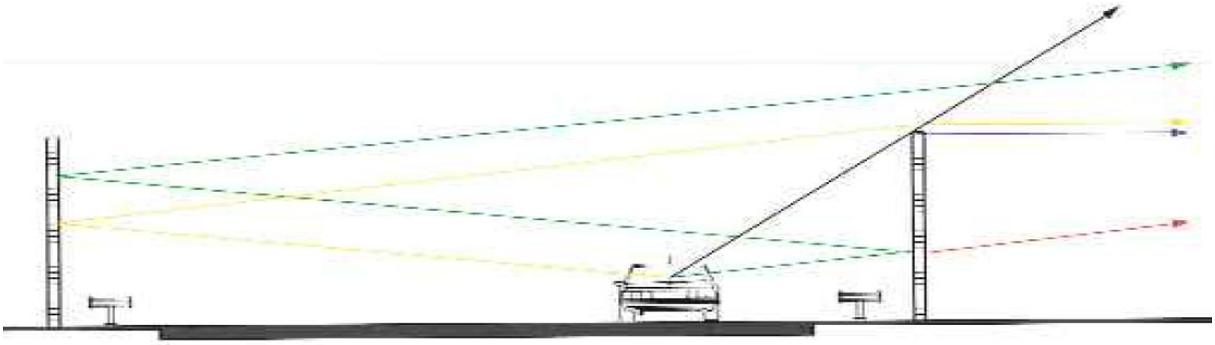


Figure 26: Schematic display of noise-transmission, -diffraction and -reflection.(source: GCW, 2012)

In general, the material of a noise barrier consists of material which reflects or absorbs the noise. When the noise barrier is installed at an angle, absorption is always possible, even with material that reflects noise. This can be achieved by reflecting the noise toward the road surface or into the sky.

For noise barriers all requirements regarding principles, loads, strength etc, are stated in the GCW-2012('Richtlijnen Geluidsbeperkende Constructies langs Wegen', 2012). The design lifetime for noise barriers at the embankment along the main road network is 50 years. The design lifetime of 50 years is also applicable for noise barriers on structures(e.g. bridge, flyover).

Modular noise barriers

When traveling by car on the highway in the Netherlands, it is obvious the design of noise barriers is very diverse. Road users perceive this situation as messy. That's why a standardized noise barrier or so called modular noise barrier is developed in order to achieve architectural consistency and cost reductions. The modular noise barrier is composed from a limited number of standardized components which can be combined in multiple manners. In this way, multiple noise barriers can be constructed with different looks, heights and acoustic specifications. It is possible to vary the angle and choose among different materials.

In 'Toepassingsadvies: Modulaire Geluidsschermen'(2006) it is stated there are four types of panels that can be chosen from, two reflective and two absorbing panels. If desirable, it is possible to develop deferent types of panels, e.g. a panel composed of plastic material or a panel with PV cells. Obviously, a new to develop panel has to comply with the guidelines for noise blocking, but it also has to comply with the dimensions that are stated for the modular noise barriers.

One of the advantage of modular noise barriers are the lower costs. Indicative prices are stated below:

- Total noise barrier(incl. foundation) € 300/m^2
- Glass elements € 100-120/m^2
- Concrete elements € 70/m^2
- Aluminum elements € 100-110/m^2

Financing

As explained in section 4.5.3, the party who's responsible for creating a situation where noise nuisance occurs, has to pay the costs for the noise barrier. Often this is a public party such as the ministry of transport or a municipality. It would be possible that a public party pays for the noise barrier, and a private party is responsible for the extra investment for the PV part. Essentially, this would be Public Private Partnership(PPP), which occurs often in the Netherlands. In case of a DBFM(O) contract, which is a variant of a PPP, the private party would be responsible for the total investment.

4.7. Efficiency near road infrastructure

The efficiency of PV panels is influenced by multiple factors. A few of these factors are already discussed in section 3.2, such as temperature. The most important factors that are especially applicable when the PV panels are installed near road infrastructure, are discussed below. It concerns contamination, reflection, shadowing and aging. Most of them have adverse consequences, only reflection could result in a positive effect. Some factors which have an adverse effect on the efficiency can be prevented, some cannot, such as aging of the PV panels.

Contamination

A frequently heard argument against PV panels near road infrastructure is contamination of the panels, and thus a decrease in efficiency. This contamination is assumed to be much higher compared with PV panels that are located at rooftops, due to the vehicles that pass by every day. It is known vehicles emit particulate matter due to combustion. In addition to this, particulate matter is created through friction of the brakes, ravel out of the tires and the road surface. Gaining insight in this issue was one of the objectives for the realization of the two photovoltaic noise barriers that are located near the A27 and the A9 in the Netherlands. Therefore, extensive monitoring was applied during a few years of operation. The findings from these projects will be elaborated in the section below.

In the monitoring of the photovoltaic noise barrier near the A27, two reference cells where used to study the effect of dust and emissions. ECN determined the electrical characteristics(i.a. current) of the reference cells at STC-conditions in a sun simulator. Thereafter, the cells where thoroughly cleaned with water and soap and the current was measured again. The current of reference cell #1 was increased with 4,5%, and of reference cell #2 with 6,6%(Betcke et. all, 2002). So the average value for the increase of the reference cells amount 5,5%.
Obviously, the number of reference cells is very limited with only 2, but Betcke et. all(2002) assumes that when the modules of the photovoltaic noise barrier are similarly exposed to dust and rain, the results are indicative for the other modules. It is noted that it may be possible some modules are more contaminated than the reference cells, because they are located closer to the ground. Furthermore, it is unknown how the contamination is accumulating in the course of time. This monitoring study proved the effect of contamination is much higher compared with PV systems on rooftops. The reduction in yield for PV systems on rooftops amount 1% in a short time period. Thereafter the reduction in yield for PV panels on rooftops varies dynamically around the 1,5% as a result of contamination and cleaning(van Zolingen, 1997). Since the layer of contamination is thicker

along the road, it could be assumed the reduction in yield for the A27 would have an equilibrium value of 5,5% ± 0,5(Betcke et. all, 2002).

The effect of traffic dust was also studied for the photovoltaic noise barrier at the A9-highway in the Netherlands. For this purpose, 4 reference cells were cleaned in the end of May 1999, while the modules remained uncleaned. The module efficiencies have been determined using the data of two weeks before the cleaning, and the data of two weeks after the cleaning. The results were compared and resulted in a seemingly decrease of the efficiency of the four modules with a similar magnitude. This shows that the dust on the reference cells and on the modules caused an irradiation loss of about 8%(van der Borg and Jansen, 2001). They added to this conclusion the loss could be even more when the dust isn't evenly distributed over the 72 cells per module. This is due to the mismatch effect which also occurs when the panel is partly shaded. van der Borg and Jansen(2001) also concluded from their results the accumulation of dust and its natural cleaning process reaches an equilibrium relatively fast. It is advised to clean the modules annually after the winter season.

The above mentioned studies conclude there is additional contamination due to traffic dust. Nevertheless, results from the PVNB in Domat/Ems, Switzerland, showed no significant degradation of the array efficiency. This is remarkable since the panels are so close to the motorway and the glass surface of the modules has never been cleaned.

Reflection

So in general it can be concluded traffic dust has adverse influence on the yield. There is also an effect which has, although very little, a positive influence on the yield of PV panels. As mention earlier in this report, the radiation that reaches the PV-system can be divided into direct and diffuse radiation. However, there is another type of radiation, namely reflected radiation. This is radiation that reaches the PV-system after it is reflected from a surface. The influence of reflection on the total radiation which reaches the photovoltaic cells, depends of the type of the ground surface, but in general it is very little. Some simulation programs do take this influence into account in order to calculate the yield. In these simulation programs the so called albedo value of a surface is used.

Albedo is the fraction of the sun's radiation reflected from a surface. The term has its origin from the Latin word albus, meaning 'white'. It is quantified as the proportion or percentage of solar radiation that is reflected by a body or surface. An ideal white body reflects all of the solar radiation that falls upon the surface so it has an albedo value of 1,00, and an ideal black body has an albedo value of 0,00. See Table 8 for the albedo values for different surfaces.

Surface	Albedo	Surface	Albedo
Grass (July, August)	0,25	Asphalt	0,15
Lawn	0,18-0,23	Forests	0,05-0,18
Dry grass	0,28-0,32	Heather and sandy areas	0,10-0,25
Untilled fields	0,26	Water surface (γ^s > 45°C)	0,05
Barren soil	0,17	Water surface (γ^s > 30°C)	0,08
Gravel	0,18	Water surface (γ^s > 20°C)	0,12
Clean concrete	0,30	Water surface (γ^s > 10°C)	0,22
Eroded concrete	0,20	Fresh layer of snow	0,80-0,90
Clean cement	0,55	Old layer of snow	0,45-0,70

Table 8: Albedo for different surfaces(Ecofys, 2005)

If PV-systems are located near road infrastructure in the Netherlands, the most likely type of surface would be asphalt or grass. These types of surface have compared with other types(see Table 8), a very low albedo value. Obviously, this isn't surprisingly since asphalt is black colored. However, this potential low percentage of ground reflection of radiation may be partly compensated if for instance

PV-cells are incorporated in noise barriers and thus have a tilt angle that approaches the vertical. When the tilt angle is for instance 70°, which is much higher than 35° that is prevailing for free standing PV-systems, the irradiance from ground reflection is higher.

Shadow
PV panels in a system are always connected in series. When a small part of the panel collects less solar radiation due to shadowing, also the other panels that are part of the same series generate less electricity. Thus, not only the PV panel that is shadowed is affected(Agentschap NL, 2010). The cell which receives no sun light due to shadowing, act as a resistor in the series. The current that is generated in the rest of the series, will be transformed into heat in the shadowed cell. This may result in adverse consequences regarding the lifetime of the panel.
Shadowing may occur in multiple manners. The most obvious one is caused by objects nearby, like buildings, trees or vegetation. Along the roadside, shadowing may be caused by traffic, road signs or portals(see Figure 27). Less obvious manners are unevenly contamination due to leaves, bird poop or moss. Since it is difficult to observe from the ground the PV panels are contaminated with such dirt, it is recommended to make use of a monitoring system. Abnormalities can be easily detected with a monitoring system.

Figure 27: Shadowing of a sub array caused by the road signs along the A27(Betcke et al., 2002)

Aging
PV panels can function for multiple years. During the life time of a panel, the efficiency drops gradually. Most commercial PV panels from renowned brands can operate at least 20 years without significant decrease in efficiency. Most manufacturers provide a guarantee of quality and they guarantee the output doesn't drop below 80% of the initial capacity within 25 years.

It is often said the lifetime of crystalline silicon cells is higher than thin layer cells. But according to the data sheets of both types of panels this is not the case. For both types of panels, the same guarantee is provided regarding the output after 25 years.

4.8. Safety and vandalism

PV panels are live components as soon as they are exposed to light. They behave as current generators, which means that breaking the circuit creates sparks and electric arcs. When PV panels are grouped in a large-scale system, they are linked to a series of electric components for DC/AC conversion and injection in the high voltage energy network(Wybo, 2013). PV systems along roads should be designed to minimize accessibility of high voltage lines and components by putting them in the earth. So the only external elements are the panels and the wiring connecting panels together, and with conversion devices. Electric hazards corresponds to two possible scenarios: live elements or wires are accessible and may cause injury or death; rupture of a circuit may cause an electric arc that in turn may start a fire in presence of flammable liquids, gas or solids(Wybo, 2013). A fence would prevent anyone unauthorized to get access to the PV panels and exposed to risks. The PV panels should be placed behind crash barriers or at a location where it is unlikely vehicles can crash into the PV panels.

Although PV panels are steadily decreasing in price, a total system represents a lot of value. Therefore it could be an interesting object for thieves. PV panels installed on rooftops are far less interesting for thieves and easy to steal than PV panels installed at a remotely located PV park. However, when the PV panels are visible from the road, there is 24/7 some form of social control. Even though, it may be advisable to install some form of protection. This could be a fence around the PV panels in the open field. A second advantage of a fence is vandalism. PV panels can resist a hailstorm, but vandals could cause serious damage to the panels. PV panels installed at a noise barrier would be more difficult to steal.

5. Model development

In this chapter the financial model, which is developed as part of this thesis, will be discussed. This financial model allows decision makers to assess the financial aspects of a PV project. Before focusing at the details of the model, an introduction is required which comprises an elaboration of the possible situations regarding ownership of the PV system and the end-users of the generated electricity. Secondly, the methodology that lays on the basis of the financial model, which is the Cost Benefit Analysis(CBA), is explained. The model is described on the basis of an activity diagram, required input, cost and benefit elements, functioning of the model and the accompanying assumptions.

5.1. Ownership situations

Before one can apply the financial model and estimate the potential, it is essential having a clear picture of the situation with the involved stakeholders. Since the PV systems are planned near the main infrastructure which is owned by Rijkswaterstaat, they hold a stake in every conceivable situation. Especially the party who owns the PV system and the end-user(s) of the generated energy are relevant. Without this information it is impossible to calculate/estimate revenues. Multiple constructions between owners and end-user(s) are possible. In this section the most likely situations for now and the near future will be explained. Obviously, more situations are possible than are discussed in this chapter because a situation changes already when for instance the owner or end users changes.

Situation 1

Nowadays, infrastructural projects are often executed in close cooperation with public and private parties. This cooperation is called a Public Private Partnership(PPP). The authorities(public) assign a project to private parties in order to fulfill a public interest, which could be the construction and maintenance of a highway. The contractual agreements of these partnerships cover a long time period, which is often 25 years in the Netherlands. The standard procedure can broadly be defined as follows: in order to bid for a contract proposed by a government, a private group of interest (consortium) creates a legal entity, so-called Special Purpose Vehicle (SPV) with a mission to build, maintain, and operate the assets (or a combination of these)(Palma, Leruth, & Prunier, 2009). Usually, the consortium consists of at least one large building company(contractor) and a group of financiers(e.g. banks).

This form of partnership is not only used in case of the construction of new infrastructure, but also when current infrastructure has to be renewed or when extra lanes have to be added. The initial investment is always provided by the consortium and they have, within the boundaries of the contract, the freedom to design and come up with creative or innovative ideas to save money during the contract period. Application of PV systems may be a manner to save money in the long term.

Now, in this situation, it is assumed PV systems will be installed within a DBFM(O) contract for the construction or renewal of a highway. This contract will create boundaries and opportunities regarding energy use and energy production. Some relevant parts regarding energy in the example 'Rijksbrede Modelovereenkomst DBFM Infrastructuur'(Rijkswaterstaat) are enclosed in Appendix 4. In the text below some conclusions will be drawn from the statements in the contract.

The principle of DBFM(O) contracts is that during the total contract period, including design, construction and maintenance, all risks go to the contractor. However, there are some exceptions to this principle. These exceptions are put in place because the contractor can't possibly bear some of these risks. That's why some risks will be transferred to the client(Rijkswaterstaat). When risks are transferred to the client, the contractor will be compensated for time or expenses. Examples of these risks are for instance hurricanes, but also when TenneT(third party) can't complete the construction of a particular electricity pylon in time or when ProRail isn't sufficiently cooperating and doesn't grant permission on time to work near the railroad.

Regarding energy, the same principle is applied. Namely, all risks are the responsibility of the contractor. The only exception is the risk regarding energy price. So this risk is covered by the client. The client, Rijkswaterstaat, has large agreements with utility companies for the delivery of electricity for their whole organization. This results in a low unit price that can be achieved through economies of scale. Therefore the contractor or Special Purpose Vehicle(SPV) is obliged to purchase the electricity from the client. In the contract, a fixed price per kWh is stated. In contrast to what is stated in the standard contract, the price will stay at the same level during the complete contract period(often 25 years) and will not be indexed. That's why the price the contractor has to pay for energy seems very high at this moment compared with the market-price for energy. But at the end of the contract period it is very likely the price will be below the market-price, due to an expected yearly increasing market-price for energy. The price the contractor has to pay equals the average between the market-price of energy at the beginning of the contract period, and the expected market-price of energy at the end of the contract period. This fact could result in opportunities for the contractor.

As explained in the paragraph above, the risk of price(Dutch: 'prijsrisico') is covered by the client. The risk of volume(Dutch: 'volumerisico'), which means the consumption of electricity, is a risk the contractor has to bear. In paragraph 18.8(see Appendix 4) of the contract, it is stated the costs for energy during the construction phase are paid by the client. From completion until the end of the contract period, the costs for energy used by infrastructural related installations are paid by the contractor. Examples of infrastructural related installations are listed in Table 7.

The amount which have to be paid for electricity usage can be calculated according to the contract with the following formula, see paragraph 1.5 in Appendix 4:

- $\text{Elektriciteitsprijsvergoeding}_t = P_{bh} \times Q_{wh,t-1} + P_{bl} \times Q_{wl,t-1}$

Where: P_{bh} = basic electricity price for supply and transportation per kWh during peak hours;
$Q_{wh,t-1}$ = actual electricity consumption(kWh) in year t-1 during peak hours;
P_{bl} = basic electricity price for supply and transportation per kWh during off-peak hours;
$Q_{wl,t-1}$ = actual electricity consumption(kWh) in year t-1 during off-peak hours.

This formula is based on two electricity prices, one during off-peak hours, and one during peak hours. In some contracts there is no distinction between these two, and only one price is provided. As already explained above, in this situation there is only one price and this price is fixed, determined by Rijkswaterstaat. Supply costs, network costs and taxes are included in this amount.

According to the standard DBFM(O) contract, it is permitted to apply net metering. This can be derived from the provision stated in paragraph 1.5 in appendix 4. Within the RWS organization, much is unknown regarding net metering, but the employees of RWS confirmed that they expect it would be possible. There isn't yet a clear policy within the RWS organization regarding energy generation within a DBFM(O) contract. Furthermore, when too much energy is generated, it can be supplied to the public grid. The SPV has to make arrangements with an utility company of their choice. They are not limited to the utility company that supplies the energy to RWS. Since the road section is managed and maintained by the SPV, no ground lease have to be paid to the Ministry of economic affairs.

Situation 2

When an existing highway isn't subject to renewal but there are potential opportunities for the installation of PV systems, the situation is completely different compared with the situation when a

DBFM(O) contract is involved. When there is no renewal involved, it isn't possible for private parties to become responsible for the state of the highway for 25 years and thus the maintenance and operation. Better said, this form of PPP never took place in the Netherlands. So in this case, the owner and investor of the PV system is not a SPV(Special Purpose Vehicle), but would be another private party who has resources available to invest. This could be one company or a group of companies who are located in the near vicinity of the road. One likely reason for a party to be interested to invest in solar energy along roads could be because they doesn't have enough space available at their own property to install PV panels. It is assumed for this situation these companies consume the main part of the generated energy themselves.

Even though the PV panels are placed at the land owned by Rijkswaterstaat, they will not purchase the generated energy from the private party who owns the PV panels. As explained earlier, Rijkswaterstaat has large agreements for the delivery of electricity for their whole organization with a utility company. RWS says they cannot purchase the generated energy due to these contracts. So the energy has to be consumed by the company of companies who own the PV panels or a part of the total generated energy can be sold to utility companies. Because of the 'grootverbruikers' connection that is assumed, utility companies are not obliged to purchase this energy and the price per kWh has to be negotiated. The price that is normally paid for renewable energy is often based on the APX-ENDEX. Specifically, this means the price that is paid lies between the €0.05 and €0.06 per kWh.
Therefore the revenues will be higher when the generated energy is directly consumed by the company or companies who own the system. Therefore a private energy grid between the PV system and the business park is in this situation assumed and essential. The electricity should be consumed directly, because 'Salderen' isn't possible for energy consumers with a grid connection larger than 3 x 80 Ampere.

A private grid may limit the potential of this situation. The possibilities and restrictions regarding private grids are discussed in section 4.5.1. A disadvantage of a situation described above can be found in how the generated energy will be transformed from the road to the companies. This depends on the situation. It may cause some difficulties to lay cables through public areas.

Situation 3
This situation is very similar as situation two, except in this case an utility company has a large stake in the investment. When an utility company invests in a sustainable PV project near the road infrastructure or is involved as one of the investors, other opportunities may arise. Utility or energy companies are already in possession of a license which allows them to deliver electricity to small consumers. This will enlarge the potential client group who can potentially buy the generated energy. The limitations which may arise in situation 2 regarding a private grid are not applicable, since there are no disadvantages for an utility company to make use of the public grid in order to deliver the electricity to consumers.

Situation 4
This situation is currently not possible due to regulation, but may be in the future. Renewable energy generation is also for small energy consumers very interesting since they have the right on net metering. Unfortunately, not every property is suitable for energy generation with PV. They could install PV panels near the road, but then net metering isn't applicable anymore. This might change in the near future since some political parties and other organizations are making efforts to make this possible. Then it would become interesting for small consumers to invest in PV near the road infrastructure since the revenues per kWh are relatively high. This is called virtual net metering, as is already explained in section 2.4.

Situation 5
Gas stations and P&R car parks are often located near the main road infrastructure. Car parks are significant electricity consumers and this may increase in the near future since more and more cars on the road are electrically powered. During parking, these cars can be recharged with electricity. This could also be the case for gas stations, where electric cars can be recharged in the near future. These cars can drive completely sustainable when the electricity is generated with PV panels near road infrastructure.

5.2. Cost Benefit Analysis(CBA)

In order to model and evaluate the financial aspects of a project, several methodologies can be applied. Based on literature, sustainable projects are often evaluated with the use of the method which is called Cost Benefit Analysis(CBA). This is an evaluation method that weigh the expected costs against the expected revenues. Based on this analysis, decisions to buy or to invest could be made. The method is still the most common and most applied economic evaluation tool in decision making processes. A French engineer used it as one of the fist in 1844 to reference the benefits of public works. The current method of CBA can be traced back to the 1930s where it was first applied to evaluate water resource projects. A great deal of the early empirical work on cost-benefit can be found in material primarily concerned with water and river resource development. Since these first studies, cost-benefit analysis has been employed in a wide range of applications, e.g. highway development, transport systems, defense, health, education, airport siting, housing and energy choices(Simpson, Walker, 1987).
Based on literature, if one flaw of this method should be named, than it is the necessity or the attempt to translate a certain effect(i.e. benefit) into monetary values. This results in a decision from the analyst(s) that could be considered as arbitrary and subjective. However, in this situation this isn't perceived as an important disadvantage, since the sustainable project will be evaluated from a private point of view. When a sustainable project would be evaluated from a public or governmental point of view, then benefits such as for instance fewer air pollution and the well fare of citizens would be transformed into monetary terms.

As already mentioned, in literature a CBA is often used in relation to sustainable projects. Kamel(2010) presented in his study a life-time cost-benefit analysis for a solar system comprising a grid-connected photovoltaic unit and a solar water heater operated at Toowoomba Queensland. The work represents technical and economic assessment of the technology at local conditions. Poullikkas(2009) carried out a feasibility study in order to investigate whether the installation of large photovoltaic(PV) parks in Cyprus is economically feasible. He carried out a parametric cost benefit analysis by varying parameters such as PV park orientation, capital investment, carbon dioxide emission trading system price, etc.

According to Boardman(2006), a decent cost-benefit analysis consist of the following sequential steps.

1. List alternative projects/programs.
2. List stakeholders.
3. Select measurement(s) and measure all cost/benefit elements.
4. Predict outcome of cost and benefits over relevant time period.
5. Convert all costs and benefits into a common currency.
6. Apply discount rate.
7. Calculate net present value of project options.
8. Perform sensitivity analysis.
9. Adopt recommended choice.

Step 7 will be complemented with calculating the payback period and the internal rate of return. Of course, the NPV, IRR and payback period are related to each other in a certain way but each of them contribute to more insight in the project and helps to assist the decision maker. Thus, these are the most important elements of the CBA, see Figure 28. A fourth important element is the sensitivity analysis. With this analysis, it is possible to gain insight in the degree of importance or influence of the input to the end result. The four elements as shown in Figure 28 are elaborated further on in this section.

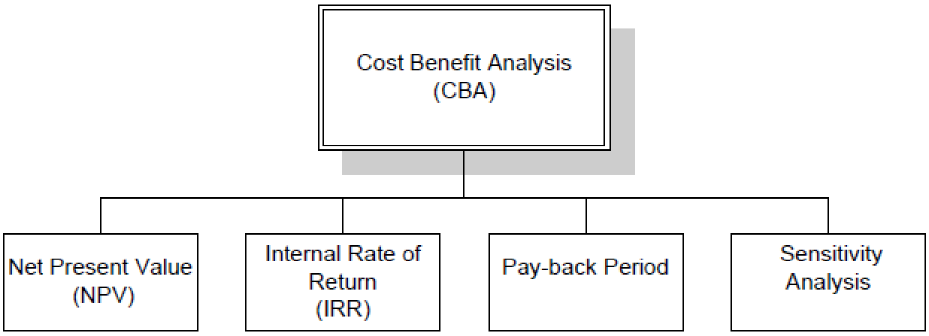


Figure 28: Elements of the CBA.

Net Present Value(NPV)

To make sensible investment decisions, we need a method of appraisal that:

- considers all of the costs and benefits of each investment opportunity;
- and makes a logical allowance for the timing of those costs and benefits(Atrill, McLaney, 2006).

The net present value method provides this. The NPV describes the summation of the present values of the cash flow of each year. Simply said, it translates the total future cash flow into what it would be worth today. With the formula below the NPV can be calculated.

NPV = Total PV of future cash flows – Initial cash flow(CF_0)

$$NPV = \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i} - CF_0 = \left[\frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots\right] - CF_0$$

Where: r = discount rate

n = time period of the project/investment(years)

CF_0 = initial cash flow

When the NPV ≥ 0, the project or investment is profitable and may be accepted. If the NPV < 0, no profit is made and the project or investment should be rejected.

Internal Rate of Return(IRR)

The internal rate of return describes the discount rate at which the present value of costs equals the present value of benefits. Difficulties may be encountered when calculating the IIR for negative cash flows, and the usefulness in regulatory CBA is limited. This is in contrast with when dealing with investment projects, as is the purpose of the model and CBA described in this report. The IRR is widely used as an indicator to assess the financial feasibility of a project/investment. It determines the return over a certain period of time. More specific, it represents the return of the sum of the yearly earnings(benefits-costs) in relation to the initial investment.

When projects approach the final investment decision, the more the IRR should be considered in coherence with other financial indicators. However, for projects that are in the early stages of the development process, the IRR is in principle a useful measurement for the feasibility of a project. Investors demand often a minimum IRR level in the assessment of project proposals. Commercial or private parties demand often a minimum IRR for equity of 8%-15%, with a lifetime of 10-15 years.

Parties who act from a social viewpoint and serve the public interest, demand often lower IRR levels and are willing to accept longer lifetimes. However, for projects where energy saving or renewable energy generation is involved, some commercial parties are nowadays willing to extent their vision for the future or accept a lower IRR.
The IRR and the NPV are related to each other. The IRR is defined as the value *r*(see the formula for the NPV) such that NPV = 0.

Payback period
The length of time it takes for an initial investment to be repaid out of the net cash inflows from a project, is called the payback period or payback time. The payback period can be determined in two ways, with and without the time value of money(NPV). In this financial model, the payback period is determined without the time value of money. In this technique, cost and benefits for each operational year are projected. The costs for interest are not taken into account. When the cumulative cash flows become positive at the end of a certain year, the payback period has ended. In other words, the payback period represents the time it takes to break even. Break-even conditions are satisfied when the system capital investment is exactly met by the savings or benefits generated over system lifetime(Kamel, 2010). This approach has certain advantages, it can be easily understood by managers and is quick and easy to calculate. Commercial parties often demand a payback time of approximately 10 years or less.

Sensitivity analysis
Investments are always made to achieve certain goals in a certain amount of time. This means the investment is made at one moment in time and revenues are expected in the future. Since it concerns the future, uncertainties are always present. So an element which is entered in the evaluation of any proposed investment could be uncertain. To gain insight in the consequences of a variation of certain elements, a sensitivity analysis is helpful. It will show which elements or variations in input are critical to the outcome of the cost benefit analysis. In this report, the CBA is used to evaluate energy investments, and these investments are usually very sensitive to the choice of discount rate as well as to future fuel/energy prices.

When the future value of a sensitive variable is uncertain, it is often suggested that a probability distribution should be used instead of a single-valued estimate(Simpson, Walker, 1987). This seems like a scientific valid approach. However, additional data and evidence from the previous years is essential and that is often not available. Simpson, Walker(1987) found it is often recommended to use a subjectively based probability distribution. The most common approach for the analyst is to propose a range of possible future values for the sensitive variable or variables, with or without a single central or most likely value. The width of the range and the number of values should be chosen based on experience. These two aspects do influence whether the sensitivity analysis is of much assistance to the decision maker.

5.3. Model description

In this section, the model is described which is used to evaluate the financial aspect of PV panels near road infrastructure. The model is described on the basis of an activity diagram, required input, cost and benefit elements. In addition to this, the functioning of the model and the accompanying assumptions are discussed.

5.3.1. Activity diagram

When one has the intention to invest in sustainable energy from solar radiation by using photovoltaic panels and combine these with road infrastructure, the activity diagram in Figure 29 will help them to overview the process that is involved and to understand the financial model that is used to perform the CBA. Although the financial model will be explained in detail further on in this chapter, this activity diagram will present a global image of the situation. It will bring forward immediately the issues that are important. First some general information about activity diagrams is briefly discussed, then the reasoning behind the activity diagram in Figure 29 is explained and the links with the financial model are identified.

Activity diagrams describe multiple activities, flows of data and/or decision nodes. The activities and decision nodes are connected by an outgoing path. The outgoing path can meet another activity, decision node, merge node or may terminate. The repetition of certain activities is indicated either explicitly using a return path to an activity following a loop test condition, or implicitly by identifying a block of activities specified with a loop condition. Activity diagrams can also include fork and join constructs that are used to indicate the execution of series of activities in parallel(Bolloju, Sun, 2012). There are multiple types of activity diagrams. The most important difference is often the layout. The layout is important because it uses symbols and shapes to identify e.g. actions, states, decision and transitions. The activity diagram in Figure 29 is based on the Unified Modelling Language. The Unified Modelling Language (UML) is the successor to the wave of object-oriented analysis and design (OOA&D) methods that appeared in the late ’80s and early ’90s. It unifies the methods of Booch, Rumbaugh (OMT), and Jacobson (3 amigo’s)(course 7M900, TU/e).

In Figure 29 the modeling method is complemented with a feature which makes it more easy for others to comprehend the link with the financial model. The activities are categorized by using colors in order to make a distinction among them.

- Some activities require to give input in the financial model(blue).
- Some activities do not require to give input in the model, but do influence the outcome of the model(green).
- Some activities will be partly conducted by the model and can be considered as output/outcome from the model(red).

The text marked with yellow can be conceived as a remark or a sub conclusion. Furthermore, the activities are numbered in order to make referencing in the report to the activities in the diagram more clear. In Appendix 5 the activities are linked with the relevant input cells in the financial model(Excel).

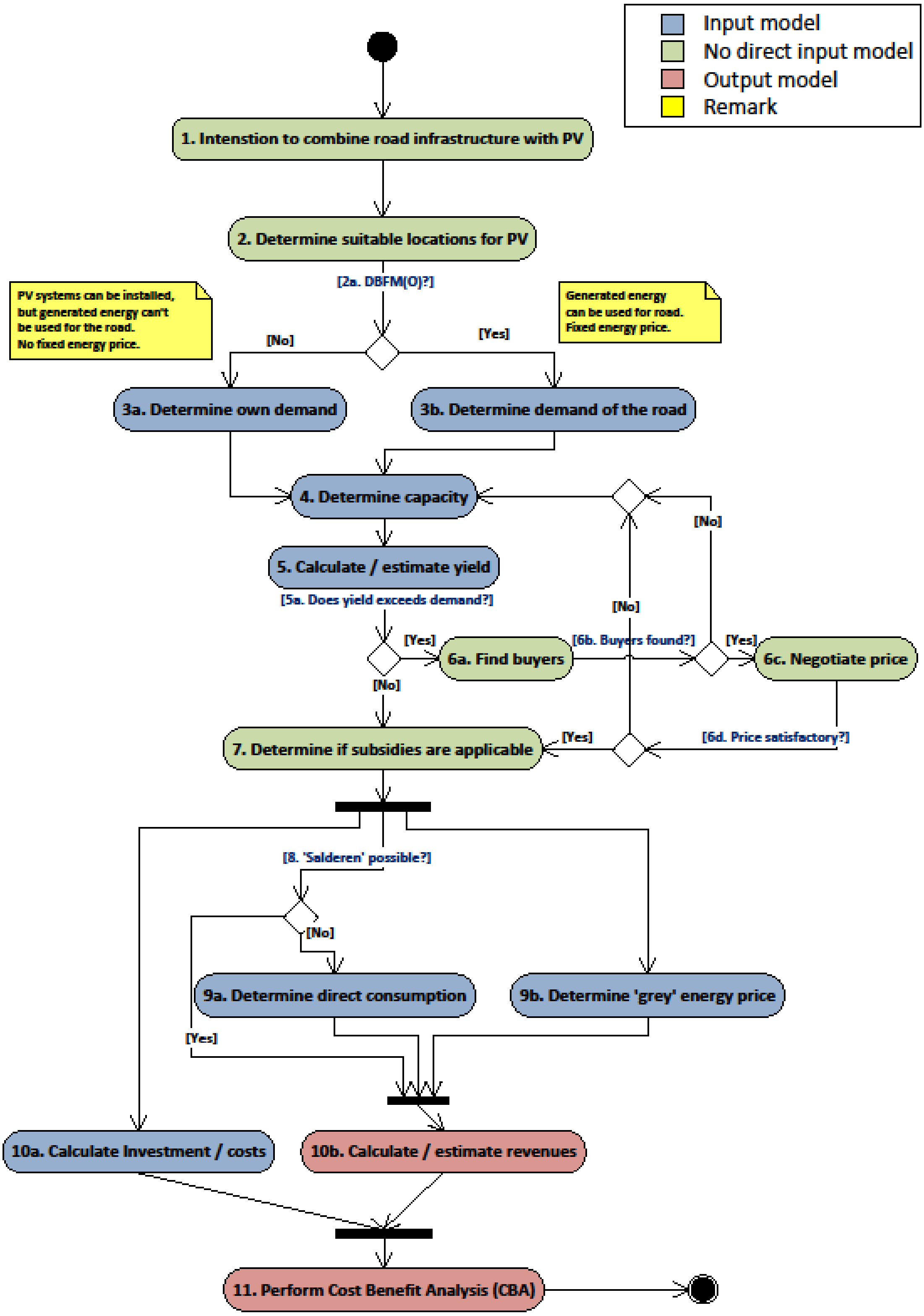


Figure 29: Activity diagram

Before the following steps in the activity diagram are implemented, it should be clear which ownership situation is applicable. This could be one of the situations described in section 5.1, but isn't limited to these. From the activity diagram can be observed there has to be an initiator who expresses the intension to install PV panels near road infrastructure. Secondly, suitable locations for PV along the roadside have to be determined. This should occur based on experience and knowledge. The knowledge can be gained from the background chapters(2-4) in this report. Suitable locations depend for instance on availability of space, regulation, location in relation to consumers or connection points etc. If no suitable locations can be found, PV near road infrastructure isn't feasible thus none of the following sequential activities have to be performed anymore.

When there are suitable locations available, it is important if a DBFM(O) contract is involved. If a DBFM(O) contract is involved, the generated energy can be used for the road. Therefore it is important to know the energy demand of the road. In all other situations, the generated energy can't be used for the road, thus the electricity demand of the user has to be determined. The electricity demand is very important since it influences the revenues which result from savings on the electricity bill. These issues have to be entered in the financial model in the input sheet under Part: 1(Figure 30).

The next step is to determine the capacity. The capacity depends of multiple factors such as available space, type of PV, orientation, tilt etc. It also depends whether or not the PV system should fulfill in the total electricity demand or not, and how much resources are available. When the capacity is known, it is possible to estimate the yield. The capacity and yield can be entered in the financial model in the input sheet under Part: 2(Figure 31). If the yield isn't as high as desired, one has to go back and determine the capacity again. When the yield exceeds the demand, there will be an excess of electricity. This electricity has to go somewhere, thus buyers have to be found. If they are found and a price is agreed, it is possible to travel further through the activity diagram. If buyers are not found or it is failed to negotiate a price, the capacity of the PV systems has to be lowered. Once a satisfactory capacity and yield is achieved, one has to find out if subsidies are applicable to this specific PV project. Thereafter, the investment and costs should be calculated and can be entered in Part:2(Figure 31) of the input sheet.

The grey electricity price is very relevant for the revenues, therefore this price should be determined. The financial model calculates the grey electricity price automatically, based on the input entered in Part: 3(Figure 32). It should be determined whether net metering(Dutch: 'salderen') is possible. If not, the direct consumption of the generated energy should be determined. This can be entered as a ratio in the input sheet under Part: 3(Figure 32). If net metering is possible, the direct consumption isn't relevant. With information about e.g. net metering, direct consumption and grey electricity price, the revenues can be estimated by the financial model. When all these activities are performed, the model is able to generate the output which is required to execute a cost benefit analysis.

5.3.2. Input

Input for the financial model is very important, thus attention should be paid when filing in the input sheet. If the input isn't reliable, the output won't be. The input sheet is divided into 5 parts, as can be seen in figures down below. The reasoning behind the input is elaborated below.

Part: 1(Figure 30) requires information about the energy demand. The energy demand is often a guideline when the capacity of the PV installation is determined. It is also important for calculating the revenue that results from savings on the electricity bill. In the model can be indicated whether or not the electricity is intended for the high way itself, thus within a DBFM contract. When that's the case, the energy demand of the road will be automatically calculated. For this calculation, there is input required regarding the energy components of the road, such as lighting, portals, CCTV camera etc. Information about quantities, power and operation hours is required. If there is no DBFM contract involved, the energy can't be used for the road. In that case, the energy can be used for instance by a nearby manufacturing company and a manual input regarding the electricity demand of that company is required.

Figure omitted

Figure 30: Screenshot of Part: 1 from the input sheet of the financial model.

Part: 2(Figure 31) requires information about the investment, capacity and the yield. In this section, also information about time is required. When will the construction start, when the system starts operating and how long it will be in operation. If an extra investment is necessary to connect to the regional grid, this can be entered. PV installations could be installed at multiple locations with different specifications, therefore it is possible to enter six locations. The model can calculate a rough estimate of the yield per location. This is done by using a rule of thumb, and is intended to present a quick indication of the yield to the user of the model. However, for further calculations in the financial model, it is asked to enter the yield manually. A more reliable amount for the yield of the installation can be obtained from PVGIS. This tool considers location, azimuth, slope, type of PV panels and system losses in the calculation. A very important input variable in Part: 2(Figure 31) is the investment for the PV system.

Figure omitted

Figure 31: Screenshot of Part: 2 from the input sheet of the financial model.

Part: 3(Figure 32) requires input which is used to determine the revenues of the PV system. Therefore, input about the grey electricity price is important. The grey electricity price is important to estimate the savings that are achieved on the electricity bill. As elaborated in section 2.2, the electricity price consist of multiple components. With the requested input, the model is able to calculate the price of every component and thus determine the total electricity price. Since the model is designed to be suitable for multiple situations, it is also possible to enter the electricity price manually. If this is the case, the model skips the steps to calculate the electricity price and uses the manually entered electricity price for further calculations. In case of a DBFM contract, a fixed electricity could be determined by RWS for the total contract period, thus it is possible to enter that value and the model will not index this value during the contract period. Since subsidies generate extra revenue, input on this subject is also required in Part: 3(Figure 32). It is possible to indicate whether or not subsidies are available to this project and to enter relevant details per subsidy.

Figure omitted

Figure 32: Screenshot of Part: 3 from the input sheet of the financial model.

Part: 4(Figure 33) comprises input about the operating costs. These are yearly costs such as land costs, variable operating costs, maintenance costs, overhead costs and insurance.

Figure omitted

Figure 33: Screenshot of Part: 4 from the input sheet of the financial model.

Part: 5(Figure 34) requires input about financing. How much is financed with equity and loans, and what interest rates should be applied. It is also possible to model a reinvestment sum. The tariff for tax should be entered, as well as the expected inflation rate for the future. The period that is desirable to pay back the loan or to amortize the installation can be entered.

Figure omitted

Figure 34: Screenshot of Part: 5 from the input sheet of the financial model.

5.3.3. Cost elements

Selecting and identifying the costs is a crucial part of the Cost Benefit Analysis. Therefore all relevant costs have to be taken into account in order to make it possible for the decision maker to make a good decision. In the activity diagram the cost elements have to be determined in activity number 10a(Figure 29) and can be entered in part: 2(Figure 31) and part: 4(Figure 33) of the input sheet. The cost elements can be divided into three parts:

- Initial investment;
- Reinvestment costs;
- Costs from yearly expenses.

These costs are quantified to a case study in chapter 5.3.6. Below the costs are briefly explained.

The initial investment comprises all the costs that have to be made in order to get the installation in operation. These are costs for the PV panels, mounting construction, inverter and monitoring, installing, […………………………], working hours(engineering, design, project guidance etc.) and foundation. These are costs which are directly related to the PV installation, but there may be other indirect costs. Indirect costs are for instance expenses that have to made to connect the installation to the public grid. This could include cables and transformer.
What type of panels and inverters are applied? What structural foundation is needed? Obviously, such variables make the initial investment differently for every project. The investment for the PV system and the investment for the connection to the grid can be entered separately in the financial model under Part: 2(Figure 31). From that point the model will sum up these values for further calculations.

Reinvestment costs are costs that occur when expenses have to be made at certain points during the lifetime of the PV system. These are not yearly expenses, but expenses that have to be made every 8 or 10 years. An example could be that it is expected that some of the inverters have to be replaced after 10 year of operation, or when it is expected a number of PV panels have to be replaced. These costs are always inherent to uncertainty because they are costs expected in the future. Reinvestment costs, together with the frequency, can be entered in Part: 5(Figure 34).

The third cost element comprises the yearly costs. These are costs that return every year during the total operation period. An example are the costs for interest. The costs depend e.g. on how much internal equity is used and how much is financed by loans. When the owner doesn't need external equity, there will be no costs for interest. Furthermore, there may be costs to rent the land, overhead costs or yearly maintenance costs. Also, when is chosen to insure the PV system, insurance costs are yearly expenses.

5.3.4. Benefit elements

Equally important as the costs are the revenues, or so called benefits. Since this CBA is based on an economic analysis, only benefits are concerned that can be easily expressed in monetary terms and thus are not disputable. Benefits which are difficult to express in monetary terms, such as environmental benefits, are not taken into account. In the activity diagram the benefit elements have to be determined in activity number 10b(Figure 29). The benefit elements can be divided into three parts:

- Savings on electricity bill;
- Subsidies;
- Selling of electricity.

These benefits are quantified in a case study in chapter 5.3.6. Below the benefits are briefly explained.

The financial model calculates, based on the input, the financial benefits/revenues. The input is derived from Part: 3(Figure 32) of the input sheet. It is expected the biggest benefits results from the savings that are achieved on the electricity bill. As already explained, to quantify these savings it is necessary to know the expenses that are paid for grey electricity. Thus, Part: 3(Figure 32) of the input sheet requires information about the total energy demand, type of connection and energy tax in order to determine the costs for grey electricity. The costs which have to be paid for the grid depend on the location in the Netherlands and thus which company operates the grid. An important factor in the revenues from saving on the electricity bill is whether or not net metering is allowed, or if the electricity is directly consumed.

Subsidies could also contribute an important share in the total benefits. In the financial model, only the SDE+ and EIA subsidy programs are incorporated. These two programs result in the highest benefits and are very suitable for large scale energy generation with PV panels. It should be noted that when the SDE+ is granted, it results in revenues for only 15 years. Obviously, there is always a chance one or both of the subsidies are not granted and thus this benefit element can be omitted.

As can be observed from the activity diagram in Figure 29, there has to be determined how much electricity will be generated and whether or not electricity will be sold. If the generated electricity exceeds the own demand, the electricity can be sold to third parties, e.g. utility companies. This result in an extra benefit element since it generates revenue.

5.3.5. Functioning of the model

So far the cost elements, benefit elements and the input that is required for the model is explained. Also, the global functioning of the model can be derived from the activity diagram. The costs, benefits and input are the most important elements of the model. The previous sections, including the activity diagram, paint a picture how the model functions and how the input, costs and benefits are used. However, in this section some additional issues about the functioning of the model are elaborated.

Based on the given input, the model calculates for each year both the costs and the benefits. The model is only suitable for operation periods with a maximum of 25 years. Costs and benefits changes every year due to multiple factors such as efficiency loss, inflation and subsidies.
The decreasing efficiency of the PV system, due to aging, is incorporated in the model. The model assumes the efficiency drops every year with [….]%. Thus, the benefits decrease every year as a result of this. Subsidies also result in changing benefits. From the input sheet it is know if the SDE+ is granted and until what year, thus the model knows exactly for which years benefits from SDE+ are applicable. Furthermore, the model knows what share of generated energy is consumed by the owner and what is sold, thus is able to automatically calculate the revenues from saved and sold electricity. Obviously, the benefits differ per kWh between saved and sold electricity. If no DBFM

contract is involved, these benefits are indexed each year. On the other hand, costs increase as a result of inflation. Thus, yearly costs such as maintenance and insurance increase every year.

When the costs and benefits for each year are calculated, the model generates for each year the profit, cash flows, overdraft, etc. As is obvious for a financial model, costs elements such as depreciation, taxes and interest are included. Based on the above named and other elements, the project and equity cash-flow are calculated. Subsequently, the payback time, Net Present Value and IRR are determined based on these cash-flows.

5.3.6. Assumptions

It should be noted some assumptions are included in the financial model. Acceptation of the assumptions is extensively contemplated and constantly is kept in mind what the influence of the assumptions are to the output of the model and objectives of this thesis. All made assumptions comply with these conditions.

It is assumed revenues are directly paid, shortages are complemented by the equity supplier and surpluses of money will be paid out directly. Working capital isn't taken into account. When the subsidy EIA is applicable, it is assumed this can be modeled as an addition to the cash flow because the company who invests makes sufficient profit. One tax tariff for the tax on profit is assumed. Furthermore, the model assumes the revenues per kWh that are saved on the electricity bill, equal the price consumers normally have to pay to the utility company.

6. Case study

This chapter aims to gain insight in the potential for PV panels near a highway in the Netherlands. More specific, to gain insight in the costs and benefits. This is done by conducting a Cost Benefit Analysis(CBA) for a specific case, namely the infrastructural project SAA. Project SAA comprises the expansion of highways between Shiphol, Amsterdam and Almere, the A9, A10, A1 and A6. It is one of the largest infrastructural projects of the coming 10 years in the Netherlands. Construction activities are already started and will last until 2020. The client is, as is usual for infrastructural projects in the Netherlands, Rijkswaterstaat. The roads are widened with at least 1 lane. This will result in a better flow of traffic and traveling times become more reliable. The randstad region will remain accessible in the future, which is essential for economic development in this region. Besides the expansion of the roads, quality of life will be enhanced. This will be achieved by new and higher noise barriers, and noise absorbing asphalt. Included in this mega project are tunnels and an aquaduct near Muiden at the A1. Since the scale of this project is enormous, the total project is divided into multiple parts. These sub projects(see Figure 35) are brought to the market in the form of DBFM contracts.

6.1. Project details

The sub project that is considered for this case study comprises the design, construction, maintenance and financing(DBFM) of the expansion of existing infrastructure and new infrastructure between intersection Diemen(A1) and Almere Havendreef(A6). In Figure 35, it is the green hatched part of the total project. In order to get an idea of the scale of this sub project, the contract period is 25 years and an amount of more than 1 billion euro's is involved.

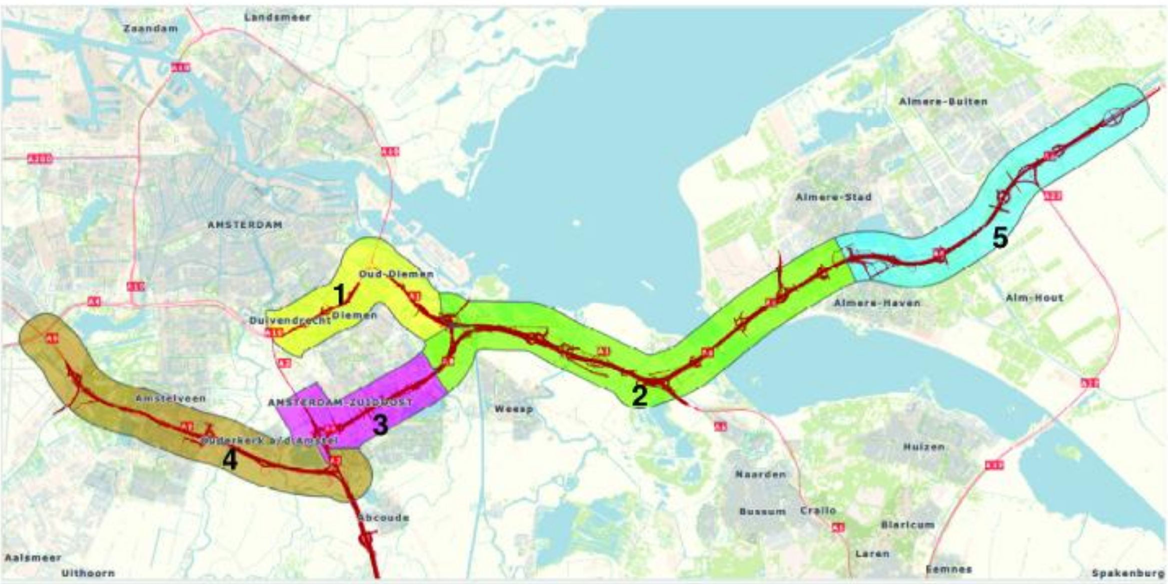


Figure 35: Project SAA, divided into sub projects.(source: RWS)

The length of the green hatched part in Figure 35 is approximately 14 kilometers. This part of the road has in total 5 entrances and exits, and two interchanges are present. The direction of the roads could be favorable regarding energy generation. The axis of the A1 lays roughly from South East East(SEE) to North West West(NWW). The axis of the A6 lays roughly from North East East(NEE) to South West West(SWW). The axis of the current A1 will be relocated towards the south near Muiden in the new situation due to the construction of an aqueduct which replaces the bridge. Due to this relocation, Rijkwaterstaat has bought some farmland and properties. Parts of the land between the current and new road will remain potentially unused. It concerns two large areas, [………….] and the [………..]. The dimensions of these areas are respectively about […] and […] acres. Besides these two large open areas, there are more potential areas where PV panels can be installed. These areas are located near exits and entrances, intersections and a petrol station. A very safe estimate will show this result in a total area of 12,75 acres, see Table 10. This road section is less suitable for PV panels in the road shoulder. Also, the shoulder in between the two driving directions doesn't offer much potential since there is very little space.

As already mentioned, an important part of the renewal and expansion of this road section are the noise barriers. More noise barriers will be present in the new situation and they will be higher. Since Rijkswaterstaat would like to create a certain degree of architectural consistency and cost efficiency, most newly developed noise barriers these day are modular noise barriers. That is also the case for this road section. In total, […] kilometers of noise barrier will be realized, of which the vast amount is placed at the A1. The height of the barriers vary from [….] meters to […] meters. In total, the surface of the noise barriers covers [……] m^2, see Table 11. The angle of the noise barriers will be […..]°. In Appendix 6 the design with dimensions of the noise barrier with a height of [….] meters is included.

The energy consumption of the road section A1/A6 is estimated at [……..] kWh per year, see Table 9. The initial goal is to make the road section self sufficient. As already mentioned, this project is brought to the market in the DBFM form. This means the contractor has to bear the costs regarding the electricity consumption of the road. The electricity has to be bought from the client whom determined an electricity price of €[……..] per kWh. There is no distinction between peak- and off peak-hours. The price is fixed during the complete contract period which is 25 years. On the basis of the standard contract, talks with experts from Ballast Nedam and talks with Rijkswaterstaat, it is assumed net metering is allowed.

Component	Amount	Power		Operation hours		Consumption
		(Watt/piece)	(Total Watt)	(h/day)	(h/year)	(kWh/year)
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]	[………]	[………]
					Total	[………]

Table 9: Electricity consumption of the road section.

6.2. Variants

Since the large scale of this project, multiple solutions would be possible for energy generation with PV. There are large open spaces available, as well as noise barriers that could be fitted with PV panels. The variants are described below.

6.2.1. Variant 1: Open field configuration

In this variant, PV panels are only installed in the open field. In the project details is already mentioned how much unused land is present within this project. This land is managed by RWS and is suitable for PV panels. A safe estimate reveals there is [………] acres available. A rule of thumb says a PV panel needs approximately 4m^2, thus can be easily calculated how much PV panels could be installed on this area. This would result in a maximum of [………] PV panels, see Table 10. Since the average crystalline PV panel such as the Canadian Solar CS6P-250P has a nominal max power of 250 Wp, the total installation could amount in theory [………]kWp. Since the PV panels can be placed in the open field, there are no limitation regarding orientation and tilt. Thus, the panels will be installed in the optimum position of 37° and an orientation to the South in order to maximize the annual yield. The estimated annual yield would be [………]kWh. This amount is obtained from the online PV potential estimation utility(PVGIS), see Appendix 7 for a screenshot of the input sheet. In Appendix 8, an example of the output from PVGIS is enclosed.

Location	Area(m^2)	Panels	Power(kWp)	Yield(kWh)/y
[………]	[………]	[………]	[………]	[………]
[………]	[………]	[………]	[………]	[………]
Exit/Entrance nr. 1 A6	[………]	[………]	[………]	[………]
Exit/Entrance nr. 2 A6	[………]	[………]	[………]	[………]
Exit/Entrance nr. 3 A6	[………]	[………]	[………]	[………]
Intersection ‘Muiderberg’	[………]	[………]	[………]	[………]
Intersection ‘Diemen’	[………]	[………]	[………]	[………]
Petrol station BP	[………]	[………]	[………]	[………]
Total	[………]	[………]	[………]	[………]

Table 10: Estimation of space available for PV near the road.

From Table 10, the maximum estimated yield is far more than the energy demand of the road section. Even without the [……….] and [………]-area, enough electricity can be generated. So the selection of locations should be made based on knowledge and practical considerations. Since the road section has multiple connection points to the grid and net metering is allowed, it would be wise to divide the PV panels over multiple connection points. Otherwise, when electricity is fed into the grid from only one connection point, the meter of that connection point will soon reach zero. Therefore, it is decided to divide the PV panels among the multiple locations that are stated in Table 10. A disadvantage of this choice is a higher costs for measures regarding cables, safety and vandalism(fences).

In order to meet the energy demand of the road when the orientation of the panels is towards the South and tilt is 37°, approximately [………]PV panels are needed with a total power of [………] kWp. Due to the scale of this project, the investment would be €[………]/Wp. This includes:

- PV panels
- Mounting construction
- Inverter and monitoring
- Installing
- [………]
- [………]
- Miscellaneous
- [………]

6.2.2. Variant 2: Photovoltaic noise barrier

In Table 11 the noise barriers which are planned near the A1/A6 are displayed. In total, [.........]m^2 of noise barrier is available. Unfortunately, not all of this space is suitable for PV. Since shadow should be avoided at all time and the noise barriers are very close by the road, only noise barriers are suitable that are higher than [….] meters. Furthermore, the noise barriers at the North side of the road are the most suitable. However, the noise barriers at the South side of the road can be positioned in such a way they become suitable for PV. Then the electricity is generated at the back of the noise barrier. The type of noise barrier that is applied will be a modular noise barrier, as is explained in section 4.6. Two variants related to noise barriers are considered, one installed with Powerglaz® BIPV and the other one is installed with standard PV panels mounted on the aluminum panels of the noise barrier.

Road	Section	Road side	Azimuth	Height(m)	Tilt(°)	Surface(m^2)	PV-surface(m^2)
A1	[.........]	North	200°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	North	varying	[.........]	[…]°	[.........]	[.........]
A1	[.........]	North	varying	[.........]	[…]°	[.........]	[.........]
A1	[.........]	North	200°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	North	200°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	North	195°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	North	220°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	South	200°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	South	varying	[.........]	[…]°	[.........]	[.........]
A1	[.........]	South	varying	[.........]	[…]°	[.........]	[.........]
A1	[.........]	South	200°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	South	200°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	South	200°	[.........]	[…]°	[.........]	[.........]
A1	[.........]	East	0°	[.........]	[…]°	[.........]	[.........]
A1/A6	[.........]	North	220°	[.........]	[…]°	[.........]	[.........]
A6	[.........]	North	143°	[.........]	[…]°	[.........]	[.........]
A6	[.........]	North	143°	[.........]	[…]°	[.........]	[.........]
A6	[.........]	North	143°	[.........]	[…]°	[.........]	[.........]
A6	[.........]	North	143°	[.........]	[…]°	[.........]	[.........]
S101	[.........]	East		[.........]	[…]°	[.........]	[.........]
				Total		[.........]	[.........]

Table 11: Quantities noise barrier A1/A6.

<u>Variant 2a</u>

Variant 2a assumes a new type of panel is developed for the modular noise barrier. This panel will consist of Powerglaz® BIPV, in general called PV in glass. PowerGlaz® BIPV is suited to a wide range of applications and can be integrated into vertical glazing, pitched glazing, canopies or walkways as well as glazed roofs such as atria and sloping slate and tile roofs. PowerGlaz® glass/glass laminates can be single or double glazed, and will fit easily into most proprietary glazing systems(www.romag.co.uk). The panels have a transparency of 70% and are covered with poly crystalline cells. The PowerGlaz® panels can be produced in almost every size with a maximum of 2,2m x 3,2m. Longer panels would be possible but then the costs will increase. In order to comply with the noise blocking requirements, the panels should weigh at least 40kg/m^2. With this weight a thickness of 2x8mm is associated.

When the PowerGlaz® panels have a transparency of 70%, the capacity is 109Wp/m^2. Since [.........]m^2 is available, the total capacity would be [.........] Wp. The orientation is 200° and tilt […]°, thus the annual yield would be [.........] kWh(PVGIS). Since the energy demand of the road is [.........] kWh, the energy production from the photovoltaic noise barriers isn't sufficient to meet the demand.

The investment costs of variant 2a are significantly higher than variant 1. The PowerGlaz® panels are more expensive than standard PV panels. The estimated investment is €[…]/Wp. This includes:

- PowerGlaz® panels
- Inverter and monitoring
- Installing
- [………]
- [………]
- Miscellaneous

However, since the PowerGlaz® panels replace the normal panels of glass in the noise barrier, costs are saved. Therefore, the costs of the normal panels of glass are deducted from the investment costs in this variant. Normal panels of glass cost about €[…]/m^2, thus the investment costs can drop to €[…]/Wp.

Variant 2b

Variant 2b assumes the standard aluminum panels of the modular noise barrier are equipped with crystalline PV panels which are also used in the open field variant. The panels of the modular noise barrier are 6,0m x 1,0m(WxH). The basic dimensions of a PV panel are 1638mm x 982mm. Thus, on 1 aluminum panel would fit 3 PV panels. In total, there would be space for approximately [………]PV panels. The maximum total capacity would be [………]Wp and the annual yield [………]kWh(PVGIS).

This variant doesn't replace the panels of the noise barrier, but the PV panels are mounted on top of the aluminum panels. Therefore no material is saved and no costs reductions are realized. The costs are a fraction lower than variant 1 because the use of material will be lower for the mounting construction and installation costs are lower. Thus the estimated investment is €[…] /Wp. This includes:

- PV panels
- Mounting construction
- Inverter and monitoring
- Installing
- [………]
- [………]
- Miscellaneous

6.3. Cost Benefit Analysis(CBA)

With the financial model(excel) that is developed, the economic feasibility is determined for each variant. With the financial model a Cost Benefit Analysis can be performed. The theoretical background and components of this method are explained in section 5.2. The assessment of each variant will occur on the basis of three criteria:

- Net present value(NPV)
- Internal rate of return(IRR)
- Payback period

On the basis of these figures, a comparison can be made among the variants. A summary of the output from the financial model is shown in Table 12. Also, some important input variables are included. Furthermore, in the calculation is assumed both the EIA and SDE+ subsidies are granted, and phase 2 of the SDE+ program 2013 is applicable. The weighted average cost of capital amounts […]%, which is used to calculate the NPV. The yearly maintenance costs amount […]% of the total investment. The system will be insured, these are yearly costs and amount […]% of the total investment.

		Variant 1	Variant 2a	Variant 2b
Input	**Investment(€/Wp)**	€[…]	€[…]	€[…]
	Power(kWp)	[………]	[………]	[………]
	Annual yield(kWh)	[………]	[………]	[………]
	Performance(kWh/kWp)	[………]	[………]	[………]
	Subsidy	SDE+, EIA	SDE+, EIA	SDE+, EIA
Output				
Project evaluation				
	NPV	€1.013.136	€-1.059.865	€614.822
	IRR	[…]%	[…]%	[…]%
	Payback period	10 years and 4 months	18 years and 11 months	10 years and 9 months
	Average kWh price	€0,1351	€0,2696	€0,1409
Equity evaluation				
	NPV	€22.251	€-1.330.334	€-58.776
	IRR	[…]%	[…]%	[…]%

Table 12: Comparison of the variants.

The outcome shown in Table 12 is a result of estimations made specific to this case and road section. From Table 12 it is obvious only variant 1 results in positive numbers. The NPV for both the project and equity evaluation is positive. Based on these figures, it is very likely a company would invest in variant 1. Variant 2b is slightly less profitable and variant 2a results only in negative numbers. There is no chance a commercial party would invest in variant 2a. Despite the negative NPV of the equity evaluation of variant 2b, it isn't unlikely a commercial party would seriously considers to invest in this variant. In the calculation it is assumed the commercial party expects an IRR of […]% on equity, but variant 2b result in an IRR of […]%, hence the negative NPV. Since it concerns a renewable energy project, investors may comply with a lower IRR.

It is worthwhile to note not one variant results in a positive NPV for equity when phase one of the SDE+ is applicable. On the other hand, if phase 3 of the SDE+ is applicable, also variant 2b result in a positive equity NPV. From the difference in output between variant 1 and variant 2b, it can be concluded the performance/efficiency plays an important role. Despite the different input between variant 1 and 2b, the results differ not very much. This can be explained because the investment for variant 1 is a little bit higher than variant 2b, but also the performance of variant 1 is higher.

6.3.1. Sensitivity analysis

As already explained in section 5.2, decisions for in the future are characterized by uncertainties. Uncertainties are inherent to risks, thus it is important to gain insight in the effect of changes in these uncertainties. Maintenance costs are a good example. What is the effect in the long term on the outcome of the project when the maintenance costs are higher than estimated? This question can be answered when a sensitivity analysis is performed. But it isn't only useful to gain insight in risks, it can also show the influence of e.g. cost reductions or changing revenue at the outcome of the project. Such analysis shows how sensitive the outcome is to changes in certain variables. [………]. The output that is used for the sensitivity analysis is the NPV and IRR of the project, the NPV and IRR of equity isn't considered. The sensitivity of the investment, maintenance costs, kWh-price and yield is determined. Also the impact of subsidies is elaborated for all variants. Only the graphs which displays the impact on the NPV is included in this section, the other graphs with impact on IRR and payback time are included in Appendix 9.

Investment

The price of PV panels is constantly changing, as is elaborated in section 3.4. Prices dropped significantly during the last 10 year, but it seems this decline reached a temporary intermission. Import taxes are also a threat for the price drops. The graph below show the impact of investment on the NPV.

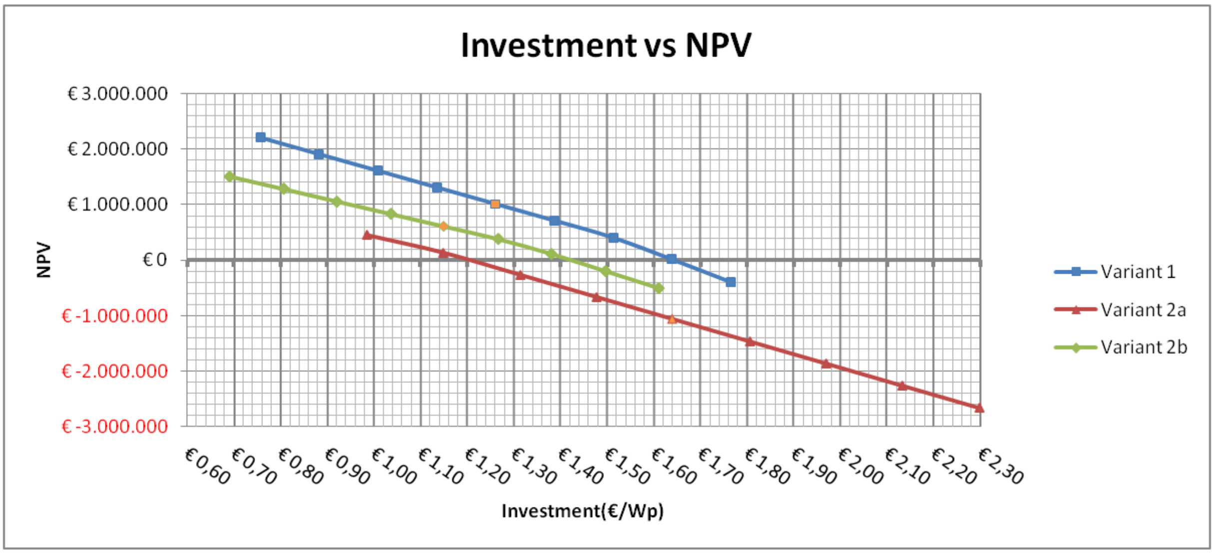


Figure 36: Change in NPV due to investment, for all variants.

The figure above presents a clear insight about from which level of investment the variants result in a positive NPV. Currently, variant 2a isn't profitable, but it will be when the investment drops below €1,15/Wp. Due to the higher performance of variant 1 and 2b, they become profitable when the investment drops below €1,65/Wp and €1,40/Wp, respectively. When the investment drops €0,10/Wp, the NPV increases with approximately €250.000 for variant 1, and with €200.000 for variant 2b.

Maintenance

Maintenance costs are often determined as a percentage of the total investment. It is interesting to know to what extent lower maintenance costs impact the NPV.

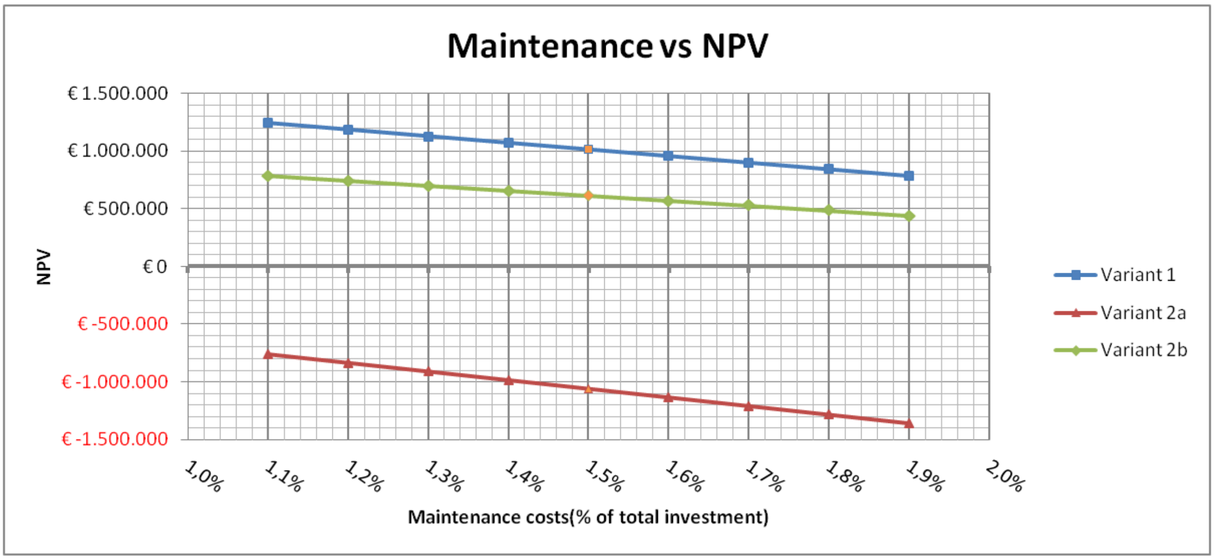


Figure 37: Change in NPV due to maintenance costs, for all variants.

Figure 37 shows that even when the maintenance costs turns out to be higher than expected, there is no risk for variant 1 and 2b the NPV becomes negative. But there is a significant decrease noticeable if the maintenance costs increase. For every increase of 0,1% in maintenance costs, the NPV of variant 1 decreases with almost € 60.000 and variant 2b with € 43.000. The effect on payback time is negligible.

kWh-price

The fixed kWh-price is in this case study determined by Rijkswaterstaat. The kWh-price influences directly the revenues of the project. It shows from what kWh-price a project becomes profitable.

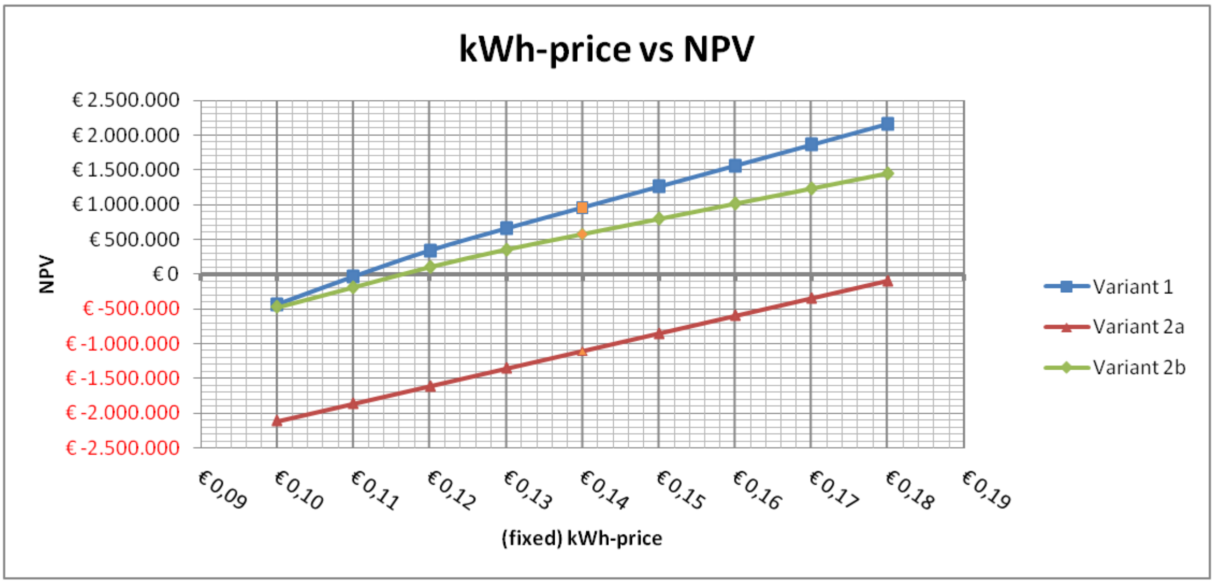


Figure 38: Change in NPV due to kWh-price, for all variants.

The graphs above show variant 1 is already profitable when a little bit more than €0,11 has to be paid per kWh. If the kWh-price is raised with €0,01, the NPV of variant 1 increases with €300.000. When

RWS determines a price higher than €0,115 per kWh, variant 2b becomes profitable. The NPV for variant 2a will become positive when more than €0,18 has to be paid per kWh.

Yield/Efficiency

From the literature it is known PV panels near road infrastructure are subject to additional contamination due to traffic dust. This may impact the efficiency and thus the yield of the system, and subsequently the NPV. This impact is visualized in Figure 39. The orange measure points represent the yield derived from PVGIS, thus without a decrease in efficiency due to contamination. The steps between the measure points represent a decrease of 2% of the yield.

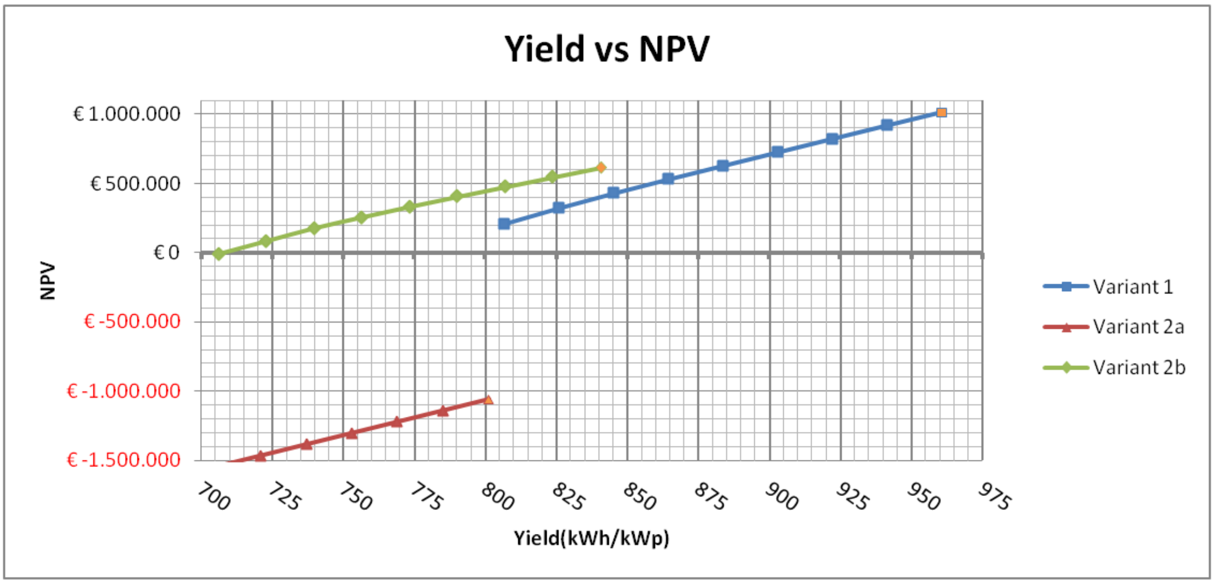


Figure 39: Change in NPV due to yield, for all variants.

The yield/efficiency of the panels seems to have an important impact on the project's NPV. The first 2% decrease in yield results in a 9,4% decrease of NPV for variant 1. For variant 2b this is even 11,4%. For every 2% decrease in yield, the relative decrease of NPV becomes higher. Even though the NPV stays positive for variant 1 and 2b in case of a decrease of 14% in efficiency, the NPV is reduced with more than 68%.

Subsidies

Subsidies are often introduced to stimulate the development and use of new technologies, but it is never certain if a project can utilize these advantages. Therefore it is important to know what the influence of subsidies are and whether a project is profitable without subsidies. The figures below will provide this insight for each variant. The NPV is determined for 4 situations per variant, namely when:

- both SDE+ and EIA are utilized;
- only SDE+ is utilized;
- only EIA is utilized;
- no subsidies are utilized.

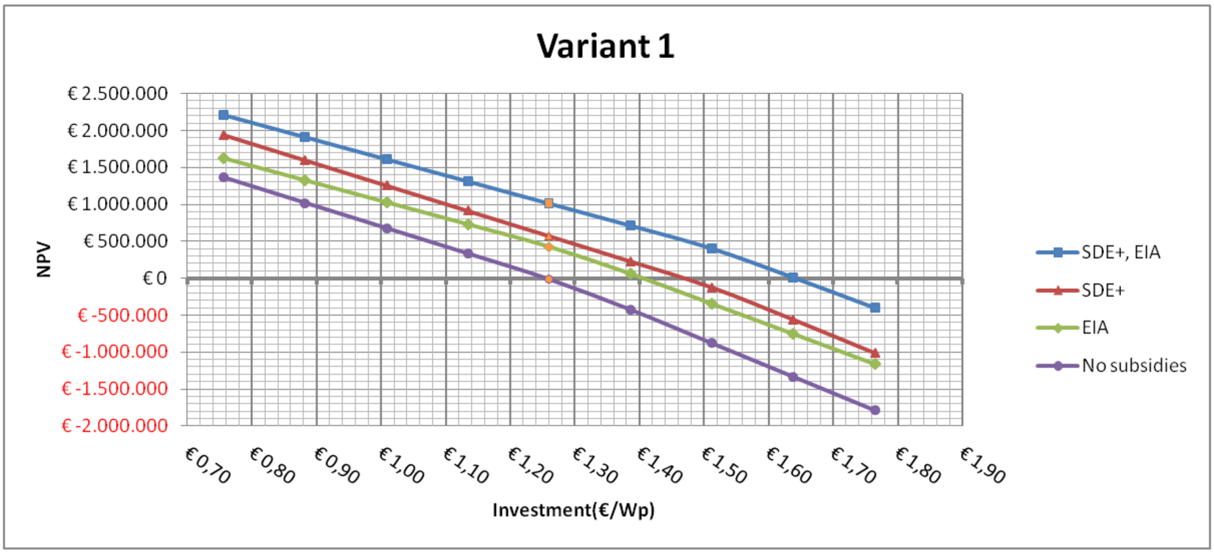


Figure 40: Impact of subsidies on NPV for variant 1.

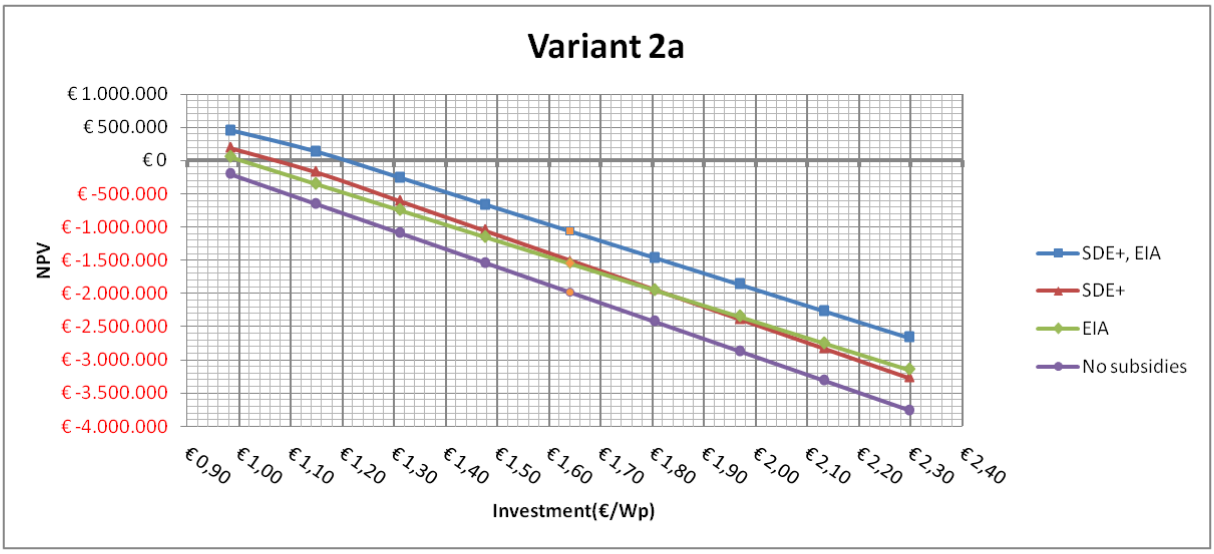


Figure 41: Impact of subsidies on NPV for variant 2a.

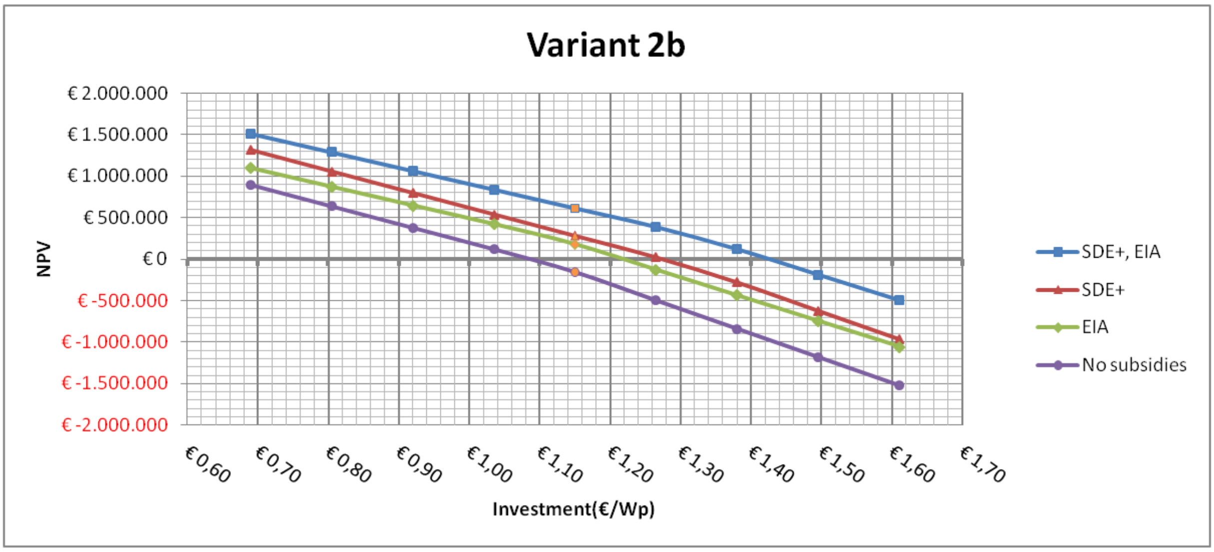


Figure 42: Impact of subsidies on NPV for variant 2b.

The figures above show that the SDE+ subsidy is more important than the EIA subsidy. Due to the scale of the graphs, the difference between the EIA and SDE+ may seem small, but on average the difference in NPV for variant 1 and 2b is more than €150.000. The figures also show subsidies are currently essential to make the investments in PV profitable. At most one subsidy application, whether it concerns the SDE+ or EIA, could be rejected in order to keep variant 1 and 2b still profitable.

7. Conclusion and recommendations

The first part of this chapter consist the conclusions which are based on the conducted research. The conclusions are an answer to the research questions as stated in the introduction of this report. Both the main research question and the sub-questions will be answered. The second part of this chapter consists recommendations for further research. Some possible directions that could be followed in order to complement this research are discussed.

7.1. Conclusion

Besides the multiple advantages and opportunities for PV systems near road infrastructure, issues or obstacles will be encountered. If there were no obstacles, PV systems would be along road infrastructure at multiple locations the Netherlands. In reality, there are only two locations in the Netherlands were PV panels are installed near road infrastructure. In both projects, the PV panels are installed on noise barriers. These projects were pilot projects in order to acquire experience and demonstrate the opportunities. The projects were realized in 1995 and 1998, and were made financially feasible with a substantial amount of subsidies from the national government and the European Commission. Other European countries such as Germany, Switzerland and Italy are, especially the previous 10 years, more active towards the implementation of photo voltaic noise barriers. In total, there are only 30 locations in the world where photo voltaic is combined with road infrastructure. There are no example projects in the Netherlands, neither in Europe, where PV panels are installed in an open field configuration in the road shoulder.

At all sorts of levels, issues could be encountered and have to be mitigated or eliminated. Problems that can be expected are technical, contractual, financial or related to the current legislation. Attention should be paid in the design process to the cable length. Especially when the PV panels are installed on noise barriers or in a long trail in the shoulder, more cable length is required thus the costs for cables per Watt peak increase. The financial aspect of PV panels near road infrastructure is influenced by many factors. The issues or variables which are very important for the return on investment are:

- Situation of the system like location, tilt, azimuth or shade;
- Interest rate and lifetime of the investment;
- Total investment of the PV system;
- Expected raise of electricity prices in the future;
- Use of subsidies;
- Tax level;
- Legal status;
- Net metering;
- Ratio of self consumed and fed electricity;
- Monitoring and/or service contract;
- Energy supplier;
- Type of contract(e.g. DBFM).

PV panels may invite vandalism or theft. Thus, when siting individual facilities, planners have to consider in the design process measures to prevent, or at least make it difficult to damage or steal PV panels or related facilities.

A very important question is always which party consumes the generated energy. The electricity could only be consumed by road installations when a DBFM contract is applicable. In every other situation, other consumers must be found. Road infrastructure projects that are executed within a DBFM contract do offer opportunities since the risk of price is covered by the client(RWS) and the price is fixed during the contract period. Based on the stipulations in the standard contract and interviews with two employees of RWS, net metering is allowed at this moment. So the revenues per kWh are relatively high. Another advantage of energy generation within a DBFM contract is that no

lease has to be paid for the ground. It is also possible to sell the electricity to third parties, this could even happen via the connection points of RWS. Despite the opportunities, there are uncertainties for the future. It seems there are still a lot of questions within RWS about the topic energy generation within a DBFM contract, and it looks like they are still searching for a vision regarding this. What the opportunities are in the future depend mainly on decisions made by RWS. For instance, currently the standard contract states feeding electricity into the grid is limitless and the price for the fed in electricity is the same as they price the electricity is supplied for. They came back on this stipulation. If net metering isn't allowed anymore in the future, it is advised to reduce the capacity of the installation in order to achieve the electricity is directly consumed and no electricity has to be fed into the grid. When the electricity has to be fed into the grid, the revenues are almost three times lower compared with a situation where the electricity is directly consumed.
It is advised to allocate the PV systems [……..] over the road section and make use of [……….] connection points in order to fully exploit the possibilities regarding net metering. When the PV systems are [………] allocated over the road section, it is less likely the capacity of a connection point has to be enlarged.

Although RWS expects from the market to take initiative regarding energy from sustainable sources, they may influence this by deciding what types of contracts are brought to the market. Assuming a DBFM contract is the ownership situation with the highest potential, they should bring as much projects to the market with this form of contract. RWS could also state certain requirements regarding renewable energy generation during public tenders, in order to oblige the private parties to incorporate solutions to generate renewable energy.
Without subsidies, PV near road infrastructure is currently not possible for the case that is considered in this report. Thus to stimulate PV-panels near road infrastructure the subsidies should remain in place, or RWS should determine a higher kWh-price in case of DBFM contracts.
The electricity law in the Netherlands results in limitations for the deployment of PV panels near road infrastructure, for cases with, and without a DBFM contract. For instance, when someone generates renewable electricity at a remote location and it is transferred via the public grid, he has to pay taxes. This doesn't seems fair compared with someone who generates electricity behind the meter. When these taxes on self produced renewable electricity weren't present, more people would invest in PV panels at remote locations such as near road infrastructure. Clear policies and regulations can help the government to achieve her goals and to set steps forward to preserve our planet.

From the cost benefit analysis conducted for the case elaborated in this report, PV panels in the open field possess currently the most potential, since it is financially feasible. There is enough open space available near the road, e.g. near entrances, exits or intersections, to install PV panels in order to cover the energy demand of the road. Until today, this space remains unused. When investors accept a lower IRR on their equity or extra revenues from subsidies can be obtained, standard PV panels mounted on noise barriers are currently a good second alternative. PV in glass won't be financially feasible in the near future. The investment and maintenance costs are currently too high. The investment has to drop with at least […]% to €[…]/Wp in order to achieve a positive NPV for the project. However, PV in glass in noise barriers is an efficient alternative regarding material usage, since it replaces the regular glass and no mounting material is needed. It is expected this technology will achieve costs reductions in the near future. Despite the orientation of the noise barriers in the case are very suitable and the availability of square meters large, photo voltaic noise barriers cannot cover the energy demand of the road. It is assumed this also applies to most other road sections in the Netherlands.

Working together for a better living environment, today and tomorrow is the vision that guides Ballast Nedam's work. PV-panels near road infrastructure would fit perfectly in that vision. The case study that is performed in this report shows it is already financially profitable in case of a DBFM contract. The risks are relatively low since the risk of price(per kWh) are covered by RWS, thus the revenues are assured and do not depend on uncertainties such as the fluctuating energy price. There is a risk regarding not obtaining subsidies and there might be some uncertainties regarding the attitude of RWS in the future towards energy generation within a DBFM contract, but the risks for commercial parties are limited.

Conclusively it can be stated PV panels can bring added value to the main road infrastructure in the Netherlands. This is demonstrated with the case study for one specific situation, a DBFM project. The most important issue, which is financial feasibility, is complied. Variant 1 of the case study, which are PV panels in an open field configuration, is definitely interesting to investors since the NPV of the project and equity are positive. Furthermore, in this ownership situation regulation does not cause constraints. Due to developments regarding price and technique, the potential will grown since the profit of variant 1 will raise and also variant 2b becomes financial feasible with only a slight decrease in costs.

7.2. Recommendations

During this research, additional issues and questions came to the surface. But due to the scope of this research and limitations regarding time, it wasn't possible to cover these in this research. Some recommendations that would complement this research are described below.

In this research, one case and thus one situation is considered. Thus only a small section of the broad infrastructural network in the Netherlands is considered. Parts of the conclusions are based on this case and the associated design, characteristics and specifications. For further research, it is recommended to consider several road sections at multiple locations in the Netherlands. When more cases are considered, stronger conclusions can be drawn about the technical and financial feasibility of PV panels near road infrastructure for the Netherlands as a whole. A comparison among different cases could result in useful insights. The financial model that is developed during this research could be used as the basis for further research.

Besides studying multiple locations in the Netherlands, a second recommendation is advised. In this research, one case is considered and thus one ownership situation. As elaborated in section 5.1, several ownership situations are possible. For further research, it would be interesting to study the difference among these situations in order to draw conclusions which one would be the most profitable.

As already discussed in section 5.2, a Cost Benefit Analysis is a suitable tool to evaluate sustainable energy projects. However, only monetary costs and benefits are included since it is extremely difficult and arbitrary to express intangible effects in monetary terms. So the financial model which lays on the basis of the CBA, can be perceived as solely an economic analysis. The decisions made by the decision maker(s) are only based on whether an investment is profitable, which is obviously important but other factors could be relevant too. Since the projects are sustainable energy projects, it would bring added value when in addition to the economic analysis, which is the cost benefit analysis as described in this report, an environmental analysis is performed. Although the need for an environmental analysis would be higher when the initiator and owner is a public or governmental body, nowadays it could be even beneficial to private parties. Examples of benefits that may arise from an environmental analysis could be:

- extra goodwill from environmental or pressure groups towards the private party;
- in case of a contractor extra bonus points in tenders;
- improvement of environment-friendly image of the private party;
- fewer emissions of CO_2 into the environment.

8. References

- APX-ENDEX, 2012. Annual report 2011 APX-ENDEX.
- AgentschapNL, 2010. Leidraad zonnestroomprojecten. Utrecht: Agentschap NL/NL Energie en Klimaat.
- Agentschap NL, Ministerie van Economische zaken. Available at: <www.agentschapnl.nl> [Accessed 26 February 2013].
- Betcke, J.W.H., Dijk van, V.A.P., Alsema, E.A., 2002. Opbrengstgegevens van het PV-geluidsscherm langs de A27 na twee jaar systeembedrijf.
- Blom, M.J., Schroten, A., Geurts, F., 2011. Belastingen op energieproducten, elektriciteit en CO2: Gevolgen van herziening van de Energiebelastingrichtlijn voor Nederland. Ecofys.
- Boardman, N. E., 2006. Cost-benefit analysis, concepts and practice. 3rd ed. Upper Saddle River, NJ: Prentice Hall.
- Borg van der, N.J.C.M., Jansen, M.J., 2001. Photovoltaic noise barrier at the A9-highway in The Netherlands: Results of the monitoring program.
- Bolloju, N., Sun, S.X.Y., 2012. Benefits of supplementing use case narratives with activity diagrams—An exploratory study. The Journal of Systems and Software, 85(9) pp. 2182-2191.
- CE Delft, Ecofys, 2011. Overheidsingrepen in de energiemarkt: Onderzoek naar het Nederlandse speelveld voor fossiele brandstoffen, hernieuwbare bronnen, kernenergie en energiebesparing.
- Centraal Bureau voor de statistiek, 2013. CBS Statline. [online] Available at: <http://statline.cbs.nl/statweb/> [Accessed 7 January 2013].
- Clavadetscher, L., Nordmann, T., 2000. 100kWp gridconnected PV plant A13 in Switzerland– 10 years and 1 000 000kWh later. *Proceedings of the 16th European Photovoltaic Energy Conference*, Glasgow, May 2000.
- De Windvogel. Zelflevering. [online] Available at: <http://www.windvogel.nl/> [Accessed 15 December 2012].
- D'haeseleer, W. ,2005. Energie vandaag en morgen, beschouwingen over energievoorziening en –gebruik.
- Dijkstra, J., Jessurun, J., 2012. Course material from 'Fundamentals of Building Information Modeling (7M900) 2012-2013', TU/e.
- Dincer, F., 2010. The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy. *Renewable and Sustainable Energy Reviews 15* (2011) pp. 713–720.
- Ecofys, German Solar Energy Society (DGS LV Berlin BRB), 2005. Planning and installing photovoltaic systems, a guide for installers, architects and engineers. London: James & James / Earthscan
- European Photovoltaic Industry Association, 2011. Solar Photovoltaics Competing in the Energy Sector: On the road to competitiveness.
- FAR Systems, 2011. Photovoltaic noise barriers. [online] Available at: <http://www.barrierafotovoltaica.it> [Accessed 18 January 2013].
- Goetzberger, A., Kleiss, G., et al., 1999. Thermie B Project: EU PVNB POT, "Evaluation of the potential of PV noise barrier technology for electricity production and market share".
- Grottke, M., Suker, T., Eyras., R., Goberna, J., Perpinan, O., Voigt, A., Thiel, A., Spendel, M., Gehrlicher, K., Frisen, G., Gambi. R., Kellner, K., n.d. PV Soundless – World Record "Along The Highway"- a PV Sound Barrier With 500 kWp and Ceramic Bades PV Modules.
- ISPRE, 2009. Research and Development on Renewable Energies. A global report on photovoltaic and wind energy. ISBN 978-0-930357-72-6. Paris: International Science Panel on Renewable Energies.
- Kamel, F., 2010. Life-time Cost-Benefit Analysis of Solar Energy Systems in Queensland. Solar2010, the 48th AuSES Annual Conference 1-3 December 2010, Canberra, ACT, Australia.

- Kennisinstituut voor mobiliteitsbeleid, 2010. Verkenning mobiliteit en bereikbaarheid 2011-2015.
- Kennisinstituut voor mobiliteitsbeleid, 2010. Krimp en mobiliteit, gevolgen van demografische veranderingen voor mobiliteit.
- Laleman, R., Albrecht, J., 2012. Comparing push and pull measures for PV and wind in Europe. Renewable Energy xxx 1-5.
- Lorenz, P., Pinner, D., Seitz, T., 2008. The economics of solar power. The McKinsey Quaterly, june 2008.
- Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013. Elektriciteitswet 1998. [online] Available at: <http://wetten.overheid.nl/BWBR0009755/geldigheidsdatum_04-02-2013> [Accessed 24 January 2013].
- Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013. Wet belastingen op milieugrondslag. [online] Available at: <http://wetten.overheid.nl/BWBR0007168/geldigheidsdatum_05-02-2013#> [Accessed 28 January 2013].
- Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013. Wet beheer rijkswaterstaatswerken. [online] Available at: <http://wetten.overheid.nl/BWBR0008331/geldigheidsdatum_06-02-2013> [Accessed 26 January 2013].
- Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013. Wet geluidhinder. [online] Available at: <http://wetten.overheid.nl/BWBR0003227/geldigheidsdatum_25-02-2013#> [Accessed 27 January 2013].
- Ministerie van Economische Zaken, Landbouw & Innovatie, 2011. Energierapport 2011.
- Nordmann, T., Clavadetscher, L., 2004. PV on noise barriers. *Progress in Photovoltaics: research and applications*, Volume 12, issue 6, p.485-495.
- Nordmann, T., Froelich A., et al., 2000. The potential of PV Noise Barrier Technology in Europe. *16th European Photovoltaic Solar Energy Conference and Exhibition*. Glasgow, United Kingdom 1 – 5 May 2000.
- Palma, A. d., Leruth, L., & Prunier, G., 2009. Toward a Principal-Agent based Typology of Risks in Public-Pravate Partnerships. International Monetary Fund.
- Photovoltaic Geographical Information System (PVGIS), 2013. [online] Available at: <http://re.jrc.ec.europa.eu/pvgis/> [Accessed 7 March 2013].
- Poullikkas, A., 2009. Parametric cost-benefit analysis for the installation of photovoltaic parks in the island of Cyprus. Energy policy 37, pp. 3673-3680.
- PV resources, 2013. [online] Available at: <http://www.pvresources.com> [Accessed 16 December 2013].
- Remmer, D., Rocha, J., 2005. Photovoltaic noise barrier – Canada. In: *SESCI 2005 Conference*. Burnaby, Britisch Columbia, Canada 20-24 August 2005.
- REN21, 2012. Renewables 2012 Global Status Report. Paris: REN21 Secretariat.
- Rijkswaterstaat, 2012. Rijksbrede Modelovereenkomst DBFM Infrastructuur [2012] RIJKSWATERSTAAT, standaard 3.0, 28 maart 2012.
- Rijkswaterstaat Ministerie van Infrastructuur en Milieu, 2012. Rijkswaterstaat Jaarbericht 2011.
- Rijkswaterstaat, 2007. Nieuwe ontwerprichtlijn autosnelwegen. Rotterdam: Rijkswaterstaat Adviesdienst Verkeer en Vervoer.
- Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, 2006. Toepassingsadvies: Modulaire geluidsschermen.
- Suna, D., Polo, A.L., Haas, R., Schiener, C., Resch, G. Report on 'Global context, environmental costs and energy portfolio analysis for urban PV'. Energy Economics Group, Vienna University of Technology. pp. 1–39.

- Schultz van Haegen, M.H., Mansvel, W.J., 2013. Betreft invulling bezuinigingen Infrastructuurfonds, kenmerk: IENM/BSK-2013/23008, Ministerie van Infrastructuur en Milieu.
- Shiao, M.J., 2012. Thin Film 2012–2016: Technologies, Markets and Strategies for Survival, [online] Available at:<https://www.greentechmedia.com/research/report/thin-film-2012-2016/> [Accessed 23 February 2013].
- Simpson, D., Walker, J, 1987. Extending cost-benefit analysis for energy investment choices. Butterworth & Co (Publishers) Ltd.
- The Encyclopedia of Earth, 2012. Albedo. [online] Available at: <http://www.eoearth.org/article/Albedo?topic=54300> [Accessed 13 January 2013].
- The world bank, 2013. [online] Available at: <http://data.worldbank.org/indicator/IS.ROD.DNST.K2?order=wbapi_data_value_2008+wbapi_data_value+wbapi_data_value-last&sort=desc> [Accessed 14 January 2013].
- The Netherlands Competition Authority, 2012. 2011 NMa Annual Report. The Hague, the Netherlands: The Netherlands Competition Authority.
- Wybo, J., 2013. Large-scale photovoltaic systems in airports areas: safety concerns. Renewable and sustainable energy reviews 21, pp. 402-410.
- Yan, H., Zhou, Z., Lu, H., 2009. Photovoltaic industry and market investigation. *IEEE Sustainable Power Generation and Supply*. Nanjing, China April: 1–4.

9. Appendices

Appendix 1

Liander
onderdeel van alliander

aansluit- en transporttarieven elektriciteit

Voor grootverbruikers per 1 januari 2012

Dit is het overzicht van de tarieven voor de aansluitdienst en de transportdienst van elektriciteit voor onze klanten in Flevoland, Friesland, Gelderland en Noord- en Zuid-Holland met een elektriciteitsaansluiting groter dan 3 x 80 Ampère (zakelijke grootverbruikers). Deze tarieven zijn:

1.1 Periodieke aansluitvergoeding

Capaciteit per aansluiting	€ p/mnd excl. BTW
> 3 x 80A af LS-net	3,00
> 3 x 80A en t/m 100kVA af alg. voedingspunt	10,80
> 100kVA t/m 160kVA af alg. voedingspunt	12,10
> 160kVA t/m 630kVA met trafo en LS-meting[1]	49,56
> 630kVA t/m 1MVA met vermogensschakelaar, trafo en LS-meting[1]	91,70
> 1MVA t/m 2MVA	145,60
> 2MVA t/m 5MVA	645,00
> 5MVA t/m 10MVA	939,00
> 10MVA	maatwerk

Toelichting tabel 1.1

- A = Ampère (stroomsterkte)
- af = aangesloten op
- LS-meting = meting aan de laagspanningszijde van de MS/LS-transformator
- kVA = kilovoltampère (elektrisch vermogen)
- MVA = megavoltampère (elektrisch vermogen)
- Met trafo = met een eigen of gehuurde transformator

1.2 Periodieke vergoeding voor de meerlengte[2] van de aansluitkabel

Capaciteit per aansluiting	€ p/maand per meter meerlengte[2] van de aansluiting (per kabel)
≥ 3 MVA t/m 10 MVA	0,150
> 10 MVA	maatwerk

2.1 Tarieven transportdiensten

Deelmarkt	Gecontracteerd transport-vermogen	Transportdiensten (excl. BTW)						Systeem-diensten (excl. BTW)
		Vastrecht transport	Variabele tarieven				Blind-energie	
			kWh hoog	kWh laag	kW contract	kW max. mnd		
		per maand in €	per kWh in €	per kWh in €	per kW per maand in €	per kW per maand in €	per KVArh in €	per kWh in €
LS	t/m 50 kW	1,50	0,0369	0,0136	0,39	-	-	0,00111
MS/LS	> 50 t/m 136 kW	36,75	0,0089	0,0089	1,96	1,45	0,00	0,00111
MS	> 136 t/m 2.000 kW	36,75	0,0089	0,0089	1,31	1,45	0,00	0,00111
TS/MS of HS/MS	> 2.000 kW	230,00	-	-	2,02	2,01	0,00	0,00111
TS	> 2.000 kW	230,00	-	-	1,67	1,94	0,00	0,00111
HS[3]	> 2.000 kW	230,00	-	-	0,73	0,81	0,00	0,00111

Toelichting tabel 2.1

- LS = laagspanning, tot en met 1 kV. In de deelmarkt LS geldt het kWh hoog tarief van 7:00 uur tot 23:00 uur van maandag t/m vrijdag.
- MS = middenspanning, van 1 kV tot en met 20 kV.
- TS = tussenspanning, 50 kV.
- HS = hoogspanning, hoger dan 50 kV.
- kWh = kilowattuur (hoeveelheid energie).
- kW = kilowatt (elektrisch vermogen).
- kWh hoog/laag = hoog of laagtarief, zie elders in deze tekstbox.
- kW contract = gecontracteerd vermogen.
- kW max. mnd = het hoogste - op enig moment - afgenomen vermogen in een maand.
- Systeemdiensten = de systeemdiensten worden door de landelijke netbeheerder TenneT verzorgd en overeenkomstig de TarievenCode Elektriciteit door Liander aan u doorberekend. De systeemdiensten worden berekend over uw totale verbruik (zowel afkomstig van het net als van uw eigen opwek).

Technische Universiteit Eindhoven University of Technology

liander onderdeel van alliander

aansluit- en transporttarieven elektriciteit

Voor huishoudelijke en zakelijke kleinverbruikers per 1 oktober 2012

Dit is het overzicht van de tarieven[1] voor de aansluitdienst en transportdienst voor onze klanten in Flevoland, Friesland, Gelderland en Noord- en Zuid-Holland met een elektriciteitsaansluiting tot en met 3 x 80 Ampère (huishoudens en kleinzakelijk). Deze tarieven zijn:

1.1 Vastrecht aansluiting

Aansluiting	€ p/mnd incl. BTW	€ p/mnd excl. BTW
1 x 6A geschakeld net	0,93	0,77
t/m 3 x 25A	1,94	1,60
> 3 x 25A t/m 3 x 35A	2,99	2,47
> 3 x 35A t/m 3 x 50A	2,99	2,47
> 3 x 50A t/m 3 x 63A	3,63	3,00
> 3 x 63A t/m 3 x 80A	3,63	3,00

Toelichting tabel 1.1

- A = Ampère (stroomsterkte).
- Geschakeld net = Een net dat door de netbeheerder aan of uit kan worden geschakeld, bijvoorbeeld voor openbare verlichting.

2.1 Vastrecht transport

Aansluiting	€ p/mnd incl. BTW	€ p/mnd excl. BTW
1 x 6A geschakeld net	0,054	0,045
t/m 3 x 25A	1,815	1,500
> 3 x 25A t/m 3 x 35A	1,815	1,500
> 3 x 35A t/m 3 x 50A	1,815	1,500
> 3 x 50A t/m 3 x 63A	1,815	1,500
> 3 x 63A t/m 3 x 80A	1,815	1,500

2.2 Capaciteitsvergoeding transport

Aansluiting	€ p/mnd incl. BTW	€ p/mnd excl. BTW
1 x 6A geschakeld net	0,1963	0,1622
t/m 3 x 25A	13,9716	11,5468
> 3 x 25A t/m 3 x 35A	69,7747	57,6650
> 3 x 35A t/m 3 x 50A	105,3335	87,0525
> 3 x 50A t/m 3 x 63A	139,5493	115,3300
> 3 x 63A t/m 3 x 80A	175,5559	145,0875

3 Meetdienst

In het tarief voor meetdiensten uitgevoerd door Liander zitten de kosten voor de meetinrichting, de opname van de meterstanden en de controle op de juistheid en volledigheid van de meterstanden (datacollectie). Bij enkele afnemers worden maandelijks de meterstanden opgenomen.

	€ p/mnd incl. BTW	€ p/mnd excl. BTW
Jaaropname enkeltarief	2,6600	2,1983
Jaaropname dubbeltarief	2,6600	2,1983
Jaaropname productie eigen opwek	2,6600	2,1983
Maandopname enkeltarief	26,8600	22,1983
Maandopname dubbeltarief	26,8600	22,1983
Maandopname productie eigen opwek	26,8600	22,1983

4.2 Voorrijkosten bij storing in binneninstallatie

	incl. BTW	excl. BTW
Werkdagen 08.00-20.00 uur	75,33	62,26
Werkdagen 20.00-22.00 uur, zaterdagen 08.00-20.00 uur	125,38	103,62
Werkdagen 22.00-08.00 uur, zaterdagen 20.00-08.00 uur, zon- en feestdagen	177,14	146,40

Appendix 2

Agentschap NL
Ministerie van Economische Zaken

Zon

	Fase 1 Vanaf 4 april 09:00	Fase 2 Vanaf 13 mei 17:00	Fase 3 Vanaf 17 juni 17:00	Fase 4 Vanaf 2 september 17:00	Fase 5 Vanaf 30 september 17:00	Fase 6 Vanaf 4 november 17:00	Basisenergieprijs	Voorlopig Correctiebedrag 2013	Max. vollasturen per jaar	Max. looptijd Subsidie (jaren)	Uiterlijke termijn ingebruikname
Zon	Basisbedrag per fase (€ / kWh)						(€ / kWh)				
Zon-PV ≥ 15 kWp	0,070	0,080	0,090	0,110	0,130	0,148	0,055	0,055	1000	15	3
	Basisbedrag per fase (€ / GJ)						(€ / GJ)				
Zonthermie apertuuroppervlakte ≥ 100 m^2	19,444	22,222	25,000	30,556	33,3	33,3	11,0	14,2	700	15	3

Hoewel deze tabel met de grootst mogelijke zorg is samengesteld kan Agentschap NL geen enkele aansprakelijkheid aanvaarden voor eventuele fouten.

Appendix 3

Station	Location	Station	Location		
210	Valkenburg	**270**	Leeuwarden	**323**	Wilhelminadorp
225	IJmuiden	**273**	Marknesse	**330**	Hoek van Holland
235	De Kooy	**275**	Deelen	**340**	Woensdrecht
240	Schiphol	**277**	Lauwersoog	**344**	Rotterdam
242	Vlieland	**278**	Heino	**348**	Cabauw
249	Berkhout	**279**	Hoogeveen	**350**	Gilze-Rijen
251	Hoorn (Terschelling)	**280**	Eelde	**356**	Herwijnen
257	Wijk aan Zee	**283**	Hupsel	**370**	Eindhoven
260	De Bilt	**286**	Nieuw Beerta	**375**	Volkel
265	Soesterberg	**290**	Twenthe	**377**	Ell
267	Stavoren	**310**	Vlissingen	**380**	Maastricht
269	Lelystad	**319**	Westdorpe	**391**	Arcen

Appendix 4

- Article 18.8 DBFM contract

18.8 [Kosten nutsvoorzieningen]

a) [In de periode beginnend op de Aanvangsdatum en eindigend op de Beschikbaarheidsdatum draagt de Opdrachtgever de kosten van het elektriciteitsverbruik van de tot Infrastructuur RWS behorende installaties.

b) In de periode beginnend op de Beschikbaarheidsdatum en eindigend op de Einddatum draagt de Opdrachtnemer de kosten (voor levering en netwerk inclusief toeslagen, belastingen en overige heffingen) van het elektriciteitsverbruik van alle tot de Infrastructuur RWS behorende installaties, te verrekenen volgens het bepaalde in Bijlage 2 (Betalingsmechanisme), paragraaf 1.5 (Elektriciteitsverbruikverrekening).

c) In de periode beginnend op de Aanvangsdatum en eindigend op de Einddatum draagt de Opdrachtnemer de kosten voor levering en netwerk inclusief toeslagen, belastingen en overige heffingen van de door hem gebruikte bouwstroom.

d) Bij een Wijziging van deze Overeenkomst zullen de Opdrachtgever en de Opdrachtnemer gezamenlijk de invloed van de Wijziging op het elektriciteitsverbruik vaststellen.]

- Appendix 2 DBFM Overeenkomst.

1.5 Elektriciteitsverbruikverrekening

a) De elektriciteitsprijsvergoeding is het bedrag dat verschuldigd is om de energiekosten (de kosten voor levering en netwerk van elektriciteit inclusief toeslag, belastingen en overige heffingen) te verrekenen.

b) De hoogte van de elektriciteitsprijsvergoeding wordt jaarlijks per 1 januari vastgesteld, voor het eerst in het kalenderjaar volgend op het jaar waarin de Beschikbaarheidsdatum valt.

c) De elektriciteitsprijsvergoeding is de uitkomst van de formule die luidt als volgt:

- $\text{Elektriciteitsprijsvergoeding}_t$ = Pbh x Qwh,t-1 + Pbl x Qwl, t-1

waarbij:

(i) $\text{Elektriciteitsprijsvergoeding}_t$ = het bedrag van de elektriciteitsprijsvergoeding in het jaar t;

(ii) P_{bh} = de basis elektriciteitsprijs voor levering en transport van [●] per kWh voor hoogtarief;

(iii) $Q_{wh,t-1}$ = de in het jaar t-1 werkelijk verbruikte hoeveelheid elektriciteit (kWh) gedurende hoogtarief zoals vastgesteld overeenkomstig Eis-[●] van de Managementspecificaties, voor zover dit verbruik valt na de Beschikbaarheidsdatum;

(v) P_{bl} = de basis elektriciteitsprijs voor levering en transport van [●] per kWh voor laagarief;

(vii) $Q_{wl,\ t-1}$ = de in het jaar t-1 werkelijk verbruikte hoeveelheid elektriciteit (kWh) gedurende laagtarief zoals vastgesteld overeenkomstig Eis-[●] van de Managementspecificaties, voor zover dit verbruik valt na de Beschikbaarheidsdatum.

(a) Indien de Elektriciteitsprijsvergoeding positief is, dan is Opdrachtgever dit bedrag verschuldigd aan Opdrachtnemer.

(b) Indien de Elektriciteitsprijsvergoeding negatief is, dan is Opdrachtnemer dit bedrag verschuldigd aan Opdrachtgever.

- Requirements out of the management specification

Figure omitted

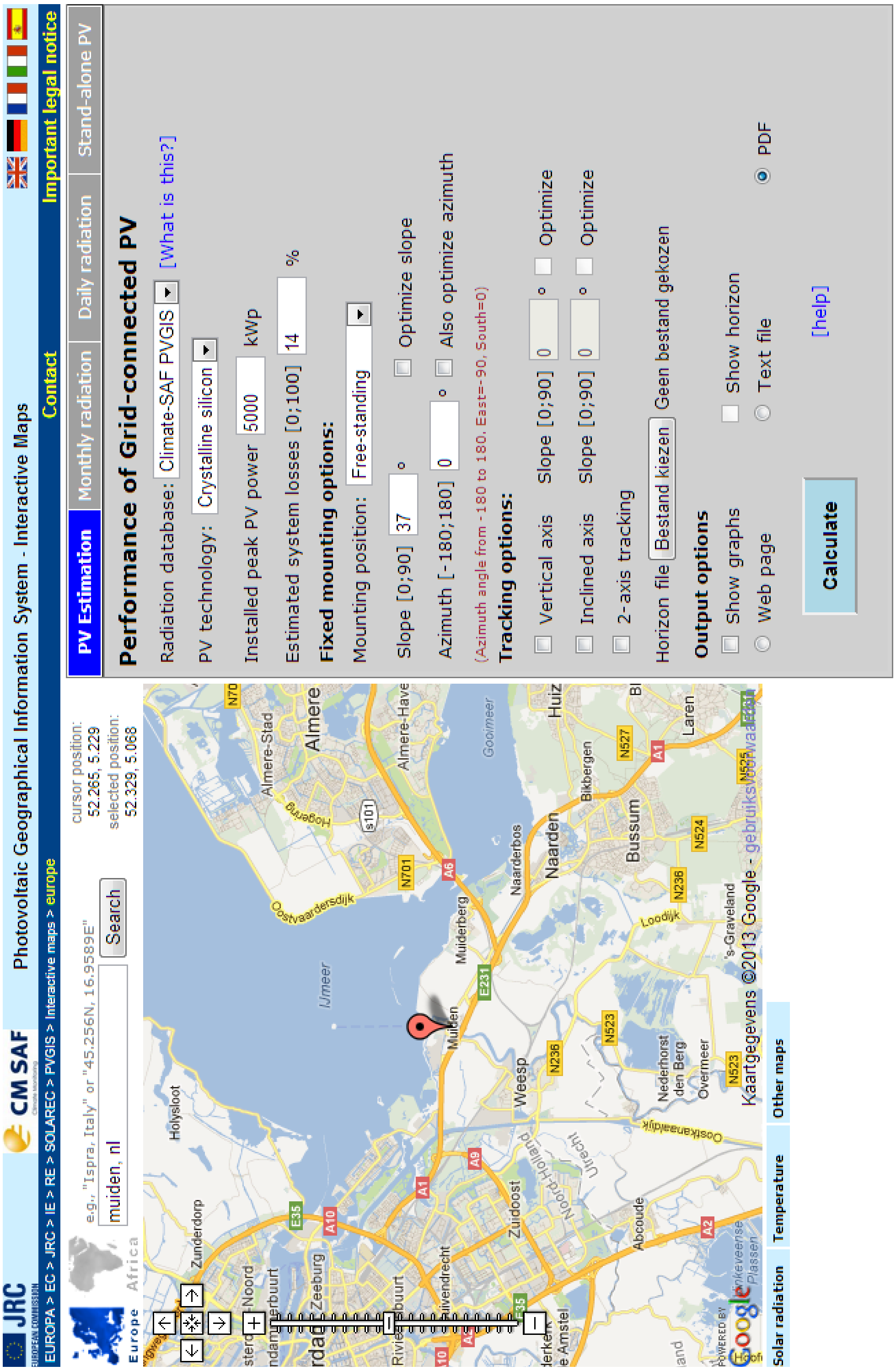
Appendix 5

Activity	Cell inputsheet Financial model
1. Intension to combine road infrastructure with PV	n/a
2. Determine suitable locations for PV	n/a
3a. Determine own demand	Part: 1 C3
3b. Determine demand of the road	Part: 1 C9:E24
4. Determine capacity	Part: 2 C33:C38
5. Calculate / estimate yield	Part: 2 F33:F38
5a. Does yield exceeds demand?	n/a
6a. Find buyers	n/a
6b. Buyers found?	n/a
6c. Negotiate price	n/a
6d. Price satisfactory?	n/a
7. Determine if subsidies are applicable	Part: 3 C78:C84
8. 'Salderen' possible?	Part: 3 C54
9a. Determine direct consumption	Part: 3 C55
9b. Determine 'grey' energy price	Part: 3
10a. Calculate Investment / costs	Part: 2/Part: 4
10b. Calculate / estimate revenues	n/a
11. Perform Cost Benefit Analysis (CBA)	n/a

Appendix 6

Figure omitted

Appendix 7


Photovoltaic Geographical Information System - Interactive Maps
EUROPA > EC > JRC > IE > RE > SOLAREC > PVGIS > Interactive maps > europe
Contact
Important legal notice
muiden, nl
Search
cursor position:
52.265, 5.229
selected position:
52.329, 5.068
PV Estimation
Monthly radiation
Daily radiation
Stand-alone PV
Performance of Grid-connected PV
Radiation database: Climate-SAF PVGIS
[What is this?]
PV technology: Crystalline silicon
Installed peak PV power 5000 kWp
Estimated system losses [0;100] 14 %
Fixed mounting options:
Mounting position: Free-standing
Slope [0;90] 37 °
Optimize slope
Azimuth [-180;180] 0 °
Also optimize azimuth
(Azimuth angle from -180 to 180. East=-90, South=0)
Tracking options:
Vertical axis
Slope [0;90] 0 °
Optimize
Inclined axis
Slope [0;90] 0 °
Optimize
2-axis tracking
Horizon file
Bestand kiezen
Geen bestand gekozen
Output options
Show graphs
Show horizon
Web page
Text file
PDF
[help]
Calculate
Solar radiation
Temperature
Other maps

Appendix 8

JRC EUROPEAN COMMISSION

Photovoltaic Geographical Information System

European Commission
Joint Research Centre
Ispra, Italy

Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Location: 52°19'43" North, 5°4'6" East, Elevation: 3 m a.s.l.,
Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 5000.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 7.9% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 3.0%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 23.2%

	Fixed system: inclination=37 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	5440.00	169000	1.30	40.4
Feb	7980.00	223000	1.96	54.8
Mar	13500.00	417000	3.37	104
Apr	20000.00	601000	5.21	156
May	19900.00	618000	5.32	165
Jun	20100.00	603000	5.41	162
Jul	18800.00	582000	5.10	158
Aug	17500.00	541000	4.70	146
Sep	14700.00	440000	3.87	116
Oct	9930.00	308000	2.52	78.2
Nov	5790.00	174000	1.43	42.8
Dec	4230.00	131000	1.01	31.3
Year	13200.00	401000	3.44	105
Total for year		4810000		1260

Ed: Average daily electricity production from the given system (kWh)
Em: Average monthly electricity production from the given system (kWh)
Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)
Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

Page 1/1

Appendix 9

Investment

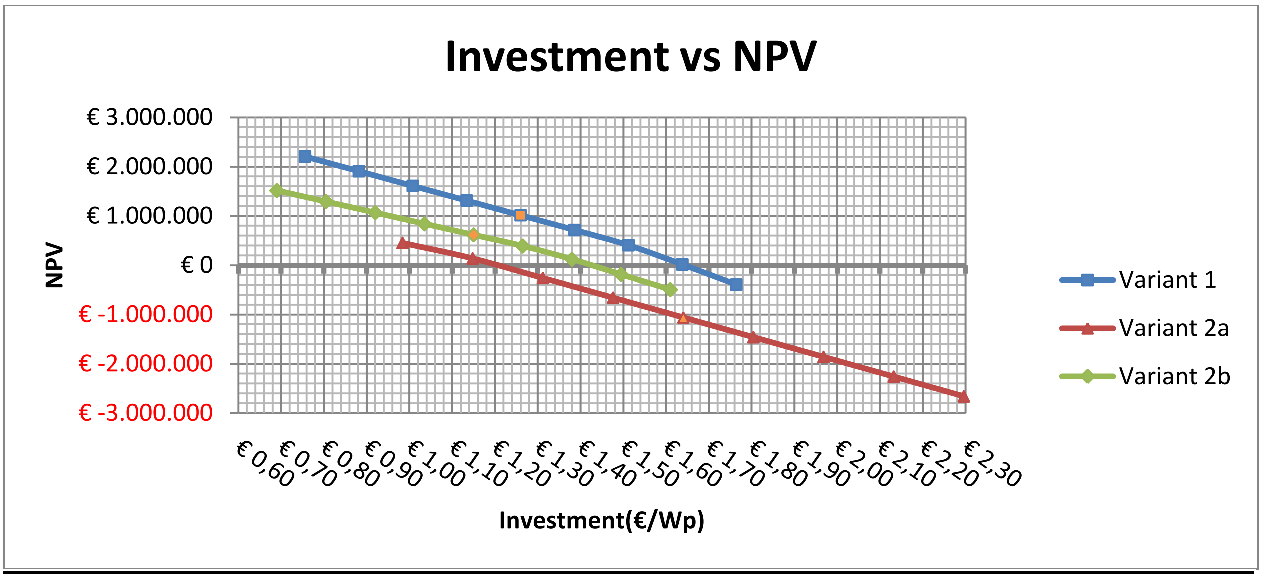
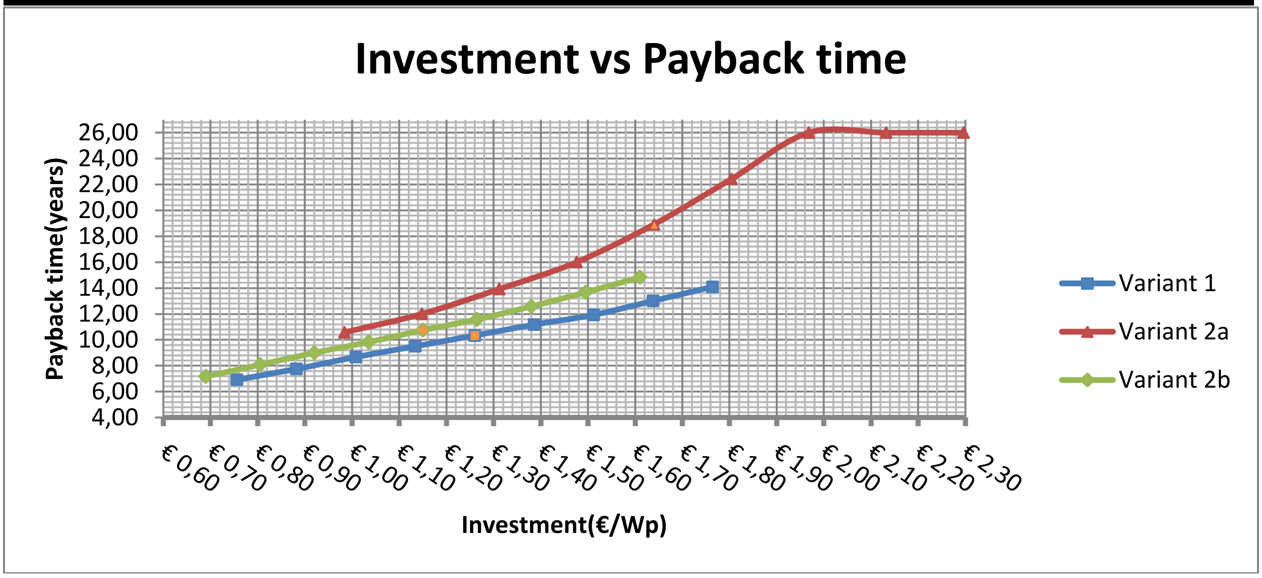


Figure omitted



Maintenance

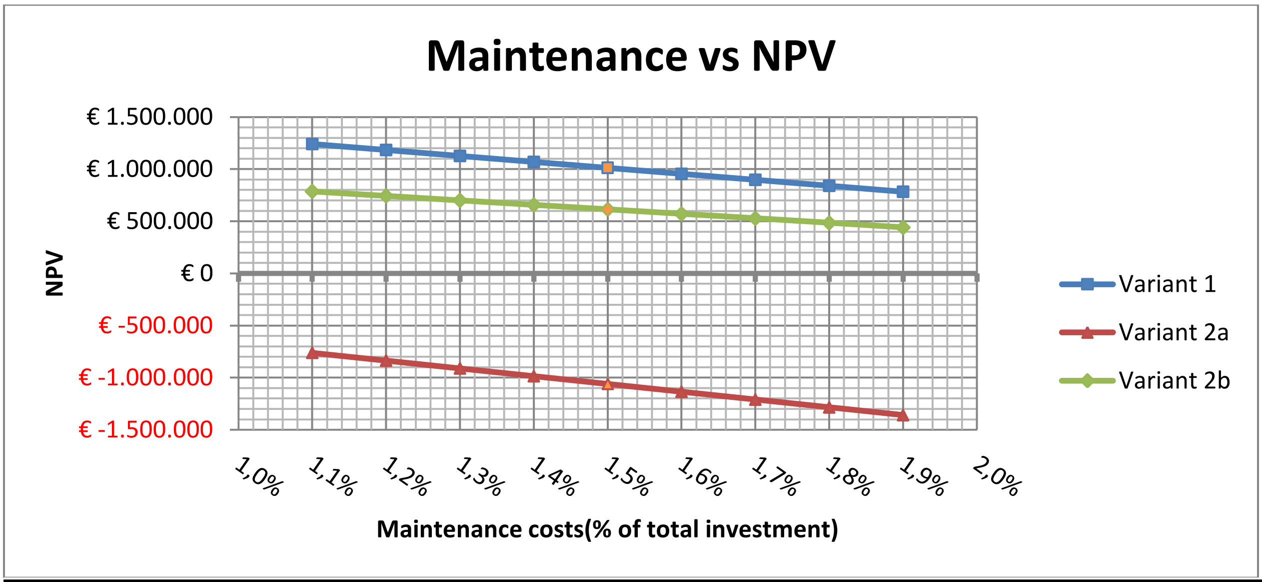
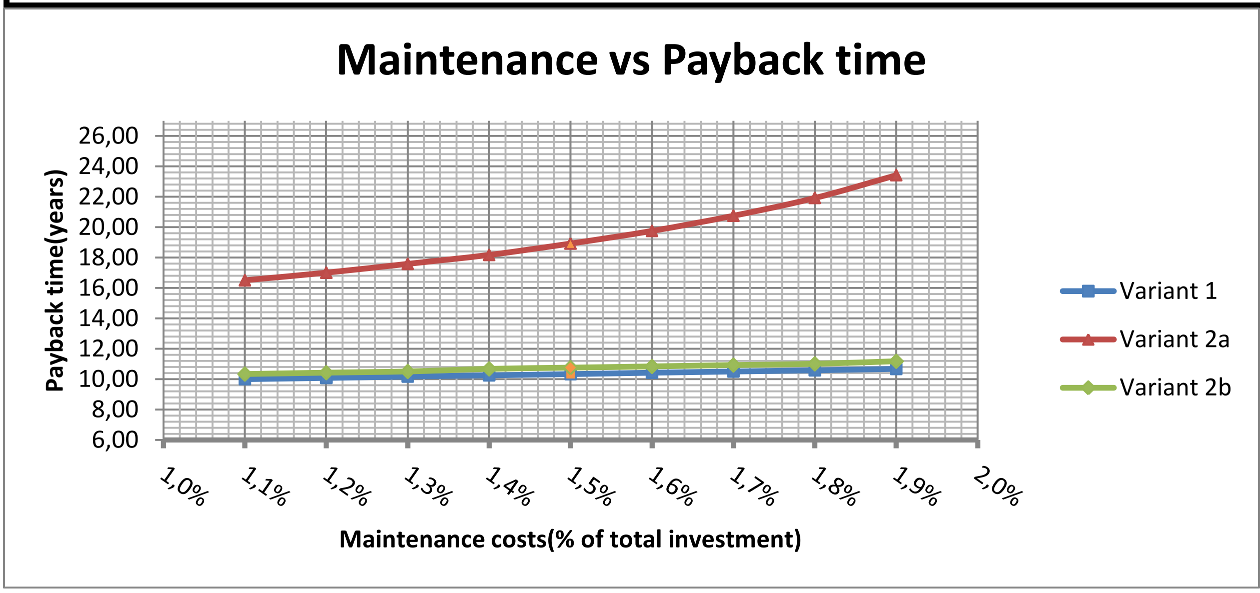


Figure omitted



kWh-price

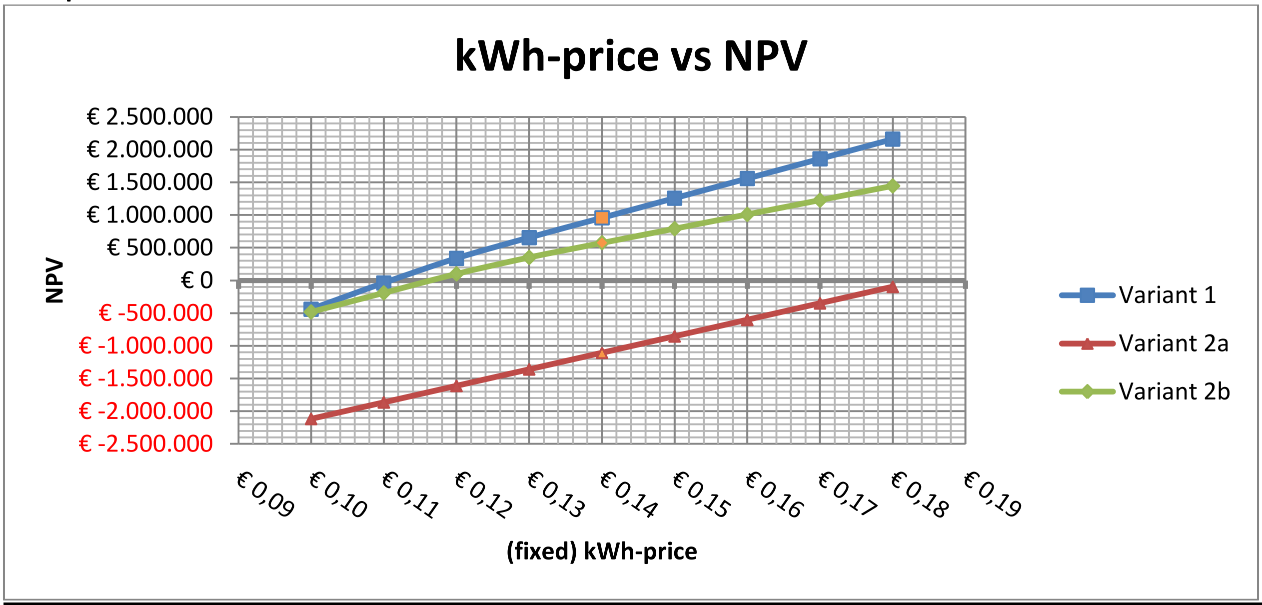
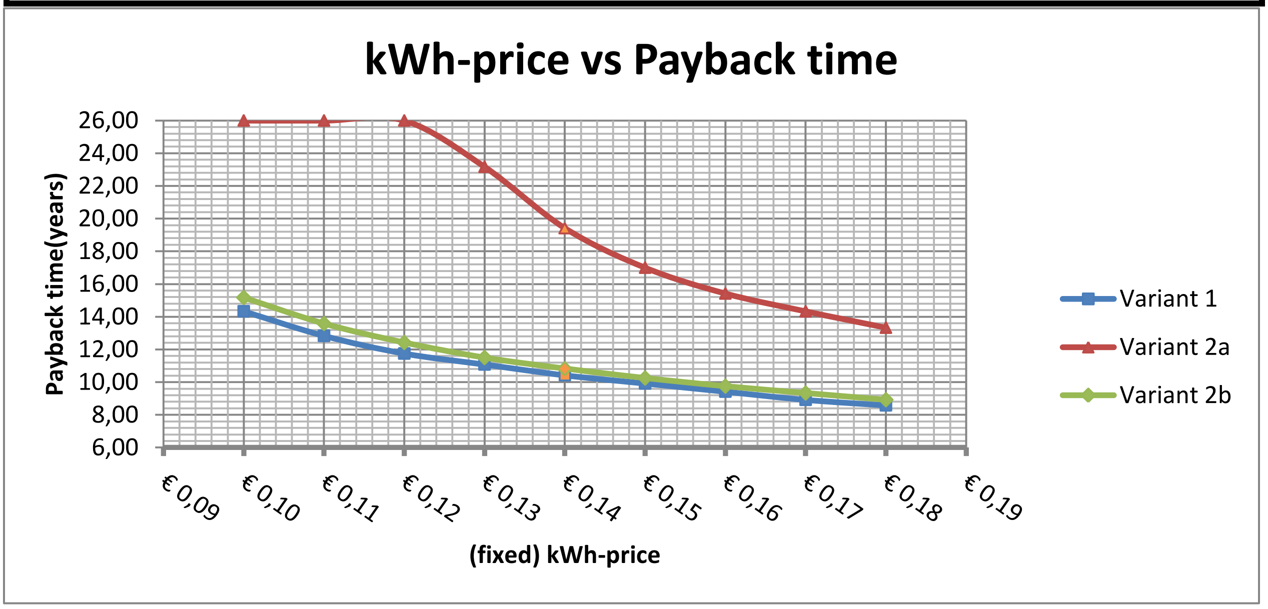
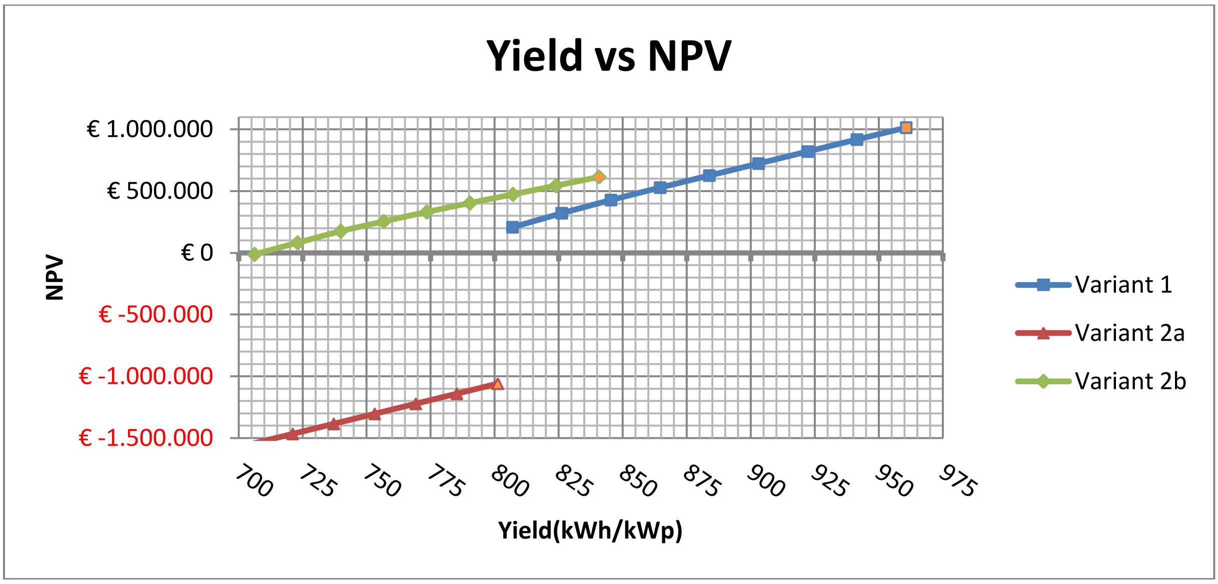


Figure omitted

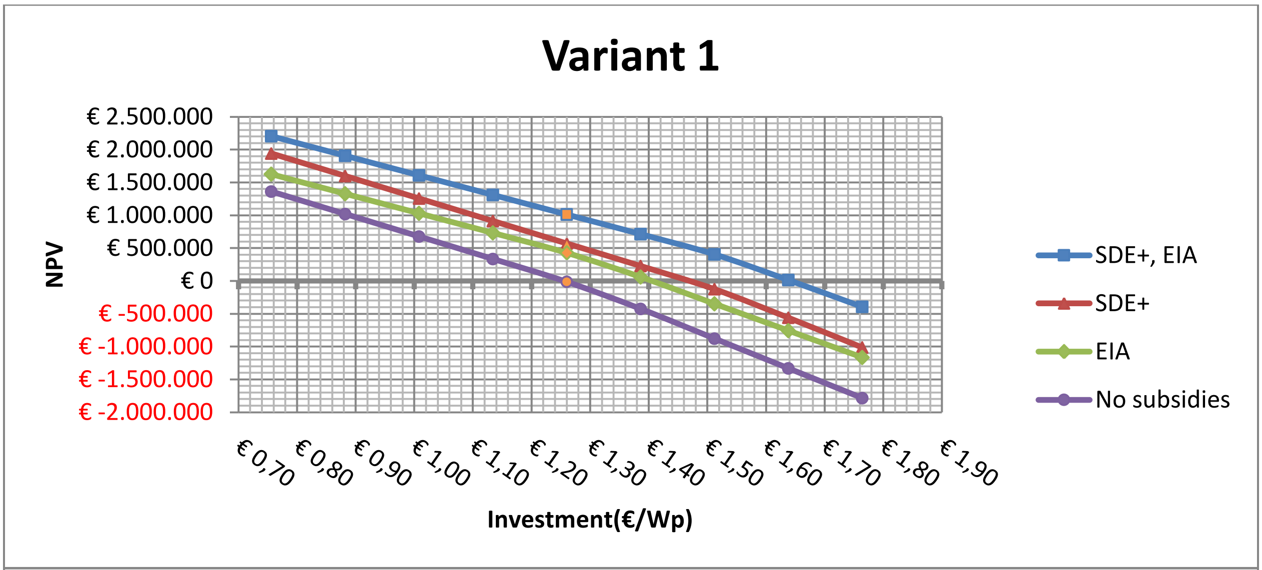


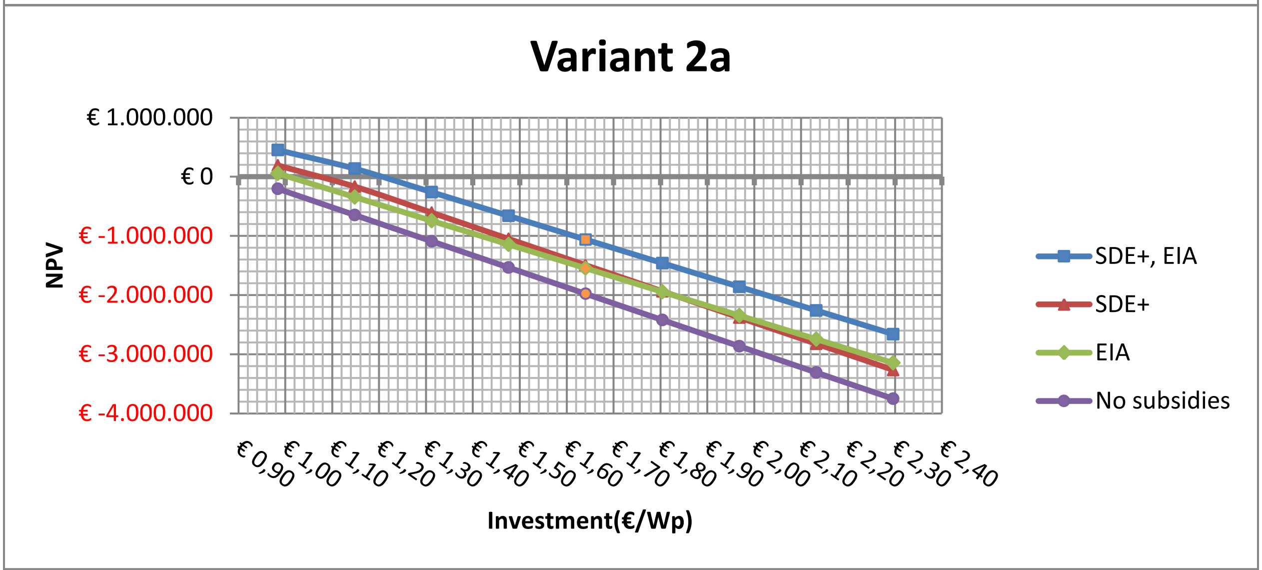
Yield

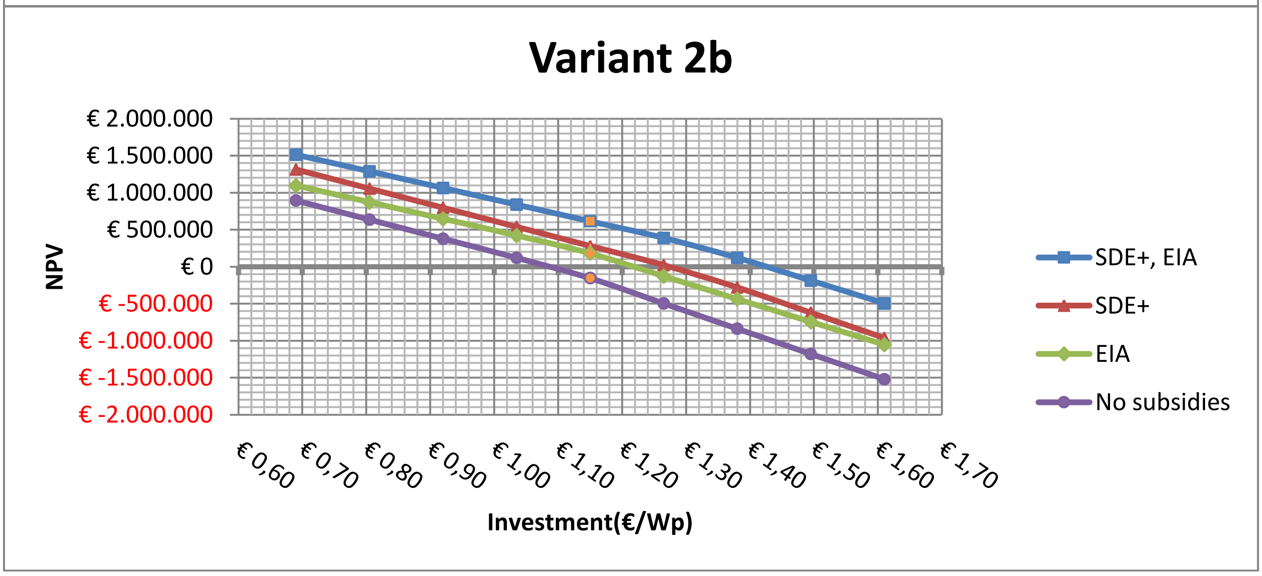


Yield vs NPV
€ 1.000.000
€ 500.000
€ 0
€ -500.000
€ -1.000.000
€ -1.500.000
NPV
700
725
750
775
800
825
850
875
900
925
950
975
Yield(kWh/kWp)
Variant 1
Variant 2a
Variant 2b

Subsidies


Variant 1
€ 2.500.000
€ 2.000.000
€ 1.500.000
€ 1.000.000
€ 500.000
€ 0
€ -500.000
€ -1.000.000
€ -1.500.000
€ -2.000.000
NPV
€ 0,70
€ 0,80
€ 0,90
€ 1,00
€ 1,10
€ 1,20
€ 1,30
€ 1,40
€ 1,50
€ 1,60
€ 1,70
€ 1,80
€ 1,90
Investment(€/Wp)
SDE+, EIA
SDE+
EIA
No subsidies


Variant 2a
€ 1.000.000
€ 0
€ -1.000.000
€ -2.000.000
€ -3.000.000
€ -4.000.000
NPV
€ 0,90
€ 1,00
€ 1,10
€ 1,20
€ 1,30
€ 1,40
€ 1,50
€ 1,60
€ 1,70
€ 1,80
€ 1,90
€ 2,00
€ 2,10
€ 2,20
€ 2,30
€ 2,40
Investment(€/Wp)
SDE+, EIA
SDE+
EIA
No subsidies


Variant 2b
€ 2.000.000
€ 1.500.000
€ 1.000.000
€ 500.000
€ 0
€ -500.000
€ -1.000.000
€ -1.500.000
€ -2.000.000
NPV
€ 0,60
€ 0,70
€ 0,80
€ 0,90
€ 1,00
€ 1,10
€ 1,20
€ 1,30
€ 1,40
€ 1,50
€ 1,60
€ 1,70
Investment(€/Wp)
SDE+, EIA
SDE+
EIA
No subsidies

THE POTENTIAL OF PV PANELS NEAR ROAD INFRASTRUCTURE IN THE NETHERLANDS

Author: P.M. Jochems (Paul)

Graduation program:
Construction Management and Urban Development 2012-2013

Graduation committee:

Prof. dr. ir. B. de Vries (Bauke)	(TU/e)
ing. J. Dijkstra (Jan)	(TU/e)
ir. J. van de Sande (Job)	(Ballast Nedam)

Date of graduation:
25-04-2013

ABSTRACT
Energy from PV panels is considered as very important to decrease the greenhouse gas emissions and leave behind some fossil energy sources for future generations. In the Netherlands space is scarce and not all buildings are suitable for PV. Unused land space or noise barriers near road infrastructure can be used for PV. Ideally, the revenues can contribute to maintain our high quality main road network.
In this paper, the feasibility or potential for a road section in the Netherlands is determined. This is done by using a costs benefit analysis, complemented with a sensitivity analysis. Three technical variants are considered and compared. Besides the economic aspects, also issues as legal, technical, practical, contract and learned lessons are considered to draw conclusions about the potential. It can be concluded that PV panels near road infrastructure can be profitable in combination with a DBFM project and is interesting to investors. PV panels in an open field configuration is currently more profitable than a Photovoltaic Noise Barrier(PVNB).

Keywords: PV panels, Road infrastructure, Photovoltaic noise barrier(PVNB), Cost benefit analysis, Sensitivity analysis

INTRODUCTION

As most people know, energy is a hot topic nowadays. The demand for energy increases every year. In order to comply to this increasing demand in the future, renewable energy is necessary. However, the share of energy from renewable sources is still very low in the Netherlands. In this regard, the Netherlands is one of the worst performing countries in Europe. This is especially the case for energy from solar radiation by using photovoltaic(PV) panels. PV panels are often installed on buildings and rooftops, thus there are often limitations regarding available space, orientation and tilt of existing buildings. Another option is to install PV panels in an open field configuration, called PV parks. But since space is scarce in the Netherlands, PV panels along the roadside could be an interesting option.
In addition to the issue regarding energy generation by using PV panels, there is an issue related to road infrastructure. Not only the demand for energy will increase the coming years, the demand for road infrastructure will increase too. In 2015, the number of kilometers travelled by car is expected to be 14% higher than in 2010 with average economic growth. Economic development and increasing population are factors that are responsible

for the increasing demand. In 2015 there will be 16% more congestion than in 2010 (Kennisinstituut voor Mobiliteitsbeleid, 2010).
The increasing demand for road infrastructure would suggest high priority will be given to investments for construction of new infrastructure and expenses for maintenance in order to keep up with the trends. However, this is not the case. Due to the economic situation, budget cuts seems necessary and are already taken by policy makers in the Netherlands.

When the two issues described above are putting next to each other, opportunities may arise. The opportunity that will be considered in this study is PV panels near road infrastructure. This could be PV panels incorporated in noise barriers or installed at the unused land near road infrastructure. In the best scenario, revenues from the generated electricity are used to finance partly road construction or road maintenance.

Research question
Could PV panels bring added value to the main road infrastructure in the Netherlands, and what will be the potential?

Research objective
Just a few studies are already published regarding PV panels near road infrastructure. Most of them only considers photovoltaic noise barriers(PVNB), none considered the option to install standard PV panels in the road shoulder, near interchanges, exits or entrances. Some studies are about technical insights, one is about the potential of PVNBs in Europe. This study isn't limited to technical insights but aims to cover all issues that are relevant regarding PV panels near road infrastructure. The most important objective is to provide insight in the economic aspect, thus costs and benefits of PV panels near road infrastructure. This is done by using a cost benefit analysis(CBA), included with a sensitivity analysis. For this, a financial model is developed. Besides the economic aspect, this study also covers aspects like technique, legislation and directives, DBFM contract and learned lessons.

In the following section, the necessary background knowledge is discussed. Next, an explanation of the model is given, including the used methodology. Then, a description of the case study is given, and the results of the different variants and the sensitivity analysis are presented. The paper ends with conclusions and recommendations for further research.

BACKGROUND KNOWLEDGE
In order to build a sufficient financial model and be able to answer the research questions, extensive background knowledge is essential. Important parts are briefly discussed in this section. Subjects like the energy market and photovoltaic systems will be discussed. Specific issues when installing PV panels near road infrastructure, are also included in the section.

Energy market
The energy market in the Netherlands consists of multiple components and is influenced by multiple factors such as regulation, taxes, EU-agreements, subsidies etc. The energy branch in the Netherlands has significantly changed as a result of the liberalization which started in 1998 and was completed in 2004. The production, trade and selling of energy have become commercial activities. Since the liberalization of the Dutch energy market the composition of the market has changed, and so are the parties involved. These parties are listed below:

- Producers;
- National grid operator(Tennet);
- Regional grid operator;
- Program-responsible parties;
- Suppliers.

The energy rates in the Netherlands are considered as the lowest in Europe, exclusive of taxes. However, the taxes that are inherent to the energy rates are high. So in the end, the rates that have to be paid are relatively high compared with other countries. The costs of energy for households have risen steadily over the previous 15 years. The energy prices are in January 2012 almost 120% higher than 15 years ago. Thus the average annual increase in the energy price is more than 5%(CBS).
The price of electricity consist of three components, which are electricity production, grid/network costs and taxes. Taxes consist of energy tax and VAT. The share for taxes at the total electricity price is dependable on the type of energy consumer. For an average household, this share varies between 40% and 45%. For companies, this share is much lower. The energy tax is based on a degressive principle. This means the energy tax per kWh decreases when the consumption increases. To keep the electricity grid safe and reliable, maintenance is necessary and thus expenses are made. Eventually, the energy consumers have to pay for this. The price that has to be paid for electricity itself depends among others on the supplier and the contract that is agreed. However, the price for which electricity is sold at the APX-ENDEX is a good indication. The APX-ENDEX is an energy exchange for electricity and natural gas in the Netherlands, the United Kingdom and Belgium.

The Netherlands isn't the best performing country in Europe regarding renewable energy generation. The share of energy from sustainable sources is very low compared with other countries. Only Malta, Luxembourg and the United Kingdom perform even more worse. One explanation for this low position is that in other countries, energy from sustainable sources is more supported by the government than in the Netherlands. For the Netherlands, the share of renewable energy at the total energy consumption was 4,3% in 2011, compared with 3,7% in 2010. The share of renewable energy consumption at the total electricity consumption was 9.8% in 2011. Approximately 58% of the consumed renewable electricity was produced with biomass, about 39% by wind turbines. The share of electricity from solar power compared with the total electricity consumption from sustainable sources is just 0.8%. Regarding PV capacity, 15 countries in Europe perform a lot better than the Netherlands does(CBS).
Every member state of the European Union is obliged to contribute their share in achieving the climate goals of the European Commission(EC). So the EC defined tailor made goals for every member state, including the Netherlands. The Dutch government committed herself to the European goals concerning renewable energy sources. The current government 'Rutte-Asscher' committed themselves to the following goals for 2020: 20% CO_2 reduction compared with 1990 and 16% of the total energy use should come from renewable sources. In 2010 the share of renewable energy in the total national energy consumption was 4,0%.
In order to achieve the climate goals which are set, the government uses subsidies and fiscal measures to stimulate renewable energy generation. Laleman and Albrecht(2012) concluded in their paper they can safely say that European governments should critically evaluate

current renewable subsidy schemes, especially for PV-systems, and raise public RD&D investments. However, the subsidies and measures which are currently in operation are:

- EIA;
- SDE+;
- KIA;
- MIA/VAMIL.

Furthermore, there is another mechanism available in the Netherlands to foster the development of energy from solar radiation. This mechanism is called net metering(Dutch: salderen). Officially it isn't qualified as a subsidy, but it can be considered as one since consumers receive a much higher price for their self produced electricity than the market prices for renewable electricity. It is regulated by law that 'small consumers'(< 3 x 80Ampere) have the right on net metering.

Photovoltaic systems

Energy from solar radiation by using photovoltaic systems is becoming more and more popular. The market share of energy from solar radiation is slowly increasing every year and gains ground against energy from conventional resources such as fossil fuels and nuclear power sources. The potential of this energy source is enormous. World photovoltaic industry has an average growth rate of 49.5% over the past 5 years (Yan, Zhou, Lu, 2009). The total PV installations grew in 2011 to 70 GW, compared with a total installed capacity of 40 GW in 2010(REN21, 2012).

The yield, the amount of produced electricity, of a photovoltaic system depends mainly on the irradiation of the photovoltaic system. The solar irradiation is influenced by the tilt and orientation of the system, but also by the solar radiation and temperature. The yield depends also on the technique and quality of the photovoltaic cell. The photovoltaic cell is able to convert light directly into electrical energy. In this process, semiconductor materials such as silicon, gallium arsenide, cadmium telluride or copper indium diselenide are used(Ecofys, 2005). One cell on itself is very small and produces very little power, therefore a PV module consists of multiple individual solar cells that are connected in series in order to increase the power. A cell consist of two differently doped silicon layers, called a p- and n-layer. An electric field is produced at the boundary of these two layers. When sunlight falls upon the cell, the charges are setting free. Metal contacts that are attached to the front and the back make it possible to generate electricity. This photovoltaic process continues as long as there is sunlight falling on the cells. No materials are being lost during this process, that's why this method is very sustainable.

The costs of PV systems has been going down for decades and is now approaching competitiveness. Over the last 20 years, PV has already shown impressive price reductions, with the price of PV modules decreasing by over 20% every time the cumulative sold volume of PV modules has doubled(learning factor).

PV systems and road infrastructure

The realization of energy generation with photovoltaic along the main road network can be considered as a complex process. Lots of stakeholders will be involved. One of the most important stakeholder is Rijkswaterstaat(RWS). RWS doesn't want to produce renewable electricity because energy production isn't a public task anymore. They say commercial parties have to take the first step. This doesn't mean they sit back and wait until others take

action. RWS will do everything in their power to create a situation in which it's possible for private parties to generate electricity at the land or objects owned by the government.
When planning a PV installation near road infrastructure in the Netherlands, one has to deal with regulation related with either road infrastructure and electricity. Therefore it is important to gain insight in the Dutch, and sometime European legislation when planning such projects. Legislation will set boundaries to develop PV installations near road infrastructure and will definitely have influence on the financial gains. Also regulation regarding noise and the zoning plan is important.
The electricity law sets boundaries regarding the operation of a energy-grid. One cannot just build her own grid and connect electricity consumers on it. Since the liberalization everyone is allowed to sell/supply electricity, except to small consumers. In general, to supply to small consumers, a supply license is required. However, there are a few exemptions when no license is required. Net metering is only allowed in case of a small consumer, a large consumer has to find buyers for the produced electricity and negotiate a price. Taxes have to be paid for all electricity that is consumed, except when net metering is allowed or when the electricity is produced in a sustainable manner behind the connection.
In accordance with the provisions in article 2 section 1(Wet beheer rijkswaterstaatwerken), it is not allowed to make use of a 'waterstaatwerk' for other purposes than it is intended for, without permission from the Minister of Transport. To receive permission, several conditions have to be met. It is very likely ground lease has to be paid to the government. This depends on the expected revenues. In case of a DBFM contract, this won't be the case. Furthermore, there are guidelines compiled in 'Nieuwe Ontwerprichtlijn Autosnelwegen'(RWS, 2007) regarding the design of highways.
If PV panels are installed on noise barriers, regulation and directives should be considered. Issues regarding finance, noise blocking and reflection are very relevant. The efficiency of PV panels near road infrastructure is influenced by contamination, reflection, shadowing and aging. Contamination is the most important one. Pilot projects in the Netherlands proved efficiency will drop with more than 5%. On the other hand, projects in other European countries showed no significant decrease due to contamination.

MODEL DEVELOPMENT

The financial model, which is developed as part of this study, is essential in order to answer the research question. This financial model allows decision makers to assess the financial aspects of a PV project. The importance of the situation regarding ownership of the PV system and the end-users of the generated electricity is explained.

Ownership situations

In general, everyone could install PV panels near road infrastructure if they comply with the required conditions. For the financial model, it is important to know which party who owns the PV system and who the end-user(s) of the generated energy are. It is also very relevant to know how the generated electricity is transported to the end-user(s). Without this information it is impossible to calculate/estimate revenues. The model is developed in such a way it is applicable for many situations, but input for the model requires knowledge about the situation.
Many situations are imaginable, but two examples are briefly mentioned. The first is a situation when PV panels are installed within a DBFM contract. In that case, a private party is responsible for the maintenance of the road section for multiple years, thus pays the costs

for the electricity demand of the road. The private party is obliged to buy this electricity from RWS, for a price which is fixed during the total contract period of for instance 25 years. The private party is allowed to use the road to generate electricity. Net metering would be possible in this situation. In another situation, a group of companies that are located near the road install PV panels at the land of RWS and consume the generated electricity themselves. When no DBFM contract is applicable, the electricity can't be used to cover the electricity demand of the road since RWS will not buy this electricity. Thus the electricity can be fed into the grid or can be transported via a private grid to the companies.

Methodology
In order to model and evaluate the financial aspects of a project, a Cost Benefit Analysis(CBA) is applied. For purpose of comparison, an assessment will be made on the basis of separate elements. These are: the net present value (NPV), the internal rate of return (IRR), the payback period (PBP) and a sensitivity analysis. To be able to perform a cost benefit analysis, the financial model is developed.
In order to understand the working of the financial model easily, a activity diagram is developed. The activity diagram describes the process that is applicable when one has the intention to install PV panels near road infrastructure. The activity diagram is based on the Unified Modeling Language.

It should be noted some assumptions are included in the financial model. Acceptation of the assumptions is extensively contemplated and constantly is kept in mind what the influence of the assumptions are to the output of the model and objectives of this thesis. All made assumptions comply with these conditions.
It is assumed revenues are directly paid, shortages are complemented by the equity supplier and surpluses of money will be paid out directly. Working capital isn't taken into account. When the subsidy EIA is applicable, it is assumed this can be modeled as an addition to the cash flow because the company who invests makes sufficient profit. One tax tariff for the tax on profit is assumed. Furthermore, the model assumes the revenues per kWh that are saved on the electricity bill, equal the price consumers normally have to pay to the utility company.

CASE STUDY
The project that is considered for this case study comprises the design, construction, maintenance and financing(DBFM) of the expansion of existing and new road infrastructure between intersection Diemen(A1) and Almere Havendreef(A6). The length of the road section is approximately 14 kilometers. The road section has in total 5 entrances and exits, and two interchanges are present. The direction of the roads are favorable regarding energy generation. Lots of unused area's are present, a very safe estimate will show this result in a total area of […] acres. Noise barriers are also included in the project, the surface of the noise barriers cover [………] m^2 with an angle of […]°. The energy consumption of this road section is estimated at [……………] kWh per year. The contractor has to bear the costs for energy and the electricity has to be bought from the client whom determined a fixed electricity price of €[……] per kWh.
Three variants are developed to generate electricity with PV panels near infrastructure:

- Variant 1: standard PV panels are installed in (multiple) open field configuration(s) near the road;

- Variant 2a: Powerglaz® BIPV replaces the standard transparent panels of the noise barrier;
- Variant 2b: standard PV panels are fitted on the aluminum panels of the noise barrier.

The numerical values of the parameters and input per variant are summarized in **Table 13**. Some values are the same for all variants, such as WACC([…]%), maintenance costs([…]% of total investment), tax on profit(25%), inflation([…]%) and efficiency degradation([…]% p/y).

	Variant 1	**Variant 2a**	**Variant 2b**
Investment(€/Wp)	€[…]	€[…]	€[…]
Power(kWp)	[……]	[……]	[……]
Annual yield(kWh)	[……]	[……]	[……]
Performance(kWh/kWp)	[……]	[……]	[……]
Subsidy	SDE+, EIA	SDE+, EIA	SDE+, EIA

Table 13: Input values and parameters per variant.

Results

The CBA indicates the PV panels in this case study are only profitable for variant 1, from an economic viewpoint, see **Table 14**. It is profitable since it gives a NPV of €1.013.136 and an IRR of […]% for the project evaluation. According to the payback period it would take 10,33 years to break even from undertaking the initial expenditure. Even the equity evaluation is positive for variant 1. The noise barrier variants(variant 2a and 2b) perform poorer.

Project evaluation		**Variant 1**	**Variant 2a**	**Variant 2b**
	NPV	€1.013.136	€-1.059.865	€614.822
	IRR	[…]%	[…]%	[…]%
	Payback period	10 years and 4 months	18 years and 11 months	10 years and 9 months
	Average kWh price	€0,1351	€0,2696	€0,1409
Equity evaluation				
	NPV	€22.251	€-1.330.334	€-58.776
	IRR	[…]%	[…]%	[…]%

Table 14: Results of the CBA.

Sensitivity analysis

To incorporate the uncertainty regarding the values of the input in the CBA, a sensitivity analysis is conducted. The sensitivity of four parameters is determined, namely investment, maintenance costs, kWh-price and yield(efficiency). The sensitivity of the maintenance costs have proved to be very little to the output. The sensitivity of the other 3 parameters is visualized in the figures below. The NPV in the figures is for the project evaluation.

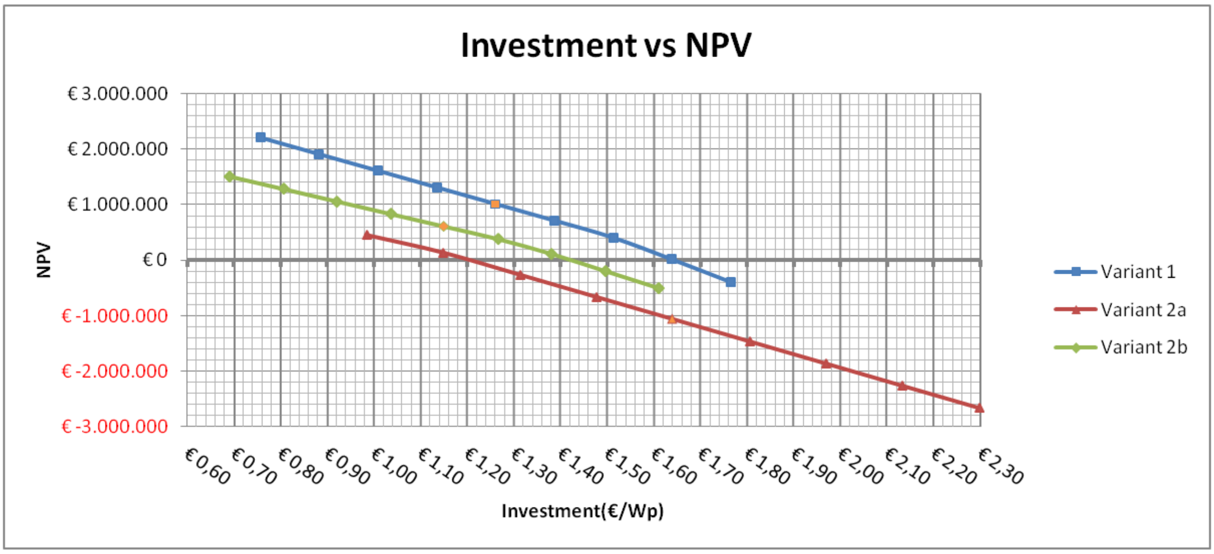


Figure 43: Change in NPV due to investment, for all variants.

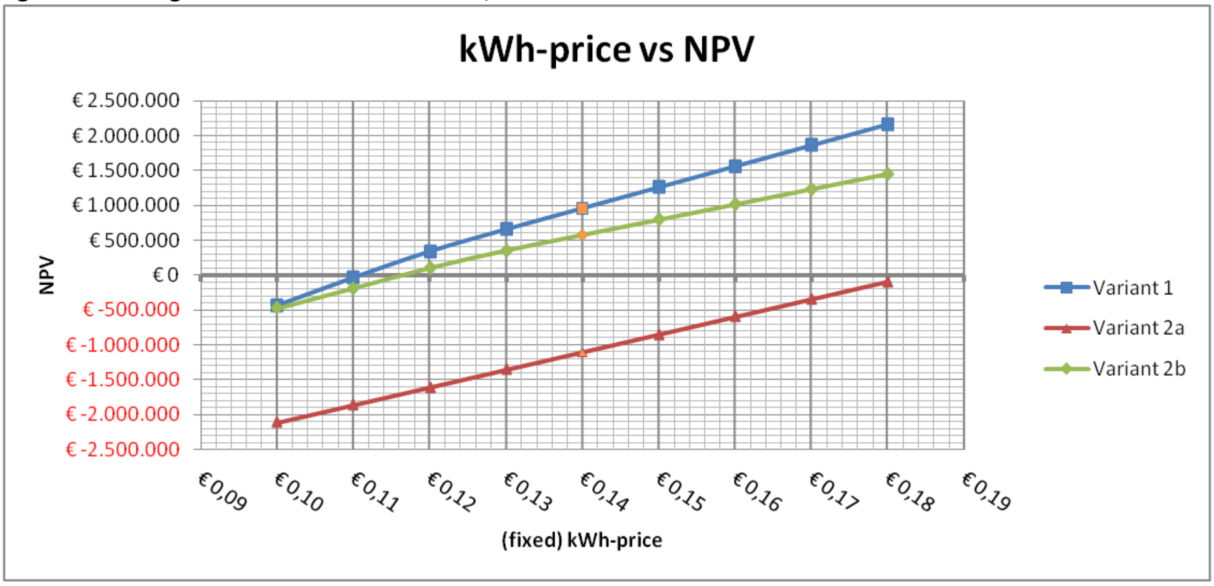


Figure 44: Change in NPV due to kWh-price, for all variants.

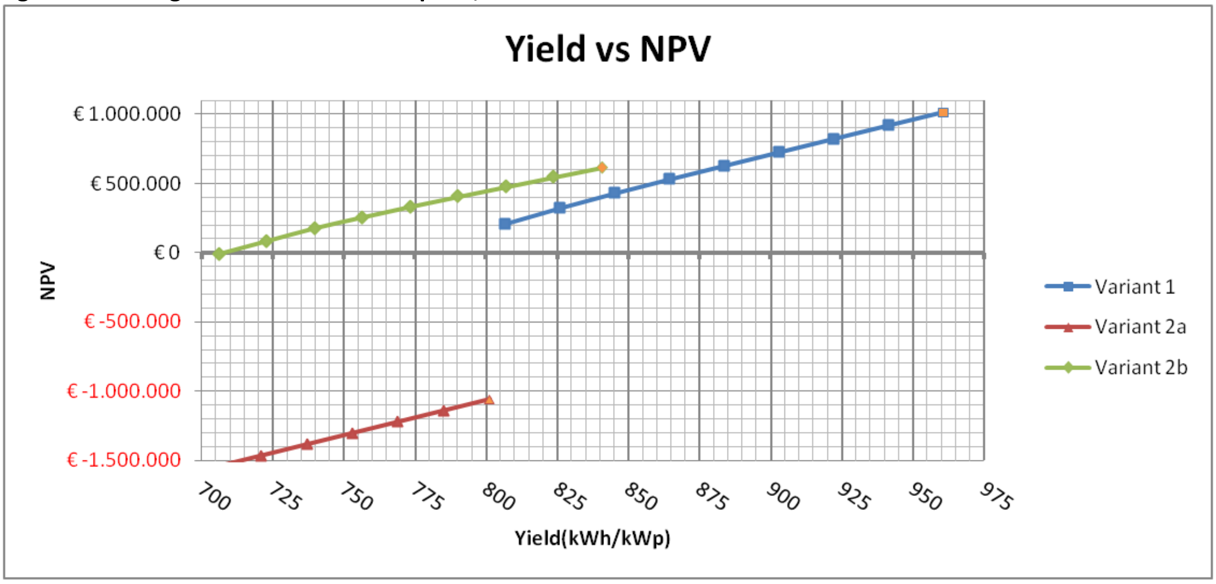


Figure 45: Change in NPV due to yield(efficiency), for all variants.

CONCLUSION

From the sensitivity analysis some interesting conclusions can be drawn. The results of the sensitivity analysis indicate the investment for variant 2a has to drop significantly to become profitable. Thus, this won't happen in the near future and will take some years from now. Also the fixed kWh-price which is determined by Rijkswaterstaat has, as expected, a significant impact on the profitability. However, to make variant 2a profitable, the kWh-price has to become higher than €0,18, which is unlikely. For the other two variants, the kWh-price can drop with €[…] and still remain profitable. Since it is expected to encounter extra contamination since the PV panels are located near road infrastructure, it is useful to know the impact of this at the profitability. This impact is significant, but even with a 14% decrease in yield, variant 1 and 2b stay profitable(project evaluation).

Furthermore, the impact of subsidies per variant is determined. This shows that the SDE+ subsidy is more important than the EIA subsidy. The results also show subsidies are currently essential to make the investments in PV profitable. At most one subsidy application, whether it concerns the SDE+ or EIA, could be rejected in order to keep variant 1 and 2b still profitable.

Conclusively it can be stated PV panels can bring added value to the main road infrastructure in the Netherlands. This is demonstrated with the case study for one specific situation, a DBFM project. With the most important issue, which is financial feasibility, is complied. Variant 1 of the case study, which are PV panels in an open field configuration, is definitely interesting to investors since the NPV of the project and equity evaluation is positive. Furthermore, in this ownership situation regulation does not cause constraints. Due to developments regarding price and technique, the potential will grown since the profit of variant 1 will raise and also variant 2b becomes financial feasible with only a slight decrease in costs. Despite the large amount of square meters of noise barrier, it is not possible to cover the energy demand of the road with just photovoltaic noise barriers.

RECOMMENDATIONS

In this research, one case and thus one situation is studied. Thus only a small section of the broad infrastructural network in the Netherlands is considered. Parts of the conclusions are based on this case and the associated design, characteristics and specifications. For further research, it is recommended to consider several road sections at multiple locations in the Netherlands. When more cases are considered, stronger conclusions can be drawn about the technical and financial feasibility of PV panels near road infrastructure for the Netherlands as a whole. A comparison among different cases could result in useful insights. The financial model that is developed during this research could be used as the basis for further research.
Besides studying multiple locations in the Netherlands, a second recommendation is advised. In this research, one case is considered and thus one ownership situation, but several situations are possible. For further research, it can be interesting to study the difference among these situations in order to draw conclusions which one is the most profitable.
Projects can bring more value other than financial. Since the projects are sustainable energy projects, it can bring added value when in addition to the economic analysis, which is the cost benefit analysis as described in this paper, an environmental analysis is performed. Although the need for an environmental analysis would be higher when the initiator and

owner is a public or governmental body, nowadays it could be even beneficial to private parties. Examples of benefits that may arise from an environmental analysis could be:

- extra goodwill from environmental or pressure groups towards the private party;
- in case of a contractor extra bonus points in tenders;
- improvement of environment-friendly image of the private party;
- fewer emissions of CO2 into the environment.

ACKNOWLEDGEMENTS

During my research several people have supported me in order to achieve this end result. Therefore I would like to like to express my gratitude to these people. Each of them supported me in a different way, whether it was by providing data, knowledge, literature, confidence or contributing their thoughts, experiences and time. I want to thank Ballast Nedam, who was willing to support me with my thesis. Ballast Nedam is actively involved in markets related to both infrastructure and renewable energy, thus I was very pleased with that opportunity. Furthermore, I would like to thank my supervisors at the university, Bauke de Vries and Jan Dijkstra. And of course I would express my gratitude to my colleagues at Ballast Nedam, especially to Job van de Sande for his guidance and input.

REFERENCES

- Laleman, R., Albrecht, J., 2012. Comparing push and pull measures for PV and wind in Europe. Renewable Energy xxx 1-5.
- Ecofys, German Solar Energy Society (DGS LV Berlin BRB), 2005. Planning and installing photovoltaic systems, a guide for installers, architects and engineers. London: James & James / Earthscan.
- Kennisinstituut voor mobiliteitsbeleid, 2010. Verkenning mobiliteit en bereikbaarheid 2011-2015.
- Kennisinstituut voor mobiliteitsbeleid, 2010. Krimp en mobiliteit, gevolgen van demografische veranderingen voor mobiliteit.
- Yan, H., Zhou, Z., Lu, H., 2009. Photovoltaic industry and market investigation. IEEE Sustainable Power Generation and Supply. Nanjing, China April: 1–4.
- REN21, 2012. Renewables 2012 Global Status Report. Paris: REN21 Secretariat.

ing. P.M. Jochems (Paul)

I am very satisfied with the end result of my research. The topics road infrastructure and solar energy are very interesting subjects. During the process I realized the complexity of the energy market in the Netherlands, but therefore the challenge is bigger and it is more tempting to stay actively involved in the working field regarding PV panels near road infrastructure.

2006 – 2010	Bachelor in Civil Engineering, University of applied sciences Utrecht
2010 – 2011	Pre-master program Construction Management and Engineering, TU/e
2011 – 2013	Master in Construction Management and Engineering, TU/e
2013	Graduation internship at Ballast Nedam

DE POTENTIE VAN PV PANELEN LANGS SNELWEGEN IN NEDERLAND

Auteur: P.M. Jochems (Paul)

Afstudeerrichting:
Construction Management and Urban Development 2012-2013

Afstudeercommissie:

Prof. dr. ir. B. de Vries (Bauke)	(TU/e)
ing. J. Dijkstra (Jan)	(TU/e)
ir. J. van de Sande (Job)	(Ballast Nedam)

Datum van afstuderen:
25-04-2013

INTRODUCTIE

Zoals veel mensen weten is energie vandaag de dag een belangrijk onderwerp en neemt de vraag naar energie elk jaar toe. Om aan deze toenemende energie vraag te kunnen voldoen zullen hernieuwbare energiebronnen in de toekomst steeds belangrijker worden. Ondanks deze noodzaak is het aandeel van hernieuwbare energie in Nederland een van de laagste in Europa. Met het aandeel van energie opgewekt met photovoltaïsche(PV) panelen is het nog slechter gesteld. PV panelen worden vaak geïnstalleerd op gebouwen en daken. Dit levert soms beperkingen op vanwege beschikbare ruimte, oriëntatie of helling van de bestaande gebouwen. PV panelen in een open veld opstelling zie je zelden in Nederland, mede omdat de ruimte schaars is.

Niet alleen de vraag naar energie zal toenemen de komende jaren, dit geldt ook voor de vraag naar mobiliteit. Bijvoorbeeld, het aantal kilometers afgelegd per auto is in 2015 naar verwachting 14% hoger dan in 2010. Economische vooruitgang en een groeiende bevolking zijn factoren die hieraan bijdragen. In 2015 zullen er 16% meer files staan dan in 2010(Kennisinstituut voor Mobiliteitsbeleid, 2010). Vanwege de toenemende vraag naar mobiliteit en de belangrijkheid van infrastructuur voor de economie, zou je voldoende investeringen in nieuwe infrastructuur en onderhoud hiervan verwachten. Echter, vanwege bezuinigingen op infrastructuur als gevolg van de economische situatie is dit niet het geval.

Wanneer bovenstaande zaken naast elkaar gelegd worden kunnen er kansen ontstaan. De kans die beschouwd wordt in dit artikel is het plaatsen van PV panelen langs snelwegen. Dit kan zijn op de ongebruikte gronden of op de geluidschermen. In het meest gunstige scenario kan met de opbrengsten van de PV panelen deels wegaanleg of onderhoud gefinancierd worden.

Onderzoeksvraag

Kunnen PV panelen toegevoegde waarde bieden aan de snelwegen in Nederland, en wat is de potentie/haalbaarheid?

Onderzoeksdoelstelling

In de literatuur is weinig geschreven over PV panelen langs snelwegen. De weinige artikelen over dit onderwerp focussen zich slechts op photovoltaic noise barriers(PVNB). Geen enkel artikel beschouwt de mogelijkheid om PV panelen in de berm langs de snelweg te plaatsen. Deze studie beschouwd beide mogelijkheden en de belangrijkste doelstelling is het inzicht geven in het economische aspect. Dit wordt bereikt met kosten baten analyse(CBA) waarvoor een financieel model is ontwikkeld. De CBA wordt aangevuld met een gevoeligheidsanalyse. Naast het economische aspect, richt deze studie zich op meerdere aspecten zoals techniek, wetgeving, richtlijnen, DBFM contract en geleerde lessen. De CBA wordt toepast op een casestudy.

ACHTERGROND INFORMATIE

Om in staat te zijn een degelijk financieel model te ontwikkelen en de onderzoeksvragen te beantwoorden is uitgebreide kennis nodig over achtergronden zoals de energiemarkt, PV systemen en wat er bij komt kijken als PV panelen en infrastructuur gecombineerd worden.

Energiemarkt

De energiemarkt in Nederland bestaat uit meerdere componenten en wordt beïnvloed door verschillende factoren zoals wetgeving, belasting, EU-overeenkomsten, subsidies, etc. De energiemarkt is compleet veranderd sinds de liberalisering in 2004. Sindsdien zijn de productie, handel en verkoop van energie commerciële activiteiten. De volgende partijen zijn nu actief in deze markt; producenten, nationaal netwerkbedrijf, regionaal netwerkbedrijf, programma verantwoordelijken en leveranciers.

De energieprijzen in Nederland zijn, exclusief belasting, een van de laagste van Europa. Echter, de belasting maakt dat uiteindelijk de totale energie prijs relatief hoog is. De kosten voor energie zijn de afgelopen 15 jaar met 120% gestegen, een jaarlijkse stijging van meer dan 5%(CBS). De elektriciteitsprijs bestaat uit 3 componenten, de kosten voor elektriciteit, netwerkkosten en belasting. De verhouding tussen die drie is afhankelijk van het type gebruiker.

The energiemix van Nederland is niet de meest duurzame in Europa. Het aandeel hernieuwbare energie is erg laag vergeleken met andere landen. Een van de verklaringen hiervoor is dat duurzame energie in andere landen meer gestimuleerd wordt door de overheid. Het aandeel hernieuwbare energie op het totale energieverbruik in Nederland was 4,3% in 2011, in 2010 was het 3,7%. Het aandeel hernieuwbare energie op het totale elektriciteitsverbruik bedroeg 9,8% in 2011. Slechts 0,8% hiervan komt van zonne-energie(CBS). De huidige regering heeft de doelstelling voor 2020 om 16% van de energieconsumptie duurzaam op te wekken. Een van de middelen om dit te bereiken is het gebruik van subsidies.

Photovoltaïsche systemen

De potentie van zonne-energie is enorm. Als alle straling van de zon die de aarde bereikt omgezet kon worden in energie, zou dit ca. 1000x de wereldwijde energie behoefte zijn. De wereldwijde gemiddelde groei van de PV industrie over de afgelopen 5 jaar bedroeg 49,5%(Yan, Zhou, Lu, 2009). Het totale aantal PV installaties groeide in 2011 tot 70GW, vergeleken met 40GW in 2010(REN21, 2012).

De opbrengst van een PV systeem hangt voornamelijk af van de instraling. De instraling wordt vervolgens weer bepaald door de hoek, oriëntatie en zonkracht. De PV cel is in staat om zonlicht direct om te zetten naar elektriciteit, waarvoor semiconductor materialen gebruikt worden.

PV systemen en infrastructuur

Een van de meest belangrijke stakeholders in het geval van PV panelen langs de snelweg is Rijkswaterstaat(RWS). RWS wil zelf geen energie produceren omdat dit sinds de liberalisatie van de energiemarkt geen publieke taak meer is. Dus commerciële partijen moeten het initiatief nemen. Vervolgens zullen zij deze partijen helpen en eventuele belemmeringen proberen weg te nemen.

Regelgeving en richtlijnen spelen een belangrijke rol aangezien dit tot beperkingen leidt. Daarom is inzicht in regelgeving en richtinglijnen op het gebied van elektriciteit, weginfrastructuur, geluid en bestemmingsplan belangrijk. De elektriciteitswet stelt grenzen aan wie een grid/netwerk mag aanleggen en werkend mag houden. Op enkele uitzonderingen na mag alleen de regionale netwerkbeheerder deze taken uitvoeren. Verder, iedereen mag elektriciteit verkopen aan derden, behalve aan kleinverbruikers. Voor levering aan kleinverbruikers is een vergunning nodig, op enkele uitzonderingen na. De wet stelt dat een kleinverbruiker recht heeft op salderen, en dat over alle verbruikte energie, belasting betaald moet worden. Echter, er hoeft geen belasting betaald te worden in het geval van salderen of wanneer de energie is opgewekt achter de aansluiting op een duurzame manier.

De wet 'beheer Rijkswaterstaatwerken'(artikel 2, sectie 1) stelt dat er zonder toestemming van de minister van Verkeer en Waterstaat geen gebruik gemaakt mag worden van een 'waterstaatwerk' anders dan waar het voor bedoeld is. Toestemming kan verleend worden wanneer aan bepaalde voorwaarden voldaan wordt. Pacht zal afgedragen moeten worden, echter niet in het geval van een DBFM contract. Installatie van PV panelen langs de weg moet voldoen aan NOA(RWS, 2007). Als PV cellen in geluidsschermen worden geïntegreerd, zullen richtlijnen en wetgeving voor geluidschermen van toepassing zijn.

Het rendement van PV panelen langs snelwegen wordt ook beïnvloed door vervuiling, reflectie, schaduw en ouderdom. Vervuiling is het meest belangrijk, pilot projecten in Nederland hebben laten zien dat het rendement daalt met meer dan 5%. Echter, projecten in het buitenland laten geen significante daling zien.

MODEL ONTWIKKELING

Het financiële model dat is ontwikkeld als onderdeel van deze studie is essentieel om een kosten baten analyse(CBA) uit te voeren en antwoord te geven op de onderzoeksvraag. Voordat het model gebruikt gaat worden is het noodzakelijk om de eigendom situatie duidelijk te hebben. Wie heeft de installatie in eigendom, wie gebruikt de opgewekte energie en hoe wordt de energie getransporteerd? Dit beïnvloedt de kosten en de baten.

De methode die toegepast wordt is een CBA. De onderdelen die beschouwd worden is de net present value(NPV), de internal rate of return(IRR), de terugverdientijd(PBP) en een gevoeligheidsanalyse. Om de werking van het financiële model snel duidelijk te maken is een activiteiten diagram ontwikkeld. Deze beschrijft het proces dat van toepassing is voor PV panelen langs de weg. Het activiteiten diagram is gebaseerd op de UML techniek.

CASESTUDY

Het project dat beschouwd wordt is een DBFM project voor de verbreding van een sectie van een snelweg met een lengte van 14km. Er is voldoende ongebruikte grond beschikbaar voor PV panelen rondom op- en afritten. Ook is er […] m^2 geluidscherm oppervlakte beschikbaar. Het energieverbruik van het wegdeel bedraagt […] kWh per jaar. De kosten per kWh zijn €[…]. Drie varianten zijn opgesteld om (deels) aan de energievraag te voldoen:

- Variant 1: standaard PV panelen opgesteld in een vrije opstelling langs de weg;

- Variant 2a: Powerglaz® BIPV vervangen de transparante panelen in het geluidscherm;
- Variant 2b: standaard PV panelen bevestigd op de aluminium panelen van het geluidscherm.

De parameters die horen bij deze varianten zijn opgenomen in **Tabel 1**. Sommige input waarden zijn gelijk voor elke variant, zoals WACC([…]%), onderhoudskosten([…]% van de totale investering), winstbelasting(25%) en rendementsdaling([…]% p/j). Looptijd van de investering is 25 jaar.

	Variant 1	Variant 2a	Variant 2b
Investering(€/Wp)	€[…]	€[…]	€[…]
Vermogen(kWp)	[…]	[…]	[…]
Jaarlijkse opbrengst(kWh)	[…]	[…]	[…]
Prestatie(kWh/kWp)	[…]	[…]	[…]
Subsidies	SDE+, EIA	SDE+, EIA	SDE+, EIA

Tabel 1: Input parameters per variant.

De resultaten van de CBA zijn weergeven in **Tabel 2**. Hieruit blijkt dat variant 1 het best presteert. Per variant is voor 4 verschillende input variabelen de gevoeligheid bepaald.

Project beoordeling		Variant 1	Variant 2a	Variant 2b
	NPV	€1.013.136	€-1.059.865	€614.822
	IRR	[…]%	[…]%	[…]%
	Terugverdientijd	10 jaar en 4 maanden	18 jaar en 11 maanden	10 jaar en 9 maanden
	Gem. kWh prijs	€0,1351	€0,2696	€0,1409
Equity beoordeling				
	NPV	€22.251	€-1.330.334	€-58.776
	IRR	[…]%	[…]%	[…]%

Tabel 2: Resultaten.

CONCLUSIE

Er kan gesteld worden dat PV panelen langs snelwegen in Nederland toegevoegde waarde bieden en dat dit vandaag de dag al haalbaar is. Dit is aangetoond met de casestudy voor een specifieke situatie, binnen een DBFM contract. Aan de belangrijkste eis, economische haalbaarheid, wordt voldaan. Variant 1 is zeker interessant voor investeerders aangezien de NPV van de project- en equity-beoordeling positief is. Variant 2b is vandaag de dag ook haalbaar als genoegen wordt genomen met een lager rendement op het eigen vermogen. Uit de resultaten van de CBA en de gevoeligheidsanalyse kan geconcludeerd worden dat variant 2a nu en in de nabije toekomst niet haalbaar is. Uit dit onderzoek is ook gebleken dat subsidies op dit moment nog essentieel zijn. Hooguit één subsidie programma kan gemist worden om de NPV(projectbeoordeling) van variant 1 en 2b positief te houden. Ondanks de aanwezigheid van grote oppervlakten geluidscherm, zal in deze situatie een PVNB niet genoeg opbrengst kunnen genereren om aan de energievraag van de weg te voldoen.
Aangezien voor dit onderzoek slechts 1 casestudy behandeld is, wordt het voor vervolgonderzoek aangeraden om meerdere snelwegtrajecten in Nederland te beschouwen. Hierdoor zullen de conclusies sterker worden. Ook is het aan te raden om meerdere eigendom situaties te beschouwen.