Domestic Solar Energy Collection:

The Sunny Side of Life?

A study about the use of photovoltaic systems in Dutch households

MSc thesis of

Lianne Elisabeth Maria Veen

WAGENINGEN UR
For quality of life

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Edited and published under direct management

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A study about the use of photovoltaic systems in Dutch households

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Abstract

Photovoltaic energy is one of the fastest growing sources of renewable energy. Domestic photovoltaic systems (PV systems) are getting more popular in the Netherlands each year but hardly any research is done on the topic. This thesis tries to fill the knowledge gap on the use of PV systems in Dutch households. It aims to get insight in the real life saving potential of domestic PV systems.

Results were based on 157 households that installed a PV system between 2008 and 2013 who filled in a questionnaire. This study shows that fifty per cent of the households with PV systems show a negative behavioural response (rebound effect) to the installation of a PV system. In the first year after installation they start to consume more electricity than before the installation. A quarter of the PV households show a positive behavioural response, leading to extra savings and a double dividend. The remaining households show no change in their energy consumption. Most PV systems in this study were proven to be profitable but have long pay back times (10-15 years). The energy consuming behaviour of households affects profitability of the systems. The main reasons for households to invest in a PV systems are financial benefits, environmental concern and independency from energy suppliers. The main experienced barriers in the decision making process were high investment costs, long payback times and uncertainty about the future. The study also showed that a typical PV household is between 45 and 56 years old, has a middle or high income, is higher educated and has high environmental concern.

This research showed that the domestic PV technology works as it should work but that the behaviour of households strongly affects the actual annual savings of the PV system.

Preface

The thesis lying in front of you, is the result of nine months of hard work. It is the final product of my master studies Management, Economics and Consumer Studies at Wageningen University (part of Wageningen UR).

I have very much enjoyed exploring the world of photovoltaics and improving my research abilities. I had to combine different skills and techniques I had learned over the last years in Wageningen such as doing literature studies, creating questionnaires and using SPSS for statistical analyses. Also, during this project I have learned how valuable social media can be for finding respondents. Twitter and Facebook have been of great help in the search for households with photovoltaic systems.

I would like to take this opportunity to thank Johan van Ophem and Paul Terpstra for guiding me through this project, for their commitment, for their critical feedback and for the interesting and lively discussions we have had about photovoltaics, consumer behaviour, research designs, travelling, sports and of course cars.

Second, I thank all the organizations, households and people that helped me during this project by promoting the study, providing me with information and filling in the questionnaire.

Last I would like to thank my family and friends who have always supported me and cheered me up in times that I was not feeling confident about my work. Their support was invaluable.

In the months I have worked on this project I have experienced highs and lows, feeling sometimes very confident and sometimes very insecure about the work I had done and every decision I had made so far. Now, with the finish line in sight I feel proud of the work I have delivered and of the end product lying in front of you.

I hope you will enjoy reading it.

Have a sunny day,

Lianne Veen, January 2014

Content

Glossary

Abbreviation	Meaning
AC	Alternating current (wisselstroom)
a-Si	Amorphous Silicon
ASTM	American Society for Testing and Materials
CdTe	CdTe Thin Film
CIS	CIS Thin Film
DC	Direct current (gelijkstroom)
EPBT	Energy Payback Time
EPIA	European Photovoltaic Industry Association
EPR	Energie Premie Regeling
ERR	Energy Return Rate
EU	European Union
FiT	Feed In Tariffs
GHG	Greenhouse Gases
GW	Giga Watt (1000 MW or 10^9 Watt)
IRR	Internal Rate of Return
kWh	Kilo Watt hour
kWp	Kilo Watt peak
LCA	Life Cycle Assessment
MEP	Milieukwaliteit Elektriciteits Productie
Mono-Si / Mono-c-Si	Mono-Crystalline Silicon
Multi-Si / Multi-c-Si	Multi-Crystalline Silicon or Poly-Crystalline
MW	Mega Watt (100000 Watt)
NPV	Net Present Value
ODE	Wet Opslag Duurzame Energie
Poly-Si / Poly-c-Si	Silicon Poly-Crystalline or Multi-Crystalline
PV	Photovoltaic, or solar energy producing technology
REB	Wet Regulerende Energiebelasting
ROI	Return on investment
SDE	Stimuleringsregeling Duurzame Energie (2008-2012)
SDE+	Stimuleringsregeling Duurzame Energie Plus (2013 -)
VAT	Value added tax
W	Watt
Wp	Watt peak

Executive Summary

Introduction

In today's society, the importance of reducing greenhouse gas emissions and the need to reduce the pressure on fossil fuels does not need much explanation any more. Over the last decades people have tried to come up with greener sources of power; photovoltaic (PV) energy being one of them. In the Netherlands, domestic PV energy is increasingly becoming a more important source of renewable energy. Between 2008 and 2013 it has experienced an enormous growth, resulting in the 155,000 to 175,000 domestic PV systems that can be found today. Remarkably there is hardly any social scientific research done in this field, resulting in a large knowledge gap on the use of PV systems in (Dutch) households.

Research aim and questions

To be able to fill the explained knowledge gap to some extent this research had the following aim: G*etting insight in the saving potential of domestic photovoltaic systems*. To reach this insight there were two main research questions formulated:

What are the real life savings for households after the installation of a PV system?
What are the factors and determinants involved in the household decision making process of PV systems?

To answer these questions, more detailed sub questions were needed. The following research questions were formulated:

How much energy is used in the entire life cycle of PV systems?
How much do households annually save after the installation of a PV system?
What factors affect PV capacity and actual PV energy production?
What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?
What are household motives and barriers for buying a PV system?
What are (social demographic) characteristics of households with a PV system?

A literature study and a quantitative research were conducted to answer these questions.

Literature

A thorough literature analysis of various academic and non-academic sources was done to answer the research questions (if possible) and to come up with a list of hypotheses that needed testing.

What factors affect PV capacity and actual PV energy production?

The literature showed that there are many factors that influence the actual electricity production of a PV system. They can basically be grouped into factors that belong to 'PV System Placing' (tilt angle, orientation, shadow), 'PV System Properties' (material, size, panel connection, age), 'PV System Location'(geographic coordination, solar irradiation, temperature) and 'Household Behaviour' (cleaning, maintenance). Some factors are more important than others but it must be clear that a PV system is only recommended under the right circumstances. Non-optimal placing could highly affect and decrease the actual output of a PV system.

How much energy is used in the entire life cycle of PV systems?

All the different stages of the life cycle of PV systems were incorporated to measure the energy consumption and environmental impact of PV systems. The Energy Payback Time of a PV system is 1.5 to 2.7 years, depending on the type of PV system. So, from a domestic point of view, installing a PV system will within three years contribute to a 'greener' way of life. From a global perspective PV technology will start contributing energy to society from 2015. Until then it is returning the energy that it cost to get to the current technological state. The carbon footprint of PV technology is ten to twenty times smaller than fossil fuel footprints.

Hypotheses

The other research questions could not be answered solely by looking at the literature. Based on a review of the literature available multiple hypothesis were formulated:

H1: The energy and financial savings are different for each household and are context dependent.

H2: Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend.

H3: Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system.

H4: High investment costs and long capital payback times are the main barriers for households for installing PV systems.

H5: Households with PV systems are typically between 45 and 64 years old, have a high environmental concern, have high incomes, are higher educated and own their home.

Methodology

To be able to test the hypotheses a questionnaire was created. The population of this research was defined as: "Dutch households with a PV system that is installed before January 1st 2013, but later than January 1st 2008. The online questionnaire consisted of 76 questions and took approximately one hour to complete. To find respondents this study used various promotion methods such as an informational website, newsletters, posters and social media. A total of 341 people started with the questionnaire, 157 respondents finished all the questions. It resulted in an extensive amount of data about 175 Dutch households and their PV system.

Results

Based on the data from the questionnaire the hypotheses were tested and the research questions were answered. The most important results are shown below.

PV system installation properties

It was found that, similar to what was expected, the PV system of each household is different. They vary among others in type of system, installation properties, orientation and presence of obstacles. Typically, the PV systems in this study are based on Mono-Crystalline PV cells, are serially connected, are placed on a tilted roof, are facing South and experience no shadow. Remarkably, the placing properties for over thirty per cent of the PV systems in this study are qualified as 'medium' (27.5%) or even 'bad' (5.5%). This means that these systems will only be able to produce a maximum of 90% (medium) or even 80% (bad) of the amount of PV energy they could have produced if they would have installed under the right conditions.

PV system capacity properties

It was found that the installed capacities vary among the respondents, but that most respondents (63.5%) have a medium PV system (1500 – 3500 Watt Peak). Based on the installed capacity and the 0.86 factor[1], individual estimations were made for the possible annual yield and savings. Also, the respondents were asked what their supplier estimated to be the savings and what the households themselves estimated to be the savings each year. On average, the yield was estimated to be 129.14 kWh/m² on the basis of calculation (Watt Peak * 0.86 hours), 126.16 kWh/m² by the supplier and 126.34 kWh/m² by the households themselves. Analyses of the individual cases, instead of the averages, showed that two third of the supplier estimations are based on a factor more optimistic than the 0.86 factor. It also showed that 38% of the households are more optimistic about their annual yield than their suppliers. They think they will produce more PV energy than what their supplier estimates. This same tendency is found for estimated financial savings: one third (32.1%) of the households expects to save more each year than what their supplier expects they will save.

Costs and subsidies

In was found that the respondents on average invested €5856.60 in their PV system. The costs are related to the year of installation: the older the system, the higher the acquisition costs. Most PV households (68.1%) in this study received a subsidy for their PV system.

[1] The 0.86 factor is based on the average production of a PV system in the Netherlands: that is 86% of its capacity in Watt Peak.

The vast majority (90%) of the PV households indicated not to have (annual) maintenance costs.

Expected profitability

Based on three different profitability analyses (accepting a set of assumptions about the future[2]) it was found that domestic PV systems are profitable investments. Whatever method used, investing in a PV system is indeed a profitable choice for most households in this research. With a 4.0% discount rate the net present value of the investment in PV is positive for over 85% of the PV households. Even with a higher discount rate of 5.5%, the net present value is still positive for three quarter of all PV households, showing that investing in a PV system is a financially desirable choice. The internal rate on investment is on average 8.5%, showing that investing in PV is typically more profitable than alternatives. Saving the money on a freely available bank account will result in a maximum of 2% interest, meaning that for 92% of the households it was indeed more profitable to invest the money in a PV system. The downside of investing in a PV system is found in the time it takes to earn back the investment and the risks that come with this time. The estimated return on investment time of PV systems is typically 10 to 15 years, accepting the assumption of no changes in the energy consumption of the household.

Real output

The households savings were measured by subtracting the electricity consumption of the year after installation of the PV system from the electricity consumption of the year before. On average households save 105 kWh per installed square meter PV system. Depending on the chosen electricity price this is roughly an annual financial saving of €27 per square meter. The estimated savings based on calculating with the 0.86 factor (129 kWh/m²) and supplier and household estimations (126 kWh/m²) are significantly higher with respectively 22.8% and 20% compared to the actual savings. Interestingly there was a difference found between the monitored yield and the savings (based on consumption before and after installation). The monitored yield, in other words the actual production of the PV system measured by a kWh meter, is on average 14.3% higher than the savings. With an average of 120 kWh per square meter it is not significantly lower than the estimated yields and savings. The photovoltaic technology seems to work just as good as expected.

The fact that the actual output of a PV system is so much higher than the savings (corrected for household and societal changes) leads to the conclusion that household behaviour is very important for the actual savings of a PV system. The system itself performs as expected but still on average households save an amount of energy that could have been a lot higher. Looking at this household behaviour, three groups (of N=65) can

[2] 0.86 factor is correct; expected decrease of 10% after ten years and 10% after twenty years; an annual increase of electricity prices of 4%; a savings interest rate of 2%, discount rates of 4% and 5.5%.

be distinguished when comparing the real savings with the expected savings (based on supplier estimations):

- *Households that save as much as expected (range -10% – 10%)*: 23%
  These households show no sign of a behavioural change. Their energy consumption patterns have not changed after installation of the PV system.
- *Households that save more than expected*: 22%
  These households show a positive behavioural response to the installation of the PV system. In the year after installation the (visual) presence of the system leads to a higher consciousness and lower energy consumption. These households save more than what is produced by the system, an effect that is called 'double dividend'.
- *Households that save less than expected*: 55%
  The biggest group of household show a negative behavioural response to the installation of a PV system. They start to consume more energy than before the installation, leading to lower savings than what they could have been on the basis of the PV power production. This effect, when households start to consume more energy because they produce this 'free' energy themselves, is called 'rebound effect'. The chance of households performing this behaviour is higher for households that install larger PV systems with a higher capacity.

For the hypothesis *Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend* is no evidence found. On the contrary, most households with PV systems seem to show a negative behavioural response, leading to an increase in energy consumption (rebound effect).

By running a logistic regression analysis, predictors for the type of behaviour were sought. The only significant predictor found was installed capacity: the higher the installed capacity the smaller the chance of a household showing a positive change in behaviour leading to a double dividend. This effect was found not to be very strong.

Real profitability

The real life data, based on the first year after installation of PV systems, shows that the average real profitability of PV systems is lower than expected. The decision itself, to invest in a PV system is profitable, but less than what it could be. For a little over 50% of the PV households counts that based on their first production year the Return on Investment Times are longer, the Net Present Values are lower and the Internal Return Rates are lower than what was estimated and what they could have been.

It was found that the previously found behavioural change or rebound effect also affects the profitability of the systems. The changes in energy consumption of households make that the profitability of PV systems is in 50% of the cases lower than what it could be.

The analysis showed that the profitability is different for each independent household, depending on the system properties but also on behavioural changes of the household. Hence, for the hypothesis *The energy and financial savings are different for each* *household and are context dependent* evidence is found. For example, negative changes in energy consumption of households (rebound effect) make that the profitability of PV systems is in 50% of the cases lower than what it could be. On the other hand, for a smaller portion of the households (25%) the profitability is higher because these households show a positive change in behaviour and save extra electricity (on top of the produced power by the system).

Motives
The hypothesis *Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system* is supported by the data found in this research. Environmental concerns (highest importance) and financial benefits (most often given as an important reason) are the two most important motives for buying and using a PV system by Dutch households. Based on the frequency that 'financial benefits' was given as the single reason for buying a PV system reason is proven to be more important than 'environmental concerns'. Independency from energy suppliers and being self-supporting when it comes to producing energy is the third most mentioned and most important reason

Barriers
There is evidence found that supports the hypothesis *High investment costs and long capital payback times are the main barriers for households for installing PV systems*. However, based on the data it was also be concluded that the hypothesis did not describe the complete situation. Uncertainty and/or knowledge gaps about (future) subsidies and legislation and about (future) technology development are also proven to be main barriers in the households decision making process of PV systems.

Characteristics
A typical PV household was found to have the following characteristics: between 45 and 65 years old, 2 adults, one or two kids living at home, middle or high income, higher educated, high environmental concern, home owner, paid employment and the initiative to buy a PV system came by the man. For the hypothesis '*Households with PV systems are typically between 45 and 64 years old, have a high environmental concern, have high incomes, are higher educated and own their home'* was found proof though was also proven to be incomplete (middle incomes should be added).

Conclusion and discussion

Conclusion
This study showed that the decision to invest in a PV system for most PV households is a profitable decision but that the savings are strongly affected by household behaviour. For fifty per cent of the households the savings are lower than what they could be, caused by

the rebound effect. The presence of a PV system causes these households to consume more electricity than they did before the installation of the PV system.
This research also showed that environmental concerns are still important in the decision making process but that financial reasons are increasingly becoming more important.

Discussion

One of the limitations of the method used was the length of the questionnaire. It led to a high number of respondents that did not complete the questionnaire. The fact that there were so many questions in the questionnaire also improved the quality of the data and therefore it should also be seen as one of its strengths. One of the experienced difficulties was that there was no list of households with PV systems available. Without knowing where they lived, PV households had to be reached via off line and online canals.

Future research

Based on this research a more specific study about the actual motives and barriers that households experience in the decision making process of buying a PV system is recommended. Especially the motives *not* to buy a PV system would be interesting. Another important recommendation for further research is a long term study. The behavioural effects found (rebound and double dividend) were only about the first year after installations. A long term study, could show if these effects remain the same over time or will increase or decrease.

I

Scope of Study

1 Introduction

'Fire caused by solar panels' (*Brand door zonnepanelen*; Haarlems Dagblad, 2013), 'Live span of many solar panels not long enough' (*Veel zonnepanelen gaan niet lang genoeg mee*; ANP, 2013) and 'Solar panels is emotion' *(Zonnepanelen is emotie*; Volkskrant, 2013a*).* These are just some of the many quotes to be found when one opens an average Dutch newspaper. In short, solar panels are 'hot'. Like any other hot item there are people in favour, people against and people with no opinions but it is safe to say that everybody in the Netherlands knows what solar panels are and what they are used for. Solar panels are based on technology that allows us to convert the power of sunlight into useable electricity. This technology is often seen as one of the high potential solutions to reduce greenhouse gas emissions and to limit negative climate changes.

All over the world solar panels are installed to produce 'green' power. Billions of dollars are involved in governmental subsidy programs to promote this form of electricity production and to stimulate the development of the solar panel markets. The development of solar panel systems is based on three main types of installations and usage: 1) commercial, grid connected installations, 2) domestic, grid connected installations and 3) off grid installations (EPIA, 2012). All of these applications have one main goal, namely saving conventional 'grey' energy. The biggest knowledge gap concerning the actual savings can be found in the second type of installations. The actual savings caused by installing solar panels in households are often guessed but not known.

A similar knowledge gap was found ten years ago in the case of solar heat collectors. In 2005 a research was conducted by Terpstra, van Ophem and Jansen to "give insight in the national saving potential of solar heat collector systems for domestic use" (p.78). The research looked at the real life energy savings of Dutch households which recently installed a solar heat collector. Solar heat collectors use, similar to solar panels, the power of the sun to limit the energy use in households. It uses the heat from the sun to warm houses and water. At the time of the research the Dutch government tried to promote the use of solar heat collectors by granting subsidies and tax benefits. However, the results of the research showed that only a part of the households experienced, after installing a solar heat collecting system, some sort of energy reduction. A substantial part had no reduction at all. The research also showed that the installation of the systems lead in the majority of the cases to no net financial benefits. The research showed that, at that time, taking household activities and behaviour into account the real life energy and financial savings were far less than predicted from a technical analysis.

1.1 Research aim and research questions

Nowadays, these results found eight years ago, lead to new questions. The subsidy on solar heat collectors does not exist anymore but is replaced by a subsidy on electricity producing solar panel systems, or photovoltaic (PV) systems (to be called PV system

from now on). The question rises if the same principle found in the 2005 research also holds for PV systems. The Dutch government spends millions on the subsidy on PV systems based on the assumption that domestic PV panels will reduce the use of ‘grey’, conventional electricity. Next to the savings on electricity use, PV systems are also marketed as a good, profitable investment.
Based on the governmental money spent and marketing campaigns done one would expect that PV systems do what the promise: saving energy. But since calculations differ a lot and hardly ever take into account household behaviour new research is needed.

In line with the research of Terpstra et al (2005), the aim of this research is therefore

Getting insight in the saving potential of domestic photovoltaic systems.

This insight can be reached by answering the following research questions.

1. *What are the real life savings for households after the installation of a PV system?*

This question covers both the net electricity savings (direct electricity – indirect energy) and the financial savings. Direct electricity is defined as all the electricity produced by the installed PV system. Indirect electricity is a lot less known and covers all the electricity needed to produce, use and dispose the solar panel system. This includes all stages of the product life cycle, from the extraction of raw materials to the disposal and recycle stage. This question also includes looking at the financial profitability of PV systems.

2. *What are the factors and determinants involved in the household decision making process of PV systems?*

This second research question is a natural follow up on the first. To get insight in the national saving potential information about potential consumers is needed. Answering this question will provide insight in why households buy and install PV systems and what the characteristics of these households are. This can help in explaining why households save (not) as much as expected. It will also result in a consumer profile that is of interest for various stakeholders like the government, PV system producers and conventional energy suppliers.

1.2 Operationalization

Before exploring the sub questions of these research questions the main concepts and definitions have to be defined. Households, energy, PV systems and savings are defined and explained.

Households

This research will focus on the domestic use of PV systems. Households, as the smallest social units, are the basis, the foundation of societies. Households are the end of many production chains and their behaviour reflects back on the entire chain.

Looking at the potential and actual savings of PV systems from a household perspective is something not done enough. Mostly the capacity and possible savings of solar panels are calculated through technical analyses without taking into account the actual users. Terpstra et al. (2005) already showed the importance of using a households level approach, this research builds on that result and uses the same focus group. If the word *domestic* is used in this research it refers to households.

Energy

To keep things clear this research will only focus on the *electricity* use and savings and will exclude natural gas from all calculations. The concepts *power* and *energy* are in this research used as interchangeable with *electricity* or *electrical energy* unless explicitly mentioned otherwise.

PV systems

In this research *PV systems* and *PV installations* are defined as installations with one or more panels that can convert sunlight into electricity. The concept 'PV system' includes all other requirements and accessories needed to get the system fully functioning. When the concept 'solar panel' is explicitly mentioned it means that it is only about the panels (excluding the cabling, inverter, etc.)

Savings

This research focusses on the *savings* after installing a PV system and not on the actual *production* of electricity. The main reason for this is that this study wants to understand the role of households in the actual savings of a PV system and not only test the technical abilities of the systems. Another reason for this is that the electricity production in households is often not measured. Most households in the Netherlands do not have a separate kWh meter installed yet that measures the produced electricity. Some of the produced electricity is directly used in the household but there is no meter measuring how much. How much electricity is put back in the grid (because it is not used in the household) can only be seen by the falling of the conventional electricity meter. For that reason it is impossible to measure how much electricity is actually produced, only how much is saved at the end of a period in comparison to a previous period. Note that the last couple of years there has been a trend in the world of PV. Suppliers include a production monitoring device in the installation making it possible for more and more households to measure their actual PV production. This is however not a widespread phenomenon yet and therefore not yet useful as a basis for this research.

1.3 Sub research questions

To answer the two research questions and to fulfil the aim of this research more detailed sub questions are needed. Answering these sub questions will lead to a fuller understanding of the real savings of households that use solar panels and what factors are important in the decision making process when buying solar panels.

Electricity and financial savings

To give an answer to the question *what the real life savings are after installing a PV system* more specific questions are necessary. Three sub questions are constructed that address all items that are needed to give a complete answer to the broad research question.

Since saving energy is the most important rationale for the usage of PV systems, it is important that the energy it takes to produce, use and dispose the PV system is not left out. To know what the real life savings of PV systems are, it is important to take into account the energy used in the entire life cycle of the system. An analysis of all the energy used in the different stages of the life cycle of PV system must be conducted. That will answer the following sub question:

> *1a. How much energy is used in the entire life cycle of PV systems?*

Technical analysis predicts a certain amount of savings per household after having installed a PV system. To know what the real life savings after installation of a PV system are, it is important to exactly measure these savings in real households instead of just predicting. It will prove the predictions to be right or wrong and will give a real life picture of the actual savings. How much (conventional) energy and money is saved by households depends on two basic factors: how much energy is produced and how much energy is consumed. Taking both into account the following sub question is constructed:

> *1b. How much do households annually save after the installation of a PV system?*

Energy production and consumption are the two key factors in how much is saved. The amount of produced energy is affected by lots of different factors. To be able to predict the saving potential it is important to know which factors affect PV power production and what the role of household behaviour is in this matter. Hence, the third sub question is:

> *1c. What factors affect PV capacity and actual PV energy production?*

Determinants and factors to install PV systems

The second research question tries to find out *what the factors are that influence the household decision making process in the case of PV systems*. To be able to give a complete answer to this question this question too must be fragmented in more detailed sub questions.

One of the more important factors influencing consumers and household decisions and investments are the costs and (financial) benefits involved. Financial costs but also time and opportunity costs play in general a key role in the decision making process. And, in some cases even more important, the return on an investment and estimated profit are very important determinants in the decision making process of households, especially in cases of bigger, long term investments like PV systems (Solomon, 2011). In short, financial reasons are important in the decision making process. Hence, the following sub question is formulated:

> *2a. What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?*

Financial motives are important for investment behaviour of households. Nevertheless, there are many other reasons why households do what they do and buy what they buy. Insight in these motives will give is very important for the marketing of domestic solar panels and development of the solar panel market. Knowing why consumers buy certain products gives valuable knowledge in the search of new consumers in the PV market. The same counts for barriers withholding households from investing in solar panel systems. These barriers show why consumers hesitate to invest in solar panel systems and what the motives not to invest. These barriers will (indirectly) show what can and possibly should be done to make solar panels a more attractive household investment. The following sub question is constructed:

> *2b. What are household motives and barriers for buying a PV system?*

The final sub question is not about the motives and barriers to invest in domestic solar panel systems, but is more about the characteristics of households who do so. Social demographic characteristics like family composition, education level and income are valuable data for all kinds of reasons. To be able to target the right group in solar panel marketing and policies, data the current users are very useful. For that reason, the following sub question is formulated:

> *2c. What are (social demographic) characteristics of households with a PV system?*

Overview

Summarizing, this research is based on two main research questions which are both split in three sub questions. An overview of all the research questions can be found in Table 1.

Table 1. Overview of the research (sub-) questions

Research (sub-) questions	
RQ 1	**What are the real life savings for households after the installation of a PV system?**
1a	*How much energy is used in the entire life cycle of PV systems?*
1b	*How much do households annually save after installation of a PV system?*
1c	*What factors affect PV capacity and actual PV energy production?*
RQ 2	**What are the factors and determinants involved in the household decision making process of PV systems?**
2a	*What are the financial benefits and bottlenecks and which role do they play in the household decision making process of PV systems?*
2b	*What are household motives and barriers for buying a PV system?*
2c	*What are (social demographic) characteristics of households with a PV system?*

1.4 Structure

For the sake of readability this thesis is divided into six parts. Part I, started with an introduction in the world of PV systems and a description of the research outline and research questions.

The next chapter in this part will explain more about the basic principles of solar systems, their history and their possible future. It shows the development and market from a world, European, Dutch and regional perspective and will go into depth on (Dutch) policies created to promote the use and production of solar panels. This chapter will also elaborate on the different ‘saving calculators’ available on websites and provided by institutions and explain their strengths and weaknesses. In short, the chapter will give an overview of all important background information that is needed to fully understand the world of solar panels.

Part II will be used to answer some of the sub research questions and to form hypotheses for the others. Each sub question will be addressed and if possible answered based on scientific literature and theories. If answering is not possible, hypotheses will be formed.

Part III will elaborate on the method used to test the hypotheses formulated in Part II. It will explain the research design, the target group, sample and the methods used to analyse and update the found data in the literature.

The results of the research and the data analysis are presented and discussed in Part IV. Based on the data answers will be given to the sub research questions.

Part V is for conclusions, discussion and managerial and household implications. The answers of the sub questions will be used to answered the two main research questions. Recommendations for further research will be given and explained.

Part VI is the last part of this research, and in this part the references and appendices can be found.

2 Photovoltaic Systems

2.1 Photovoltaic technology

Solar panels, or photovoltaic cells are used to convert solar power into electricity. Photovoltaic (PV) is a combination of the words photo ('light') and voltaic (electricity). PV converts solar irradiance into electricity that can be used in on-grid and off-grid applications (Milieucentraal, 2011).

2.1.1 Basic principles

Without going too much in to detail photovoltaic technology basically means that light particles (photons) are transformed in to electricity. One solar panel consists of multiple connected photovoltaic cells (PV cells). PV cells are generally based on two layers of semi-conductors (often silicon), one positively charged and one negatively charged. The field between the two layers causes a current to flow when light shines on the first layer of silicon (see Figure 1). The more light and the higher the intensity of the light, the greater the flow of current. The current from all the connected panels is collected and fed into an inverter, which changes the direct current (DC, or 'gelijkstroom in Dutch) from the panels into alternating current (AC, or 'wisselstroom' in Dutch). This makes it possible to use it for appliances at home, to feed the electricity into the (national) electrical grid or to use in off-grid systems. (Powersun, 2011). The two main components of solar cells are sunlight and silicon, both with no limitations to its availability and therefor attractive alternatives for conventional power generation from fossil fuels (Anders & Ebihara, 1982). However, the purification of silicon is a time and energy consuming process. Over the last decade a lot of research is done on using less pure silicon without losing productivity. This has led to cost reductions and is one of the main reasons why solar panels are getting cheaper each year (Photo Voltaic Technology Platform, 2010; Zonnefabriek, 2013) (more about this can be found in chapter 2.3.1).

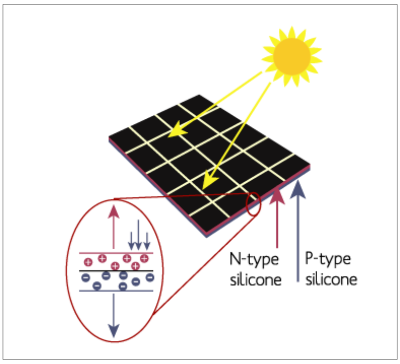


Figure 1. Basic principle of photovoltaic power generation. Source: Powersun (2011)

Figure 2 shows the basics of residential PV power production. Solar panels are needed to create power which is changed from DC to Ac by an inverter. When electricity is needed in the household it will stay in the house. If it is not needed at that time it will flow back to the electricity grid. A kWh meter keeps track on how much electricity is given back to the grid. In the Netherlands this means that the conventional electricity meter will fall, in many other countries you can sell the electricity that is fed back to the energy supplier. Later in this report, more about these concepts will be explained.

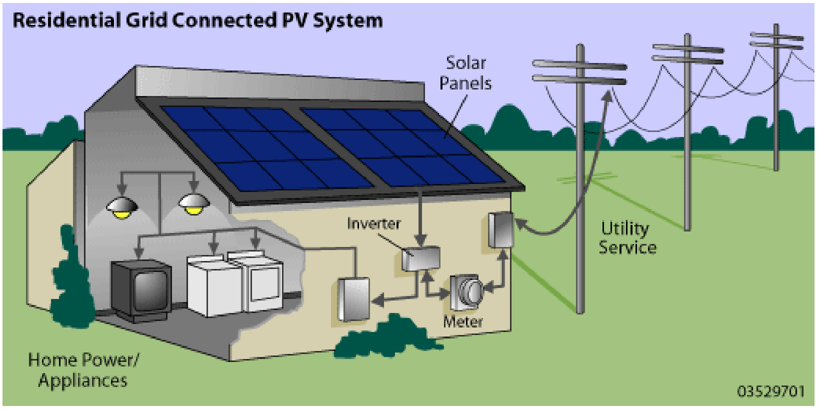


Figure 2. Schema of domestic PV installation. Source: Energy Education (2013)

2.1.2 Important features of PV technology

Before going into depth about how and where PV technology is used it is important to look at the most important features of the technology. They seem pretty obvious, and they are, but they must be taken into account at all times.

Light dependent

The first, and probably the most, important feature of PV technology is that it needs light. The technology is very simple in the sense that no light means no power. This makes PV power a somewhat unreliable source of electricity since it depends on weather conditions and time of the day how much power it produces. It means that if a house (or entire grid) is depending solely on PV power a secure supply of energy is not possible (yet). It also means that, until better and cheaper options are found to store or save electricity, PV power cannot be used as the only power production unit in a system that needs supply security. Other sources of energy are needed to back up the shortage of electricity when PV power supply is low (Fleischhauer & Neubacher, 2012).

Distributed generation

Another important feature of PV technology is that it allows individuals and households to generate their own (green) electricity. Unlike most windmills or hydro power systems, PV systems are small enough to install for domestic use. The production of energy in households (instead of in large central power plants) is called *residential distributed generation* or *micro generation* (Pepermans et al., 2005; van der Veen & de Vries, 2009). It requires changes in the electricity grid because households no longer only take electricity *from* the grid put also return power *to* the grid. The grid must be able to handle large peaks of electricity uploaded to the grid (for example on a sunny day) from an enormous amount of places on the same time. Not only the grid must be ready for this, also policies had and have to be made how to pay for this energy produced by households. One of the most common policies are the so called 'feed-in-tariffs' (FiTs). It basically means that households get paid for all the electricity they produce. Energy distributors are obliged to buy this electricity from households for the money it cost to produce it. Since the investment costs for solar panels are relatively high it means that the FiTs are often higher than the price for conventional energy. In countries with high FiTs it is very attractive to produce your own electricity and feeding it back in to the system. In the Netherlands there are no FiTs but a slightly different system called 'salderingsregeling'. In short this means that the electricity that is returned to the system is subtracted from the amount of grey energy taken from the grid. It means that, on sunny days, the kWh meter will spin backwards. More about this can be found in chapter 2.6.

Productivity place and context dependent

A third important feature is that the real capacity of a solar panel differs depending on where it is placed. In the Netherlands, one solar panel produces on average 160 to 190 kWh per year (Consumentenbond, 2013a). In countries closer to the equator, where the years are filled with more sun hours, the production potential of a solar panels is a lot higher. For example, the Sahara has three times more available solar energy potential than Scandinavia (Atama, 2013). The available sunlight is not even the biggest problem for countries far away from the equator. The extreme seasons make the supply of PV power very uncertain and therefore less popular.

There are more factors and determinants important for the success and productivity of solar panels. More are listed and explained in the chapter 3.1.

Watt Peak

The electricity produced by PV systems is measured in Watt. Since the amount of power produced by a PV system depends on many different (contextual) factors it can be difficult to compare the actual performance of different systems. For that reason there is a concept called 'Watt Peak'. This is the capacity of a solar panel system under set conditions. These Standard Reporting Conditions are globally set by the ASTM (2011). When, in the world of PV technology and in this research, the concepts 'capacity' is mentioned this always means under the set conditions of 25° Celsius, 1.5 air mass and a light intensity of 1000 $W/m^{2.}$ More about this can be found in chapter 3.1.

2.2 Renewable energy

PV power is what is called a ‘renewable’ energy source. Renewable energy means that it comes from sources that in principle do not run out and are continuously replenished like wind, sunlight and water. In a world where fossil fuels are running out quickly but where the energy demand is continuously growing – a global growth of approximately 2.5% per year – renewable energy is an attractive alternative for conventional sources (Islam & Meade, 2013; BP, 2012). The worries about energy security are one reason why renewables are seen as the future, another reason can be found in the global concerns about the climate change and global warming.

20-20-20 targets

To keep the previously mentioned negative environmental effects of this era limited it is important that the greenhouse gas emissions are reduced or at least restricted. One of the bigger initiatives to do so is the European ‘20-20-20 targets’. These targets were set in 2008 and have three objectives for 2020:

- A 20% reduction in EU greenhouse gas emissions from 1990 levels;
- A 20% improvement in the EU's energy efficiency;
- Raising the share of EU energy consumption produced from renewable resources to 20%

  (EC Climate Action, 2012)

The most important target (reduce emissions) is already adjusted over the last three years. The EU now aims for a 30% reduction in greenhouse gas emissions by 2020 (Europese Commissie, 2010).

> *The greatest potential for further emission reductions is in electricity generation. This potential comprises a combination of power savings by industrial users and households, reduced transmission losses through more efficient grids and greater investment in low-carbon means of electricity production such as renewable energy.*
>
> (EC Climate Action, 2012: p.FAQ).

The European 20-20-20 targets are just one example of political measures to limit the global warming and climate change, but shows how important renewable energy is and that it is going to be even more important in the future.

That renewable energy is getting more important can also be derived from the annual growth of renewable energy capacity (see Figure 3).

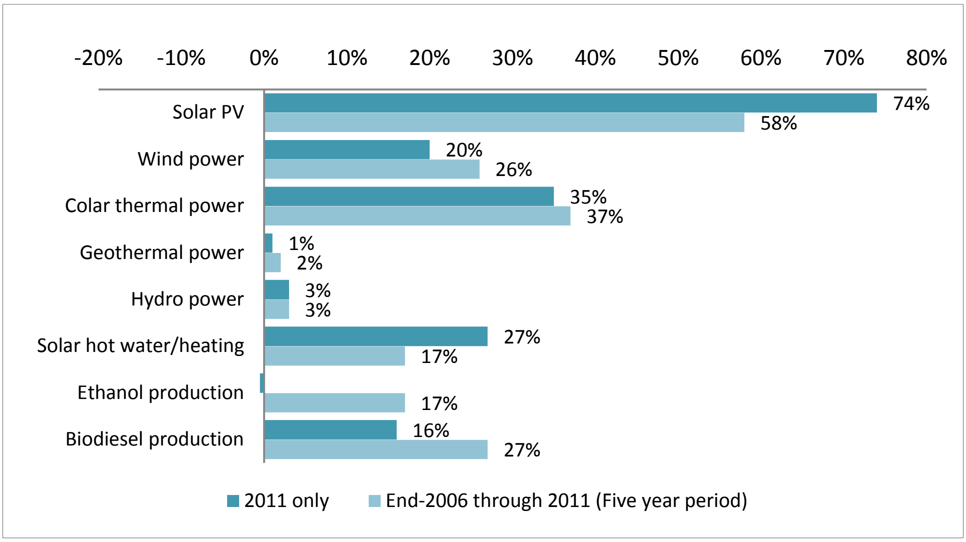


Figure 3. Average annual growth rates of renewable capacity in Europe (2006-2011). Source: own picture based on data from REN21 (2012)

It is important to notice that in comparison to the entire world production and consumption of energy, renewables still play a very small role (see Figure 4). Depending on future policies, technological development and consumer acceptance renewables can continue to grow, but so will the demand for energy. Interesting to see in Figure 3 is that solar power experiences *relatively* the biggest growth compared to other renewables. More details about the history and the rise of the photovoltaic technology will be discussed in the next part of this chapter. Later the technical details of different PV systems will be explained.

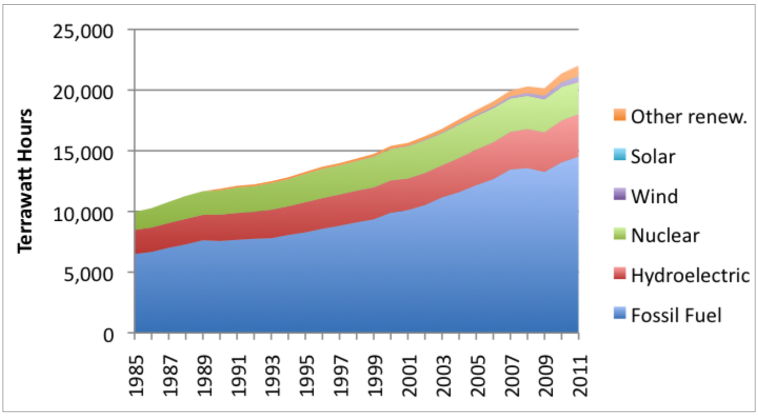


Figure 4. World Energy Mix (in terra watt hours). Source: BP (2012)

2.3 History of PV technology

PV technology is often held for a twentieth century invention but that is not true. This chapter will give a brief overview of the history of PV technology.

In 1839, at the age of nineteen, a Frenchman called Alexandre-Edmond Becquerel, accidently discovered the photovoltaic effect. He experimented with electrolytic cells made from two metal electrodes and found out that exposing certain metals and materials to the sun made them generate small bits of electricity. In his experiment he "used an electrode consisting of a sheet of platinum covered with a thin layer of silver chloride. The nature of the second electrode is not entirely clear from his account, but it was probably a sheet of platinum" (Williams, 1960: p.1505). By doing so he generated photo voltage and photocurrent. Because of his work on this topic the photovoltaic effect is sometimes also referred to as the Becquerel effect (Anderson & Chai, 1976).

It takes forty more years before Adams and Day see the same effect in a solid, selenium (Rappaport, 1959). Even though that the basic knowledge was already there it takes a lot more time to realize the actual potential and need for PV technology. In the fifties of the twentieth century interest in the technology increases but it takes until the eighties that scientific and commercial interest grows. From that moment on technology develops steadily resulting in a growth in efficiency and a decrease in price per produced Watt (see Figure 5).

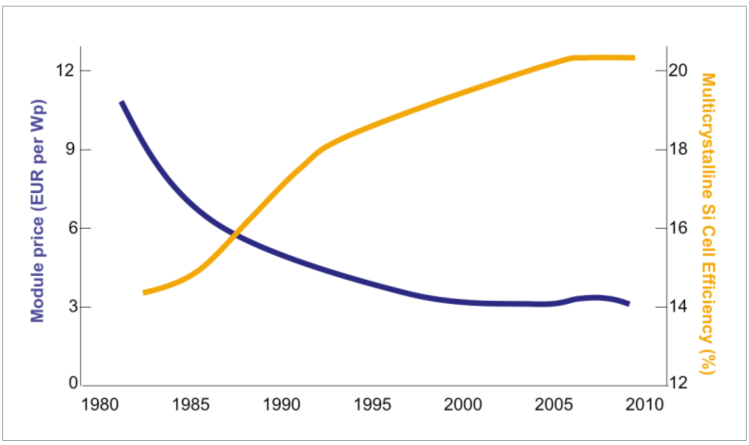


Figure 5. Module price and Cell efficiency over time (1980-2010). Source: Photo Voltaic Technology Platform (2010)

In the eighties the application of the PV technology could mostly be found in small household devices like calculators, radios and lamps (Sunlight Electric, 2010). After extensive subsidy programs by among others the German government the application of solar cells on rooftops experienced a big growth.

For a very long time solar panels were an investment with a very long payback time with no security of actual profit. Nowadays, PV technology continues the trend of rising efficiencies and decreasing prices. This combined with the increased life span of domestic solar cells results in a lower return on investment time (ROI time). The option to produce your own electricity on the rooftop is therefore a more and more attractive alternative to conventional energy.

2.3.1 Grid parity

Conventional energy costs are rising every year and due to the technological developments in the PV sector photovoltaic energy is, in Europe, very close to competing with conventional energy. This momentum at which the "present value of the long-term net earnings (considering revenues, savings, cost and depreciation) of the electricity supply from a PV installation is equal to the long-term cost of receiving traditionally produced and supplied power over the grid", is called *dynamic grid parity* (EPIA, 2012: p.9). This grid parity may be in range for some countries, others are not even close. The PV market has, due to the high investments required from the buyer, always been driven by incentives like subsidies or tax benefits. At the moment, "PV market deployment still depends on the political framework of each country" (EPIA, 2012: p.9). It must be clear that, depending on national initiatives and policies, the PV market is different. The next section will look at the PV development and markets from a global, a European, a Dutch and a local perspective.

2.4 PV development in the world

From a global perspective the last decade showed that PV technology has big potential. The growth over the last ten years has been substantial and continuous enough that it is safe to say that PV technology will take over a growing part in the world's energy mix (EPIA, 2012; IRENA, 2012). Solar energy is currently the third most important renewable energy source, after hydro power (water) and wind power. However, it must be noted that compared to the conventional sources of energy (like nuclear, gas or fuel oil) solar power is still a very tiny player on a very big market (see Figure 6).

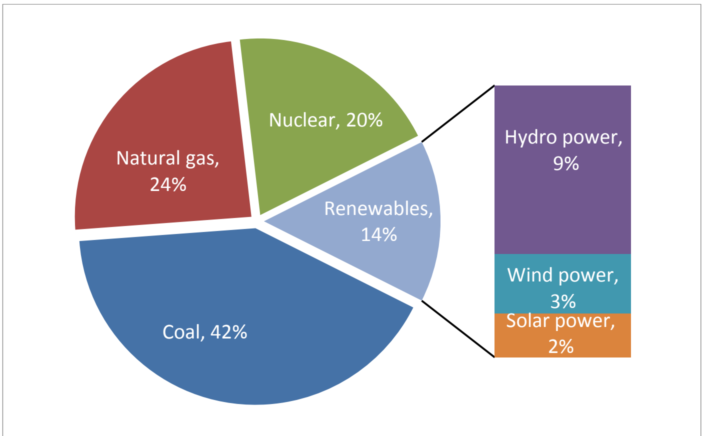


Figure 6. Global Energy Mix – 2012. Source: own figure based on data from B&V (2012)

The world's cumulative installed PV capacity reached the level of 100 GW in 2012 (see Figure 7). In terms of new installations this means that in 2011 and 2012 respectively 29.6 and 30.1 GW were connected to the grid and made operational.

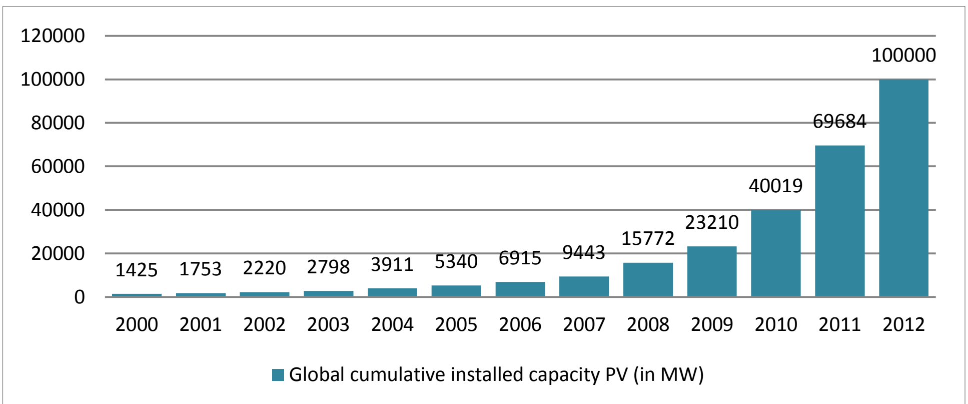


Figure 7. Global cumulative installed capacity of PV connected to the grid 2000-2012 (in WM). Source: own figure based on data from EPIA (2012)

The capacity of 100 gig watts means the same amount of power capacity as 16 coal power plants or nuclear reactors. It also means that each year, "the world's PV installations reduce CO2 emissions by 53 million tons" (Winneker, 2013).

This massive growth in PV installations is mainly due to effective policies and government action in frontrunner countries like Germany, Italy and the most recently also China. In the year 2011 (more recent figures are not available yet), about 60% of the globally installed capacity was installed in Germany and Italy alone (IEA, 2012). "If China, the US, France and Japan were also included, then over 86% of PV installations in 2011 occurred in six countries with over 1 GW" (IEA, 2012: p.4). These numbers also show that there are very large differences between countries. More details can be found in Figure 8. It must be noted that this 2011 map shows the PV capacity per habitant and not the total PV capacity of a country. The total PV capacity of the different continents can be found in Table 2.

Table 2. Total installed PV capacity at 2011 (MW). Source: EPIA (2012)

Europe (excl. Russia)	51,718
APAC	7,769
America	5,053
China	3,093
MEA	1,717
Rest of the world	336
Total	69,684

From the figures and table it is obvious that there are some big differences between countries. Were Europe (and most importantly Germany) has been installing new PV capacity for years, some 'new' parts of the world are now slowly starting to catch up. "Many of the markets outside Europe, in particular China, the USA and Japan, but also Australia and India, have addressed only a very small part of their enormous potential…" (EPIA, 2012: p. 11). To ensure growth in the PV sector investments and developments in PV in these countries are very important.
Europe, with 51,718 MW installed PV capacity is by far the market leader in this industry. It has shown big growth year after year, mainly caused by a few countries that have taken the lead (like Germany and Italy). The next section will show that within Europe there are some big differences between countries and elaborate on the causes and future scenarios.

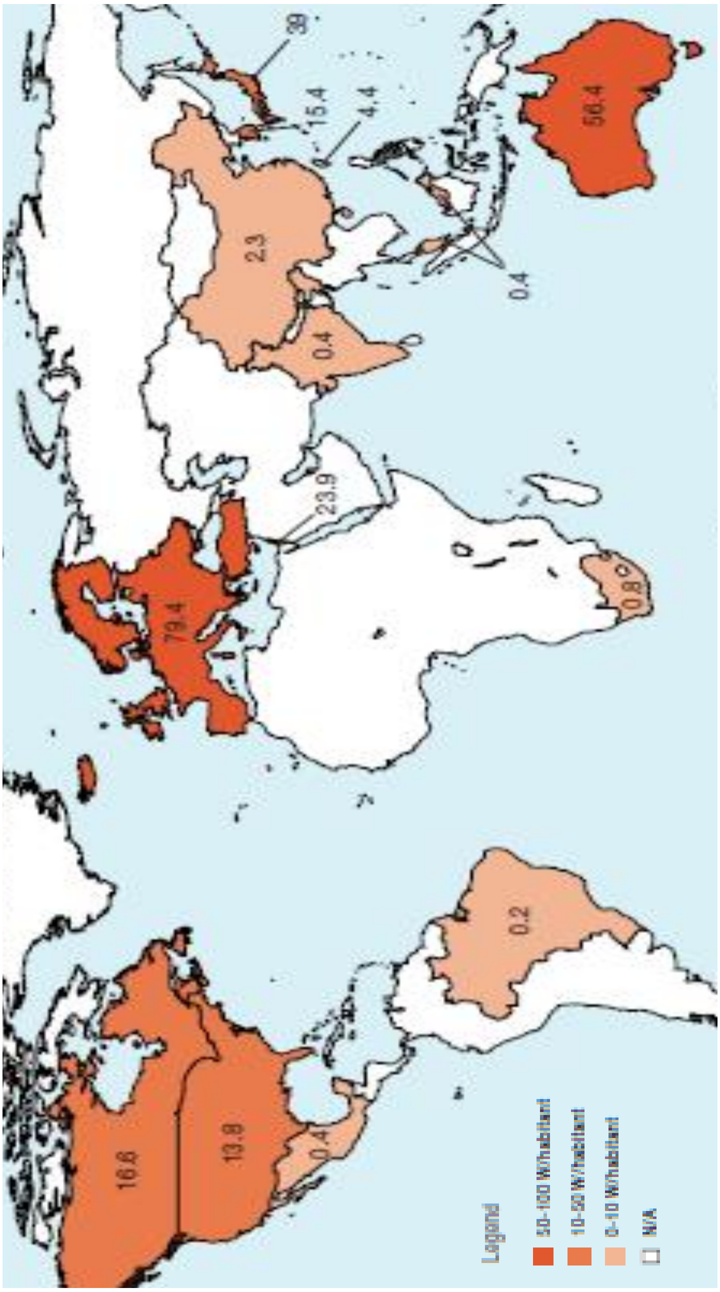


Figure 8. Global PV power map (in W per habitant). Source: EPIA (2012)

2.5 PV development in Europe

Over the past three decades Europe has always been the world leader in PV installations. In 2011 Europe produced on average 79.4 Watt per habitant, the highest average in the world (see also Figure 8). As explained before, is this mainly the result of a few countries that have been very active in this field. When giving a good look at Figure 9 and Table 3 it is obvious that the international differences are significant. Germany and Italy are the big players, followed upcoming countries by Spain, France, Belgium and the Czech Republic.

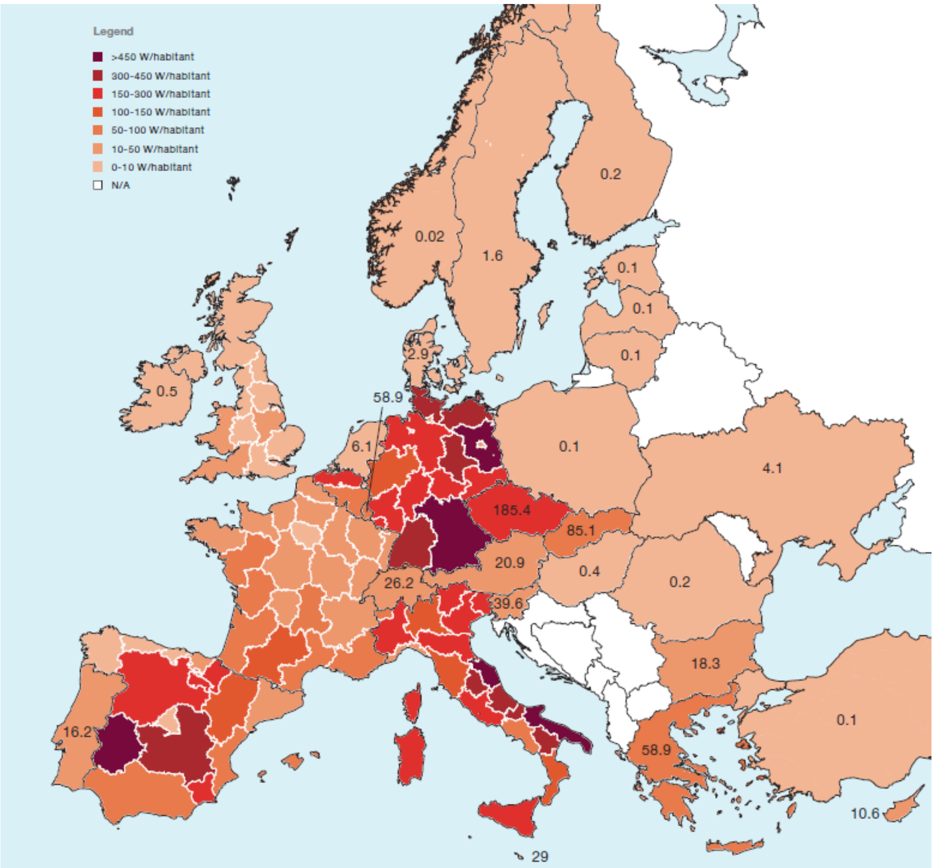


Figure 9. European PV power map (W/habitant). Source: EPIA (2012)

Table 3. Total installed capacity in Europe (in MW) at 2011. Source: EPIA (2012)

Austria	176	**France**	2,659	**Luxembourg**	30	**Slovenia**	81
Belgium	2,018	**Germany**	24,678	**Malta**	12	**Spain**	4,400
Bulgaria	135	**Greece**	631	**Netherlands**	103	**Sweden**	15
Cyprus	9	**Hungary**	4	**Norway**	0.1	**Switzerland**	216
Czech Republic	1,959	**Ireland**	3	**Poland**	3	**Turkey**	6
Denmark	16	**Italy**	12,754	**Portugal**	184	**Ukraine**	190
Estonia	0.2	**Latvia**	0.2	**Romania**	3	**United Kingdom**	875
Finland	1	**Lithuania**	0.3	**Slovakia**	468		

The Netherlands, often self-proclaimed front runner in so many technological fields, can in the case of PV power be found somewhere in the middle with total installed capacity of 103 MW in 2011. The Netherlands do not belong to the countries that hardly produce any PV energy (like some countries in Northern or South-eastern Europe) but they are not even close to catching up with the top ten PV producing countries of the EU. More on the Netherlands can be found in the next section.

Interesting to see is that, besides Germany and Italy other EU countries are rapidly increasing their installed PV power (see Figure 10). This growth line is often not a linear line representing steady growth but is, since PV growth is still strongly depending on national policies and Feed-in-Tariffs (FiTs), a line hard to predict on forehand. A good example in this case is Spain. Spain experienced a massive growth in installed PV capacity from 2007 to 2008. However, policy changes in 2008 and 2009 and low governmental support on FiT levels made the rise of PV power stop in Spain. It is an important lesson for other countries and the PV industry in general: it is still hard to grow without good (supported) FiT tariffs (or similar system) and without the government financially and legally supporting.

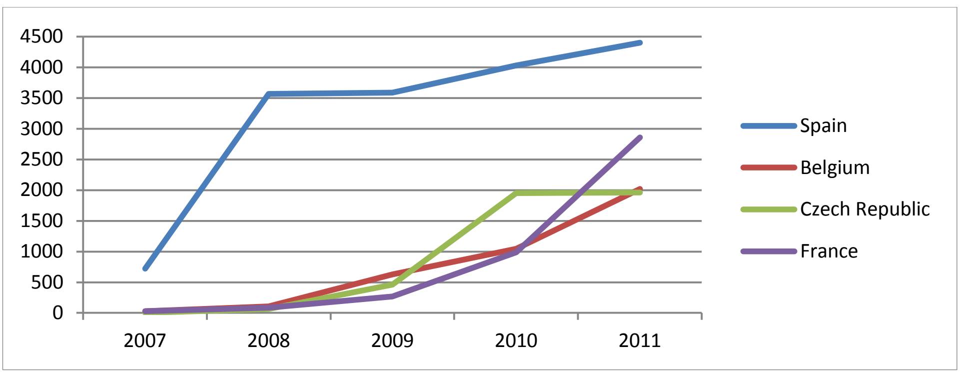


Figure 10. Cumulative installed PV Capacity 2007-2011 (in MW) in the countries Spain, Belgium, Czech Republic and France. Source: own figure based on data EPIA (2012)

2.5.1 Germany

History and current situation

Germany has been the number one PV country in Europe and in the world from the very beginning and has shown "a constant commitment from policymakers to support the development of PV" (EPIA, 2012: p.15). This also shows in Figure 9 and Table 3 in the previous section: Germany has the highest PV capacity per habitant (302.8 W/habitant) and the highest installed in 2011 (24,678 MW). At the end of 2012 the total installed capacity in Germany was 32.3 GW (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2012). Enough to provide on average 3% of all the energy in Germany. But, since PV power is light dependent it has peak times which means that it can produce a share that is a lot higher than 3% on sunny days. On May 26th 2012 Germany set the world record in solar production, over 40% of the total electricity consumption that day was PV power. At that day solar technology in Germany produced over 22 GW per hour (Kirschbaum, 2012).

The question why Germany is so far ahead of every other country in the world is easy to answer. Over the last two decades the German government has given the PV power technology a massive 'push' by putting billions of euros in subsidies and promotion policies. In 1990 a first attempt was made by introducing the Feed-in-Tariffs for renewable energy in the "Electricity Feed Law" (Stromeinspeisungsgesetz, 1990). This was the start of a very successful governmental subsidy program to promote renewable energy. In 2000 the German government replaced the Electricity Feed Law by the 'Renewable Energy Act' or EEG (Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz - EEG), 2000). This act meant the real take-off of renewable energy in Germany. In the last 12 years the installed capacity grew with more than 25,000 MW, doubling every 1.5 year (see Figure 11).

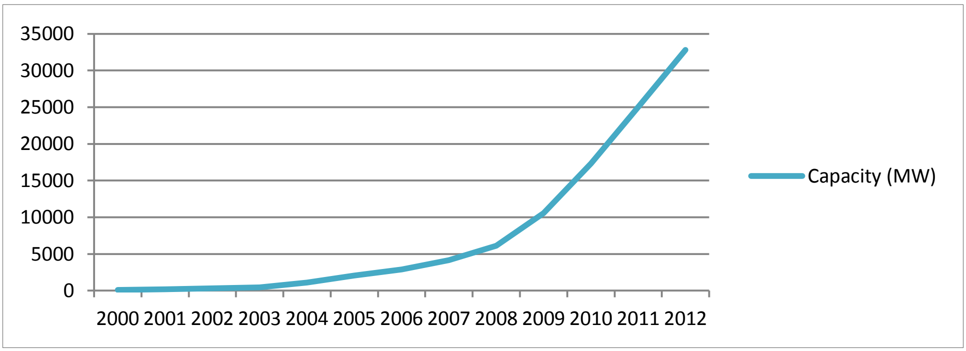


Figure 11. Cumulative installed PV Capacity 2000-2011 (in MW). Source: own figure based on data from German Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2012)

The main driver of the success of the German policy is the previously mentioned system based on Feed-in-Tariffs (FiTs) (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2012; ECN, 2008). These FiTs offer long term contracts to all renewable energy producers, including households and individuals. The FiTs offer a fixed price for every produced kWh for a set period of time of approximately 20 years. It basically means that every (domestic) producer is entitled to receive a price (that covers the investment) from the utility company which buys the energy and resells it to consumers (European Commission, 2009; ECN, 2008).
Especially in the beginning years, the high FiTs made PV systems a popular investment because it guaranteed a (profitable) return. Nowadays PV producers still get a generous payment for the electricity produced. In fact, the tariffs are often higher than the price for conventional energy. This difference is covered by all German electricity consumers who pay a fee of 3.5 cents per kWh (Dekker, 2012). Up to today there is no boundary or maximum number of installed PV systems that can benefit from these FiTs, making the policy even more popular (Sinke, 2011). On the other side, its popularity makes it also an extremely expensive policy.

The front runner position of German on the PV market has, according to supporters of the German Renewable policy, proven the success of the policy and the FiTs. However, as in the case of many expensive policies and programs, there are also many people and institutions against the German pro-solar policies. It is an interesting debate that is very valuable for future policy making.
Before going into depth about this debate, it is necessary to know something about the 'why'. The German government has set two main targets for itself concerning renewable energy. In 2020, 35% of all energy consumption should come from renewable sources. In 2030 this should be 50%, in 2040 65% and in 2050 it should be 80% (Gesetz für den Vorrang Erneuerbarer Energien, 2008; Osborne, 2012). These renewable energy targets are at the basis of the Erneuerbare-Energien-Gesetz (2000) but are not the only reason for spending billions of dollars on it. Another important reason and argument is the creation of jobs by developing the PV industry in Germany.

The debate in Germany is mainly about one important question: are all the billions spent on this PV subsidies and FiTs worth it? By 2030 the money spent on PV subsidies will probably exceed the 100 billion euros. In an era where the world is faced with financial crises, €3 billion spend per year is of course a lot. People and groups against the German solar power policy claim that there are better, more effective ways to spend this much money on renewable energy.
In January 2012 the German newsmagazine Der Spiegel placed a criticizing article about what they called "Germany's blind faith in the sun" (Neubacher, 2012a). Their main point is that "solar is by far the most inefficient technology among renewable energy sources, and yet it receives the most subsidies". One of the arguments they give is that 56% of all the available subsidies for renewable energy goes to PV technology but that it

only produces 21% of all subsidized energy. It is one of the many articles and publications that fight the idea that the German PV policies works perfectly and should be the example for the rest of the world. Another argument against this policy is that it is turned out to be, a as the opponents call it, 'subsidy bubble', especially in the field of job creation. They basically claim that the subsidies have indeed led to job creation, but for a very short period of time. The German PV industry grew very rapidly, providing thousands of jobs but became a victim of its own success (Müller & Neubacher, 2012). The demand for PV systems became so high that Chinese producers started (cheap) mass production of solar panels, causing lots of PV manufacturers to close and thousands of Germans to lose their job. "In 2004, Germany held a 69 per cent share of the global solar panel business… by 2011 it had declined to 20 per cent" (Neubacher, 2012b).
From a global perspective however, the development of the Chinese PV industry has been a very good thing. It has led to major price drops in PV technology of approximately 45% per year since 2006. "Chinese PV cell producers have reduced costs by 4.5 times in just the last 5 years" (Mathews, 2012).

The German subsidy debate is very interesting and there are some good arguments for both sides but in general the conclusion is that Germany has by far the largest installed PV capacity of the world. For sure, without the German policies this would not have been the case. Germany, but also other countries like Italy and Spain have proven the success of governmental intervention and subsidies. The success of those countries stands out against countries like the Netherlands, that are far behind on PV technology. Since this research will focus on the Netherlands the next chapters will look into its current situation, its PV history, the policies and its targets.

2.6 PV development in the Netherlands

The Netherlands have, compared to other countries in Europe still a long way ahead of them, concerning PV technology. With a total of 260 MW grid and non-grid connected installed capacity at the end of 2011 the Netherlands are not even close to a top ten place on the list of countries with the highest amount of PV energy production (CBS, 2012a; DNV Kema, 2013). Nevertheless, being far behind on the rest of Europe does not mean that the Netherlands have not been trying. The share of PV power in the total electricity mix of the Netherlands has grown from 0.01% in 2001 to 0.09% in 2011 (CBS, 2012a). The growth since 2000 can be found in Figure 12 which shows the total installed capacity and the actual PV electricity production, which is always lower than the installed capacity (see chapter 3.1.).

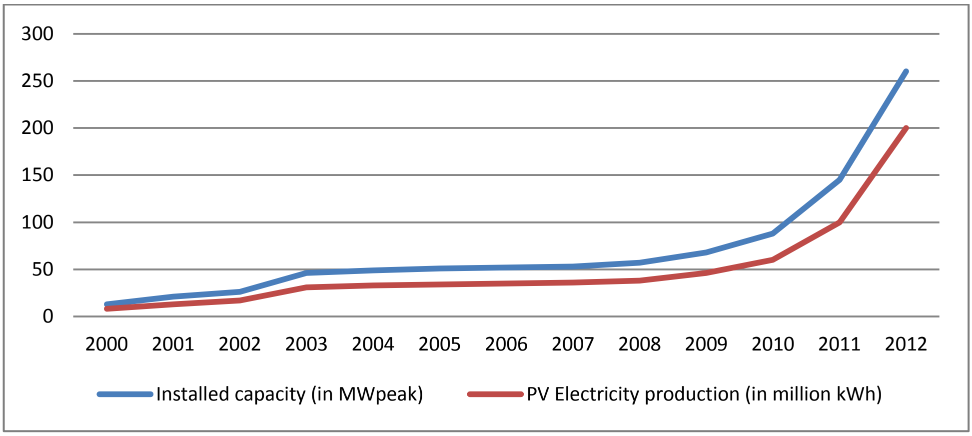


Figure 12. Installed capacity and PV electricity production in the Netherlands 2000 - 2011. Source: own picture based on data from CBS (2012a)

To get a full picture of the (domestic) PV market it is useful to look at the governmental policies and subsidies. The next section will elaborate on that topic.

2.6.1 History of policy and subsidies

Over the last two decades the Dutch government has tried to promote and encourage the use and production of renewable energy by the use of different measures and policy. The most important regulations are described in this section. Figure 13 shows a timeline of these measures and regulations.

In 1996 the 'Regulating Energy Tax', or REB (Wet Regulerende Energiebelasting, 1995) was set. This was a fee (duty) on the use of electricity and gas. Green power was excluded from this tax to promote the use of green electricity. The tax still exist as the 'Energy Tax' (Energie belasting) but the original REB was in 2003 replaced by the

Environmental Quality Electricity Production Regulation, or MEP (Ministeriële Regeling Milieukwaliteit Elektriciteits Productie, 2003).

In the meantime, between 2001 and 2003 the ‘Energy Premium Regulation’, or EPR (Energiepremieregeling, 2001) was active as well. This subsidy program focused on households and individuals that invested in energy saving measures (including isolation of houses and AAA washing machines) or renewable energy production systems (including PV systems and solar heat collectors). Depending on the type of investment an investment subsidy was granted. This regulation was for many people a reason to buy more sustainable appliances, hence the EPR was very popular. The EPR had a maximum of granted subsidies of 54 million, which was reached in 2003; this meant the end of the EPR.

The in 2003 introduced ‘Environmental Quality Electricity Production Regulation’, or MEP (Ministeriële Regeling Milieukwaliteit Elektriciteits Productie, 2003) was a subsidy program that subsidized companies and individuals who produced renewable ‘green’ power from wind, sun, hydro and biomass. This subsidy was a fixed amount per kWh (with a maximum of €0.07 per kWh) given for a period of ten years. The regulation had an open end, meaning that the maximum number of participants and subsidies granted was not set. This made the regulation extremely popular but also financially uncontrollable. Halfway 2005 the minister of economic affairs at the time, Laurens Jan Brinkhorst, showed the Dutch government that the MEP was getting too popular and therefore too expensive. This lead to an adjustment of the subsidy maximum to €0.00 in 2006. The result was that the ‘frozen’ MEP did not give any more subsidies, until the end of its existence in 2008 (Bontebal, 2010).

A new regulation, to replace the ‘old’ MEP regulation, was accepted in 2008 and is still in place. The new policy measure is called the ‘Regulation for Promotion of Sustainable Energy Production’, or SDE (Besluit Stimuleringsregeling Duurzame Energieproductie, 2007). The main aim of the SDE is to promote renewable energy production. Since the SDE is at this moment still in place, the next section about the current situation will go into depth about the SDE.

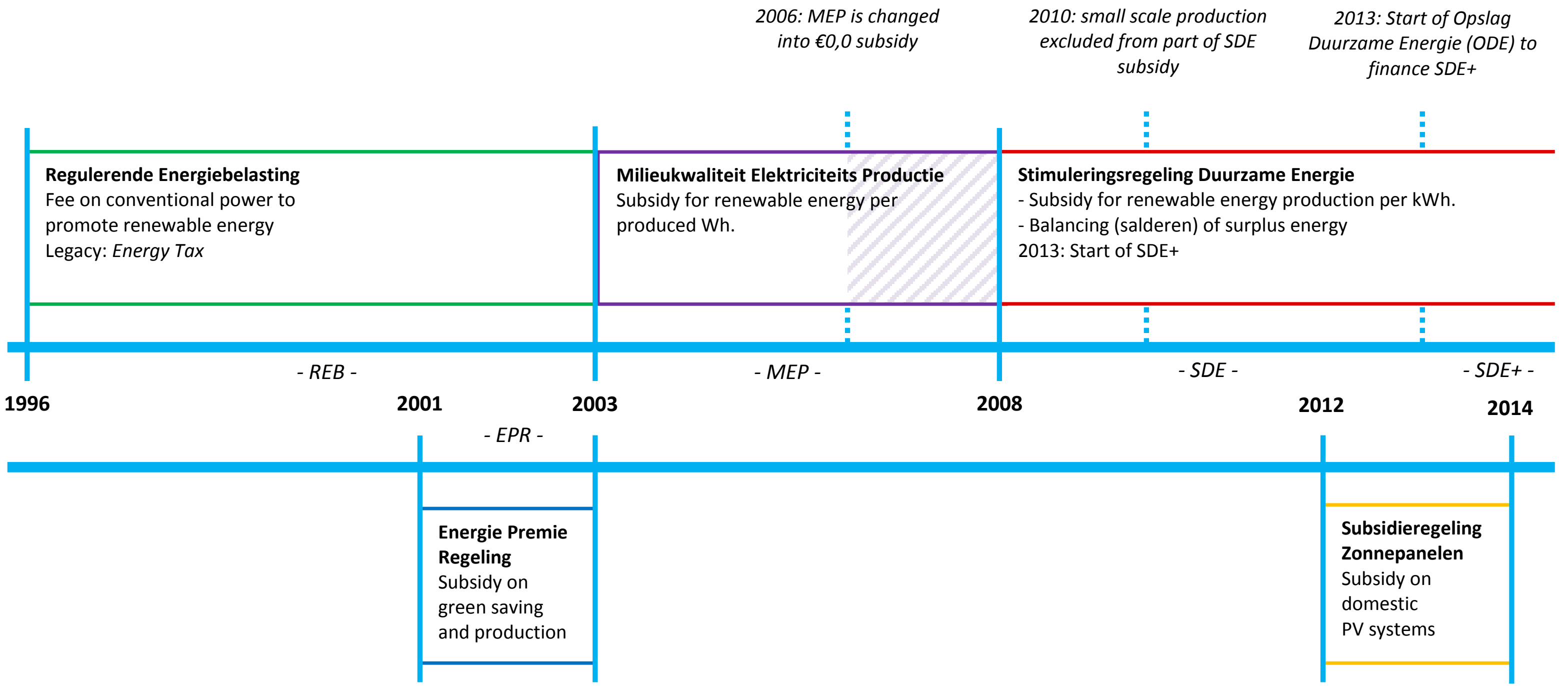


Figure 13. Timeline of Dutch policies to promote renewable energy use and production

2.6.2 Current situation of policy and subsidies

The 'Regulation for Promotion of Sustainable Energy Production', or SDE (Stimuleringsregeling Duurzame Energieproductie, 2007) is at the moment the most important 'general' regulation of the Dutch government to promote sustainable energy production. Next to this more general regulation for many types of sustainable energy production there is also a separate investment subsidy available for households and individuals that invest in domestic PV systems. Both will now be discussed.

SDE

The SDE regulation is, as explained before, mainly there to promote the small- and large scale production of renewable energy (including PV systems). The SDE was started in 2008 to replace the frozen MEP regulation. The SDE is based on the principle that the producer of renewable energy is reimbursed for the difference between the costs of producing the energy and the earnings from the produced energy. The earnings of the producer (from feed-in-tariffs and savings from own direct use of the power) are often not enough to earn back the investment made. The SDE compensates the differences between the costs and the earnings (Agentschap NL, 2013a; Besluit Stimulerings Duurzame Energieproductie, 2007). The two most important pillars of the SDE are:

- Depending on a 'basic price' (basisbedrag) and a 'correction price' (correctiebedrag) the subsidy per kWh is set each year (see Figure 14).
    - The *basic price* is the average cost price of a renewable production system (e.g. a PV installation) in euros per kWh. This basis amount is set per year but once assigned to a request it is fixed for a certain period of time. In the case of PV systems it means that this number is fixed for 15 years.
    - The *correction price* is the average electricity price per kWh in a year and should be equal to the feed-in-tariffs of conventional energy suppliers.
    - The SDE subsidy per kWh is set each year by subtracting the correction price from the assigned basic price.
- The SDE makes it possible to 'balance' (salderen) the produced surplus. This means that energy that is fed back in to the grid may be subtracted from the conventional energy consumption.
    - Balancing means that for every kWh that is put back in to the grid the producer or household gets the same price as it pays for conventional electricity (including taxes and transport costs). This happens when the electricity produced on a certain moment is more than the electricity needed at that same moment. The power is than fed back to the electricity grid: on that moment the kWh meter will spin backwards.
    - This balancing can be done up to 5,000 kWh. In 2011 the original maximum of 3,000 kWh was increased to 5,000 kWh. If the balancing maximum is exceeded the conventional energy supplier is obliged to give a 'reasonable' price for the extra energy fed back in to the grid.

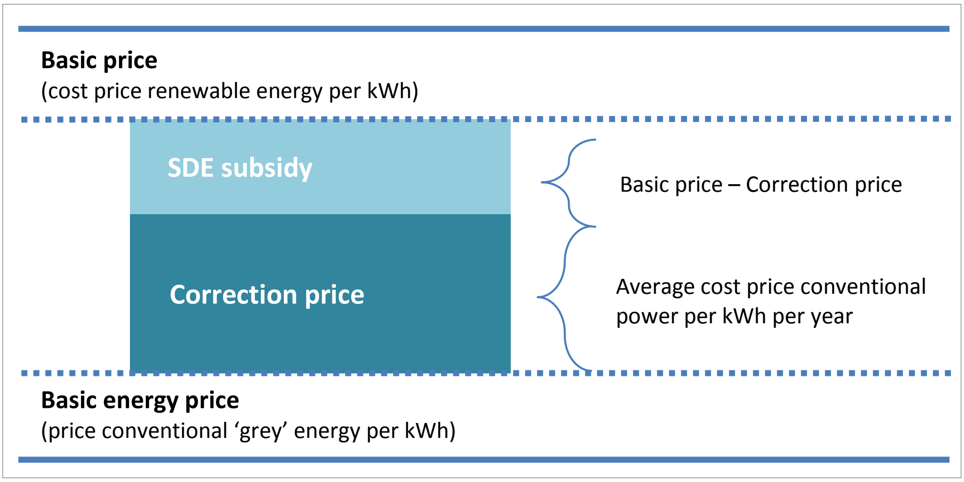


Figure 14. How the SDE subsidy works. Based on SDE+ 2013 (Agentschap NL, 2013a)

It must be noted that in 2010 the first part of the subsidy was cancelled for small scale (domestic) energy production, it now only applies for producers of more than 3x80 Ampere or more. The balancing regulation (up to 5,000 kWh) of the SDE does still apply for households and small scale renewable production (Bontebal, 2010; Rijksoverheid, 2010). The chance of households actually exceeding the maximum of 5,000 kWh for balancing are not that high in the current situation, especially in urban areas. To produce that that much electricity a households needs at least 26 correctly placed solar panels (34 m^2). But household use is subtracted from it first so approximately 44 panels (45 m^2) are needed to be able to feed 5,000 kWh back in to the grid. Houses in urban areas simply do not have that much space. Nevertheless, if households do exceed the maximum balancing amount they SDE states that the must still get a 'reasonable' price for the extra electricity they feed in to the grid.
Every year the SDE budget and the correction prices are determined on the 1st of April. On this same day the subsidy application period opens. This application period stays open until December 19th of that year or until the maximum amount of granted subsidies is reached (a first come, first served system) (Agentschap NL, 2013a).

SDE+
Since January 2013 there have been some small adjustments to the original SDE regulation, resulting in a 'new' regulation called 'SDE+'. Besides some technical changes that are relevant for large scale energy producers, is the most important change that the budget is drastically increased. Kabinet Rutte-I and Rutte-II increased the budget from 1.4 billion to 3.8 billion until 2020 (PBL, 2012). For the year 2013 the budget is 3 billion euros (Agentschap NL, 2013c). The main target groups of this policy are companies and non-profit organizations that generate renewable energy (Agentschap NL, 2013a).

ODE

Untill the end of 2012 the SDE regulation was paid from the Dutch natural gas benefits (in Dutch 'aardgasbaten') but to finance this SDE+ extra funds were to be found. That resulted in a new (extra) tax which has to paid by households and companies. This is defined in the 'Tax for Sustainable Energy Act', or ODE, (Wet Opslag Duurzame Energie, 2012) which is active since the 1st of January 2013. It means that an extra duty or tax has to be paid on every used kWh (electricity) and m3 (gas). This extra fee will increase every year, see Table 4.

On average this means that a regular household will pay nine to ten euros extra in 2013; in the future it will experience a steady growth. For example in 2018, an average family will pay approximately 150 euros for the ODE and that will only increase in the future (Energiemaatschappijen, 2012; Wet Opslag Duurzame Energie, 2012).

Table 4. ODE tax per unit of used electricity/gas in euros until 2016 (excl. VAT) Source: Own table based on Wet Opslag Duurzame Energie (2012).

Electricity	**2013**	**2014**	**2015**	**2016**
0 - 10.000 kWh	0.0011	0.0023	0.0036	0.0056
10.000 - 50.000 kWh	0.0014	0.0027	0.0046	0.007
50.000 - and more	0.0004	0.0007	0.0012	0.0019
Gas				
0 - 170.000 m3	0.0023	0.0046	0.0074	0.0113
170.000 - 1.000.000 m3	0.0009	0.0017	0.0028	0.0042
1.000.000 - 10.000.000 m3	0.0003	0.0005	0.0008	0.0013
10.000.000 and more	0.0002	0.0004	0.0006	0.0009

The introduction of the ODE tax means another addition to the already high tax share (Energy Tax and VAT of 21%) in the energy bills of Dutch households. Figure 15 shows the composition of the energy bill of an average Dutch household (2.2 persons) with an annual power consumption of 3500 kWh and 1650 m^2 gas (Milieucentraal, 2013a; NUON, 2013). It shows that less than half of the money spent on power pays for the actual electricity and gas supply. The rest is paid for taxes and grid management.

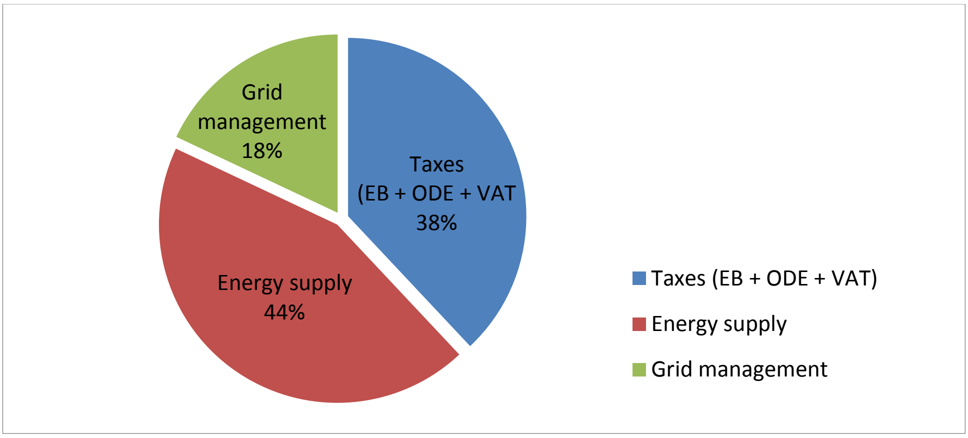


Figure 15. Composition of energy bill of average household in the Netherlands. Source: own picture based on NUON (2013).

Subsidy on solar panels

An important but somewhat controversial step in the development of the Dutch domestic PV market is the new subsidies available since 2012. Based on the governmental agreement (Lente-akkoord), during the cabinet Rutte-I, new subsidy arrangements were set in 2012 by the former Minister of Economic Affairs, Agriculture and Innovation Maxime Verhagen. Technically this new subsidy on PV installations is part of the adapted Regulation Subsidies for Energy and Innovation (Subsidieregeling Energie en Innovatie, 2008), but it is very often referred to as the 'Subsidy on Solar Panels' (Subsidie op Zonnepanelen) (Staatscourant, 2012; Ministerie van Economische Zaken, Landbouw en Innovatie, 2012).

The most important points of this Subsidy on Solar Panels are:

- The solar panel subsidy is only accessible for individuals and households, not for businesses use and companies (one application per address).
- The subsidy can be requested for 15% of purchase amount, including material costs and converter. Labour costs are excluded. De maximum amount of subsidy per address is €650.
- Only PV installations with a kilowatt peak of 0.601 or higher qualify for subsidy, with a maximum of 3.5 kilowatt peak per household. The solar panels must be bought on or after July 2nd 2012.
- The budget for this subsidy was 22 million euro in 2012 and 30 million in 2013. If the budget is exceeded no new subsidies will be granted (first come, first served system). The official application period ran from the 2nd of July 2012 until the 28th of December 2013, 17:00h.

- To prevent this subsidy and the SDE+ from overlapping, PV systems connected to the grid via a connection with a pass value of more than 3*80 Ampere are not subsidized.
  (Ministerie van Economische Zaken, Landbouw en Innovatie, 2012; Staatscourant, 2012)

In 2012 the entire subsidy budget of that year was granted within five months. The very first day (July 2nd) the number of applications was so high that it caused errors and eventually shut down the application website of Agentschap NL (Subsidie Zonnepanelen, 2013). The latest data provided by Agentschap NL (2013b), the official executor of the subsidy regulation, showed that on the 8th of August 2013 a little over 90,000 solar panel subsidies were applied for. This meant a subsidy request of €50,882,000 and the end of the application period. In the period after the 8th of August until the end of December 2013 no more subsidies were granted. What will happen in 2014 and later is still highly uncertain.

The recent subsidy debate

The Subsidy on Solar Panels was a temporary policy measure to give the Dutch PV market a positive push (Ministerie van Economische Zaken, Landbouw en Innovatie, 2012). The fact that the new regulation only lasted for two years makes it a regulation that calls for debate. The opinions about it often conflict. On the one hand supporters claim that a subsidy like this is a good way to support small household initiatives to create a more sustainable country and future (Milieucentraal, 2012). On the other hand, opponents state that a short term subsidy arrangement will only mean a temporary run on solar panels followed by a complete standstill of the entire Dutch PV market and industry. They claim that subsidy budgets run out quickly meaning that people who missed the boat will wait for a new subsidy to be announced, which may take years or not come at all (Uneto-Vni, 2012; Ottens, 2012; Hoe-koop-ik.nl, 2012). Another point they make is that nowadays subsidies are no longer needed to make domestic PV installations profitable. As an alternative they advocate among others a greener and more sustainable tax system (Uneto-Vni, 2012).

EIA

(Small) businesses, entrepreneurs and companies that invest in PV systems or other forms of renewable energy production are not included in the previously mentioned Subsidy on Solar Panels. They are supported via the SDE+ but also can benefit from other governmental regulations and tax rebates. The most important benefit granted by the Dutch government, together with the SDE+, is the ‘Energy Investment Rebate’ or EIA (Energie-Investeringsaftrek, 2013; Agentschap NL, 2013d). In 2013 the EIA means that companies can subtract 41.5% of the investment costs from the taxable profit. In reality this means on average a 10% tax benefit per year and in the case of PV systems a reduced use of conventional energy. The EIA is not only used to promote PV systems but to promote and encourage the production and use of renewable energy in general. On the ‘Energy List 2013’ approximately 160 green investments are listed that are deductible (Agentschap NL, 2013e). The budget for 2013 is 151 million euro and the minimum investment is €2,300,- to qualify for the EIA (Agentschap NL, 2013e).

Government targets and PV future

The main reason for the previously explained and other governmental measures and policies can be found in the ‘renewable energy targets’ the Dutch government has set for itself. Derived from and based on the European 20-20-20 targets the Dutch government has set a similar goal for renewable energy. In 2020, 16% of the energy consumption in the Netherlands should come from renewable sources. As a reference point, in 2012 this share was only 4.7% so there are some big steps to make the coming years (Rijksoverheid, 2013). The targeted share of PV power within this “16% target” is only 3.75% (12PJ), the equivalent of 0.6% of all energy consumption. This seems small, almost insignificant, but is in fact a PV capacity growth of approximately 600 MW per year, resulting in 4 GW peak installed PV capacity in 2020 (ECN, 2013). Eventually, in 2050, all energy supply most come from renewable sources (Rijksoverheid, 2013). The latest data about the Dutch PV capacity growth in 2012 show a positive future perspective. “The development of the Dutch PV sector has gone a lot quicker than expected in 2012…the 4 GW target for 2020 has been a very conservative target” (Sinke in DNV Kema, 2013). On the long run we will learn what the share of PV power will be in the future Dutch energy mix.

2.7 Local initiatives and collectives

Even though the costs of PV installations have decreased drastically over the last ten years it is still for many households considered to be a large investment. Before 2012, when there was no subsidy on solar panels people tried to create their own financial benefits. To be able to lower the cost for Dutch households different 'collectives' were founded. The basic principle of these collectives is that they are able to negotiate good prices with suppliers because they have come with large orders. The more people join a collective, the bigger the order, the more suppliers who want to win that order, the higher the discounts. But collectives are not only useful for lower prices; they also serve as service point for questions and help. They often arrange information days where they inform people about the world of solar panels. An example can be found in Box 1.

Box 1. Example Solar Collective: Wij Willen Zon

wijwillenzon

Betaalbare zonne-energie voor iedereen

As an example of how solar collectives work, we will now look at one the first big solar panel collectives in the Netherlands. This collective was called *We Want Sun* ('Wij Willen Zon' in Dutch) and started in January 2010. With more than 5000 participants, it was the first large scale solar panel collective in the world. At the end of 2011 all the panels from China had arrived and were installed. The households and benefitted from a 32% discount on the original price (Wij Willen Zon, 2012). In this collective the installation was not included, later collectives did offer the entire package. Even so, *We Want Sun* has been a successful pioneer in the world of solar panels.

II

Literature Review

3 Findings Answers

The previous chapter has elaborated on all the important basic (background) information needed to understand the world of PV technology and its potential. This chapter will go more into depth on the topics related to the research questions. Scientific literature, reports and other sources will be used to find answer on the research question formulated in chapter 1.1. Some questions will be answered completely in this chapter, for some questions hypotheses will be formulated. For details see Table 5.

Table 5. Research (sub-) questions and the strategies

Research (sub-) questions		Strategy
RQ 1	**What are the real life savings for households after the installation of a PV system?**	
1a	*How much energy is used in the entire life cycle of PV systems?*	Answer found in literature
1b	*How much do households annually save after the installation of a PV system?*	Hypotheses based on literature
1c	*What factors affect PV capacity and actual PV energy production?*	Answer found in literature
RQ 2	**What are the factors and determinants involved in the household decision making process of PV systems?**	
2a	*What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?*	No answer or hypotheses found
2b	*What are household motives and barriers for buying a PV system?*	Hypotheses based on literature
2c	*What are (social demographic) characteristics of households with a PV system?*	Hypotheses based on literature

At the end of this chapter all the answers and hypotheses will be schematically depicted. The hypotheses will than later be tested by analysing data collected from a questionnaire. The first section of this chapter will look for the answers related to the actual savings and saving potential (questions 1a – 1c). For the sake of readability the order is slightly different than the order depicted above. The chapter starts with answering research sub question 1c, followed by 1a. The questions 1b and 2a are combined and answered in one section. The second part will elaborate on households and PV technology (questions 2b-2c). The title of every section relates to the research question.

3.1 Actual savings and saving potential: Factors

What factors affect PV capacity and actual PV energy production?

How many households save from producing their own electricity by a PV system depends, as explained before, on the consumption of power and how much power is produced. Manufacturers and suppliers of PV installations often give a technical prediction of how much electricity the system can produce. This ‘capacity’ assumes ‘standard’ set conditions (ASTM Standard Reporting Condition) to be able to compare different types of installations (ASTM, 2011; King et al., 2002). These conditions are internationally set at a solar irradiation of 1000 W/m^2, a 1.5 air mass and a temperature of 25° Celsius. The maximum power production under the these set conditions is called the Watt peak (Wp) of a system (Sinke, 2001).

Since ‘perfect conditions’ do not exist in real life, especially not in the Netherlands where nothing is so unpredictable as the weather, the ‘real capacity’ in the Netherlands is estimated based on the factor 0.86 (Milieucentraal, 2012). This means that in the Netherlands it is, based on experience, generally accepted that on average 1 Watt peak will produce 0.86 kWh. The actual production of PV power is never the same, and often a lot lower than the peak power because there are many variable factors involved that affect the actual production of PV power in households (Mani & Pillai, 2010; King et al., 2002). To predict how much power a PV system will produce suppliers often use this factor to inform their customers about the possible yield. In most cases the capacity in Wp is given accompanied by the predicted yield. For example, *PV system X has a 2000 Wp capacity and a 1800 kWh yield* (Zonnepanelen.nl, 2013). However, the factors suppliers use are, like in this example, often higher than 0.86. This can lead to overly positive predictions of the possible power production and leads to situations in which it is difficult to compare different PV systems. This research will use the more conservative 0.86 factor.

Based on the current knowledge found in scientific literature and other sources a model showing all the important and determining factors was composed (Figure 16). It was found that four main factors are important: the properties of the PV system, the placing of the PV system, the location of the PV system and the behaviour of households concerning the PV system. This chapter will look at all these factors and explain how they affect the actual household production of PV power.

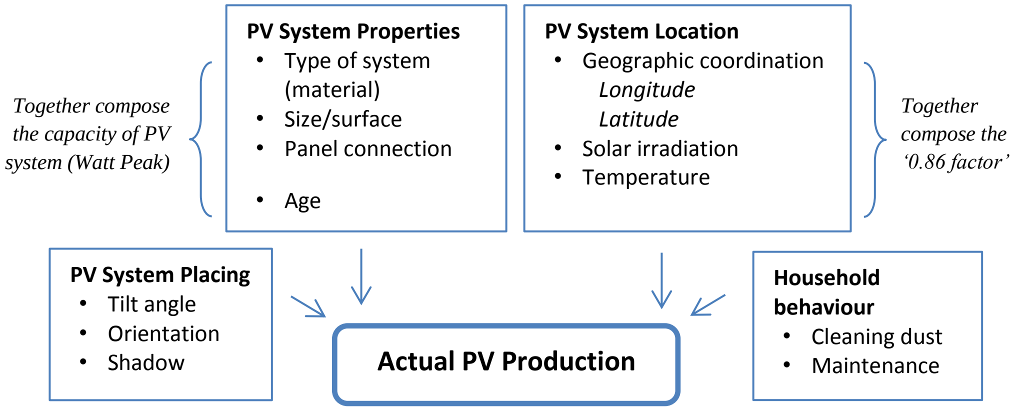


Figure 16. Factors determining the actual PV power production. Source: Own depiction based on various sources (see text).

3.1.1 PV System Properties

One of the determining factors of how much power a PV system produces is what type of system it is. There are different types of solar panels, made from different materials that result in different yields. How many panels are installed, its size, its age and whether the panels are interconnected all influence the final output (Mani & Pillai, 2010; King et al., 2002).

Panel type

There are three main types of photovoltaic cells that can be used for domestic applications.

- Mono-crystalline
- Poly-crystalline
- Amorf/thin film

The most important differentiating factors between these material types are cell efficiency, costs, weight and flexibility. Of these differentiating characteristics only cell efficiency has a real influence on the actual power production of a PV panel. To be able to fully understand this effect on the power production it is important to take a closer look at all three types of materials. It will also provide some insight in why households decide to choose a certain type of system.

The concept 'PV cell conversion efficiency' (or simply called cell efficiency) is addressed in this chapter and before reading a definition is needed. "The conversion efficiency of a photovoltaic (PV) cell, or solar cell, is the percentage of the solar energy shining on a PV device that is converted into electrical energy, or electricity" (EERE, 2011: *Photovoltaic Cell Conversion Efficiency*).

Mono-crystalline

The most efficient, but also most expensive type of PV installations is based on mono-crystalline (single-crystal Si) solar panels. The cells in these panels consist of solid, unbroken silicon from cylinder shaped silicon ingots created by the Czochralski process (NREL, 2012). "To optimize performance and lower costs of a single mono-crystalline solar cell, four sides are cut out of the cylindrical ingots to make silicon wafers, which is what gives mono-crystalline solar panels their characteristic look" (Energy Informative, 2012: *Which Solar Panel Type is Best?*). See Figure 17 for these characteristic blackish wafer shaped cells. On the current market mono-crystalline cells reach an efficiency of 14% to 20%, the highest available. This means that 14 to 20 percent of all the sunlight falling on a cell is converted into electricity. Because of its high efficiency but also high costs these panels are mostly used in households with limited space available (EPIA, 2012; Energy Informative, 2012; Solarwijzer, 2013).

Figure 17. Mono-crystalline solar panel

Polycrystalline

The most commonly used type of domestic PV systems is based on polycrystalline cells (multi-crystal Si). Solar panels based on polycrystalline cells are cheaper but also less efficient than solar panels based on mono-crystalline cells (GH Solar, 2012; NREL, 2012). To produce poly-crystalline cells "raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers" (Energy Informative, 2012: *Which Solar Panel Type is Best?*). These types of solar panels can easily be recognized by their blue, mottled appearance (see Figure 18). Today, poly-crystalline cells reach efficiency levels of 12% to 16%. Due to the lower efficiency, more PV cells and therefore more space is needed to reach the same output as mono-crystalline systems. It is, on the other hand, significantly cheaper than mono-crystalline systems (EPIA, 2012).

Figure 18. Poly-crystalline solar panel

Thin Film

The last type of PV cells is called Thin Film Photovoltaic Cells (TFPV) and is by far the least frequently used type in domestic applications. The main reason for this is that they may be cheap but also require a lot of space. Compared to mono-crystalline based

Figure 19. Thin film solar panel

systems thin film systems need up to four times more space and are therefore not very attractive for domestic use. But, since they cost a lot less, "in situations where space is not an issue, thin-film solar panels can make perfect sense" (Energy Informative, 2012: *Which Solar Panel Type is Best?*). There are different materials and processes used to produce thin film cells but in general they have a homogenous black appearance and their efficiencies vary between 6% to 12% (EPIA, 2012; Energy Informative, 2012). This is a lot lower than the previously explained type of cells. One of the big advantages of thin film cells is that they can be made flexible and that they weigh a lot less than mono- and polycrystalline cells (GH Solar, 2012).

In conclusion, it can be said that there are three types of domestic PV systems used in the Netherlands. Table 6 shows their general characteristics and differences. It must be taken into account that the technology improves every year and the efficiency can and will increase in the future.

Table 6. Comparison of mono-crystalline, poly-crystalline and thin film PV panels

	Mono-Crystalline	Poly-Crystalline	Thin Film
Cell efficiency	14% - 20%	12% - 16%	6% - 10%
Costs	Expensive	Cheaper than mono-crystalline	Cheap
Weight per m^2	High	High	Low
Flexible possible	No	No	Yes

Capacity

Related to the cell efficiency is the Watt peak (capacity) of a system. The higher the cell efficiency, the higher the capacity per square centimetre. However, the capacity is always provided and calculated for the entire system and not per square centimetre. This means that system X with a higher cell efficiency might still have a lower Watt peak than system Y with a lower cell efficiency. Hence, cell efficiency is not the only factor that is important in determining the Watt peak: the number of installed panels, its size and whether they are connected or not also affect the capacity of the system. System Y might have been a lot bigger than system X, leading to the difference in capacity. In general, the larger the panel surface, the higher the yield (taken into account the cell efficiency differences).

Linkage

The linkage (in Dutch 'schakeling') of PV panels also affects capacity (Diaz-Dorade et al, 2010; King et al, 2002). In domestic application PV systems are either serially or parallel connected. Serial connection means that all panels are connected resulting in a 'string' of panels. The advantage of this system is that the inverter adds all the voltages to one before it reaches the inverter. The downside is that in this system the weakest link affects the entire string of panels. Partial shadowing on one of the panels will lower the power production of the entire system.

The alternative is a parallel connection, meaning that all panels are separately connected to the inverter. In this situation the individual performances of the panels do not affect other panels but it can never reach the accumulated voltage from serial linkage. Parallel linkage is recommended when one or more panels are partially overshadowed (Kajihara & Harakawa, 2005).

Age

A system property affecting the PV production but not directly related to watt peak system is the age of the system (King et al, 2002; Mani & Pillai, 2010; Nelson et al, 2004). In the course of time the performance of an installed PV system will slightly go down. The most optimistic predicted lifespans of solar panels go up to 35 years, depending on the type of material the solar panels are based on. On average it is assumed that a PV system is properly working for 25 years (Milieucentraal, 2012; Consumentenbond, 2013a). It is however, generally accepted that the performance of the panels in the system will decrease. Many suppliers and manufacturers offer 'performance guarantees'. For example de Dutch PV supplier MetDeZon, offers one mono-crystalline 100 Wp panel with a 12 year performance guarantee of 90% and a 25 year performance guarantee of 80%. In short this means that they predict that after 12 year the performance will have gone down to 90% of the original Watt peak. After 25 years it will be maximally decreased to 80% (Zonnepanelen.nl, 2011). The actual PV production of a system is influenced by its age, the older the lower the performance (compared to its original Watt peak).

3.1.2 PV System Placing

How a PV system is installed and placed is very important for the actual production of power. The tilt angle of the panels, the orientation of the panels and the presence of obstacles that block the sun all affect the productivity of the PV system.

In general, the highest productivity level is met when (unobstructed) sun light falls in on a solar panel from a straight angle. In the summer the sun stands higher in the sky than in the winter, hence, the optimal solution would be adjusting the gradient of the solar panels depending on the season. Since this is a difficult and often costly procedure the panels are often placed in the optimum gradient (Rowlands et al, 2011). The optimum gradient is, due to its position with respect to the sun, different for each country. In the Netherlands

the absolute optimum gradient is 36 degrees, but the average guidelines are stated as 'between 30 and 40 degrees' (Direct Solar, 2013; Agentschap NL, 2010). The optimum angle for PV systems in the Netherlands can also be found in Figure 20. The white dot (36° angle) shows the absolute optimal solution (100%) for the Netherlands, but it also shows that '95%' can still be met using a 15° to 55° angle. It shows that the angle a solar panel is placed in is important, but small changes from the optimal only slightly affect productivity. (Agentschap NL, 2010).
The figure also provides information about the orientation the PV installation must be placed in. In the Netherlands, solar panels are only usefull when they face southwest to southeast. The perfect solution can be found five degrees west from the south (see also Figure 20). Panels facing north are, in the Netherlands, per definition not profitable (Sinke, 2001; Agentschap NL, 2010).
In general for a PV system to be profitable in the current market, suppliers and collectives advice households to install PV systems under the conditions that it will at least be able to produce 95% of the production level (Milieucentraal, 2011).

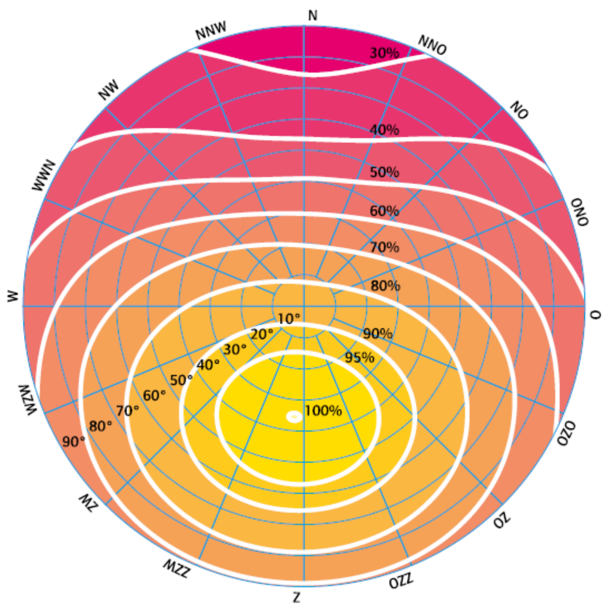


Figure 20. Irradiation in the Netherlands used to show the optimal angle and orientation of PV installations *(N = North, W = West, Z = South, O = East)*. Source: Agentschap NL (2010).

When PV systems are placed it is very important that there are no (big) obstacles around that will block the sunlight. (Partial) shading is "one of the main causes of losses in energy generation within photovoltaic systems" (Diaz-Dorado et al., 2010: p.134). As explained before, especially when panels are serial connected, partial) shadow on only one panel can cause the entire array to produce less power. In general for households it is recommended only to install a PV system when there are no or only very small obstacles blocking the sun, like antennas and chimneys (Woyte et al, 2003).

In conclusion we can say that the tilt angle, the orientation and shadow are important factors that influence the actual generation of PV power. For the Netherlands the absolute optimum placing is: in a 36° angle, facing 5° west of south and with no obstacles blocking the sunlight. Since there are many rooftops and buildings that cannot meet these criteria the following divisions will be used in this research, based on the research explained before. For the definitions of the placing conditions in this research see Table 7.

Table 7. Different conditions of placing based on tilt angle, orientation and shadowing

Conditions of placing	Tilt angle	Orientation	Shadow
Excellent	30° - 40°	South	None - small
Good	15° - 30° and 40° - 55°	South west – south east	Small - medium
Medium	5° - 15° and 55° - 65°	South west – south east	Small - medium
Bad	0° - 15° and >55°	North, south or west	Medium - large

Explanation of shadow levels
Small: *Short term shadows caused by small/medium obstacles like antennas, chimneys, etc*
Medium: *Long term shadows caused by small/medium obstacles like chimneys, trees. etc*
Large: *Long term shadows caused by medium/large obstacles like trees, buildings etc.*

3.1.3 PV System Location

Related to the rooftop placement of the solar panels is the geographical location of a PV system. The conditions for a household in the Netherlands are very different than for example a household in the Northern part of Australia. The geographic location of the PV system affects the production of PV power, mainly because of climatic differences. The Dutch '0.86' factor, is composed based on average conditions caused by the geographical location of the Netherlands (Milieucentraal, 2012).

The main reason why geographical location (longitude and latitude) is such an important factor for PV power generation, can be found in the concept 'solar irradiation' (IRENA, 2012). Since the earth is a globe the irradiation differs for different geographical locations. The amount of solar irradiation logically affects the amount of produced PV power. The annual irradiation depends on the *intensity* of the light and the *total number of sun hours* in that year.

In general the rule for solar intensity is the higher the light intensity, the higher the yield (see Figure 23a; Houssamo et al., 2010). In the Netherlands the intensity is seen as stable and is approximately 1.000 Watt per square meter surface (Agentschap NL, 2010; Meteonorm, 2012). Note that the light intensity in the Netherlands is the same as the standard reporting conditions (ASTM, 2011). Due to the geographic position of the Netherlands, the irradiance intensity is logically a lot lower than in other, more southern countries (see also Figure 21) closer to the equator.

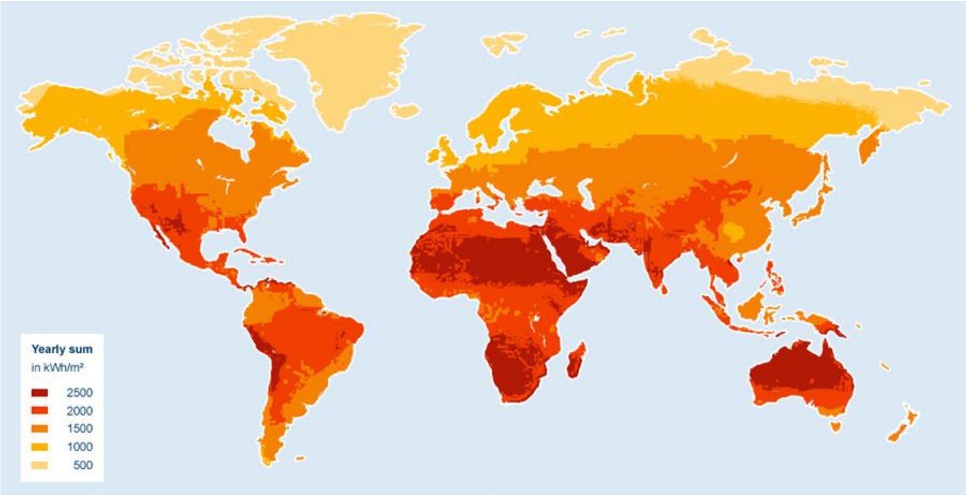


Figure 21. Global Solar Irradiance. Source: Creativ Handz Energy Solutions (2013), based on Meteonorm (2012).

Next to the intensity, the actual number of sun hours is also an important factor influencing the productivity of PV installations (Agentschap NL, 2010; Energie-technologie, 2010; Mani & Pillai, 2010). Unlike the intensity, which is more or less the same throughout the Netherlands, there are regional differences when it comes to sun hours. On average the (north-) west of the Netherlands has the highest annual number of sun hours, up to 1800 hours per year. Comparatively, for the east this is 250 hours less (KNMI, 2010). The long term average sun hours of the Netherlands can be found in Figure 22. In contrast to what many people think, PV systems do not only produce electricity when it is a clear day. Diffuse light on a cloudy day can still, to some extent, be enough light for PV panels to produce energy. How much this is, is very context dependent and different in every situation. This feature makes it harder to predict how much a PV system will produce on a certain day (Direct Solar, 2013; IRENA 2012).

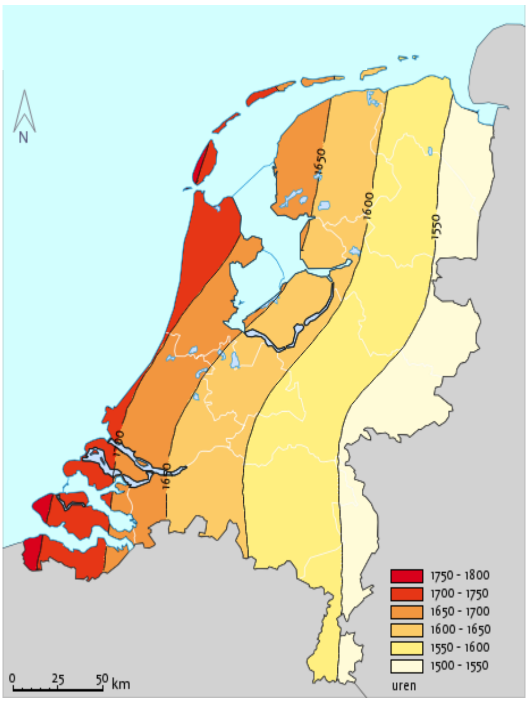


Figure 22. Long term average of annual sun hours in the Netherlands 1981 – 2010 (*Uren = hours*). Source: KNMI (2010)

Another factor involved in the actual PV power generation and related to the geographic location of the PV system is the operating temperature (King et al., 2002); Skoplaki & Palyvos, 2009). The operating temperature, or the ‘in-cell temperature’, is affected by different factors (among others wind and placing) but is mostly determined by the ambient temperature and solar irradiation. “Both the electrical current generated by a module and its voltage are independently influenced by the operating temperature” (King et al., 2002: p.1358). The peak power (Wp) of PV systems is, as explained before, measured under 25°C conditions. Unlike what is often assumed, the amount of PV generation decreases in case of high temperatures (King et al., 2002; De Haan, 2009). Figure 22 shows that higher temperatures do not lead to a higher yield. Predicting the in-cell temperature is very difficult because it depends on so many factors, hence the ambient temperature is often used as a tool to roughly predict the PV power production.

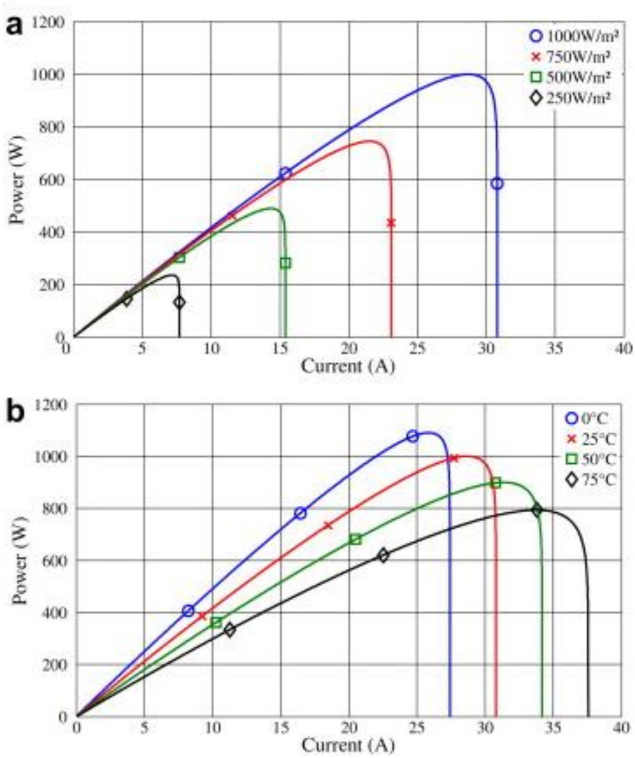


Figure 23. Effect of light intensity (a) and cell temperature (b) on PV power production. Source: Houssamo et al. (2010).

Concluding it can be stated that the geographical position is important for the actual PV power production. Since this paper is about the Netherlands, in further chapters the light intensity is assumed to be stable on 1000 W/m^2. The annual sun hours is on average 1400 – 1850 but are different per region and per year. Differences should therefore be taken into account when comparing different power outputs. The same holds for temperature differences. The ambient temperature of different locations should be taken into account when one is comparing PV power output. In short, when calculating and comparing the annual savings between households the location of the PV system must be taken in to account.

3.1.4 Household behaviour

There is only little research done in the field of PV household behaviour. PV systems are promoted as low maintenance, but they still ask some effort from the owners. For example by cleaning the panels or cutting leaves that cause shadow.

Cleaning

The impact of dust and soiling on the PV performance is recently only looked at by very view studies. Dust is generally defined as “minute solid particles with diameters less than 500 μm” but in this section it also refers to pollens and microfibers. These are “omnipresent and easily scattered in the atmosphere and consequently settle as dust” (Mani & Pillai, 2010: p.3125).
Sellers and manufacturers of PV systems often claim that the effect of dust on the PV yield is so little that cleaning is only needed every three to five years. They state that rain and wind are sufficient to keep the panels clean. A review of Mani and Pillai (2010) suggests otherwise. They reviewed all the available literature and studies on the effect of dust on PV output and concluded that there is indeed a strong decreasing effect on the yield. Type and amount of dust are the most determining factors when predicting the effect of dust on PV yield (Moharram et al., 2013). Mani and Pillai (2010) also state however that the amount and characteristics of dust are highly context dependent; making it difficult to generalize predictions for yield decreases in different areas and contexts.
The settlement of dust is affected by different factors, depicted in Figure 24. The local environment and the properties of the dust are the two main factors. The amount and type of dust in the Sahara is for example very different from dust in the northern parts of Scandinavia. To be able to give a precise prediction of the effect size of dust on the PV yield, measurements and study of the local dust properties and environmental characteristics are needed.

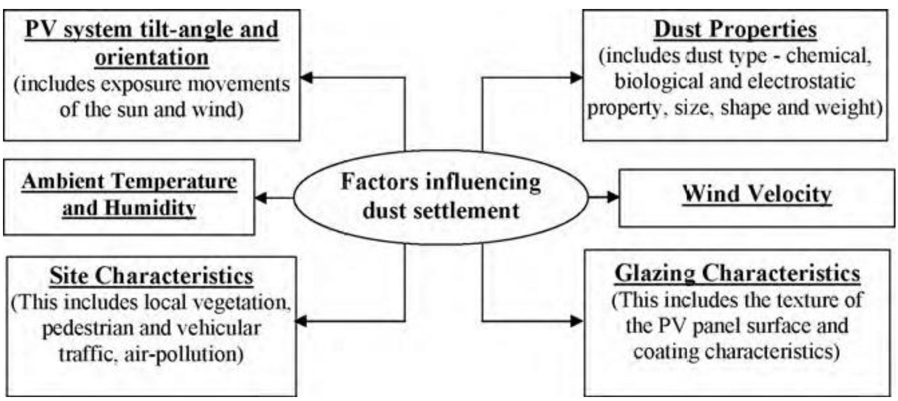


Figure 24. Factors influencing dust settlement. Source: Mani & Pillai (2010)

Because it is so difficult to give a generalizable prediction of the impact of dust the estimations often vary a lot. In the Netherlands TNO estimates a decrease in PV yield of 4.4% to 7.7% per year caused by dust and soiling lies in the range (TNO, 2009). More recent estimations are not available. An older research by the Solar Electric Power Association (SEPA) predicted that the decrease of PV production can be found somewhere between 10% to 25% in urban areas with lots of dust, bird droppings and city pollution.
Solar panel cleaning companies in the Netherlands often use the TNO and SEPA predictions as prove for the need of cleaning. Cleaning can also easily be done by the household members themselves with just a soft brush and clean water. Given the delicate surface and materials used in PV panels soap and hard brushes could affect the top layer and are not recommended. Provided that the panels are easily and safely accessible it should not be too much work to clean the panels.

There is no scientific research done among Dutch PV system owners if and how often they clean their PV panels. Based on the findings of TNO and SEPA cleaning is recommended but research is needed to see if consumers act upon this recommendation. For that reason this is included in the data collection of this research (read more in section 6.1.3).

Maintenance

Besides the cleaning needed once or twice a year, PV systems do not require a lot of maintenance. Making sure that the sunlight is not hindered by trees, bushes or leaves is the most important task. Since even small parts of shadow can decrease the PV yield significantly maintenance in this field is important.
Another type of maintenance is repairing or replacing parts of the systems that in time stop working properly. On average, after ten to 12 years the inverter must be replaced.

3.1.5 Conclusion

In this chapter there were many factors found that influence the actual electricity production of PV systems. They can basically be grouped into factors that belong to 'PV System Placing' (tilt angle, orientation, shadow), 'PV System Properties' (material, size, panel connection, age), 'PV System Location'(geographic coordination, solar irradiation, temperature) and 'Household Behaviour' (cleaning, maintenance). Some factors are more important than others but it must be clear that a PV system is only recommended under the right circumstances. Non-optimal placing could highly affect the performance of a PV system and decrease its actual electricity output.

The large number of factors involved shows that predicting what the energy output of the system will be is a very complex process because all the factors must be taken in to account. The effect size of each factor might be different for each location and context. Today an individual approach on household basis is needed for an accurate prediction of the output, and even then it is still extremely difficult. Nevertheless, rough estimations are important for comparison between different systems in the decision making process of households and in marketing practices.

Since in the Netherlands energy output meters are not installed in every PV system it will also remain difficult to accurately measure the actual PV production of an already installed domestic PV system. Nevertheless, once a PV system is installed, the real savings can be measured and compared to the estimated output. Accepting the assumption that the energy consumption remained the same, the savings can be treated as the energy output of the PV system.

3.2 Actual savings and saving potential: Life Cycle Analysis

How much energy is used in the entire life cycle of PV systems?

Like in many other power markets one of the statements often heard in the PV sector is "it takes power to make power" (Zehner, 2012: p.70). Milieucentraal (2012) states on their website that on average, a domestic PV system in the Netherlands needs three years before it has produced as much energy as was needed to manufacture the system. "From the mining of quartz sand to the coating with ethylene-vinyl acetate, manufacturing a photovoltaic solar cell requires energy" (Biello, 2008: in *Dark Side of Solar Cells Brightens).* Most PV production plants use fossil fuel energy (and release CO2) but lately there are more and more factories founded that use renewable energy sources, often hydropower. To find out what the exact savings are for households after installing a PV system it is important that the energy used in the entire life cycle of the system is taken into account. To know the actual production of a PV system the energy requirements for the entire life cycle should be subtracted from its yield. The entire life cycle of a PV system consists of all the different steps in the life of a PV system, from the raw materials, to the transportation to the end-of life disposal. All (general) steps can be found in Figure 25. A Life Cycle Assesment (LCA) means that for every single step in the cycle for example the amount of required energy and greenhouse gas (GHG) emissions are measured.

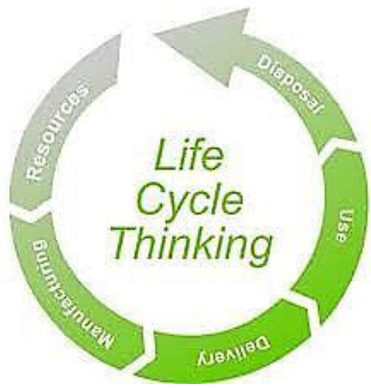


Figure 25. Steps of the Product Life Cycle

3.2.1 Energy Payback Time

To measure the amount of energy used in the entire life cycle the concept 'Energy Payback Time' (EPBT) is used. The EPBT is actually the "the time it takes (the PV system) to produce all the energy used in its life cycle" (Fthenakis, 2012: p.16). To calculate this EPBT the various steps in the life cycle of a PV system are taken into account, from manufacturing to the use to the disposal. The formula used is the following:

$$\textbf{Energy Payback Time} = (E_{mat}+E_{manuf}+E_{trans}+E_{inst}+E_{EOL}) / (E_{agen}-E_{aoper})$$

With the following definitions:

E_{mat} Primary energy demand to produce materials comprising PV system

E_{manuf} Primary energy demand to manufacture PV system

E_{trans} Primary energy demand to transport materials used during the life cycle
E_{inst} Primary energy demand to install the system
E_{EOL} Primary energy demand for end-of-life management
E_{agen} Annual electricity generation in primary energy terms
E_{aoper} Annual energy demand for operation and maintenance in primary energy terms

Until the eighties it was very difficult to create a PV system that had a ‘Energy Return Rate’ (ERR) of more than 1:1. This meant that, in general, a PV system never produced as much energy as it cost to create the PV system, to use it and to dispose it. However, over the last 30 years there is a large amount of research done and technology developed. So “today’s PVs return far more energy than that embodied in the life cycle of the PV system” (Fthenakis, 2012: p.16). This trend can also be found in Figure 26 where the EPBTs of the most common PV types are displayed. What the exact EPBT of a specific PV system is depends on the actual yield and therefore location, solar irradiation and technology type should be taken into account.

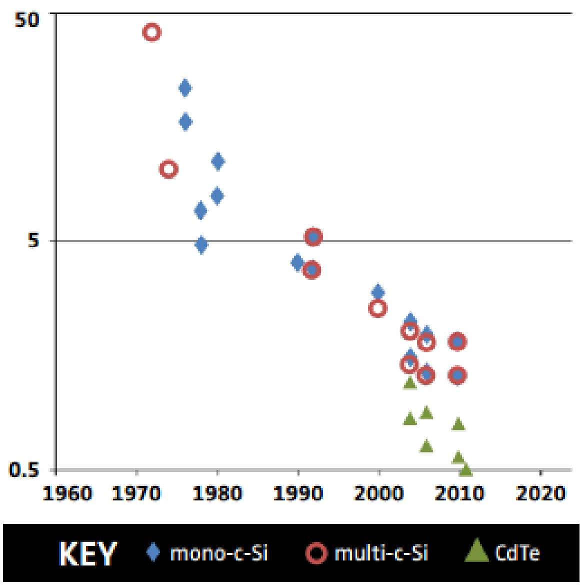


Figure 26. Energy Payback Time of PV systems from 1960 to 2010. Source: Fthenakis (2012)

On average the ERRs of PV systems can be found nowadays (with an expected life time of 30 years) somewhere between 60:1 and 15:1. This means that PV systems return “15 to 60 times more energy than they use, depending on the location and technology” (Fthenakis, 2012: p.16; Peng et al., 2013; Raugei et al., 2012). As material and system utilization and efficiencies continue to improve these ERRs will only continue to get better and better. The EPBTs and the greenhouse gas emissions are important to be able to determine if, from a collective perspective, PV power is saving as much power, money and gas emission as promised.

3.2.2 Greenhouse gas emission

Related to the energy requirements are the GHG emissions that are the by-products of conventional energy use. One of the reasons for promoting solar power is that it is much ‘greener’ than conventional power from for example coal and nuclear sources. The ecological footprint of PV systems are advocated to be a lot smaller than that from conventional energy sources like fossil fuels. This is true. Various LCAs over the last ten years show that the carbon footprint of PV technology is ten to twenty times smaller than fossil fuels (Fthenakis et al., 2008; Dominguez-Ramos et al., 2010; Sherwani & Usmani, 2010). The more technology develops the smaller this footprint will be.

3.2.3 Differences between PV types

It was already pointed out that the type of PV system used is important to determine the EPBTs and the GHG emissions. This section will highlight the biggest differences between the technology types.
A recent study by Peng, Lu and Yang (2013) reviewed the abundance of LCA’s done in the field of PV technology. They compared five different PV types on energy requirement, energy payback time and greenhouse gas emission rate during the entire life cycle (from cradle to grave). They concluded that, “in general, mono-Si PV systems had the highest life cycle energy requirement, while thin film PV systems had the lowest energy demand” (p.271). This result can also be found in Figure 27.

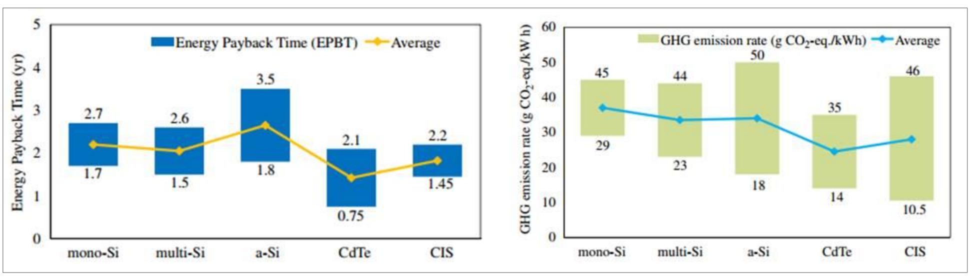


Figure 27. Review of Energy Payback Times and Greenhouse Gas emission rates for various PV systems. Source: Peng et al. (2013)

In the previous section it was already shown that mono and poly-crystalline solar panels are the most commonly used in the Netherlands. The results about these two types are therefore the most interesting to look at. In Figure 27 it can be seen that the energy payback time for mono and poly-crystalline solar panels lies somewhere between 1.5 to

2.7 years. This is calculated by combining the energy requirements with the expected lifespan of the technologies. Similar results could also be found be found in Figure 26. This figure shows the trend of declining EPBTs in the PV technology caused by high technological development. The trend is expected to continue. A recent study by Mann et al. (2013) estimates that the EPBT of crystalline silicon modules "can be reduced to below 0.5 years by 2020, which is less than half of the current energy payback time" (p.1099). The greenhouse gas emission rates are measured in gCO2 per produced kWh (Figure 27). It shows that on average these gas emissions are slightly higher for the most commonly used panel types. Note that this is still more than ten times less than the amount of gasses produced by the fossil fuel industry (US EPA, 2013; Fthenakis & Kim, 2011).

3.2.4 Global versus household perspective

When comparing the energy requirements needed to produce PV power with grey power it is not only important to look at the energy it requires to produce one solar panel. One should also look at all the energy it took to come to the technological state we are in now. Figure 28 shows schematically what this means for an energy producing industry like the PV industry. The phenomenon, when "any energy production industry requires more energy inputs than is produced by its outputs" is called 'energy subsidy' (Dale & Benson, 2013: p.3484). Years of research and development were needed to get to the efficient PV technology there is today. Many years of energy consumed before PV systems were spread worldwide and started to produce enough power to pay back the inputs. The year in which "a growing energy production industry crosses the breakeven threshold and makes a positive net energy contribution" is called the breakeven year. After this year the industry will pay back the energy used in the past until the payback year is reached. This is the year in which the growing industry "pays back all of the energy subsidy required during its early growth" (Dale & Benson, 2013: p.3484).

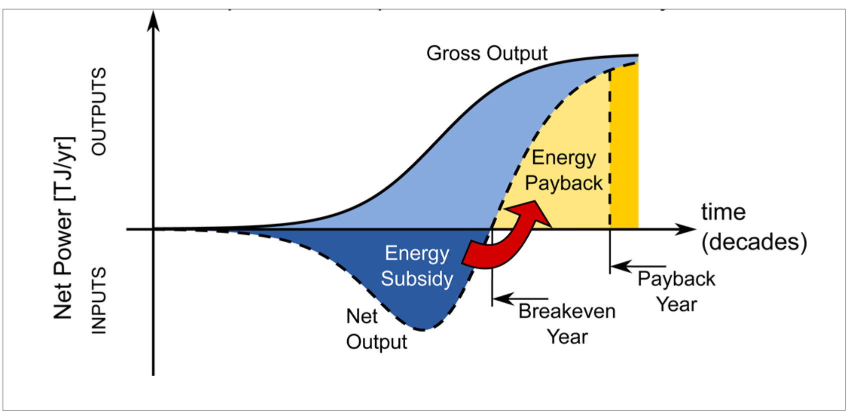


Figure 28. Inputs and outputs for the PV industry (or any other energy producing industry). Source: Dale & Benson (2013).

In a recently published Daily Express article (2013), Michael Dale, a postdoctoral fellow at Stanford's Global Climate & Energy Project (GECP), said "Despite its fantastically fast growth rate, PV is producing – or just about to start producing – a net energy benefit to society." He also claims that "The world's solar photovoltaic (PV) panels won't contribute any 'real' energy to the globe until 2015 at the earliest and no later than 2020". A study by Dale and Benson (2013: p.3482) is slightly more positive and claims that "there is a >50% chance that in 2012 the PV industry is a net electricity provider and will 'pay back' the electrical energy required for its early growth before 2020". They state that the breakeven year was most likely in 2010.

For households however, this does not mean anything to their own savings. Nevertheless, from a global perspective this is very important to take into account when looking at the footprint of PV technology.

3.2.5 Conclusion

In this section all the different stages of the life cycle of PV systems were incorporated to measure the energy consumption and environmental impact of PV systems. The Energy Payback Time of a PV system is 1.5 to 2.7 years, depending on the type of PV system. So, from a domestic point of view, installing a PV system will within three years contribute to a 'greener' way of life. From a global perspective PV technology will start contributing energy to society from 2015. Until then it is returning the energy that it cost to get to the current technological state.

The carbon footprint of PV technology is ten to twenty times smaller than fossil fuel footprints. This fact alone already makes the choice for PV technology very defendable. The future is predicted to be even brighter with technological development resulting in even less greenhouse gas emissions coming from the PV industry.

3.3 Actual savings and saving potential: Savings and Output

How much do households annually save after the installation of a PV system?

What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?

3.3.1 Electricity production

In the previous sections it was already made clear that the savings from installing a PV system are based on both the energy production and the energy consumption of a household. Due to the technological developments and changes in the field of PV technology it is difficult to accurately predict how much PV power a household will produce in a year. In the previous section we have seen that there are many factors influencing the actual production of a PV system, such as the type of installation, weather conditions and cleaning. It is therefore difficult to exactly predict what the annual yield of a system will be. To be as accurate as possible, all factors that were presented in Figure 16, should be taken in to account. But even by doing so, there are many uncertainties in the calculation such as weather conditions and cleaning habits.
Nevertheless, rough estimations for average situations can of course be made. To be able to make estimations the PV installations are divided in three groups, namely ‘small’, ‘medium’ and ‘large’ PV systems. Calculating the average annual production is than just a matter of multiplying the capacity with the Dutch factor of 0.86 (see chapter 3.1). Again, when looking at Table 8 it should be taken into account that the “average” PV system does not exist.

Table 8. Examples of average annual production of PV systems in the Netherlands

Size	Number of panels*	Capacity	Average annual production
Small	≤ 6	Less than 1500 Wp	Less than 1260 kWh
Medium	7 - 14	1500 – 3500 Wp	1260 – 3010 kWh
Large	≥ 15	More than 3500 Wp	More than 3010 kWh

**Assuming the average capacity of 240 Wp per solar panel.*

The amount of money annually saved per household is directly related to the yield of the installed PV system. In the previous chapter it was shown that the produced amount of energy is either directly used in the household or is fed back to the grid. This basically means that monetary value of the generated power can be calculated using the following formula:

$$Yield\ in\ kWh\ in\ year\ X \times electricity\ price\ per\ kWh\ in\ year\ X$$

The electricity prices have been increasing in the last decades and in all probability will continue to increase over the next. The value of the produced PV power will therefor also increase per year. In the Netherlands the current electricity price lies around 22.5 cent per kWh and in the more negative predictions it is expected that the electricity prices will increase with 5% each year (Milieucentraal, 2013b). To understand what that means for the world of PV a calculation example will now be provided. This will also give some insight in how the return on investment can be calculated and how the formula mentioned above is used.

The example of family X

Family X from a small town somewhere in the middle of the Netherlands decides to buy a PV system this year. They annually consume 3500 kWh and want to produce at least half of this amount with their own PV system. This means that they need at least an installed capacity of 2035 Watt Peak (1750/0.86hrs=2035), which means at least eight to nine solar panels (2035/240=8.5). The costs for the PV system are €4000 and the installation costs are €1000 making it an investment with a total of €5000. Assuming that the system performs well and accepting (fictive) constant weather conditions, the annual yield will be 1750 kWh until the end of year 10. To the end of its life time (often estimated at 25 years) the yield will decrease with 10 per cent after ten years and 20 per cent after 20 years. With an increase in electricity prices of 5% per year the annual financial savings will go up from €403 in year one to €1051 in year twenty five (see Table 9). At the end of the PV system life time a total of 40,340 kWh is generated, worth over €17,000. Again, this only counts when the PV system performs exactly as expected. It takes up to year ten until the initial investment is returned. Hence, the return on investment (ROI) is in this example ten years (see blue bar and * in Table 9).

Table 9. Example of energy and financial savings per year for Family X. Based on data from 'Hoe-Koop-Ik' (2013)

Year	Electricity price €-cent/kwh	Annual yield in kWh	Monetary value yield	Accumulated monetary value yield
1	23.0	1750	€ 403	€ 403
2	24.2	1750	€ 423	€ 825
3	25.4	1750	€ 444	€ 1269
4	26.6	1750	€ 466	€ 1735
5	28.0	1750	€ 489	€ 2224
6	29.4	1750	€ 514	€ 2738
7	30.8	1750	€ 539	€ 3277
8	32.4	1750	€ 566	€ 3844
9	34.0	1750	€ 595	€ 4438
10	35.7	1750	€ 624	€ 5063*
11	37.5	1575	€ 590	€ 5653
12	39.3	1575	€ 620	€ 6272
13	41.3	1575	€ 651	€ 6923
14	43.4	1575	€ 683	€ 7606
15	45.5	1575	€ 717	€ 8323
16	47.8	1575	€ 753	€ 9076
17	50.2	1575	€ 791	€ 9867
18	52.7	1575	€ 830	€ 10,697
19	55.4	1575	€ 872	€ 11,569
20	58.1	1575	€ 915	€ 12,484
21	61.0	1418	€ 865	€ 13,349
22	64.1	1418	€ 908	€ 14,258
23	67.3	1418	€ 954	€ 15,211
24	70.6	1418	€ 1001	€ 16,213
25	74.2	1418	€ 1051	€ 17,264

From literature and as could be seen in this example it can be concluded that, when calculating the financial output and ROIs there are a couple of components needed:

1. Price of PV system (including panels, inverter, cables, etc.)
2. Installation costs
3. Costs for replacement of the inverter (expected life time ten years)
4. Electricity price
5. Expected development electricity prices
6. Expected life time of PV system

7. Installed PV capacity (depending on the factors shown in the previous section)
8. Expected decrease in production capacity of installed PV system (E.g. 10% after ten years, 20 after 20 years)

To be able to calculate the actual output and savings of a PV system all these components need to be known. Assumptions about the future are needed just as detailed information about each specific PV system. It shows that even when the PV system is already installed, it is hard to calculate the actual savings. Predicting the output is even harder because it relies on many uncertainties about the future that affect each household differently. It is not possible to use one set formula to calculate the (future) output and return on investment times of all PV systems. This is very dependent on the characteristics of each PV system, its placing and on contextual differences per location and household. Concluding, it can be said that it is hard to accurately predict the actual energy production of PV systems, especially when trying to predict the output for multiple systems at once. Individual (household and system) characteristics and differences highly affect the actual savings coming from installing a PV system. The hypothesis is therefore the following:

H1: The energy and financial savings are different for each household and are context dependent.

3.3.2 Electricity consumption

What the actual savings are, after installing a specific PV system on a specific location, is something not often researched and is therefore the starting point of this study. The actual yield of the installed PV system and the monetary value can be estimated and calculated as could be seen in the previous example of Family X. But the savings are not only depending on the energy production. It also depends on the amount of energy consumed. The installations of a PV system can lead to a behavioural change resulting in a higher or lower energy consumption than before the installation. The results in this matter are ambiguous. In the literature two trends can be divided.

Double dividend

One line of research suggests that people with PV systems or other micro generation systems tend to be more conscious about their energy consumption. This results in less energy consumed and extra savings. An older study by the European Commission (1997) already found this effect in 1997. They stated “increased awareness of the value of electricity generated has led to take other energy saving measures in their homes” (p.5). Keirstead (2007) uses the concept ‘double dividend’ to explain this “positive behavioural response leading to further energy conservation” (p.1249). His studies in the UK showed a positive relation between the installation of PV systems and greener behaviour. Respondents reported an estimated 6% reduction in overall electricity use and evidence was seen of an increase in general energy awareness and the use of efficient lighting (Keirstead, 2007: p.4135). It must be taken into account that in the research of Keirstead an important role for the information feedback was found. Feedback on how much energy was produced by the PV system could be found on a monitoring device, installed in 86% of the households that participated. Households are likely to get extra motivated if they are able to monitor their own energy production. For that reason Keirstead (2007) predicts that the double dividend is larger for households with a monitoring device to keep track on their PV power production.

Rebound effect

A completely different line of research, predicts a contrasting effect called a ‘rebound effect’. The concept rebound effect stems from the theory that (in certain contexts) people tend to increase energy consumption when energy prices drop due to a larger supply (Greening et al, 2000). The possible positive financial savings are undone by the increase in demand. The research in this field states that “energy efficiency has failed to deliver its promised savings”. In the case of micro generation systems there are some studies that suggest that the rebound effect is more prominent than the previously explained double dividend. They claim that by direct and indirect rebound the savings in the end are a lot lower than predicted or there are even no savings at all (Sorrel, 2007). Direct rebound after installing a PV system could be using the washing machine more frequently. Advocates for this theory claim that for example when people know that they have plenty of energy on a sunny day they tend to use more energy than they would have used without the PV system (Bergman et al., 2008).

Feedback and monitoring systems

Recently more and more often data feedback systems are installed with the PV systems. Meters, displaying the amount of electricity produced are often offered within the installation package of the PV system (Consumentenbond, 2013a). As seen in this section information feedback is important for extra saving behaviour. This research therefore expects that the installation of PV systems has a positive effect on consumer behaviour and will lead to a double dividend. This double dividend effect is expected to be stronger than the rebound effect.
The hypothesis is therefore:

H2: Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend.

3.3.3 Conclusion

In this chapter two hypotheses were formulated based on different studies and literature. New data is needed to test the two hypotheses:

- H1: The energy and financial savings are different for each household and are context dependent.
- H2: Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend.

In this research data required from an online questionnaire (see chapter 0) will be used to test these hypotheses and to look at the profitability of PV systems. It will give a more detailed answer to both the research questions from this chapter.

3.4 Households and PV systems: Motives and Barriers

What are household motives and barriers for buying a PV system?

A consumer research done in 2012 by USP Marketing Consultancy in the Netherlands showed that 58% of the consumers is "willing to put solar panels on their roof now or in the future". Nevertheless, only 1.73% of all households is expected to have a PV system by the end of 2013 (CBS, 2013c; Agentschap NL, 2013b). To find out why the difference between these percentages is so big insights in the motives and barriers for consumers is essential.

Even when taking into account the fact that PV technology is still a young technology in domestic life, there is relatively little research done in the field of consumer motives and barriers for buying PV systems. Most of the research in this field is about the adoption of micro generation technologies in general, only a few researches focus specifically on PV technology. Nevertheless, the studies that focus on multiple micro generation technologies (that include PV , wind, solar thermal and hydro technologies) can be very useful to get insight in this specific decision making process of households.

3.4.1 Motives

A review study by Balcombe, Rigby and Azapagic that was recently published (2013) looked at all the relevant research done so far in the field of motives and barriers associated with adopting micro generation energy technologies. Based on 18 reviewed articles they concluded that "the most commonly identified motivations to installing micro generation are environmental benefits and earning or saving money" (Balcombe et al, 2013: p.664). This finding is in line with more older but also more specific research only focussing on PV systems by Jager (2006). This research was conducted in the Netherlands and showed that, at that time, 'contribution to a better natural environment' was seen as the most important reason to adopt the PV technology. The financial benefits were, at that time, not relevant because the payback time of a PV system before 2006 was often longer than the predicted life span of the system. More recent research by Leenheer et al (2011) showed that again environmental concerns was the most important driver. About the financial motives they state that they "do not play a role" (Leenheer et al, 2011: p.5627). It must be taken into account that at the time of the data collection for this study, the beginning of 2010, the production capacity of 1 PV panel was a lot lower than it is now. This can also be found in non-scientific sources like forums and blogs for PV system users. Often 'financial benefits' are on these websites mentioned as the most important reason to buy a PV system today. There is no up to date research available proving this, but there are strong indications in that direction. One of the main reasons for this is that the capital payback time is falling rapidly. An argument often used on forums and websites is that, within ten years, households will start to produce 'free' energy.

Balcome et al. (2013) also mention a third motive important for households, namely ‘security of supply’. This motivation contains the “motivation for increased energy self-sufficiency, being able to reduce reliance on the gas or electricity grid and being less susceptible to future energy price increases” (p.660). This finding is among others based on the research done by Leenheer et al (2011) and Jager (2006).

Based on the review of the little existing literature on motivations for buying PV systems the hypothesis for this part of the research sub question will be formulated as:

H3: Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system.

3.4.2 Barriers

When it comes to the research done, specifically focussing on the barriers why households hesitate to buy PV systems, the options are limited. Mainly because of the rapidly changing context and falling prices of PV systems older research is often outdated and likely to be less useful. Nevertheless, it can give some insights and predictions to create a hypothesis that can be tested later in this research. The previously mentioned review of Balcombe et al. (2013) has researched among others the barriers for installing micro generation technologies. For installing PV systems they conclude that capital costs are the main barrier. They see a “significant gap between the WTP (willingness to pay) by potential adopters and the capital costs” (p.664). This means for households that the high investment costs are seen as a barrier to start with producing PV power. The same result is found by other authors who have proven that high initial costs often slow down the adoption of micro power producing technologies, generally called the direct price effect (see e.g. Moukhametshina, 2008). A study by Leenheer et al. (2011: p.5627) state that “consumers may have an high intention to generate their own power, but financial hurdles may withhold them from actually doing so”. It shows that the price of PV systems is a barrier to invest in the technology. It must be taken into account that nowadays the prices are dropping rapidly which may lead to the decrease of importance of price as a barrier.

Another related barrier, is the long capital payback time for PV systems (Balcombe et al., 2013; Jager, 2006). Even when taking into account the rapid decrease in the length of the payback time, the return on the investment comes relatively late. Especially for households that consider moving within the first ten to fifteen years, this is a reason for not buying a PV system. The same holds for people older than 70, they tend to hesitate because they do not know if they will outlive the payback time (Balcombe et al., 2013).

Other barriers, indicated as less important by different studies are the hassle of installations (Palm & Tvengard, 2011; Claudy et al., 2011), fear of neighbour disapproval regarding the aesthetics (Claudy et al., 2011) and performance uncertainties (Ahmad, 2011; Palm & Tvengard, 2011).

When looking at non-scientific sources like forums and commercial websites, high investment costs is also indicated as the main reason to hesitate before buying a PV system. The costs for an average PV system vary between 4000 and 8000 Euros, which is a relatively high investment.

Balcombe et al. (2013) do point out that, based on their review, it can be concluded that governmental incentives and subsidies can reduce this barriers. For the Netherlands, that have just introduced a subsidy on solar panels in 2012, this could mean that the barrier will lose some of its strength. However, the initial costs remain high and will therefor maintain to be a barrier or even motivation not to buy a PV system.

Based on the literature the following hypothesis is formulated:

H4: High investment costs and long capital payback times are the main barriers for households for installing PV systems.

3.4.3 Conclusion

To find out why there is such a big difference between households willing to buy a PV system and households that actually do it the literature and studies about motives and barriers for buying a PV system or other micro generating technologies were reviewed. This review resulted in the formulation of two hypotheses:

- H3: Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system.
- H4: High investment costs and long capital payback times are the main barriers for households for installing PV systems.

The data from an online questionnaire (see chapter 0) in this research will be used to test these hypotheses.

3.5 Households and PV systems: Characteristics

What are (social demographic) characteristics of households with a PV system?

3.5.1 Typical PV households

A household in the Netherlands, as described in literature and on Dutch governmental websites, consists on average of 2.2 people and consumes 3.340 kWh electricity in a year (CBS, PBL & Wageningen UR, 2013a; Nibud, 2013). To equip a household with enough solar panels to produce at least 3.340 kWh per year, on average 17 to 18 solar panels are needed which will cost approximately six to eight thousand Euro. As explained before, most households that choose for a PV system do not have that many panels installed. The previous research question addressed why households choose for PV systems and what barriers made them hesitate. The final research sub question is about the characteristics of the households that choose for a PV system. Insights in the characteristics of households with PV systems are important to understand the current PV market and can be very valuable for future development and marketing.

A study about the solar heat collectors in the Netherlands (2005) by Terpstra et al. (that was used as a starting point for this research) found that households with solar heat collectors typically differ from the average Dutch households. “The majority of the men and women are higher educated and to be found in the higher income groups. All households are owner-occupiers of their house” (p. 84). It could be the case that this description also holds for PV owners. To see what the (social demographic) characteristics are of households with a PV system this section looks at multiple studies and formulates multiple hypotheses about these characteristics.

There is hardly any specific data available about the characteristics of Dutch PV system owners, but there are some more general researches done that show the tendencies in this field. These studies, combined with the little specific data that is available will give a more or less complete overview of the (social demographic) characteristics of households with PV systems. Please keep in mind that this is about the typical characteristics and obviously do not apply for every household with a PV system.

The most typical feature of households with PV systems is that they tend to have a high environmental concern (Balcombe et al., 2013; Leenheer et al., 2011). Households with a high environmental concern are more likely to install a PV system. However Urban & Scasny (2012) state that environmental concern is often not enough to directly cause purchasing behaviour. “Environmental concern has either no effect or a relatively weak one on those energy-saving actions which are more demanding in terms of their capital costs, time needed for their purchase and implementation” (p.77). But, for household that already have a PV system, high environmental concern is a very common characteristic.

Another household characteristic, common for PV owners is that it tend to be somewhat older households. Typically young households, indicate to be interested in buying a PV systems but this group does not show the behaviour accordingly (Leenheer et al, 2011). Multiple studies have shown that age has a positive effect on energy saving and generating behaviour (Leenheer et al., 2011; Urban & Scasny, 2012). The review of Balcombe et al. (2013) shows that the “number of micro generation installations is lower amongst those who are below 45 and those above 65 years old” (p.662). This finding is in line with specific PV research from Keirstead (2007) among 91 solar adopters from the UK. He found that 92% of the respondents (all PV system owners) were older than 45 but younger than 65. Balcombe et al. (2013) suggest in their study that this is probably related to several phenomena. One of them being that older age groups seem to be less inclined to adopt new energy generating technologies, “exhibiting a greater resistance if they have been using their existing system for many years” (Balcombe et al, 2013: p.662; Palm & Tvengard, 2011; Willis et al., 2011). The high financial investment needed could also be a reason for the decrease in PV owners above 64. “Pensioners are likely to have lower incomes than before retirement, which may reduce their willingness to pay for costly micro generation” (Balcombe et al., 2-13: p.662). Since the payback time of PV systems is more than ten years there is a risk for pensioners that they will not ‘survive’ this period and will therefore not experience financial benefits from the PV system.
Younger groups, who are generally the most environmentally concerned are (contrary to their attitudes towards energy savings matters) less likely to invest in PV systems (Leenheer et al., 2011; Keirstead, 2007; Balcombe et al., 2013). Young households often have (young) kids causing higher expenses, leaving less room for big investments. They are also often not yet sure if they will move houses within a relatively short period of time and are therefore less inclined to put (expensive) solar panels on their roof.

Another characteristic, related to age, is income. On average, PV system owners have a higher income which allows them to invest in micro generation (Claudy et al., 2010). This income factor can also be found in the age characteristic: on average the group of 45 to 64 year olds have the highest amount of money available for capital investments (Balcombe et al., 2013).

Related to income is education and social class. According to Fischer and Sauter (2003) a high percentage of the ‘academic elite’ can be found among PV system owners. Keirstead (2007) showed that PV owners were more likely to be better educated (77% had degree-level qualifications versus 30% nationally).

PV owners are also more likely to own their own (relatively large) home, which is again related to income and age. Keirstead (2007) found in his research that 97% of the respondents that installed PV systems were the actual owners of the house (versus 71% nationally). Fischer and Sauter (2003) propose that this is caused by the fact that only family home owners (as opposed to tenants and flat owners) have direct control over the decision to install a PV system.

The size of the house is on average larger than other homes. Solar panels need a substantial amount of space and large homes are simply more likely to have the space needed. They also "tend to use more energy due to larger space heating requirements, which may increase the importance of energy production within the house" (Balcombe et al., 2013: p.663).

Answering the research question, the following hypothesis can be formulated:

H5: Households with PV systems are typically between 45 and 64 years old, have a high environmental concern, have high incomes, are higher educated and own their home.

Or in parts:

H5a: Households with a PV system are between 45 and 64 years old
H5b: Households with a PV system have a high environmental concern
H5c: Households with a PV system have higher incomes
H5d: Households with a PV system are higher educated
H5e: Households with a PV system are the owners of their home

3.5.2 Conclusion

To be able to give characteristics of a 'typical' PV household various sources were consulted. Because scientific sources about PV households are limited other more general papers on micro generating systems in households were used. Based on all the data found the following hypothesis was formulated:

H5: Households with PV systems are typically between 45 and 64 years old, have a high environmental concern, have high incomes, are higher educated and own their home.

The data from an online questionnaire (see chapter 0) in this research will be used to test these hypotheses.

3.6 Hypotheses

In conclusion and as a compact overview all the answers found and hypotheses formulated are schematically depicted in Table 10. This can be used as a short summary of this chapter and as a starting point for the next chapter.

The hypotheses and (partially) unanswered research questions form the starting point of the data collection in this research. The methodology, strategy and data used to test these hypotheses will be explained in the next chapter.

Table 10. Summary of chapter 3: answers and hypotheses

Research (sub-) questions		*Answer or hypothesis*
RQ 1	**What are the real life savings for households after the installation of a PV system?**	
1a	*How much energy is used in the entire life cycle of PV systems?*	The Energy Payback Time of a PV system is 1.5 to 2.7 years, depending on type of PV system. Carbon footprint of PV technology ten to twenty times smaller than fossil fuel footprints. Seen from a societal perspective PV technology will start contributing energy to society from 2015. Until then it is returning energy that it cost to get to current technological state.
1b	*How much do households annually save after the installation of a PV system?*	H1: The energy and financial savings are different for each household and are context dependent Data needed to test hypothesis and answer sub research question.
1c	*What factors affect PV capacity and actual PV energy production?*	Actual PV production is affected by four main factors: - PV System Placing (tilt angle, orientation, shadow) - PV System Properties (material, size, panel connection, age) - PV System Location (geographic coordination, solar irradiation, temperature) - Household Behaviour (cleaning, maintenance)
RQ 2	**What are the factors and determinants involved in the household decision making process of PV systems?**	
2a	*What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?*	H2: Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend. Data needed to test hypothesis and answer sub research question.
2b	*What are household motives and barriers for buying a PV system?*	H3: Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system. H4: High investment costs and long capital payback times are the main barriers for households for installing PV systems.
2c	*What are (social demographic) characteristics of households with a PV system?*	H5: Households with PV systems are typically between 45 and 64 years old, have a high environmental concern, have high incomes, are higher educated and own their home.

III

Methodology

4 Methods and Research Design

To test the formulated hypotheses and to be able to answer the two main research questions data was collected and analysed. The methods for this data collection and why these methods were chosen are explained in this chapter. It elaborates on how respondents were found, the sample size, how the questionnaire was constructed and which corrections were made within the data set.

4.1 Research design

This research is designed to measure the real life savings from PV systems in households and to find out why households install PV systems. Households with PV systems that are not installed before 2008 or after 2012 are asked for data about their energy consumption, energy costs and motivations for having a PV system. The data collection for this research is, next to the literature study in the previous chapter, done through a survey. This method is chosen because a large amount of quantitative data is needed, to be able to make relevant statements about the hypotheses. With the data collected, the hypotheses can be tested. The questions in the survey are designed in such a way that the answers accordingly should be able to provide enough information to answer the research questions.

4.2 Population

The population of this research can be defined as: Dutch households with a PV system that is installed before January 1st 2013, but later than January 1st 2008. ‘Households with PV systems' are chosen because they are the group of interest in the research questions. To be able to look at the real life savings it is important that the households use their PV system at least one year. For that reason the criterion is set at the time frame between January 1st 2008 and January 1st 2013. The households that fit these criteria should be able to provide data about their actual savings. If the installation date would be later than January 1st 2013 it could be that they do not have the energy bills yet to be able to answer the questions. If the installation date would be before January 1st 2008 the PV technology would be a lot less efficient, making it harder to compare the data with younger installations. Older installations also mean that it might be harder for respondents to find the energy bills for those years and to remember motivations and drawbacks to purchase the PV system.

4.2.1 Population search and sample

To be able to find a sample of respondents within the population different organizations were contacted. These organizations all had something to do with PV technology or

consumers that (possibly) own PV systems. Table 11 shows the different organizations that were contacted for this research and if and how they collaborated. These organisations were asked to promote the survey on their website, Twitter or via email to their clients. For more information people could visit the research's website: www.zonnepanelenonderzoek.blogspot.nl. This website was designed to provide people with all the information they needed about the survey, the research in general and the researcher. Questions and remarks could be sent to an email address via the website. Emails on different topics were sent to this email address. The topics varied from specific questions about the questionnaire to general questions about the research. All emails and questions were answered on the same day as they came in.
Other methods of promoting the questionnaire were social media, posters and mouth-to-mouth advertising. One of the (Dutch) posters used is depicted in Figure 29, others promotion example can be found in Appendix 6.

Table 11. Organizations and individuals that were contacted and did (not) cooperate and promote the research

Negative or non-response	Tweets and retweets	Advertisements, posters and texts on websites, forums, etc.
MetDeZon	Vincent Dekker (Trouw)	Greenem
Energy Guard	Zonneplan	WijHebbenZon
Milieu Centraal	Zon_IQ	Compare My Solar
Zonneplan	Greenem	Zonnepanelen Facebook
Polder PV	Ahtlam	Transition Towns
Deventer zonnecollectief	Adriaan van Rossum	Zonne-Energie Facebook
Compare My Solar	GJ Kanis	Organisatie voor Duurzame Energie
Urgenda	Nudge	Natuur & Milieu: Zon Zoekt Dak
Karel Knip (NRC)	Milieudefensie	Texel Energie
WijWillenZon	Monica Falck	VanAtotZonnepanelen
Helga van Leur		Zonnepaneelforum
Eneco		Zonne Energie Forum
Consumentenbond		Syntronixs Solar BV
Milieuloket		
Stichting Zonne-Energie Wageningen		

Figure 29. Promotion poster questionnaire

4.3 Expected response rate

The questionnaire is, with over 70 questions, rather large. It required an active role of the respondent since the respondent might needed to look for information or data in its own administration. This might have scared of people and lowered the response rate.

On the other hand, households with PV systems were expected to be more conscious about the environment and their energy use. They can be seen as pioneers when it comes to domestic solar energy and might therefore be more enthusiastic to collaborate. They might understand the importance of their knowledge and experience for future PV system buyers and are probably more willing to put their time and effort in answering the questions.

Due to the criteria for the population it was taken into account that the number of responses could be limited. There might have been households that did have a PV system and were willing to respond but did not fit the population criteria.

Since the Internet is used as the main source of promoting the response rate was difficult to estimate. The Internet can reach large groups of people, but by using this medium also big groups of people without PV systems were reached.

4.4 Questionnaire

To be able to collect data that would answer the research questions an online self-completion questionnaire was created. This method is chosen because it provides quantitative data that will allow statistical analyses and comparisons. The Dutch questionnaire created for this research can be found in Appendix 1. The survey is not in English because this might lead to confusion, since the mother tongue of the respondents will probably be Dutch.

The questionnaire has a standardized design, with open, half open and closed questions. It is an online survey, meaning that respondents received and responded the survey on the web. The online tool 'Qualtrics' is used to publish the questionnaire. The advantages of an online survey is that it can reach large groups of people without needing their home addresses, the data is immediately collected, item non-response is not possible because the program will force the respondent to answer all the questions and the respondent can be routed through the questions. This routing means that people do not get to see questions that are not applicable in their situation. For example, if a respondent indicates in a question that he or she does not have a partner, the question '*What is your partner's age*?' will not be shown.

Before the questionnaire was launched online it was pre-tested in a hard copy version. Two members of two different households with installed PV systems answered all the questions on paper. Their comments were used and incorporated in the web version of the questionnaire. This version was also tested by two people from two households, different from the hard copy pre-testers. The results from this second pre-test were used to finalize the questionnaire.

The next section elaborates on the questions in the questionnaires. It will explain why they are chosen and which research question they belong to. Since the research questions *How much energy is used in the entire life cycle of PV installations* (RQ 1a) and *What factors affect capacity and actual power production and what is the role of household behaviour in this matter* (RQ 1c) are answered in the previous chapter by the use of existing literature there are four research sub questions left that need answering by the questionnaire. For each research sub question it will now be explained which questions were used in the questionnaire.

RQ 1b. How much do households annually save after the installation of a PV system?

This topic covers the largest part of the questionnaire. In previous chapters of this report it was shown that energy savings are influenced by the energy production and the energy consumption of a household. Hence, to answer this research question data is needed about the actual energy production and the energy consumption of each household. Since it was found in literature that among others the tilt angle, orientation, type of panels, shadow, size and age of the PV system affects the actual energy production of the system, these are all variables that need to be known for each respondent. Questions 3-17, 28 and 76 address all of these factors by asking for details about how the PV system is installed.

The guaranteed capacity of the PV system over different periods of time is also important for the energy production and is covered by questions 29 and 30.

The energy consumption is measured by a question that asks respondents to fill in data from energy bills of three years. Respondents are asked to indicate what their electricity use in kWh and costs in Euro's are (as found on the energy bill) of the year before, of and after installation of the PV system (question 33). In the same question they are asked to, if they know it, indicate how much electricity the solar panels had produced. The data from this question should technically provide enough information to calculate the savings (in kWh and Euro's) after installation of the PV system.

To be able to compare the energy consumption within years and to measure actual savings it is important that factors affecting this consumption are not overlooked. Changes within composition of the household (questions 39 and 40) should be taken in to account, just like changes in the structure of the house (question 47) and the use of new energy saving or energy consuming equipment and household devices (questions 41-46). Each of these questions only needs answering when the household change has taken place in the year of or the year after installation of the PV system.

Since this research question is also about financial savings it is important to know that there were no financial changes that could have affected the energy bill. For example switching energy suppliers (question 34) or discounts and financial allowances that affected the energy costs (question 37 and 38).

RQ 2a. What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?

To be able to answer this question it is important to have data about the costs and benefits of the PV system of each household. The actual costs for the complete installation (question 18) and the maintenance costs (question 19) are therefore important questions. Subsidies and tax benefits should be subtracted from this total cost to calculate the actual costs of the PV system. The questions 24-26 cover this topic.

To learn something about the expected return on investment two questions (20 and 21) are included that compare the promised payback time (by the supplier) and the expected payback time (by the respondent). This will also give some insight in possible scepticism of the households towards supplier promises. The same concept can be found in questions 22 and 23 where the respondent is asked for the promised savings (by the supplier) and the expected savings (by the respondent) both in kWh and in Euros.

RQ 2b. What are household motives and barriers for buying a PV system?

To find out why (or why not) households decide to buy a PV system multiple questions are constructed. The most obvious, and most important one is question 49 that directly asks for the most important reasons why the decision for a PV system was made. Other more indirect questions also provide some insights on why the decision was made (questions 2, 27, 31, 32 and 48).

Questions 50 and 51 ask for reasons why the respondent or other households might hesitate to install a PV system. Together the data collected from these questions will provide an answer what the barriers for buying a PV system are.

RQ 2c. What are (social demographic) characteristics of households with a PV system?
The last block of the questionnaire covers the last research sub question. Since based on the literature analysis it was expected that households with PV systems are more environmentally conscious different questions are inserted to test this (questions 52-56). For questions 52, 53 and 54 reference data from the Special Eurobarometer can in the analysis be used to compare the data with average households in the Netherlands (European Commission, 2011). The sub questions in question 55 are equal to questions asked in annual surveys by the CBS making it possible to compare these data as well (CSB, 2011d). The last question testing environmental involvement is question 56, asking for information about possible memberships of environmental organizations like Greenpeace and the World Wide Fund for Nature. The data collected from this question can be compared with data from average households (Compendium, 2011).
To measure how involved the households are in their energy consumption and costs respondents are asked if they have switched between energy suppliers within the last five years and if so, why they did it (questions 35 and 36).
The final part of the questionnaire is for questions about the social demographic characteristics of the households. The sex, age, education and occupation is asked of the respondent and if applicable of his or her partner in questions 57-61 and 63-67. Question 57, 62, 68, 69 and 70 are about the household in general: the place and province, the amount of persons in the household, the gross income and type of house. It will provide data that will make it possible to create a general household profile of PV system owners.

Before the questions start in this survey there is a short introduction text. This text provides the main goal of the research, defines the concept ‘PV installation’, explains that there are no right or wrong answers and thanks the respondent in advance for participating. It also provides an email address to which respondents can email if they have a comment or questions. Specific questions or comments about the questions in the survey can be given in the final item of the survey.

For an overview of all the topics and the corresponding survey questions see Table 12.

Table 12. Research topics and the associated questions

Research questions	Topics	Survey questions
RQ 1b. *How much do households annually save after the installation of a PV system?*	PV system details	3-17, 28, 76
	Guaranteed capacity	29, 30
	Electricity consumption and costs	33
	Household composition	39, 40
	Changes in household equipment	41-46
	Changes in building structure	47
	Financial changes	34, 37, 38
RQ 2a. *What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?*	Total costs PV system	18, 19
	Subsidies and tax benefits	24-26
	Return on investment	20-23
RQ 2b. *What are household motives and barriers for buying a PV system?*	Motives	49
	Barriers	50, 51
	Indirect reasons	2, 27, 32, 32, 48
RQ 2c. *What are (social demographic) characteristics of households with a PV system?*	Environmental consciousness	52-56
	Switching energy suppliers	35, 36
	Household characteristics	57, 62, 68-70
	Respondent characteristics	58-61
	Respondent's partner characteristics	63-67
Others	Introduction text	1
	Epilogue	71

IV

Results

5 Sample Description

Before describing the results of the questionnaire and explaining the findings, this part starts with a brief description of the households that participated in the research and elaborates on their basic characteristics and electricity consumption.

5.1 Respondents

5.1.1 Sample size

The number of households that started the online survey is 395, of which 341 actually answered the first question. Of this group 218 people answered more than half of all the questions, 157 respondents finished the entire survey. For this data analysis only the complete questionnaires will be used unless indicated differently at specific parts of the analysis.

5.1.2 Basic characteristics

Since the method for this research was an online survey, accessible for everyone with the link and promoted extensively online the participants were not visible. It was therefore during the data collection hard to predict the distribution of men and women who participated. After the data analysis it was found that 144 men and 13 women completed the questionnaire, leading to a male share of almost 92% (see Table 13). It does not mean that only men own PV systems because the respondent represents its entire household. It does seem to show that they are more involved or inclined to fill in the questionnaire.

Table 13. Distribution of men and women among respondents

	Frequency	*Percentage*
Male	144	91.7%
Female	13	8.3%
Total	157	100%

The average age of the respondents was 48,9 years (*SD* = 10.33). More about their age, and the age of their partners can be found in chapter 8.

Since this research is about household decisions it is important to know a little more about the general characteristics of the households of the respondents. On average, the households of the respondents consisted of 2.8 people (*SD* = 1.208). For more about the household size, see chapter 8.6.1.

5.1.3 Electricity consumption

Before even looking at the role of PV systems in households it is interesting to learn something more about them and their energy consuming behaviour. On average, the households in this study used 3324 kWh the year before they installed their PV system (*SD* = 1636.27). Assuming that this is an accurate reflection of the average annual electricity consumption of households, it is interesting to see what causes the differences between the households. This research was not created to find this out, so there are probably determinants that affect the energy consumption that are not in the dataset. To see if the data from the questionnaire could explain at least to some extent the differences in the energy consumption of households a multiple regression analysis was executed. The role of different predictors in the annual consumption of electricity (dependent variable) were tested by a regression analysis, using the enter method for each independent variable. The most important results can be found in Table 14.

Table 14. Predictors of electricity consumption of PV households

		B	*SE B*	*β*
Step 1	(Constant)	1711.39	402.91	
	Household size	566.60	128.91	.45*
Step 2	(Constant)	487.18	740.92	
	Household size	529.45	128.00	.42*
	Environmentally friendly behaviour	973.39	498.09	.20**
Step 3	(Constant)	-50.38	795.39	
	Household size	524.02	121.08	.42*
	Environmentally friendly behaviour	1017.49	471.85	.21**
	Income high	1595.53	397.79	.41*

Note: R^2 = .20 for step 1 ($p < 0.001$)., ΔR^2 = .04 ($p < 0.05$)., ΔR^2 = .12 for step 3 ($p < 0.001$).

* $p < 0.01$

** $p < 0.05$

It was found that household size is the factor that accounts for the largest share (20.3%) of the variability in electricity consumption. Environmental behaviour also positively affects the variability in the electricity consumption. In step 2 of the model (household size and environmentally friendly behaviour) 24% of the variability is explained. On the eye this seems strange, because it looks like it means that the higher someone scores on environmental behaviour the higher his energy consumption is. This is not true, since for environmental behaviour low scores mean performing more environmental friendly behaviour than high scores (for more on environmental behaviour, see chapter 8.2). So what was found means that the less environmentally friendly households behave the higher the electricity consumption will be. The last significant determinant that was found was the role of income. High incomes explain a little over ten per cent of the variability. So 36% of the variability in electricity consumption can be explained by household size, environmentally friendly behaviour and income. Middle income, type of house and education were not found to be accountable for the variability in electricity consumption.

6 Estimated and real yield and savings of PV systems

6.1 PV system installation properties

Before going in to depth on the real life energy and financial savings from PV systems it is useful to look at the basic characteristics of the respondents and their PV systems. These average properties can be used to form an overall picture of the average PV systems of the respondents. It also shows why the analyses later in this chapter is done on a smaller group of respondents than the original 157.

6.1.1 General PV properties

Year of installation.

Of all respondents (N=157) a share of 75% (N=118) installed their PV system within the timeframe 2008 to 2012. The remaining 25% are households that installed a PV system before 2008 or after 2012. This group is not incorporated in some of the analyses later in this chapter. Motivations for this strategic decision can be found in chapter 4.2.

Type of system (installation process)

A share of 25% (N=40) of all respondents (26.1%) have a 'combined PV system', meaning that they have more than one set of solar panels installed or extended the system in the course of time. This makes them not suited for answering questions about 'before-after'-situations later in this chapter. They were excluded from questions specifically about the PV systems. These question were not shown to the respondents when there were more PV systems installed or when they were a combination of different panels and placing. Therefore in some of the following results they are indicated as 'combined PV systems' and left out the analyses. A total list of all the detailed information about the respondents who installed multiple PV systems or installed them spread through time can be found in Appendix 2.

PV system already present at purchase of house

None of the respondents moved into their house with the panels already present. All the respondents made the conscious choice to buy a PV system, none of the respondents bought or rented a house with an already present PV system.

DIY installation or other parties involved

Almost 25% (N=38) of the respondents indicated that they installed the installation themselves. Three quarter of the households had the system installed by the supplier or third parties.

Location

The PV households in this study came from all over the Netherlands. The largest shares of PV households are found in Noord-Holland (17.8%), Noord-Brabant (13.4%) and Gelderland (12.1%). The smallest shares of PV households can be found in Friesland (3.2%), Drenthe (1.9%) and Zeeland (1.3%). For the vast majority of the households the long term average of annual sun hours are between 1550 to 1700 (see for more information section 3.1.3). For that reason it was chosen later in this study not to adjust the data for those differences (among others in section 6.5).

Type of solar panels

The type of solar panel used affects the expected efficiency and yield of the PV system. Table 15 shows the frequencies and shares of the different type of panels used in the PV systems of the respondents. One third of the PV owners (N=53) did not know the type of panel used. Of the respondents that did know what type of panels are used in their system, almost 60% (N=61) have a PV system based on mono-crystalline panels. This is the most expensive type of panel, with the highest capacity. With a cell capacity of 14% to 20% the highest yield is expected to come from this type of panel. It seems to show that, the fact that mono-crystalline panels are more expensive than other types is not strong enough to withhold the PV owners from purchasing this expensive type. They choose quality over price.

Table 15. Type of solar panels in PV system of respondents

	Frequency	*Percentage (of N=157)*	*Percentage (of N=104)*
Mono-Crystalline	61	38.9%	58.7%
Poly-Crystalline	39	24.8%	37.5%
Amorf/Thin Film	2	1.3%	1.9%
Others	2	1.3%	1.9%
I don't know (13)/Combined PV systems (40)	53	33.8%	n.a.
Total	157	100%	100%

Type of connection

The type of linkage between the solar panels (serial or parallel connection) could affect the capacity of the total PV system. If the panels are serially connected the capacity can decrease strongly if one panel is not working correctly or overshadowed. The advantage of serial connections is that the yield of all the panels adds up to an accumulated voltage before reaching the inverter. This amount of produced electricity can never be reached when the panels are parallel connected, meaning that al the panels are separately connected to the inverter. The positive feature of this type of connection is that the production of other panels is not affected by one failing panel.

A little over 80 per cent of all households have a system that is serially connected (see Table 16). This includes 10% of the respondents that have multiple strings serial connected to one inverter and 5% that have multiple strings serial connected to multiple inverters. Less than ten per cent of the respondents have a system based on parallel connected solar panels.

Table 16. Type of linkage of solar panels

	Frequency	*Percentage (of N=157)*	*Percentage (of N=110)*
Serial (one string) connection	79	50.3%	71.8%
Parallel connection	9	5.7%	8.2%
Serial (multiple strings, one inverter) connection	11	7.0%	10.0%
Serial (multiple strings, multiple inverters) connection	6	3.8%	5.5%
Others	5	3.2%	4.5%
I don't know (7)/Combined PV systems (40)	47	29.9%	n.a.
Total	157	100%	100%

PV system placing: roof/free field

Table 17 shows the data about the type of roof the PV systems were placed on. Almost two third (64.1%) of the PV owners have their PV systems placed on a sloping roof. Thirty per cent have a PV system installed on a flat roof. This does not mean that the panels are not tilted in a certain angle. The next section will go into depth on the average tilt angle.

Table 17. PV system placing

	Frequency	*Percentage (of N=157)*	*Percentage (of N=117)*
Tilted roof	75	47.8%	64.1%
Flat roof	35	22.3%	29.9%
Free field	5	3.2%	4.3%
Others	2	1.3%	1.7%
I don't know (0)/Combined PV systems (40)	40	25.5%	n.a
Total	157	100%	100%

Tilt angle

Of the total PV owners that were asked about the tilt angle of their solar panels (N=117), 80% have PV systems with tilted panels. Twenty per cent have panels that are horizontally installed, meaning that they have a tilt angle of 0°. This is relatively large considering the decrease in expected yield when the panels are installed horizontally. It shows that, even when the properties of the house are not optimal these PV owners were still willing to invest in the panels.

The respondents that indicated that their panels are installed in a tilted angle (N=93) were asked to indicate the exact installation angle. On average the panels in this group of respondents are tilted in 34.8 degrees (*SD* = 11.39). This is very close to the optimum tilt angle in the Netherlands of 36 degrees. In Table 18 the systems are grouped based on the ranking 'bad'- 'excellent', which was already used in chapter 3.1.2. Around 85% of all respondents have their panels installed in a good or excellent tilt angle. It shows that, if a tilted installation is possible the fast majority of PV households make sure that it is done in the best way possible.

Table 18. Tilt angle PV systems

		Frequency	*Percentage (of N=157)*	*Percentage (of N=93)*
Bad	(1°-5° or >66°)	1	0.6%	1.1%
Medium	(6°-15° or 56°-65°)	12	7.6%	12.9%
Good	(16°-30° or 41°-55°)	50	31.8%	53.8%
Excellent	(31°-40°)	30	19.1%	32.3%
Horizontal (24)/Combined PV Systems (40)		64	40.8%	n.a.
Total		157	100%	100%

Shadow

Of all PV owners (N=117), 37.6% (N=44) have obstacles near their PV system that limit the light. A little over 60% of the respondents have unhindered light on their system and experience no shadow. It means that over one third of the PV owners have a PV system with conditions that are not optimal.

The duration of the experienced shadow is influential for the actual decrease in yield. Small shadows of short duration are often negligible but the larger the shadow and the longer the duration the larger the decrease in yield. Table 19 and Table 20 show the size of the obstacles the duration of the shadow and the share of the panels that is overshadowed.

Table 19. Duration of shadow per day (in groups*) and the share of the PV system that is then overshadowed.

		Respondents *(N=44)*		**Percentage of PV system overshadowed**	
		Frequency	*Percentage*	*Mean*	*SD*
Very short	*(<10 minutes)*	3	6.8%	11.0%	8.185
Short	*(10-30 minutes)*	5	11.4%	49.6%	46.209
Medium	*(31-60 minutes)*	12	27.3%	31.8%	17.258
Long	*(61-120 minutes)*	16	36.4%	58.0%	37.259
Very long	*(>120 minutes)*	8	18.2%	44.1%	37.972
Total		44	100%		

* Groups are defined on the basis of literature in chapter 3.1.2

What shows in Table 19 is that the duration of the shadows is connected to the share of the total panels that is overshadowed: large shadows often mean a long duration of the shadows. Over 50% (N=24) of the PV systems that receive limited lighting caused by shadows experience this shadow more than one hour per day. The share of the panels covered by this shadow is on average 53.4% (*SD* = 37.25). The shadows are likely to be of a long duration and cover a large part of the system. For seventy per cent of the PV systems that experience limited light, this is caused by large or very large obstacles (see Table 20).

Table 20. Size and type of obstacles limiting the light (in groups*)

		Respondents (N=44)	
		Frequency	*Percentage*
Small	*(Antennas, branches, small chimneys)*	3	6.8%
Medium	*(satellite dishes , chimneys, small trees)*	10	22.7%
Large	*(medium trees, dormers)*	20	45.5%
Very large	*(large trees, houses, buildings)*	11	25.0%
Total		44	100%

* Groups are defined on the basis of literature in chapter 3.1.2

Orientation

The yield of a PV system is highly affected by the orientation of the solar panels. Facing South is the most optimal orientation, as could be seen in chapter 3.1.2 and Figure 20. PV panels that are oriented South West or South East (and every orientation closer to South) still can produce 95% of their capacity if tilted in the right angle. If the panels turn further away from the South the productivity goes down. It is remarkable that only 74.8% of the respondents fall within the 95% group (see Table 21). It means that a quarter of the PV systems produce ten per cent or more less energy than their capacity when it would have been installed under the optimal conditions. The PV panels of most respondents are installed in the right orientation, see Figure 30.

Table 21. Orientation of PV systems

	Respondents (N=91)	
	Frequency	*Percentage*
West South West	5	5.5%
South West	7	7.7%
South South West	13	14.3%
South	33	36.3%
South South East	22	24.2%
South East	4	4.4%
East South East	2	2.2%
West, North or East	5	5.5%
Total	91	100%

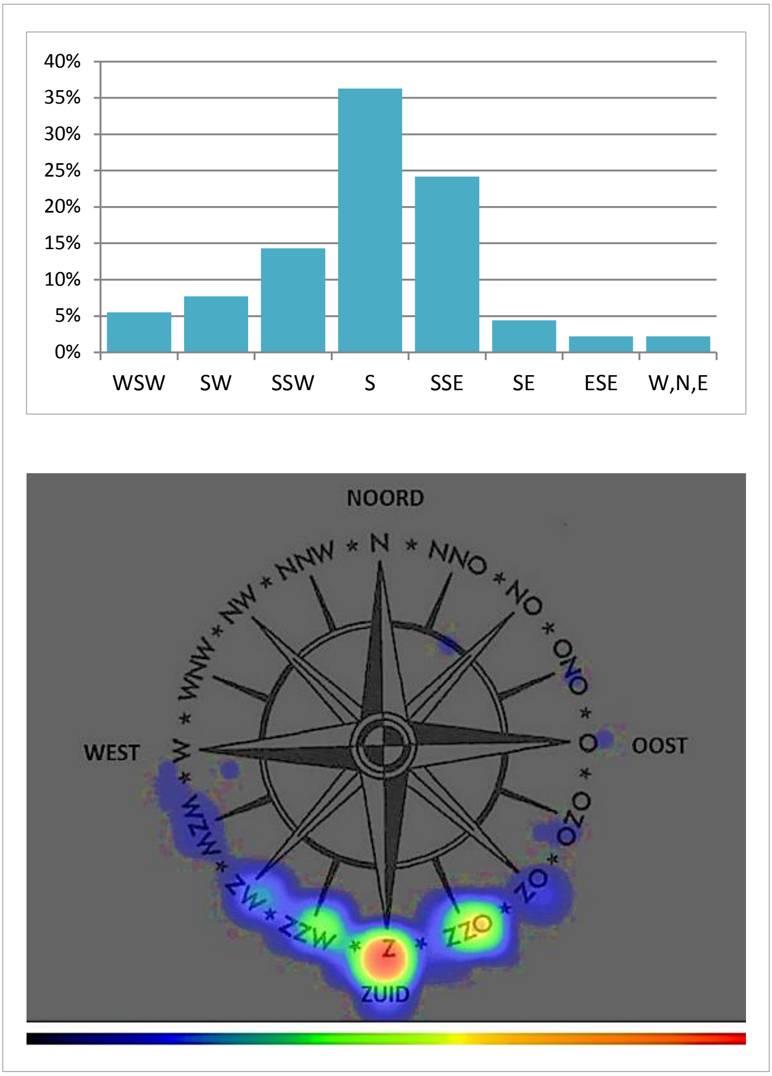


Figure 30. Orientation of PV systems

6.1.2 Total placing

To be able to determine how many PV owners have a PV system that is not installed under good or excellent conditions the criteria of chapter 3.1.2 were used. To fit in the group ‘excellent placing’ all criteria should be met. If one of the criteria is not met it will be ranked as one group lower. The criteria for each placing type can be found in Table 22. What the qualification on average means for the productivity of a PV system is also displayed in the table. For example, if a PV system is qualified as ‘good’ it means that it can only reach a productivity level of 95%. This is 5% lower than what it could have been in case of optimum placing conditions for the Netherlands.

Table 22. Criteria for judgement about placing qualification

Total placing qualification	Tilt angle	Orientation	Shadow*	Max. productivity level
Excellent	30° - 40°	South	None - small	100%
Good	15° - 30° and 40° - 55°	South West – South East	Small - medium	95%
Medium	5° - 15° and 55° - 65°	South West – South East	Small - medium	90%
Bad	0° - 15° and >55°	North, South or West	Medium - large	80%

* Explanation of shadow levels
Small: *Very short-short term shadows caused by small/medium obstacles like antennas, chimneys, etc.*
Medium: *Medium-long term shadows caused by small/medium obstacles like chimneys, trees. etc.*
Large: *Long-very long term shadows caused by medium/large obstacles like trees, buildings etc.*

Table 23 shows the results of the qualification of the PV systems of the respondents. It is a combination of the data retrieved from questions about the tilt angle, the orientation and possible shadowing.
Since the criteria for ‘excellent’ are rather strict and means perfect placing it is expected that a little less than ten per cent of all PV systems meet these criteria. The largest group (58.2%) can be found in the category ‘good’, meaning that the PV systems placed under these conditions can reach a productivity that is 95% of their potential if installed under perfect conditions in the Netherlands.
Remarkably a rather large share of the PV systems is installed under conditions that are far from optimum. One third of all the PV systems (33%) could be qualified as medium (27.5%) or even bad (5.5%) placing, resulting in a productivity loss of at least ten percent but often more.

Table 23. Qualifying the PV installation based on tilt angle, orientation and shadow

	Maximum productivity level PV system	Respondents *(N=93)*	
		Frequency	*Percentage*
Excellent	100%	8	8.8%
Good	95%	53	58.2%
Medium	90%	27	27.5%
Bad	80%	5	5.5%
Total		93	100%

Generally suppliers and PV producers advice people to install a PV system when the placing conditions are at least good or even excellent. When the properties of the PV placing, caused for example by the rooftop orientation, will result in a maximum productivity level of less than 95% it is often worth reconsidering the decision to buy a PV system. The profitability of a PV system decreases rapidly if the maximum productivity level decreases. Lower energy production and longer payback times make it an investment difficult to earn back.

For that reason it was not expected that, based on these criteria, one third of all the PV systems of the respondents can be qualified as slightly profitable or not profitable at all. Apparently, the households that despite the not optimum properties of the placing still decided to install a PV system, have strong motives or believes to do it anyway. Most likely, these motives are not related to the financial benefits. However, this is only speculating because when analysing this group of PV owners there are no significant differences found with the other groups. Among others, the households that have a bad or medium placing of their PV system show not significantly more environmentally friendly behaviour, do not experience more or less barriers, and do not significantly mention ‘environmental concerns’ more frequently as an important motive than households with good or excellent placing.

6.1.3 Cleaning

Related to the PV system characteristics but also to PV household behaviour is the cleaning of the PV system. Chapter 3.1.4 already showed the effect of cleaning on the electricity production. In the questionnaire the respondents were asked to indicate how often they on average clean there PV system. The following definition of cleaning in this matter was given to the respondents: *wiping off dust with a moist cloth or similar product or a similar or more extensive cleaning process.* The answers to this question can be found in Table 24. The table shows that, almost 40% of the households never clean their PV system. As seen in chapter 3.1.4 this might cause a decrease in production in time. How large this decrease is, is very context dependent and specific for each PV system. A long term study is needed to test this and to find out how specific characteristics of a PV system and placing affect the size of the effect of cleaning.

Table 24. Answers to the question 'How often do you, on average, clean your PV system?'

	Frequency	*Percentage*
More than once a year	33	21.0%
Once a year	52	33.1%
Less than once a year	11	7.0%
Never	61	38.9%
Total	157	100%

6.1.4 Conclusion

In this section it was found that, similar to what was expected, the PV system of each household is different. They vary among others in type of system, installation properties, orientation and presence of obstacles. Typically, the PV systems in this study are based on Mono-Crystalline PV cells, are serially connected, are placed on a tilted roof, are facing South and experience no shadow.

Remarkably, the placing properties for over thirty per cent of the PV systems in this study are qualified as ‘medium’ (27.5%) or even ‘bad’ (5.5%). This means that these systems will only be able to produce a maximum of 90% (medium) or even 80% (bad) of the amount of PV energy they could have produced if they would have installed under the right conditions. It is important to keep in mind that in this study it remains unclear whether the households knew this at the point of sale (and still wanted the PV system) or that they were misinformed.

6.2 PV system capacity properties: saving estimations

In the previous section the installation properties of the PV systems were explained. This chapter will go into depth on the estimations that come with each systems. These estimations are among others about the annual yield and the financial savings. Different calculations and assumptions lead to different estimations. All are explained in this chapter. The respondents were also asked to make their own estimation about the annual savings of their PV systems. These too, are described in this chapter.

For this section the 'Combined PV systems' (N=40) that are explained before are excluded from the analyses. If total scores or average scores are depicted or explained than the data from 'combined PV systems' are not included. Missing scores or respondents answering 'I don't know' are also not included. This number is specified for each question.

6.2.1 Installed capacity in Watt Peak

The accumulated installed capacity of the PV systems in this research (N=115, 2 missing) is 290152 Watt Peak. This translates to an average of 2523 Watt Peak per household (*SD* = 1211.078). Since PV systems, and especially their size and installed capacity are different for pretty much every household, it is much more relevant to look at the installed capacity per panel or per square meter. On average the PV systems have an installed capacity of 218.27 Watt Peak per solar panel (*SD* = 35.598). However, panels are sometimes different in size, so it is much more relevant to look at the average capacity of the PV systems per square meter. The PV systems have an average capacity of 150.17 Watt Peak per square meter (*SD* = 30.81). In general, PV suppliers and information websites claim that on average the Watt Peak per square meter is 150 Watt Peak. Assuming that this is a correct statement we see that the respondents probably did not make too many mistakes when filling in the questionnaire. Strange answers or outliers would have shown at this point.

In chapter 3.3.1 PV systems were classified on the basis of their total installed capacity. The same criteria are used in Table 25 to group the PV systems of the respondents. It shows that almost two third (63.5%) of the systems can be classified as 'middle capacity size'.

Table 25. Classification of capacity (in Watt Peak) of PV systems

Capacity classification PV systems		PV Systems (N=115) Frequency	Percentage
Small	*Less than 1500 Watt Peak*	23	20.0%
Medium	*1500 – 3500 Watt Peak*	73	63.5%
Large	*More than 3500 Watt Peak*	19	16.5%

6.2.2 Expected yield based on ‘0.86-factor’

To be able to estimate the amount of energy that a PV system will annually produce the capacity in Watt Peak is multiplied by 0.86 hours. The reasoning behind this factor can be found in chapter 3.1.2. Using this factor, that is commonly accepted in the Netherlands, will give insight on the possible energy production. On average, the estimated yield for the installed capacity of the PV owners (N=115, 2 missing) is (*2523*0.86hrs*) 2169.83 kWh. This translates to 187.72 kWh (*SD* = 30.614) per panel and 129.14 kWh (*SD* = 26.49) per square meter.

6.2.3 Expected yield based on supplier estimation

When buying a PV system all suppliers will provide the customer a general estimation of the annual yield of the system. The respondents were asked to give this estimation in the survey. The total sum of all the supplier estimations of the respondents (N=111, 5 missing) is 237.949 kWh, on average this is 2143.68 kWh (*SD* = 1082.26) per PV system. The average supplier estimation per panel is 184.19 kWh (*SD* = 38.746) and 126.16 kWh (*SD* = 31.282) per square meter.

6.2.4 Expected yield based on household estimation

The same respondents were also asked to estimate themselves how much energy they thought their PV system would annually produce. The accumulated estimation is a production of 239284 kWh per year, with a mean of 2117.56 kWh (*SD* = 1079.712) per system. For the households this means that, based on their own estimation, they will on average produce 183.99 kWh (*SD* = 39.159) per panel and 126.339 kWh (*SD* = 30.774) per square meter.

6.2.5 Comparing the estimations

Since the scores that are measured per square meter are most interesting to compare, all the data is summarized in Table 26. This table makes it possible to compare the average estimations based on the ‘0.86-factor’, the suppliers and the households themselves.

Table 26. Annual yield estimation (calculated, supplier and household) in kWh/m²

	Average annual yield in kWh/m²	
	Mean	*SD*
Calculated estimation *(Watt Peak * 0.86hrs)*	129.14	26.49
Supplier estimation	126.16	31.28
Household estimation	126.34	30.77

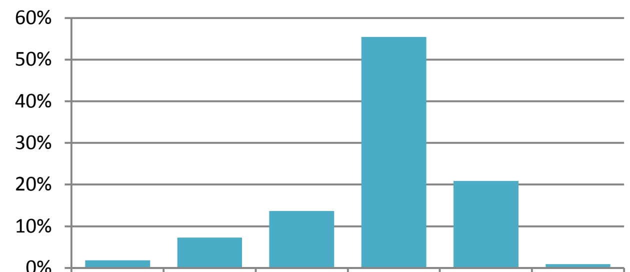
Calculated estimation versus supplier estimation

T-testing shows that there is a difference between the calculated estimation of the annual production of kWh/m² and the supplier estimation, this difference is (2-tailed) not significant but relevant enough to take in to account, t(109) = 1.703, *p* = 0.091. It was 2-tailed tested because there was no specific expectation prior to the T-test. It shows that on average the suppliers of the PV systems of the respondents seem to be a bit more reserved on their estimations than the 0.86-factor estimates. There seems to be a difference between the 0.86 factor used this research and the factors the suppliers have used. To test this the factor for each respondent were calculated via the formula:

$$\frac{Supplier\ estimation}{Calculated\ estimation} = factor.$$

The average of these factors (*M* = 0.848, *SD* = 0.009) is not significantly smaller than the 0.86 factor, t(108) = -1.215, *p* = 0.227.

Despite the fact that the average factors do not differ significantly, the range (0.31-1.05) shows that there are some big differences within the group of factors. Figure 31 shows the distribution of the factors. Most suppliers use a factor of 0.8 to 0.9 (55.5%).



	< 0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	> 1.0
PV systems	1,82%	7,27%	13,64%	55,45%	20,91%	0,91%

Figure 31. The factor used by the suppliers to calculate the annual yield (supplier estimation/calculated estimation)

It is remarkable that there are also many suppliers using a factor lower than this 0.86. Calculating the difference between the 0.86 factor and the factors used in the situation of the respondents (*Factor – 0.86)* shows that there are some interesting differences.

Figure 32 shows that 53.2% of all the factors are lower than the 0.86. Only 4,6% use the 0.86 factor in their estimations, and 42.2% use a more positive factor than 0.86.

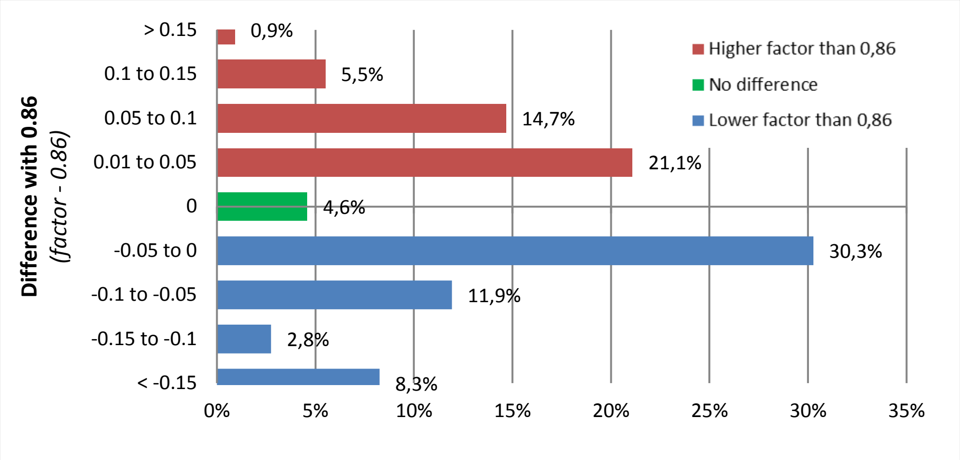


Figure 32. Differences between the 0.86 factor and the factor used by the supplier

The fact that so many supplier estimations are based on a lower factor can be explained in a number of ways. It might be possible that these suppliers know, based on experience, that the commonly accepted 0.86 factor is too optimistic. Another explanation might be that these suppliers have taken into account what the household specific properties are that may cause the PV system to perform less, such as shadowing or horizontal placing. To test this the differences were grouped again, in the groups 'higher factor', 'equal factor' and 'lower factor'. Since the factors 0.85 and 0.87 are so close to 0.86 they are treated as equal. The Chi-square test shows no significant correlation between the type of placing ('Excellent-Good' versus 'Medium-Bad' see chapter 3.1.2) and the factor used by the supplier, $X^2 = 1.901$, $df = 2$, $p = 0.387$. It means that there is no proof for the explanation that suppliers that use lower estimation factors do this because of bad placing properties. More detailed data, including supplier information, is needed to test this possible explanation.

Another explanation might be that the difference is caused by differences in years of installation. It could be possible that PV systems installed in 2008 used a different, less optimistic factor, than PV systems installed in 2011 due to technological improvements. However, for this explanation too, there is no proof found in the data. PV systems were low factors were used are not significantly older than high factor systems.

A last possible explanation could be that some suppliers are cautious when estimating the yield of a PV system to make sure that they do not disappoint the customer in the end. Setting low expectations increase the chances of success.

Future research is needed to test if these explanations are correct.

Figure 32 also shows that over two third of the supplier estimations are based on a more optimistic factor than 0.86. It means that these suppliers are possibly overestimating the productivity of the panels or use a more promising estimation to convince customers of

the profitability of their panels. Research has shown (see chapter 3.1.2) that it is very unlikely that in the Netherlands panels will actually produce more than a 86% share of their true potential. Marketing is most likely the reason why suppliers claim the yield to be higher than a 0.86 share of the total capacity (Watt Peak).
Remarkable is that for 6% (N=7) of the PV systems the estimation by the supplier is equal to the total capacity of the system. Either the PV owners interpreted the capacity in Watt Peak as the estimated yield or the suppliers provided an estimation that is totally infeasible in the Netherlands. If the latter would be the case this means that these customers were being lied to by their PV supplier.

Supplier estimation
Another interesting difference between the yield estimations in kWh/m² is the difference between the supplier estimations and household estimation. The mean found in Table 26 shows no significant difference. However, when looking at each household separately we can calculate the individual differences between the estimated yield by the supplier and the estimated yield by the households themselves (*supplier estimation – household estimation)*. A positive difference means that the households estimates their annual yield to be lower than what the supplier estimates it will be. A negative difference means that a household estimates that their PV system will produce more energy than predicted by the supplier. Either way, a difference means that those households have some sort of distrust in the supplier estimation.

Table 27. Differences between supplier estimations and household estimations about the annual yield of the PV system (*supplier estimation - household estimation)*

		Respondents *(N=109)*	
		Frequency	*Percentage*
Positive difference	*Household estimation < Supplier estimation*	34	31%
No difference	*Household estimation = Supplier estimation*	34	31%
Negative difference	*Household estimation > Supplier estimation*	41	38%

In Table 27 we find that there are basically three groups of households to be described. The group of households that copy the supplier represents almost one third of the households, namely 31%. This group name exactly the same annual yield as their supplier.

The second group is of equal size (both represent 31% of the PV households) but shows a different direction. This group expects the yield to be lower than the supplier estimation. They show a more sceptical approach towards the supplier and are less optimistic about the actual yield than what the supplier estimated. It indicates that almost one third of all the PV households are somewhat suspicious about the reliability of the supplier estimation, and already take into account that their annual energy production might be lower than estimated by the supplier. This could be caused by distrust in the supplier. It could also be related to the fact that often the supplier does not know the house specific details, especially if the households have installed the system themselves. It might be the case that they take into account that their PV system is not placed under optimum conditions (e.g. right tilt angle, orientation, shadow) and therefore lower their yield estimations. More research on this specific topic should be done to draw significant conclusion about the explanations for this phenomenon.

The last group of households, is the largest group. These households are very optimistic about the amount of energy their PV system will produce. Almost forty per cent (38%) of all households expect their PV system to produce a higher yield than what is expected by the supplier of the system.

Combining the data from this section with the data from the previous section resulted in Table 28. It shows a possible explanation for the fact that there is such a large group of households that is more positive about their annual yield than the suppliers. Almost half (46.2%) of all the households that are optimistic about their PV production also have a supplier that uses a low factor to estimate the yield. This relation is also found in the opposite direction. Households that have a more negative estimation about their yield more frequently have a supplier that uses a very optimistic factor. The differences in this table are significant, $X^2 = 10.594$, $df = 4$, $p = 0.032$.

Table 28. Cross Tabulation of 'Supplier versus household estimations' and 'Supplier Factor'

Respondents *(N=107)*	*Supplier factor*							
	< 0.85		**0.85 – 0.87**		**> 0.87**		**Total**	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*
Household estimation < Supplier estimation	7	20.6%	11	47.1%	16	47.1%	34	100%
Household estimation = Supplier estimation	11	32.4%	6	17.6%	17	50.0%	34	100%
Household estimation > Supplier estimation	18	46.25	13	33.3%	8	20.5%	39	100%

Based on Table 28 we can conclude that households seem to do their own research when it comes to possible yields. On various websites, forums and in information brochures the commonly accepted '0.86-factor' to calculate the yield can be found. Sometimes the factor 0.85 or 0.87 is used. If the estimation of the supplier is based on a factor lower than 0.85 households seem to be more likely to estimate the actual yield to be higher. If the supplier bases its estimation on a factor higher than 0.87 the households become more sceptical and expect the yield to be less.

It shows that PV households have enough knowledge about PV technology to make their own estimation instead of accepting blindly what the supplier estimates. It proves the PV households to be involved and motivated to invest time in the process of finding information.

6.2.6 Expected savings (€) based on supplier estimation

Suppliers often not only estimate what the yield of a PV system will be but they also use financial estimations to persuade households to buy a PV system. These estimations are about what the direct financial savings will be for the household placing the system. It does not take into account the investment costs; it is only about what a household will pay less for their conventional energy each year. The respondents in the survey were asked to indicate what their suppliers estimated as annual savings in Euros. On average the PV households (N=109) were estimated to save €495.21 on an annual basis (*SD* = 246.353). This is on average an annual financial saving of €42.55 (SD = 10.628) per panel and €29.11 (*SD* = 9,708) per square meter.

6.2.7 Expected savings (€) based on household estimation

The respondents (N=109) were also asked to indicate what they thought they were going to save each year (in Euros). On average they estimated to save €481.71 per year (*SD* = 244.172). This is not significantly less than what the suppliers estimated. This is an average annual saving of €41.97 per panel (*SD* = 11.763) and €28.79 per square meter (*SD* = 10.149).

6.2.8 Comparing the individual supplier and household estimations

The difference between the average supplier and household estimations is found not to be significant but it does not say anything about the individual situation of each household. It is very relevant to compare the supplier estimation with the household estimation because it will give some insight on how household deal with information given by suppliers. Do they just accept it is a given fact or do they do their own research and information search? The data about the differences can be found in Table 29. Similar to what was found in the data of the yield estimations, three equal groups can be distinguished. One third of the households follow their supplier and give the same saving estimation; one third estimates that their savings will be lower than the supplier estimation; and the last group estimates that their annual savings will be higher than the supplier estimation.

Table 29. Differences between supplier estimations and household estimations about the annual savings in Euros (supplier estimation - household estimation)

		Respondents (N=106)	
		Frequency	*Percentage*
Positive difference	*Household estimation < Supplier estimation*	37	34.9%
No difference	*Household estimation = Supplier estimation*	35	33.0%
Negative difference	*Household estimation > Supplier estimation*	34	32.1%

6.2.9 Conclusion

This section looked at the capacity properties of the PV systems in this study and what this installed capacity means for yield and saving estimations. It was found that the installed capacities vary among the respondents, but that most respondents (63.5%) have a medium PV system (1500 – 3500 Watt Peak). Based on the installed capacity and the 0.86 factor, individual estimations were made for the possible annual yield and savings. Also, the respondents were asked what their supplier estimated to be the savings and what the households themselves estimated to be the savings each year. On average, the yield was estimated to be 129.14 kWh/m² on the basis of calculation (Watt Peak * 0.86 hrs), 126.16 kWh/m² by the supplier and 126.34 kWh/m² by the households themselves.

Analyses of the individual cases, instead of the averages, showed that two third of the supplier estimations are based on a factor more optimistic than the 0.86 factor. It also showed that 38% of the households are more optimistic about their annual yield than their suppliers. They think they will produce more PV energy than what their supplier estimates. This same tendency is found for estimated financial savings: one third (32.1%) of the households expects to save more each year than what their supplier expects they will save.

6.3 Costs and subsidies

To value profitability and savings of a PV system not only its placing properties, capacity and estimated yield and savings are important, also the initial investment costs are important. The respondents were asked to indicate what the costs were for their PV system (subsidies excluded), what the maintenance costs are and how many subsidies they have received. For this section the 'combined PV systems' (N=40) that are explained before are excluded from all the analyses.

6.3.1 Acquisition costs

In total, the respondents (N=115) spent €673,543 on their PV systems. On average, this is €5856.90 (*SD* = 3093.806*)* per household. These costs involve the system itself, installation, modifications to the house and all other costs involved. Table 30 shows more detailed data about the costs of the PV systems. In this table it can be found that on third of all PV households spent between €4000,- and €6000 on their PV system. The median of the costs lies at €5410. A small portion of the respondents (5.2%) spent more than €10,000, one of the households even spent €20,000.

Table 30. Costs of PV systems

Costs	Respondents *(N=115)**	
	Frequency	*Percentage*
< €1000	3	2.6%
€1000 - €2000	7	6.1%
€2000 - €3000	10	8.7%
€3000 - €4000	13	11.3%
€4000 - €5000	18	15.7%
€5000 - €6000	21	18.3%
€6000 - €7000	9	7.8%
€7000 - €8000	11	9.6%
€8000 - €9000	8	7.0%
€9000 - €10,000	9	7.8%
> €10,000	6	5.2%
Total	115	100%

*11 respondents did not answer the question

Based on the knowledge that the prices of PV systems decreased over the last ten years a Spearmans Correlation Test was conducted. This test showed that there is a significant relationship between the year a PV system was purchased and the price of the PV systems per square meter, $r = -.432$, $p < .001$. It shows that, as expected, the total price of a PV system (measured per square meter to allow comparison) decreased over time. On average, the prices for a PV system in 2012 are lower than in 2008, consistent with the tendency claimed by the PV market.

6.3.2 Subsidies

In total, the PV households (N=116) received €98,193 in subsidies. A little over thirty per cent (31.9%) did not receive any subsidies at all; 46.6% received a subsidy lower than €1000; 16.4% received a subsidy larger than €1000 but smaller than €2500 and the remaining 5.1% received a subsidy larger than €2500. Worth mentioning is that one household received an SDE subsidy of €9000 in 2008 for a system of 18 panels.

6.3.3 Maintenance costs

Over 90% of all respondents (N=117) have no annual maintenance costs. Only nine respondents state that they have annual maintenance costs. These costs vary from €10 to €150 a year, with an average of €62.22 (SD = 47.835). The maintenance costs in this question did not include the expected replacement costs for the inverter after ten to fifteen years.

The large share of PV households without any maintenance costs shows that the ‘high costs’ that are often claimed to be a barrier in the decision making process (see chapter 7.2) are caused by the initial investment and not by high maintenance costs.

6.3.4 Conclusion

In this section was found that the respondents on average invested €5856.60 in their PV system. The costs are related to the year of installation: the older the system, the higher the acquisition costs. Most PV households (68.1%) in this study received a subsidy for their PV system. Interesting to see is that, as claimed by the industry, the PV systems come with low maintenance costs. The vast majority of the PV households indicated not to have (annual) maintenance costs.

6.4 Expected profitability

We have now seen what the PV system placing properties are, what the saving estimations are and what the costs for the investment were. To value if the investment was actually a 'right' decision, from a financial point of view, this chapter will look at the profitability of the investment. This is a concept very important for purchases where this big of an investment is involved. Measuring if an investment is profitable can be done in various ways. Three of these methods are discussed here.

In the PV world the most frequently used method is calculating the *Return On Investment Time* (ROI time) or payback time. This method shows how long it takes to earn back all the total costs of the system. In marketing this method is often used because it is a method, easy to understand for customers. A major disadvantage of this method that it does not take into account the value of money over time.

A method that does take the value of money over time into account is calculating the *Net Present Value* (NPV). Using this method means comparing the present value of money today with the present value of money in the future; the NPV is the present value of future cash flows minus the purchase price.

A last method, often found in the world of PV is comparing the *Internal Rate of Return* (IRR) of a PV system with the effective interest rate that comes with saving the money on a bank. This method is interesting because it allows comparison with the interest of saving the money instead of investing it in a PV system.

All three methods that are explained above are interesting to look at in itself and are therefore used in this chapter to be able to examine the profitability of PV systems. The chapter starts with explaining the choices made and assumptions accepted to be able to calculate the return on investment times, net present values and internal rates of return. Second the predicted ROI Times, NPVs and IRRs are explained and calculated. The second part of the chapter will show the real ROI Times, NPVs and IRRs based on the actual measured yields in the research.

6.4.1 Choices and assumptions

Calculating future profitability of an investment accepts a certain level of uncertainty. Estimations and assumptions about the future are needed to be able to say something about the profitability. This section will show which assumptions are used in the profitability calculations of this chapter.

For PV systems, the profitability depends on many factors. The following data is needed to be able to calculate profitability:

PV system characteristics (individual)

1) Total costs
    a) Price of PV system (including panels, inverter, cables, etc.)

    b) Installation costs
    c) Maintenance costs
    d) Costs for replacement inverter
    e) Subsidies
2) Installed PV capacity
    a) Expected yield
    b) Real yield (based on survey)

General PV system characteristics
3) Expected life time of PV system
4) Expected decrease in production capacity of installed PV system

Contextual characteristics
5) Development electricity prices
6) (Predicted) savings interest rates
7) Discount rate

1) Total costs

The total costs (TC)is the sum of the price of the PV system (including panels, inverter, cables, etc.), the installation costs (I_{nst}), maintenance costs (M_{aint}) and the costs involved in the replacement of the inverter. The inverter must be replaced after ten to fifteen years (the average of 12.5 years is used in this calculation) and costs on average €1000 (Natuur&Milieu, 2013). The expected lifetime of a PV system is 25 years, hence the inverter must be replaced at least once.

Since the aim here is calculating profitability and financial attractiveness of PV systems for each individual household, the subsidies (S) are subtracted from the costs, resulting in the *total costs*: $TC = (I + I_{nst} + M_{aint} + 1000) - S$

2) Installed PV capacity

The size and capacity of the PV system affects the annual yield and therefor the amount of time it takes to earn back the investment. In the predictive calculations the 0.86 factor is used to predict the average annual yield per system. In chapter 3.1.2 the detailed reasoning for using this factor can be found. Later the actual annual yield (derived from the survey) is used.

3) Expected lifetime of PV system

The expected lifetime of a PV system is commonly accepted to be 25 years. This is also the number of years this research uses as the expected life time.

4) Expected decrease in production capacity

The production capacity of a PV system is expected to decrease in time. The respondents were asked to state what productivity level the supplier guaranteed after 10 years and after 25 years. Commonly accepted standards are a productivity level decrease of 10% after ten years and 20% after twenty years. For a share of almost 80% of the respondents the supplier used those standards. For that reason the return on investment is calculated with an expected decrease of 10% after ten years and 20% after twenty years.

5) Development electricity prices

The price of electricity is used to calculate the value of the yield in euro's. In 2013, the electricity price is on average 22.5 euro cents per kWh (CBS, 2013e; Milieucentraal, 2013b). Over the last 15 years the prices have multiplied with a 2.5 factor. On average, the electricity price has increased with 6.2% each year (CBS, 2012b).

Predicting the future energy prices is difficult and different institutions predict different price increases. Changes in fixed costs such as connection costs are excluded because they will remain present when installing a PV system. The predictions vary between 2,5% (CBS, PBL, Wageningen UR, 2013a) to 10% (Natuur&Milieu, 2013).

Here the more conservative prediction used by Milieucentraal (2013b) is used. They predict an annual increase of electricity prices of 4% (based on 2% inflation and 2% product typical price increase). Milieucentraal base their predictions on data from studies of the EPBD (Energy Performance Building Directive of the European Union) on the expected energy price developments until 2040.

As an example, the electricity prices for the years 2008 to 2013 are depicted in Table 31.

6) (Predicted) savings interest rates

The predicted saving rates are used to compare the return rate of PV system investment with what could be the return if the same amount of money would have been saved on a bank. The savings interest rate used in this research is 2%, and is based on the average interest rate in 2013 on a freely available savings account in the Netherlands (Consumentenbond, 2013b). Depending on the bank this could even be lower.

In the Netherlands there is a tax called 'capital gains tax' which means an extra tax for high saving balances. This could limit the return on the saving. This capital gain tax only holds for very high savings and will be left out of the analysis.

7) Discount rates

The discount rate can be used to calculate the return of the investment with taking into account the fact that the risks are much higher when you invest in a PV system than when the money is put in to a long term deposit account. This research accepts a real discount rate of 5.5% based on an agreement between ECN, the Ministry of Internal and Royal Affairs, Agentschap NL and Milieu Centraal. This discount rate seems rather high, since the real risk-free discount rate is currently set at 2.5% (Ministry of Finance, 2009). However, the 5.5% is based on the fact that investing in PV systems is not risk free and is about individual households. This justifies a higher discount rate (Natuur&Milieu, 2013). As a form of testing its sensitivity the more conservative discount rate of 4% is used at the end of this chapter. It will give more insight in what different scenarios mean for the profitability of PV systems.

Table 31. Electricity prices 2008-2013

year	Electricity price *in €/kWh*
2008	0.185
2009	0.192
2010	0.200
2011	0.208
2012	0.216
2013	0.225

Calculating Total Output (in €)

Based on the assumptions and decisions that are explained above, the following formula is created to calculate the total production of a PV system. This formula can be used to predict what any PV system is predicted to produce in its life (25 years) and is needed to be able to calculate the ROIs, NPVs and IRRs.

$$TO = \sum_{t=0}^{9}(y \cdot p(1.04)^t) + \sum_{t=10}^{19}(y \cdot 0.9p(1.04)^t) + \sum_{t=20}^{24}(y \cdot 0.8p(1.04)^t)$$

TO	Total Output. The total production of the PV system in
t	time in years. *Time is measured in years. The year of installation is year 0 (t=0), the second year is year 1 (t=1), etc.*
y	yield. *The predicted annual yield in kWh based on the 0.86 factor.*
p	electricity price. *The starting point of this electricity price depends on the year the PV system started to produce electricity.* Table 31 *can be used to find out the electricity price for each starting year. After that, the electricity price will increase with 4% each year*.

6.4.2 Return on Investment Time

In general holds, the longer it takes to earn back an investment, the higher the uncertainty, the less attractive an investment becomes.

The ROI Time of a PV system is often provided by the supplier but can also be calculated. This section will show the ROI Times based on the calculation, the suppliers estimations and the household estimations. Before doing so it will explain the method used and provide an example of the calculations used.

ROI Times

The formula to predict total yield can also be used to look at the accumulated yield after a certain amount of time. The year in which the accumulated total output is equal to the total costs ($TC = TO(t)$) is the year in which the investment is returned. This break-even year is the ROI Time. After this point the output of the PV system will be profit only. The total profit (P) can be calculated by subtracting the total costs from the total output after 25 years: $P = TO_{t=25} - TC$.

Example

An example of how to calculate the ROI time and the total profit can be found in Table 32 and Figure 33. This is a real life example from one of the respondents in this research. This household paid €10,000 for their PV system and installation. They had no maintenance cost and received a total of €2000 in subsidies. After 12.5 years they are expected to replace their inverter (€1000). The total costs for this household are: €10,000 + €1000 - €2000 = €9000. The predicted annual yield is 3300Wp*0.86hrs = 2838 kWh. The PV system was installed in the beginning of 2009, meaning an electricity price in the first year of 19.23 Eurocents. Using the TO-formula shows that after 25 years this household has a total output of €20,466. This is a total profit of €20,466 - €9,000 = €11,466 at the end of the expected lifetime of the PV system.
Looking at Table 32 (see blue bar and *) and Figure 33 shows that in the fourteenth year this household will reach their break-even point. The ROI Time for this household is therefore 14 years. From this year on the yield is direct profit.

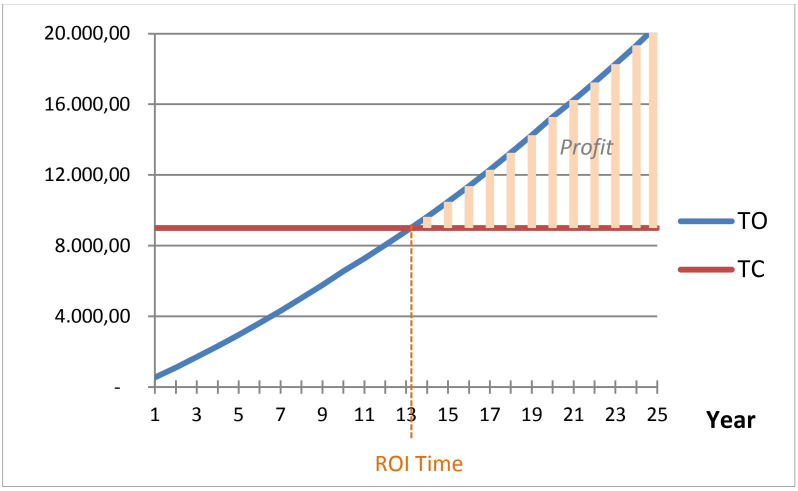


Figure 33. Example of Return on Investment Time and total profit calculation

Table 32. Example of ROI and Total Output calculation

Year	Electricity price €-cent/kWh	Annual yield (y) in kWh	Monetary value yield in €	Total Output (TO) *(Accumulated yield in €)*	Total Profit *(€9000 – TO)*
1 (2009)	19.23	2838	€ 545.83	€ 545.83	€ -8454.17
2	20.00	2838	€ 567.67	€ 1113.50	€ -7886.50
3	20.80	2838	€ 590.37	€ 1703.87	€ -7296.13
4	21.63	2838	€ 613.99	€ 2317.86	€ -6682.14
5	22.50	2838	€ 638.55	€ 2956.41	€ -6043.59
6	23.40	2838	€ 664.09	€ 3620.49	€ -5379.51
7	24.34	2838	€ 690.65	€ 4311.15	€ -4688.85
8	25.31	2838	€ 718.28	€ 5029.42	€ -3970.58
9	26.32	2838	€ 747.01	€ 5776.43	€ -3223.57
10	27.37	2838	€ 776.89	€ 6553.32	€ -2446.68
11	28.47	2554	€ 727.17	€ 7280.49	€ -1719.51
12	29.61	2554	€ 756.26	€ 8036.75	€ -963.25
13	30.79	2554	€ 786.51	€ 8823.25	€ -176.75
14*	32.02	2554	€ 817.97	€ 9641.22	€ 641.22
15	33.31	2554	€ 850.68	€ 10,491.91	€ 1491.91
16	34.64	2554	€ 884.71	€ 11,376.62	€ 2376.62
17	36.02	2554	€ 920.10	€ 12,296.72	€ 3296.72
18	37.46	2554	€ 956.90	€ 13,253.62	€ 4253.62
19	38.96	2554	€ 995.18	€ 14,248.80	€ 5248.80
20	40.52	2554	€ 1034.99	€ 15,283.79	€ 6283.79
21	42.14	2270	€ 956.79	€ 16,240.58	€ 7240.58
22	43.83	2270	€ 995.06	€ 17,235.64	€ 8235.64
23	45.58	2270	€ 1034.86	€ 18,270.50	€ 9270.50
24	47.40	2270	€ 1076.26	€ 19,346.76	€ 10,346.76
25	49.30	2270	€ 1119.31	€ 20,466.07	€ 11,466.07

The expected ROI time based on calculations

Based on the PV system specifics in the dataset it was found that on average the expected ROI Time or payback time for a PV system bought between 2008 and 2012 is 12.5 years (*SD* = 4.482). Table 33 shows the different ROI Times for the PV households (N=109)

Table 33. Expected Return on Investment Time of the PV systems for the respondents based on calculation

ROI Time	Respondents (N=109)*	
	Frequency	*Percentage*
0-5 years	1	0.9%
5-10 years	38	34.9%
10-15 years	48	44.0%
15-20 years	13	11.9%
> 20 years	9	8.3%
Total	109	100%

* 8 respondents did not answer the question

A *Pearson's Correlation Test* showed that the expected ROI Time is strongly related to the year the PV system was installed, $r = -.670$, $p < 0.001$. From a today's point of view it means the older the system, the longer it takes to earn back the investment. This is in line with what is commonly accepted in the PV industry.

There is also a strong correlation found between the installed capacity and the payback time, $r = -.491$, $p < 0.001$. On general it means, the lower the installed capacity the longer it respectively takes to earn back the investment. Hence, from a consumers point of view it is more rational to invest in a larger PV system with a higher installed capacity.

The expected ROI time based on supplier estimations and household estimations

The previous ROI Times are based on the calculations as explained before. However, the survey also asked the respondents to indicate what their provider predicted to be their ROI Time and what they predicted to be their ROI Time. This was a closed question, and to make comparison possible all the ROI Times were grouped in similar groups as was found in Table 33. In Table 34 the percentages of the ROI Times can be found. Without individual comparison of estimations within each case, in this table it can already be seen that there are some large differences between the ROI Times based on calculation, based on supplier estimations and based on household estimations. Based on the calculations of the previous section it was found that a little over 20% of the PV systems have e ROI Time of more than 15 years. Based on supplier estimations this holds for only 6% of the cases and based on the households themselves this is only 3.4%.

Table 34. Comparing Return on Investment Times based on calculation, supplier and household estimations

Return on Investment Time	Calculation *(0.86 factor)*	Supplier estimation	Household estimation
< 5 years	0.9%	3.5%	7.8%
5 – 10 years	34.9%	53.5%	51.7%
10 – 15 years	44.0%	36.8%	37.1%
15 – 20 years	11.9%	3.5%	3.4%
> 20 years	8.3%	2.6%	0%
Total	100%	100%	100%

If the different categories of the first column of Table 34 are given scores from 1 to 5 the means of the three different ROI estimations can be compared. By doing so, it was found that all the groups differ significantly from each other.

On average, the ROI Times based on the calculation in this research (M = 2.93) are higher than those based on the supplier estimations (M = 2.48), $t(106) = 0.448$, $p < 0.001$. On average, the ROI Times based on the calculation in this research (M = 2.93) are higher than those based on household estimations (M = 2.36), $t(108) = 0.560$, $p < 0.001$ On average the supplier estimations (M = 2.48) are higher than household estimations (M = 2.36), $t(113) = 0.123$, $p = 0.03$.

ROI Times are largely depending on who makes the estimation and what calculations are used. All the estimations are based on estimations and assumptions about the annual yield of a system and of future electricity prices. These are two uncertain variables, but variables that strongly affect the actual estimations of the ROI Time. Especially in marketing making certain assumptions for the future can be very convenient when providing customers with ROI Time estimations. Assuming a strong increase in electricity prices for example will lower the payback time and will increase the attractiveness of the product.

6.4.3 Net present value

The second method used in this research to value profitability of PV systems is calculating the Net Present Value (NPV) of the systems. In essence, the NPV compares the value of money today to the value of the same amount of money in the future, taking into account inflation and returns. Valuing the present value of an amount in the future is called discounting. Calculating the NPV is a method often used in capital budgeting to analyse if an investment is profitable and should be accepted. In general holds, a positive NPV means that the investment is favourable, a negative NPV means that the investment is not profitable and should probably be rejected. The basic formula for calculating the NPV is the following:

$$NPV = \sum_{t=0}^{24} \frac{R_t}{(1+d)^t} - TC$$

NPV	Net Present Value
TC	Total Costs
t	Time in years. *Time is measured in years. The year of installation is year 0 (t=0), the second year is year 1 (t=1), etc. The expected lifespan is 25 years.*
R_t	Return. *The monetary value of the yield of the PV systems in year t* *Affected by the increase of electricity prices (+4%) and the decrease in production capacity over time*
d	Discount rate *(5.5%, 4.0%)*

Calculating the NPVs is strongly dependent on the choices that are made concerning the discount rate. The discount rate takes into account inflation but also possible risks involved in the investment. As explained before this research accepts a real discount rate of 5.5% based on an agreement between ECN, the Ministry of Internal and Royal Affairs, Agentschap NL and Milieu Centraal.

Risks

An important concept for calculating the NPV are the risks that are involved in the investment. There are more risks involved in investing in a PV systems then immediately meets the eye. One of the risks easily overlooked is insecurity about the future regulations in the PV world. A change in the 'salderingsregeling' (see chapter 2.6) could heavily affect the financial return of a PV system. Another risk involved is the insecurity about the energy prices. If they, for example, do not increase as much as predicted than this will immediately affect the return of the PV system. A risk that is more household related, is the 'risk' of moving. NPVs and return rates are calculated on the basis of a life and production time of 25 years. If a household in the meantime decides to move (and leave the PV system behind), they will not receive any return on the initial investment. Moving the PV system to a new house is not recommended because the costs involved are relatively high. These and other risks all should be taken into account when comparing this investment with putting the money in a long term deposit account and are therefore incorporated in the discount rate.

NPV of PV systems

In Table 35 the NPV results of the respondents can be found. The NPVs are calculated with a 5.5% discount rate and under the assumption that the PV system will produce electricity for 25 years. A negative NPV means that the discounted return of the PV investment is lower than what it would have been if the investment was used to put on a long term risk free deposit account. A positive NPV means that the investment is more favourable than saving it. Despite the high discount rate Table 35 shows that for 75% of the PV respondents the investment in a PV system will turn out to be a more profitable investment than savings would have been. A Pearson's correlation test shows that whether a NPV is negative or positive is strongly correlated with the year a system is installed. The older the system, the higher the chance that the NPV will be negative, r = .586, $p < 0.001$.

Table 35. Net Present Values of respondents (5.5% discount rate)

	Frequency	*Percentage*
Negative NPV	25	22.7%
Positive NPV	85	77.3%
Total*	110	100%

* 7 respondents did not answer the question

Table 36 shows the NPV results of the respondents when a 4.0% discount rate is used. It is found that for ten per cent of the PV household a PV system will become a more favourable choice than saving when a discount rate of 4.0% is used. For a little over ten percent (12.7%) of the respondents saving would have been a more favourable choice than investing in a PV system.

Table 36. Net Present Values of respondents (4.0% discount rate)

	Frequency	*Percentage*
Negative NPV	14	12.8%
Positive NPV	96	87.2%
Total*	110	100%

* 7 respondents did not answer the question

6.4.4 Internal Rate of Return

The last method that is used in this research to value the profitability of PV systems is comparing the Internal Rate of Return (IRR) with the interest rates of saving accounts. By comparing the two it can be shown if it would have been more profitable to put the money on the bank instead of investing it in a PV system. It will show with which savings interest rate the PV return is comparable. The IRR of the PV investment can be defined as the interest rate received for the investment, based on the total costs and the anticipated (monetary value of the) yield that will occur for 25 years. To calculate the IRR (i) the NPV is set to zero.

The formula, to calculate the IRR is the following:

$$NPV = \sum_{t=0}^{24} \frac{R_t}{(1+i)^t} - TC = 0$$

NPV	Net Present Value
TC	Total Costs
t	Time in years. *Time is measured in years. The year of installation is year 0 (t=0), the second year is year 1 (t=1), etc. The expected lifespan is 25 years.*
R_t	Return. *The monetary value of the yield of the PV systems in year t*
i	Internal Rate of Return (IRR)

Typically, the IRR is calculated on the bases of guessing. This research used the predictor of Excel to calculate the IRRs. Figure 34 shows the calculated IRRs of the respondents. The median is found at an IRR of 8.5%.

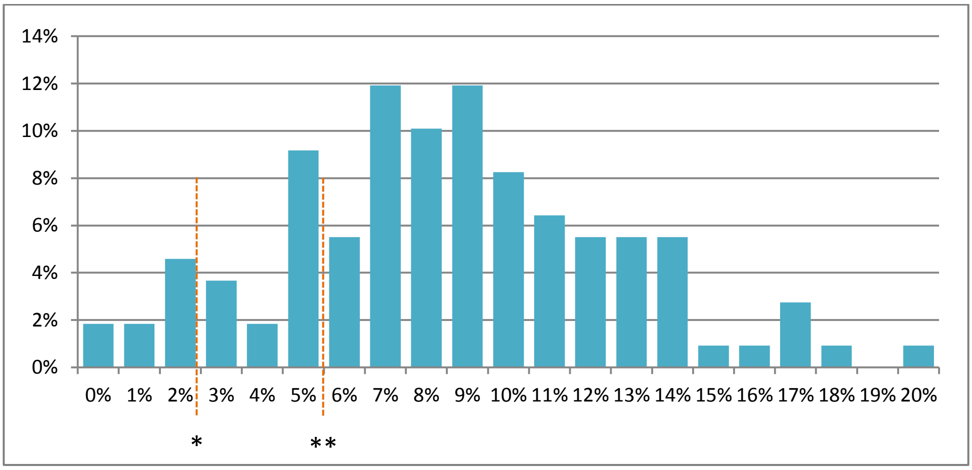


Figure 34. Internal Rates of Return of PV investment of respondents (N=109), *8 respondents did not answer the question*

Comparison with savings interest rates.

Milieu Centraal uses the IRRs of PV systems to compare the return of investing in a PV system with the return of saving the money. As explained before, the predicted savings interest rate used here is 2.0% for a risk free freely available savings account (Consumentenbond, 2013b). Keep in mind that the interest rates depend on the bank and are more likely to be lower than higher. Figure 34 (left from *) shows that 8% of the respondents have a PV system with an IRR lower than the savings return rate. This means that these households would have been, based on these data, better off if they had saved the money on the bank instead of investing it in a PV system. It also means that the vast

majority seemed to have taken the right decision if the criterion would have been having a higher interest rate than the savings interest rate.
The interest rates are often even lower than 2% and are predicted to decrease even more. For PV households this means that in almost every case investing in a PV system is more favourable than saving the money on a bank account.

Comparison with long term deposit account
A long term deposit is money saved on the bank that is, opposed to freely available saving accounts, not freely accessible. The money is fixed for a period of time and the size of the interest rate often depends on the length of the deposit and the amount of money saved. Generally speaking, deposit account interest rates are higher than the interest rates for freely available bank accounts. For a deposit account with a duration of ten years the average interest rate is in 2013 3.5% (Consumentenbond, 2013). For the sake of comparability the rate is here rounded to 4%. This takes into account that the interest rates for deposit accounts that have a duration of 25 years are often higher than 3.5%. Figure 34 (on the left of **) shows that 14% of the respondents have a PV system with an IRR lower than the interest rate of a long term deposit account.

6.4.5 Conclusion

Based on three different profitability analyses (accepting a set of assumptions about the future, see 6.4.1) it was found that domestic PV systems are indeed profitable investments. Whatever method used, investing in a PV system is indeed a profitable choice for most households in this research. With a 4.0% discount rate the net present value of the investment in PV is positive for over 85% of the PV households. Even with a higher discount rate of 5.5%, the net present value is still positive for three quarter of all PV households, showing that investing in a PV system is a financially desirable choice. The internal rate on investment is on average 8.5%, showing that investing in PV is typically more profitable than alternatives. Saving the money on a freely available bank account will result in a maximum of 2% interest, meaning that for 92% of the households it was indeed more profitable to invest the money in a PV system.
The downside of investing in a PV system is found in the time it takes to earn back the investment and the risks that come with this time. The estimated return on investment time of PV systems is typically 10 to 15 years, accepting the assumption of no changes in the energy consumption of the household.
Data about the first year of PV production can test to some extent if the NPVs, IRs and ROIs (that are here based on assumptions and estimations) are indeed true. Chapter 6.6 will go into depth on this ‘real’ profitability.

6.5 Real output

The previous chapter was all about estimations. To test accuracy of these predictions the actual yield and savings were measured in this research. In the questionnaire the respondents were asked to fill in the form that can is depicted in Table 37. The answers from this form led to data on the savings from a PV system. This chapter will go into depth on this data.

The effort needed from the respondents to fill in this form was quite large which resulted in high numbers of missing values. Only complete answers are used in the analyses in this chapter. Also 'combined PV systems' (N=40) that are explained before are excluded from the analyses in this chapter.

Table 37. Form used in questionnaire to measure energy costs and yield of year 1, 2 and 3.

	Period Energy Bill [month] [year] t/m [month] [year]	**Electricity consumption** *in kWh*	**Electricity costs** *in Euros*	**PV output (yield)** *in kWh*
1. Last year before installation PV system		kWh	€	kWh
2. Year of installation PV system		kWh	€	kWh
3. Year after installation PV system		kWh	€	kWh

6.5.1 Electricity production

Since the energy produced by the PV system is fed back to the grid, calculating the difference between the amount of electricity used in the year before installing the PV system and the year after installation will give a first insight in the energy savings caused by the PV system. Assuming equal energy consumption in both years, the difference will show the annual energy production of the PV system. Based on that calculation the PV systems in this research (N=67) on average produce 1638.75 kWh per year (*SD* = 1113.089). Since all PV systems have a different size and capacity it is more interesting to look at the electricity production per square meter. On average the PV systems produce 105.29 kWh/m^2 (*SD* = 59.650). Keep in mind that this is purely based on the difference between the electricity used in the year before and the year after installation, it does not take contextual factors or differences between the two years in to account.

Some households have a monitoring device connected to their PV system that keeps track on the amount of electricity that the system produces. Every respondent was asked to fill in the actual production of the system if they had that information available. This is the most accurate measurement of the yield and is in this research on average 120.12 kWh per square meter (*SD* = 34.129) on an annual basis. This average is based on 31 respondents. These results and the estimations found in the previous chapter are depicted in Table 38 and Figure 35

Table 38. Estimations and calculations of average annual yield (in kWh/m²)

	Average annual savings in kWh/m²	
	Mean	*SD*
Calculated estimation (Watt Peak * 0.86hrs)	129.14	26.490
Supplier estimation	126.16	31.282
Household estimation	126.34	30.774
Savings (Year before – Year after installation)	105.29	59.650
Yield (monitor)	120.12	34.129

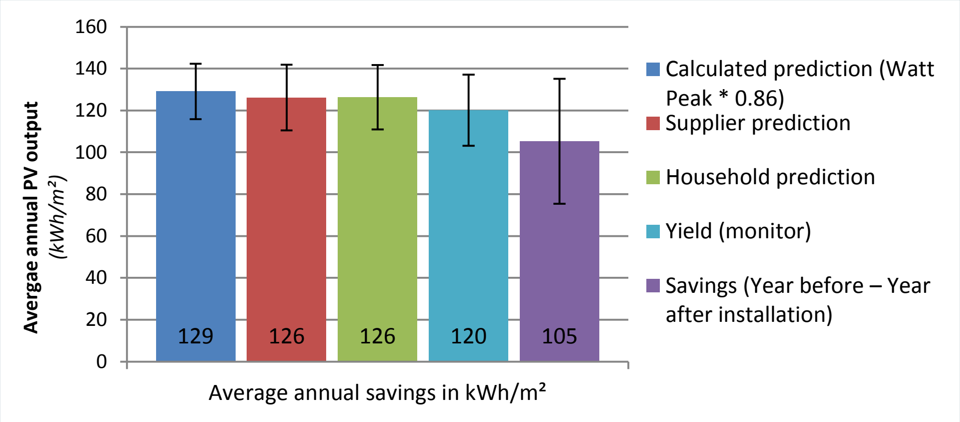


Figure 35. Estimations and calculations of average annual PV output (in kWh/m²)

Comparing the different means has led to Table 39. It shows that the annual savings based on the difference between electricity consumption in the years before and after the PV installation, differs significantly from the calculated, supplier and household estimations. The estimation that came closest is the supplier estimation, however still significantly higher than the actual savings. It also seems to show that the real PV production is a lot lower as expected. However, the average yield provided by the households with production monitors (N=31) shows that the actual yield is a lot higher and is a lot closer to the estimations. The PV systems seem to work similar to what was expected; the yield is not significantly lower than the suppliers estimations. On the basis of this the conclusion can be drawn that on average, the savings are lower than what they could have been.

Table 39. Differences between means of (predicted) annual savings in kWh/m²

	Differences between means (predicted) annual savings in kWh/m²				
	Calculated estimation	*Supplier estimation*	*Household estimation*	*Savings*	*Yield (monitor)*
Calculated estimation					
Supplier estimation	-1.78				
Household estimation	-2.64	-0.73			
Savings	-21.99*	-19.07**	-21.45***		
Yield (monitor)	-6.61	-4.93	-6.33	19.59	

* $t(49) = (-)2.78$, $p < 0.05$
** $t(47) = (-)2.24$, $p < 0.05$
*** $t(49) = (-)2.62$, $p < 0.05$

6.5.2 Comparing real output with estimations

The previous section was, as was explained, about the averages of the respondents. It treats the group as a whole. Splitting the group up in smaller subgroups that show similar behaviour can give more detailed insight in the real savings from PV systems. Different formats and classification will be used to find subgroups in the dataset.

Difference with supplier estimation

Subtracting the savings in kWh from the supplier estimation of the annual savings will show the accuracy of the supplier estimation.

Figure 36 shows the difference with the supplier estimation depicted in percentages of the supplier estimation. For example, an household was predicted by the supplier to save 2500 kWh on an annual basis. In real life, the calculation (electricity consumption year after PV installation – electricity consumption year before PV installation) showed that they saved 1500 kWh. The difference is 1000 kWh, which is 40% of the supplier estimation. This household saved 40% less than the supplier predicted. On average, the PV households saved a share of 83% of the savings that were predicted by the supplier. This means that on average, households save 17% less than what could have been expected based on the supplier estimation.

From the red bars in Figure 36 we learn that 70% of the PV households do not save as much as the supplier predicted in the first full year. For 14% this is only a small difference of maximal 10% less than the supplier estimation. However, the same share of PV households saves over 70% less than what was predicted by the suppliers.

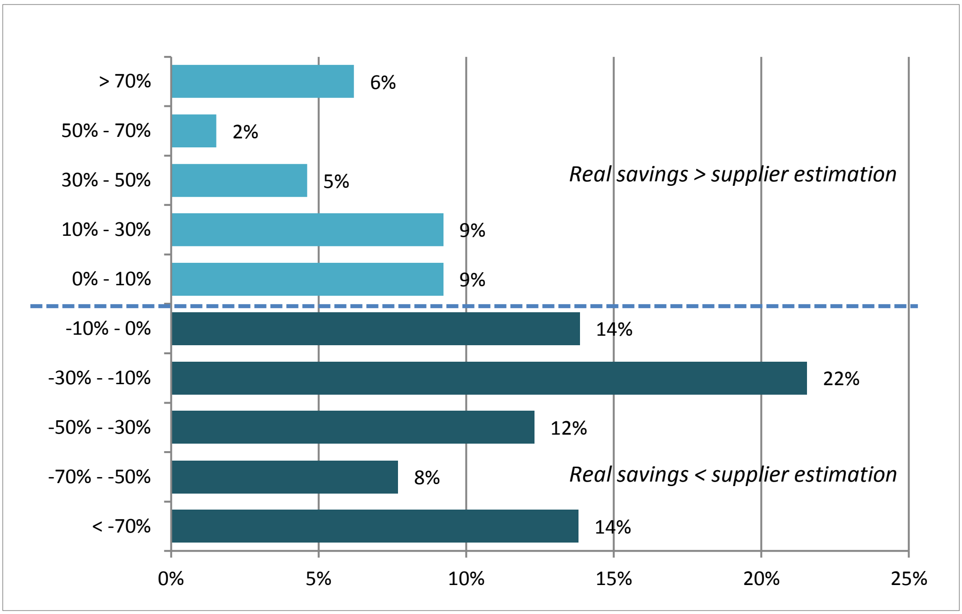


Figure 36. Share of respondents (N=65) that saved more or less energy than what the supplier predicted, expressed in percentage of the supplier estimation. Example: -'-50% - -70%' means that the household saved 50 to 70 per cent less than what was predicted by the supplier.

Figure 36 also shows that 30% of the respondents saved more energy than what was predicted by the supplier. To test if this phenomenon was related to the households that predicted their yield to be higher than what the supplier predicted a *Pearson Chi-square Test* was performed. From this analysis was learned that this was not significantly related, $X^2 = 2.434$, $df = 2$, $p = 0.296$. Of the households that predicted their yield to be higher than what the supplier predicted only 38% was right and indeed saved more energy than what was predicted. Apparently there are other reasons why thirty percent of the households save more energy than what was expected, and 70% saves less than what was expected.

In 23% per cent of the cases, the supplier was more or less right (with a range of -10% to 10%) about the amount of energy a household would save. It also indicates that in 77% of the cases the suppliers were either too negative but in most cases too positive in their estimations.

Difference with household estimations

The households also had their own estimations of how much electricity they expect to save each year. Comparing these estimations with the real annual savings shows that most respondent overestimated their possible energy savings. On average, PV households save 17% less electricity than what they expected to save on an annual basis.

Figure 37 shows that, similar to the previous section, over two third of the respondents (69%) saves less than what they expected to save in a year. The results in Figure 37 correlate strongly with the results from Figure 36, $X^2 = 39.88$, $df = 1$, $p < 0.001$. It indicates that the same factors are involved in both figures. Over 20% of the households save less than 50% of the amount they predicted they would save. This could mean that they are very bad at guessing, consumed a lot more energy in that year or that the PV system did not work appropriately. The following sections will go into depth on possible explanations for this.

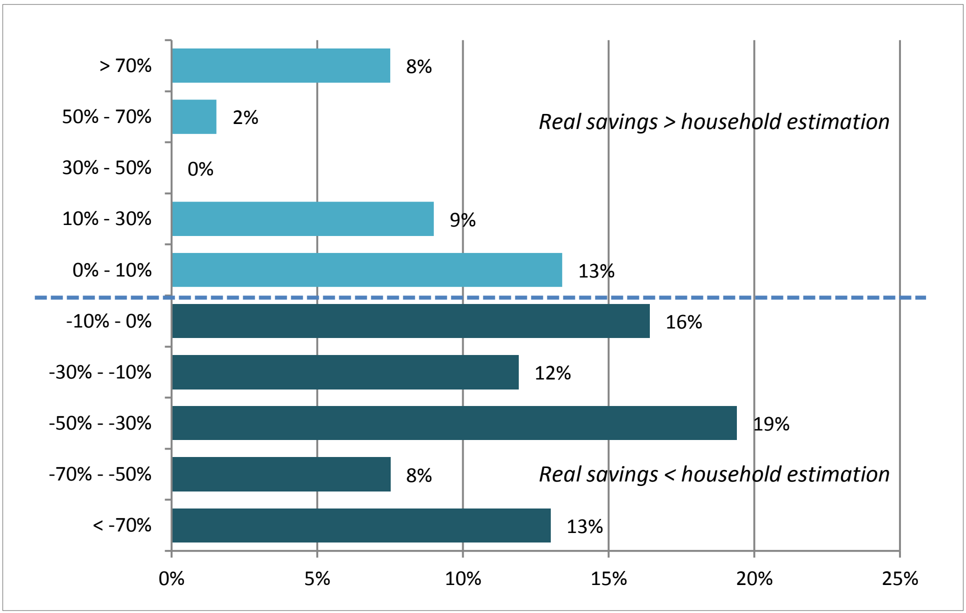


Figure 37. Share of respondents (N=67) that saved more or less energy than what they predicted they would save, expressed in percentage of the household estimation. Example: -'-50% - -70%' means that the household saved 50 to 70 per cent less than what they predicted to save.

In 29% per cent of the cases, the household was more or less right (with a range of -10% to 10%) about the amount of energy they would save. It also indicates that in 71% of the cases the households were either too negative but in most cases too positive in their estimations.

Groups

Based on the previous section we can conclude that there are three groups of PV households: PV households that save more than they expected (19%), PV households that save a similar amount of electricity as they expected (29%), and PV households that save less than expected (52%).

To find out what is causing these differences correlation tests were performed with different variables. To rule out if the consumption of electricity was affected by something other than the PV system the respondents were asked to indicate of there were any changes in the households in the year before, during and after installation of the PV system. Among others, they were asked to indicate if the household size changed, if they installed new energy saving or (heavy) consuming appliances and if they had their home renovated or remodelled. Before calculating the real output these changes are included in the data. The data was adjusted for the household changes. The changes can however still be used to see if the explanation for the differences between real yield and predicted yield can be found in one of those directions.

The important results are described below:

- There is no correlation between *changes in the household size* and whether or not households save more, equal or less than they predicted
  (year before installation: r = -.073, p = 0.554; year of installation: r = .012, p = 0.926)
- There is no correlation found between *the installation of other energy saving or consuming appliances* and whether or not households save more, equal or less than they predicted.
  (energy consuming: r = -.039, p = 0.757; energy saving: r = -.064, p = 0.605)
- There is no correlation found between *the remodelling or renovation of the house* and whether or not households save more, equal or less than they predicted.
  (r = -.004, p = 0.974)
- There is no correlation found between *the first year (and number of sun hours) after installation* and whether or not households save more, equal or less than they predicted.

All these results show that the explanation for the differences must be found in other directions. The largest group of households save less energy than they expected. One of the hypotheses of this research was *Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend*. For this hypothesis, no evidence was found. The data here seems to point in the opposite direction. Over fifty per cent of the PV households show behaviour that is related to the 'rebound effect' (see chapter 3.3.2). It means that they save less than they expected because they start to consume more energy. This could be caused by the thought that 'I have plenty of energy because I produces it myself'. This leads to a large group of households saving less than they could have saved, directly caused by an increase in their energy consumption.

The group that saves more than expected is probably the group that do experience a ‘double dividend’. They save more energy than what was predicted. Assuming that the estimation was right, it means that these households show extra energy saving behaviour. For this group the installation of a PV system leads to a change in behaviour and in the end to a lower energy consumption than what could have been expected on the basis of the PV output.

Concluding, the hypothesis is not confirmed. Only a small group (20%) of the respondents experience a positive behavioural response. For half of the PV households holds that they show the opposite behaviour: a negative change in their behaviour and an increase in their energy consumption. An effect called the rebound effect.

The remaining 30% saves more or less an equal amount of energy as what was expected.

Difference with monitored yield

In Table 38 it was found that the average monitored yield (120 kWh/m²) was a lot closer to the expected yield by the calculated estimation (129 kWh/m²) than the measured savings (105 kWh/m²) (based on the calculation *year before – year after installation*). Again, this data seems to indicate that the actual PV systems seems to work fine, but that the household consumption of energy changes.

To test this, for the households (N=27) with a monitoring device the savings and the actual yield were compared (in kWh/m²). From that comparison was found that there are basically three groups to be described: the households that some more than they produced, the households that saved less than produced and the households that save an equal amount as what they produced,.

Save more than production

The first group of households (30%) save more energy than what the PV system produced. This means that their behaviour changed in such a way that they started to consume less energy than the year before they installed the PV system. For example (real life), the monitor of the PV system of family X showed that the system produced 107 kWh/m² in the year after installation. The energy savings (based on the difference of energy consumption *year before – year after installation*) are a lot higher than 107 kWh/m², namely 218 kWh/m².

The most obvious reason for this phenomenon would be that the households started to perform extra energy savings behaviour due to the installation of the PV system. This is called a double dividend (see chapter 3.3.2). However, before this statement can be made information is needed about other changes in the same period that could have affected the behaviour or energy consumption of the household.

Correlation tests were performed to see if these changes were related to whether the households saved more, equal or less than what was produced by the PV system. Keep in mind that the number of respondents with a monitor was small (N=27).
The results are not correlated with changes in the household size. For all households in this group the household size remained the same in the years before, during and after installation of the PV system.
Interestingly half of this group indicated to have added more electricity saving appliances or features (in the year of and/or after installation of the PV system) to their household.
There is also no significant relation (due to the small size of this group) but it could be one of the explanations for these households to save more energy than what was produced by the PV system. It also means that there is still a group of respondent that show 'double dividend' behaviour. They started showing extra energy savings behaviour after the installation of the PV system. This could be caused by the extra awareness or the fun of seeing the energy meter go down.

Save less than production
The biggest group of households with a PV monitor show opposite (rebound effect) behaviour. Almost 45% of this group save less energy than what their PV system produced in energy. From correlations tests it was learned that there were no changes in the households that affected the energy consumption significantly. Again, like what was found in the previous sections there seems to be more evidence for the rebound effect than the double dividend. Apparently, the energy consuming behaviour of almost 45% of the people changes after installation of a PV system.
More research among PV owners with monitors is needed to confirm this prediction. A research over a longer period of time (comparing multiple years) could show if these groups will change over time if the 'newness' of the PV system diminishes.

Savings equal to production
The final group of households (25%) is the group that does not show a change in behaviour. This group saves more or less the same amount of energy as they produce. This implies that the energy consumption of this household did not change by the installation of the PV system.

Conclusion
The results in this section, even though based on a small number of respondents, confirms the conclusions earlier drawn on the basis of the savings. The technology works, but the behaviour of the households affects the actual savings. The fact that the share of households that show a positive behavioural change (double dividend) is here larger than based on the savings (30% versus 23%) might be related to the presence of a monitoring device. It could evoke a more conscious way of living and lead to a reduction in the energy consumption by a positive change in the households behaviour. Further research is needed to test this.

6.5.3 Prediction variables for type of behaviour

What we have learned from the small amount of data available from the households with a monitoring device, is that apparently almost half of all households save less energy than they produce after installation of a PV system. This implies that there has been a change in household energy consumption behaviour, caused by the presence of the PV system. Interesting would be, to see what the characteristics of these households are. It could be used to predict the behaviour of specific households but also for informational purposes.

We have seen that there are basically three groups of households to be distinguished: households that save more energy than produced (showing 'double dividend' behaviour), households that save less energy than produced (showing 'rebound effect' behaviour) and households that save more or less the same amount of energy as they produced (showing the generally predicted, rational behaviour).

Interesting to know now is if there are any specific features that can be seen as related to or predictors of the specific behaviour households (will) perform. A stepwise multinomial logistic regression analysis testing is needed to find out what the predictor variables are for which behaviour households will perform. The households that do not show a change in their behaviour are used as the reference group. They show no change in energy consumption and save as much as produced by the system; they are the basis of every profitability analysis because they are based on the assumption that there will be no change in behaviour. Therefore, this group is used as the reference category. The other two groups mean some sort of change in behaviour. The results show what variable are involved in predicting whether or not, and even more specific which behavioural change a household will show.

The number of respondents with feedback systems is too small for this analysis and therefor again the assumption is accepted that the savings of the households can be seen as the actual production level of the PV system. This is based on the outcome found in Table 39 where it was found that the estimated production of PV systems is not significantly bigger than what was actually produced by the system. The comparison between the actual savings and the estimated yield is used as the outcome variable in the logistic regression analysis.

A multinomial logistic regression analysis was executed to find what variables are significant predictors of the behavioural change (or not) of households after installation of a PV system. As explained before, the households that show no behavioural change are the reference category in the analysis. A stepwise, forward entry approach was used because the testing is exploratory. No predictions or hypothesis were formulated on forehand. See Table 40 for the likelihood ratio tests.

Table 40. Multinomial logistic regression test of variables that possibly affect behaviour of PV households

Variables	Likelihood Ratio Tests		
	Chi-Square	*df*	*Sig.*
(Intercept)	.000	0	.
Age	1.418	2	.492
Electricity consumption	2.877	2	.237
Year of installation	2.219	2	.330
Installed capacity	11.618	2	.003
Household size	1.925	2	.382
Placing	.242	2	.886
Education	2.144	2	.342
Readiness to buy environmentally friendly products	1.009	2	.604
Perceived importance of protection environment	.310	2	.856

Note: R^2 = .42 (Cox & Snell), .48 (Nagelkerke)

There was one variable found to be a significant predictor of the type of behaviour a household is most likely to perform (see also :

- Installed capacity
  $X^2(2) = 11.618, p < .005$

The following variables were found not to be significant predictors.

- Placing (Bad-medium versus good-excellent)
  $X^2(2) = 0.242, p = .886$
- Household size (1-6)
  $X^2(2) = 1.925, p = .382$
- Electricity consumption (before installation)
  $X^2(2) = 2.877, p = .237$
- Year of installation (2008-2012)
  $X^2(2) = 2.219, p = .330$
- Education (high versus low)
  $X^2(2) = 2.144, p = .342$
- Readiness to buy environmentally friendly products
  $X^2(2) = 1.009, p = .604$
- Perceived importance of protection environment
  $X^2(2) = 0.310, p = .856$
- Age (household)
  $X^2(2) = 01.418, p = .492$

Double dividend versus no behavioural change

The size of the installed capacity only significantly predicts whether a household will show no behavioural change or will show a double dividend (save more than produced, extra energy saving behaviour), $b = -.002$, Wald $X^2(1) = 4.487$, $p < .05$. With every unit the installed capacity increases, the change in the odds of performing double dividend behaviour is 0.99. In other words, as capacity increases, households are less likely to show extra energy saving behaviour. Note that the effect is very small. A similar effect is not found when comparing rebound effect with no behavioural change, $b = .000$, Wald $X^2(1) = 0.00$, $p < .412$.

Although found to be a very small effect, this analysis has showed that the larger the installed PV capacity, the smaller the chance that the household will show a behaviour related to double dividend. Earlier it was shown that larger PV systems with more capacity are more profitable or have a quicker return on investment time. Here, however it is found that there are also disadvantages related to larger PV systems, since the owners of these systems are less likely to positively changing their behaviour after installation of a PV system. Households with less installed PV capacity are slightly more likely to show a positive behavioural response, related to the double dividend effect.

6.5.4 Conclusion

This section aimed to answer the research question '*How much do households annually save after the installation of a PV system?'*. The households savings were measured by subtracting the electricity consumption of the year after installation of the PV system from the electricity consumption of the year before. On average households save 105 kWh per installed square meter PV system. Depending on the chosen electricity price this is roughly an annual financial saving of €27 per square meter. The estimated savings based on calculating with the 0.86 factor (129 kWh/m²) and supplier and household estimations (126 kWh/m²) are significantly higher with respectively 22.8% and 20% compared to the actual savings.

Interestingly there was a difference found between the monitored yield and the savings (based on consumption before and after installation). The monitored yield, in other words the actual production of the PV system measured by a kWh meter, is on average 14.3% higher than the savings. With an average of 120 kWh per square meter it is not significantly lower than the estimated yields and savings. The photovoltaic technology seems to work just as good as expected.

The fact that the actual output of a PV system is so much higher than the savings (corrected for household and societal changes) leads to the conclusion that household behaviour is very important for the actual savings of a PV system. The system itself performs as expected but still on average households save an amount of energy that could have been a lot higher. Looking at this household behaviour, three groups (of N=65) can be distinguished when comparing the real savings with the expected savings (based on supplier estimations):

1. *Households that save as much as expected (range -10% – 10%)*: 23%
   These households show no sign of a behavioural change. Their energy consumption patterns have not changed after installation of the PV system.
2. *Households that save more than expected*: 22%
   These households show a positive behavioural response to the installation of the PV system. In the year after installation the (visual) presence of the system leads to a higher consciousness and lower energy consumption. These households save more than what is produced by the system, an effect that is called ‘double dividend’.
3. *Households that save less than expected*: 55%
   The biggest group of household show a negative behavioural response to the installation of a PV system. They start to consume more energy than before the installation, leading to lower savings than what they could have been on the basis of the PV power production. This effect, when households start to consume more energy because they produce this ‘free’ energy themselves, is called ‘rebound effect’. The chance of households performing this behaviour is higher for households that install larger PV systems with a higher capacity.

Even though that the group of households with monitoring devices was low, similar groups were found. A share of 25% belongs to the group that saves as much as produced by the system, 30% saves more than the system output and 45% saves less than the actual production. The shares were somewhat different indicating that there might be an extra ‘feedback’ effect for households with a monitoring device. The share of households that save more than produced is slightly higher than based on the savings. It could mean that having a monitoring device makes the chance of households experiencing the double dividend effect larger. Further research is needed to test this hypothesis.

By running a logistic regression analysis, predictors for the type of behaviour were sought. The only significant predictor found was installed capacity: the higher the installed capacity the smaller the chance of a household showing a positive change in behaviour leading to a double dividend. Keep in mind that this effect was found not to be very strong.

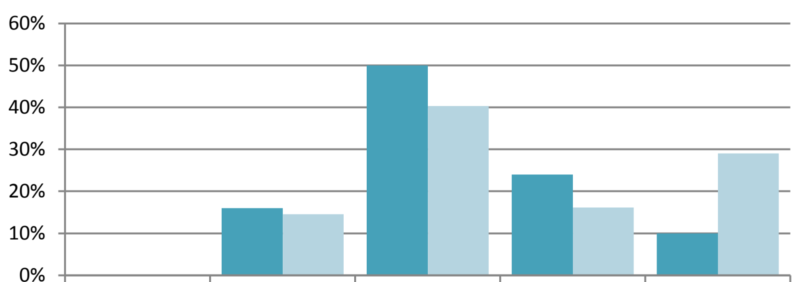
Concluding, for the hypothesis ‘*Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend’* is no evidence found. On the contrary, most households with PV systems seem to show a negative behavioural response, leading to an increase in energy consumption (rebound effect).

6.6 'Real' profitability

Chapter 6.4 looked at the real electricity output and the *Return on Investment Times* (ROIs), *Net Present Values* (NPVs) and *Internal Rates of Return* (IRRs) based on the annual yield that was predicted by the formula *yield*0.86 hrs* and based on an increase of electricity prices of 4% (2% inflation, to 2% product typical price increase). For a more objective point of view, electricity prices will remain difficult to predict but the actual production of a PV system can be and was measured. To decrease the uncertainty of this variable the household savings are used as the output of the first full year after having installed their PV system. This PV output, is affected by the household behaviour and can be used to give more accurate predictions about the real ROI Time. A certain level of uncertainty will of course remain, because the assumption here is that the savings of the first year can be used as the average production for the following years. Nevertheless, the uncertainty decreases which makes it attractive to look at the ROI Times, NPVs and IRRs based on real yields. The ROI Times, NPVs and IRRs based on these yields are described in this section.

6.6.1 'Real' Return on Investment Time

The same method that was explained and used in chapter 6.4.2 is used here to calculate the Return on Investment Times. The difference here is that instead of the expected yield (on the basis of the 0.86-factor), the actual savings of the first year after installation are used. Since not all respondents answered all the questions important for this calculation, only the respondents (N=50) that provided all the information are taken in to account here. Their estimated ROI Times and their 'real' ROI Times can be found in Figure 38. The estimated ROI Times (based on 0.86-factor) (M = 13.26) are significantly lower than the real ROI Times (M = 15.16), $t(49)$ = -2.98, p = 0.004. Because the savings are a lot lower than expected (see chapter 6.5.1) the ROI Times are a significantly longer than expected.



	0-5 years	5-10 years	10-15 years	15-20 years	> 20 years
Predicted ROI	0%	16%	50%	24%	10%
'Real' ROI	0%	15%	40%	16%	29%

Figure 38. Estimated Return on Investment Times versus real Return on Investment Times based on savings in first year after installation PV system (N=50)

Figure 38 compares the predicted ROI Times and real ROI Times but from this figure the individual differences cannot be found. Similar to findings found before, there are three groups to be distinguished:

1. The households that have a shorter real ROI Time than expected (more than 1 year shorter than expected),
2. the households that have a similar ROI Time as expected (maximum of 1 year longer or 1 year shorter than expected) and
3. the households that have a longer ROI Time than expected (more than 1 year longer than expected).

The share of respondents per group can be found in Table 41. In this table it is found that a little over 20% of the respondents will earn back their investment faster than what was estimated (based on the 0.86 factor). One third of the respondents will have earned back their investment in the time that was estimated (with a range of -1 to +1 year). Almost 50% of the respondents will need more time to earn back their investment than what was calculated. Based on the data in chapter 6.5.2 we know that the behaviour of these households is affecting this ROI Times. This is the group of households that does not save as much energy as it could save. By doing so, they increase the time it takes to earn back the initial investment.

Table 41. Differences between predicted Return on Investment Times and 'Real' Return on Investment Times (N=50)

	Respondents *(N=50)*	
	Frequency	*Percentage*
Predicted ROI > Real ROI	11	22%
Predicted ROI = Real ROI	16	32%
Predicted ROI < Real ROI	23	46%

6.6.2 'Real' Net Present Value

The Net Present Values of the PV systems of the PV systems were also calculated again using the savings of the first year as the annual output. The formula and the assumptions and choices are the same as explained in chapter 6.4. Figure 39 shows the differences between the shares of respondents that have a positive calculated NPV and positive real NPV. The share of households with a positive real NPV (with a discount rate of 5.5%) is 15% lower than the predicted share. It is found that, based on the actual data, the choice to invest in a PV system is favourable for a little over 60% of the households. It also means that the decision to invest is not favourable for 40% of the households. Keep in mind that the savings of the first year are treated here as average for all 25 years of the lifespan.

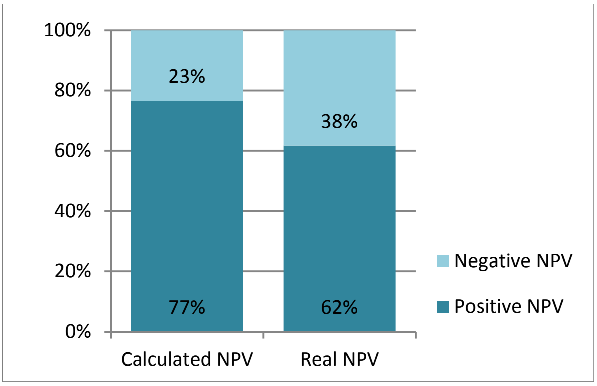


Figure 39. Calculated Net Present Values versus Real Net Present Values (5.5% discount rate)

With a more conservative discount rate of 4.4% the share of PV households that has taken the right decision (based on the first year) does not change a lot with respect to the higher discount rate of 5.5%. In Figure 40 it can be found that, based on their first full year of PV production, for only 64% of the respondents the decision to invest in a PV system was financially favourable. The chosen discount rate did not affect the outcome that for a large share of households (almost 40%) the decision to invest in a PV system is in retrospect (and based on the savings of the first year) not a favourable decision.

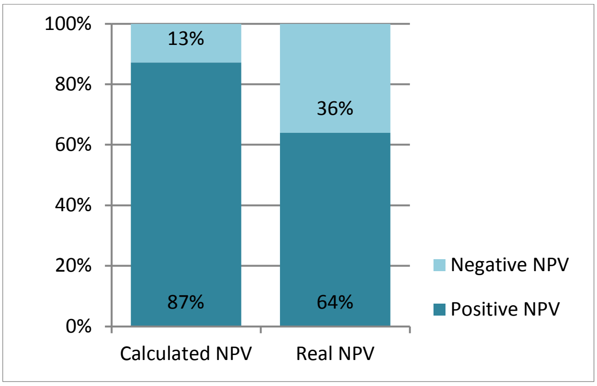


Figure 40. Calculated Net Present Values versus 'Real' Net Present Values (4.0% discount rate)

6.6.3 'Real' Internal Rate of Return

The Internal Rate of Return is the last profitability measurement that is recalculated with the real savings of the first year after installation. These real IRRs (M = 6.3%) are significantly lower than the predicted IRRs (M = 7.9%), $t(46) = 2.363$, $p = 0.02$. Again it is found that in real life the return of the investment in PV is lower than predicted.

6.6.4 Conclusion

This section aimed to answer the research question '*What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?'*. To find out what the financial benefits and hold backs for households are the question was split into two parts. The financial benefits were answered in this section in the form of a 'real life' profitability analysis. The second part about the experienced financial motives and barriers is answered in the next chapter. In the profitability analysis the assumption was made that the household behaviour would not change after installation of the PV systems. Based on this assumption it was found that in general investing in a PV system is a profitable decision for households. However the real life data, based on the first year after installation of PV systems, shows that the average real profitability of PV systems is lower than expected. The decision itself, to invest in a PV system is profitable, but less than what it could be.

For a little over 50% of the PV households counts that based on their first production year the Return on Investment Times are longer, the Net Present Values are lower and the Internal Return Rates are lower than what was estimated and what they could have been. In section 6.5 we have seen that the average output of PV systems is not that different from what was expected, but that the savings are lower than what they could be. This is caused by changes in the household behaviour: they show a higher energy consumption pattern (rebound effect). In this section it was found that this behavioural change or rebound effect also affects the profitability of the systems. The changes in energy consumption of households make that the profitability of PV systems is in 50% of the cases lower than what it could be.

The analysis showed that the profitability is different for each independent household, depending on the system properties but also on behavioural changes of the household. Hence, for the hypothesis '*The energy and financial savings are different for each household and are context dependent'* evidence is found. For example, negative changes in energy consumption of households (rebound effect) make that the profitability of PV systems is in 50% of the cases lower than what it could be. On the other hand, for a smaller portion of the households (25%) the profitability is higher because these households show a positive change in behaviour and save extra electricity (on top of the produced power by the system).

6.7 Financial savings

We now know that in general, PV systems are a profitable investment but that the amount of energy saved is affected by household behaviour. To be able to give a complete answer to the research question '*How much do households annually save after the installation of a PV system'* it is necessary to look at the financial value of the savings. The respondents did not only answer questions about how much energy they used, they were also asked to indicate how much money their electricity consumption cost. The financial value of household consumption patterns and energy saving behaviour is directly related to the amount of energy they consume and save. Hence, correlations are equal to what was found before. Nevertheless, basic descriptives are interesting to look at because they give a clear picture of what the energy savings mean for the household finances.

The results of subtracting the households electricity costs (in Euros) after the installation of a PV system from the electricity costs before the installation of the PV system results in an estimate of the financial savings in the first year after installation. The number of households that actually filled in this question is very low (N=23). On average, this group saved €364 (*SD* = 275.66) per year and per household. Since the financial savings depend on the electricity price household pay per kWh it is interesting to look at the financial savings if the average electricity prices are used. The group of respondents is bigger this time (N=67) because it is based on the savings in kWh data. The savings are in that case affected by the year the installation took place but taking that into account and using the price of electricity in 2013 (22.5 eurocents) the average annual savings are €368.71 (*SD* = 250.45) per household. This does not take into account that PV system sizes differ among household. Taking this into account it is found that on average the households annually save €23.69 per square meter solar panels (*SD* = 13.42) in the first year after the installation of their PV system.

6.7.1 Share of total consumption

As a share of their total energy consumption (based on the year before installation) households save on average 55.8% the first year after installation (*SD* = 41.22). It means that for an average households their electricity consumption will halve after installation of a PV system. This research already showed that the actual savings are highly context and behaviour dependent.

Rebound effect – missed financial savings

For the group of households that experience a rebound effect it is interesting to see what their behaviour means for their total consumption. On average this group misses out on a share of 22.8% (median) of savings of their total consumption. In other words, their behaviour affects their actual energy consumption so strongly that the bill could have been one fifth smaller. Depending on how strong the rebound effect is present in a household, the missed savings in this research went up to more than 100% of the energy consumption of the year before installation. How much money this rebound effect costs, depends on the installed capacity, the electricity price (year) and the size of the rebound effect. To make it all clear a calculation example can be found in Box 2 of a real life household from the research, named Family Y.

Box 2. Real life calculation Example of Family Y

Family Y

This family consists of three household members. The year before they installed their PV system they consumed 2455 kWh. In 2011 they installed a PV system of 20.48 m² (16 panels) with a capacity of 3130 Watt Peak. Their supplier predicted an annual yield of 2496 kWh. The placing of the system is classified as 'good'. They had no changes in the household size in the year of and the year after installation. They also did not install any other significant energy consuming or energy savings appliances or equipment.

The year after installation they saved 2055 kWh. This is (2496-2055) 441 kWh less than what the supplier predicted. Based on the data found before the supplier prediction for the output is often correct. Therefore, if we assume that this also holds here, it means that this household changed their behaviour in such a way that they started to consume over 400 kWh more than before installation of the PV system. This is a share of 18% of the total consumption of energy. They now still have to pay almost 20% of what they used to pay. This percentage could be zero because their predicted yield is more than their consumption. Using the average electricity prices for 2012 we know that this costs them 441*0.216 = €95.25. In other words, they could have saved almost hundred euros more in 2012 if they had not shown a change in their behaviour.

7 Motives and Barriers

In the previous chapter we have seen that installing a PV system was for most PV households indeed a profitable decision, but that household energy consumption behaviour strongly affects the real savings at the end of each year. Now, it is interesting to look at the decision making process of the household. Knowing the motives and barriers of household why or why not they chose a PV system can give very valuable insights in the decision making process.

7.1 Motives

Based on the literature review the following hypothesis was created: *Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system.* To find out what the most important reasons are for PV system owners to buy a system and to test the hypothesis the respondents of the questionnaire were asked for their main reasons why they decided to install a PV system. They were asked in this open question to name their most important reasons in order of importance, starting with the most important reason. After extensive analysis the answers were sorted into groups. The answers could be divided in to the following motives:

- Financial benefits:
  - *Direct savings* on energy costs
  - *High return on investment* (better than interest rates at banks)
- Environmental concern (less CO2 emissions, less fossil fuel use)
- Independency (from energy suppliers and government)
- Personal motives:
  - *Interest in technology*
  - *Fun*
- Setting an example (for community, neighbourhood)
- Other motives

Examples (translated from Dutch to English) of each group of motives can be found in Table 42. The complete list of motives (in Dutch) can be found in Appendix 3.

In this section the motives ‘direct savings’, ‘high return on investment’, ‘interest in technique’ and ‘fun’ are often referred to as separate motives for the sake of accuracy. However, since the hypothesis is more generally formulated they are also combined to respectively ‘Financial benefits’ and ‘Personal motives’.

Table 42. Examples of answers of each group of motives

Group of motives	Examples of answers
Financial benefits	
Direct savings	*Reduce monthly expenses on electricity* *Cost reduction* *Lower electricity bill* *Reduce fixed costs*
High return on investment	*Keep money on bank only costs money* *Long term profitable investment* *Good alternative for low saving interest rates* *Save investment*
Environmental concerns	*My contribution to environment* *Reduce CO2 emissions* *Sustainable* *Reduce footprint of household* *Reduce use of fossil fuels*
Independency	*Escape from influence of big power corporations* *Being self-sufficient* *Autonomy* *No trust in energy companies and government*
Personal motives	
Interest in technology	*Interested in technology of PV system* *Gain experience in technology* *Interesting to monitor results*
Fun	*Hobby* *Fun*
Setting an example	*Setting an example* *Be frontrunner in neighbourhood* *'Green face' in street* *If I do it, others might follow*
Others	*Legacy for future generations* *Feeling like an entrepreneur* *Keep economy going*

In Table 43 the frequencies are displayed for the number of responses per group of motives. Important to notice is that most respondents gave more than one reason and that all the reasons (first, second and third important reasons) are treated as equal. The importance of every motive will be explained further down in this section.

The motives that were given most frequently for buying a PV system were based on financial reasons. Almost 80% of all respondents gave one or more reasons that were related to cost-reduction or gaining money. A little more than 50% of all respondents named 'direct savings' as one of the important reason; 26% named high return on investment often combined with the statement that investing in PV results in a better return than the savings interest rates at banks.

'Environmental concerns' is the second most given motive for buying a PV system. Almost 70% of all PV owners claim that environmental concerns is one of the important reasons why they have installed their PV system.

Being independent from energy suppliers and being self-sufficient in energy production is a reason that almost 20% of all respondents gave. A substantial part of the PV owners say that distrusting the 'Power Giants' is a reason to become self-supporting. Wanting to be less dependent seems to fit in a society where consumers get more conscious and aware of their role in the supply chain and the power of big corporations.

The last relatively big group of motives are all related to the respondent himself. A little more than ten per cent gave personal motives as reasons for buying the PV system. 'Interest in the technology' and 'fun' where the two main types of personal motives. Interest in the technology of PV systems, the fun of keeping records of the yield and just the joy of having the 'gadgets' turn out to be important factors in the decision making process.

Table 43. Motives for buying a PV system

	Motives*		**Respondents**
	Frequency	*Percentage*	*(N=157)*
Financial motives	123	41.3%	78.3%
Direct savings	*82*	*27.5%*	*52.2%*
High return on investment	*41*	*13.8%*	*26.1%*
Environmental concerns	105	35.2%	66.9%
Independency	29	9.7%	19.5%
Personal motives	19	6.4%	12.1%
Interest in technology	*10*	*3.4%*	*6.4%*
Fun	*9*	*3.0%*	*5.7%*
Setting an example	4	1.3%	2.5%
Others	18	6.0%	11.5%
Total (subgroups excluded)	298	100%	189.8%

*Answering the question with multiple motives was allowed, keep in mind that not every respondent gave multiple motives.

Based on the frequency table (Table 43) it seems likely that financial benefits, environmental concerns and independency are the most important motives to install a PV system, which is corresponding with the hypothesis. The hypothesis however is not only about the frequency answers are given, it is also about its importance. To find out what the most important motives are the ranking should be taken into account. The respondents had to rank their own motives, leading to a top three. The most important motive got a 1, the second a 2 and the third important reason a 3. The lower the mean of each group, the higher its importance. Table 44 shows the ranking means of the different groups and their standard deviation. Keep in mind that not all respondents gave more than one motive for buying their PV system. The total score shows that only 61% and 28% of all respondents gave respectively a second and third important reason.

Table 44. Ranking for each group of motives

	Most important reason		Second important reason		Third important reason		Mean total ranking	
	N	*%*	*N*	*%*	*N*	*%*	*M*	*SD*
Financial benefits	64	40.8%	37	23.6%	22	14.0%		
Direct savings	*49*	*31.2%*	*21*	*13.4%*	*12*	*7.6%*	1.549	0.739
High return on investment	*15*	*9.6%*	*16*	*10.2%*	*10*	*6.4%*	1.878	0.781
Environmental concerns	70	44.6%	29	18.5%	6	3.8%	1.391	0.596
Independency	11	7.0%	16	10.2%	2	1.3%	1.689	0.604
Personal motives	5	3.2%	7	4.5%	8	5.1%		
Interest in technology	*0*	*0.0%*	*5*	*3.2%*	*5*	*3.2%*	2.5	0.527
Fun	*5*	*3.2%*	*2*	*1.3%*	*3*	*1.9%*	1.8	0.919
Setting an example	1	0.6%	0	0.0%	3	1.9%	2.5	1.0
Others	7	4.5%	7	4.5%	4	2.5%	1.889	0.9
Total of respondents	157	100%	96	61.3%	44	28.0%		

In Table 44 it can be found that, based on the average ranking, ‘environmental concerns’ is the most important motive in the decision making process. With an average of 1.39 (*SD* = 0.596) environmental concerns has the lowest score which means that it is, on average, ranked as most important. The same table also shows that almost 45% of all the ‘most important reasons’ are about environmental concerns. In order of importance this motive is followed by 'direct savings' (*M* = 1.549, *SD* = 0.739) and 'independency'(*M* = 1.689, *SD* = 0,604) which supports the hypothesis. Important to notice is that 'financial benefits' is given as the most important reason in 40% of the cases. This means that 'environmental concerns' and 'financial benefits' are together responsible for almost 85% of all most important reasons. This means that those two groups of motives are by far the two most important reasons. Independency is, if indicated as a reason, often an important reason (high ranking) leading to a low mean. However it must be noted that it only covers 10% of all given reasons (see Table 43). Notable is the low mean of the motive 'fun'. It indicates that, if fun is mentioned as a reason it is often an important and high ranked reason.

A critical remark about the importance 'environmental concerns' is at place here. Of all the respondents (N=105) who gave 'environmental concerns' as a motive for buying a PV system 65% also gave 'financial benefits' as a reason. Of the same group of respondents (N=105), only 18.1% gave environmental reasons as the single reason for buying a PV system. That translates to 12.1% of all respondents. The same calculation can be done for the group of respondents that gave one or more reasons related to 'financial benefits' (N=110). Of this group 30% gave 'financial benefits' as the single reason for buying a PV system. This is 21% of all PV owners. It shows that 'financial reasons' are most likely more important than environmental concerns'.

The hypothesis '*Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system'* is supported by the data found in this research. Environmental concerns (highest importance) and financial benefits (most often given as an important reason) are the two most important motives for buying and using a PV system by Dutch households. Based on the frequency that 'financial benefits' is given as the single reason for buying a PV system reason it is proven to be more important than 'environmental concerns'. Independency from energy suppliers and being self-supporting when it comes to producing energy is the third most mentioned and most important reason.

7.2 Barriers

The second part of the previously explained sub-research question is about the barriers that play a role in the decision making process of PV systems. Based on literature the following hypothesis was created: *High investment costs and long capital payback times are the main barriers for households for installing PV systems.*

To find out what barriers and doubts households experience in the decision making process of a PV system the respondents were asked in an open question if they experienced any barriers or doubts and if so what these barriers and doubts were about. In Table 45 it can be found that more than 40% (43.9%, N=69) of the respondents did not experience any doubts or barriers in the decision making process of their PV system. It shows that a substantial part of the PV owners was very determined and decisive and not bothered by hesitations or barriers. However, almost 60% (N=88)of the respondents did experience one or more barriers.

Table 45. Are barriers experienced in decision making process of PV system.

	Responses	
	Frequency	*Percentage*
No barriers experienced	69	43.9%
Barriers experienced	88	56.1%
Total	157	100%

In the data analysis the answers (given by the respondents that did experience barriers) were studied closely and groups of similar or closely related barriers were formed. The answers given can be divided into the following groups:

- High investment/high costs of PV system
- Uncertainty and/or knowledge gap about (future) subsidies and regulations
- Uncertainty and/or knowledge gap about (future) technology developments
- Installation and/or house related issues
- Return on investment and/or long payback times
- Choice stress and chaos on market
- Aesthetics
- Others
- No barriers

Examples (translated from Dutch to English) of the answers belonging to each group of barriers can be found in Table 46. The complete list of barriers can be found in Appendix 4.

Table 46. Examples of answers of each group of barriers

Group of barriers	Examples of answers
High investment/high costs of PV system	*High acquisition costs* *High investment* *Very expensive*
Uncertainty and/or knowledge gap about (future) subsidies and regulations	*Will subsidy maintain to exist* *Uncertainty about future government policies* *Lurching government*
Uncertainty and/or knowledge gap about (future) technology development	*Uncertainty about lifespan PV system* *Will efficiency level increase in future* *Unclear current yield*
Installation and/or house related issues	*Holes in wall were required* *Placement on flat roof* *Dormer windows on wrong place*
Return on investment and/or long payback times	*Long payback time* *Low return on investment*
Choice stress and chaos on market	*Wild West on PV system market* *Uncertain about supplier and panel type* *Too much choice* *Too many 'shady' suppliers*
Aesthetics	*Ugly blue panels* *Aesthetics house and property*
Others	*Not Cradle to Cradle* *Afraid of theft* *Resistance neighbourhood* *Maybe moving out* *No significant increase in value property* *Lack of interest*

In Table 47 the frequencies are displayed for the number of responses per group of barriers. Important to notice is that some respondents gave more than one reason and that all the reasons are treated here as equally important. An overview of the share of each group (barriers experienced versus no barriers experienced) and the type of barriers can be found in Figure 41.

Table 47. Groups of barriers experienced in decision making process of PV system.

	Barriers*		Percentage of total respondents that experienced barriers
	Frequency	*Percentage*	*(N=88)*
High investment/high costs of PV system	38	29.7%	43.2%
Uncertainty and/or knowledge gap about (future) subsidies and regulations	17	13.3%	19.3%
Uncertainty and/or knowledge gap about (future) technology development	15	11.7%	17.0%
Installation and/or house related issues	11	8.6%	12.5%
Return on investment and/or long payback times	20	15.6%	22.7%
Choice stress and chaos on market	7	5.5%	8.0%
Aesthetics	2	1.6%	2.3%
Others	18	14.1%	20.5%
Total	128	100%	145.5%

*Answering the question with multiple barriers was allowed, keep in mind that not every respondent gave multiple barriers.

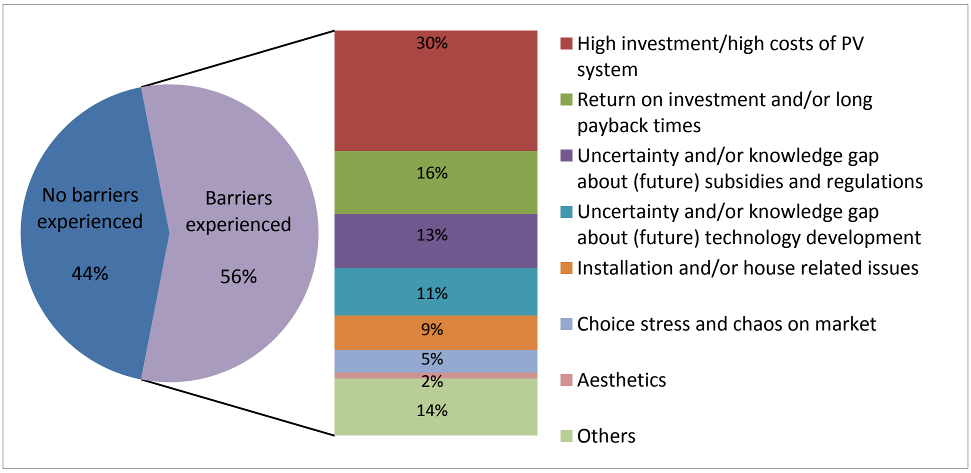


Figure 41. Barriers in the household decision making process of PV systems

Financial barriers like 'high investment and high costs' are the barriers most experienced by the respondents. Thirty per cent (30%) of all barriers are about the high costs involved, more than 40% of the respondents that experienced barriers mention this barrier. The hypothesis expected that 'high investment costs' was one of the main barriers for households and the data collected here supports this hypothesis.

The long payback time is the other main barrier the hypothesis names. This part of the hypothesis also seems correct. 'Return on investment and/or long pay back times' is the second most often named barrier. A little more than twenty per cent (22.7%) of all respondents that experienced barriers name 'return on investment and/or long pay back times' as one of them. The long time it takes to earn back the initial investment is seen as a barrier in the decision making process of PV systems.
The third barrier that follows the two expected barriers is 'uncertainty and/or knowledge gap about (future) technology development'. Almost twenty per cent (19.3%) of all respondents that experienced barriers name this barrier. Especially the lurching government and the uncertainty about what the next step in legislation and subsidisation is going to be is indicated as a barrier. It is remarkable that uncertainty and knowledge gaps about (future) subsidies and regulations is such an important barrier for households. It is a barrier that, unlike the first two important barriers, could be addressed relatively easy. The first two barriers are related to the characteristics of PV systems: they require high investments and the return on the capital payback time is long. These two barriers are therefore hard to address without changing the concept of PV systems as they are now. The third barrier however is a barrier that is not necessary in nature. It is about knowledge gaps and how (often) people are provided with information. Better governmental communication could probably minimize this barrier substantially.

The same concept holds for the fourth barrier that can be found in Table 47, namely 'uncertainty and/or knowledge gaps about (future) technology development'. This is also related to communicating about the current technological state of the PV industry. Better information provision and communication by suppliers and producers could reduce the frequency this barrier is experienced.

The conclusion can be drawn that there is indeed evidence found that supports the hypothesis '*High investment costs and long capital payback times are the main barriers for households for installing PV systems'*. However, based on the data it can also be concluded that the hypothesis does not describe the complete situation. Uncertainty and/or knowledge gaps about (future) subsidies and legislation and about (future) technology development are also proven to be main barriers in the households decision making process of PV systems.

7.3 Doubts and barriers of other households

Since in this research only households with PV systems were asked to participate the reasons why not to buy a PV system rely on estimations by the respondents. They were asked to predict what the reason might be for other households not to buy a PV system. PV owners are likely to have talked to their peers and communicated in their community about their decision to buy a PV system. The chances that they have learned in this process about the opinions of others are substantial. That is the reason that this research has asked the respondents to indicate what they think that are the most important reasons and barriers for others not to buy a PV system. By doing so the respondents provided useful information about other households and how they look toward the current state of PV industry. By estimating what other households may see as barriers they will also indirectly show the things they find important.

All respondents provided at least one, but mostly multiple reasons why they think other households choose not to buy a PV system. Reasons and barriers that were similar were collected in groups. These groups and examples of the answers (translated from Dutch to English) belonging to each group can be found in Table 48. The total list of answers can be found in Appendix 5.

Table 48. Examples of answers of each group of expected barriers and motives not to buy a PV system

Groups of most important barriers/ motives not to buy a PV system	Examples of answers
High investment/high costs of PV system	*Too expensive* *Large investment needed* *Not enough savings*
Uncertainty and/or knowledge gap about (future) subsidies and regulations	*Uncertainty about regulation* *Discouraging policies government* *Distrust in government about subsidies*
Ignorance/knowledge gap PV systems	*Ignorance* *Unfamiliarity with PV systems and technology* *Incomplete information*
Installation and/or house related issues	*Roof not oriented on south* *House not suitable* *Too much demolition work required*
Return on investment/long payback time	*Payback time too long* *Low return on investment* *Distrust in actual return on investment*
Aesthetics	*Solar panels are ugly* *Aesthetical reasons* *Beauty of house affected*
PV perceived as not necessary	*Not necessary* *Other measurements more useful*
Not owner of house	*Not owner-occupied housing* *Rental house*
Fear and misperception caused by media	*Fear caused by false stories in media (e.g. solar panels might cause fire)* *Misrepresentation of facts by media*
Not interested in environment	*No environmental concern* *Not conscious about current state of environment and climate*
Choice stress and chaos on market	*Too many choices*
Others	*Protest from neighbourhood* *No status* *Aversion to 'left-wing' ideas* *Cold feet*

The number of groups of reasons is much larger than the groups formulated about personal motives and barriers. The predicted reasons vary from 'high costs' to 'fear and misperception caused by media'. Most groups could also be found in the previous chapter about barriers for PV owners. However, there are also predicted reasons why not to buy a PV system that were not found in the previous section. 'Ignorance/knowledge gap about

PV systems', 'PV perceived as not necessary', 'Not owner of the house', 'Fear and misperception caused by media' and 'Not interested in environment' are barriers that were not indicated as important by the owners themselves. Nevertheless these barriers are expected to be important in the decision making process of not buying a PV system and should therefore be taken into account as barriers. The frequencies of each group of expected barriers can be found in Table 49.

Table 49. Expected motives for not buying a PV system

	Expected Barriers*		**Percentage of respondents** *(N=157)*
	Frequency	*Percentage*	
High investment/high costs of PV system	106	34.9%	67.5%
Ignorance/knowledge gap PV systems	55	18.1%	35.0%
Installation and/or house related issues	37	12.2%	23.6%
Return on investment/long payback time	17	5.6%	10.8%
Aesthetics	17	5.6%	10.8%
Uncertainty and/or knowledge gap about (future) subsidies and regulations	16	5.3%	10.2%
PV perceived as not necessary	12	3.9%	7.6%
Not owner of house	9	3.0%	5.7%
Fear and misperception caused by media	8	2.6%	5.1%
Not interested in environment	6	2.0%	3.8%
Choice stress and chaos on market	2	0.7%	1.3%
Others	19	6.3%	12.1%
Total	304	100%	193.6%

*Answering the question with multiple expected barriers was allowed, keep in mind that not every respondent gave multiple expected barriers

Table 49 shows that the 'High investment/high costs of PV systems' is the expected barrier for other households that is mentioned most frequently. Two third of all respondents indicated this as a barrier or as (one of) the reason(s) that other household decide not to buy a PV system (67.5%). Almost 35% (N=106) of all given answers are related to this barrier.

This finding is in line with the results found in the previous section about the barriers experienced by the respondents. The high financial costs for PV systems is the barrier that is important for most households. Depending on every individual household this barrier can be over won or will be big enough to hold back households in the decision to buy a PV system.

The second most predicted barrier is ‘Ignorance and knowledge gaps about PV’. A little over a third of all respondents think that one of the reasons why other households do not buy a PV system is that they are not familiar enough with it or do not have sufficient knowledge about PV (35%). Near twenty per cent (18.1%, N=55) of all the predicted barriers was about the ignorance of other households.

The last group of predicted barriers and motives why not to buy a PV system is about the properties of the housing. ‘Installation and/or house related issues’ is mentioned by over 20% (23.6%) of all respondents as a possible reason why other households choose not to buy a PV system. They predict that the housing conditions of other households are not favourable for PV systems (e.g. no South oriented rooftop, demolition work needed) and that that might be one of the barriers for households. This barrier was logically found a lot less as a barrier for households who did end up buying a PV system. The properties of their houses matched the requirements for installation.

Notable is that both ‘High investment/high costs of PV system’ and ‘Installation and/or house related issues’ are related to features of PV systems in general. In the current situation PV systems are a relatively large expenditure for households. Unless prices will drop very dramatically this will probably maintain to be a stable feature of PV. The houses or roofs need specific properties to be suitable for a PV system is also seen as a stable feature of PV. Both barriers are therefor hard to address on short notice. The barrier ‘Ignorance/knowledge gap PV systems’ is on the other hand a barrier that should be possible to address on short notice. This barrier is not directly related to a feature of PV and could be minimized by changes in communication and information provision.

In the previous section it was shown that only 1.3% of all respondents who experienced barriers named ‘aesthetics’ as a barrier for their own households. In Table 49 we can see that when the households need to guess the barriers for other households the barrier ‘aesthetics’ is named by 10.8%. This is over four times more and shows that aesthetics is more looked at as a barrier important for others than for the respondents themselves.

Concluding, the high pricing of PV system is expected to be an important barrier for households in the decision making process. This barrier is thought of as one of the main reasons why households do no choose for a PV system. Another important barrier is ignorance of the households without PV systems. Technical features of the houses of households is the third most mentioned barrier.

7.4 Conclusion

As a conclusion and to summarize the results found in this chapter and to answer the sub-research question '*What are household motives and barriers for buying solar panel system?*' a model is created (see Figure 42). This model is a depiction of the household motives and barriers in the decision making process of PV systems. It shows the motives and barriers that are most experienced among PV owners. It also shows the expected barriers for other households (in italic).

To what extent the barriers are strong enough to hold off households from buying a PV system is most likely dependent on the characteristics of each household. For example a household with an high income might value the barrier 'high investment costs' as less decisive than a household with a low income. This research did not have the correct data to test the influence of household characteristics on the perceived importance of barriers. Further research is needed to test this prediction.

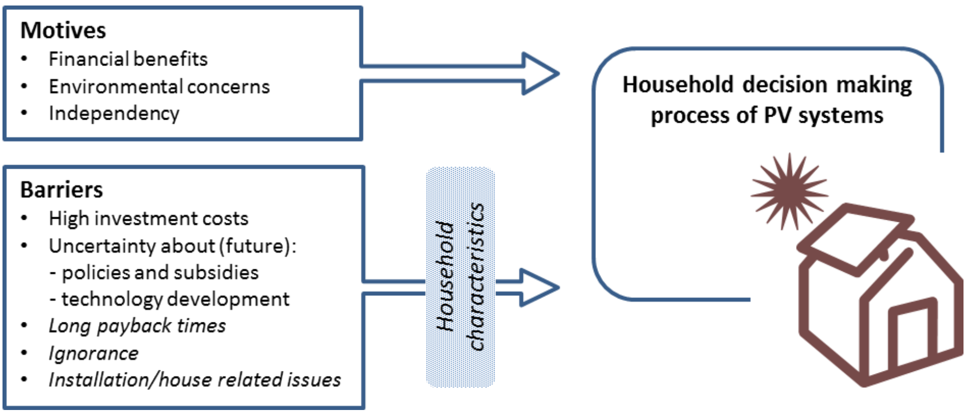


Figure 42. Motives and barriers involved in the decision making process of PV systems. Source: own figure.

8 Characteristics of PV households

Based on the literature and previous studies the following hypothesis was formulated to predict what the main characteristics are of households with PV systems: *'Households with PV systems are typically between 45 and 64 years old, have a high environmental concern, have high incomes, are higher educated and own their home'*. To test this hypothesis the survey was used to collect data on different household characteristics. In this section all the sub-hypotheses will be discussed and tested with the data collected from the survey.

H5a: Households with a PV system are between 45 and 64 years old
H5b: Households with a PV system have a high environmental concern
H5c: Households with a PV system have high incomes
H5d: Households with a PV system are higher educated
H5e: Households with a PV system are the owners of their home

8.1 Age

To be able to test the hypothesis '*Households with a PV system are between 45 and 64 years old'* the age of all respondents was asked. But since this research is about households, and households often exist of more than one person the respondents were also asked (if applicable) to indicate age of the partner. This lead to a group of 290 members of PV owning households with an average age of 47.98 (*SD* = 10.38).
On average the respondents are 48.9 years old (*SD* = 10.33) and the partners are 46.9 years old (*SD* = 10.3). For the sake of readability the respondents are divided into different age groups that each represent ten years. In Figure 43 and Table 50 these groups and the distribution of the respondents, partners and the total are depicted.

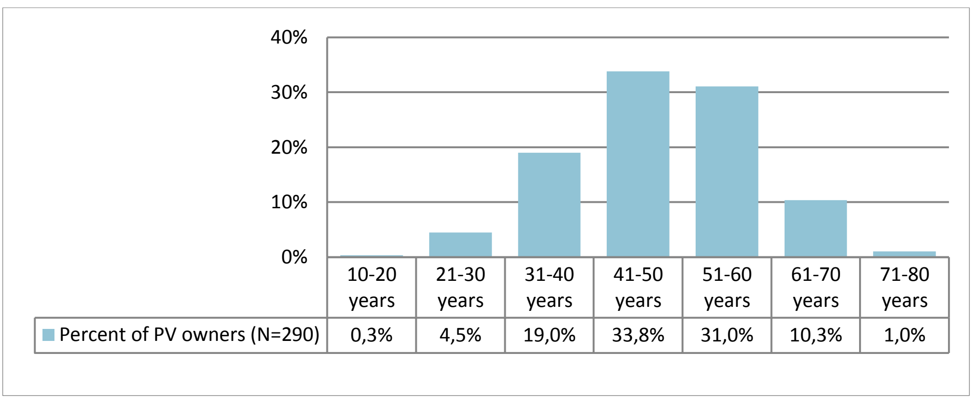


Figure 43. Age of PV owners (respondents and partners) in age groups of ten years.

Table 50. Frequency and share of respondents, partners and total per age groups (ten year per group)

Age group	Respondents		Partners		Total	
	N	*%*	*N*	*%*	*N*	*%*
11-20 years	0	0%	1	0.8%	1	0.3%
21-30 years	7	4.5%	6	4.5%	13	4.5%
31-40 years	25	15.9%	30	22.6%	55	19.0%
41-50 years	56	35.7%	42	31.6%	98	33.8%
51-60 years	48	30.6%	42	31.6%	90	31.0%
61-70 years	19	12.1%	11	8.3%	30	10.3%
71-80 years	2	1.3%	1	0.8%	3	1.0%
Total	157	100%	133	100%	290	100%

Over 65% of all PV system owners are between 40 and 60 years old. The description that PV owners are middle aged therefore seems to fit well. The literature from the previous chapters predicted that the average PV owner is between 45 and 66 years old. When the groups are arranged differently proof for this hypothesis is found. Almost 60% (57.9%) of the 290 respondents and partners are in the age group 45-64 years old.

8.2 Environmental concern

A characteristic that is expected to be salient is that households with a PV system are concerned about the environment. The hypothesis that was formulated is: *'Households with a PV system have a high environmental concern'*. To test this hypothesis multiple questions measuring this topic were included in the online questionnaire. The combination of these indicators will show whether the environmental concern of PV owners can be qualified as high and to what extent their environmental concern is higher than the average Dutch environmental concern.

8.2.1 Importance protecting environment

To measure the respondents perceived personal importance of protecting the environment he was asked to indicate on a five item scale how important the environment is for him (1=very important, 3=I do not know, 5=very unimportant). The results can be found in Table 51. More than 95% indicated to perceive the environment as very important or fairly important (M = 1,61, SD = 0,67). This is slightly more than the 93% score of Dutch inhabitants (see also Table 51) found in the Eurobarometer of 2011. Overall this question shows that over 95% of the PV owners perceive protecting environment as important.

Table 51. Results question 'How important is protecting the environment for you personally?' compared to the Netherlands (Eurobarometer, 2011).

	PV owners		The Netherlands
	Frequency	*Percentage*	*Percentage*
Very important	72	45.9%	50%
Fairly important	79	50.3%	43%
I do not know	1	0.6%	0%
Fairly unimportant	5	3.2%	6%
Very unimportant	0	0.0%	1%
Total	157	100%	100%

$X^2 = 5.287$, $df = 4$, $p = 0.224$

8.2.2 Ready to buy environmentally friendly products

The respondents were also asked to indicate to what extent they agreed to the statement: 'I am ready to buy environmentally friendly products even if they cost a little bit more' (1=totally agree, 3=I do not know, 5=totally disagree). The results of this question can be found in Table 52, together with the average Dutch results (Eurobarometer, 2011). Almost 87% of all respondents agree (totally agree or tend to agree) with the statement. In the Netherlands 77% of the people agree with the statement, which is about ten per cent lower than the share of the respondents. The result of this question is again proof for the hypothesis that PV owners are highly environmentally concerned.

Table 52. Results of the statement 'I am ready to buy environmentally friendly products even if they cost a little bit more' compared to the Netherlands (Eurobarometer, 2011).

	PV owners		The Netherlands
	Frequency	*Percentage*	*Percentage*
Totally agree	67	42.7%	37%
Tend to agree	70	44.6%	40%
I do not know	6	3.8%	1%
Tend to disagree	6	3.8%	15%
Totally disagree	8	5.1%	7%
Total	157	100%	100%

$X^2 = 15.562$ $df = 4$ $p = 0.002$

8.2.3 Important environmental issues

A third question used to measure the level of environmental concern in the questionnaire was about different environmental problems. The respondents were asked to choose the five environmental issues they worry about most and to rank them in order of importance. The list of issues used was based on the Special Eurobarometer (2011) allowing comparison between the respondents and the Netherlands. The results can be found in Table 53.

The most remarkable difference between PV owners and the Netherlands is that climate change seems to be more important for PV owners than on average in the Netherlands. For the PV owners it is the issue that is chosen the most (52%), in the Netherlands it is found on the fourth place with only 37% of the people finding it important. Depletion of natural resources, the issue that is very closely related to the initial reasoning behind PV technology, is equally important for the PV owners and the Netherlands.

Looking at the frequency of the answers that were given climate change (51.6%), consumption habits (49%) and depletion of natural resources (47.8%) are the environmental issues that the respondents seem to worry about most frequently. In the Eurobarometer this top three was slightly different namely depletion of natural resources (49%), man-made disasters (45%) and water pollution (40%). Based on the data in Table 53 the following top three of environmental issues that PV owners worry about most can be found:

1. Climate changes
2. Our consumption habits
3. Depletion of natural resources

Table 53. Results of the question 'From the following list, please pick the five main environmental issues that you are worried about most' of respondents and the Netherlands (Eurobarometer, 2011).

From the following list, please pick the five main environmental issues that you are worried about most.	Respondents		The Netherlands
	Frequency	*Percentage*	*Percentage*
Climate change	81	51.6%	37.0%
Depletion of natural resources	75	47.8%	49.0%
Our consumption habits	77	49.0%	35.0%
Water pollution (seas, rivers, lakes and underground sources)	67	42.7%	40.0%
Loss of biodiversity (extinction of species, loss of wildlife and habitats)	63	40.1%	29.0%
The impact on our health of chemicals used in everyday products	52	33.1%	35.0%
Air pollution	48	30.6%	34.0%
Agricultural pollution (use of pesticides, fertilizers, etc.)	41	26.1%	21.0%
Man-made disasters (oil spills and industrial accidents, etc.)	37	23.6%	45.0%
Growing waste	33	21.0%	30.0%
The use of genetically modified organisms in farming	28	17.8%	17.0%
Impact of current transport modes (more cars, more motorways, more air traffic, etc)	27	17.2%	22.0%
Urban problems (traffic jams, pollution, lack of green spaces, etc.)	26	16.6%	18.0%
Noise pollution	15	9.6%	8.0%
Natural disasters (earthquakes, floods, etc.)	10	6.4%	17.0%
Other	11	7.0%	1.0%
Total answers	691		
Total completed	138		

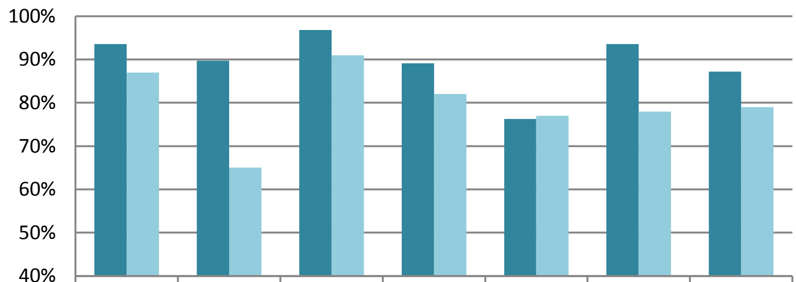
8.2.4 Environmental friendly behaviour

Another part of environmental concern is the actual behaviour of people. To see whether the respondents show environmental friendly behaviour and to test whether the behaviour of PV owners is more environmental friendly than that of average Dutch households the respondents were asked how often they displayed certain behaviour. For seven statements they were asked to indicate how often they performed that behaviour on a five item scale (always-never). The results can be found in Table 54.

Table 54. Frequency answers given to question 'Statements on environmental friendly behaviour'

#	Question	Always	Regularly	Sometimes	Rarely	Never
1	How often do you separate your glass waste?	143	5	3	1	5
2	How often do you separate your organic waste?	132	10	6	1	8
3	How often do you separate your paper waste?	152	2	2	0	1
4	How often do you separate your chemical waste?	120	21	10	2	4
5	How often do you try to save water by reducing the time the water tap is on?	55	65	31	5	1
6	How often do you try to save energy by reducing the amount of time the lights are on?	88	59	7	2	1
7	How often do you use your own shopping bag or crate based on environmental concerns?	91	47	16	1	2

Figure 44 shows the comparison of the PV owners with average Dutch households. The answers ‘always’ and ‘regularly’ are grouped showing the percentage of people who conduct environmental friendly behaviour. On all the statements the PV owners show a similar but mostly larger share of households performing the behaviour. It shows that PV owners are on average more inclined to perform different types of environmental friendly behaviour. Almost 94% of the PV owners try to save energy by reducing the time the lights are on. This is 15% more than the share of average Dutch households. It shows that PV owners not only show energy saving behaviour by installing a PV system but also by taking other measurements.



	Seperate glass waste	Seperate organic waste	Seperate paper waste	Seperate chemical waste	Save water	Save energy	Save plastic
PV owners	93,6%	89,7%	96,8%	89,1%	76,3%	93,6%	87,2%
The Netherlands	87,0%	65,0%	91,0%	82,0%	77,0%	78,0%	79,0%

Figure 44. Percentages of households who answered 'always' or 'regularly' on the ‘Statements on environmental friendly behaviour: PV owners versus Netherlands (2003-2011)

8.2.5 Membership environmental organizations

The final question asked in the survey to test the environmental consciousness of the respondents was about the memberships of environmental organizations like the World Wildlife Fund (Wereld Natuur Fonds), Greenpeace and IFAW. Sixty per cent (58.2%) of all PV households are a member of one or more environmental organizations (see Table 55). Of the Netherlands it is known that there are approximately four million registered memberships of environmental organizations. There is however no data on how many of these households are a member of more than one organization. This makes it impossible to compare the Netherlands with the PV owners in terms of total share with a membership of environmental organizations.

Comparing the percentages per environmental organization is possible and this shows that of all organizations the PV owners are more likely to be a member of than on average in the Netherlands. Especially on memberships of Natuurmonumenten, Greenpeace, WWF and Provinciale Landschappen the share of PV owners is higher than that of the Netherlands.

Table 55. Results of questions 'Membership of environmental organizations' compared to the Netherlands (CBS, PBL, Wageningen UR, 2013b)

	PV owners *(households)*	**The Netherlands** *(households)*
Membership of environmental organization(s)	58.2%	No data
Organization	**Percentage of total PV owners**	**Percentage of total households in the Netherlands**
Natuurmonumenten	32.7%	9.7%
Wereld Natuur Fonds	17.6%	10.6%
Provinciale Landschappen	11.1%	4.1%
Vogelbescherming	7.8%	2.0%
Greenpeace	21.6%	6.4%
Dierenbescherming	5.9%	2.5%
Internationaal Dierenfonds IFAW	2.6%	2.3%
Other nature/environmental organizations	21.6%	12.7%

8.2.6 Conclusion

Based on the results of the previous questions asked in the online survey it can be concluded that for the hypothesis '*Households with a PV system have a high environmental concern'* is found evidence. PV owners score equal or higher than average Dutch households on all indicators. Summarizing, PV owners are more likely to be willing to pay more for environmental friendly products, they show more environmental friendly behaviour and they are more likely to be a member of one or more environmental organizations. In conclusion, PV owners have a high environmental concern.

8.3 Income

The third sub-hypothesis focusses on the gross income of households. Since households have to invest a substantial amount of money when they decide to buy PV system, it is expected that the owners of PV systems have relatively high incomes. The hypothesis is the following: *'Households with a PV system have higher incomes'*. To test this prediction the respondents were asked to indicate the gross annual income of their households. Table 56 shows the results of this question. It also shows the distribution in percentages of the different groups of income of the respondents.

Table 56. Gross annual income of PV households

	Frequency	*Percentage*
No income	4	2.7%
< 10,000 euro	0	0.0%
10,000 – 25,000 euros	12	8.1%
25,000 – 40,000 euros	28	18.8%
40,000 – 55,000 euros	33	22.1%
55,000 – 70,000 euros	31	20.8%
70,000 – 95,000 euros	21	14.1%
> 95,000 euro	20	13.4%
Total	149*	100%

* 8 respondents did not answer the question

Almost 50% of all respondents indicated to have a gross income of over €55,000 a year. CBS estimated that the average gross income (modal) per household was around 56,000, meaning that almost half of all PV households has an income that could be classified as 'modal' (CBS, 2013g).

In Figure 45 the income distribution of the PV households is compared to the average Dutch households. This picture shows that there is a peak of PV households with a gross income between 40,000 and 70,000 euros. The peak for Dutch households lies further left, with an income between 10,000 to 40,000 euros.

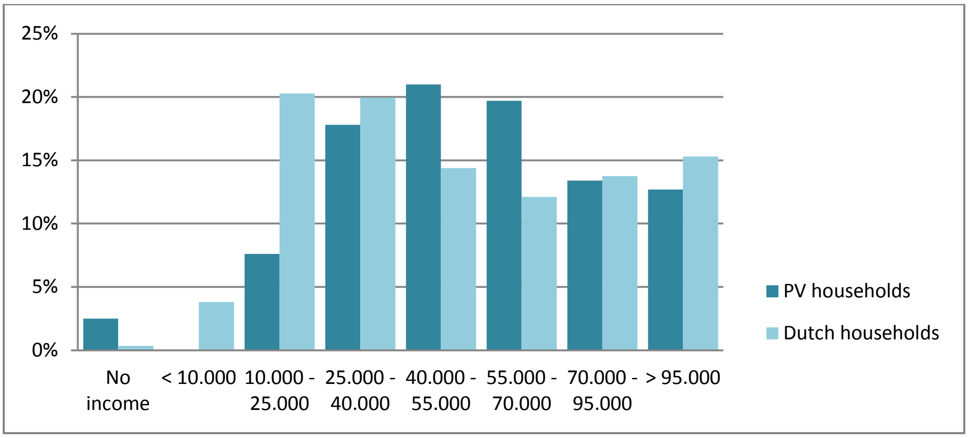


Figure 45. Gross income distribution PV households versus average Dutch households (CBS, 2013g)

There are many different institutions in the Netherlands that divide households in classes based on their income. This research uses the definition of the Ministry of Social Affairs and Employment (2013) in the Netherlands. They base their 'low-middle-high' income groups on the following rule: modal to two times modal is a *middle income household*. All households with a lower income than modal are classified as *low income* households and all households with a higher income than two times modal are classified as *high income households*.

When applying this 'low-middle-high' income classes it is found that the largest share of PV owners is found in the 'middle income' class (see Table 57). Over 43% of the PV owners have a middle income of €40,000 to €70,000. The hypothesis expected a high income for PV households, but the data found prove this wrong. The table also shows that thirty percent of the PV owners have a low income. This is remarkable since the investment involved is relatively large for this group. Over two third of the PV owners cannot be indicate as high income households.

Table 57. Distribution PV owners in income classes

	Frequency	*Percentage*
Low incomes	44	29.5%
Middle incomes	64	43.0%
High incomes	41	27.5%
Total	149*	100%

* 8 respondents did not answer the question

Classes: low €0-€40,000,
middle €40,000-€70,000 (rounded number based on modal to two times modal)
high: >€70,000

8.3.1 Explaining income groups

Due to the high investment needed it seems much more rational and logical for high income households to buy a PV system than for low and middle incomes. It was just shown that this is not the case. The large presence of low and middle income households among PV owners is interesting and for that reason this section provides a more detailed explanation about these groups. Chi-square tests are used in this section to see if there are specific characteristics to point out of these groups of households that might explain why the share of low and middle incomes is so present among all PV owners. Data from different parts of the survey are used to find possible explanations why the income groups are differently distributed than expected. Only the significant or remarkable data findings are described.

8.3.2 Low income PV households

Importance of environment

One of the explanations for the large share of low income households among PV owners can be found in the environmental consciousness of this group. Households with low incomes score higher on the question ‘How important is protecting the environment for you’. They are more likely to answer this question with ‘very important’ than middle and high incomes (X^2 =5,034, df = 2, p = 0,08). These households are probably so motivated that they are willing to use a large share of their money to invest in a PV system.

Environmentally friendly behaviour

To test this the data about environmental friendly behaviour was used (1 = always, 5 = never). By combining the different statements a mean score was computed for each respondent (*Cronbach’s* α = 0.738). A number of conclusions can be drawn based on the mean score and on some.

- On average, low income PV households (M = 1.35, SD = 0.410) show more environmentally friendly behaviour than middle income PV households (M = 1.52, SD = 0.623). This difference is close to significant $t(106) = -1.632$, p = 0.053.
- On average, low income PV households (M = 1.35, SD = 0.410) show equal environmentally friendly behaviour to high income PV households (M = 1.39, SD = 0.348). The small difference between the two groups is not significant $t(83) = -0.602$, p = 0.55.
- Low income PV owners are more likely to show environmentally friendly behaviour in terms of saving energy by reducing the time the lights are on. Low income households indicated significantly more often to ‘always’ try to reduce energy than middle incomes (X^2 = 5.898, df = 1, p = 0.015).

Motives

The most important motive for low income PV households is the environment: over 60% names this as an important reason for buying their PV system. Of the low income households nearly 50% (47.7%) indicates that 'direct savings' are an important reason for the decision to buy a PV system. Nevertheless, compared to high income households (58.5%) and middle income households (51.6%) this share is lower. Direct savings seems important for low income households, but not remarkably more or less important than for middle and high income households.

Barriers

When looking at the type of barriers low income PV households experience it seems logical to expect that the high price of a PV system is a barrier or at least causes some doubt. Remarkably, it is found that 'high investment costs' were only experienced as a barrier by 16% of all the low income households. A little over 50% of the low income households did not experience any barriers at all.

Conclusion

Based on the analyses low income PV households seem to be motivated and willing to perform environmentally friendly behaviour. This might explain why they are also willing to invest a relatively large amount of money on a PV system. The high investment does not seem to be a big barrier, which is possibly caused by their strong will to conduct environmentally friendly behaviour.

8.3.3 Middle income

In contrast to what was expected by the hypothesis it was found that the largest share of PV households can be defined as middle income households instead of high income households.

Environmentally friendly behaviour

Remarkably, as seen in the previous section, the middle income PV households score worse on environmentally friendly behaviour than low income households. Middle income households (M = 1.52, SD = 0.623) also score worse than high income households (M = 1.39, SD = 0.348), this difference is not significant $t(103) = 1.172$, p = 0.12. It shows that middle incomes show less environmentally friendly behaviour than low and high income PV households. Apparently, the explanation for the large share of middle income PV owners cannot be found in environmentally friendly behaviour.

Motives

When looking at the motives of this group it is found that middle incomes are more likely to name 'environmental concerns' as an important motive for buying a PV system than low income households ($X^2 = 2.285$, $df = 1$, $p = 0.065$) and high income households (X^2 = 3.143, $df = 1$, $p = 0.038$). Of all middle income households 75% named 'environmental concerns' as an important reason. There is a significant correlation between middle incomes and naming the environment as an important motive for buying a PV system, $r = 0.157$, p *(one tailed)* < 0.05.

Barriers

A little more than 60% of all middle income PV households indicated that they experienced one or more barriers in the decision making process. There seems to be a tendency that households with middle incomes are more likely to experience barriers than low and high incomes ($X^2 = 1.580$, $df = 1$, $p = 0.209$). However, this statement is not significant and more research is needed to test this.

When looking at the barriers of this group it is found that they are more likely to experience 'high investment costs' as a barrier ($X^2 = 1.721$, $df = 1$, $p = 0.190$) than low or high income households. Over 25% (26.6%) of all the middle income PV households experience this barrier.

In general these results seem to show that the middle income households that chose to buy a PV system experienced barriers that are related to the high invest needed for a PV system.

Conclusion

The most salient feature of the middle income group is that over 75% of this group names environmental concern as an important reason for buying a PV system. However, this environmental friendly mind-set is not reflected in the actual environmental friendly behaviour (e.g. separating waste): they score worse than low and high incomes. The costs involved in the acquisition of a PV system are by this group most frequently indicated as a barrier.

8.4 Education

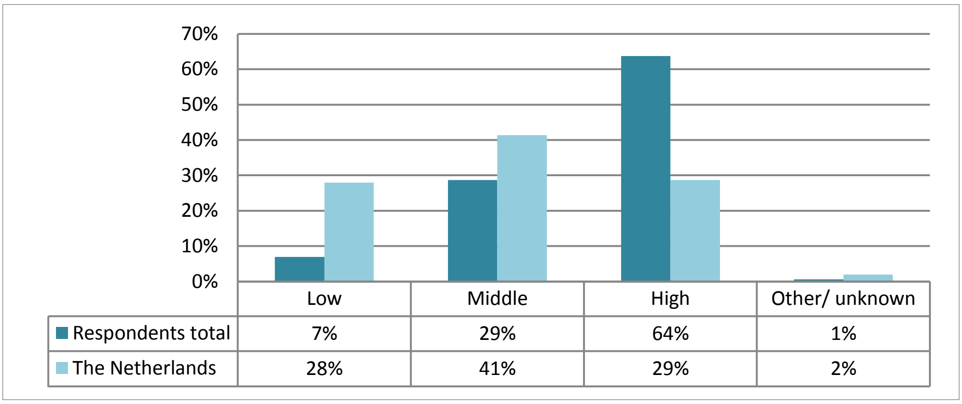
Another important predicted characteristic of PV owners is their level of education. Based on the literature the following hypothesis was formulated: *'Households with a PV system are higher educated'*. In the questionnaire the respondents were asked to fill in their highest achieved level of education. Since the characteristics of the entire household are important for this hypothesis, the respondents were also asked to fill in the highest completed education of their partners (if applicable). These results, combined with the results from the respondents themselves give an overview of the total educational level of the households with a PV system. The results of these questions can be found in Table 58 and Figure 46. The percentages show that a little more than 60% of the PV owners has finished higher professional or academic education. More than 90% of all PV owners have followed further education after secondary school. Almost the same holds for their partners. Almost 60% of the partners has finished higher professional education or academic education (56.6%). Over 90% (91.9%) of the partners of the respondents followed further education after secondary school.

Table 58. Educational level of PV owners and partners (highest completed education)

Education	Respondents		Partners		Total	
	N	*%*	*N*	*%*	*N*	*%*
Primary School	1	0.6%	1	0.7%	2	0.7%
Secondary school	10	6.4%	10	7.4%	20	6.8%
Lower professional education*	5	3.2%	5	3.7%	10	3.4%
Middle professional education**	40	25.5%	41	30.1%	81	27.6%
Higher professional education ***	61	38.9%	46	33.8%	107	36.5%
University/PhD	39	24.8%	31	22.8%	70	23.9%
Other/unknown	1	0.6%	2	1.5%	3	1.0%
Total	157	100%	136	100%	293	100%

* Lager beroepsonderwijs
** Middelbaar beroepsonderwijs
***Hoger beroepsonderwijs

In Figure 46 the same data is presented. In this figure the educational level of the PV households is compared to the educational level of the Netherlands (CBS, 2013h). For the sake of comparability the different educations are grouped in to three levels: low, middle and high education. The share of higher educated people in the PV households is twice as big as in the Netherlands. This shows that on average households with PV systems are higher educated than average Dutch households. The hypothesis is supported by the data, PV owners are highly educated and higher educated than average in the Netherlands.



	Low	Middle	High	Other/ unknown
Respondents total	7%	29%	64%	1%
The Netherlands	28%	41%	29%	2%

Figure 46. Educational level of PV households and the Netherlands (highest completed education) (CBS, 2013h)

Classes

Low: Primary school, Secondary school
Middle: Lower professional education, middle professional education
High: Higher professional education, University, PhD

8.5 Home owners

The final characteristic that is named in the hypothesis is about being a homeowner or renter. Based on literature and previous studies the hypothesis predicts: '*Households with a PV system are the owners of their home'*. A question to test this hypothesis was included in the questionnaire. The results of this question can be found in Table 59. A share of 98% of the PV owners are the owners of their home. The hypothesis predicts that the houses were PV systems are installed are owner-occupied and the data supports that. The contrast with the average situation in the Netherlands is depicted in Figure 47. In the Netherlands 59% of the houses is homer occupied, which is significantly less than the 98% within the group of PV system owners. The prediction that households with PV systems are homeowners is correct.

Table 59. Type of ownership PV households

	Respondents* (N=153)	
	Frequency	*Percentage*
Owner-occupied	150	98.0%
Rental house	3	2.0%
Total	153	100%

*4 respondents did not answer the question

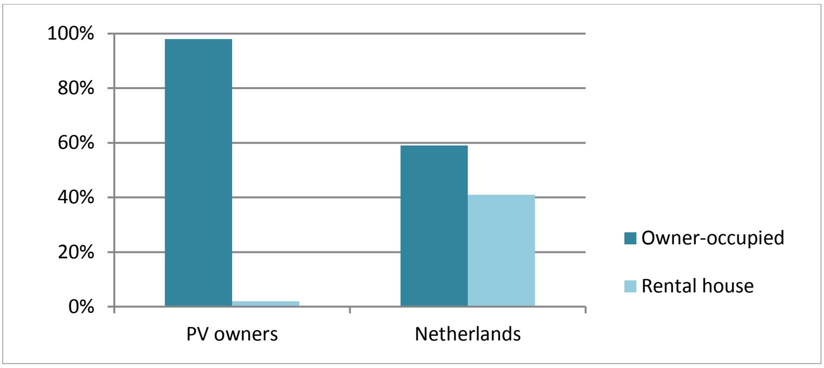


Figure 47. Share homeowners and renters of PV households and Dutch households (CBS, 2013i)

8.6 Other characteristics

Since the research question is about the characteristics of PV households it is also interesting to look at other characteristics that came to the fore in the data analysis that were not predicted by the hypotheses.

8.6.1 Household size

In the introduction of this section (see chapter 5.1.2) the household size were already briefly explained. On average PV households consist of 2.82 people (SD = 1.208) which is significantly larger than the average household size (2.19) in the Netherlands, $t(156) = 6.486$, $p < 0.001$. It is however important to keep in mind that household size is commonly accepted to be related to age. This correlation (however small) also shows in the data, $r = -0.278$, $p < 0.001$. The older, the smaller the household size. Table 60 shows the different households sizes and the corresponding frequencies and percentages of the respondents.

Table 60. Household size of respondents

	Frequency	*Percentage*
1 person	16	10.2%
2 people	64	40.8%
3 people	26	16.6%
4 people	38	24.2%
5 people	10	6.4%
6 or more people	3	1.9%
Total	157	100%

8.6.2 Type of work/occupation

The respondents were asked to indicate what type employment they and their partners are in. Over 80 per cent (82.8%) of the respondents has a paid job. Ten per cent of the respondents is retired, see also Table 61. The partners tend to work less hours, the majority (36%) has a paid job for 15 to 32 hours per week. Compared to the respondents, a larger share of the partners has no paid employment because they are houseman or wife (15.4% versus 2.5%). This is most likely related to the fact that the vast majority of the respondents is male. Keep in mind that whether a person is retired or is still working is related to age.

Table 61. Type of employment of respondents and their partners

	Respondents		Partners	
	N	*%*	*N*	*%*
Paid employment, ≥ 32 hours/week	104	66.2%	34	25.0%
Paid employment, 15 to 32 hours/week	13	8.3%	49	36.0%
Paid employment, < 15 hours/week	2	1.3%	11	8.1%
Entrepreneur, no set hours	11	7.0%	5	3.7%
No paid employment: unemployment benefits	5	3.2%	7	5.1%
No paid employment: (early) retirement	16	10.2%	6	4.4%
No paid employment: houseman/wife	4	2.5%	21	15.4%
Others	2	1.3%	3	2.2%
Total	157	100%	136	100%

8.6.3 Initiative

In the respondent descriptives (see chapter 5.1.2) it was already shown that over 90% of the respondents in this research is male. Before assuming that men are more likely to buy a PV system than women, it is necessary to know who took the initiative in the household to buy the PV system. That question was asked in the survey and Table 62 shows the results. Almost 95% (94.3%) of the respondents took the initiative in the household themselves to buy the PV system. The fact that they initiated it in the household and that they were also the one that filled in the questionnaire is related. They are probably more interested in the topic and more motivated to spend time on related issues such as filing in a questionnaire. More research is however needed to test this.

Table 62. Who took the initiative to buy a PV system?

	Frequency	*Percentage*
Me	148	94.3%
My partner	3	1.9%
My landlord/housing corporation	1	0.6%
Others	5	3.2%
Total	157	100%

Taking into account the partners, in 89.2% of the cases the man took the initiative in the household to buy a PV system. It shows that men are more likely to initiate buying a PV system than women.

8.6.4 Type of house

In the previous sections it was already shown that over 95% of all PV households are the owners of their home. The live in owner-occupied houses. Since PV systems need actual space to install the systems on, the respondents were asked to indicate in what type of house they live. The results can be found in Table 63. Less than one per cent of all PV household live in a flat or apartment. This can be logically explained by the fact that it is basically impossible to install a PV system on a roof that you do not own. The bureaucratic burdens are rather large and you need a very cooperative housing association to get it done. Not taking into account the options ‘others, we see that the remaining respondents are more or less distributed among the other three groups of houses. The largest group is found in row housing (35%).

Table 63. What type of housing do you live in?

	Frequency	*Percentage*
Detached house	46	29.3%
Semi-detached house	42	26.8%
Row house	55	35.0%
Flat or apartment	1	0.6%
Others	13	8.3%
Total	157	100%

8.7 Conclusion

As a conclusion, based on this chapter the description of a typical PV household can be put together. Keep in mind that this is based on averages findings for informational purposes. Deviations, exceptions and individual differences are very common and should be taken in to account when using this data for future application.

A typical PV household has the following characteristics:

- Between 45 and 65 years old
- 2 adults, one or two kids living at home
- Middle or high income
- Higher educated
- High environmental concern

V

Conclusions and Discussion

9 Conclusions

In this chapter the most important findings are described. A table is used to schematically show the main results of the hypotheses testing. Further, the main findings are explained and addressed in a short textual summary. This is followed by some practical implications.

9.1 Hypotheses confirmed?

Table 64 schematically shows the results and whether or not the hypotheses were confirmed or rejected.

Table 64. Research questions, answers and confirmation of hypotheses

Research questions	Answer or hypothesis	Confirmed?
RQ 1. What are the real life savings for households after the installation of a PV system?		
How much energy is used in the entire life cycle of PV systems?	The Energy Payback Time of a PV system is 1.5 to 2.7 years, depending on type of PV system. Carbon footprint of PV technology ten to twenty times smaller than fossil fuel footprints. Seen from a collective perspective PV technology will start contributing energy to society from 2015. Until then it is returning energy that it cost to get to current technological state.	n.a.
How much do households annually save after the installation of a PV system?	H1: The energy and financial savings are different for each household and are context dependent	Yes
What factors affect PV capacity and actual PV energy production?	Actual PV production is affected by four main factors: - PV System Placing (tilt angle, orientation, shadow) - PV System Properties (material, size, panel connection, age) - PV System Location (geographic coordination, solar irradiation, temperature) - Household Behaviour (cleaning, maintenance)	n.a.

Research questions	Answer or hypothesis	Confirmed?
RQ 2. What are the factors and determinants involved in the household decision making process of PV systems?		
What are the financial benefits and bottlenecks and what role do they play in the household decision making process of PV systems?	H2: Most households with PV systems will show a positive behavioural response leading to a reduction in energy consumption and to a double dividend.	No
What are household motives and barriers for buying a PV system?	H3: Environmental concern, financial benefits and independency from energy suppliers are the most important motives for households to install and use a PV system. H4: High investment costs and long capital payback times are the main barriers for households for installing PV systems.	Yes Yes
What are (social demographic) characteristics of households with a PV system?	H5: Households with PV systems are typically between 45 and 64 years old, have a high environmental concern, have high incomes, are higher educated and own their home.	Not completely*

*To be complete, 'middle incomes' should have been added

9.2 Main conclusions

Domestic PV systems a profitable investment…

One of the main strengths of PV systems is that it delivers a green energy contribution to society. It is a renewable source of energy and has the potential to take some of the pressure of fossil fuels. PV systems contribute to a greener world but is also claimed to be financially interesting for households. This research tested if this was actually the case and whether PV systems installed between 2008 and 2012 are indeed a profitable investment. Based on three different profitability analyses (accepting a set of assumptions about the future (explained in chapter 6.4.1)) it was found that domestic PV systems are indeed profitable investments. Whatever method used, investing in a PV system is a profitable option provided that the placing properties of the household are suitable. The return on investment times are affected by type of placing, but also by the installation year and the installed capacity. Technological developments have made the investment in PV more and more interesting. This is reflected in the finding that the younger the system is, the shorter the payback times. Also, the larger the installed capacity the shorter the payback time.

With a 4.0% discount rate the net present value of the investment in PV is positive for over 85% of the PV households in this research. Even with a higher discount rate of 5.5%, the net present value is still positive for three quarter of all PV households, showing that investing in a PV system is a financially desirable choice. The internal rate on investment is on average 8.5%, showing that investing in PV is typically more profitable than alternatives. Saving the money on a freely available bank account will result in a maximum of 2% interest, meaning that for 92% of the households it was indeed more profitable to invest the money in a PV system.

…but long payback time…

The downside of investing in a PV system is found in the time it takes to earn back the investment and the risks that come with this time. The predicted return on investment time of PV systems is typically 10 to 15 years, accepting the assumption of no changes in the energy consumption of the household. This assumption immediately shows the weakness of these ROI Times and further analysis in this study showed that the real ROI Times are higher than the predicted times for almost 50% of all PV households. The long payback time also leads to a certain level of insecurity. There are a lot more risks involved in investing in a PV system than in for example in the safe option of putting the money in a long term deposit account. The PV system could malfunction, the legal environment could change or the households could decide to move.

…and strongly affected by households behaviour

The actual profitability of a PV system is very context dependent and is affected by the behaviour of the household. For about half of all the households that install a PV system the profitability will be lower than it can be, because these households show a negative behavioural response to the installation of a PV system. They start using extra energy resulting in a lower profitability than expected and anticipated. This behaviour strongly affects the profitability of the system. Accepting the first year as average it was found that for a little over 50% of the PV households counts that their 'real' ROI Times are longer, the NPVs are lower and the IRRs are lower than what they could have been. For about 25% of all household they opposite holds. They start to save extra energy (on top of what the system already produces) and by doing so they increase the profitability of the PV system.

The technology works…

One of the important conclusions that can be drawn from this research is that the PV technology actually works almost as good as predicted. Based on the share of respondents that have a monitor device installed, this research showed that the actual output of PV systems is only 7% less than what was predicted on the basis of the 0.86 factor. The supplier predictions come even closer to the truth. The real output of PV systems in households is on average only 5% lower than what was predicted by the supplier. It means that, in contrast to many other energy sectors, the suppliers seems to tell the truth and more or less accurately predict the output of PV systems. Still, households stay somewhat sceptical towards suppliers predictions.

… but households change their behaviour

Despite the fact that the technology works almost as good as predicted, the household savings are on average 13% less than the real output. This is an average for the all PV households together, but when splitting the PV households into groups it is found that for 50% of all the PV households are the savings lower than what they could have saved based on the output of the PV system. After installing the PV system, the behaviour and energy consumption pattern of these households changed in such a way that they started to consume more energy than before they had the PV system; a phenomenon called the 'rebound effect'. This group still benefits from the PV system, but not as much as they could have done.

The two other groups are households that save as much as produced by the system and show no behavioural response and households that save more than produced by the system. This group shows a change in behaviour leading to extra savings (on top of the savings caused by the PV power production). This effect is called 'double dividend' and leads to a higher profitability of the system.

This research led us to the important conclusion that households behaviour is key in the real savings from PV systems. Probably without realizing it, the consumer itself plays a determining role in whether or not installing a PV system is profitable and how large the savings will be.

Environmental concern important…

There are various reasons why households decide to install a PV system, from contributing to society to being a 'gadget addict'. One of the two most important self-declared reasons for PV households to buy and install a PV system, is that it is good for the environment. 'Environmental concerns' is one of the two reasons most frequently mentioned as important in the decision making process of PV systems. Important to remember is that hardly any household environmental reason give as the only reason to buy a PV system. PV systems are hardly even solely bought for environmental reasons but they are very often mentioned as important.

Another, less important motive but still very saliently present in the decision making process of many household is independency from conventional energy suppliers. A feeling of dependency from the 'energy giants' and a growing distrust in them are part of the important reasons why households install PV systems: they want to be independent.

…but financial reasons even more

The final and other most important motive for households to buy a PV system is for financial reasons. Financial motives are most frequently mentioned as an important reason in the decision making process. In contrast to environmental reasons, financial reasons are often named as the only important reason to buy a PV system. Therefore, it is probably a more important reason for households than environmental concerns.

Despite the fact that financial benefits is very important reasons to choose for a PV system, high costs is one of the most important barriers experienced by households. The investment involved is experienced as high and is therefore a barrier or reasons for doubt.

A typical PV household….

This research tried to describe a typical PV household. A typical household is between the 45 and 65 years old and consists of two adults and one or two kids. They have a middle or higher income, are higher educated and have paid employments. They are the owner of their home. This last characteristic is very typical and is directly related to the high administrative burdens involved in installing a PV system on a rented house. PV households are typically a little more environmentally concerned than the average Dutch households. The initiative is most likely coming from a man, making a PV system a typical 'toy for the boy'.

…is not always typical

Keep in mind that, however typical, these characteristics do not apply for all PV households. The characteristics can vary for each individual household. It will be interesting to see if these characteristics will change over time, when PV systems are becoming more popular.

9.3 Practical implications

This research, like many others, could lead to many implications and could be very interesting for real life implementations. One of the implications that could be drawn from this study is that households should be made more aware of the role of their behaviour. Since there is such a large group of households that save less than they could save, it would be very valuable to inform them about their behaviour. Pre-sale information could be useful, leading to an awareness of the possible rebound effect. Another measure, that is already more and more applied, is the standard installation of a feedback monitor. This could enhance the household's awareness of their energy use and limit the negative behavioural effect. It could also stimulate the energy savings behaviour of households, leading to a positive behavioural response and to higher savings.

Another interesting result that came up in this research is that a large group of middle income households invest in a PV system. This is likely caused by the fact that low income groups cannot afford a system, where high income groups probably have the money but do not necessarily need the savings. Based on the future predictions of the PV technology (cheaper technology, higher electricity prices) PV systems will probably remain popular among middle income households. The financial benefits and profitability will only grow larger. One of the determinants in this process will be the future policy making and available subsidies. The possibility to apply for a subsidy will probably remain to be important in the decision making process of households. The financial value is not even the most important factor in this, the cognitive effect is much larger (but more research is needed on this topic). The coming year, in which the solar panel subsidy funds are empty in the Netherlands will give some important data on if households are still interested in PV systems if there is no financial support available. Possibly, the popularity of the (already very popular) collective initiatives will increase.

From a marketing point of view, it is very interesting that mostly men take the initiative to buy a PV system. Men are typically more interested in new technology and gadgets, and that was also reflected in the results from this study. For marketers it means that focussing on a male target group could be a defendable choice.

10 Discussion

10.1 Methodology

In a study like this, many decisions had to be made regarding the design of the research, the methodology used, the statistical analyses applied and assumptions made. About all these decision discussion could be started, but the most important discussion points and weaknesses are described and explained in this chapter.

This research rests heavily on two pillars: data from relevant literature and data from an online questionnaire. The decision to use a questionnaire was based on the argument that the data for this research needed to be comparable and quantifiable. It created the possibility to show averages, predictions and general tendencies. It allowed testing for correlations and regression. Nevertheless, there were also some shortcomings to this method, for example the risk of respondents only giving socially desirable answers . An alternative could have been to use a mix method design, for example by doing in depth interviews with PV owners or set up focus groups. This would allow the researcher to ask for clarification if something would not be clear.

During the data analysis we found out that, even having tested the questionnaire very thorough, there were still some obstacles experienced by the respondents. The respondents were able to comment on the questionnaire in the last question of the questionnaire, and based on this data the most important obstacles were found.
The most important obstacle experienced by the respondents was the length of the survey. With 76 questions the questionnaire was rather long and the effort asked from the respondent rather large. The average amount of time respondents needed to complete the questionnaire was one hour and three minutes. That this is (too) long is also reflected in the number of partial questionnaire. Only 157 of the originally started questionnaires (341) was actually finished. A smaller or shorter questionnaire could have led to more responses. On the other hand, the data would also have been less complete and more questionnaires would have been needed to answer all the research questions. The fact that it is so comprehensive is an important strength of the research.
Next to the length of the complete questionnaire, there was also one specific question that was responsible for a large part of the dropout rate. This question asked for a (large) effort by the respondent. They had to look through their administration to find old energy bills and PV outputs. This was for some respondents too much of an effort or took too much time and led to them not finishing the questionnaire. Nevertheless, the respondents who did fill in the questionnaire provided us with some very valuable data.
The last important obstacle was that the questionnaire was built on the assumption that the PV system of each respondent was placed as one system. In reality, we found out that a substantial share of the respondents built up their PV systems over the years. This share

was much larger than anticipated. The questionnaire did ask whether or not that was the case but other questions were not created with that in mind. It led to confusion for many respondents because they were, for example, not able to fill in what the supplier prediction of the annual yield was. Some of them sent emails with questions, for example if they had to add up the different parts of the systems. To be able to compare the actual data on production and savings all the respondents with ‘combined PV systems’ were eliminated from the dataset. If the questionnaire was created with this phenomenon in mind this would probably not have been necessary.

One of the difficulties of the practical side of research was that there was no ‘way in’ in the world of households and photovoltaics. To makes sure that the research was as independent as possible this research did not make use of supplier databases to reach possible respondents. The difficulty was that, by not having access to a database with registered PV owners, the PV households had to be found in the blank. The questionnaire was promoted via various offline and online mediums. For example via forums, ads in newsletters, posters in supermarkets and cafeterias and by using various forms of social media. By doing so we tried to reach as many PV households as possible. But, since there was hardly any personal contact or connection between the researcher and the respondents people had to be intrinsically motivated to fill in the questionnaire. There was an incentive (a chance to win €100,-) but still complete strangers had to take the time and put the (large) effort in to fill in the questionnaire. This could have resulted in a group of respondents that are all excessively motivated to be green or to help the world of photovoltaics. It could be that only the ‘fanatics’ participated in the research, but if this is true cannot be tested based on the available data. The advantage of this method of recruiting respondents was that the respondents were completely independent. If the respondents were found using a third party (e.g. a PV system supplier) the households could have been biased or more likely to give socially responsible answers. Now, by not knowing the researchers, the perceived pressure to give the ‘right’ answers was probably lower.

Since there was no real (social or financial) binding with the research combined with the fact that the questionnaire took so much time to complete, there were many respondents that only partially filled in the questionnaire or filled in nonsense answers. This led to many variations in the number of respondents that filled in each questions. The N values for different questions varied from 278 to 41. The most complete questionnaires (157) were used in this research but while assessing the data it was found that sometimes respondents just typed in a few random figures or symbols to fill in the questions. Filtering them out has, as said before, led to large variations in the N’s.

10.2 Calculation models

One of the things that I came across while researching the world of photovoltaics is that on the Internet, consumers are overloaded with different information and advice on websites about PV technology, renewable energy and how to reduce household energy consumption. There is so much information and data available that websites can freely choose and frame, depending on their goal, the most beneficial and promising 'facts' and still tell the truth.

Many websites and institutions have calculation models and tools on their website to allow consumers to calculate what they could save when they would install a PV system or other energy saving or producing appliances. Like the calculations in our research, those models heavily rely on (future) assumptions. Depending on the assumptions, the outcomes can vary very strongly. Depending on the goal of the tool, the assumptions chosen can steer the output in the direction wanted by the creator. For example, a supplier website promoting PV systems used a predicted energy price raise of 15% each year. This means for example that the profitability of PV systems will increase compared to more conservative predictions. This is 11% more than the prediction of Milieu Centraal, which is a much more independent website with informational instead of commercial purposes. For consumers it is very important that they use different (independent) sources to find out if buying a PV system is a favourable option in their situation. A critical eye and a healthy amount of scepticism is recommendable for consumers that are new to the market of energy saving appliances. Multiple sources should be consulted and awareness about the underlying assumption of each calculation model and the goal of each website and institution should be stimulated.

10.3 Future research and recommendations

Research in the field of PV technology is a relatively new area of research. The rise of the popularity of domestic solar panel systems was accompanied by the increase of (social scientific) research in that field. Nevertheless, the number of social scientific studies executed and amount of literature available in this field is rather limited. The PV technology is developing so quickly that research in the field can hardly keep up. The published articles are often already out dated at the day of their release. Hence, Any research in the field of photovoltaics will be useful and should be stimulated.

When looking at the specific topic of household decision making processes and their behaviour with regard to PV systems there is even less literature found. Based on this research a more specific study about the actual motives and barriers that households experience in the decision making process of buying a PV system is recommended. Especially the motives *not* to buy a PV system is interesting. A study that includes households without PV systems is needed and could provide interesting information on how to set up a successful marketing campaign for PV systems in the Netherlands. A study that includes in-depth interviews and focus groups might also give more detailed information about the motivations of household why (not) to buy a PV system.

Another important recommendation for further research is more in the field of long term results. The behavioural effects found in this study (rebound and double dividend) were only about the first year after installations. A long term study, for example over the first five to ten years would be very interesting and is essential for future managerial decision making. It could show if these effects remain the same over time or will increase or decrease.

This research also showed that households with a monitoring system on their PV system save more energy than households without this monitor. Due to the small number of respondents with such a monitoring system statistic testing was difficult. More research into this topic (with a larger group of respondents) and over a longer period of time could confirm the results. It would be interesting to see if this effect will maintain the same over time, or that the effect will diminish.

10.3.1 A Sunny Future?

Many times during this research I was asked what my recommendation would be for Dutch households; install a PV system or not? I believe that if the following three criteria are met, a household should seriously consider investing in a PV system:

- The house and/or roof has the right properties (in terms of orientation, available space, etc.)
- There is money available to invest (accepting that the return on investment time is ten to fifteen years)
- The household (and neighbourhood) has no problems with the somewhat 'industrial' look

Even when these three criteria are met households should still do some serious research. Within the PV market there are some very big differences found between suppliers when it comes to prices, quality and service. Before installing just any PV system, households should really compare different options. What is a good PV system for one household does not have to be the right PV system for the next.

Even so, technology is at the verge of becoming 'main stream' in the Netherlands. Especially the last couple of years the number of households that installed a PV system was booming. Interesting would be to see what changes in the near future. The entire PV market may possibly change, due to the fact that PV systems are not only a very green contribution to society but becoming a real (short term) money saver. Environmental consciousness will start to grow less important and will be even more overtaken by the financial reasons and benefits, changing the decision making process of households and their characteristics.

Very recently, different stakeholders in the Netherlands have come to an agreement that for the coming four years the feed-back arrangements ('salderingsregeling') will continue to exist. Clarity about this and about governmental decisions will provide possible PV households more certainty in their decision making process (Solarmagazine, 2014).
Based on the data and knowledge I gathered during this research I believe that the future of PV technology will be a bright one. My prediction is that the market will notice a small decline in demand now, caused by the psychological effect of no more available subsidies. Nevertheless, I believe that the PV market is already strong enough to survive this dip. Clarity about the future will decrease the uncertainty about the future for both suppliers and consumers. A market not driven by subsidies will in the end develop into a more healthy and independent market.

So, will the future of photovoltaics be a sunny future? I believe it will.

VI

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Appendices

Appendix 1. Questionnaire (Dutch)

Q1
Beste respondent,
Allereerst ontzettend bedankt dat u aan deze enquête wilt deelnemen. Deze enquête heeft als doel inzicht te verkrijgen in het gebruik van zonnepanelen (voor electriciteit) door huishoudens. Door het invullen van deze enquete levert u een belangrijke en zeer gewaardeerde bijdrage aan dit onderzoek.
Omdat ieder huishouden verschillend is zijn er geen goede of foute antwoorden. Alle antwoorden zijn even bruikbaar. Ik vraag u goed de tijd te nemen om de vragen te lezen en eventueel informatie op te zoeken in uw administratie.
Zoals u misschien wel weet wordt een stroomopwekkende installatie op basis van zonnepanelen ook wel een photovoltaisch (PV) systeem genoemd. In deze enquête wordt daarnaar verwezen met de term 'PV installatie'. Als er in de vraag gesproken wordt over 'zonnepanelen' dan wordt er specifiek verwezen naar de zonnepanelen zelf en dus niet naar de complete PV installatie (bedrading, omvormer, etc).
De enquete wordt automatisch opgeslagen en u kunt ten alle tijden de enquete even stoppen en op een later moment of andere dag weer verder gaan. Vergeet alstublieft dan niet de enquete af te maken. Vragen of opmerkingen over de enquête zelf kunnen aan het eind van de enquête worden ingevuld.
Als u geïnteresseerd bent in de uitkomsten van dit onderzoek, nadere informatie wilt of als u een andere vraag of opmerking heeft dan kunt u een mailtje sturen naar zonnepanelen.onderzoek@gmail.com of kijk op www.zonnepanelenonderzoek.blogspot.nl.

Q2 Heeft u uw PV installatie zelf laten plaatsen of was deze al aanwezig toen u uw woning betrok? Kies de situatie die van toepassing is.

- Toen ik de woning betrok was de PV installatie al aanwezig.
- De PV installatie heb ik laten plaatsen toen ik al in het huis woonde.
- Anders, namelijk ____________________

Q3 In welk jaar is uw PV installatie in gebruik genomen?

- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- Eerder dan 2008

Q4 In welke maand is uw PV installatie in gebruik genomen?

- Januari
- Februari
- Maart
- April
- Mei
- Juni
- Juli
- Augustus
- September
- Oktober
- November
- December

Q76 Bestaat uw PV installatie uit meerdere delen die los van elkaar of na elkaar geinstalleerd zijn? Bijv. 'Ja, een aantal panelen is geinstalleerd in 2010 en in 2011 is nog een aantal extra bijgeplaatst' of later 'ja, een deel ligt op een plat dak, een deel op een schuin dak'.

- Nee
- Ja, namelijk ____________________

Q5 Wat voor type PV installatie heeft u? Een installatie met...
- ❍ Monokristallijne zonnepanelen
- ❍ Polykristallijne zonnepanelen
- ❍ Amorfe zonnepanelen
- ❍ Weet ik niet
- ❍ Anders namelijk, ____________________

Q6 Hoe groot is uw PV installatie?
    Oppervlakte (in m2)
    Aantal panelen

Q7 Wat is het totale geinstalleerde vermogen (capaciteit) van uw PV installatie?
    Vermogen (in Watt Piek)

Q8 Op welke manier staan uw zonnepanelen geschakeld?
- ❍ Serieel geschakeld (alle zonnepanelen zijn in één lijn aan elkaar gekoppeld voordat de omvormer bereikt wordt)
- ❍ Parallel geschakeld (alle zonnepanelen staan individueel aan de omvormer gekoppeld)
- ❍ Ik weet het niet
- ❍ Anders namelijk, ____________________

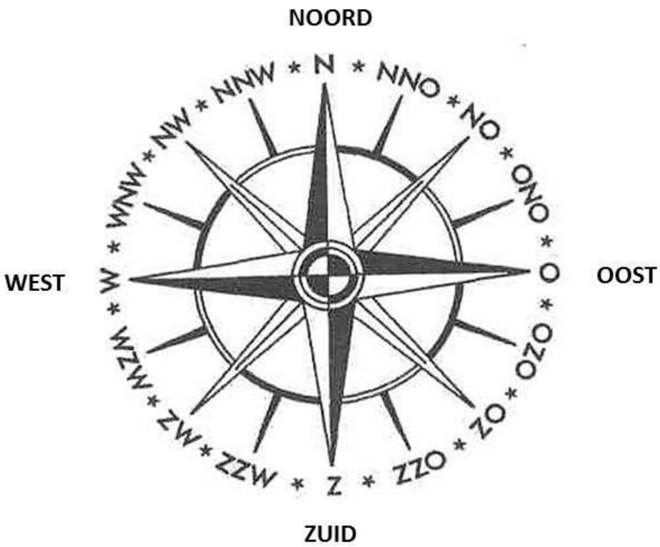
Q9 Op wat voor type dak staan uw zonnepanelen opgesteld?
- ❍ Op een schuin dak
- ❍ Op een vlak dak
- ❍ Anders namelijk, ____________________

Q10 Staan uw zonnepanelen horizontaal of gekanteld opgesteld?
- ❍ Horizontaal (vlak)
- ❍ Gekanteld (schuin)

Q11 In welke hoek staan uw zonnepanelen opgesteld? (In graden) 0 graden is horizontaal, 90 graden is verticaal

Q12 In welke richting staan de zonnepanelen opgesteld? Omcirkel de richting (bij benadering) op het kompas.

Met de richting waarin de zonnepanelen staan opgesteld wordt bedoeld in welke richting de panelen ‘wijzen’. Als uw panelen bijvoorbeeld richting het Zuiden wijzen houdt dat in dat ze midden op de dag vol in de zon staan (omcirkel dan ‘Z’ op het kompas). Wijzen ze iets naar links te opzichte van het zuiden dan staan ze in de richting van het zuidzuidoosten opgesteld (geef dan ZZO aan op het kompas). Vaak heeft de installateur aangegeven in welke richting de zonnepanelen staan opgesteld. Mocht u het echt niet weten vraag ik u te gokken.



Q13 Is uw PV installatie gekoppeld aan het elektriciteitsnet? Oftewel, levert uw systeem het opgewekte elektriciteitsoverschot terug aan het net of is het alleen voor eigen gebruik?

- Ja, het PV systeem is gekoppeld aan het net
- Nee, de opgewekte stroom is alleen voor eigen gebruik
- Anders, namelijk ____________________

Q14 Staan er obstakels in de buurt (bijv bomen, flats, etc) die de lichtinval op uw zonnepanelen beperken of zorgen voor schaduw?

- Ja
- Nee

Q15 Hoe lang is de duur van de schaduw/beperking van de lichtinval? (Totale duur per dag)

- Zeer kortdurend (minder dan 10 minuten)
- Kortdurend (10 tot 30 minuten)
- Gemiddeld durend (30 tot 60 minuten)
- Langdurend (60 tot 120 minuten)
- Zeer langdurende (120 minuten of meer)

Q16 Hoe groot zijn de obstakels die de lichtinval beperken?
- ❍ Klein (antennes, takken, smalle schoorstenen)
- ❍ Gemiddeld (tv schotels, schoorstenen, kleine bomen)
- ❍ Groot (middel grote bomen, dakkappellen)
- ❍ Zeer groot (grote bomen, gebouwen)

Q17 Hoe groot is het percentage van het totale oppervlakte aan zonnepanelen dat (soms) beschaduwd wordt?
_______ Procent van het totale oppervlakte aan zonnepanelen

Q18 Wat waren de kosten voor uw gehele PV installatie? Graag aangeven exclusief eventuele subsidies. Inclusief omvormer, bedrading, installatie kosten, arbeidskosten, etc.
€

Q19 Wat zijn (gemiddeld) de jaarlijkse onderhoudskosten? Het gaat hier om extra kosten, bovenop de installatiekosten van de voorgaande vraag. Mocht onderhoud gratis verleend worden door uw PV leverancier of installateur, of inbegrepen zijn bij de installatiekosten van de vorige vraag dan verzoek ik u deze vraag met '0' te beantwoorden.
€

Q20 Wat is de (door de fabrikant/leverancier) beloofde of geschatte terugverdientijd van uw PV installatie? Inclusief eventuele subsidies
- ❍ Minder dan 5 jaar
- ❍ 5 tot 7,5 jaar
- ❍ 7,5 tot 10 jaar
- ❍ 10 tot 12,5 jaar
- ❍ 12,5 tot 15 jaar
- ❍ 15 tot 20 jaar
- ❍ Meer dan 20 jaar
- ❍ Nooit

Q73 In hoeveel tijd denkt u zelf de PV installatie terug te verdienen?Inclusief eventuele subsidies
- ❍ Minder dan 5 jaar
- ❍ 5 tot 7,5 jaar
- ❍ 7,5 tot 10 jaar
- ❍ 10 tot 12,5 jaar
- ❍ 12,5 tot 15 jaar
- ❍ 15 tot 20 jaar
- ❍ Meer dan 20 jaar
- ❍ Nooit

Q22 Wat is de (door de fabrikant/leverancier van uw PV installatie) beloofde of geschatte gemiddelde besparing per jaar op uw energierekening? In kilo Watt per uur (kWh) en in Euro's.

kWh

€

Q23 Hoeveel denkt u zelf dat uw gemiddelde besparing per jaar is? In kilo Watt per uur (kWh) en in Euro's.

kWh

€

Q24 Heeft u in het verleden subsidie(s), belastingkortingen of een andere vergoeding voor uw PV installatie ontvangen of ontvangt u deze nog steeds? Meerdere antwoorden mogelijk.

- ❑ Ja, subsidie(s)
- ❑ Ja, een belasting korting of andere vergoeding, namelijk [naam/uitleg] ______________________
- ❑ Nee

Q25 Onder welke regeling valt/vallen de subsidie(s) die u heeft ontvangen en in welk jaar heeft u deze aangevraagd? De looptijd van de regeling is aangegeven achter de regeling. Meerdere antwoorden mogelijk.

- ❑ Energie Premie Regeling (2001-2003), aangevraagd in het jaar: ______________________
- ❑ Milieukwaliteit Elektriciteits Productie (2001-2006), aangevraagd in het jaar: ______________________
- ❑ Stimuleringsregeling Duurzame Energie (2008-2010), aangevraagd in het jaar: ______________________
- ❑ Subsidieregeling Zonnepanelen (2012-2014), aangevraagd in het jaar: ______________________
- ❑ Gemeentelijke subsidieregeling, aangevraagd in het jaar: ______________________
- ❑ Weet ik niet
- ❑ Anders namelijk, ______________________

Q26 Hoeveel heeft u in totaal aan subsidie(s), belastingkortingen of andere vergoedingen voor uw PV installatie ontvangen? In Euro's, als u het niet weet vragen we u een benadering te doen.

€

Q27 Als er geen subsidie, korting of andere vergoeding voor uw PV installatie verleend werd had u de installatie dan ook aangeschaft?

- ❍ Ja, zeker wel
- ❍ Ja, waarschijnlijk wel
- ❍ Nee, waarschijnlijk niet
- ❍ Nee, zeker niet
- ❍ Weet ik niet

Q28 Hoe vaak maakt u gemiddeld de zonnepanelen schoon?Onder schoonmaken wordt verstaan: afnemen met vochtige doek of uitgebreider.

- ❍ Meer dan 1 keer per jaar
- ❍ 1 keer per jaar
- ❍ Minder dan 1 keer per jaar, namelijk [.... keer per .... jaar] ____________________
- ❍ Nooit

Q29 Hoeveel jaar verleent de fabrikant en/of leverancier van uw zonnepanelen productgarantie op de volgende onderdelen van uw PV installatie? Vermogensgarantie is geen onderdeel van de productgarantie. De vermogensgarantie van uw zonnepanelen kunt u bij de volgende vraag invullen. Bij geen garantie ‘0’ invullen. Als u het niet weet graag '111' invullen.

	Aantal jaar productgarantie
Omvormer	
Constructie (bedrading, koppelstukken, etc)	
Zonnepanelen	

Q30 Hoeveel procent vermogensgarantie op uw zonnepanelen verleent de fabrikant en/of leverancier van uw PV installatie bij 10 en 25 jaar? Vermogensgarantie wordt verleend voor bepaalde percentages van het oorspronkelijk vermogen. Bijvoorbeeld 10 jaar voor 90% van het oorspronkelijk vermogen en 80% van het oorspronkelijk vermogen 25 jaar. Bij geen garantie ‘0’ invullen. Als u het niet weet graag '111' invullen.

	Percentage vermogensgarantie
Vermogensgarantie voor 10 jaar	
Vermogensgarantie voor 25 jaar	

Q31 Neemt u deel of heeft u deelgenomen aan een zonnepanelen collectief? Zo ja, aan welke? Bijvoorbeeld 1-2-3 Zonne-Energie, De Windvogel, Zoncollectief, etc.

- ❍ Nee
- ❍ Ja, aan: ____________________

Q32 Wat was/is voor u de belangrijkste reden om mee te doen aan dit collectief?

Q33 Voor deze vraag vragen wij u de energierekeningen van drie jaren op te zoeken. Namelijk (1) het jaar voordat u de PV installatie heeft aangeschaft, (2) het jaar dat u de PV installatie daadwerkelijk heeft aangeschaft en (3) van het jaar daarna. U heeft alleen de gegevens over het elektriciteitsverbuik nodig (dus geen gas). Wat waren het electriciteitsverbuik en de bijbehorende kosten van het jaar voor, tijdens en na de aanschaf van uw PV installatie? Op een energierekening lopen jaren vaak niet van januari tot december. Kunt u daarom invullen van welke maand tot welke maand uw energierekening loopt? Sommige huishoudens hebben een vermogen meter in hun PV systeem, die exact aangeeft hoeveel kWh de zonnepanelen hebben opgewekt. Mocht u deze ook hebben, en deze gegevens nog hebben, wilt u dan het jaarlijks opgewekt vermogen in de meest rechter kolom aangeven?

	Start periode energierekening (bijv. april 2006)		Start periode energierekening (bijv. april 2007)		Elektriciteits verbuik	Kosten elektriciteit	Opgewekt vermogen door PV installatie
	Maand	Jaar	Maand	Jaar	in kWh	in Euro's	in kWh
1. Laatste jaar voor aanschaf PV installatie							
2. Jaar van aanschaf PV installatie							
3. Jaar na aanschaf PV installatie							

Q34 Bent u in het jaar voor, tijdens en/of na aanschaf van uw PV installatie één of meerdere malen gewisseld van energieleverancier?

❍ Ja

❍ Nee

Q35 Bent u in de afgelopen 5 jaar gewisseld van energieleverancier? Zo ja, hoe vaak was dit?

❍ Nee

❍ Ja, aantal maal gewisseld: ______________________

Q36 Wat is de belangrijkste reden dat u één of meerdere malen bent gewisseld van energieleverancier?

Q37 Heeft u in het jaar voor, tijdens en/of na aanschaf van uw PV installatie korting(en) of andere financiële tegemoetkoming (aanbieding of dergelijke) ontvangen van uw energieleverancier (anders dan kortingen of subsidies voor de zonnepanelen)?

- ❍ Nee
- ❍ Ja
- ❍ Weet ik niet

Q38 Hoe groot was het totale bedrag dat u door deze korting(en) of financiële tegemoetkoming(en) bespaarde? In Euro's, eventueel invullen bij benadering.

Q39 Heeft zich in het jaar van de aanschaf van uw PV installatie een verandering in de samenstelling van het huishouden voorgedaan? Zo ja, met hoeveel personen is het huishouden toe of afgenomen ten opzichte van het jaar voor de aanschaf de PV installatie?

- ❍ Ja, het aantal personen in het huishouden is toegenomen met [aantal personen] ____________________
- ❍ Ja, het aantal personen in het huishouden is afgenomen met [aantal personen] ____________________
- ❍ Ja, maar het aantal personen is gelijk gebleven.
- ❍ Nee

Q40 Heeft zich in het jaar na de aanschaf van uw PV installatie een verandering in de samenstelling van het huishouden voorgedaan? Zo ja, met hoeveel personen is het huishouden toe of afgenomen ten opzichte van het jaar voor de aanschaf van de PV installatie?

- ❍ Ja, het aantal personen in het huishouden is toegenomen met [aantal personen] ____________________
- ❍ Ja, het aantal personen in het huishouden is afgenomen met [aantal personen] ____________________
- ❍ Ja, maar het aantal personen is gelijk gebleven.
- ❍ Nee

Q41 Heeft u in het jaar van en/of na aanschaf van uw PV installatie niet eerder aanwezige elektriciteit besparende apparaten en/of voorzieningen in huis geplaatst? Bijv. energie zuinige wasmachine, spaarlampen, etc.

- ❍ Ja
- ❍ Energie zuinige droger (A-label)

Q42 Welke niet eerder aanwezige elektriciteit besparende apparaten en/of voorzieningen heeft u in het jaar van en/of na aanschaf van uw PV installatie in huis geplaatst? In welk jaar was dat?

	Jaar van aanschaf PV installatie	Jaar na aanschaf PV installatie
Energie zuinige wasmachine (A-label)	❑	❑
Energie zuinige droger (A-label)	❑	❑
Energie zuinige koelkast (A-label)	❑	❑
Energie zuinige vriezer (A-label)	❑	❑
Energie zuinige vaatwasser (A-label)	❑	❑
Spaarlampen (de helft of meer van alle aanwezige lampen)	❑	❑
Anders, namelijk	❑	❑
Anders, namelijk	❑	❑

Q43 Heeft u in het jaar van en/of na aanschaf van uw PV installatie niet eerder aanwezige gas besparende apparaten of voorzieningen in huis geplaatst?Bijv. dubbelglas, zonneboiler, isolatie, etc.

❍ Ja

❍ Nee

Q44 Welke niet eerder aanwezige gas besparende apparaten en/of voorzieningen heeft u in het jaar van en/of na aanschaf van uw PV installatie in huis geplaatst? In welk jaar was dat?

	Jaar van aanschaf PV installatie	Jaar na aanschaf PV installatie
Vloerisolatie	❑	❑
Energie zuinige droger (A-label)	❑	❑
Isoleren spauwmuren	❑	❑
Dubbelglas	❑	❑
Zonneboiler	❑	❑
Hoog rendement (HR) ketel	❑	❑
Anders, namelijk	❑	❑
Anders, namelijk	❑	❑

Q45 Heeft u in het jaar van en/of na aanschaf van uw PV installatie niet eerder aanwezige grote elektriciteit verbruikers in huis geplaatst? Bijv. extra koelkast, airconditioning, eletrische boiler, etc.

❍ Ja

❍ Energie zuinige droger (A-label)

Q46 Welke niet eerder aanwezige grote elektriciteit verbruikers heeft u in het jaar van en/of na aanschaf van uw PV installatie in huis geplaatst? In welk jaar was dat?

	Jaar van aanschaf PV installatie	Jaar na aanschaf PV installatie
Elektrische boiler	❑	❑
Energie zuinige droger (A-label)	❑	❑
Elektrische kachel	❑	❑
Koelkast	❑	❑
Vriezer	❑	❑
Spaarlampen (de helft of meer van alle aanwezige lampen)	❑	❑
Vaatwasser	❑	❑
Wasdroger	❑	❑
Wasmachine	❑	❑
Kookplaat	❑	❑
Thuistap/Beertender	❑	❑
Elektrische wijnkoeler	❑	❑
Televisie	❑	❑
Tuinvijverpomp	❑	❑
Tropisch aquarium	❑	❑
Waterbed	❑	❑
Infrarood sauna	❑	❑
Stoomcabine	❑	❑
Airconditioner	❑	❑
Elektrische errasverwarmer	❑	❑
Anders, namelijk	❑	❑
Anders, namelijk	❑	❑

Q47 Heeft u in het jaar van en/of na aanschaf van uw PV installatie uw huis op zo'n manier verbouwd dat het uw energieverbruik (gas en elektra) zou kunnen beïnvloeden (zowel positief als negatief)? Zo ja, op welke manier?Bijv. aanbouw serre, uitbouw woonkamer, etc.

- ❍ Nee
- ❍ Ja, namelijk ____________________

Q48 Wie nam het initiatief tot de aanschaf van uw PV installatie?

- ❍ Ik
- ❍ Mijn partner
- ❍ Mijn huisbaas/woningcorporatie
- ❍ Anders, namelijk ____________________

Q49 Wat waren de belangrijkste redenen dat u voor een PV installatie gekozen heeft?In volgorde van belangrijkheid, met de belangrijkste reden bovenaan.

Q50 Indien van toepassing, wat waren de belangrijkste redenen dat u twijfelde over de aankoop van een PV installatie?In volgorde van belangrijkheid, met de belangrijkste reden bovenaan.

Q51 Wat denkt u dat de belangrijkste redenen zijn voor andere huishoudens om geen PV installatie aan te schaffen?In volgorde van belangrijkheid, met de belangrijkste reden bovenaan.

Q52 Geef aan in hoeverre u het eens bent met de volgende stelling.

	Helemaal mee eens	Een beetje mee eens	Ik weet het niet	Een beetje mee oneens	Helemaal mee oneens
Ik ben bereid milieuvriendelijke producten te kopen, ook als deze meer kosten.	❍	❍	❍	❍	❍

Q53 Hoe belangrijk is bescherming van het milieu voor u persoonlijk?

- ❍ Erg belangrijk
- ❍ Redelijk belangrijk
- ❍ Ik weet het niet
- ❍ Redelijk onbelangrijk
- ❍ Erg onbelangrijk

Q54 Kies de vijf milieukwesties waar u zich de meeste zorgen over maakt.Sleep de keuzes naar het rechtervak, in volgorde van belangrijkheid, met de belangrijkste reden bovenaan.

Milieukwesties waar ik mij de meeste zorgen over maak (kies 5)
_______ Uitputting van fossiele brandstoffen
_______ De hedendaagse consumptie gewoontes
_______ Groeiende hoeveelheid afval
_______ Klimaatveranderingen
_______ Verlies van biodiversiteit (uitsterven soorten flora en fauna, verlies leefgebied wildlife, etc)
_______ Natuurrampen (aardbevingen, overstromingen, etc)
_______ Rampen veroorzaakt door de mens (olierampen, industriële ongelukken, etc)
_______ Watervervuiling (Zeeën, rivieren, meren, etc)
_______ Agrarische vervuiling (gebruik van pesticiden, meststoffen, etc)
_______ Gebruik van genetisch gemodificeerde organismes in landbouw
_______ Impact van chemicaliën in dagelijkse producten op gezondheid van mensen
_______ Luchtvervuiling
_______ Geluidsoverlast en vervuiling (door snelwegen, luchthavens, industriegebieden, etc)
_______ Problemen door vestedelijking (files, vervuiling, weinig groen, etc)
_______ Invloed van vervoersmiddelen (groeiend aantal auto's, snelwegen, vliegverkeer, etc)
_______ Anders, namelijk
_______ Anders, namelijk

Q55 Er volgt nu een aantal korte vragen. Wij vragen u het antwoord aan te vinken dat van toepassing is.

	Altijd	Vaak	Soms	Zelden	Nooit
Hoe vaak levert u uw glasafval gescheiden aan?	❍	❍	❍	❍	❍
Hoe vaak levert u uw groente-, fruit- en tuinafval (GFT) gescheiden aan?	❍	❍	❍	❍	❍
Hoe vaak levert u uw papierafval gescheiden aan?	❍	❍	❍	❍	❍
Hoe vaak levert u uw chemisch afval gescheiden aan?	❍	❍	❍	❍	❍
Hoe vaak probeert u water te besparen door minder vaak en/of minder lang de kraan te laten lopen?	❍	❍	❍	❍	❍
Hoe vaak probeert u energie te besparen door minder vaak en/of minder lang het licht te laten branden?	❍	❍	❍	❍	❍
Hoe vaak gebruikt u een eigen tas of krat voor de boodschappen uit milieuoverwegingen?	❍	❍	❍	❍	❍

Q56 Bent u lid van één of meerdere van de volgende natuur- en milieuorganisaties? Zo ja, geef aan welke. Meerdere antwoorden mogelijk.

- ❑ Nee
- ❑ Natuurmonumenten
- ❑ Wereld Natuur Fonds
- ❑ Provinciale Landschappen
- ❑ Vogelbescherming
- ❑ Greenpeace
- ❑ Dierenbescherming
- ❑ Internationaal Dierenfonds IFAW
- ❑ Anders, namelijk ____________________

Q57 Waar woont u?

Stad

Provincie

Q58 Wat is uw geslacht?

- ❍ Man
- ❍ Vrouw

Q59 Wat is uw leeftijd?

Q60 Wat voor type werk heeft u?

- ❍ Betaalde baan, 32 uur per week of meer
- ❍ Betaalde baan, 15 tot 32 uur per week
- ❍ Betaalde baan, minder dan 15 uur per week
- ❍ Geen werk, ik ontvang een uitkering
- ❍ Geen werk, ik ben gepensioneerd/met de VUT
- ❍ Huisvrouw/huisman zonder betaalde baan
- ❍ Anders, namelijk ____________________

Q61 Wat is uw hoogst genoten voltooide opleiding?

- ❍ Basisschool
- ❍ Middelbare school
- ❍ Lager beroepsonderwijs
- ❍ Middelbaar beroepsonderwijs
- ❍ Hoger beroepsonderwijs
- ❍ Universiteit/WO
- ❍ Anders, namelijk ____________________

Q62 Uit hoeveel personen bestaat uw huishouden?

Q63 Heeft u een partner die onderdeel is van uw huishouden?
- Ja
- Nee

Q64 Wat is het geslacht van uw partner?
- Man
- Vrouw

Q65 Wat is de leeftijd van uw partner?

Q66 Wat is de hoogst genoten voltooide opleiding van uw partner?
- Basisschool
- Middelbare school
- Lager beroepsonderwijs
- Middelbaar beroepsonderwijs
- Hoger beroepsonderwijs
- Universiteit/WO
- Anders, namelijk ____________________

Q67 Wat voor type werk heeft uw partner?
- Betaalde baan, 32 uur per week of meer
- Betaalde baan, 15 tot 32 uur per week
- Betaalde baan, minder dan 15 uur per week
- Geen werk, hij/zij ontvangt een uitkering
- Geen werk, ik ben gepensioneerd/met de VUT
- Huisvrouw/huisman zonder betaalde baan
- Anders, namelijk ____________________

Q68 Wat is het bruto inkomen van uw huishouden per jaar?
- Geen inkomen
- Tot 10.000 euro
- 10.000 tot 25.000 euro
- 25.000 tot 40.000 euro
- 40.000 tot 55.000 euro
- 55.000 tot 70.000 euro
- 70.000 tot 95.000 euro
- 95.000 euro of meer

Q69 Wat voor type woning heeft u?
- ❍ Koophuis
- ❍ Huurhuis
- ❍ Anders, namelijk ____________________

Q70 Wat voor soort woning heeft u?
- ❍ Vrijstaande woning
- ❍ Twee onder een kap/half vrijstaand
- ❍ Rijtjeshuis
- ❍ Flat/appartement
- ❍ Anders, namelijk ____________________

Q71 Dit was het einde van deze enquête. Ontzettend bedankt voor uw deelname!

Q72 Heeft u nog vragen, ideeën, dingen die niet duidelijk waren? Die kunt u hieronder invullen. Indien van toepassing, graag aangeven over welke enquête-vraag u een opmerking en/of vraag heeft.

Q75 Wilt u meedingen naar een Irischeque ter waarde van 100 euro? Vul dan hier uw emailadres in.Mocht u gewonnen hebben nemen wij contact met u op. Over de uitslag wordt niet gecorrespondeerd.

Q74 Als u geinteresseerd bent in de uitkomsten van dit onderzoek kunt u een mailtje sturen naar zonnepanelen.onderzoek@gmail.com, in onderstaande balk uw emailadres achterlaten of kijk op zonnepanelenonderzoek.blogspot.nl

Appendix 2. Combined PV systems

The respondents who answered ‘yes’ to the question “Bestaat uw PV installatie uit meerdere delen die los van elkaar of na elkaar zijn geinstalleerd?” elaborated on their answer. The answers are depicted below in random order.

- wij hebben de panelen wel op dezelfde dag laten installeren maar op twee afzonderlijke dakvlakken
- tweedehands panelen in 2010, nieuwe panelen in 2011, tweedehandspanelen in 2013, verschillende hellingshoeken
- Panelen 6 x Sharp 180 Wp in 2009 later een zonne boiler in 2012 bij geplaats
- op plat en schuine dak
- Op 12 juli 2012 10 panelen laten installeren op woonhuis met schuin dag en op 20 april 2013 zelf nog 4 panelen op het platte dak van de schuur geplaatst.
- maart 2012 zijn er 9 bijgeplaatst
- Maart 2012 6x 190w= 1140W --> December 2012 12x 195w=2340W Er is totaal 3480 W geplaatst
- in twee delen
- In oct. 1999 reeds 6 st. 93 Wp modules in gebruik
- in november 2010 gestart met 1140 W/p en op 21juli 2012 uitgebreid met 1560 W/P daarbij installatie aangepast
- In de 2013 deel bijgeplaatst
- in 2013 8 panelen bijgeplaatst
- In 2012 uitgebreid.
- in 2003 gestart met 8*110 Wp, vergroot naar 20*175 Wp in 2009 Nu dus 3,5 kWp totaal
- elk jaar een paar panelen bijgeplaatst
- eerste 440 Wp in 2003, daarna + 600 Wp in 2005, + 700Wp in 2009 en + 3500 Wp in 2013
- eerst panelen op dak, daarna op bijkeuken en daarna op schuur
- Een klein deel zelfgebouwde panelen in 2011 op een aparte omvormer. De rest in feb. 2013 op een SMA omvormer
- een deel is op schuindak, geintegreerd, een deel op plat dak
- deels 2004, deels 2010. 1e deel plat dak 2e deel schuin dak
- deel plat, deel schuin dak
- deel op plat dak, deel op een schuin dak
- Deel is geinstalleerd in 2006 (440Wp) , daarna in 2009 (440Wp) en in 2012 (600 Wp)
- Deel geplaatst in 2011, tweede deel in 2012
- de panelen liggen in twee strings op hetzelfde dak

- de installatie is in 2010, 2011, 2012 en 2013 steeds verder uitgebreid, een deel ligt op een plat dak, verder zijn er panelen op het schuine dak geplaats
- achterzijde woning 2010, voorzijde woning 2012
- 8x240Wp in aug.2011 schuin dak, 5x327Wp in juni 2013 plat dak
- 6 panelen mei 2011. 6 panelen juli 2011. 3 panelen februari 2012
- 4 panelen van 100 wp waren in gebruik sinds 1999
- 3 panelen 2009 aan muur en 7 panelen in 2011 in tuin
- 3 delen elk +/- 600wp
- 2011 4 panelen gekocht, 2012 3 panelen gekocht, 2013 7 panelen gekocht
- 2004 en 2008
- 2003: 660 Wp, 2009:600Wp,2010:2240Wp,2011:1120Wp,2012:3840Wp
- 1e set 10 x 180Wp 5-5-2004 liggen pal zuid op het pannendak,de 2e set WWZ 6 x 235Wp 23-82011 liggen ook pal zuid op de aanbouw en 1 op het platte dak van de garage
- 1e in 2009, 2e in 2012. 2009 op schuin dak, 2012 op carport plat dak.
- 18 panelen in 1 dec. 2011 en 8 panelen bijgeplaatst 1 feb. 2012
- 18 panelen 3330 Wp nov. 2011, 12 panelen 2340 Wp mrt 2012.
- 1000 Wp in 2002, 1000 Wp in 2003 en 3000 Wp in 2013

Appendix 3. Motives for buying a PV system

1. Duurzaamheid
 Financiële onafhankelijkheid
2. terug dringen energie rekening
 besparen op de langere termijn
 dak is uitermate geschikt, zon schijnt gratis, waarom geen gebruik maken van de mogelijkheid
 geld op de bank houden kost geld ivm inflatie en lage rente
3. Milieu, duurzaamheid, eigen groene energie opwekken
4. kostenbesparing, milieu
5. duurzaam
 goede investering
 leuk
6. Bewustwording
7. Groene energie
 Verlaging maandelijkse last energie
8. financieel
9. rendement op lange termijn
 - sustainable zijn
10. Klimaat
 Techniek
11. financieel rendement
12. milieu
 - subsidie
 - goed alternatief voor lage rente op spaarrekening
13. Duurzaamheid
 Geld
14. Geld
15. Kostenbesparing
16. Verlagen milieubelasting, geld op spaarrekening beter op het dak
17. Beter voor het milieu, goede investering (betere spaarrente),
18. maand last naar beneden brengen voor de langere termijn
19. Besparen op elektriciteitsrekening; duurzaamheid
20. Stroomrekening verlagen
21. Duurzaamheid, onafhankelijkheid , prijs
22. hoge regionale subsidieregeling (schipholfonds, toen nog €2 per Wp/)
 daardoor korte terugverdientijd
 lagere electriciteitsrekenign
23. Duurzaamheid, Teckniek en kosten besparen
24. milieu
25. Duurzame bijdrage milieu, onafhankelijkheid
26. Geld
27. Milieu-aspecten, zie eens de zonzij.
28. milieu, zelfvoorzienendheid, rendabel
29. Duurzaamheid
 leuk
 besparing kWh en €
30. Duurzaam leven
31. leuk, zelf energie produrene, duurzaamheid
32. milieu
 autonomie
 leuke techniek
33. Bijdrage aan besparing op energierekening
 Bijdrage aan een beter milieu
 Interesse in de techniek
34. Duurzaamheid
 Energie besparen

35. Zelfredzaamheid
36. eigen stroom kunnen maken, zelfvoorzienend zijn
37. hoger rendement dan spaarrekening
38. mijn eigen portemonee, energie terug verbruik terug dringen, economie gangbaar houden
39. energie besparing
mileu
40. Besparing in geld.
41. Energierekening naar beneden brengen
42. Kostenbesparing
Milieuaspect
43. Energiebesparing
44. Verlagen van de vaste kosten va het huishouden. Rendement hoger dan spaarrekening.
45. Milieu, Testen, goedkoper
46. Geld besparen na de investering.
Beter voor het milieu.
Interessante verzameling van data; invloed van hoeveelheid licht en temperatuur op de opbrengst.
47. Onafhankelijkheid/zelfvoorzienendheid, milieubewustheid, geldbesparing
48. Energieverbruik
interessante techniek
Lagere milieubelasting
49. besparing op het maandelijks voorschotbedrag
- meehelpen aan het milieu
50. Verlaging vaste lasten,
51. Besparing, milieu en minder afhankelijk van energie reuze
52. onafhankelijk zijn van prijs (belasting) voor de stroom
53. Kosten electra te beperken en eventueel op 0 zien te krijgen
54. Besparing stroom
55. Energie en kosten besparing.
56. Goede investering van spaargeld, goed voor het milieu
57. Aanvaardbare terugverdientijd
58. Goede leverancier gevonden.
59. Te veel inkomen --> nuon
Was al jaar of 15 van plan
60. Doel 85 % minder CO2-uitstoot te bereiken (zowel binnenshuis als buitenshuis) en betaalbaarheid tov beschikbare financien
61. klimaat, klimaat en klimaat
62. Al langer met de gedachte. Energiebesparing; dus geld verdienen op de langere termijn, milieu.
63. Meedoen met energiebesparing en daarmee het huis wat betreft elektriciteit energie neutraal maken
64. oplopende energieverbruikt
65. bijdrage milieu, bewustwording electra verbruik
66. besparingen
milieu
binnen 3 jaar aanschaf electrsche auto (nu Hybride)
67. Als investering
Milieu
Techniek
68. milieu, groene stroom
69. energiebesparing
70. lAGERE ENERGIE KOSTEN
71. de schoonste manier van energie opwekking, maandelijkse vastekosten naar beneden, geld levert te weinig op bij de bank, subsidie beschikbaar, importbelasting chinese pv
72. statement voor politiek leiderschap
73. Milieu
2. Energieonafhankelijkheid

3. Pesthekel aan energiebedrijven en overheid
74. Kan eenvoudig zelf geinstalleerd worden en precies te meten hoeveel het produceert.
En natuurlijk milieubewustheid
75. Milieu, Geldbesparing na de 13 jaar terugverdientijd
76. duurzaamheid, financiële redenen, minder afhankelijk van energieleverancier
77. duurzaam en de techniek en besparing. En goed investering met alle subsidies zeer rendabel.
78. energie kosten
79. energie-besparing
milieu
kosten
80. Besparing van de stroomkosten
81. besparen
beter milieu
82. besparen. milieu.
83. Prijs, besparing energiekosten
84. 1.Rendement spaargeld.
2.Belasting betalen over spaargeld.
3. In de toekomst vermijden van energiebelasting
4.In de toekomst vermijden van belasting op CO2 uitstoot.
5.Groen gezicht hebben in de buurt!!
85. Duurzaamheid
Financiële besparing op termijn
Lage rente bij banken op spaargelden
86. verminderde afhankelijkheid energiebedrijf
duurzaam, beter voor het milieu
leuk
87. groene zelf opgewekte energie --- spaargeld inzetten voor vergroening en uiteindelijk een langdurige lasten verlichting.
88. Alternatieve energiebronnen zijn veel beter dan fossiele;
Minder afhankelijk van energiebedrijven
89. Milieu
Financiele besparing
90. Energie besparing
91. Kostenbesparing
92. groen bezig
goede investering, levert meer op dan geld op spaarrekening
93. Duurzaamheid, onafhankelijkheid,
94. besparing
95. bijdragen aan vermindering C02 uitstoot. Besparen. Voorbeeldfunctie
96. Goede deal
97. milieu, besparing
98. Lagere energielasten
99. "Onafhankelijkheid" stroomleverancier, het groene doel, roi
100. verduurzaming energie voorziening, energie belasting voor onze aardbol verminderen
101. Zelfvoorzienend
lage maandlasten
milieu-oogpunt
102. milieu
besparen
103. bijdrage aan groene energie
meer rendement dan spaarrekening
104. Omlaag brengen van de vaste lasten
105. kostenbesparing
ervaring opdoen met systeem
106. Minder energie verbruiken en duurzaam stroom zelf opwekken.

107. Bevorderen van mijn eigen duurzaamheid: opwekken wat je opwekken kunt.
108. Milieu, besparing
109. Minder energiekosten.
 - Stijgende energieprijzen en energiebelasting (melkkoe van de overheid).
110. zelf groene stroom opwekken
 rendament investereing
111. Energiekosten verlagen
112. Zelf elektriciteit opwekken
 Subsidie
113. durzame energiebron
 co2-reductie
 onafhankelijkheid van energieleverciers
 spaargeld levert weinig op
 als ik het doe doen anderen het ook
114. milieu, lagere energielasten
115. Hoger rendement dan spaarrekening
116. nu kon ik nog investeren volgend jar niet meer
117. Milieu, geld, leuk.
118. Goedkope aanbieding via importeur zonder tussen handel
119. Rente op spaargeld brengt niets meer op; investering in panelen wèl.
120. kostenbesparing
 energiebesparing
121. Milieu
 Zelfvoorzienend worden qua energie
122. leuk
123. eigen energie produceren.
 Schone stroom maken.
 Stukje ondernemer voelen.
124. Gebruik duurzame energien en geld op de bank levert ook niks op.
125. milieu bewustzijn
 kostenbesparing
 besluit om in dit huis te inversteren en niet te verhuizen
126. Eigen duurzame stroom voorziening
127. Energiebesparing.
128. milieu, besparingen op termijn, nu ook rendement op investering
129. zonnepanelen werden betaalbaar
 dus was er sprake van reeel rendement
 heb zelf een deel van de installatie gebouwd (3 x 24 Volt -80 AH accublok + 3 spanningsregelaars). De koelkast werkt 's-zomers op 400 Watt aan zonnepanelen/accu + 230 V inverter en de olderkamer werkt het hele jaar op 400 Watt aan zonnepanelen/accu en inverter. Wilde zoveel mogelijk van het net onafhankelijk worden. Zie mijn boekje "small scale solar energy systems" op de website van Lulu, auteur Ko Tilman (invuller van deze enquete).
130. milieu
 onafhankelijkheid
 lage vaste lasten voor de ouwe dag
131. minder energie kosten
 beter voor het milleu
132. Ik wilde de energierekening verlagen, verder speelt het opraken van allerlei energiebronnen ook een rol, tenslotte is het ook goed voor het milieu.
133. Rendement investering (spaarrente)
 milieu
 besparing kosten
134. milieu

135. Minder CO2 uitstoot, minder afhankelijk grote energiebedrijven, minder energiekosten
136. CO2 besparing, self supporting, gebaar tegen onze slappe landelijke overheid, geldbeparing/investering toekomst.
137. Gratis stroom
 duurzaam
 nuttige besteding spaargeld
138. Duurzaamheid, toekomstige besparingen, technische interessen
139. Hobby, interesse, besparing, milieu.
140. de bespaaring
141. verbruik voor verwarming is al laag
 verbruik voor electra kon nog worden verbeterd
 vermindering van electra is direct merkbaar
142. kosten op termijn
143. Duurzaamheid
144. hobbyisme
145. ervaring opdoen
 zelf stroom opwekken
 kosten reduceren
146. Na pensionering verlaging vaste lasten
 Goede besteding van eenmalige bate
 Verlaging milieudruk van onze levensstijl
147. Milieu-effect
148. Maandelijkse energie kosten naar beneden brengen (Maandelijke vaste lasten)
149. Kostenneutrale huurkoop.
150. zuinig met elektra
 hobby
151. Zoals ik in een voorgaande vraag al aangegeven heb, ben ik al jaren bezig met wat wij onze jeugd aangaande Energie en milieu NAlaten,
152. Poen en milieu
153. Besparing, milieu
154. Een bijdrage leveren aan beperking verbruik fossiele brandstoffen.
 Energiebesparing.
155. milieu
156. Zorgen voor Milleu,en eigen portemonnee
157. Co2 vermindering, geldbesparing, technische interesse

Appendix 4. Barriers for buying a PV system

1= no barriers

1. Onzekerheid over prijsontwikkeling
   Onzekerheid over regelgeving
2. aanschaf prijs
   crisis
3. Hoeveel jaar het mee kon gaan, kosten
4. ontwikkeling is nog volop gaande: nu instappen of even wachten
5. aansluiting op het net leek even door gaten in de wanden te moeten. Gelukkig was dat uiteindelijk niet het geval.
6. Onduidelijkheid of aanschaf wel goed was tav samenstelling set
7. 1
8. financieel
9. aanschafprijs
   - twijfel dakconstructie
10. Wel/niet toewijzen van een SDE subsidie
11. 1
12. levensduur/kwaliteit
    - kosten
13. Passend krijgen
    Techniek
    Garantie
    Terurverdientijd
14. Geld
15. Geen
16. 1
17. zekerheid over de levensduur van de producten
18. merk panelen
19. Twijfel over terugverdientijd (onzekerheid t.a.v. salderingsregeling)
20. Of ik wel de subsidie ging krijgen, en of ik het zelf kon installeren.
21. Terigverdientijd
22. 1
23. Prijs dalingen
24. geen
25. 1
26. Welke leverancier
27. 1
28. nvt
29. Kleur blauw niet mooi (esthetisch), dit waren de eerste zwarte panelen.
30. Geen
31. veel keuzemogelijkheden, veel aanbieders, toen nog hoge prijs
32. kosten
33. Prijs
34. 1
35. 1
36. prijs
37. onzekerheid over de toekenning van subsidie
38. kosten van installatie, zwabber beleid overheid ivm subsidie
39. kosten
    heffing op zonnenergie
    redement panelen
40. 1
41. Of de subsidieregeling (alle kosten retour van Overheid) wel waar waren.
42. Redelijk grote investering
43. Prijs
44. Terugverdientijd.

45. Prijs, werking
46. 1
47. geldgebrek
48. Kosten
 Montageperikelen
 Rendement op dit moment, betere panelen in de toekomst
 Angst voor diefstal
49. 1
50. 1
51. Geen twijfel
52. tegenstand buren
53. 1
54. 1
55. Geen zekerheid over terugverdientijd. Uiteindelijk valt die langer uit door niet ingecalculeerde kosten voor aanbrengen extra elektra groep en kosten voor Certiq, etc.
56. Kwaliteit van de panelen
57. 1
58. jMooie panelen en een fijne leverancier
59. 1
60. Geen
61. 1
62. welke leverancier en welke panelen. Het is een ondoorzichtig bos waar je geen verstand van hebt.
63. De plaatsing op het platte dak. Mijn dak ik een kalzip dak van aluminium en omdat ik alles zelf wil installeren heb ik goed moeten zoeken naar een leverancier van de installatie die mij een passende installatie kan leveren
64. prijs
65. terugverdientijd
66. levensduur omvormer
67. 1
68. prijs
69. financieel
70. Beleid van de overheid bijvoorbeeld salderen ongunstiger maken
71. 1
72. kosten
 - effect op waarde van het pand
73. Kosten
 2. Behoud saldering/onbetrouwbare overheid
74. kosten
75. De mate waarin de subsidie daadwerkelijk uitgekeert wordt zonder addertjes onder het gras (was een hele studie !),Dit omdat de subsidie jaarlijks gedurende 15 jaar uitgekeert wordt.
76. prijs, duurzaamheid van fabricageproces en transport van zonnepanelen (geen cradle to cradel principe)
77. Kosten, hoge aanschaf. Vermogen van paneel paar jaar geleden erg laag.
78. geen twijfel
79. rendement
 hoe werkt de zonnepanelen
 subsidie regeling
 hoe te installeren
80. 1
81. 1
82. 1
83. geen
84. Schijdingsangst van mijn spaargeld.
 2. Terugverdientijd.
 3.gebrek aan interesse
85. 1
86. nvt
87. Hoge kosten
 zuidzijde van het dak had een

dakkapel (deze is nu verplaatst naar de noord zijde) dus nu perfect voor de PV instalatie
hoe lang blijf ik hier in deze woning wonen.

88. 1
89. nvt
90. 1
91. Milieuvriendelijkheid
92. kosten, rentabiliteit
93. Geen twijfel gehad, de prijsdaling hielp wel destijds
94. 1
95. dak voldoende opbrengst wegens stand t.o.v. zon?
96. 1
97. nvt
98. Niet getwijfeld
99. 1
100. 1
101. Flinke investering
Ligging woning en schaduw
102. duurzaamheid
103. komt er een grote prijsdaling
blijft het salderingssysteem wel bestaan
104. 1
105. terugverdiendtijd
106. Geen enkele twijfel.
107. Complexiteit van offertetraject
108. Of ik het benodigde geld niet anders nodig zou zijn.
109. Belachelijk lage subsidie in vergelijking met andere Europese landen, zoals Duitsland en Belgie.
- De Nederlandse overheid is hypocriet t.o.v. de particuliere alternatieve energieopwekking.
110. zicht huis (dak)
opbrengst in Kwh
111. 1
112. n.v.t.
113. rendement onduidelijk
terugverdientijd
technologie is nog niet volwassen
mogelijke verhuisplannen
lange duur
114. de hoogte van de investeringskosten
115. prijsdalingen
116. opbrengst en levensduur
117. kosten
118. niet, nu veel goedkoper dan 10 jaren terug.
119. keuze; er zijn nogal wat rommelaars in deze branche.
120. onzekerheid ontwikkeling prijs zonnepanelen
onzekerheid ontwikkeling prijs electriciteit
121. Kosten
Wipkip beleid van de overheid
122. geen
123. Hoge kosten.
124. 1
125. 1
126. kosten
127. 1
128. in eerste jaren grote investering die je wel moest voorschieten. Nu bij laatste uitbreiding niet
129. geen twijfel meer gehad nadat de panelen betaalbaar werden en dus reeel rendement konden opleveren
130. kosten.
131. te duur
duurzaamheid
132. 1
133. Rendement investering
134. beleid van onze regering
135. Nvt
136. Levensduur installatie. Zwalkende overheidsbeleid (onbetrouwbaar).
137. Geen

138. geen
139. Geen twijfel, het is een hele leuke investering.
140. de t v t
141. 1
142. aankomend pensioen, vaste lasten vermindering
143. 1
144. 1
145. nooit twijfel gehad
146. Wordt het voorgespiegeld rendement wel gehaald?
147. 1
148. NVT
149. Geen financieel voordeel, aanzicht van de woning.
150. 1
151. 1
152. geen twijfel
153. Nvt
154. geen
155. geen
156. eigen Leeftijd
157. geen enkele twijfel!

Appendix 5. Expected barriers for other households for buying a PV system

1. Ongunstige ligging / geen dak
   Te duur
   Onzekerheid over prijsontwikkeling
   Onzekerheid over regelgeving
   'Lelijk'
   'Het heeft geen zin'
2. is geen goede rede voor
   kosten
3. Kosten, onwetendheid,
4. aanschafkosten, niet in bezit van koopwoning, geen gunstige dakligging
5. onwetendheid
   laksheid
   geen geld voor de aanschaf
6. Onduidelijke info tav of een set goed op elkaar is afgestemd en prijs/investering
7. Kosten van aanschaf
8. financieel
9. aanschafprijs
   - niet willen investeren voor lange termijn, korte termijn denken
   - lelijk aanzicht
10. Onwetendheid
    Geld voor de initiele investering
11. onwetendheid
12. Onduidelijk beleid overheid. Subsidie regelingen veranderen jaarlijks, geen garanties voor de toekomst, ook niet mbt salderen. Hier zou Nederland VEEL van Duitsland kunnen leren.
    - Kosten
    -Onbekendheid
    -Geen goede plaatsings-mogelijkheid
13. Onzekerheid
    Angst
    Geen geld
    Geen idee
14. Geld
15. Initiele kosten
16. Onbekend met werking en opbrengst
17. investering ligt aan de hoge kant
18. onbekendheid en men denkt dat zonnepanelen niet rendabel zijn
19. Onwetendheid; gebrek aan financiële middelen
20. Het is vaak geen all-in prijs (excl. ballast, excl. montage);
    * Ze vergelijken appels met peren in aanbiedingen bv. 8 panelen (maar van welk vermogen)?
    * Stunten met prijzen en met terugverdienjaren over ALLEEN de zonnepanelen (wat dus niet klopt, exc. omvormer, plaatsing etc.)
21. Terugverdientijd, niet weten wat erbij komt kijken
22. Onbekendheid (geen massaproduct, mensen denken dat je dan ook accu's nodig hebt en zo)
    hoge eenmalige aanschaf
23. Kosten
    Aanzicht
    En denken dat het complex is
24. investering

25. Investeringskosten, niet geïnteresseerd in leefmilieu
26. Geld
27. Zogenaamd niet mooi, maar volgens mij gaat het niet om uiterlijk vertoon van zonnepanelen maar om de schoonheid en dat rijkt verder dan het oog kijken kan.
28. gebrek aan spaargeld voor de investering
29. Denken dat het veel duurder is: overschatten kosten, onderschatten besapring €€
30. Onbekend met het rendement
    Grote investering
31. geen makkelijke keuze, denken dat het veel kost, geen geschikt dak
32. te weinig inzicht in hoe makkelijk het is
    sfeer van ingewikkeldheid die gecreerd is door SDE regeling
33. Wijdverbreide misverstanden en broodje-aapverhalen
    Prijs
    Desinteresse
34. Prijs
    Regelen
35. Onzin verhaal van terugwin tijd en investeringskosten. Maak er een auto van en deze gedachte bestaan niet meer.
36. investering, onzekerheid over opbrengst
37. onbekendheid waardoor het lastig lijkt
38. investering, ontmoedigings beleid van overheid, geen geloof in de panelen, fossiele leefwijze
39. aanschaf kosten/terug verdientijd
    plaatsing
    wispelturigoverheid
40. Geen idee, ik kan niet in het hoofd van een ander kijken.
41. Kosten zijn te hoog, gaan ongeveer 4x over de kop dan nodig is. Of de 6%-regeling wel doorberekend is in de kosten, velen denken dat de aannemer die 15% naar zich zelf rekent, vaak zijn de prijzen vergeleken met vorig jaar kunstmatig verhoogd met 15%.
42. Het idefix dat de gemaakte investeringskosten nooit terugverdiend zullen worden
    Jonge techniek. Daardoor geen bewijs mbt levensduur van de panelen.
43. Prijs
44. Geen dak in de goede richting. Geen geld voor over. Panelen geen mooi gezicht op het dak.
45. prijs
46. De onzekerheid over de regelgeving van de overheid.
    Veel mensen zien het voordeel op de langere termijn niet of vinden de besparing niet de moeite waard.
47. geldgebrek, kennisgebrek, ruimtegebrek
48. Kosten
    Gedoe rondom montage (breek-hakwerk, zoals kabels die langs de gevel lopen)
    Esthetische bezwaren (zichtbaarheid panelen op schuin dak)
49. dure aanschafprijs
    - ontwetendheid over het te behalen rendement van de zonnepanelen
50. Geen geld voor, Geen geld voor over hebben, niet mooi vinden

51. Financiele middelen niet beschikbaar en onbekendheid met zonnenenergie en het financiele rendement hiervan
52. buren, niet mooi op het huis
53. De investeringskosten
54. Men kijkt erg naar terugverdientijd
55. Geen ruimte, lelijk aanzicht en te lange terugverdientijd.
56. Imago dat het duur is
57. gedoe
58. gebrek aan geld en lef.
59. Onwetendheid
    Financiën
60. Vermeende complexiteit, geen geld ervoor over hebben (= liever aan iets anders besteden), en onwetendheid
61. klimaat ontkenning
62. geen eigen dak?
63. het wisselende beleid van de overheid. nu is het even zonne-energie promoten, maar als het aanslaat... wat dan?
    wonen in appartement of bovenwoning bijv, waarbij VVE en Energiebedrijven overeenstemming moeten bereiken
    onbekendheid met het fenomeen en teugverdientijd
64. onbekendheid,prijs, installatie
65. geen belangstelling
66. aanschaf kosten
    huurhuis
    geen intresse (kennis van pv)
67. Geen interesse,
    Lelijk
68. prijs
69. financieel met rekent te veel met TVT
70. Kosten
    ongunstige locatie
71. kosten, terug verdientijd
72. te wenig budget
    - technisch niet (goed mogelijk)
73. Kosten
    2. Twijfel aan het nut ervan
    3. Twijfel over veiligheid ("zonnepanele vliegen in de brand", met dank aan de KIWA)
74. aanschafkosten, zwabberbeleid voor ondersteuning door rijk
75. Geen ruimte op het dak, geen geld om te investeren, geen dwang van de overheid (neem PV op in bouwbesluit)
76. prijs, of geen goede plek op dak of geen huiseigenaar
77. Onbekendheid plus kosten.
78. terug verdien tijd,ligging en ruimte om te plaatsen
79. gedoe
    kosten
    twijfels over het rendement
    zijn te oud om dit nog te gaan doen
80. Budget
81. lelijke panelen
82. geld, en onbekendheid
83. Inverstering in moeilijke tijden.
84. 1.De voor financiering.
    2.Geen of geen goed dakvlak op het zuiden.
85. De investering die gedaan moet worden
    Weinig duurzaamheidsbesef
86. geen geld beschikbaar
    zonnepanelen heeft geen status
87. Kosten
    toestemming van evt huurbaas / eigenaar
    geen geschikt dak
88. Angst, aangewakkerd door onzinnge informatie ('s nachts heb

je geen energie, dus geen electriciteit). Zonenpanele ontploffen
89. te duur
geen geschikt dak
90. Kosten van de PV instalatie
91. Onbekendheid
92. investering, aversie tegen "linkse"ideeen, twijfel over saldering, regels overheid niet betrouwbaar
93. Onbekendheid, twijfel over opbrengsten
94. gebrek aan kennis
95. hoogte investering, gedoe, kabels door hele huis.
96. Kosten, estetik
97. mogelijke invoering van heffing op productie eigen elektriciteit
98. Onbekendheid, geen geschikt dak
99. onbekendheid, duur, ongunstige dakorientatie
100. Men heeft geen werkelijke weet van de energie die men verbruikt per seconde en hoeveel moeite het kost om deze energie met eigen spierkracht op te wekken. Men vind dat de PV installatie meer geld moet opleveren dan hij gekost heeft. Men vind het aanschaf edrag te hoog, men gaat er liever van op vakantie. Men vind de panelen op het dak niet mooi. Men vind de energie nog te goedkoop. Men ziet NIET waarom men dit zou moeten doen voor de komende generatie. Men vind de aarde niet belangrijk genoeg om deze stapte zetten.
101. helaas vaak korte termijn denken
geen financiële mogelijkheid of niet bereid te sparen
onwetendheid
102. investering
103. Het is nogal ingewikkeld
men kent het rendement niet
104. Geld en negatieve berichtgeving in de media
105. onbekendheid met kosten en ingewikkeldheid
106. De prijs van aanschaf van de zonnepanelen.
107. Onzekere toekomst van salderen
Niet weten wat kosten zijn en daarover onjuist zijn geinformeerd
Aanschaftraject te complex
Voor aantal mensen nog te duur, vooral jongeren en starters op woningmarkt
108. De investering, zijn hun geld anders nodig.
109. Te weinig subsidie.
Lage rendement van zonnepanelen (theoretisch 1000W/m2, maar in de praktijk maar 150W/m2.
110. investering
111. Kosten, ligging/oriëntatie dak
112. Kosten
Onbekendheid
113. ongeschikt dak
initiele koste te groot
verbouw of verhuisplannen
wordt vast nog veel goedkoper en beter
als het goedkoop zou worden dan heft de overheid wel weer belasting erover
onzinnige technologie
114. de hoogte van investeringskosten
115. duurzaamheid
116. risico voor defect raken apparaten
117. kosten, geen intresse in milieu

118. Wachten op zekerheid omdat vroeger de Inverter niet zo lang mee gingen.
119. geen plaats voor panelen!
120. investering
 onbekendheid
121. Onwetendheid mbt kosten en opbrengsten
 Mind setting
 Onbekendheid over de kosten van energie
122. geen enkel idee
123. Kosten.
 Geen geschikt dak.
 Koudwater vrees.
124. Geld en niks hebben met duurzaamheid.
 Verkeer dak.
125. geen eigen huis
 dak niet in juiste richting
 de hoogte van de investering
126. dak ligt niet goed, te veel werk, te duur
127. Te hoge kosten.
128. geen goede ligging van het dak.
 geen geld om te investeren
129. Niet voldoende ruimte om panelen te plaatsen, geen inzicht in de materie, geen besef dat het renderen kan, onzekerheid over de vraag of teruglevieringsvergoeding blijft, onbekend met elektrische systemen
130. kosten
131. tweifeld over het nut
 te duur
132. Onbekendheid met de voordelen, en bang voor ingewikkelde romslomp.
 Bang voor een te grote investering, twijfel of het ooit kan worden terugverdiend.
133. Rendement investering (terugverdientijd)
134. beleid van onze regering
135. Onbekendheid met mogelijkheden en voordelen, huurhuis, geen geschikt dak (bvb appartement), geen geschikt dak (oriëntatie en of soort dak, schaduw)
136. Duurt te lang voor investering is terug verdiend, geen geschikt dak.
137. Geld
138. bangmakerij door overheid en energieleveranciers (brandgevaar, van dak waaien, nooit terugverdienen etc), huurhuis, denken dat je technisch geschoold moet zijn om de install. te beheren
139. Uitstraling huis, niet willen investeren, verkeerd liggend dak.
140. de prijs en het onbekende
141. directe investeringskosten die nodig zijn
 lange terugverdientijd
 soms is de infrastructuur een hindernis [mbt bijv. dak constructief niet geschikt voor plaatsing panelen, geen goede plaatsing/ruimte van panelen, moeilijke routing van extra kabels, moeit/kosten ombouw van meterkast]
142. aanschaf kosten
143. Te duur
144. enge onbegrijpelijke techologie
 jlelijk, die panelen op het dak
145. onbekendheid
 geen idee van de kosten of denken dat het heel duur is
 geen idee wat het voordeel zal zijn
 ongeschikt dak

146. Grote investering, lange terugverdientijd
147. Gedoe met aanschafkeuze, plaatsing
 Het haalt toch niets uit
 Investeringbedrag
148. Aanschaf kosten
149. Hoge investeringskosten, onzekerheid overheidsbeleid m.b.t. sladeren en 'slimme' meters, panelen niet mooi op dak woning, lange terugverdientijd investering voorschot elektriciteit, veel regelwerk en 'gedoe' (installatie- en breekwerk) in de woning.
150. geld
 onwetendheid
 onwil
151. Het voordeel wat ZonneEnergie oplevert, ondanks de broodjes AAp verhalen die je her en der wel leest van vervente TEgenstanders van lees Energie boeren / bedrijven die vroeger gesticht of opgericht door Gemeente's en die daar nog vandaag de dag nog steed meedelen in de winst of opbrengst, zij zijn dus partijdig in deze!!
152. Terugverdien periode is te lang.
153. Geen geschikte locatie, geen eigenaar, flatwoning
154. Investeringskosten.
 Moeilijke keuzes die gemaakt moeten worden.
155. onbenul
156. Woning of verblijf niet geschikt voor zonnepanelen
157. Heeft geen zin, veel te duur, onkunde, m'n dak ziet niet uit.

Appendix 6. Examples of promotion material

Poster

Research website www.zonnepanelenonderzoek.blogspot.com

Website Organisatie voor Duurzame Energie

https://www.duurzameenergie.org/180-wageningen-ur-zoekt-huishoudens-met-zonnepanelen

Forum: Zonnepanelen

https://www.zonnepanelen.nl/community/forums/topic/763/wageningen-universiteit-zoekt-hu

Website 'Van A tot Zonnepanelen'

http://vanatotzonnepanelen.nl/10/06/2013/onderzoek-zonnepanelen/

Lianne Elisabeth Maria Veen
Domestic Solar Energy Collection:
The sunny Side of Life?