MASTER

BIPV as a pitched roofing solution
a feasibility study for the Dutch market

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BIPV as a pitched roofing solution

A feasibility study for the Dutch market

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Abstract

This thesis focuses on the development and status of building integrated photovoltaics (BIPV) as a roofing solution in the Netherlands. BIPV holds large promises in terms of cost savings on material, operation and installation, and aesthetics. The biggest challenges for BIPV are related to initial costs, regulations and market acceptance.

This thesis consists of four parts. In the first part, the concept of BIPV as a roofing solution is explained and described next to other BIPV applications. Furthermore, the Dutch market for BIPV roofing solutions is investigated through an extensive benchmark study. More than 20 Dutch suppliers of BIPV products participated in the survey. This is the biggest BIPV market survey conducted in The Netherlands so far. Typical installed prices for detached newly built houses were 15.000 euro for a normal tiled roof with BAPV on top,16.000 euro for a roof with in-roof mounted PV, and 25.000 euro for a roof tiled with BIPV tiles. From the benchmark we concluded there is increasing interest for BIPV in the Netherlands. Multiple new products have been introduced or are being developed at the moment. It is however, not clear if there is a favorable market for BIPV as a niche yet.

The second part of this thesis focuses on the barriers and opportunities that are involved in the learning processes of the niche. BIPV as a niche is discussed as a multi-regime interaction of the Dutch electricity regime and the roof regime. We concluded that BIPV has some technical hurdles to overcome. The small variety of products available on the market is one of the barriers. Besides, BIPV has yet to prove itself to meet the required physical building properties. From a market perspective, we see a large price range among different BIPV roofing products. Furthermore, we found a significant price gap between building applied photovoltaics (BAPV) and BIPV roofing solutions, in favor for BAPV. Whether these products are technically and economically feasible depends for a significant part on government policies. Net metering is here the most important policy. Net metering makes it possible for tenants or house owners to use the grid as ‘virtual storage’, *i.e.* generate electricity at one moment and use it at another moment. Changing or abolishing this net metering scenario will have a big impact on the economic feasibility of privately owned PV systems.

In the third part of this thesis, the effects of these policies today and in the future on the economic feasibility are investigated from a household perspective. Through a sensitivity analysis, which is conducted using a techno-economic model, different roofing solutions are analyzed. From the results of the analysis, we concluded that there is partially a business case for BIPV. The most important factor that influences the economic feasibility of BIPV systems is the applied discount rate. A second important factor is the net-metering scenario: If net-metering would be completely abolished there would be no positive business case for BIPV.

The fourth part focuses on a case study of a specific BIPV roofing product which is called aesthetic energy roof (AER). This product is based on a full roof BIPV solution that replaces the complete conventional roof envelope. The AER is competitively priced with respect to the other BIPV roofing solutions. However, there is still a price gap of about 20% compared to average BAPV roofing solutions. From the sensitivity analysis, we found a business case for the AER under two out of the three net metering scenarios.

Finally, based on the extensive desk studies, market benchmarks, techno-economic modelling and statistical analyses conducted throughout this report, the following key conclusion can be drawn: The successful emergence of BIPV depends on the technical and economic feasibility, which depend on multiple elements: an enabling technology, a favorable market but also on the existence of favorable governmental policies. These elements are interrelated and all have to be favorable to some extent at a given moment.

The technical feasibility of BIPV is determined by the quality and variety of the BIPV products. The quality of the BIPV roofing products should match the current conventional building standards. The quality (i.e. in terms of yield, guarantee, and lifetime) of the generating part of a BIPV system must be able to compete with the BAPV systems. Furthermore, there is need for a wide variety in shapes and colors for the PV panels in order to fulfil the promise of an aesthetic innovation. The economic feasibility has to be favorable regarding the turnkey prices of the BIPV solutions. To be successful the price should be competitive with BAPV roofing solutions because the market is mainly price driven. When BIPV can compete with BAPV on product prices than the aesthetics can be a great asset. In order to be able to compete with BAPV, the government policies have to be favorable to some extent. The uncertainty about the net metering policy results in a risk when ones invest in BIPV. Due to the higher investment costs is the payback time under some net metering scenarios unacceptable. Increasing the amount of self-consumption can perhaps overcome this uncertainty in the future. Finally, BIPV suffers from the inequality regarding the reclamation of VAT legislation.

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1. Introduction

1.1. Problem definition

Energy is mentioned as one of the key problems of humanity (Woodward et al., 2014). On the hand, the use of fossil fuels and associated CO_2 emissions leads to global warming (Field, Barros, Mach, & Mastrandrea, 2014). Furthermore, scholars argue that the world is running out of cheap and easily obtainable fossil fuels (Kerschner, Prell, Feng, & Hubacek, 2013). Prices of oil, coal and gas are increasing due to the inability of production sites to keep pace with the increasing demand. To solve the worldwide energy problem, new, renewable, and clean energy sources are needed. Solar energy can play a very important role in the future energy mix, especially because it is available in tremendous amounts. The Earth's atmosphere absorbs more energy in one day than the world uses in a full year (Lewis & Nocera, 2006). Although the potential of solar power is huge, efficiently harvesting the energy is difficult. The French physicist A. E. Becquerel first demonstrated the conversion of solar irradiation into electrical energy in 1839. It took more than 100 years before in 1954 at Bell Laboratories the first practical photovoltaic (PV) cell was built. The technology has been improving ever since. The first photovoltaic cell had a conversion efficiency of around 5%. The most efficient laboratory PV cell nowadays can convert around 47% of the solar energy into electrical energy.

The EU 20-20-20 targets state that by 2020, 14% of the total Dutch energy production must come from renewable energy sources. The national government and Dutch industry invest in the PV market to contribute to the fulfillment of this EU target. In 2009, 28,2 M€ of the total national spending for PV was invested in PV related research and development (Kema Nederland & J-OB & TU/e, 2010). The total installed PV capacity in 2012 in the Netherlands was 365 MWp. In 2013, this increased to 722 MWp, which is almost a 200% increase in one year (CBS, 2014) .

In literature, scholars and scientists argue which factors influence the low adoption rate of PV in the Netherlands. Examples of discussed arguments are governmental regulations, aesthetics, business models, and costs. There are positive developments in the PV sector. Retail grid parity[1] is already achieved in the Netherlands (W van Sark & Muizebelt, 2012). Whether grid parity is met depends on factors such as geographical location, the PV technology, and the regulations. Nonetheless, all earlier mentioned hurdles (e.g. governmental regulations, aesthetics, business models, and the costs of products) from which some negatively influence the adoption of PV in the Netherlands must be tackled.

An advantage of photovoltaic energy over most other renewable energy sources is that it can easily be applied in the built environment. For PV systems installed in or on buildings we make a distinction between Building Applied photovoltaics (BAPV) and Building Integrated photovoltaics (BIPV). BAPV refers to PV systems applied on the already existing building that

[1] 'Grid parity' is generally described as the point in time at which the levelized cost of electricity of a PV system equals ('pars') the grid price of electricity. One can define the type of grid price further by using the terms 'Retail parity' (~20 ct/kWh), 'Commercial parity' (~12 ct/kWh) and 'Utility parity' (~5 ct/kWh).

have no other function in the building envelope. BIPV refers to PV systems that are an integral part of the building envelope. A BIPV system thus functions as a substitute for a conventional building material as well as a device to generate electricity (Jelle & Breivik, 2012). BIPV can be both an economical and technical improvement with respect to BAPV solutions (James, Goodrich, Woodhouse, Margolis, & Ong, 2011; Peng, Huang, & Wu, 2011; Urbanetz, Zomer, & Rüther, 2011).Examples of building parts in which PV can be integrated are roofs, facades, and applications for sun-shading. Examples of functions that BIPV systems show besides electricity generation are heat insulation, shading modulation, weather protection, noise protection, thermal isolation and electromagnetic shielding (Heinstein, Ballif, & Perret-Aebi, 2013).

Although there are multiple applications for BIPV, this study focuses mainly on the roof Building Integrated Photo-Voltaic (BIPV) system. The problem that the thesis addresses is that BIPV holds large promises, yet is not massively applied in The Netherlands.

1.2. Project partners

The choice for the BIPV niche originates from the collaboration between the Solar Energy Application Centre (SEAC), Aerspire and the student. SEAC is the result of the cooperation between ECN, TNO, and Holland Solar. The mission of SEAC is stimulating research and development in the field of solar energy systems and applications. SEAC stimulates economic activities in the Netherlands and neighboring regions (SEAC, 2012). Achieving these goals is done through collaborating with institutes, universities, and companies. One of the collaborations is with the high tech start-up Aerspire, who is developing a new "aesthetic energy roof" (AER) for houses. The AER is a concept of an innovative roof with exquisite looks that also generates electricity. In order to accomplish this, Aerspire develops a product that differs from its potential competitors. Nearly all BIPV systems are restricted to the dimensions of the panels and therefore not covering the complete roof. Although, the AER of Aerspire also works with standard solar panels, they use dummies to accomplish a complete coverage of the roof. Therefore, it is a complete substitute for a conventional roof. Due to the glass-glass PV modules and dummies, the roof has a modern and homogeneous appearance. In short, Aerspire develops an aesthetic roof with the capability to generate electricity. Not a PV solution that one can integrate in the roof.

1.3. Research questions

Introducing a new technology or innovation is complex and uncertain. There is no guarantee for success even though the investments are high. In the beginning, one lacks the expectations, experience, and network. These are necessary for a successful emergence of a new technology or innovation. Strategic Niche Management (SNM) is a theoretical framework which facilitates sustainable innovations through the creation of technological niches (Kemp, Schot, & Hoogma, 1998; Schot & Geels, 2008). Moreover, SNM suggests that sustainable innovation journeys can be facilitated by technological niches in a protected environment. The environment allows experimenting and learning in order to develop a mature technology, which is self-sustainable. BIPV is a niche that has yet to reach maturity. Moreover, BIPV has a market that has yet to be developed. Considering the AER as a BIPV application, developing a market has yet to be done. The barriers and opportunities are learning processes and important factors to a sustainable technology. These are discussed in this thesis with respect to the niche "BIPV" and the concept of the AER. How to identify and address these learning processes is unclear. Moreover, how to successfully introduce BIPV as a roofing product has yet to be investigated. Therefore the main research question states;

Under which circumstances might the successful emergence of the BIPV roofing market take place?

The SNM theory is used to investigate this research question (R. P. J. M. Raven, 2006; Schot & Geels, 2008). In accordance with this theory, the main research question is subdivided into four distinguished sub-research questions:

1. *What is the status of BIPV with respect to residential pitched roofing in the Netherlands, and how can the Dutch BIPV roofing market best be segmented?*
2. *What are the barriers and opportunities involved in the niche-development of BIPV for residential pitched roofing?*
3. *What are the consequences of the barriers and opportunities for the technical and economic feasibility of BIPV?*
4. *What are the barriers, opportunities, and techno-economic feasibility of the "aesthetic energy roof"*

1.4. Thesis outline

This thesis is organized into nine chapters. In chapter 2, the theory that is used as theoretical framework discussed. Chapter 3 describes the research methodology. In chapter 4, the concept of building intergrade PV is explained. Moreover, the introduction and transition of BAPV and BIPV is briefly discussed. Chapter 5 focuses on the price benchmark study of different roofing solutions. In chapter 6, the barriers and opportunities of BIPV are discussed. The results from the benchmark together with the barriers and opportunities are used to develop a techno-economic model in chapter 7. The model is the basis for a sensitivity analysis to determine the techno-economic feasibility of different roofing solutions. In chapter 8, the AER is investigated as a business case. The final chapter presents and discusses the main findings of this thesis. Furthermore, the limitations and future prospects of this thesis are discussed.

2. Theory

In this chapter, we will briefly describe the theory belonging to the technology transition of BIPV as sketched in Figure 1. First, the theories of Multi-level perspective (MLP) and strategic niche management (SNM) are reviewed. Next, BIPV is discussed as a multi-regime interaction. Moreover, BIPV is discussed as a technology that emerged from the interaction of the roof regime and the Dutch electricity regime.

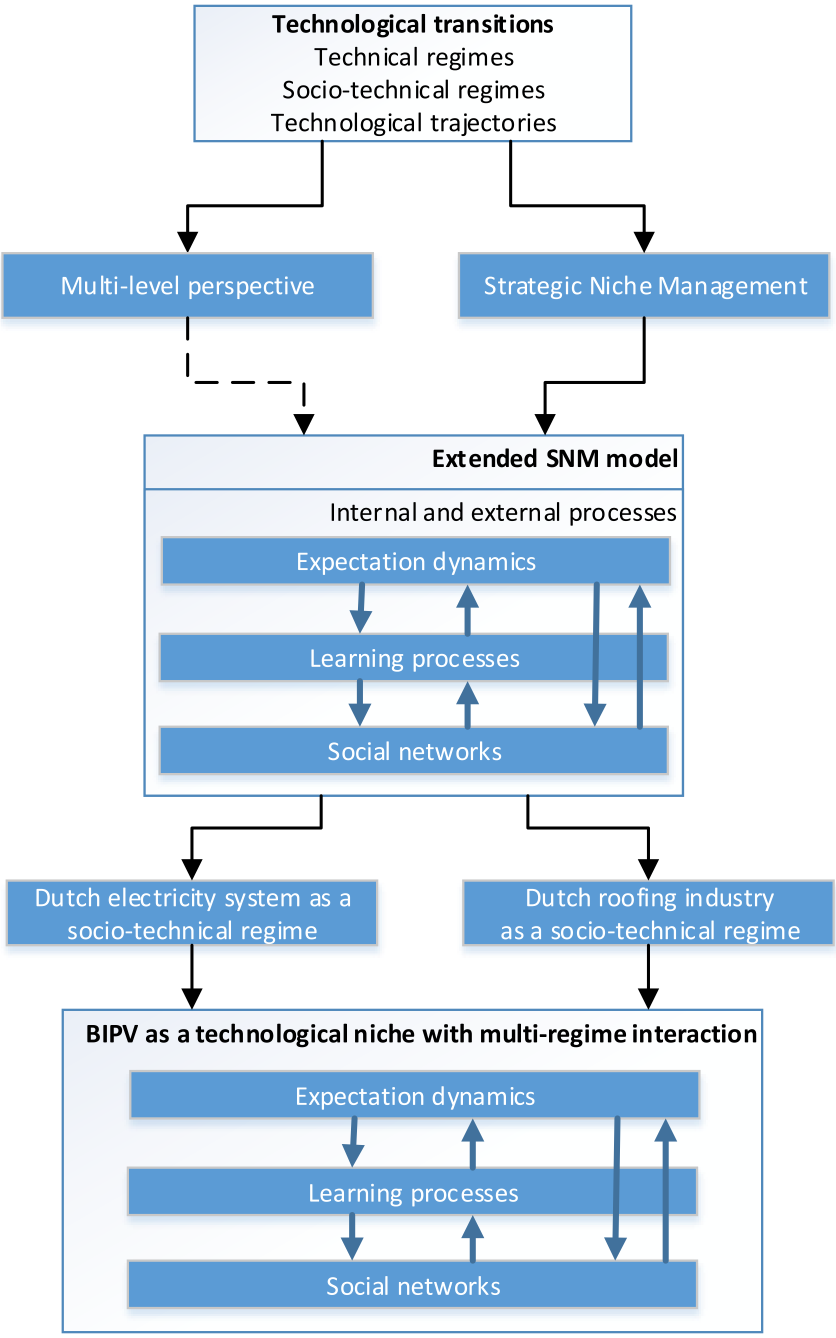


Figure 1: Outline of the theory "BIPV as a technological niche".

2.1. Multi-level perspective (MLP)

Socio-technological regime shifts are complex phenomena. Therefore, there was a need for a theoretical framework to analyze these changes. MLP is this theoretical framework. MLP has three levels, the macro-level which refers to the socio-technical landscape. A meso-level, which refers to the different regimes, and a micro-level that refers to the niches. In the theoretical framework of Geels (2004), the meso-level refers to the socio-technical regime. The stability of socio-technical regimes are important for the participating parties because it provides some security. Moreover, investments are less risky. It creates consensus about the current design of the socio-technical regime (Witkamp, Raven, & Royakkers, 2011). The same as in a paradigm shift, a socio-technical regime can collapse. This can happen when a technology no longer meets the requirements of its users. Another reason can be the emergence of a superior technology that outperforms the existing one. Landscape is the overall concept of society as a whole (macro-economics, cultural patterns, macro-political developments, etc.) and is driven by topics such as oil prices, wars, lifestyle, economic growth, environmental problems and political culture (F. Geels & Schot, 2007; F. W. Geels, 2002; R. Raven, 2005). Landscapes can change, although, this is very slow process. It proceeds slower than the change in socio-technical regimes.

2.2. Strategic Niche Management (SNM) of BIPV

Today a new technology has to have more than merely an economical function. Society demands innovation transitions which are sustainable on a social as well as on an environmental level (Smith, Voß, & Grin, 2010). To facilitate the transition to a more sustainable technology, Strategic Niche Management was developed. Figure 2 explains the dynamics involved in the development of niches. It explains the interactions between the internal processes and experiments that should nurture and mature the niche.

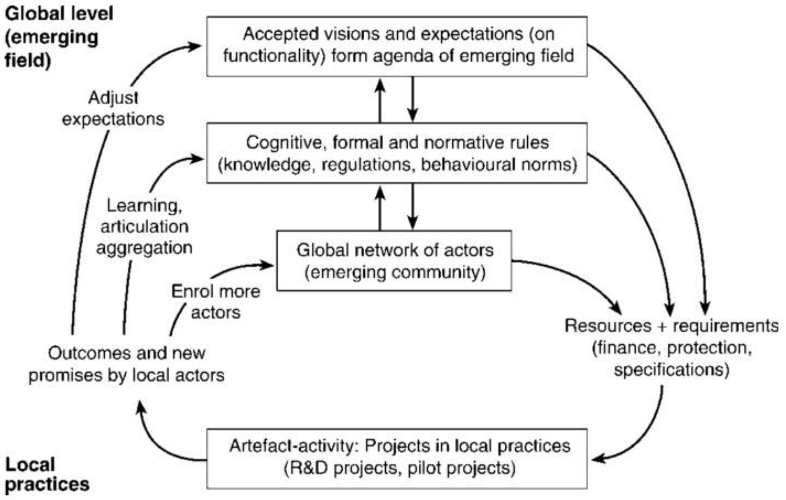


Figure 2: The dynamics of niche development trajectories. Source: Geels & Raven (2006).

The three elements of state of the art Strategic Niche Management by Johnson and Suskewicz (2009) are:

- An enabling technology. This includes the systems that co-evolve around the technology. The technology and its infrastructure together make up the system. What are the technological opportunities and barriers for the niche in the system as a whole? In PV, the technology includes PV panels, mounting systems, battery technology and grid interfacing.
- A favorable market. A perfect product or technology is no guarantee for success. Many BIPV developments in de past failed simply because there was no PV market yet. Analyzing the opportunities and barriers in a specific market will provide insights that help steer the niche development. For example, gathering and analyzing information about prices of competitive technologies.
- A favorable government policy. The government plays an important role in the development of a new technology. The need for governmental intervention is widely discussed. Some scholars argue it distorts the technology to become self-sustainable. Others argue it is a necessary means to protect a technology in the transition to a self-sustainable state. Regulations result in opportunities and barriers that both need to be investigated.

2.3. Multi-regime interactions for BIPV

From the multi-regime interaction of the Dutch electricity regime and the roofing regime, a new technological niche 'BIPV' emerged (See Figure 3). Raven and Verbong (2010) discuss different multi-regime interactions. Four different types of regime-interactions are discussed. First, the competition between regimes. Competition occurs when regimes start fulfilling similar functions. In the example of BIPV, both roof tile products and PV products fulfill the same roofing function. Moreover, it competes on the same roof renovation market. The next regime-interaction is symbiosis. This occurs when both regimes benefit from each other's existence. The third regime- is spill-over, here regimes will copy each other's experiences. The last regime-interaction interaction is integration of regimes and occurs when earlier separated regimes become one, partly or completely. This is the case with BIPV, where two regimes (the roof regime and the Dutch electricity regime) together create a new technological niche.

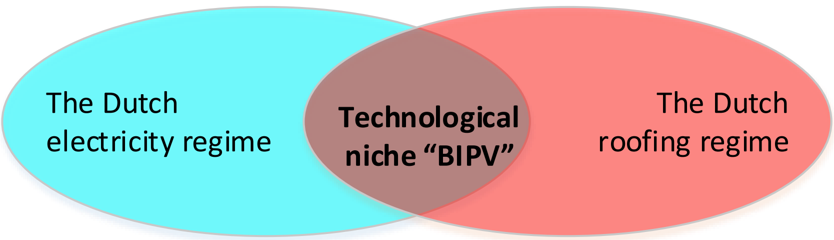


Figure 3: Multi-regime interaction.

The multi-regime interaction of the two mentioned socio-technical regimes is investigated in detail in chapter 6. Moreover, the opportunities and barriers are discussed within these regimes per learning process element.

2.4. Conclusion and discussion

This thesis focuses on BIPV as a niche. A niche that causes the multi-regime interaction of the roof regime and the Dutch electricity regime. We used three elements to describe the learning processes of SNM with respect to BIPV. For the successful emergence of a niche market, there is a need for an enabling technology, a favorable market and a favorable governmental policy. These three elements are considered as interdependent and must to a certain extend coexist simultaneously.

3. Research Methodology

This chapter covers the methods that contribute to fulfillment of the research questions described in chapter 1.3. The research methodology is discussed and analyzed separately for the four sub-research questions and is explained with reference to Figure 4.

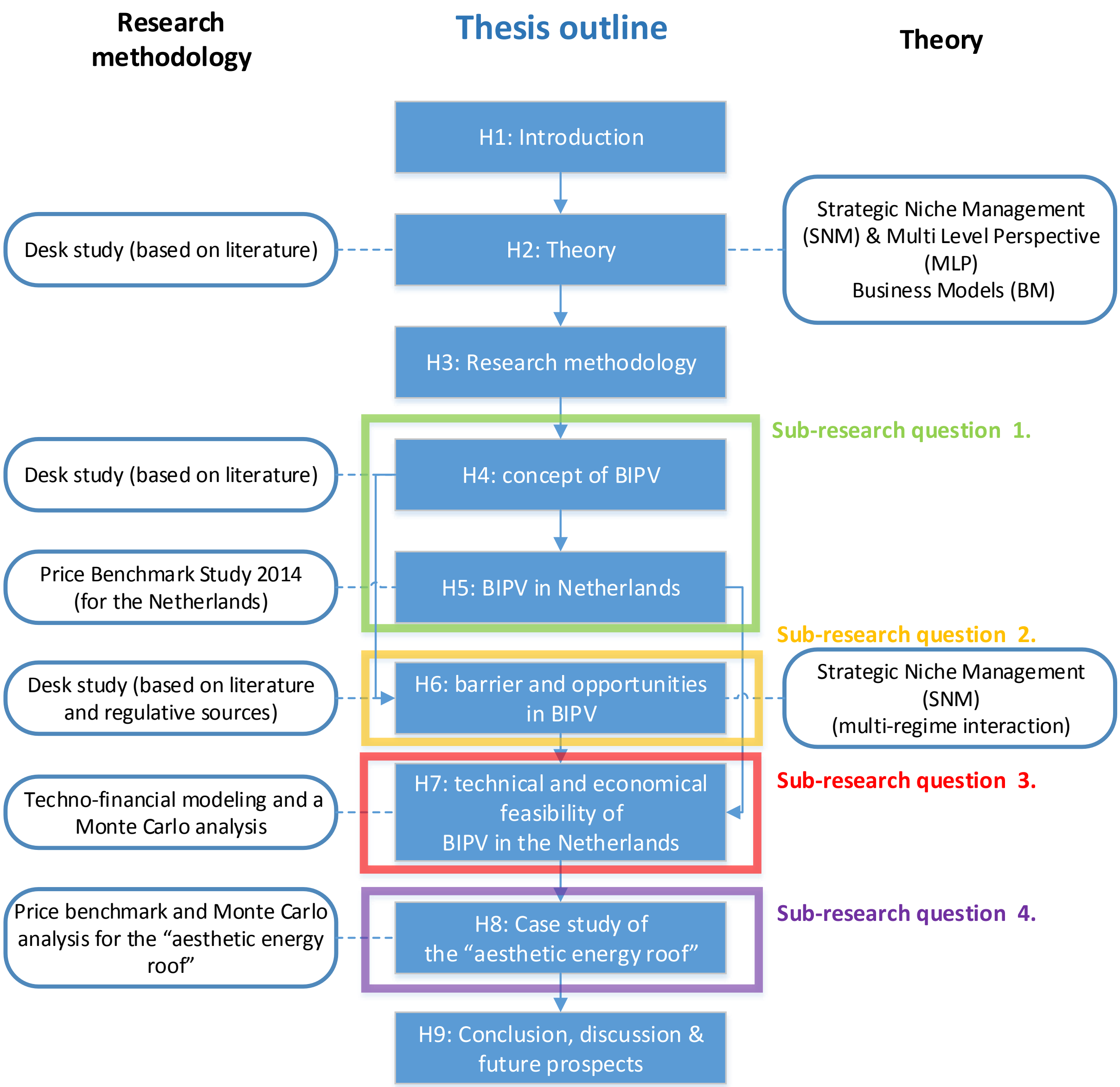


Figure 4: Thesis outline including the chapters, theories, and research methodologies.

- Sub-research question 1) is discussed in chapter 4 and 5. Determining the concept of BIPV is done through an extensive literature study. Using articles, web pages and blogs. Moreover, through the discussion with scholars who are experts in this field. Furthermore, an extensive benchmark study is conducted to create an overview of the Dutch BIPV pitched roofing market. Here both product characteristics as well as financial aspects are investigated.

- Sub-research question 2) is discussed in chapter 6. The SNM theory is used to determine the barriers and opportunities within the BIPV niche. The BIPV niche originates form the multi-regime interaction of the Dutch electricity regime and the roof regime. The different interactions are analyzed through an extensive literature study. The barriers and opportunities are reviewed using SNM as the supporting theoretical framework. Moreover, they are discussed as learning processes. The obtained knowledge is essential to answer the next sub-research question.

- Sub-research question 3) is discussed in chapter 7. A Techno-economic model is used and adjusted to conduct a Monte Carlo analysis. Next, this analysis is used to investigate the economic feasibility of BAPV and BIPV under different net metering scenarios. Moreover, BAPV and BIPV as roofing solutions are investigated in terms of policies and costs of electricity, and components. The investigated scenarios are repeated for the study case, AER in chapter 8.

- Sub-research question 4) is discussed in chapter 8. The turnkey prices of the AER are used to conduct another Monte Carlo Analysis. The analysis is based upon the ones we conducted in chapter 7. The results of the analysis determine if the AER is economically feasible. Finally, innovative business models are developed for the AER. Through, a workshop and the use of a business model generation tool. In the workshop, multiple potential partners of Aerspire were invited. Potential partners such as architect's, a municipality and a construction company.

4. The concept of BIPV roofing

4.1. Introduction

The concept of the BIPV roofing is a merger of the PV and roofing socio-technical regime. Therefore, these regimes are discussed separately in the first two subchapters. Starting with an estimation of the Dutch pitched residential roofing market. After a short introduction into PV, the focus in on the building related PV. Moreover, BAPV and BIPV. Next, the BIPV roofing concept is further investigated. How PV for the residential roofing market evolved is explained next. The roofing solutions BIPV, BAPV and conventional roofing are compared to analyze their (dis)advantages. This chapter finalizes with a conclusion on the status of BIPV as a roofing solution in the Netherlands.

4.2. Conventional roofing

The Dutch conventional pitched roofing market is categorized by different types of dwellings (See Figure 5). In this thesis, we focus on the residential pitched rooftops. In total, this number sums up to about 5.4 million dwellings (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013). Of these dwellings, 95% have a potential functional roof shape. Furthermore, 95% of potential dwellings are roofed with tiles, slates, metal roofing, bound thatch or corrugated sheets ("Interview Hein Huibers, Heijmans," 2013). In total, we estimate that there are about 4.8 million residential pitched rooftops in the Netherlands.

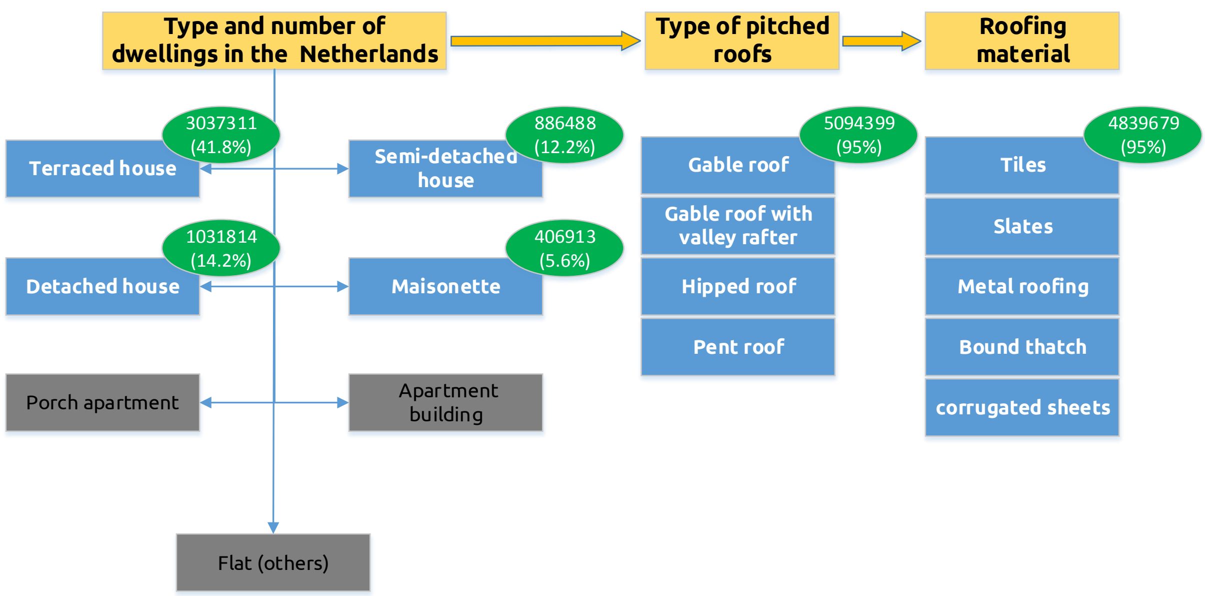


Figure 5: Segmentation of the Dutch residential pitched roofing market

4.3. PV

Photovoltaics (PV) is a technique where the generation of electricity occurs through the conversion of solar irradiation into direct current electricity. Semiconductors that exhibit the photovoltaic effect create the current. Together the semiconducting materials form a solar cell. Multiple solar cells make up a PV module or solar panel. Common materials for producing solar cells are; monocrystalline silicon, polycrystalline, amorphous silicon, cadmium telluride, copper indium gallium selenide/sulfide. Although, the share of PV in the Netherlands is relatively small, the installed electricity generation capacity has doubled over the last year. Electricity production out of renewables already accounted for more than 2% in 2012 (CBS, 2012). The expectation on a landscape level articulates that PV energy production will triple over the next 7 years. In the 14% energy mix for 2020, PV is expected to account for 3% of the total energy production (Sinke, 2013).

We distinguish four types of PV applications (See Figure 6). In the ground mounted PV application, large areas are filled with PV panels. Examples of these kind of power plants are the Agua Caliente Solar Project (USA, 247MW) and the Brandennrug-Briest Solarpark (Germany, 9 MW). Next, building related PV, which refers to PV applied or integrated in any type of building. In the thesis, we will focus on PV for residential buildings. Residential PV can be divided into building applied photovoltaics (BAPV) and building integrated photovoltaics (BIPV). PV can also be applied or integrated in infrastructure. Examples are PV noise barriers, solar roadways, and bridges. The discussed PV application refers to all other possible applications. Examples are satellites, transportation, and portable devices.

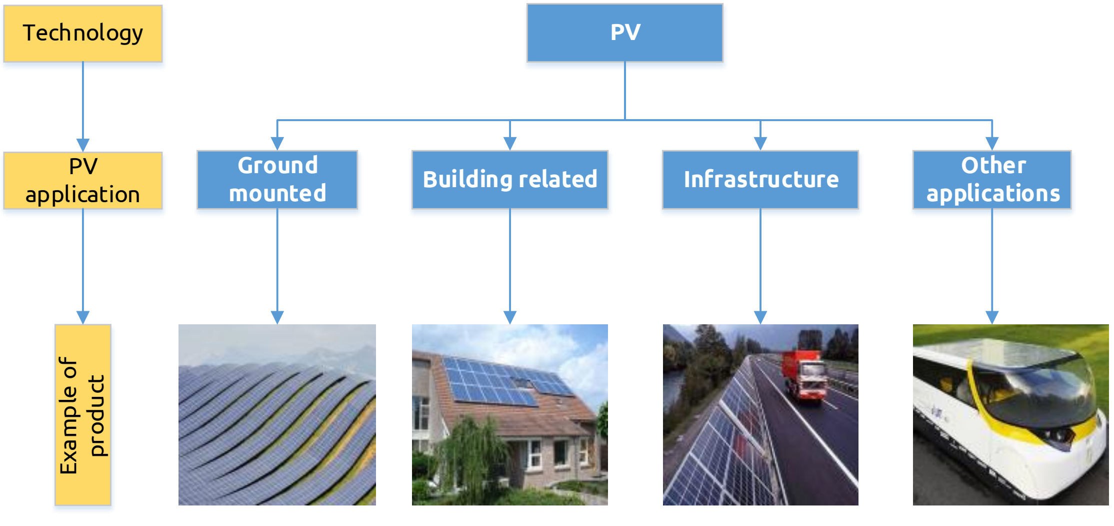


Figure 6: Applications for PV

4.4. Building applied Photovoltaics (BAPV)

BAPV is the technology in which a PV system attached to a building or construction without replacing or removing any of the original building envelope materials (See Figure 7Figure 8Figure 9). BAPV has no additional building functions and therefore its only function is generating electricity. BAPV can be applied to parts of the building such as a facade, a roof, or balcony. Furthermore, BAPV is a type of retrofitting. Retrofit refers to the addition of a new technology or feature to older systems. According to the report “Building Attached Photovoltaics Market - 2012” by ASDReports, BAPV can reach a global revenue of 4.6 billion dollar by 2015 (ASDReports, 2013). Next to building applied PV there is also the possibility to integrate PV in buildings. This is discussed in the next paragraph.

Figure 9: BAPV roof system 3

Figure 8: BAPV roof system 2

Figure 7: BAPV roof system 1

4.5. Building integrated Photovoltaic (BIPV)

Building integrated photovoltaic (BIPV) replaces the conventional building envelope. BIPV acts partly as a substitute for the functional envelope of a building. Examples are pitched roofs, flat roofs, facades and windows (Jelle & Breivik, 2012). Next to the building functionality, it acts as a device to generate electricity. Within the BIPV roofing market, we distinguish six product groups (See Figure 10). Due to the scope of the thesis and the availability of BIPV roofing solutions, four of them are further investigated. The in-roof mounting system, the full roof BIPV solution, large sized solar tiles-shingles, and small sized solar tiles-shingles. The last two are in this thesis merged together and referred to as BIPV tiles. The different BIPV roofing products available in the Netherlands are described in more detail in chapter 5.

According to a recent report from Transparency Market Research, BIPV is expected to reach a 1.15 GW installed global capacity by 2019. This can be realized with a constant year-on-year increase rate of 20% from now until 2019. Moreover, this market research organization expects that of the installed capacity, 67% is installed on rooftops. In geographical terms, Europe is the market leader for BIPV with 41% of the annual installations. The commercial sector accounts for 67% of the BIPV systems. The residential and industrial systems are likely to remain niches, at least for the near future. The PV materials are now dominated by crystalline silicon. Although, analysts expect an increase of around 20% in the thin film segment (Clover, 2014). Note that these forecasts are based upon many uncertain variables and therefore mere calculated predictions.

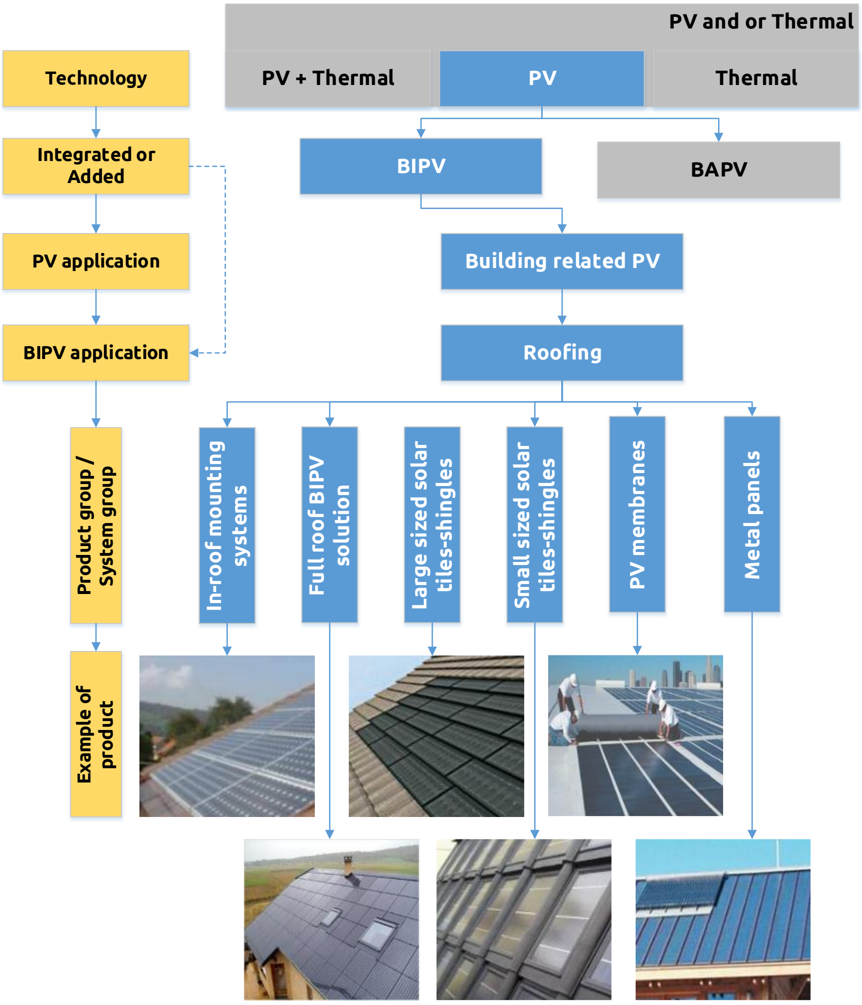


Figure 10: BIPV roofing segmentation

4.6. The development of privately owned PV systems

The first privately owned PV systems were bought from an environmental perspective (See Figure 11). Another reason to invest in a PV system was the curiosity in the PV technology. Due to the policies and maturity of the PV technology, it was not price competitive with the electricity from the grid. Net metering made a price competitive position for privately owned PV possible. Together with rapidly declining prices of PV modules, privately owned PV gained market share. These price competitive systems are BAPV systems and are mostly applied to existing roofs. So, it changed from an early adaptor product, to a product for the mass market with economic benefits. Furthermore, there has been shift going on towards more external driven incentives. External factors such as the earlier mentioned net metering play a major role in the adoption of privately owned PV systems today. For the near future, we see the importance of the “Energy Prestatie Coefficiënt” (EPC) norm. This driver for renewable energy in the building environment stimulates the use of PV applications. In the next paragraph, the three discussed roofing solutions (concentional roofing, BAPV and BIPV) are compared.

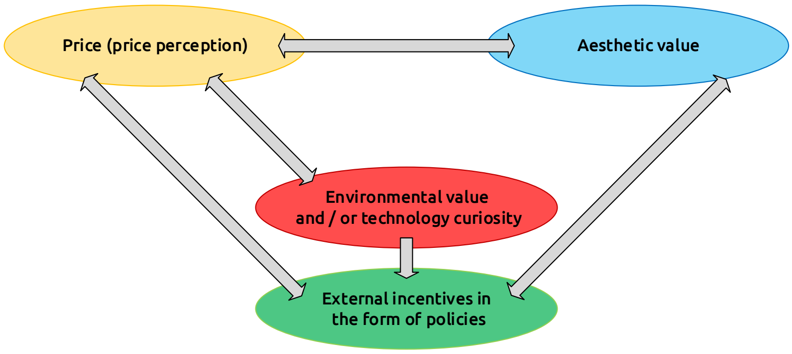


Figure 11: Main drivers for privately owned PV.

4.7. Comparing the different roofing solutions

Three roofing solutions are discussed, conventional roofing, BAPV and BIPV. Here we compare these roofing solutions on different aspects. The advantages and disadvantages of the solutions today are depicted in Table 1. Differences regarding technical, financial, aesthetic, and environmental related factors are discussed. The overview with pros and cons is used in chapter 8.2 to help analyzing the concept of the AER. The input of the table is an indication and is based upon the experience of the writer and SEAC employees.

	BIPV	**BAPV**	**Conv. Roof.**
Technical			
Has a double function. As a building envelope and a means to generate electricity.	+	n.a.	n.a.
Less weight due to integration of roof envelope and solar panel. Also suitable for weaker constructions.	+	-	n.a.
Can be used for transparent building products (e.g. skylights and semi-transparent windows)	+	-	+
Industry standards have been developed and are well-known to experienced installers	-	+	+
Can easily be installed on top of a roof on a building that does not require any structural overhaul	-	+	n.a.
Financial			
Profitable over time because generates net income in the form of electricity savings.	o	+	n.a.
Price of the roofing solution	-	o	+
Can improve the value of a building. Green image of the house and added value because it generates electricity.	+	+	n.a.
Can replace parts of the external building materials and thereby reduce the long-term over-all costs of a building via operational cost savings and reduced embodied energy	+	-	n.a.
Aesthetic			
The roof gives the house a sustainable green appearance.	+	+	-
The roof has a homogeneous appearance	+	-	+
Increase in variation, much more architectural applications possible.	+	-	+

Environmental			
When applied or integrated in new construction or renovation it can reduce the environmental foot-print.	+	+	-
The production process of the roofing material has a negative influence on the environment	-	-	o
The product is recycled (recycling program)	+	+	-

Table 1: Comparison pros and cons of BIPV, BAPV and Conventional roofing. + pro; - con; o neutral; n.a. not applicable.

4.8. Conclusion

This chapter partly answers the sub-research question "*What is the status of BIPV with respect to residential pitched roofing in the Netherlands, and how can the Dutch BIPV roofing market best be segmented?"*

In this chapter we concluded that the Dutch conventional roofing business is dominated by pitched roofs with tiles. Moreover, most common houses with these roofs are the terraced house and the detached house. We investigated the existing BIPV solutions for this roof type and concluded with a segmentation in six product categories: 'in-roof mounting systems', 'full roof BIPV solutions', 'large sized solar tiles', 'small sized solar tiles, 'PV membranes' and 'metal panels'. Finally, we investigated the key market drivers for the BIPV products and identified them to be Price, Aesthetic value, Environmental value and Incentives/Policies.

If we look to the learning processes of BIPV with respect to residential pitched roofing in the Netherlands, we see an enabling technology. Since the last two decades, we see that privately owned PV emerged as a high-tech gadget. There are several BIPV roofing products on the market, which suggests it is technically possible. Although, this not elaborates on the quality, the technology holds. For example, are these roofing solutions watertight? Furthermore, BIPV holds the promise that its multi-functionality results in savings in material, operation, and installation. Another important promise of BIPV over BAPV are the aesthetics. BIPV claims to have a more homogeneous appearance due to its integration. However, these promises have not been fulfilled yet.

So, whether there is a favorable market for BIPV roofing solutions, it is not yet clear. Although, we were able to segment multiple product groups within the BIPV roofing solution (See Figure 10). The technical and economic feasibility of BIPV as roofing solution in the Netherlands is yet unknown. A first step is to investigate the Dutch BIPV market in more detail. For example, which BIPV roofing solutions are available on the Dutch market? What are the consumer prices of those systems? What are the price differences with BAPV roofing solutions? In chapter 5, we conduct an extensive price benchmark study to answer these questions. In chapter 6, we will elaborate on the technical, market and policy barriers and opportunities, which partly determine the technical and economical feasibility of BIPV as roofing solution for the Netherlands.

5. BIPV in the Netherlands

5.1. Introduction

Building-integrated PV (BIPV) is not extensively investigated in The Netherlands so far. Topics such as; what are the different BIPV products; what is their performance, and what are the costs of these products. Due to the broad scope of different BIPV applications (e.g. roofing, façades, skylights, glazing, etc.) this study limits itself to the BIPV applications for pitched roofing in the Dutch residential sector. Moreover, the focus is on the financial part of privately owned PV systems. To put the results of this study into perspective the executed benchmark consisted next to BIPV also out of conventional roofing and BAPV roofing solutions. Here we discuss the benchmark study to create more insight in the Dutch BIPV roofing market. The main purpose of the benchmark was to provide an overview of the BIPV market in the Netherlands and their price position in comparison to alternative roofing solutions. The conclusion is divided into three parts. One part analyzes the roofing solutions separately and the other part compares the roofing solutions with each other. The last part of the conclusion elaborates on status of BIPV in the Netherlands as a residential pitched roofing solution.

5.2. Method of the benchmark study

Outline benchmark study

As mentioned in the introduction the focus is on the residential pitch roofing applications, where we have three main categories. First, the Dutch conventional roofing, which represents the most common roofing solution and consist of different types of tiles. The second category is BAPV (See Figure 18) solutions for pitched roofs, by far the most common PV pitched roof solution. The last category is BIPV and can be sub-divided into two different roofing solutions, namely in-roof mounting systems (See Figure 17) and BIPV tiles (See Figure 19). These BIPV categories or roofing solutions are based upon the research explained in chapter 4.5.We discuss these categories into more detail later in this chapter.

Reference roof

A survey was conducted to gather all the data regarding the three different roofing solutions. In order to make the results of the survey comparable, two reference roofs were defined. The two chosen roofs represent the largest share of dwellings in the Netherlands. For the exact dimensions of both roofs, see Figure 12 and Figure 13. One is an average terraced house (NL: rijtjeshuis) with a total roof area of ± 60 m² (source: AgentschapNL). The second roof is that of an average detached house (NL: vrijstaand huis) with a total roof area ± 125 m² (source: AgentschapNL).

PV system size

A very important boundary condition for our survey was that we investigated the case of 'electricity neutral'-houses, *i.e.* the PV system was sized to match the yearly electricity consumption of a household.

In the terraced house, one roof side was oriented to the South. For this roof side the specific annual yield of the considered PV systems was chosen to be 900 kWh/kWp. The electricity consumption of a terraced house was chosen to be 3300 kWh/year (source: CBS). The resulting required PV system size was 3650 Wp. PV systems with a power density below 120 Wp/m^2 were unable to fully cover the electricity demand using the South sided roof. For these systems, additional PV panels were placed on the north roof with a specific annual yield of 540 kWh/kWp (source: Hofsommer-Energietechnik, Globale jährliche Einstrahlung, Neigungswinkel und Dachausrichtung).

For the detached house, the electricity consumption was chosen to be 4600 kWh/year (source: CBS). One roof side was oriented to the South. The required PV system was 5100 Wp. A minimum power density of 85 Wp/m^2 was needed to place the full 5100 Wp on the roof. All respondents matched with this criterion.

Due to the discrete power steps of typically 250 Wp, not all suppliers were able to perfectly match the required system size. The maximum deviation in system size that we allowed was 150 Wp, this to ensure the validity of the benchmark.

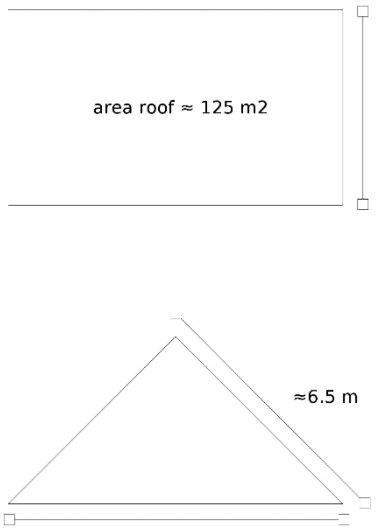


Figure 12: Reference roof – Terraced house

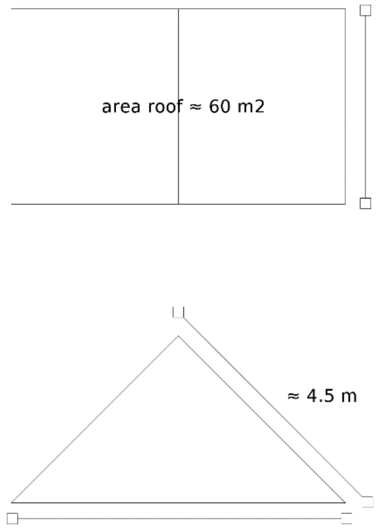


Figure 13: Reference roof – Detached house

Roofing solutions

Gathering the required data for the benchmark is done differently for the three categories (conventional roofing, BAPV and BIPV). The data from NBI - Bouwprijzen Gebouwelementen Renovatie (2013) is used to determine the prices for roofing a conventional roof. Moreover, three roofing materials are included for conventional roofing. Concrete tiles (See Figure 14) which are often used today because of their low costs and easiness to install. Next, ceramic tiles (See Figure 16) which represent the most common roofing material for existing Dutch pitched roofs. The ceramic tiles are more expensive than concrete tiles but less expensive as slates (See Figure 15) which is the third roofing material. Slates are not very common in the Netherlands and mostly known from historical buildings such as churches and town houses. The turnkey prices of these conventional roofing solutions are checked and compared for validity with the prices of roofer contractors and a construction company.

Figure 14: Concrete tile

Figure 16: Ceramic tile

Figure 15: Slates

For the second and third category (BAPV and BIPV roof solutions) a survey was conducted. Quotations were asked for the two described roofs. In order to reduce the bias in the responses it was important to only gather that data from a quote that is related to the PV part of BAPV installation. For BAPV and BIPV roofing solutions, the quote was divided into 3 material components; PV panels, the BAPV fastening system and the inverter together with other electronic components. Furthermore, two labor costs were determined. The installation costs for installing the mechanical part (PV panels and fastening system). Furthermore, the installation cost for the electrical part of the PV system. The BAPV panels, fastening systems and the installation of the mechanical part of the PV system are variable per quote. For the electrical components and installation of these components fixed prices were used. This applied for both BAPV as well as for BIPV. Additional information was needed for BIPV roof tile solutions. Here we can distinguish PV tiles, Non-PV tiles (custom made conventional tiles) and the inverter and other electronic components. Furthermore, two labor costs were determined. The installation costs for installing the mechanical part (PV tiles and non-PV tiles), and the installation costs for the electrical part of the PV system. The defined material components for the BIPV in-roof mounting systems are similar to those of the BAPV. Only the fastening system is a special in-roof frame instead of an on-roof frame. Note that for the BIPV tiles the component “non-PV materials” thus refers in most cases to custom-made tiles. Furthermore, note that no fastening system is used in a BIPV tile roofing solution.

Figure 18: BAPV

Figure 17: BIPV in-roof system

Figure 19: BIPV tiles

Types of integration

The moment of integration plays a big role to determine which roofing solution is suitable. Here three types of integration are determined and discussed: retrofit, renovation and newly built.

- Retrofit refers in this context to the addition of a PV system to existing roofs. The majority of PV installations in The Netherlands are constructed using retro-fitting. The retro-fitting is executed by specialized solar installers, the so-called 'solarteurs'. For BAPV this means adding the BAPV system to the original roof, thereby keeping the original roof intact. For an in-roof mounting system, a part of the original roof will be removed and replaced by PV panels.
- Renovation refers to the process of the complete replacement of the original roof. Renovation is the largest market in the conventional roofing sector. Motives for renovation are usually the end of the economic lifetime of the existing roof. About 2% of the roofs are renovated each year. Included in the renovation is the removal of counter battens, tile battens (Dutch: tengels en panlatten) and tiles. Installing new battens, tiles and a roofing or combination of roofing solutions are included in the renovation process. Material costs and labor costs are taken into account separately. All roofing categories are investigated regarding to renovation.
- Newly built refers to the construction of completely new roofs on new buildings. The newly built market for conventional roofs is about half the size of the conventional roof renovation market. The construction activities that are taken into account are similar to that of renovation. The only difference is that there is no dismantling of the original roof.

Participants of this benchmark study

In an extensive desk study 30 companies that are active in the BIPV installation sector were identified. Of these 30 approached companies, a total of 22 participated in the survey. If we divide these in the different categories and sub-categories the distribution is the following:

- Conventional roofing: 3 participants
- BAPV roofing solution: 8 participants
- BIPV in-roof solution: 6 participants
- BIPV tiles: 5 participants

The high attendance of 73% indicates the interest in a rapidly evolving PV market. Producers and installers see the possible prospects and want to stay up to date regarding the developments in the BI(PV) residential market.

Financial analysis

The trend today is using €/Wp as a KPI to indicate the price position of a PV system. This may be convenient for BAPV systems because the complete system represents only one function namely producing electricity. However, BIPV roofing solutions have (partly) another function, that of functioning as a building envelope. To be able to compare this function with the electric generating function of the roof, the turn-key price is used as the KPI. The turn-key price represents the final consumer price including all the VATS and taxes. In this thesis the turn-key price can be represented as the total costs of a complete roof solution or as the turn-key price / m² / component. The different components are described earlier in this chapter. All turn-key prices are average prices calculated per roofing category. To give more insight in the price range of a particular roofing category box-and-whisker plots are used. These graphs depict the range of all the participating companies in a category.

5.3. Results

This paragraph provides an overview of the results from the benchmark study. The results are separately displayed per integration level. A part retrofit, renovation, and newly built. Due to the large size of the benchmark and limited space, only the most essential results are discussed here.

5.3.1 Retrofit

Figure 21 shows the results for the case of retrofitting. We have chosen to include BAPV and BIPV in-roof mounting systems as viable options for this retrofit. The price for a PV roof retrofit ranged from 6.000 to 12.000 euro. Retrofitting a detached house with a BIPV in-roof mounting system was on average 35-40% more expensive than with a BAPV system.

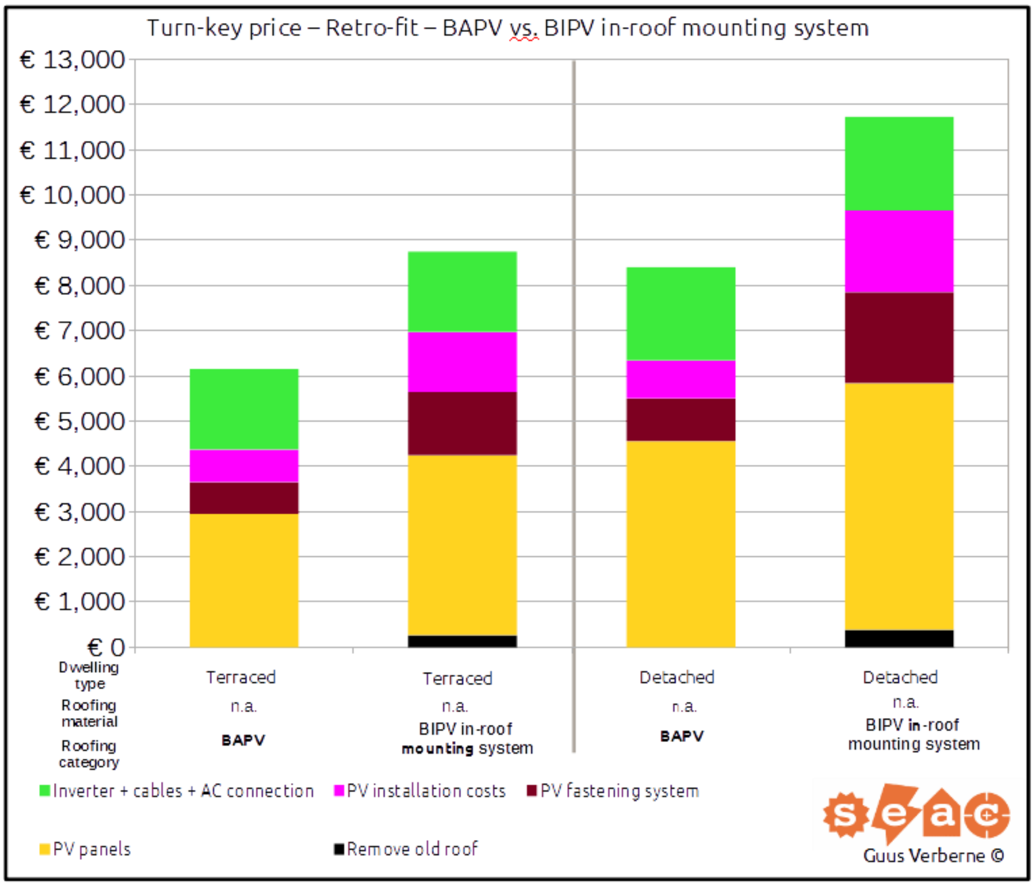


Figure 20: Average turn-key price - retrofit - BAPV vs. BIPV in-roof mounting systems.

Due to the price differences within the two roofing categories, we also included the box-and-whisker plot for a retrofit integration (Figure 37 in appendix I). A box-and-whisker plot is a convenient way of graphically depicting groups of numerical data through their quartiles. The body of one box plot represents 50% of the turnkey prices. The up- per horizontal line represents the highest turnkey price. Furthermore, the area between the body and the upper horizontal line is containing 25% of the turnkey prices. This is similar for the lower part of a box plot. There is no overlap between the two solutions, not for the terraced house nor for the detached house.

5.3.2 Renovation

An overview with the average turn-key prices for roof renovation using four different roofing categories is depicted in Figure 21. From left to right, Fig. 22 shows the turn-key prices for roof renovation in case of conventional roofing materials; in case of concrete tiles with BAPV on top; in case of concrete tiles with BIPV in-roof system in between; and in case of a BIPV tiled roof.

Roof renovation using conventional materials ranged from 3.000 to 13.000 euro depending on the type of house and type of roofing material. When a BAPV system was applied in the course of the roof renovation the price levels were approximately 10.000 for a terraced house and 16.000 for a detached house. The difference between the cheapest and most expensive solution among the 8 respondents in the BAPV category was 9%.

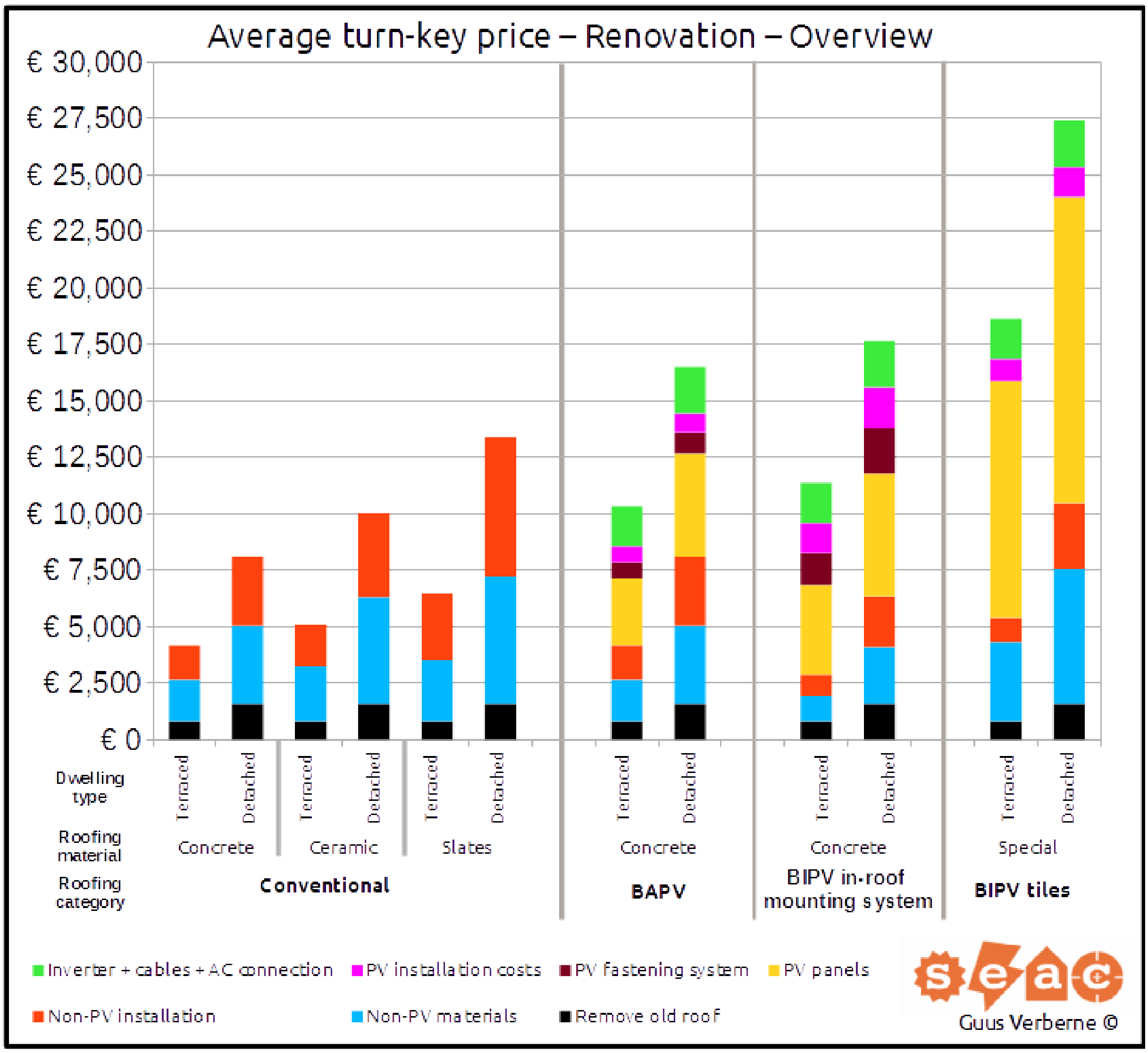


Figure 21: Average turn-key price - four roofing solutions - Terraced vs. Detached.

For the case of roof renovation with an in-roof mounting system, the price ranged from 11.000 for a terraced house to 17.000 for a detached house applied with concrete tiles as roofing material (See Figure 21). See Figure 38 in Appendix I for the average prices of all the in-roof mounting systems, applied with the different roofing materials. The difference between the cheapest and most expensive solution in these categories was between 17 up to 20% depending the roofing material that was used (concrete, ceramic, slates).

Roof renovation using BIPV tiles was significantly more expensive than the other options. Prices ranged from 18.000 for a terraced house to 28.000 for a detached house. We suggest to also look to Figure 39 and Figure 40 in Appendix I. Here a box- and-whisker plot visualizes the broad price range of the BIPV tile turnkey prices. For example,we see a price range from about 21.000€ up to 35.000€ for a detached house. The turnkey price difference between the cheapest and most expensive solution is in this category almost 70%.

An important note regarding BIPV tiles on the terraced house is that some respondents could not fit the full 3650 Wp on the south roof. For 3 suppliers of BIPV tiles for the terraced house we had to place PV panels on the north roof. This negatively affected the price by approx. 10%, as compared to detached houses in which the south roof was large enough to fit the required system size.

5.3.3 Newly built

The newly built integration level results were very similar to the renovation integration level shown and discussed in section 5.3.2. The only difference was the component category “removing old roof” which was not technology dependent and equal for all solutions. Therefore, the results for the newly built category are not further explained here. For an overview of the average turnkey prices of the four roofing solutions in case of newly built see Figure 41 and Figure 42 in appendix I

5.4. Discussion and conclusion

In the competitive market of BAPV the observed price differences were small: The turnkey price difference between the cheapest and most expensive solution in this category was only 9%. A hypothesis for this observation is that there were many installers in a highly competitive and price-driven market. In the BIPV in-roof mounting systems segment we observed a somewhat bigger variation. This variation was mainly caused by a stronger spread in the price of the used PV panels. A hypothesis for this effect is that more European panels were used in in-roof mounting systems, which are more expensive than the Asian manufactured PV panels. Furthermore, the fastening systems were more complex and more expensive than those for BAPV roofing solutions. The strongest spread in prices was observed for BIPV tiles. As example, we observed a price range from about 21.000€ up to 35.000€ for roofing the detached house. The turnkey price difference between the cheapest and most expensive solution in this category was almost 70%. These higher prices and price ranges suggest there is a proto niche market within the residential PV market. Reasons for this relatively big price difference could be the higher development costs due to its higher complexity and pioneering (the standard panels are more mature in their development, BIPV tiles are not yet benefiting from the economies of scale). Furthermore, where the BAPV market is standardized in types of panels and fastening systems, we see a wide range of completely different products in the BIPV tile segment.

When comparing the results for retrofitting a detached house. We can conclude that on average BAPV systems were 35-40% cheaper than BIPV in-roof mounting systems, depending on the roof type (detached or terraced). The identified reasons for the price gap between the two roofing solutions were:

- Removing a part of the old roof.
- The use of more expensive PV panels.
- A more expensive fastening system.
- Higher installation costs for the fastening system.

The high end tail of the price distribution for BAPV systems overlapped with the low end tail of the BIPV distribution. In other words, the most price competitive BIPV in-roof mounting systems were cheaper than the most expensive BAPV systems.

Analyzing the renovation of a roof, we see a more positive development. When one renovates a complete roof, a BIPV in-roof mounting system could be cheaper than a BAPV solution. Here we see a price difference between the detached and terraced renovation. A larger PV system size positively influenced the relative price difference of the turnkey price of the two discussed roofing solutions. On average, a BIPV in-roof mounting system was 7% to 10% more expensive than a BAPV system. The last type of integration that is discussed is the newly built houses. Also here we observed that on average the prices of BAPV and BIPV in-roof mounting systems overlapped each other.

The price differences within the BIPV tile segment were relatively high (See Figure 39 and Figure 40). The average turnkey price for renovating a complete roof of a detached house using BAPV as the PV roofing solution and compare this to the cheapest turn-key price using BIPV tiles as roofing solution results in a 4800€ difference. In summary, one pays 30% more when renovating his roof using BIPV tiles. Of course, the question here will be what is the customer is willing to pay more for a more aesthetic roof solution. Due to the price gap, we expect the BIPV roof solutions to be more suitable for detached houses than for terraced houses. The additional investment for such a system requires a significant larger budget by the house owner. On average, we expect that house owners of detached houses have more money to spend. We therefore suspect that BIP tile solution might be more successful on the detached housing market than on the terraced housing market.

In chapter 4.8 we found the segmentation for different BIPV roofing solutions. In the benchmark study, we succeeded to match all products within these categories, which validates the earlier defined segmentation.

As final conclusion, the BIPV price benchmark study shows that at least 13 products have been developed for the Dutch BIPV market. The success of the companies indicates that the BIPV market holds promises as a roofing solution in the Netherlands. However, due to the relatively high price it is not clear if there is already a favorable market yet. Whether or not there is a favorable market depends mainly on the economic feasibility of BIPV. The economic feasibility depends on multiple elements such as, an enabling technology, a favorable market but also on the existence of favorable governmental policies. Therefore, the elements are investigated as BIPV barriers and opportunities, and discussed in the next chapter.

6. Opportunities and barriers for (BI)PV

6.1. Introduction

This chapter elaborates on the learning processes within the technological niche BIPV. The chapter is based on a literature study and interviews with various active players in the BIPV sector. The insights from these sources were thoroughly discussed and reviewed, leading to a complete picture of the opportunities and barriers that emerge in the learning processes with respect to BIPV for residential pitched roofing. This also includes the topics related to the two earlier mentioned socio-technical regimes. The opportunities and barriers are categorized by the three elements of the state of the art SNM (See chapter 2.1). Identifying the opportunities and barriers contributes to the understanding of this emerging niche. This knowledge is used in de following chapter to develop the technical-economic model. Next to the model, it contributes to the development of new innovative business models for BIPV as a roofing solution.

6.2. An enabling technology.

This includes the systems that evolve around the technology. The technology and its infrastructure together make up the system. What are the technological opportunities and barriers for the niche in the system as a whole. Here we discuss those opportunities and barriers that are related to BIPV for pitched roofing.

BIPV technology

The most important technology that enables BIPV is the low cost manufacturing of customizable modules. The mainstream bulk markets for PV (ground-mounted or large flat roof mounted) rely on 250 Wp PV modules of 0.9 x 1.6 m. By incremental technology improvements, production capacity increases and related economy-of-scale, and by the shift of production sites to low cost countries, these standardized PV modules are now available at low cost of around 0.50 €/Wp by large Chinese manufacturers such as Yingli, Trina and Canadian Solar (PVinsights, 2014). BIPV applications typically require modules of strongly varying appearance, color, and sizes. In addition, BIPV applications typically require co-development of the module demanding frequent communication and site visits, which makes it difficult for European BIPV suppliers to work together with Chinese manufacturers. Only a few PV manufacturers are able to deliver these products, among which are the European companies Scheuten, Soltech, ISSOL, Ertex and NMGT. These suppliers have installed highly flexible production lines and have incorporated advanced logistic systems that allow the production of a multifold of PV products on a project-specific design.

A second important enabling technology is the availability of BIPV mounting systems. Most BIPV product manufacturers use an in-house developed mounting system. The function of the mounting system is to provide mechanical strength for the system as a whole and to provide water tightness for the system as a whole.

A third important enabling technology is the so-called module level power management. Conventional residential rooftop systems will only be installed on the sunny, shadow-free part of the roofs. The reason is that these modules are series-connected to a single grid-tied inverter. Due to the series connection, a shadowed module would strongly limit the output of the entire system. BIPV systems will cover the entire roof and will need technology to deal with the shadow problem. The recently emerging module level power management technology field includes suppliers such as Enphase and Solar Edge. These suppliers deliver devices that allow the independent optimization of separate modules and reduce the impact of shadows. Enphase and Solar Edge show a rapid market share increase in The Netherlands in the past 2-3 years.

6.3. A favorable market.

A perfect product or technology is no guarantee for success. If there is no need for the product or technology, it will fail. Develop a product when there is a market demand or create the market demand. Analyzing the opportunities and barriers in a specific market provides insights that help steer the niche-development. Here we discuss those opportunities and barriers that are related to BIPV for pitched roofing. This includes the topics related to the two earlier mentioned socio-technical regimes. In the following chapters, these opportunities and barriers are taken into account to develop the techno-economic model and business models.

Dutch electricity price structure.

The electricity structure for households can be divided into three parts; the energy costs, the distribution and transport costs, and the VAT and taxes. The market electricity price can be divided in a part fixed costs and a part variable costs. The variable costs are directly related to electricity consumption of a household. With regard to this thesis, we only focus on the variable electricity costs (See Table 2). These costs are involved in the net-metering policy in the Netherlands and vary with the amount of electricity purchased and returned to grid.

Variable costs	Tariff 2014 (€/kWh)	Share of total (%)
Supply costs (appendix III)	0,0682	29,50%
Energy tax (0-10.000 kWh)	0,1185	51,25%
Renewable energy charge	0,0023	0,99%
VAT over these variable costs	0,0422	18,25%
Total	0,2312	100%

Table 2: Tariffs variable components electricity price for 2014 (belastingdienst, 2014; http://www.overstapgids.nl/elektriciteit/prijs/)

The electricity price for a consumer to purchase or return electricity to the grid has a big impact on the economic feasibility of a home owned PV system. Whether the electricity price is an opportunity for PV or a burden depends on its future price development. Including a uncertainty factor for the electricity price change in the techno-economic model provides insight in the importance of the electricity price.

Returns on investment

New technologies often did not fulfil the promises regarding performance and price. An important factor for a consumer to invest in a PV system is the return on investment (ROI). It has to be economically profitable. Grid parity often have been described as the “coming of age moment" for photovoltaics (PV). It refers to the moment when electricity from PV will be cost competitive with that from conventional electricity generation sources (Elliston, MacGill, & Diesendorf, 2010).

Two definitions of grid parity are discussed. The first definition is static grid parity. It refers to the moment when electricity produced by a PV system is cheaper than the electricity which one can buy from the grid. A metric to define whether static grid parity is met is the Levelized Cost of Electricity (LCoE). Where LCoE is defined as the cost per unit electricity delivered (€/kWh), divided over the average lifetime of the generating system. The lifetime of the system has yet to be defined and is not necessarily a fixed constraint. The LCoE includes the capital costs (depreciation, financing costs, etc.), operating and maintenance costs (incl. Insurance, etc) of the system (WIP - Renewable Energies, 2013). The second way to define grid parity is a more dynamic one. The parity project which consists out of multiple parties (e.g. EPIA, TU VIENNA, Imperial College London Consultants and the WIP) argued the usefulness of dynamic grid parity. From the investors point of view it is more relevant to compare the total revenues generated by a PV system with the total costs of ownership. Where revenues can be avoided costs of electricity, self-consumption and the sold electricity to the grid. The Net Present Value (NPV) can then be used to determine whether we can speak of grid parity. In summary, when the NPV of PV produced electricity is equal or lower than the NPV of electricity purchased from the grid, grid parity is met. Therefore, we use the NPV to determine under which conditions grid parity in the Netherlands is met.

The aesthetic value of BIPV

As mentioned in chapter 4.4, there is an ongoing transition in privately owned PV. A decade ago, the motives for acquiring a PV system were environmental or driven on techno-logical curiosity. Today the motive can be also a financial one. This is the case with BAPV, which is financially appealing but also has one psychological disadvantage. A certain fraction of the population experiences BAPV as less attractive in the sense of (Blog, 2012; Hillege, 2014; Telegraaf, 2014). In opposite, BIPV tends to blend in with the existing structure and might convince also this part of the population to install solar energy on their roof. However, one disadvantage of BIPV is the price-competitiveness in comparison to BAPV (Heinstein et al., 2013). In the Netherlands BIPV products are more expensive than BAPV solutions. Although, when renovating a roof, cheap BIPV in-roof solutions are only 10% more expensive than average BAPV roof solutions (See chapter 0). However, overall most BIPV products are not price competitive yet. Therefore, there is a trade-off between the costs (perception of costs), aesthetic value, and environment value of BIPV. How much is a house owner willing to pay for aesthetics. Furthermore, to what extent are people willing to compromise on aesthetics and still be environmental sustainable. At last, what is the added value of environmental sustainability in comparison to the price one has to pay. Analyzing the market BIPV is mostly price and aesthetic driven. The trade-offs between aesthetics, price and to a lesser extent environmental value differ per person. Where price is quantifiable, this is not possible for aesthetics. Although there is some research done towards the 'Home buyers appreciation of installed photovoltaic systems', more market research is needed to better understand the motives investing in a BIPV roofing solution (Wissink, 2013).

6.4. A favorable government policy

The government plays an important role in the development of a new technology. The need for governmental intervention has been widely discussed. Some scholars argue it distorts the technology to become self-sustainable. Others argue it is a necessary means to protect a technology in the transition to a self-sustainable state. At the moment, there are several policies regarding BIPV and PV in general in the Netherlands. Here we discuss the opportunities and barriers that are related to BIPV for pitched roofing. This includes the topics related to the two earlier mentioned socio-technical regimes. In the following chapters, these opportunities and barriers are taken into account for the development of the techno-economic model.

Net metering in the Netherlands today

During the last decades, the Dutch government often changed legislations regarding the production of electricity by households. In this study, the focus is on net metering for residential households. Net metering makes it possible for tenants or house owners to return the electricity back to the grid. It concerns electricity that is generated by their PV system but is not used at that moment. It is possible to settle your electricity bill by generating electricity at one moment and use it another moment. The grid is used here as the storage medium (see Figure 22). There are some constraints regarding net-metering for households (Agentschap NL - Ministerie van Economische Zaken, 2013b). In the current situation, the law implies that privately generated electricity, which is distributed behind the meter, is tax free (EW98, Art. 1, sub i and WBMG, Art. 50, clause 1). When the consumer/producer uses the generated electricity directly for household purposes this is tax-free as well. When the consumer/producer generates more than uses at that moment, it may return the surplus electricity back to the grid. Although, there are some preconditions regarding this returning of electricity. We can divide the preconditions in rules regarding electricity and taxes. First, the preconditions are electricity related.

- The electricity supplier has to subtract the returned electricity (unlimited) from the electricity delivered to the consumer (EW98, Art. 31c).
- The consumer/producer has a small consumer connection (max. 3 x 80 A)

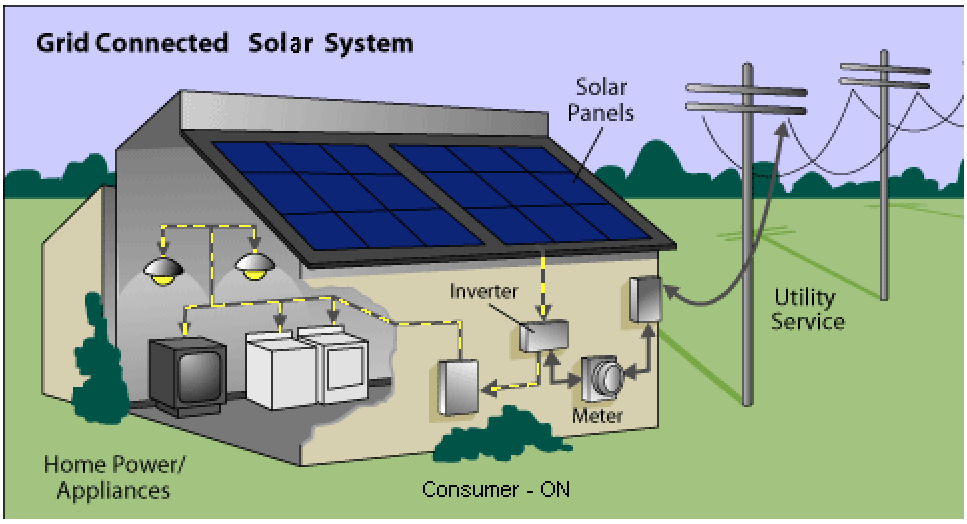


Figure 22: Net-metering for residential housing (Tod, 2012).

However, this only applies when the consumer complies with the following tax related preconditions.

- Return of electricity is less than the purchased electricity. If the consumer returns less electricity to grid per year than it purchases, the consumer does not have to pay taxes or VATs.
- Return of electricity is more than the purchased electricity: Over the part above the purchase level, a fair price of about 0.06€ per kWh is defined.

Self-consumption

Self-consumption under the net metering policy refers to that part of the PV generated electricity that a household directly consumes (See Figure 23). Under the current net metering conditions the amount of self-consumption does not affect the economics. The case is different when the net metering policy is changed or abolished. When the remuneration of electricity is lower than the total variable costs of the electricity for the end-consumer, the amount of self-consumed electricity will have a significant impact on the economics of the PV system. Namely, for self-consumed electricity the consumer will still avoid the total variable costs of 23 cents/kWh. The electricity not self-consumed will be sold on the electricity market for approx. 5 cents/kWh.

As an example, a household produces 4.000 kWh per year. They consume exactly 4.000 kWh. However, 1250 kWh is consumer directly, which represents 1250 kWh x 0,23€ = 287,5€. The part is 4.000 – 1250 = 2750 kWh. Assume that due to a different net metering policy, the remuneration for one kWh is 0,15€. 2750 kWh x 0,15€ = 412,5€. In total this adds up to a saving of 700€ per year for the PV system. In the case the household would self-consume 2.000 kWh, the total savings would add up to 760€ per year. Under different net metering scenarios, the self-consumption plays an important role in the total energy saving. The impact of self-consumption is estimated in the techno-economic model in the next chapter.

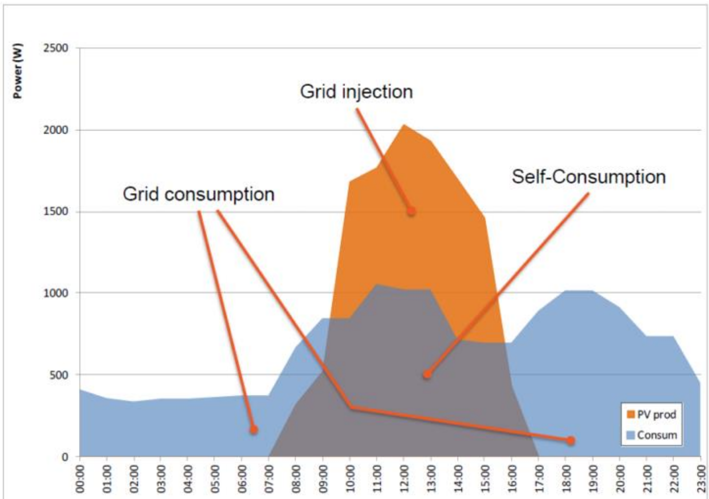


Figure 23: PV production peak-shaving strategy at household level (European Photovoltaic Industry Association, 2013).

Net metering in the Netherlands in the future

Henk Kamp, Minister of Economic Affairs announced that in 2017, the net-metering policy will be reevaluated. After this period, there probably will be a transition period. An proposed transition would be the merger of net-metering and the reduction in energy tax (Duijnmayer, 2013). This implies that all energy that is produced by the private producer and is not used at that same moment can be returned to grid. For a tax reduction of around 9.0€/cent plus a fair price for electricity without taxes. In total, this would add up to about 16€/cent for every kWh returned to the grid. However, another ongoing transition could also influence the electricity regime in the Netherlands. Real-time pricing (RTP) or smart pricing (SP) is the instant dissemination of prices through linking all market participants via the Internet. Examples where RTP is used nowadays are stock exchanges, flight tickets, and public transport. Many studies have demonstrated that RTP would be beneficial for welfare (Allcott, 2011). Although, this pricing structure is promising it has not been implemented yet. A reason is the incomplete infrastructure. In order to use RTP in the electricity regime, real-time electricity monitoring must be available on a local scale. Now, utility companies, the government and third parties are involved in the development of such an infrastructure. It is called the smart grid and makes RTP possible. However, this is still in an early phase and not operational yet. When the smart grid is operational, RTP is a potential pricing strategy in the Netherlands. Electricity is then more expensive during peak hours and cheaper when the demand is low. In addition, RTP would contribute to a more stable grid because the electricity demand would be better divided.

Future net-metering policies will have a big impact on the economic feasibility of (BI)PV in the Netherlands. For example, what is the NPV of a privately owned PV rooftop system after a period of 25 years when net metering is abolished. A techno-economic model is used in the next chapter to investigate the economic feasibly of certain PV systems under different net metering scenarios.

Levying of VAT for PV systems

20th June 2013 (case C-219/12), the European Court of Justice has ruled that owners of solar panels from that moment on have to pay VAT over their own generated electricity. Generating electricity is an economic activity and therefore paying VAT is obligated. However, in the Netherlands this legal statement does not affect the small electricity producers (households) because there are no incentives for electricity suppliers to charge private electricity producers. The bureaucracy consumes too much time and money of the electricity suppliers. However, one precondition is that the private electricity producer produces not much more electricity than it purchases from the supplier.

There is a tax benefit regarding the verdict (case C-219/12). Due to this verdict, it is possible to reclaim the VAT over your bought PV system. Because a private person becomes a small producer of electricity, it has the right to make use of the “small business legislation” (SBL). The SBL states that when a private person pays less than 1345€ VAT there is no need to pay any amount of VAT. An example, a PV system produces around 4600 kWh a year. 30% is consumed directly and is therefore not net-metered, 30% x 4600kWh = 1380 kWh a year. This means that 4600 – 1380 = 3220 kWh is sold to the electricity supplier trough net-metering. Assuming the price of electricity 7 €/cent per kWh, ((3220 x 7) /100) x 0.21 = € 47.33 which is the amount of VAT over one year. This is much lower than than the maximum of 1345€. Preconditions for the SBL are:

- You are an individual or a combination of individuals, such as a sole proprietorship, a partnership, or a general partnership.
- Your (company/household) is located in Netherlands.
- You meet your administrative obligations for the VAT.

When one meet these preconditions, it may be possible to reclaim your VAT over the purchased PV panels. However, there are a few other preconditions before one can reclaim the VAT namely:

- You are a private consumer.
- You are the one who bought the PV system and had them installed.
- The PV system is installed on top or near your dwelling, (it concerns your own territory).
- The PV system was installed or in operation after 20 June 2013.
- You return a share of the produced electricity back to grid.

If you meet all these preconditions, the only obligation left is declaring the VAT to the tax authorities every year. However, if you can make it plausible that your VAT is less than

1345€ per year. If it is assumable it remains like this for the near future, it is possible to file a request for exemption regarding the yearly declaration of VAT.

Over which part of the PV system you can reclaim the VAT differs for a BAPV and BIPV system. When it concerns a BAPV system one can reclaim the VAT over the total PV system, both material and installation costs. However, one must pay a so called ‘tax forfeit’, which is predefined and depends on the PV system size. For a BIPV system, one can only reclaim 50% of the VAT over that part of the roof that produces electricity. This is because the roof has two functions, it acts as a roof but simultaneously as electricity generator (Rijksoverheid, 2013). Over the 50%, one can only reclaim 67%, assuming 33% of the electricity is directly used by the consumer and therefore not returned to the grid. Why this is only applies for BIPV and not for BAPV is not clear.

The EPC norm

The Energieprestatiecoëfficiënt (EPC) norm or the European Energy Performance Building Directive (EPBD) is a dimensionless number indicating the energy performance or efficiency of new constructed buildings. Moreover, it is a calculation method with the aim to reduce energy consumption in building caused by heating, cooling, hot water production, lighting and ventilation. The lower the number the more efficient a building operates. An EPC of 0.0 defines a building that is energy neutral. The building does not consume more energy than it generates. The EPC of utility buildings must be close to zero by 31 December 2018. For residential dwellings this is 31 December 2020 (Agentschap NL - Ministerie van Economische Zaken, 2013a).

In order to achieve the EPC norm of 0.6 valid per January 2013, the roof has to comply with a few construction values (NEN 7120). A PV system is an option to meet the EPC norm. For all new houses, build after January 1, 2015 the EPC norm is set at 0.4. To achieve these even stricter energy efficiency values PV is good option. An average roof that is for about ⅔ filled with PV panels can provide in the annual electricity production and is therefore perfectly suitable to meet the EPC norm today and in the future.

In this study, we acknowledge the importance of EPC as an incentive for BIPV as a niche market. For newly built houses, PV will be an important means to comply with the EPC norm, especially when this norm is getting stricter. This leads to new opportunities for BIPV as roofing product. First of all the PV market in general will increase because the EPC regulation acts as an additional market driver, next to the use of PV to save on energy and the use of PV to achieve a good return on investment. Furthermore, there is less freedom for the house owner, if one wants a PV system or not. So, BIPV could benefit from those house owners who have to install a PV system but do not appreciate the aesthetics of the currently installed BAPV systems.

Requirements for RE in roof constructions

In the Netherlands there are many regulations regarding the construction of roofs. In scope of the literature review, the NEN 7250 norm is most important (Agentschap NL - Ministerie van Economische Zaken, 2011; Nl, Energie, & Boom, 2010). The NEN 7250 norm describes the performance requirements and refers to test methods for the constructional aspects. Included are PV(T) systems, both as an integrated part of the roof or facade as well as separated roof or facade elements. The requirements, which are determined in this norm, are; constructional related, concerning to fire safety, noise levels, moisture resistance, and thermal insulation.

Building permitting process

In addition to the regulations of the NEN 7250 norm mentioned in the previous chapter. There are also regulations regarding the aesthetics of PV systems. The Ministry of Internal Affairs made some permit regulations with respect to aesthetics. It deals with the liberty of a private house owner to build a solar system on his or her property. Therefore, the following preconditions have to be met (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2012).

- The solar collector or PV panel has to be mounted on top of a roof.
- The solar collector or PV panel has to be a part of the installation for respectively collecting water or generating electricity. When this is not the case, the installation has to be placed inside the building.
- When the solar collector or PV panel is mounted on a pitched roof then;
  - ➢ The solar collector or PV panel has to be mounted within the roof area and may not overlap the edges of the roof
  - ➢ The solar collector or PV panels is mounted in or directly on top of the roof deck.
  - ➢ The angle of the solar collector or PV panel has to be equal to the roof angle
- When the solar collector or PV panel is mounted on a flat roof than it has to be positioned ***x*** meters from the roof edge, where ***x*** is equal to the height of the panel or solar collector.

Changes to the solar installation are allowed, same as for multiple solar collectors or PV panels. As long one complies with the preconditions mentioned above (See Figure 24). The planning and zoning legislations such as the reasonable requirements of prosperity from the municipal welfare commission do not apply in that case. However, the Building act and neighbor legislation from the civil code do apply.

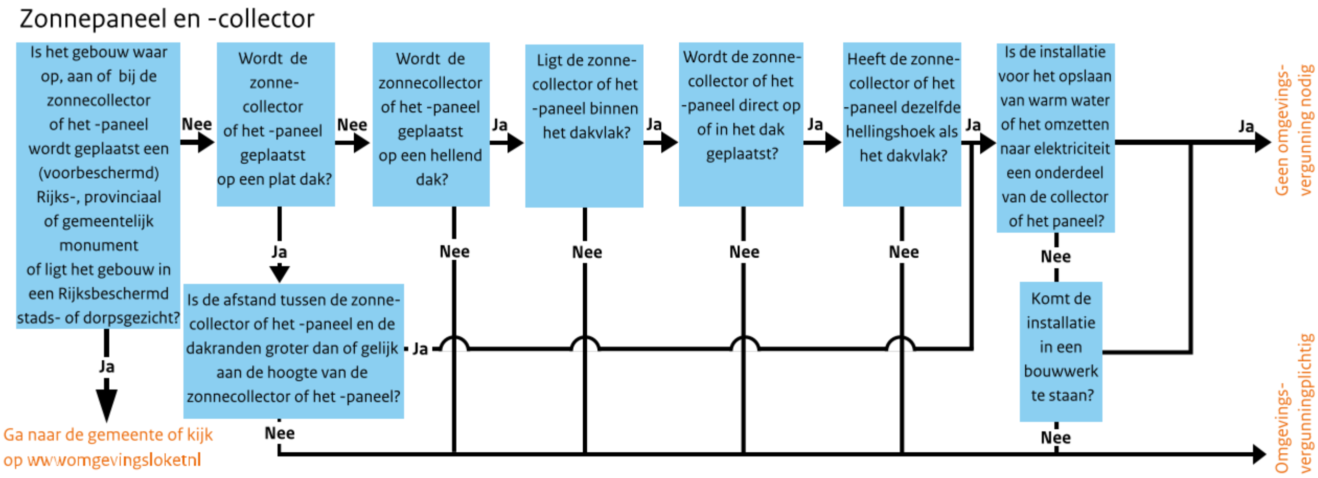


Figure 24: Scheme to check necessity of an environmental permit (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties., 2012)

When one does not meet all the preconditions mentioned above one has to deal with the zoning plan of the relevant municipality. In principal, this means you have to file a request for an environmental permit. In the zoning plan the municipal established rules for spatial planning. Moreover, the use of land is defined in the plan. These rules are binding for civilians. An exception is a permit free construction plan. A second legislation is the building regulations regarding the external appearance of buildings. As mentioned before permit free constructions do not have to meet this legislation. However, there is an exception for excessive cases. If you need an environmental permit to build, the municipal submits your construction plan to the urban aesthetics commission or city architect. The city architect than advises based on the local regulations whether the structure fits within the area. To make the assessment as clear as possible, the municipal has to make sure that the memorandum explains the regulations regarding external appearance of buildings explicitly. Every municipal must have determined a memorandum. If not, no requirements regarding external appearance of buildings may be imposed.

6.5. Conclusions

This chapter is concluded per learning process element. For an enabling technology, we see a few barriers for BIPV. The mainstream bulk market for standardized PV modules results in a price competitive market. Competing on a price level is for BIPV difficult. Especially because BIPV requires a wide variation of products and not merely one size and color. Benefitting from the economies of scale is therefore more complex. Another barrier are the required physical building properties such as water tightness. To achieve these requirements, there is need for resources in terms of money, knowledge and time. A last technology related barrier is the ‘module level power management’. BIPV solutions have to perform under shadow conditions.

From the results of the desk study, two market drivers for BIPV were identified. The economic profitability of a (BI)PV system. We defined that a (BI)PV system is beneficial when the electricity cost produced by a (BI)PV system is equal or lower than cost of electricity purchased form the grid. Second, the aesthetics of a BIPV solution were discussed. The aesthetics are part of the trade-off between aesthetics, price and to a lesser extent environmental value. Where price is quantifiable, this is not possible for aesthetics. A study is needed to determine what the added value of BIPV roofing solutions is for house owners. In chapter 5 we concluded that it is not clear if there is a favorable market for BIPV. Moreover, whether there is favorable market from an economic perspective will investigated in chapter 7. Here we discuss the opportunities and barriers that will have an influence on the outcome, if there is favorable market for BIPV for residential pitched roofing in the Netherlands. From an economic perspective, the NPV of a BIPV roofing solution determines its feasibility.

The element regarding favorable government policies play a major role in the feasibility of PV in general. In the Netherlands, net metering is the most important policy for privately owned PV (Huijben & Verbong, 2013). This policy has a large share in the success of PV. Changing or abolishing this net metering scenario will have a big impact on the economic feasibility of privately owned PV systems. Opportunities lie in those measurements that make PV less policy dependent. Self-consumption is such an opportunity. Increasing the self-consumption increases the policy independence of PV. However, policies can also stimulate the PV market. The EPC norm is expected to be an important driver for PV in the coming years. What the influence is of the opportunities and barriers on the economic feasibility of privately owned PV in the Netherlands is investigated in the next chapter.

7. Technical and economic feasibility of BIPV in the Netherlands.

7.1. Introduction

To utilize new technologies in commercial applications its economic feasibility needs to be determined. In this case, this means that the economic feasibility of BIPV as a roofing application for households needs to be determined. There are multiple techno-economic studies executed on the economic feasibility of residential PV in general (Bazilian et al., 2013; Roy, Basu, & Paul, 2014). However, on the topic of BIPV these are scarce. Moreover, no studies were found where the economic feasibility of different roofing solutions were compared. In order to put the results into perspective, BAPV as a roofing solution is included. We only compare the roofing solutions for the large PV system size (See chapter 5.2). Moreover, due to the price gap between BAPV and BIPV, we think that BIPV at this moment is most suitable for the detached housing market. A techno-economic model is used here as a means to investigate the economic feasibility of BAPV, BIPV in-roof and BIPV tiles as a roofing solution.

A techno-economic model is a construct representing the conjunction between technical and economic processes. This is achieved by a set of variables and a set of logical relationships between these variables. The techno-economic model is used to analyze the economic feasibility of the in chapter 5 discussed roofing solutions. A sensitivity analysis is integrated in the techno-economic model to assess the feasibility of a roofing solution under variable parameters and thus conditions. Assessing the economic feasibility of BAPV and BIPV from a household perspective through a Monte Carlo analysis is new. No literature was found on this topic. The results of the analysis provide new insights in the barriers and opportunities that have an impact on the feasibility of BIPV as a roofing solution.

7.2. Techno-economic model

The techno-economic model consists of three main parts. One part input that includes both technical and financial input. One part, calculations that produce both technical and financial outcomes. The last part is the output, which are derived from the calculations and are forecast parameters. Figure 25 provides an overview of all the parameters that are discussed in the model. The basis of the model is built by Ecofys, which is a consultancy company specialized in sustainable energy technologies. To fit the net metering scenarios, we slightly adjusted the model. The net metering scenarios are described later on in this chapter. Furthermore, we added some input and output parameters to make the model more suitable for BIPV calculations.

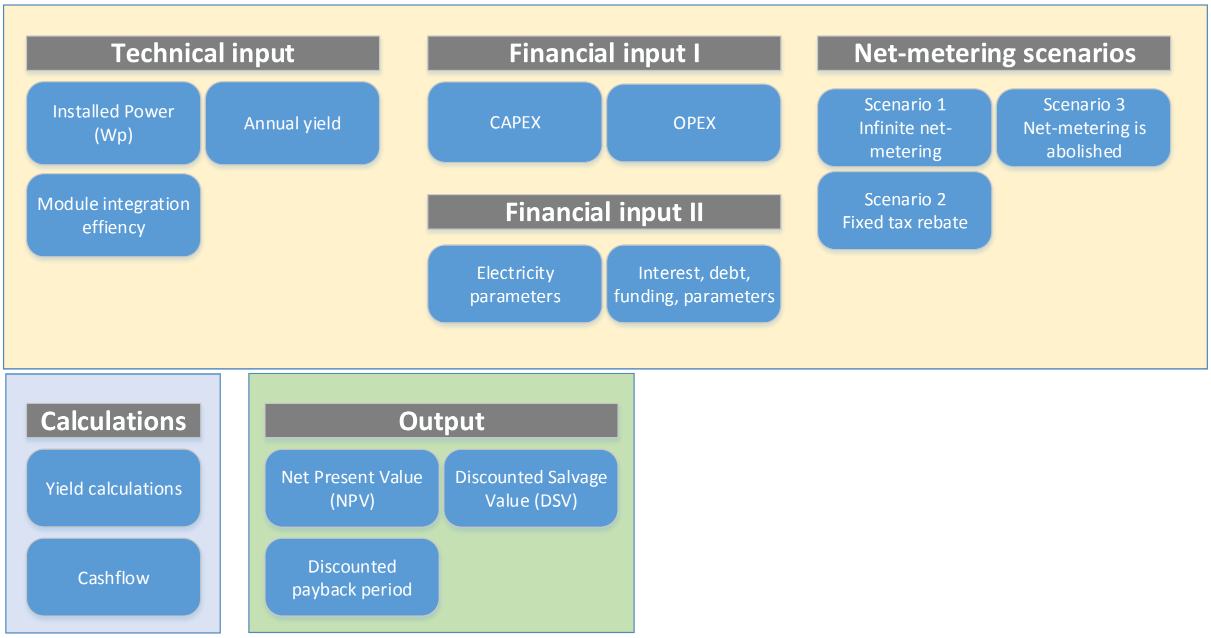
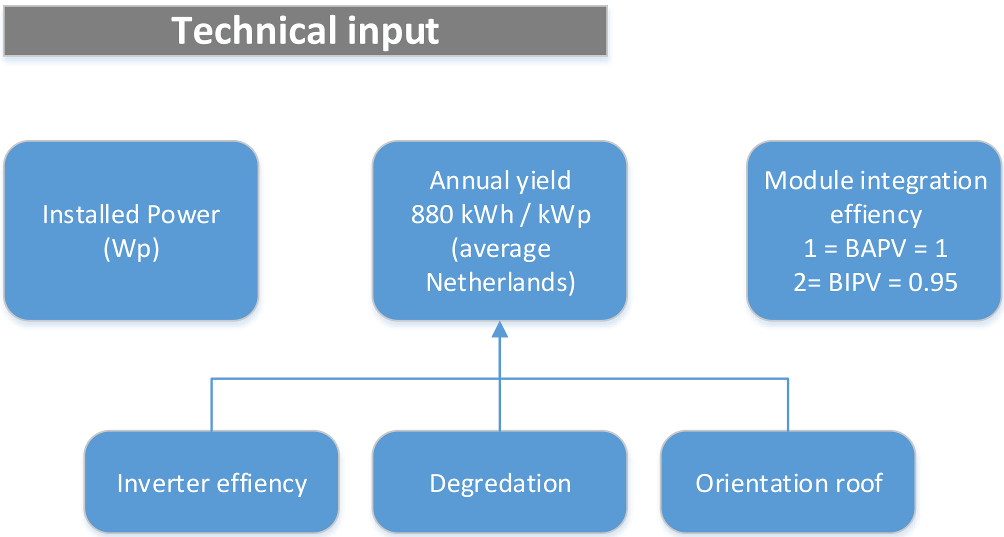


Figure 25: Techno-economic model for privately owned PV systems.

7.2.1. Technical input



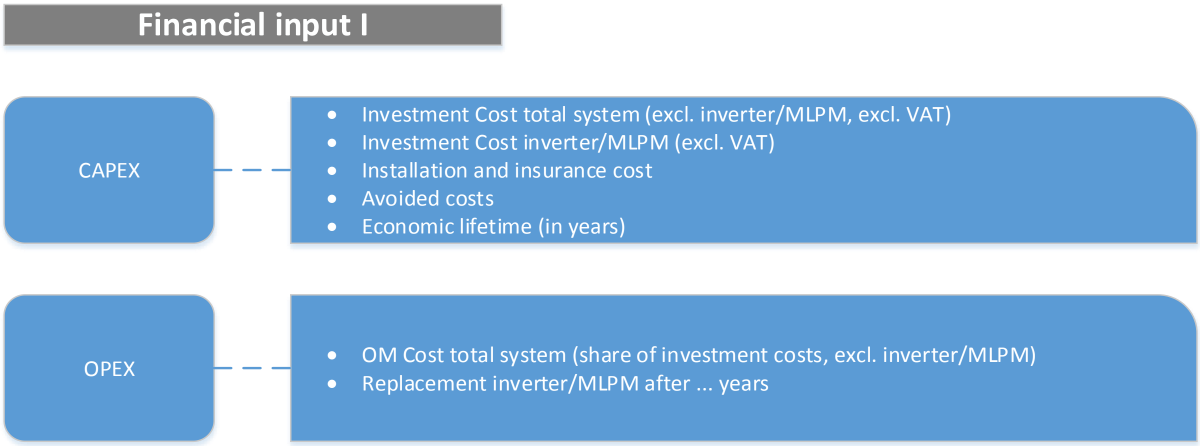
Installed power refers here to a certain PV system size measured in Wp. In this model, one PV system size is defined (See chapter 5.2).

- 5.1 kWp system for a detached house

Annual yield is the expected kilowatt-hours per kilowatt-peak installed. The exact number depends on multiple factors such as geographical location, weather, orientation, degradation of panels and inverter efficiency. In this thesis, we use an average that is determined for the Netherlands. The annual yield is set at 880 kWh/kWp (Wilfried van Sark, 2014). This number is an average for the Netherlands and is the latest established value. For the benchmark (See chapter 5) we used 900 kWh/kWp, which is around 2% more.

Module integration refers to the energy losses due to the level of system integration. Due to the increase in temperature levels of panels, efficiency is reduced. Here we distinguish three types of roofing integration, BAPV and BIPV in-roof systems and BIPV tiles (Sinapis, Donker, & Litjens, 2013).

7.2.2. Economical input

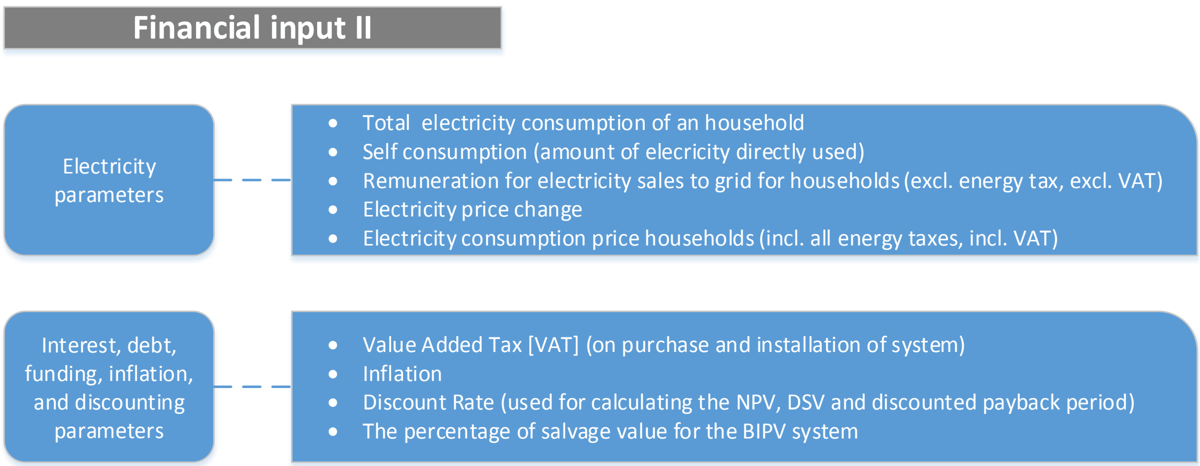


Capital expenditures (CAPEX) are funds used by a company or individual to acquire or upgrade fixed assets with a useful life, extending beyond the taxable year. Examples are properties, industrial buildings, and equipment. The CAPEX parameters in this model are:

- Investment cost total system (excl. inverter/Module Level Power Management (MLPM), excl. VAT). The investment costs in this model are based on the investment costs from the price benchmark study (See chapter 5). The investment cost total system refers in the techno-economic model to the complete turnkey price of a roof. More specific a newly built roof, PV and non-PV part.
- Investment cost inverter/MLPM (excl. VAT) (See chapter 5).
- Installation and insurance cost (excl. VAT) (See chapter 5).
- Avoided costs (savings in material and labor that are also needed when one choses for a conventional roof). The avoided costs are deducted from the total investment (See chapter 5). In the model, the costs for building a new roof with concrete tiles are regarded as avoided costs.
- Economic lifetime is the expected period in which an asset has an economic value to its owner. For privately owned PV systems, there is not a fixed number. However, based upon some literature we have chosen for an economic lifetime of 25 years (Kannan, Leong, Osman, Ho, & Tso, 2006; Pickrell, DeBenedictis, Mahone, & Price, 2013).

Operating Expense (OPEX) are ongoing costs for running a product, business, or system. Examples are wages, utilities, maintenance, and repairs. The OPEX parameters in this model are:

- Operation and Maintenance (OM) costs of the total system (share of investment cost, excl. inverter/MLPM, excl. VAT). In the model is chosen for a range between 0% and 0,5%. There is no literature yet, concerning OM costs for privately owned PV systems. Now most individuals do not take OM costs into account. However, in 25 years there presumable are OM costs involved in order to keep the PV system in operation. Therefore, a small percentage is included in the model. Moreover, to see the effect of OM costs on the outcome parameters.
- Replacement inverter/MLPM after 10 - 15 years. Normally the guarantee on the string inverters is 10 years. Therefore, the minimum in this model is 10 years. However, inverters have often a longer lifetime. Therefore, we have chosen for a range between the 10 and 15 years.



Electricity parameters are all costs related to the use of electricity for households in the Netherlands. The electricity parameters in this model are:

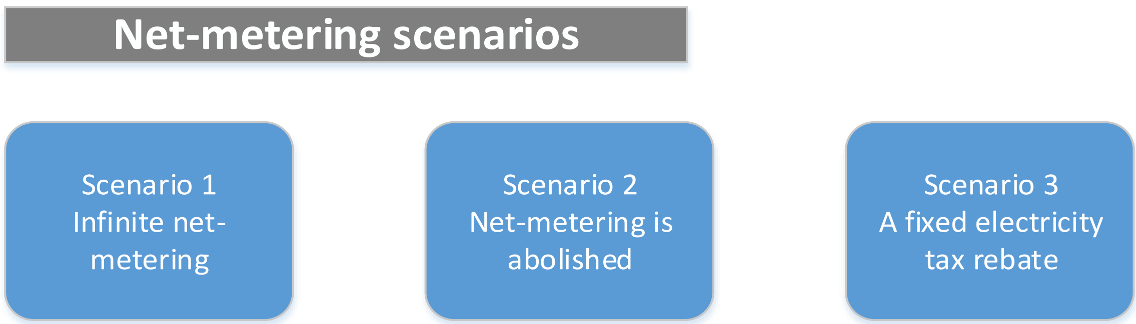
- The total electricity consumption, which refers to the amount of electricity that is used by a household, purchased from the grid, as well as directly consumed. In this analysis, we assume the yearly electricity consumption is equal to the annual yield of the system.
- Self-consumption, which refers to the amount of electricity that is directly used by the consumer. Therefore, that part is not net-metered.
- Electricity consumption price, which refers to the variable electricity price for households. Moreover, the part of the electricity price that is variable and is affected by policies such as net metering. This price is expressed in €/kWh and includes all energy taxes and VATs.

- Remuneration for electricity sales to the grid for households refers to that part of electricity that is returned to grid at a price equal to the retail electricity price. The price is in €/kWh and is excluding the energy tax and VAT.
- Electricity price change refers to the annual increase or decrease of the electricity consumption price. The change is expressed in %/a (annual). The monetary inflation is included in this parameter. Based on the electricity price of the last 11 years, the increase is 2,8% per year (van de Water, 2014).

Additional economic and financial parameters are external values imbedded in the economy and in policy legislations. The additional economic and financial parameters in this model are:

- The Value Added Tax (VAT) refers to the amount of VAT one has to pay over its purchased system. There is a law, which makes it possible to reclaim the VAT over your purchased system. A more detailed explanation is stated in Chapter 6.4.
- Monetary inflation is a sustained increase in the money supply of a country. In this model, it is used calculating the investment costs of the total system and inverter. The number is expressed in %/a (annual). For the Netherlands the average monetary inflation is 1,76% per year, calculated over the last 10 years (See Table 5 in appendix III). The standard deviation is 0,5 (See Table 6 in appendix III).
- The discount rate is the rate of return used in a discounted cash flow analysis to determine the present value of future cash flows. In this model, it is a preferred value that can differ per consumer. We found that experimenting with discount rates varying between 0 to 5% is viable strategy to test the sensitivity of the model (Viton, 2013).
- The percentage of rest value for the BIPV system. This percentage defines the amortization factor for the salvage value of a BIPV system. The percentage input varies between 25% and 75%.

7.2.3. Scenario input

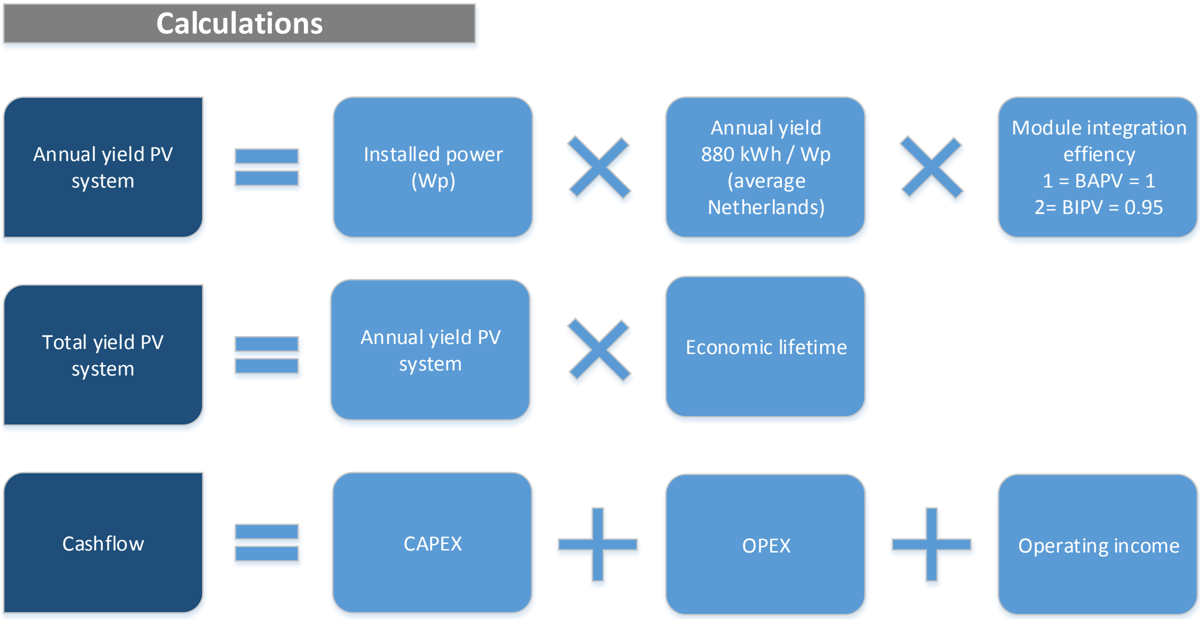


Scenario 1 - Infinite net metering: Under this scenario, we assume that the current net metering policy continues for an infinite period. Households with privately owned PV systems are fully compensated on their electricity consumption. Over the self-consumption part one saves on the variable electricity price which is at the moment around 0,23 €/kWh. Over the electricity fed into the grid one saves around 0,23 €/kWh as well. A note is that the amount of electricity bought from the grid is equal to the amount fed to grid. We assume the maximum amount of electricity one can return to the grid is 10.000 kWh. This is the maximum for households at this moment. For the surplus electricity that is fed into the grid, one is paid the retail electricity price. The retail electricity price differs per electricity supplier and at the moment is about 0,06 €/kWh a 0,07 €/kWh. Detailed information about the net metering policy is described in chapter 6.4.

Scenario 2 – A fixed electricity tax rebate: Under this scenario, we assume that the current net metering policy will be changed. This scenario is derived from the policy, collective electricity production. Individuals who collectively own a PV system can divide the produced electricity among them. For the produced electricity, the owners get a tax reduction. The tax reduction equals 0.091€ (0.075€ energy tax rebate, VAT 21%). In this scenario, the tax reduction is constant over time (van de Water, 2014). However, inflation is taken into account. Over the self-consumption part one saves on the variable electricity price. Over the electricity fed into the grid one saves around 0,16 €/kWh. This is the tax rebate (0.091 €/kWh) plus the retail electricity price (0,07 €/kWh). For the surplus electricity that is fed into the grid, one gets the retail electricity price.

Scenario 3 – net metering is abolished: Under this scenario, we assume that the current net metering policy is completely abolished. Over the self-consumption part one saves on the variable electricity price which is around 0,23 €/kWh. Electricity generated by the PV system can be returned to the grid at a price equal to the retail electricity price. At the moment this is about 0,06 €/kWh a 0,07 €/kWh. We assume the maximum amount of electricity one can return to the grid is 10.000 kWh. This is the current maximum for households at the moment.

7.2.4. Calculations



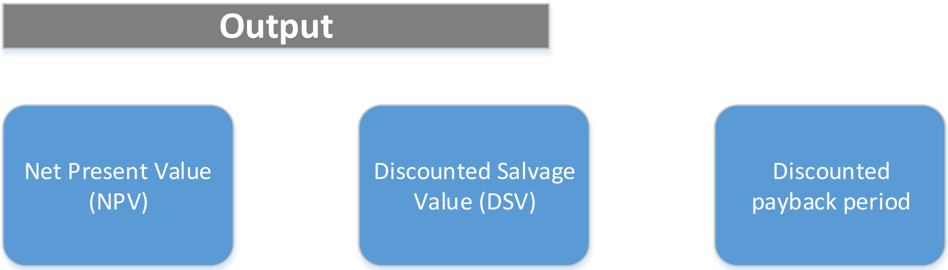
Annual yield PV system is based on the earlier defined technical input. The annual yield of the PV system can be calculated by multiplying, the installed power, the annual yield, and the module integration efficiency. The annual yield is expressed in kWh/a.

The total yield PV system is calculated by multiplying the annual yield of the PV system with the economic lifetime. In this model the economic lifetime is 25 years. The total yield is expressed in kWh.

The cash flow is the sum of the CAPEX, OPEX and operating income. The operating income is based on the revenue of the electricity sales and the VAT forfeit paid on the electricity sales. The cash flow is expressed in €/year.

The cumulative cash flow is the difference between current cash flow and cash flow from the previous period. The cash flow is expressed in the total amount of € over a period.

7.2.5. Economic output



Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyze the profitability of an investment or project. With the following formula, one can calculate the NPV:

$$NPV = \sum_{t=1}^{t} \frac{C_t}{(1+\mathrm{r})^t} - C_0$$ Where:

- C_t = net cash inflow during the period
- C_o= initial investment
- r = discount rate, and
- t = number of time periods

Discounted Salvage Value (DSV) is based on the NPV. It gives an estimation of the potential value of the PV system at any given time. Taken the remaining economic lifetime and predefined input parameters into account. The DSV refers in this context to the potential electricity savings over the remaining economic lifetime. The salvage value is a percentage of the potential remaining electricity savings of the system. In the year 0, this is a percentage over the total electricity savings for the total economic lifetime. The DSV is especially interesting for BIPV systems. Due to their integration, the system is a fixed part of the house. The DSV gives an estimation of the residual value of a BIPV system at any given time within the economic lifetime. In the case of a BIPV roofing solution, the DSV can be incorporated into the value of the house. In the case of a BAPV system it can be sold separately.

Discounted payback period refers to the number of years it takes for an investment to break even from the initial expenditure. The discount rate is taken into accounted here.

7.3. Analyzing BIPV using the Monte Carlo method

The Monte Carlo Method uses computational algorithms that rely on repeated sampling to compute a certain outcome. The method is called after Monte Carlo and has its origin in gambling theory (Hammersley & Handscomb, 1964). The Monte Carlo method is a multivariate model which is often used to forecast investment outcomes. The method provides more insight in the possibilities and risks of an investment. In this thesis, the method is used to assess the possibilities and risks for the investment in privately owned BAPV or BIPV solution.

Moreover, to assess the investment possibilities and risks under the three net metering scenarios. How likely is the economic feasibility of certain BAPV or BIPV solution under a predefined scenario and set of parameters? The parameters are defined per scenario.

The described input, calculations and output parameters are analyzed under three different scenarios. These three net metering scenarios are described in the previous paragraph. Within the input parameters, we distinguish fixed and variable parameters. Fixed parameters are determined by a fixed value that does not change. Variable input parameters are independent variables that can change depending on the range and distribution. By executing a Monte Carlo simulation, the variable parameters change with every iteration. Furthermore, there are variable outcome parameters that are the dependent variables, and referred to as the forecast parameters. All the input, calculation, and forecast parameters are discussed earlier in this chapter.

7.3.1. Net metering scenario 1

Under the infinite net metering scenario, we study three different business cases. These cases are based on three roofing solutions, BAPV, BIPV in-roof mounting system, and BIPV tiles. Moreover, a fixed PV system size is defined for the roofing solutions, based upon the BIPV price benchmark study. In Table 3, which is displayed below, all input variables for a detached house are defined.

Input variable	**Roofing solution**	**Distribution**	**Range**	
Technical parameters				
Installed Power	All	Fixed	5.1 kWp	
Annual yield	All	Fixed	880 kWh/a	Ratio
Module integration	BAPV	Fixed	1	Ratio
	BIPV in-roof	Fixed	0.98 (862,5 kWh/a)	Ratio
	BIPV tiles	Fixed	0.96 (845 kWh/a)	Ratio
Degradation factor	All	Fixed	0,5% per year	
CAPEX				
Investment costs total system, excl. inverter (excl. VAT)	BAPV	Uniform Distribution (Concrete tiles)	€ 2048 - € 2335 per kWp	Min - Max
	BIPV in-roof	Uniform Distribution (Ceramic tiles)	€ 1933 - € 2557 per kWp	Min - Max
	BIPV tiles	Uniform Distribution (Custom tiles)	€ 3054 - € 5151 per kWp	Min - Max
Investment cost inverter/MLPM	All	Fixed	€ 206 per kWh	

Installation and insurance cost (insurance not included)	BAPV	Uniform Distribution	€ 113 - € 288 per kWp	Min - Max
	BIPV in-roof	Uniform Distribution	€ 275 - € 487 per kWp	Min - Max
	BIPV tiles	Uniform Distribution	€ 209 - € 362 per kWp	Min - Max
Avoided costs	BAPV	Fixed (Concrete tiles)	€ 6535	
	BIPV in-roof	Fixed (Concrete tiles)	€ 6535	
	BIPV tiles	Fixed (Concrete tiles)	€ 6535	
Economic lifetime	All	fixed	25 years	
OPEX				
Operation and Maintenance (OM)	All	Uniform Distribution	0 - 0,5%	Min – Max
Replacement inverter	All	Discrete Uniform Distribution	10 – 15	Min – Max
Electricity related parameters				
Total electricity consumption	All	Fixed	4488 kWh	
Self-consumption	All	Uniform Distribution	10% – 50 %	Min – Max
Electricity consumption price	All	Fixed	0,23 €/kWh	
Remuneration for electricity sales	All	Fixed	0,23 €/kWh (equal to electricity consumption price)	
Electricity price change	All	Normal Distribution	2,8% (plus) (van de Water, 2014)	Std.Dev. 0,5
Additional economic and financial parameters				
The Value Added Tax (VAT)	BAPV	Fixed	0% (chapter 6.4)	
	BIPV in-roof	Fixed	14%, 4%(chapter 6.4)	
	BIPV tiles	Fixed	14%, 4%(chapter 6.4)	
Monetary inflation	All	Normal Distribution	1,76%	Std.Dev. 0,5
The discount rate	All	Uniform Distribution	0% - 5%	Min – Max
% of salvage value for the BIPV system	All	Uniform Distribution	25% - 75%	Min – Max

Table 3: Parameters for a detached house under net metering scenario 1.

7.3.2. Net metering scenario 2

Under the fixed tax rebate net metering scenario, we analyze the same three business cases as in net metering scenario 1 and 3. The difference in this scenario is the remuneration for electricity sales. The remuneration for electricity sales price is a fixed average (0,159 €/kWh).

Remuneration for electricity sales	All	Fixed	0,159 €/kWh

7.3.3. Net metering scenario 3

Under the abolished net metering scenario, we analyze the same three business cases as in net metering scenario 1. In this scenario, we assume the net metering scenario is abolished. The difference in this scenario is the remuneration for electricity sales. The remuneration for electricity sales price is a fixed average (0,068 €/kWh).

Remuneration for electricity sales	All	Fixed	0,068 €/kWh (III)	

7.4. Results of the Monte Carlo analysis

As discussed in the previous paragraph we analyzed three different roofing solutions. Within each roofing solution, the NPV is analyzed for each of the three net metering scenarios. Next, the discounted payback period is discussed per roofing solution. The results are concluded per roofing solution. The DSV is discussed for the three net metering scenarios. In each net metering scenario, the three roofing solutions are discussed with respect to the DSV.

The effect of the input variables are explained by the contribution to the variance in the forecast parameters. Explaining the variance is also known as a variance-based sensitivity analysis. It is a global sensitivity analysis because it measures the sensitivity over the whole input area. It considers non-linear responses, and can measure the effect of interactions in non-additive systems (Wainwright, Finsterle, Jung, Zhou, & Birkholzer, 2014). For example, a model with two inputs and one output. One might find that 80% of the output variance is caused by the variance in the first input and 15% by the variance in the second. The last 5% is due to interactions between the two. At last, the validity for each analysis is discussed. Through a multivariate regression, the validity of each variable input and forecast parameter is reviewed.

7.2.1. BAPV as a roofing solution

Net Present Value (NPV)

Under the first net metering scenario, the NPV ranges between 9.695€ and 26.593€. The average NPV is 16.772€ (See Figure 26). The NPV is calculated with a 95% certainty, thus 95% of the 7500 iterations from the simulation resulted in the displayed NPVs. The declining lines represent the decreasing NPV (incl. confidence interval) under net metering scenario 2 and 3. Although, under these less favorable net metering scenarios, the NPV is in nearly all cases positive. When net metering is abolished, the average NPV after 25 years is around 4.500€ for a BAPV roofing solution.

The results from the variance-based analysis explains the effects within the 'NPV' parameter. The effect of the dependent input variables on the forecasted variable 'NPV' is explained in Figure 26. Only significant effects are included and discussed here. Under net metering scenario 1, The NPV is for 85,5% explained by the discount rate. A lower discount rate results in a higher NPV. A one percent increase in the discount rate results in an average decrease of almost 3.000€ in the NPV (See Table 8 in appendix IV). Considering, we defined a broad range (0% - 5%) for the discount rate, there can be difference in the NPV of about 15.000€. Another, smaller effect on the NPV is that of the electricity price change. A higher electricity price change results in a higher NPV. Under net metering scenario 2, self-consumption is introduced. The amount of electricity self-consumed has a minor effect on the NPV under the tax rebate net metering scenario. Furthermore, there is decrease in the effect of the discount rate in comparison to scenario 1. Under net metering scenario 3, the effect (50,6%) of self-consumption on the NPV is increasing. The input distribution range of the self-consumption varies between 10% and 50%. A ten percent increase in the self-consumption results in an average increase of almost 1.950€ in the NPV (See Table 9 in appendix IV). The effect of the chosen discount rate continues decreasing under the abolished net metering scenario. On average, a one percent increase in the discount rate results in an average decrease of almost 1.390€ in the NPV. Another less stronger but still significant effect is that one of electricity price change (5,8%).

In order to check the validity of the analysis, we conduct a regression analysis per net metering scenario. Where the NPV is the dependent variable and all the input parameters are independent variables. The regression statistics of the NPV in Table 8, Table 9 Table 10 of appendix IV show that the models have an average r^2 of about 0,98. This is not unusual because the variance in the model is explained by the calculations of the model only. The regression is therefore more useful to check the significance of the separate variable parameters. In this case, the NPV and all but one input parameters are significant. Under net metering scenario 1, the input variable 'self-consumption' is not significant. Under this scenario, the electricity consumption price and remuneration for electricity sales price are equal. It does not matter how much one self-consumes, if the amount purchased and returned from and to the grid are equal.

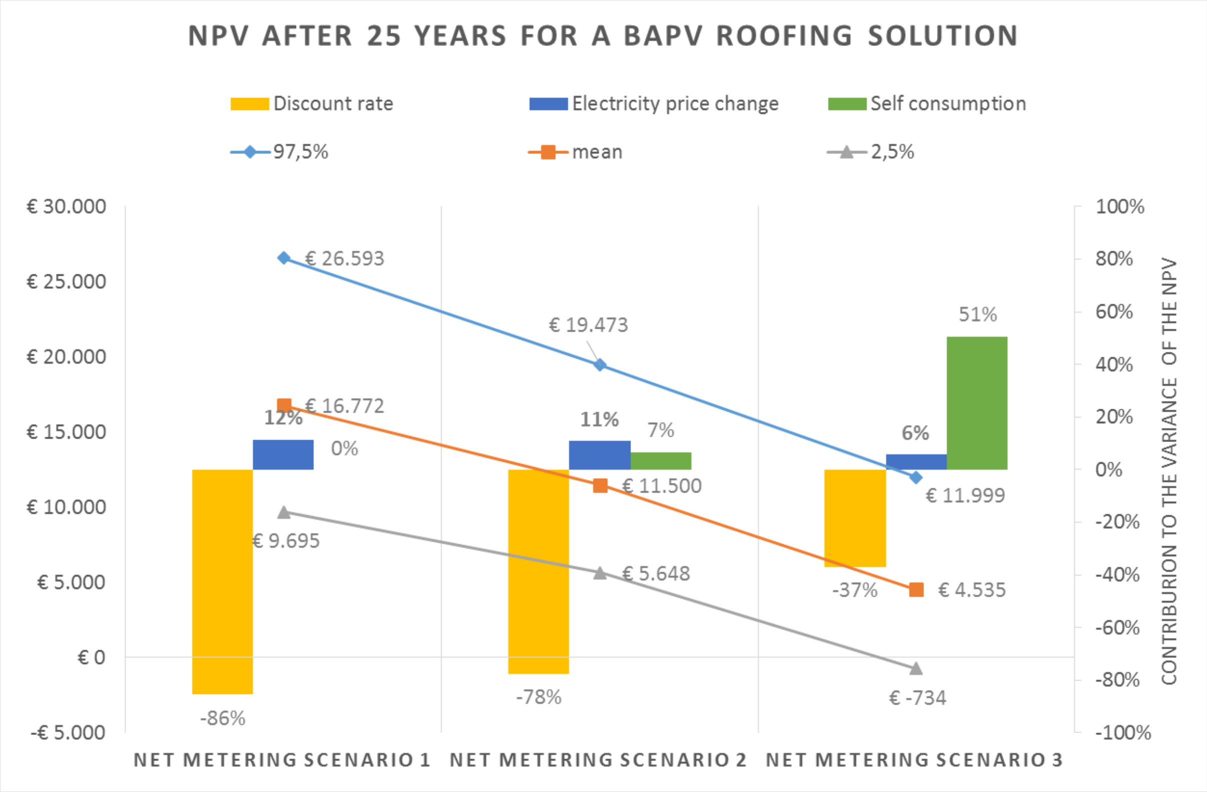


Figure 26: The NPV after 25 years for a BAPV roofing solution.

Discounted payback period

The discounted payback period of a BAPV roofing solution varies between 6 and 9 years under net metering scenario 1 (See Figure 27). The ascending lines represent the increase in the payback period (incl. confidence interval) under net metering scenario 2 and 3. When net metering is abolished, the discounted payback period varies between 10 and 29 years, with an average of 17 years.

Under net metering scenario 1, the most important variable input parameters are the investment related parameters and the discount rate. These parameters have the largest effect on the short-term NPV. Moreover, the discounted payback period is determined when the NPV becomes positive. Due to significant effect of the investment related parameters and their small input distribution range, the forecast range of the payback period is relatively small as well. A 1.000 euro increase in the investment cost total system (excl. inverter and VAT) results in an average increase of a year in the discounted payback period (See Table 11 in appendix IV) Under net metering scenario 2 and 3, the 95% confidence interval of the payback periods increases. While, the effect of the investment related parameters decreases. This stresses the large effect of these parameters on the payback period and short-term NPV. Furthermore, it stresses the value of the tax reclamation legislation. The tax reclamation over the purchased PV system is the same as a discount on the investment costs. Under net metering scenario 2 and 3, the self-consumption has significant effect. A lower self-consumption results in a longer payback period.

Verifying the validity of the model, we found that under net metering scenario 1, the replacement of the inverter is not significant (See Table 11 in appendix IV). This is because the first time an inverter is replaced is after a minimum of 10 years, which is lower than the discounted payback period of 9 years (See Figure 27). Under net metering scenario 2, the inflation over the inverter is not significant. Probably because the effect is too small.

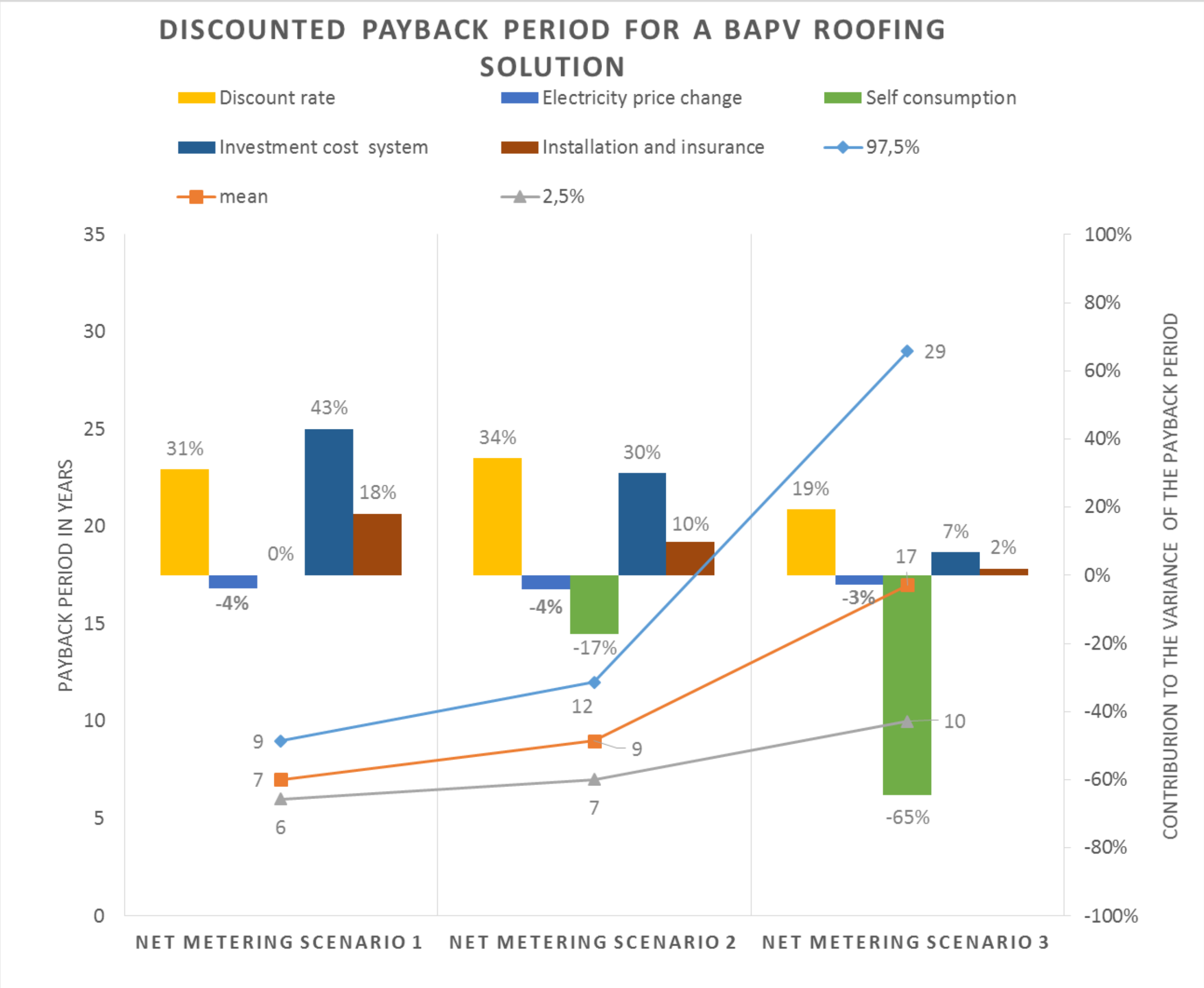


Figure 27: Discounted payback period for a BAPV roofing solution.

Conclusion

BAPV as a roofing solution is on average economically feasible under all net metering scenarios. There is thus a business case for BAPV under all conditions. The profitability depends strongly on the discount rate when the remuneration price for electricity is high. However, when the remuneration price decreases, which is the case in the abolished net metering scenario, the NPV depends strongly on the amount of self-consumption. The discount rate has than less impact on the NPV. Under the first two net metering scenarios, the payback period is in all cases within the economic lifetime of 25 years. When net metering is abolished, the NPV is on average about 4.500€. There is a strong effect of the cost of the total BAPV system (excl. inverter) on the payback period. This stresses the impact of the reclamation of VAT legislation, which is currently in act. The effect of the investment cost for a BAPV system decreases when the remuneration price for electricity decreases. Also here we see an increase of the effect of self-consumption.

7.2.2. BIPV in-roof mounting system as a roofing solution

Net Present Value (NPV)

Under the first net metering scenario, the NPV ranges between 7.185€ and 24.323€. The average NPV is 14.502€ (See Figure 28). The declining lines represent the decreasing NPV (incl. confidence interval) under net metering scenario 2 and 3. Under net metering scenario 1 and 2 all cases are positive. However, when net metering is abolished, 25% of the cases have a negative NPV (See Figure 44 appendix IV). The average NPV after 25 years is around 2.380€ for a BAPV roofing solution. The cost of total system (excl. Inverter and VAT) has now a negative effect on the NPV.

The results from the variance-based analysis explains the effects within the 'NPV' parameter. The effect of the dependent input variables on the forecasted variable 'NPV' is explained in Figure 28. Only significant effects are included and discussed here. Under net metering scenario 1, The NPV is for about 80% explained by the discount rate. A one percent increase in the discount rate results in an average decrease of almost 2.850€ in the NPV (Table 14 in appendix IV). Another smaller effect on the NPV is that of the electricity price change. Under net metering scenario 3, the variation in the NPV can be for 45% explained by the self-consumption, which is lower than in the case of the BAPV roofing solution. A ten percent increase in the self-consumption results in an increase of almost 1.920€ in the NPV (See Table 15 in appendix IV). The total investment cost (excl. inverter and VAT) has a significant effect (11.7%) now. This is the result of the larger price difference among the BIPV in-roof products.

Under these net metering scenarios, the NPV and all but one input parameters are significant. This is the input parameter '% Rest Value of BIPV system', which is not included in the calculation. The parameter is used to determine the DSV, which is discussed later.

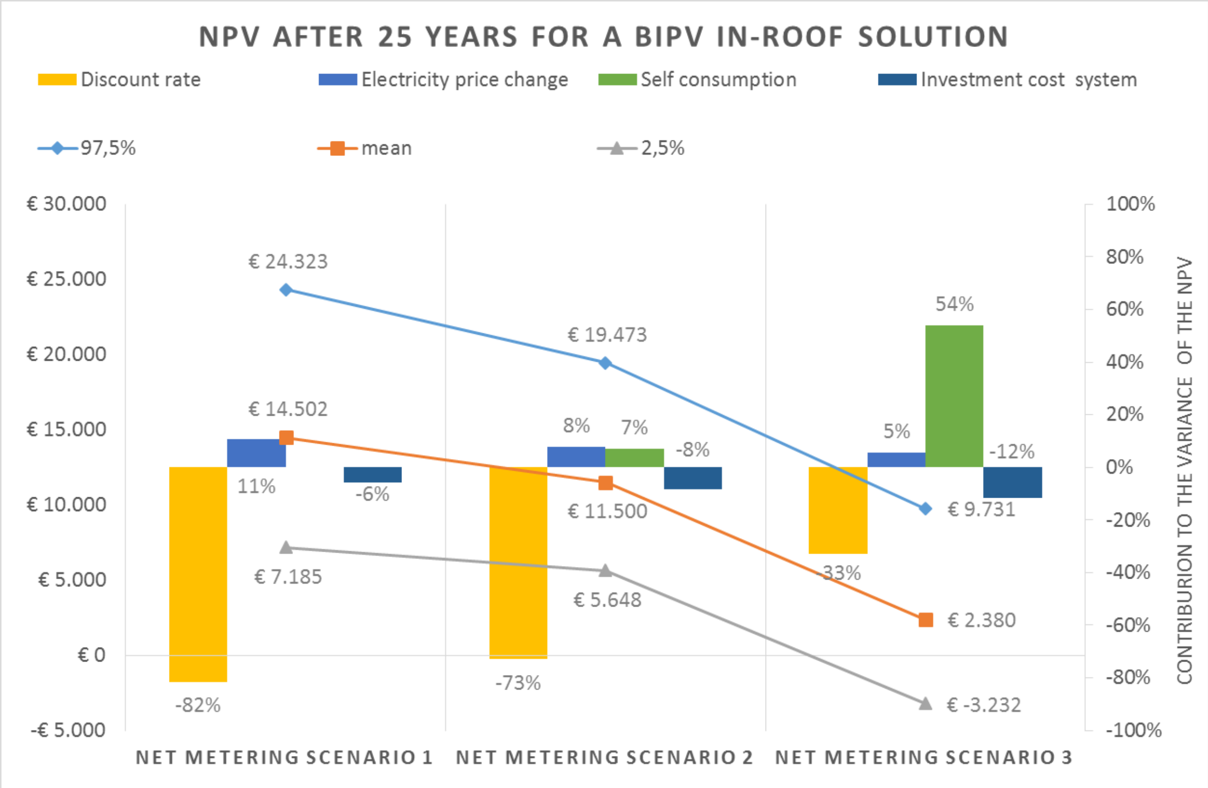


Figure 28: The NPV after 25 years for a BIPV in-roof solution.

Discounted payback period

The discounted payback period of a BIPV in-roof solution varies between 7 and 13 years under net metering scenario 1 (See Figure 29). The ascending lines represent the increase in the payback period (incl. confidence interval) under net metering scenario 2 and 3. When net metering is abolished, the discounted payback period varies between 12 and 46 years, with an average of 22 years.

Under net metering scenario 1, the most important variable input parameters are the investment related parameters and the discount rate. A 1.000 euro increase in the investment cost total system (excl. inverter and VAT) results in an average increase of a on 1,3 year in the discounted payback period (See Table 17 in appendix IV). Under net metering scenario 2 and 3, the self-consumption has a significant effect. A lower self-consumption results in a longer payback period. Under the abolished net metering scenario, a 10% increase in the self-consumption results in an average decrease of 4,5 year in the discounted payback period (See Table 18 in appendix IV).

Verifying the validity of the model, we found that under net metering scenario 1, the inflation over the inverter is not significant (See Table 17 in appendix IV). This is probably because the effect on the discounted payback time is too small.

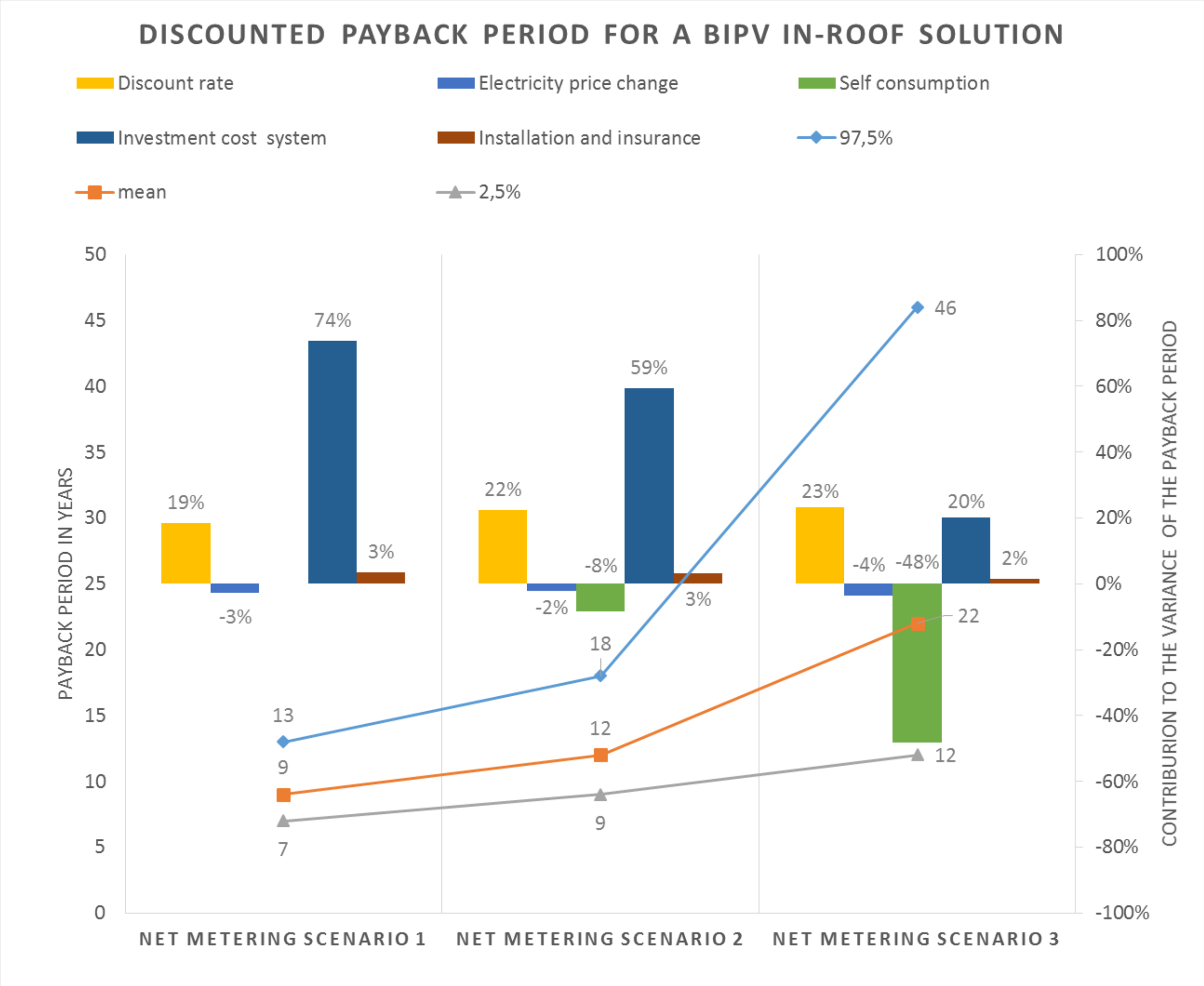


Figure 29: Discounted payback period for a BIPV in-roof solution.

Conclusion

The BIPV in-roof mounting system as a roofing solution is economic feasible under the unlimited and fixed tax rebate scenario. When net metering is abolished, the NPV is negative in 25% of the cases. There is a business case under the net metering scenario 1 and 2. Under the right conditions also under scenario 3, only this uncertain. Similar to BAPV roofing solutions results a decreasing remuneration price for electricity results in a decrease of the effect of the discount rate. In contrast, will the self-consumption increase. Under the first two net metering scenarios, the investment will pay off. When net metering is abolished this is uncertain. In this business case, the cost of the total BIPV system (excl. inverter) and self-consumption have significant effect on the discounted payback period. A lower self-consumption results in a longer payback period.

7.2.3. BIPV tiles as a roofing solution

Net Present Value (NPV)

Under the first net metering scenario, the NPV ranges between -7.144€ and 14.943€. The average NPV is 3.165€ (See Figure 30). There is a one-third possibility that the NPV of a BIPV tiles solution is not positive after 25 years (See Figure 45 in appendix IV). Under net metering scenario 2 and 3, the average of the cases have a negative NPV. The average NPV for respectively scenario 2 and 3 are -2.011€ and -8.679€. Under these net metering scenarios, there no business case for BIPV tiles as a roofing solution.

The effect of the dependent input variables on the forecasted variable 'NPV' is explained in Figure 30. Under net metering scenario 1, The NPV is for 48% explained by the discount rate. A one percent increase in the discount rate results in an average decrease of almost 2.700€ in the NPV (See Table 20 in appendix IV). Considering, we defined a broad range (0% - 5%) for the discount rate, there can be difference in the NPV of about 13.500€. The investment cost total system (incl. inverter and VAT) has a strong effect (42%) on the NPV. A 1.000€ increase in the investment cost of the total system (excl. inverter and VAT) results in an average decrease of around 1.650€ in the NPV (See Table 20 in appendix IV). Under net metering scenario 2 and 3, the effect of the investment cost increases to respectively 55% and 63%. Under net metering scenario 3, there is an effect (19%) of self-consumption on the NPV. A ten percent increase in the self-consumption results in an average increase of almost 1875€ in the NPV (See Table 21 in appendix IV). Under these net metering scenarios, the NPV and all input parameters are significant.

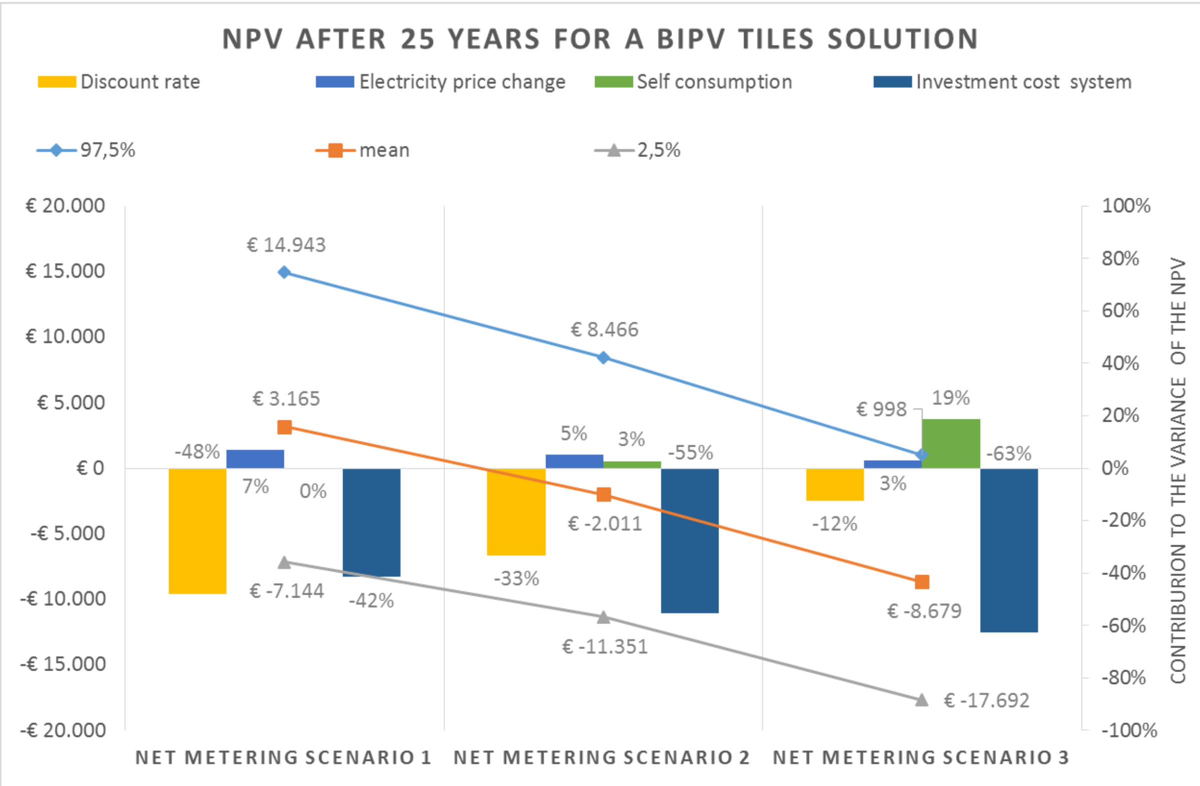


Figure 30: The NPV after 25 years for a BIPV tiles solution.

Discounted payback period

The discounted payback period of a BIPV tiles solution varies between 14 and 44 years under net metering scenario 1 (See Figure 31). In 69% of the cases the solutions is paid off within the 25 years (See Figure 46 appendix IV). The ascending lines represent the increase in the payback period (incl. confidence interval) under net metering scenario 2 and 3. Note that the maximum discounted payback period of the model is 50 years. Under net metering scenario 2 and 3, it is unlikely that a BIPV tiles solution will pay off within 25 years. For the first net metering scenario it does pay off, here the average is 24 years.

Under net metering scenario 1, the most important variable input parameters are the investment related parameters and the discount rate. Under net metering scenario 2 and 3, the self-consumption has a significant effect. The discount rate increases when the remuneration on the electricity sales price decreases. The investment cost decreases when the remuneration on the electricity sales price decreases.

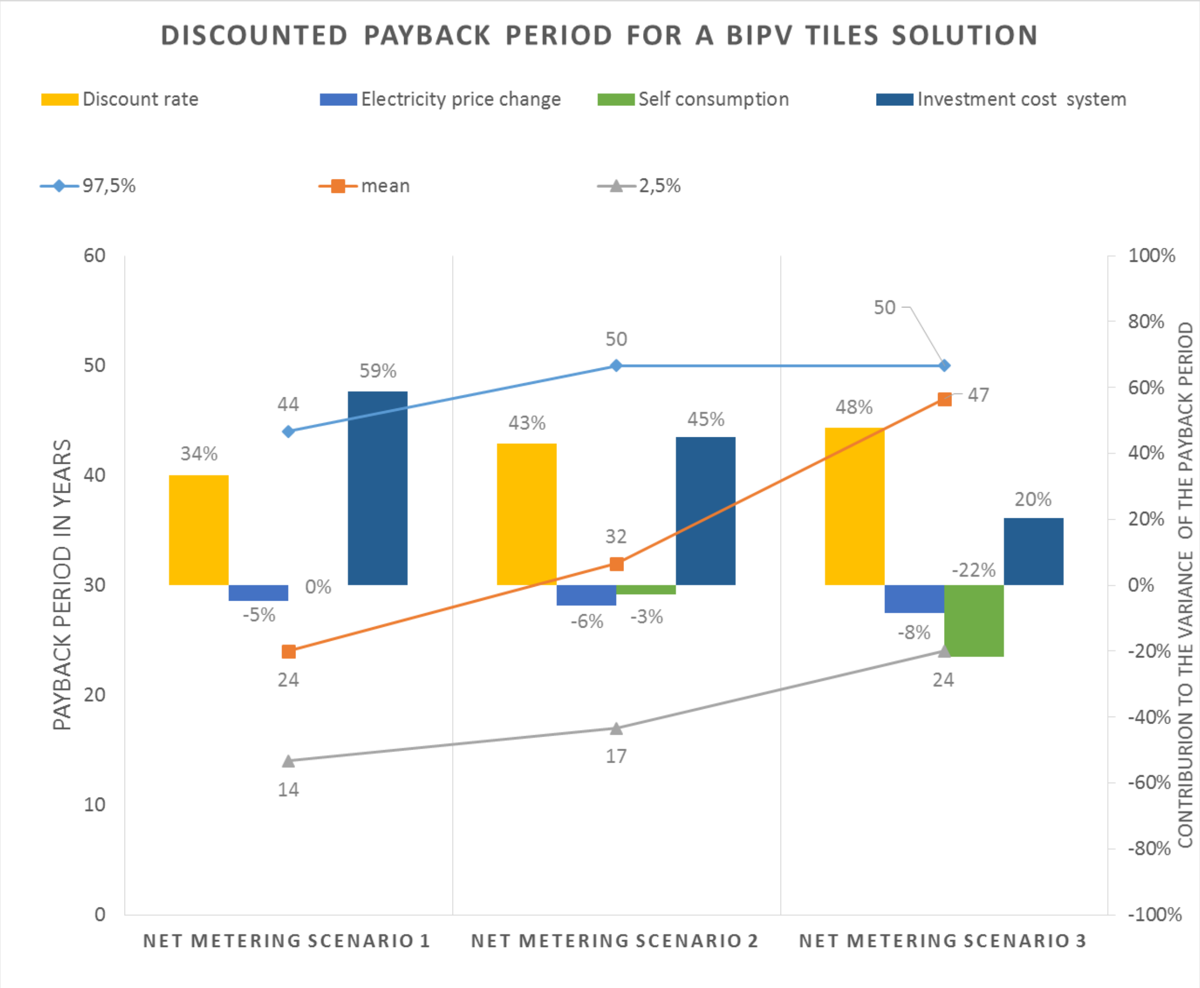


Figure 31: Discounted payback period for a BIPV tiles solution.

Conclusion

There is no business case for the BIPV tiles solution. Although, under unlimited net metering there might be a business case. About 67% of the cases have a positive NPV after 25 years. However, under the other two scenarios, there is no positive average NPV. The chosen discount rate has a large impact on the NPV under unlimited net metering. However, when the remuneration price for electricity decreases, the effect of the discount rate decreases. Furthermore, we see a large effect on the NPV by the investment cost. This effect increases when the remuneration price for electricity decreases. The BIPV tiles market is a niche segment, where the price difference among product is high. The relatively expensive products and the large price difference among them, result in less significant effect of the self-consumption. Under net metering scenario 3, the amount of self-consumption is less important. The distribution electricity savings versus investment cost is too big. The payback period is on average longer than 25 years in all cases.

7.2.4. Discounted Salvage Value (DSV)

Discounted Salvage Value (DSV) under net metering scenario 1

Under net metering scenario 1, the DSV varies between 5.744€ and 18.759€ with average DSV of 11.376€ in year 0 (See Figure 32). Note that in year 25 there are still potential electricity savings. This is because it is the start of year 25 and therefore not included. In year zero, the average DSV is around 11.500€. The average turn-key price of a BIPV in-roof system is around 10.500€[2]. Concluding that if a house owner would sell his house immediately, he would make a profit of 1.000€. In the case of a BAPV roofing solution (6.645€), there certainly will be a profit within the 95% confidence interval. For the BIPV tiles solution it is unlikely one would make a profit. Note that the wide distribution in the "% of the rest value over the BIPV system" has a substantial effect on the DSV. Furthermore, the chosen discount rate has a significant effect on the DSV. The DSV is derived from the NPV, which explains the significant effect of the discount rate on the DSV. The input parameter "% of the rest value over the BIPV system" varies between 25% and 75% what explains its large effect on the DSV (See Figure 47 of appendix IV). Note that the effect of the "% of the rest value over the BIPV system" decreases over time where the discount rate increases.

[2] In the BIPV price benchmark, all prices are included VAT. Therefore, the VAT over the roofing solutions are subtracted to use it in this analysis.

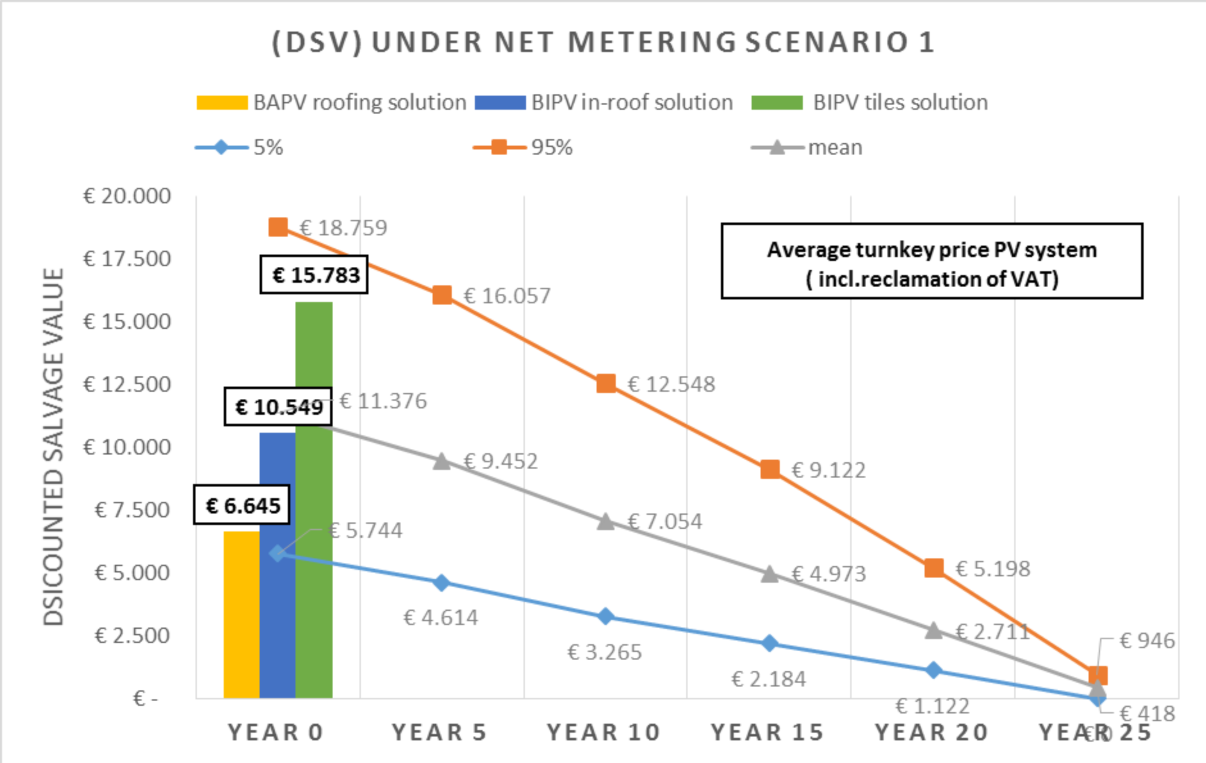


Figure 32: Discounted Salvage Value (DSV) under net metering scenario 1.

Discounted Salvage Value (DSV) under net metering scenario 2

Under net metering scenario 2, the DSV varies between 3.977€ and 15.999€ with average DSV of 8.840€ in the year 0 (See Figure 48 in appendix IV). For a BAPV roofing solution it is plausible that the PV system can be sold with a profit in year 0. Assuming that the input variables (percentage of salvage value and discount) are reasonable. The BIPV in-roof solution costs on average about 1.750€ more than the total electricity savings over 25 years. The roofing solution itself does not represent a measurable value otherwise than using the potential electricity savings. Although, the aesthetics of a BIPV roofing solution could for someone also represent a salvage value. However, this is not included in the study.

Discounted Salvage Value (DSV) under net metering scenario 3

Under net metering scenario 3, the DSV varies between 2.098€ and 10.876€ with average DSV of 5.541€ in the year 0 (See Figure 49 in appendix IV). The BAPV roofing solution costs on average about 1.100€ more than the total electricity savings over 25 years. Under this scenario, none of the roofing solutions would break even when sold in year 0. When comparing the average turnkey price with the average discounted salvage price. The total electricity savings over 25 years are lower than the market value of the roofing solution.

Conclusion

The DSV can be used to value a PV system within its economic lifetime. Under the unlimited net metering scenario, the DSV ranges between 5.477€ and 18.759€. The large range is the result of the large variation in salvage value of the system. Nevertheless, under this scenario it assumable that the DSV is higher than the turnkey price of the BAPV roofing solution. Under the fixed tax rebate scenario, the turnkey price is just above the DSV. Under the abolished net metering scenario, it is unlikely that one will make money on the system if sold in year 0. For the BIPV in-roof solution, only net metering scenario 1 results in profitable outcome. The BIPV tiles solution costs in all scenarios more than the average profit on electricity savings (under the DSV assumed input variables).

7.5. Conclusion and discussion

The results of the Monte Carlo analysis emphasizes there is not yet a business case for BIPV tiles. In the best-case scenario, the average payback period is still 24 years with a NPV of about 1.000€. The BIPV in-roof solution is economically feasible under the unlimited and fixed tax rebate scenario with average NPVs of respectively 14.500€ and 11.500€. The average discounted payback period is under these scenarios is 9 and 12 years. Under the abolished net metering scenario, there is a business case under right conditions. Moreover, that depends mainly on the amount of electricity a household self-consumes. Overall, the discount rate has a large impact on the NPV and therefore the profitability of a roofing solution. For BAPV roofing solutions, there is a business case under all net metering scenarios. The average NPV between the three net metering scenarios vary between about 16.500€ for unlimited net metering and 4.500€ under the abolished net metering scenario. The average discounted payback period varies between 7 and 17 years. In summary, there is partly a favorable market for the BIPV in-roof solutions. For the BIPV tiles is under these conditions no favorable market. For the BAPV as roofing solution there is a possible business case under all scenarios.

8. Case study of the “aesthetic energy roof”

8.1. Introduction

A part of this thesis focuses on the AER developed by Aerspire (See Figure 35). According to Aerspire, the pitfall of the current BIPV roofing products is the price. These are higher than the on-roof BAPV products. Aerspire proposes a product that should overcome this price barrier.

The first part of this chapter focuses on the concept of the AER. The pros and cons in comparison to the other two BIPV solutions is discussed. Next, the price of the AER is compared. A Monte Carlo analysis determines the economic feasibility of the AER under different net metering scenarios. These results are compared with results from the analysis in chapter 8. This chapter is finalized with a conclusion.

8.2. Aesthetic Energy Roof

In the light of this thesis, the AER is discussed as a full roof BIPV solution. Where the other BIPV roofing solutions only replace parts of the original roof, a full roof BIPV solution replaces the complete conventional roof envelope (See Figure 33 and Figure 34). For BIPV roofing solutions, this is the most homogeneous solution. Only one material is used for the outer layer of the roof envelope. In order to construct such a roof it is necessary to completely fill the roof with solar panels. However, this is complex since every roof has different dimensions and most producers produce the panels only in standard dimensions. Roof obstacles such as chimneys, windows, and dormers make this even harder. A solution to overcome this problem and maintain the homogeneous appearance are dummies. Dummies are similar to the original panels only do not contain solar cells. The dummy panel is also made with a glass top layer. However, with the current techniques these dummies are still relatively expensive. In order to put the characteristics of the AER into perspective it is compared with the characteristics of the two earlier discussed BIPV roofing solutions (See Table 4).

	(AER)	**BIPV tiles**	**BIPV in-roof mounting system**
Technical			
Less degradability of the panels	+	o	o
easiness of installation	+	+	o
Ventilation of BIPV system	o	-	o
Customizability	+	+	-
Financial			
Price of the roofing solution	o	-	+
Costs of installation	+	o	+
Aesthetic			
The glass roof solution provides a total roof filling solution, which results in a more homogeneous look.	+	o	-

Table 4: Comparison pros and cons of (AER), BIPV full roof solutions, BIPV tiles and, BIP in-roof mounting systems. + pro; - con; o neutral; n.a. not applicable.

Figure 33: BIPV full roof (1)

Figure 34: BIPV full roof (2)

Figure 35: Aesthetic Energy Roof (3)

8.3. Price benchmark AER vs. BIPV roofing solutions

In this paragraph, the turnkey prices of the AER are compared to the other two roofing solutions. First, the AER is compared to the BIPV in-roof solution. Moreover, the solution is compared with the BIPV in-roof quotations separately and not merely as an average of these quotations. Next, the same is done for the BIPV tiles quotations. The results provide an overview of the price position of the AER within the BIPV roofing market. The results of the benchmark study taught us the price gap between BAPV and BIPV. Moreover, it made clear that these roofing solutions are more suitable for detached houses. A first indication of the price showed that this price gap also existed for the AER. Therefore, we chose to compare the AER with the other BIPV solutions only for a detached house.

Comparing the AER with the BIPV tiles and in-roof solution

The turnkey prices of the BIPV tiles solution products vary between around 32.500€ and 21.000€. The AER has a turnkey price of about 19.000€ (See Figure 50 and Figure 51 in appendix V). Note the difference in the prices for the PV panels. The PV panels for the BIPV tiles solution products vary between 11.000€ and 17.500€. Where the PV panels for the aesthetic energy roof cost about 7.500€ for the detached house. The conventional roofing materials or customized non-PV panels vary between 3.000€ and 9.000€ for the BIPV tiles solution products. For the aesthetic energy roof, this is about 7.500€. A last noticeable difference between the component prices is the installation costs (PV and non-PV installation). For the aesthetic energy roof, these costs are respectively around 1.000€ and 700€. For the BIPV tiles solution products the non-PV installation cost varies between 2.000€ and 3.000€. For the PV installation, this is between 1.000€ and 2.000€.

The turnkey prices of the BIPV in-roof solution products vary between around 18.000€ and € 14.000 (See Figure 51 in appendix V). The PV panels for the BIPV in-roof solution products vary between 4.000€ and 7.500€. The conventional roofing materials for the BIPV in-roof solution products are 2.500€. The installation costs of non-PV installation is around 4.000€. The installation costs of PV installation varies between 1.000€ and 5.000€.

Conclusion

The turnkey price of the AER is positioned between the BIPV tiles solution and the BIPV in-roof solution. The AER is more expensive than the BIPV in-roof products but cheaper than the BIPV tiles products. By using standardized panel dimensions, the AER panels are cheaper than the custom made PV tiles. However, the AER panels are also slightly customized and therefore more expensive than the standard PV panels used in most the BIPV in-roof products. The non-PV part of the AER solution is more expensive than most of the customized non-PV roofing material of the BIPV tiles products. Moreover, also more expensive than the conventional concrete tiles. This can be explained by the non-PV glass-glass panels that cover most of the roof. The cost price of these non-PV panels are relatively high. Moreover, because these are customized separately for every roof.

The AER cannot deliver on the promise that it is price competitive with a BAPV roofing solution. An average BAPV roofing solutions costs around 15.000€ (See Figure 42 in appendix I), where the AER costs around 19.000€. There is a price gap of about 22% between these solutions. These are the prices based on a newly built house. So, a new roof (See 5.2) including the PV roofing solution. However, with a price gap of 20% on the complete roof plus PV solutions, we see possibilities for the AER. Again, we come back to the question, what is the customer willing to pay more for a more aesthetic roof solution.

In the next paragraph, we will analyze the techno-economic feasibility of the AER under the different net metering scenarios.

8.4. Technical and economic feasibility of the AER

8.4.1. Technical, economical and scenario input

The technical, economical and scenario input for the AER, is stated in Table 23 of appendix VI. The input is similar to the other BIPV roofing solutions, although there are some adjustments. The module integration is similar to that of a BIPV in-roof solution. Therefore the annual yield of the system is 862,5 kWh/a. However, the yield over 25 years is higher. This due to the degradation factor of the glass-glass module. The change in the degradation factor is included in the calculations. Furthermore, the investment costs (system and installation) are fixed in this model. The reclamation of VAT legislation is the same as for the BIPV solutions. The remaining input parameters are equal to the other two BIPV roofing solutions. In the next paragraph the input parameter are used to run a Monte Carlo analysis for the case study.

8.4.2. Results for the “aesthetic energy roof” as a roofing solution

Net Present Value (NPV)

Under the first net metering scenario, the NPV ranges between 6.745€ and 23.818€. The average NPV is 13.991€ (See Figure 36). For the second net metering scenario, all cases are positive as well, the average NPV drops here to € 8412. For the third scenario, about 57% of the cases have a positive NPV (See Figure 52 in appendix VI).

The effect of the independent input variables on the forecasted variable ‘NPV’ is explained in Figure 36. Only significant effects are included and discussed here. Under net metering scenario 1, The NPV is for 86% explained by the discount rate. A one percent increase in the discount rate results in an average decrease of about 3.000€ in the NPV (See Table 24 in appendix VI). Another smaller effect on the NPV is that of the electricity price change. A one percent increase in the electricity price change results in an average increase of about 3.350€ in the NPV. Under net metering scenario 2, self-consumption is introduced. The amount of electricity self-consumed has a minor effect on the NPV under the tax rebate net metering scenario. However, under the abolished net metering scenario this parameter has the largest impact (50%). A ten percent increase in the self-consumption results in an average increase of about 1.900€ in the NPV (See Table 25 in appendix VI). Under all net metering scenarios, the NPV and all input parameters are significant.

There is a business case for the AER under the unlimited and fixed tax rebate net metering scenarios. Under the abolished net metering scenario, the business case is uncertain. Under these conditions, it depends on the amount of self-consumption and the chosen discount rate.

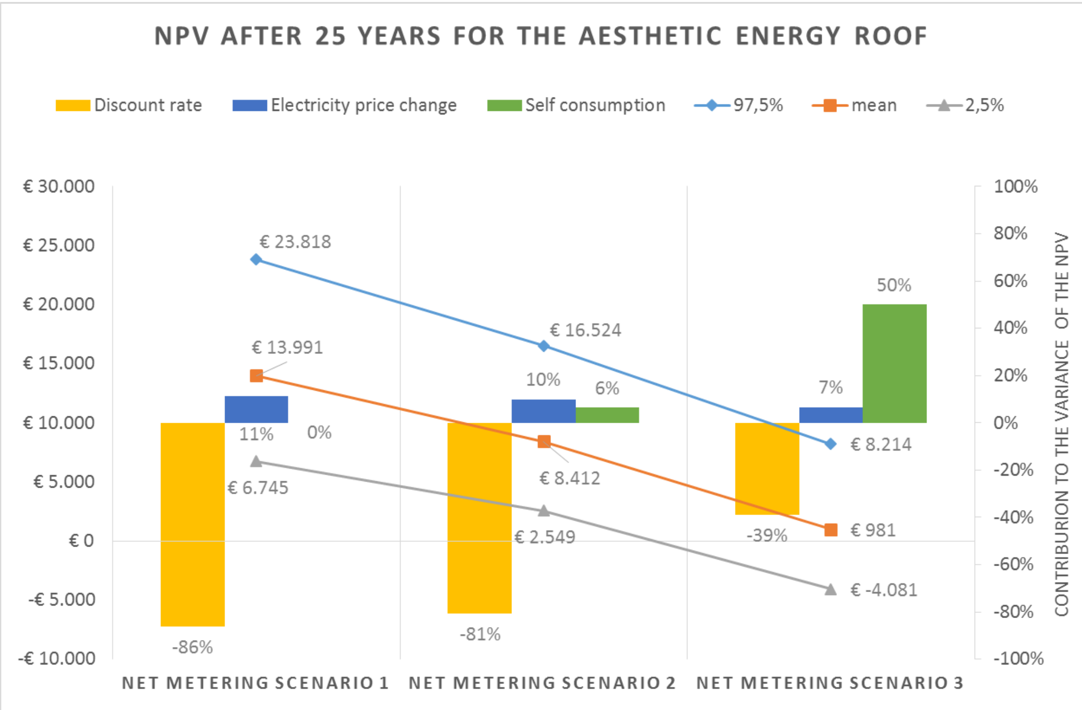


Figure 36: The NPV after 25 years for the aesthetic energy roof.

Discounted payback period

The discounted payback period of the AER varies between 9 and 13 years under net metering scenario 1 (See Figure 53 in appendix VI). This increases to respectively 11 and 19 under net metering scenario 2. For the third net metering scenario, the average discounted payback period is 26, which is longer than the economic lifetime. In 58% (derived from the NPV) of the cases the AER is paid off within the 25 years. As mentioned earlier there is a business case for the first two net metering scenarios.

8.4.3. Comparing results AER with the other two BIPV roofing solutions.

As concluded in the benchmark between BIPV roofing solutions and the aesthetic energy roof. The AER positions itself between the BIPV in-roof and BIPV tiles solution. The Monte Carlo analysis confirms this conclusion. Similar to the BIPV in-roof solution there is a business case for the AER under the first two scenarios. For the third scenario, it depends on the amount of self-consumption and the discount rate if there is a positive NPV after 25 years. Increasing the self-consumption will probably come with extra investments in the form of storage and/or smart appliances. Therefore, we do not see a business case here yet. However, for the first two net metering scenarios there are definitely opportunities for Aerspire to compete with the other BIPV roofing solutions.

With a discounted payback period between the 9 and 13 years (net metering scenario 1); the AER cannot compete yet with the BAPV roofing solution where the payback period varies between 6 and 9 years. Under metering scenario 2, the minimum and maximum difference between the two roofing solutions is respectively 4 and 7 years. Under the third net metering scenario, there is no business case.

8.5. Conclusion

There is no full roof solution on the Dutch BIPV market at this moment. AER is when introduced, the first full roof solution. However, before Aerspire can introduce their roofing solution, multiple barriers have to be overcome. Next to the technical challenges, the product must be cost-competitive. Although the AER is cost comparable with the BIPV in-roof solutions and cheaper than the BIPV tiles solutions, this is this not the case for BAPV as a roofing solution. However, with a price gap of just over 20%, we see opportunities for the AER. Although longer payback periods for the AER have to be taken into account. Furthermore, we found a business case for the AER under the unlimited and fixed tax rebate net metering scenario.

9. Conclusion and discussion

9.1. Introduction

In the introduction chapter, we have shown that the installed capacity of solar PV in the Netherlands has increased rapidly in the past few years. In 2013, the installed capacity almost doubled from 365 MW to 665MW. More than 80% of it is installed on privately owned rooftops. The increase is mainly the result of the Dutch net metering policy and the decreasing PV system prices. Today the Dutch on-roof PV market is dominated by Building-Applied PV roof solutions. A small niche market is the so-called Building Integrated PV (BIPV). BIPV solutions hold large promises for the future. Due to its double functionality, it should have multiple advantages over the BAPV roofing solutions such as savings in material, operation, and installation and improved aesthetics.

In this thesis, we have investigated the potential technical and economic benefits of BIPV from a household perspective. Moreover, the impact of the barriers and opportunities from a technical, market and policy perspective were analyzed. With these constraints, BIPV as a roofing solution was compared to BAPV as a roofing solution. Finally, a case study was conducted on a specific BIPV roofing solution that was being developed at the time of writing conducting the research. In summary, this thesis elaborated on “how and under which circumstances does the successful emergence of the BIPV roofing market take place?”.

9.2. Sub-conclusions

Chapters 1 through 3 described the introduction, theory and methodology. The theory concludes that BIPV as a niche causes the multi-regime interaction of the roof regime and the Dutch electricity regime. We used three elements to describe the learning processes of SNM with respect to BIPV. For the successful emergence of a niche market, there is a need for an enabling technology, a favorable market, a favorable governmental policy.

Chapter 4 described a desk study in which the BIPV market was investigated. In this chapter we concluded that the Dutch conventional roofing business is dominated by pitched roofs with tiles. Moreover, most common houses with these roofs are the terraced house and the detached house. We investigated the existing BIPV solutions for this roof type and concluded with a segmentation in six product categories: ‘in-roof mounting systems’, ‘full roof BIPV solutions’, ‘large sized solar tiles’, ‘small sized solar tiles, ‘PV membranes’ and ‘metal panels’. Finally, we investigated the key market drivers for the BIPV products and identified them to be Price, Aesthetic value, Environmental value and Incentives/Policies.

Chapter 5 described a benchmark study conducted using a survey sent to Dutch BIPV industry parties to investigate the current status and price levels of the Dutch BIPV market. The survey was conducted using a fictional reference roof of a terraced house that needed to be equipped with a PV system of which the electricity production matched the consumption of the resident. Three types of integration were considered: Retro-fitting, Renovation and Newly built. Furthermore, three product categories were considered: BAPV, in-roof systems and BIPV tiles. Out of the 30 approached parties, 22 responded making the survey the most complete survey of the BIPV sector in The Netherlands known to date. From the benchmark study, we conclude that the renovation and newly built markets are the most favorable for BIPV, as the costs for regular roof materials can be prevented in this case which leads to a cost saving of typically 1.500 euro per project for a terraced house. In the renovation market, the average prices were 10.000 euro for a BAPV roof renovation project, 12.000 for a BIPV in-roof mounting system roof renovation project and 18.000 euro for a BIPV tiles roof renovation project. Regarding the price levels within the product categories, we observed a 10% price spread within the BAPV product category, 20% within the BIPV in-roof mounting product category and 70% within the BIPV tiles product category. The conclusion that can be drawn from these figures that in the BAPV segment there was strong competition on price, whereas in the BIPV tiles segment no tough price competition took place at the moment of conducting the survey. As final conclusion, the BIPV price benchmark study showed that at least 13 products have been developed for the Dutch BIPV market. The success of the companies indicated that the BIPV market holds promises as a roofing solution in the Netherlands.

In chapter 6, we conducted an extensive desk study and investigated the barriers and opportunities within the BIPV niche. This chapter is concluded per learning process element. There is a challenge for BIPV from a technology perspective. The demand for variety in color and shape makes BIPV complicated to achieve. Benefiting from the economies of scale is hard to achieve which makes it difficult to compete with the establihed PV solutions. Furthermore, are the additional physical building requirements for BIPV more complex than for BAPV. These barriers demand for innovative entrepreneurs and engineers, who can benefit from the promise of BIPV as a multi-functional technology. From a market perspective, we identified two important drivers fort BIPV, the profitability and the aesthetics. We defined that a system is profitable when the NPV of PV produced electricity is equal or lower than the NPV. Second, the aesthetics of a BIPV solution were discussed. The aesthetics are part of the trade-off between aesthetics, price and to a lesser extent environmental value. From a policy perspective, we concluded that net metering is the most important driver for privately owned PV. Changing the net metering policy will have significant effects the economic feasibility of privately owned PV systems. When the net metering policy changes, there are opportunities for self-consumption. Increasing the self-consumption increases the policy independence of PV. Other opportunities lie in the EPC norm legislation. The new EPC norm will probably contribute to an increase in privately owned PV systems. BIPV could benefit from those house owners who have to install a PV system but do not appreciate the aesthetics of the currently installed BAPV systems. A barrier of governmental policies is the legislation concerning the reclamation of the VAT over a BIPV system. For a BAPV system, one can reclaim the VAT over the complete PV system. For a BIPV system, one can only reclaim 1/3 of the VAT over the complete PV system.

Chapter 7 emphasizes the techno-economic feasibility of BAPV and BIPV as roofing solutions. The results of the Monte Carlo analysis shows that there is no business case for BIPV tiles. In the best-case scenario, the average payback period is still 24 years with a NPV of about 1.000€. The BIPV in-roof solution is economically feasible under the unlimited and fixed tax rebate scenario with average NPVs of respectively 14.500€ and 11.500€. The average discounted payback period is under these scenarios is 9 and 12 years. Under the abolished net metering scenario, there is a business case under right conditions. Moreover, that depends mainly on the amount of electricity a household self-consumes. Overall, the discount rate has a large impact on the NPV and therefore the profitability of a roofing solution. For BAPV roofing solutions, there is a business case under all net metering scenarios. The average NPV between the three net metering scenarios vary between about 16.500€ for unlimited net metering and 4.500€ under the abolished net metering scenario. The average discounted payback period varies between 7 and 17 years. In summary, there is partly a favorable market for the BIPV in-roof solutions. For the BIPV tiles is under these conditions no favorable market. For the BAPV as roofing solution there is a possible business case under all scenarios.

In chapter 8, we conclude the results for the aesthetic energy roof (AER). For the concept of the aesthetic energy roof, the turnkey price is positioned between the BIPV tiles solution and the BIPV in-roof solution. Moreover, the AER is more expensive than the BIPV in-roof products but cheaper than the BIPV tiles products. With a turnkey price of about 19.000€, the price gap with the BAPV roofing solutions is just over 20%. Overall, we see opportunities for the AER, also because of its aesthetics. The homogenous and modern appearance of the roof makes the product unique and different from the BIPV solutions currently available on the Dutch market. Analyzing the results from the sensitivity analysis, we conclude there is a business case for the AER under the unlimited and fixed tax rebate net metering scenario.

9.3. Final conclusion and discussion

Finally, based on the extensive desk studies, market benchmarks, techno-economic modelling and statistical analyses conducted throughout this report, the following key conclusion can be drawn: The successful emergence of BIPV depends on the technical and economic feasibility, which depend on multiple elements: an enabling technology, a favorable market but also on the existence of favorable governmental policies. These elements are interrelated and all have to be favorable to some extent at a given moment.

The technical feasibility of BIPV is determined by the quality and variety of the BIPV products. The quality of the BIPV roofing products should match the current conventional building standards. The quality (i.e. in terms of yield, guarantee, and lifetime) of the generating part of a BIPV system must be able to compete with the BAPV systems. Furthermore, there is need for a wide variety in shapes and colors for the PV panels in order to fulfil the promise of an aesthetic innovation. The economic feasibility has to be favorable regarding the turnkey prices of the BIPV solutions. To be successful the price should be competitive with BAPV roofing solutions. Not the last because the PV market is mainly price driven. When BIPV can compete with BAPV on product prices than the aesthetics can be a great asset. In order to be able to compete with BAPV, the government policies have to be favorable to some extent. The uncertainty about the net metering policy results in a risk when ones invest in BIPV. Due to the higher investment costs is the payback time under some net metering scenarios unacceptable. Increasing the amount of self-consumption can perhaps overcome this uncertainty in the future. Finally, BIPV suffers from the inequality regarding the reclamation of VAT legislation.

9.4. Limitations and future prospects

Here we discuss the limitations and future prospects with respect to this thesis. The role of the aesthetics of BIPV with respect to the economic feasibility is recognized but not investigated in this thesis. More research is needed to determine the added value of the aesthetics of BIPV as a roofing product.

For earlier explained reasons, we focused for the sensitivity analysis of the roofing solutions merely on detached houses. Therefore, it is not determined what the technical and economic feasibility of the different roofing solutions is for smaller (terraced) houses. Another sensitivity analysis is needed to determine this. Although, the price benchmark study showed the difference of turnkey prices between terraced and detached roofing solutions. These price differences can be used to roughly estimate the NPVs for the terraced roofing solutions.

The choice for a discount rate within the distribution range (0% – 5%) has a big impact on the NPV of a PV roofing solution. In order to predict the NPV more precisely, there is need for more clarity on the concept 'discount rate'. Moreover, there should be some kind of standard discount rate for comparing the economic feasibility of PV roofing solutions.

The amount of self-consumption is an important factor for the economic feasibility of BIPV. Especially when the remuneration for electricity sales price decreases. Increasing the self-consumption helps making a business case economically feasible. However, increasing the self-consumption is associated with other investments such as smart appliances and electricity storage. What the costs of these implementations will be is not included in the techno-economic model. Future research can investigate the impact of these measurements on the economic feasibility of BIPV and other PV roofing solutions.

This thesis does not further investigate why the legislation regarding the reclamation of VAT over a privately owned PV system is unequally distributed. Moreover, why there is a difference for BAPV and BIPV systems over the self-consumed part of the produced electricity. It is a discouragement for the BIPV niche. Future research should investigate this legislative inequality. The niche should lobby for the alteration of this legislation.

This thesis does not elaborates on the declining system prices of the different roofing solutions. The best moment for investing in a (BI)PV system depends also on the expected future turnkey prices. An extended sensitivity analysis could provide more insight in the effect of changing system prices on the economic feasibility of a roofing solution.

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Appendix

I. Results BIPV price benchmark report 2014

Results retrofit

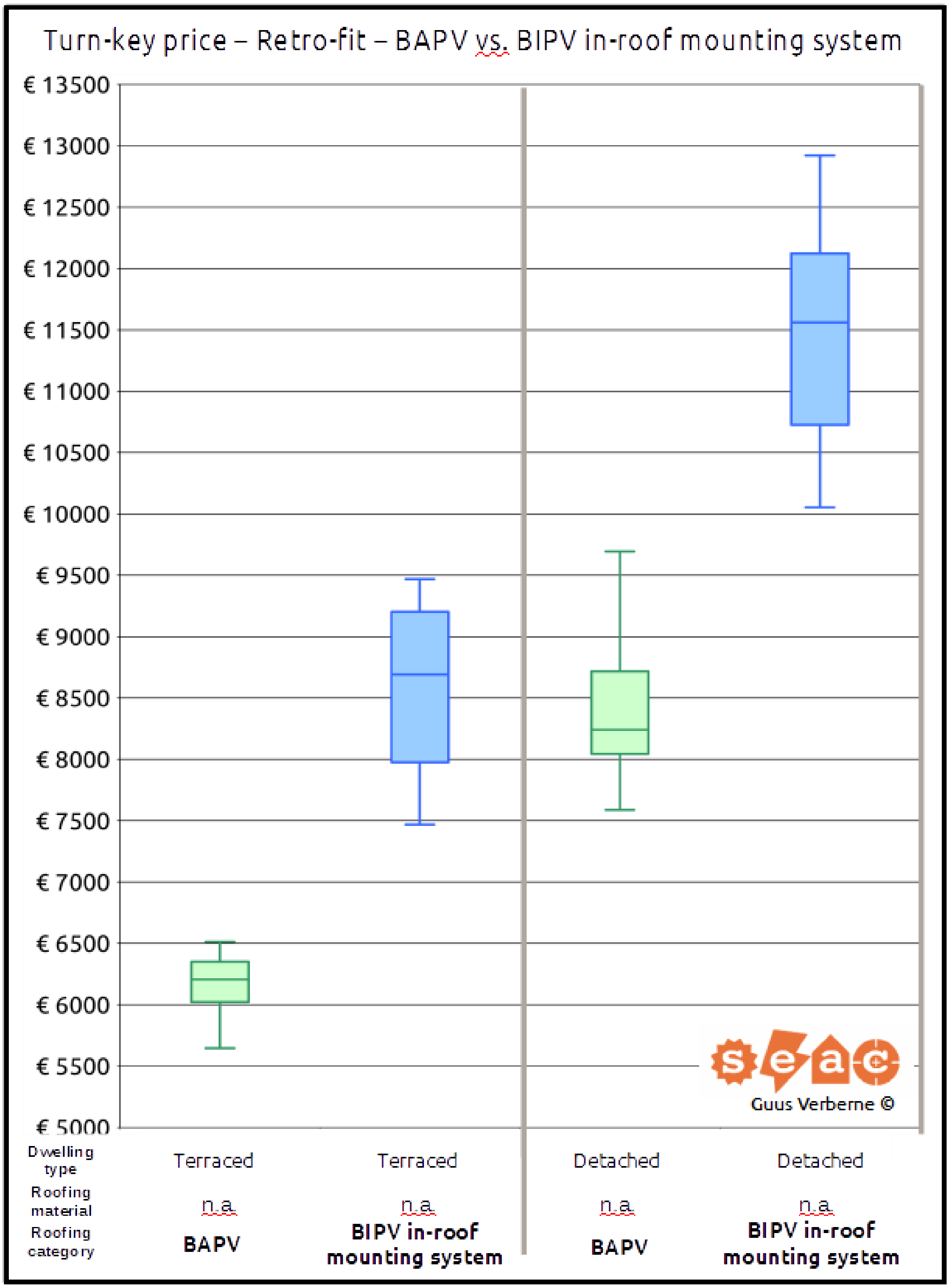


Figure 37: Box-and-whisker plot of turn-key price – Retro-fit – BAPV vs. BIPV in-roof mounting system

Results renovation

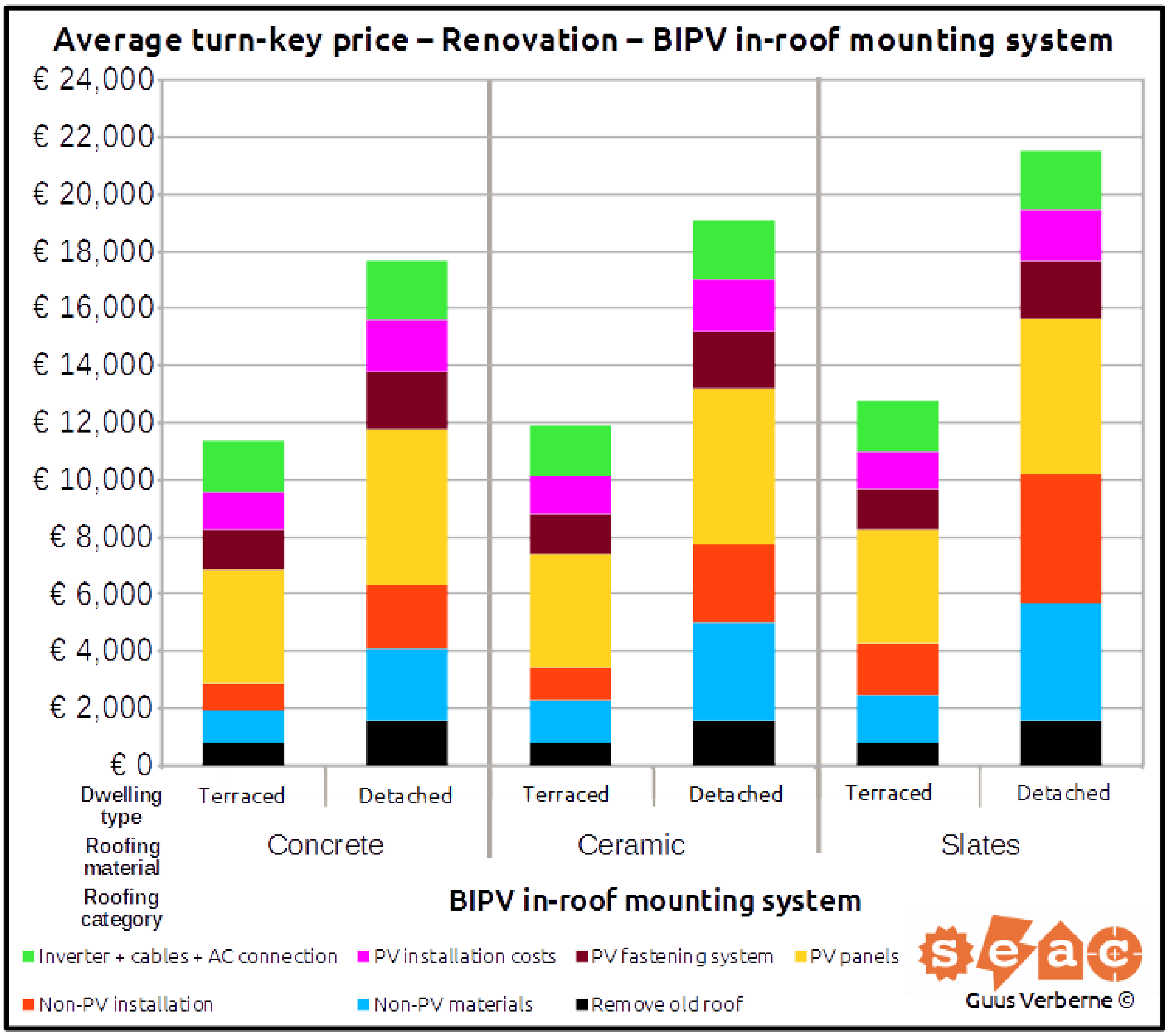


Figure 38: Average turn-key price BIPV in-roof mounting system - Concrete/Ceramic/Slates - Terraced vs. Detached

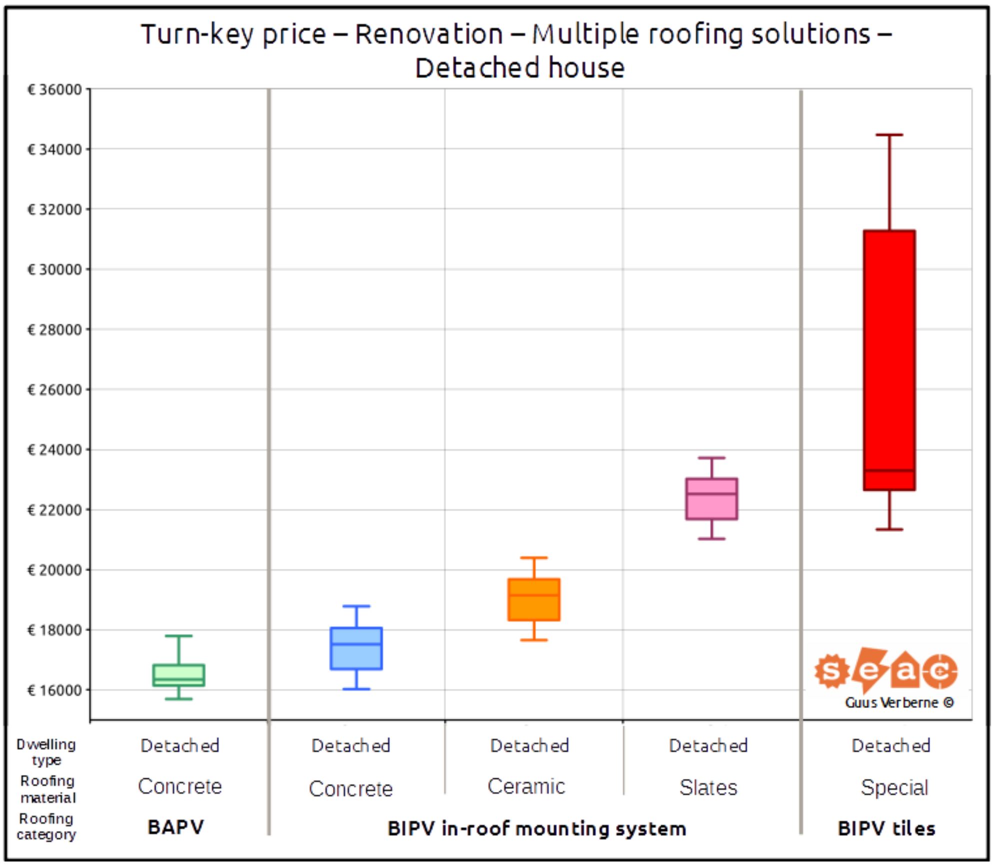


Figure 39: Box-and-whisker plot of turn-key prices of multiple roofing solutions for renovating a detached house.

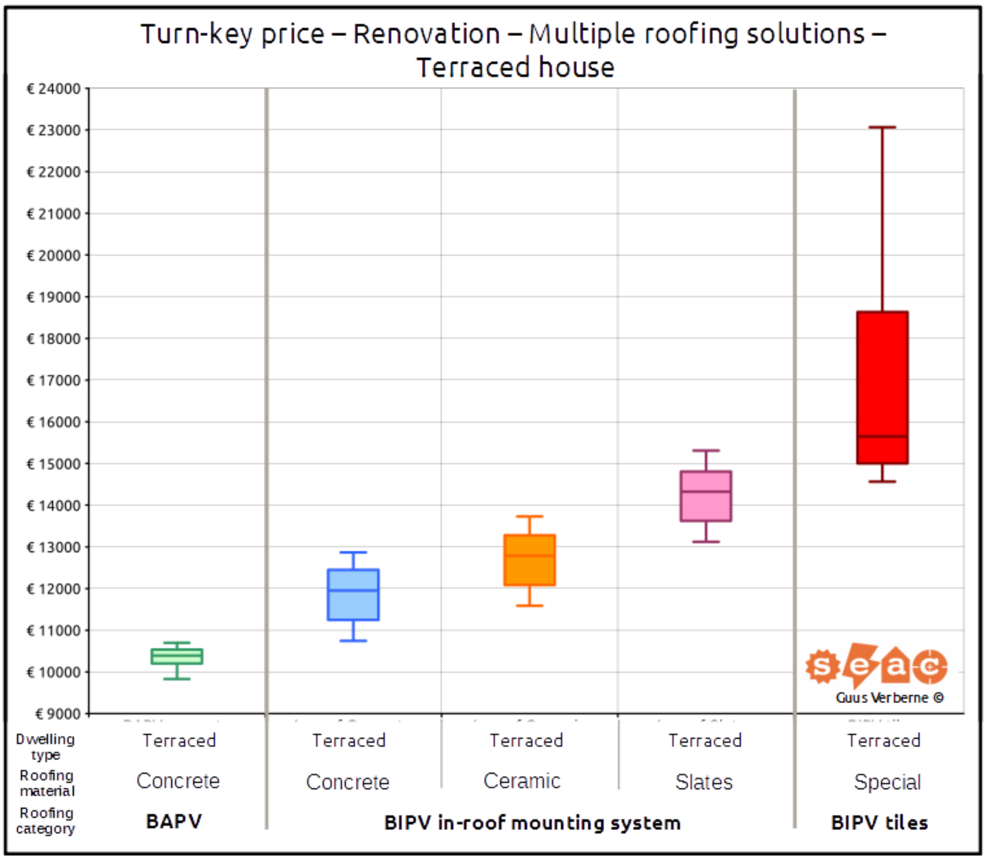


Figure 40: Box-and-whisker plot of turn-key prices of multiple roofing solutions for renovating a terraced house.

Results newly built

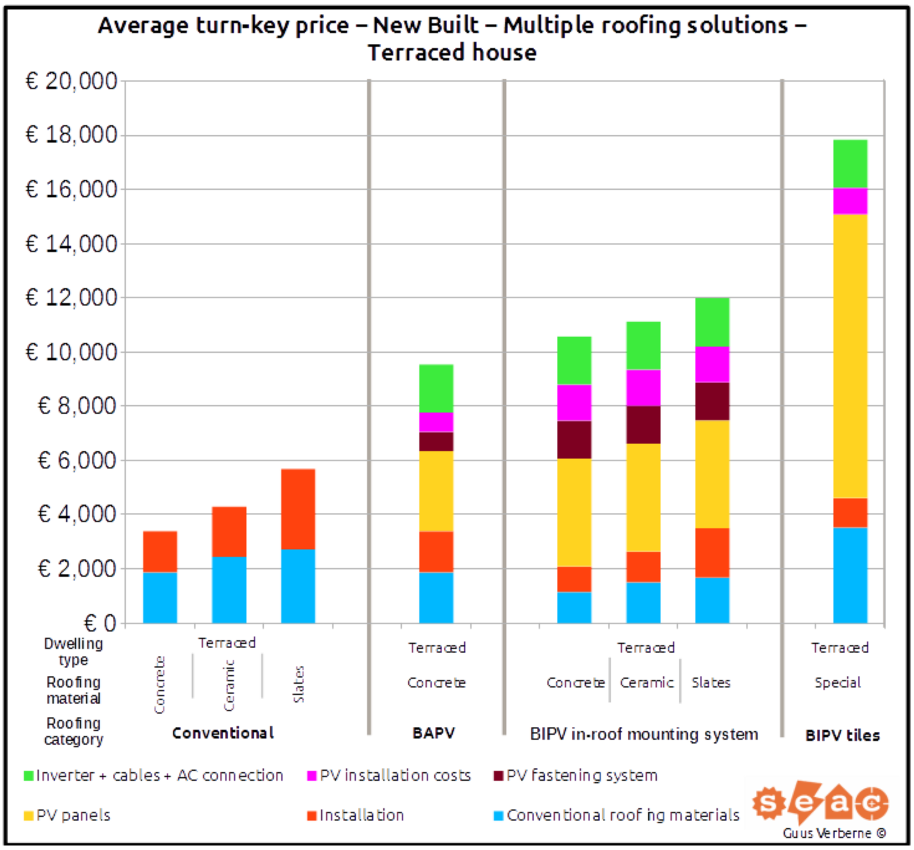


Figure 41: Average turn-key price - Newly built - Multiple roofing solutions - Terraced house.

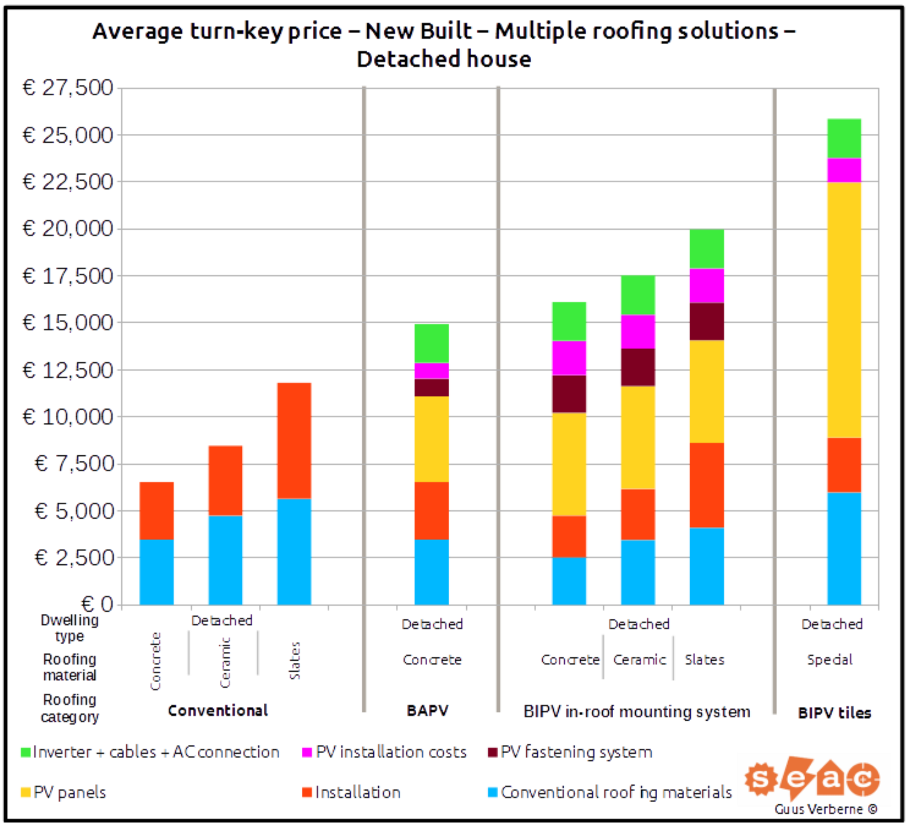


Figure 42: Average turn-key price - Newly built - Multiple roofing solutions - Detached house.

II. Dutch energy price structure

The energy structure can be divided into three parts; the energy costs, the distribution and transport costs, and the VAT and taxes (See Figure 1.8). The largest part of the pie chart (45%) are energy costs. This part can be sub-divided into electricity consumption and a part standing charge. The total electricity price per kWh is € 0.23, thus the energy costs per kWh are around € 0.10. The distribution and transport costs can be sub-divided into the connection, transport, and metering costs. In total, it represents 17% of the electricity price, which is about € 0.04. The last VATs and taxes account for 38%, which is € 0.09. The VATs comprise of metering, consumption and transport VATs. The composition of the price structure varies per energy supplier. It concerns here the price structure for small consumers.

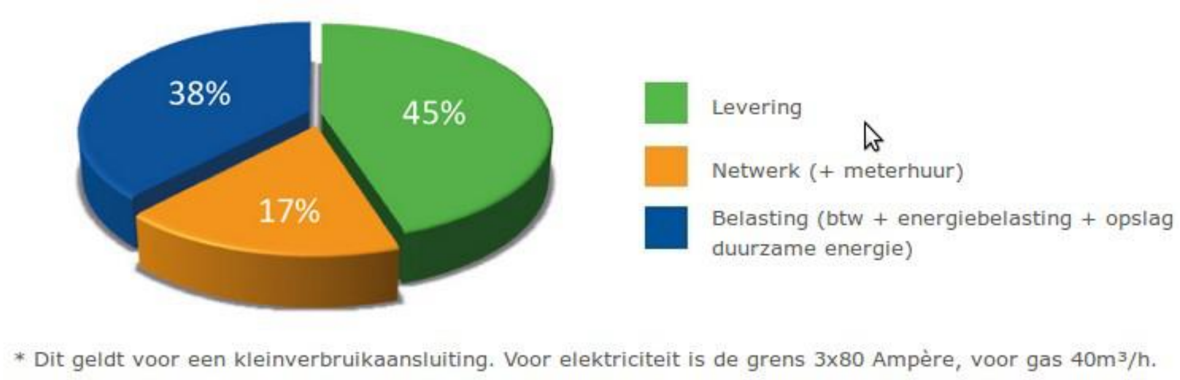


Figure 43: Price structure energy in the Netherlands (source: https://www.mainenergie.nl/thuis/tarieven).

III. Input, calculation and output parameters.

Monetary inflation

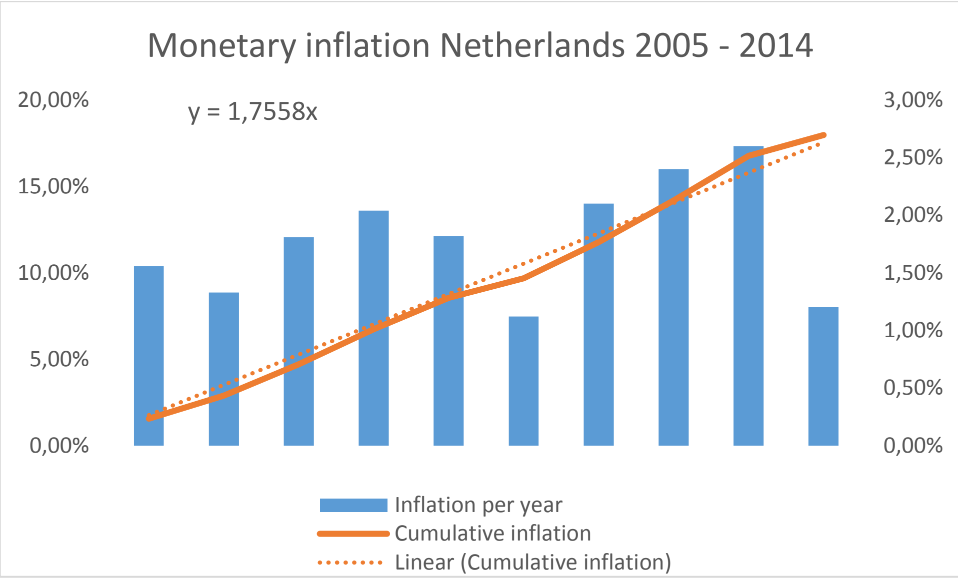


Table 5: Monetary inflation Netherlands 2005 - 2014

Mean	1,798
Standard Error	0,158077337
Median	1,815
Mode	#N/A
Standard Deviation	0,499884431
Sample Variance	0,249884444
Kurtosis	-1,028661189
Skewness	0,149267747
Range	1,48
Minimum	1,12
Maximum	2,6
Sum	17,98
Count	10
Confidence Level (95,0%)	0,35759578

Table 6: Descriptive statistics monetary inflation.

Contractduur *12 maanden*

Leverancier	Price excl. btw	VAT	total
Energiedirect.nl	€ 0,056	€ 0,019	€ 0,075
Qurrent Energie	€ 0,052	€ 0,011	€ 0,063
Greenchoice	€ 0,050	€ 0,011	€ 0,061
Anode	€ 0,053	€ 0,011	€ 0,064
Robin Energie	€ 0,047	€ 0,010	€ 0,057
Vastelastenbond	€ 0,058	€ 0,012	€ 0,070
E.ON	€ 0,057	€ 0,012	€ 0,069
DONG energy	€ 0,060	€ 0,013	€ 0,073
Nuon	€ 0,062	€ 0,013	€ 0,074
Essent	€ 0,060	€ 0,013	€ 0,073
Average	**€ 0,055**	**€ 0,012**	**€ 0,068**

Table 7: Average market electricity price (source: http://www.overstapgids.nl/elektriciteit/prijs/)

IV. Results net metering scenarios (chapter 7)

BAPV as a roofing solution

SUMMARY OUTPUT - BAPV roofing solution - Net metering scenario 1.				
Regression Statistics				
Multiple R	0,989049245			
R Square	0,978218409			
Adjusted R Square	0,978195147			
Standard Error	689,7564493			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	1,60058E+11	20007258094	42052,91
Residual	7491	3563947820	475763,9594	
Total	7499	1,63622E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	26082,2863	227,498661	114,6480871	0
Discount rate	-2930,288913	5,53443651	-529,4647264	0
Electricity price change	3290,957179	15,79054691	208,413122	0
Inflation over inverter/MLPM	-337,9245401	15,75910971	-21,44312378	4,8E-99
Installation and insurance cost (i	-5,423081882	0,148013097	-36,63920278	1,7E-270
Investment cost total system, ex	-5,363718672	0,095415821	-56,21414362	0
OM cost total system	-3004,976484	54,85412829	-54,78122755	0
Replacement inverter/MLPM	240,7767066	4,705547649	51,1686895	0
Self_consumption	132,1841383	68,75495133	1,922539915	0,054576

Table 8: Regression statistics of the NPV of a BAPV roofing solution under net metering scenario 1.

SUMMARY OUTPUT - NPV - BAPV roofing solution - Net metering scenario 2.				
Regression Statistics				
Multiple R	0,987768058			
R Square	0,975685736			
Adjusted R Square	0,97565977			
Standard Error	587,4521689			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	1,03737E+11	12967123904	37574,97
Residual	7491	2585144480	345100,0508	
Total	7499	1,06322E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	18488,81572	194,5642924	95,02676723	0
Discount rate	-2259,381023	4,743142045	-476,3469028	0
Electricity price change	2584,37768	13,51088433	191,2811638	0
Inflation over inverter/Ml	-344,9493302	13,59693089	-25,36964651	2,73E-136
Installation and insurance	-5,209946829	0,134836597	-38,63896697	5,34E-298
Investment cost total syst	-5,421456136	0,081532771	-66,4941968	0
OM cost total system	-3034,769224	46,52212123	-65,23282137	0
Replacement inverter/ML	243,9792172	3,954597746	61,69507819	0
Self_consumption	8597,297528	58,59485991	146,7244318	0

Table 9: Regression statistics of the NPV of a BAPV roofing solution under net metering scenario 2.

SUMMARY OUTPUT - NPV - BAPV roofing solution - Net metering scenario 3.				
Regression Statistics				
Multiple R	0,983011612			
R Square	0,966311828			
Adjusted R Square	0,966275851			
Standard Error	606,8335142			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	79125919076	9890739884	26858,989
Residual	7491	2758537632	368246,914	
Total	7499	81884456708		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8433,438751	200,8009236	41,9990038	0
Discount rate	-1390,161543	4,863316477	-285,8464074	0
Electricity price change	1749,58157	14,13087038	123,8127252	0
Inflation over inverter/MLI	-309,8058663	13,90378485	-22,28212459	1,5E-106
Installation and insurance (	-5,451925245	0,138385894	-39,39653893	0
Investment cost total syste	-5,450982541	0,08436499	-64,61190286	0
OM cost total system	-3116,477117	48,59760327	-64,12820608	0
Replacement inverter/MLI	253,9195267	4,080620458	62,22571525	0
Self_consumption	19434,00328	60,41904813	321,6535825	0

Table 10: Regression statistics of the NPV of a BAPV roofing solution under net metering scenario 3.

SUMMARY OUTPUT - Payback period - BAPV roofing solution - Net metering sc				
Regression Statistics				
Multiple R	0,915412266			
R Square	0,837979617			
Adjusted R Square	0,837806588			
Standard Error	0,297320122			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	3424,93398	428,1167	4842,99
Residual	7491	662,1988204	0,088399	
Total	7499	4087,1328		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-5,564212615	0,098063497	-56,7409	0
Discount rate	0,264371038	0,002385624	110,8184	0
Electricity price change	-0,272291453	0,006806529	-40,0045	0
Inflation over inverter/MLI	0,014247054	0,006792978	2,097321	0,035999
Installation and insurance	0,005417942	6,38012E-05	84,91915	0
Investment cost total syste	0,005317337	4,11291E-05	129,2842	0
OM cost total system	0,924985915	0,02364492	39,11986	9,3E-305
Replacement inverter/MLF	-0,001932753	0,00202833	-0,95288	0,340682
Self_consumption	-0,018422372	0,029636882	-0,6216	0,534222

Table 11: Regression statistics of the discounted payback period of a BAPV roofing solution under net metering scenario 1.

SUMMARY OUTPUT - Payback period - BAPV roofing solution - Net metering sce				
Regression Statistics				
Multiple R	0,937270681			
R Square	0,87847633			
Adjusted R Square	0,878346549			
Standard Error	0,41812853			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	9467,353343	1183,419168	6768,91
Residual	7491	1309,662524	0,174831468	
Total	7499	10777,01587		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-6,744258271	0,138484265	-48,70053861	0
Discount rate	0,451979056	0,003376008	133,8797492	0
Electricity price change	-0,481110839	0,009616589	-50,02925956	0
Inflation over inverter/	0,016680774	0,009677834	1,723606075	0,08482
Installation and insuran	0,007328968	9,59721E-05	76,36560216	0
Investment cost total sy	0,007283241	5,80323E-05	125,5033205	0
OM cost total system	1,643098558	0,033112868	49,62114894	0
Replacement inverter/I	-0,030573458	0,002814749	-10,86187881	2,8E-27
Self_consumption	-3,988850531	0,041705834	-95,64250728	0

Table 12: Regression statistics of the discounted payback period of a BAPV roofing solution under net metering scenario 2.

SUMMARY OUTPUT - Payback period - BAPV roofing solution - Net mete				
Regression Statistics				
Multiple R	0,92009282			
R Square	0,846570798			
Adjusted R Square	0,846406944			
Standard Error	2,044675793			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	172800,0903	21600,01	5166,6
Residual	7491	31317,61693	4,180699	
Total	7499	204117,7072		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-6,291923835	0,676582255	-9,29957	1,8E-20
Discount rate	1,529312031	0,016386546	93,32729	0
Electricity price chan	-2,057718787	0,04761281	-43,2178	0
Inflation over inverte	0,502287645	0,046847664	10,72172	1,3E-26
Installation and insu	0,014753195	0,00046628	31,64021	2E-206
Investment cost tota	0,015163231	0,000284261	53,34265	0
OM cost total system	5,792446691	0,163745641	35,37466	1E-253
Replacement inverte	-0,321696391	0,013749316	-23,3973	7E-117
Self_consumption	-32,26378935	0,203577031	-158,484	0

Table 13: Regression statistics of the discounted payback period of a BAPV roofing solution under net metering scenario 3.

BIPV in-roof mounting system as a roofing solution

SUMMARY OUTPUT - NPV - BIPV in-roof solution - Net metering scenario 1.				
Regression Statistics				
Multiple R	0,989520167			
R Square	0,97915016			
Adjusted R Square	0,979127894			
Standard Error	672,2293381			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	1,58972E+11	19871530465	43974,04
Residual	7491	3385125092	451892,2829	
Total	7499	1,62357E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	26768,51954	137,7045553	194,3909516	0
Discount rate	-2851,664596	5,38996991	-529,0687413	0
Electricity price change	3230,197878	15,60391338	207,0120361	0
Inflation over inverter/M	-365,3540899	15,54601988	-23,50145521	6,7E-118
Installation and insuranc	-5,718197827	0,150883076	-37,8982056	1,1E-287
Investment cost total sys	-6,225697642	0,042879323	-145,1911355	0
OM cost total system	-3507,573467	53,73003368	-65,28143064	0
Replacement inverter/M	243,2703315	4,511549102	53,92168544	0
% Rest Value of BIPV syst	38,55545201	53,84861021	0,715997161	0,474015

Table 14: Regression statistics of the NPV of a BIPV in-roof solution under net metering scenario 1.

SUMMARY OUTPUT - NPV - BIPV in-roof solution - Net metering scenario :				
Regression Statistics				
Multiple R	0,988035812			
R Square	0,976214766			
Adjusted R Square	0,976186186			
Standard Error	596,6250454			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	9	1,09427E+11	1,216E+10	34157
Residual	7490	2666151221	355961,44	
Total	7499	1,12093E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	18781,5679	123,2685218	152,36305	0
Discount rate	-2195,849712	4,73998264	-463,2611	0
Electricity price change	2570,421823	13,73791799	187,10418	0
Inflation over inverter/	-339,4713196	13,72517654	-24,73348	7E-130
Installation and insura	-5,63149795	0,13520735	-41,65083	0
Investment cost total s	-6,124221679	0,038575392	-158,7598	0
OM cost total system	-3528,401289	47,20631409	-74,74427	0
Replacement inverter/	248,7925336	4,043104768	61,53502	0
Self_consumption	8532,445563	59,54183533	143,30169	0
% Rest Value of BIPV sy	20,30097745	47,63356768	0,4261906	0,67

Table 15: Regression statistics of the NPV of a BIPV in-roof solution under net metering scenario 2.

SUMMARY OUTPUT - NPV - BIPV in-roof solution - Net metering scenari				
Regression Statistics				
Multiple R	0,983194			
R Square	0,966671			
Adjusted R Square	0,966631			
Standard Error	616,4351			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	9	8,25E+10	9,17E+09	24137,45
Residual	7490	2,85E+09	379992,2	
Total	7499	8,54E+10		
	Coefficients	*tandard Err*	*t Stat*	*P-value*
Intercept	9103,621	126,4988	71,96605	0
Discount rate	-1341,29	4,922588	-272,476	0
Electricity price change	1690,436	14,35089	117,7931	0
Inflation over inverter/MLPM	-331,583	14,06876	-23,5687	1,5E-118
Installation and insurance cos	-5,4971	0,13864	-39,6502	0
Investment cost total system,	-6,08474	0,039753	-153,062	0
OM cost total system	-3486,74	49,36081	-70,6378	0
Replacement inverter/MLPM	241,462	4,149307	58,19334	0
Self_consumption	19045,64	61,6779	308,792	0
% Rest Value of BIPV system	-3,46378	49,32296	-0,07023	0,944015

Table 16: Regression statistics of the NPV of a BIPV in-roof solution under net metering scenario 3.

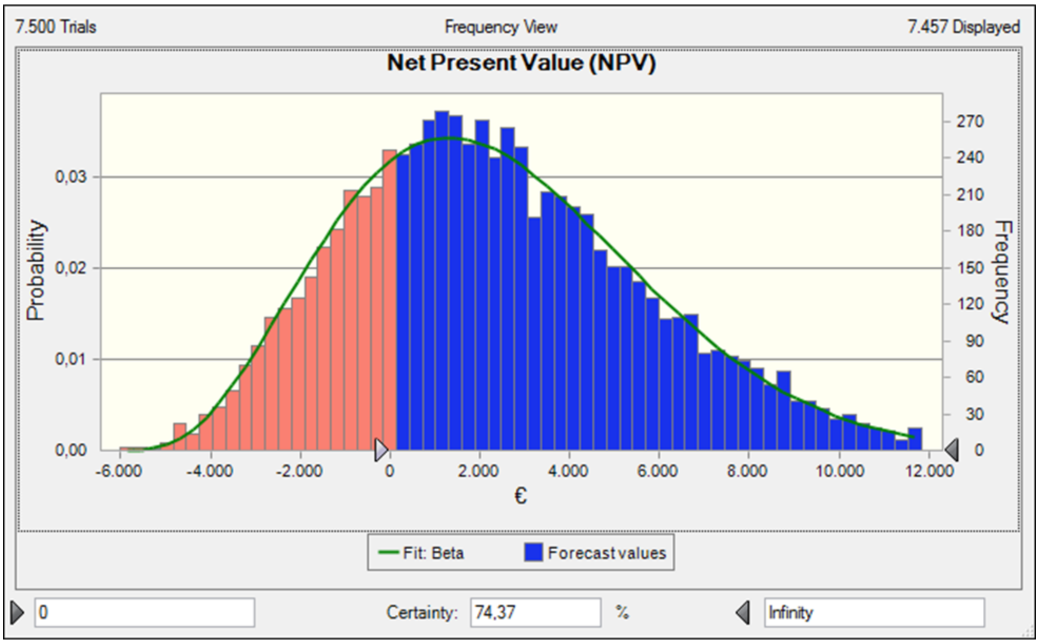


Figure 44: % with a positive NPV of a BIPV in-roof solution under net metering scenario 3.

SUMMARY OUTPUT - Discounted payback period - BIPV in-roof solution - I				
Regression Statistics				
Multiple R	0,956524002			
R Square	0,914938167			
Adjusted R Square	0,914847326			
Standard Error	0,439229389			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	15544,60135	1943,075	10071,8
Residual	7491	1445,18212	0,192922	
Total	7499	16989,78347		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-7,13625992	0,089975079	-79,3137	0
Discount rate	0,463010731	0,003521764	131,4712	0
Electricity price chan	-0,502471432	0,010195475	-49,2838	0
Inflation over inverte	0,016562503	0,010157648	1,630545	0,10303
Installation and insur	0,006079386	9,85858E-05	61,66592	0
Investment cost total	0,006645589	2,8017E-05	237,1983	0
OM cost total system	1,460952765	0,035106784	41,61454	0
Replacement inverte	-0,034479259	0,002947811	-11,6966	2,5E-31
% Rest Value of BIPV	-0,031381972	0,035184261	-0,89193	0,37246

Table 17: Regression statistics of the discounted payback period of a BIPV in-roof solution under net metering scenario 1.

SUMMARY OUTPUT - discounted payback period - BIPV in-roof solution - Net m				
Regression Statistics				
Multiple R	0,960269479			
R Square	0,922117472			
Adjusted R Square	0,922023888			
Standard Error	0,706838144			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	9	44306,55486	4922,951	9853,386
Residual	7490	3742,155007	0,49962	
Total	7499	48048,70987		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-8,837024153	0,146039617	-60,5111	0
Discount rate	0,862639619	0,005615588	153,6152	0
Electricity price change	-0,952227441	0,01627569	-58,5061	0
Inflation over inverter/ML	0,126270259	0,016260595	7,765414	9,22E-15
Installation and insurance	0,00886383	0,000160184	55,33534	0
Investment cost total syste	0,00991307	4,57013E-05	216,9099	0
OM cost total system	2,780281433	0,055926622	49,71302	0
Replacement inverter/MLI	-0,189440207	0,004789978	-39,5493	0
Self_consumption	-5,942726497	0,070540854	-84,2452	0
% Rest Value of BIPV syste	-0,07274648	0,056432801	-1,28908	0,19741

Table 18: Regression statistics of the discounted payback period of a BIPV in-roof solution under net metering scenario 2.

SUMMARY OUTPUT - Discounted payback period - BIPV in-roof solution - Net m				
Regression Statistics				
Multiple R	0,900895426			
R Square	0,811612568			
Adjusted R Square	0,811386202			
Standard Error	3,770159872			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	9	458667,734	50963,082	3585,3879
Residual	7490	106463,6499	14,214105	
Total	7499	565131,3839		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-4,622416757	0,773675689	-5,974618	2,412E-09
Discount rate	2,789564151	0,030106891	92,655338	0
Electricity price char	-3,867984779	0,087771022	-44,06904	0
Inflation over invert	1,02820495	0,086045544	11,949543	1,29E-32
Installation and insu	0,01547465	0,00084793	18,249914	7,723E-73
Investment cost tota	0,018221	0,000243135	74,941907	0
OM cost total systen	8,952324978	0,30189417	29,653852	8,08E-183
Replacement invert	-0,398538861	0,025377448	-15,70445	1,045E-54
Self_consumption	-45,47715222	0,377226321	-120,5567	0
% Rest Value of BIP\	-0,464000886	0,30166267	-1,538145	0,1240554

Table 19: Regression statistics of the discounted payback period of a BIPV in-roof solution under net metering scenario 3.

BIPV tiles as a roofing solution

SUMMARY OUTPUT - NPV - BIPV tiles solution - Net metering scenario 1.				
Regression Statistics				
Multiple R	0,992799381			
R Square	0,98565061			
Adjusted R Square	0,985635286			
Standard Error	688,3102631			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	8	2,4378E+11	3,0472E+10	64319,012
Residual	7491	3549018698	473771,018	
Total	7499	2,47329E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	26640,79888	106,8724853	249,276498	0
Discount rate	-2721,150241	5,502006533	-494,57416	0
Electricity price change	3158,600129	16,06373969	196,62919	0
Inflation over inverter/MLPM	-440,0436743	16,0351823	-27,442387	4,58E-158
Installation and insurance cost (	-5,710508808	0,157290901	-36,305398	5,34E-266
Investment cost total system, ex	-6,160732716	0,013222424	-465,93065	0
OM cost total system	-5800,0639	54,793174	-105,85377	0
Replacement inverter/MLPM	251,8835939	4,682535087	53,7921424	0
% Rest Value of BIPV system	-29,60223069	55,33693896	-0,5349452	0,5927036

Table 20: Regression statistics of the NPV of a BIPV tiles solution under net metering scenario 1.

SUMMARY OUTPUT - NPV - BIPV tiles solution - Net metering scenario 2.				
Regression Statistics				
Multiple R	0,993187885			
R Square	0,986422175			
Adjusted R Square	0,986405859			
Standard Error	602,571811			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	9	1,97575E+11	2,195E+10	60460,52
Residual	7490	2719564978	363092,79	
Total	7499	2,00295E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	19158,42664	94,11540804	203,56313	0
Discount rate	-2063,750308	4,806888747	-429,3318	0
Electricity price change	2476,959985	13,77454744	179,82151	0
Inflation over inverter/N	-412,2845169	13,85948202	-29,74747	6,7E-184
Installation and insuranc	-5,558012763	0,137566479	-40,40238	0
Investment cost total sys	-6,168581979	0,011461154	-538,2165	0
OM cost total system	-5907,229357	47,88942641	-123,3514	0
Replacement inverter/N	254,2899513	4,085911818	62,23579	0
Self_consumption	8237,560105	60,9092085	135,24326	0
% Rest Value of BIPV sys	13,55450151	47,94708407	0,2826971	0,777417

Table 21: Regression statistics of the NPV of a BIPV tiles solution under net metering scenario 2.

SUMMARY OUTPUT - NPV - BIPV tiles solution - Net metering scenario 3.				
Regression Statistics				
Multiple R	0,9919881			
R Square	0,98404039			
Adjusted R Square	0,98402121			
Standard Error	619,737889			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	9	1,77373E+11	1,97E+10	51313,3
Residual	7490	2876722130	384075,1	
Total	7499	1,8025E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	9702,34094	97,60016024	99,40907	0
Discount rate	-1239,80049	4,992862394	-248,315	0
Electricity price change	1648,77641	14,10951396	116,8556	0
Inflation over inverter/MLPI	-437,230923	14,35935715	-30,4492	4E-192
Installation and insurance cc	-5,38906171	0,142125982	-37,9175	6E-288
Investment cost total systen	-6,16395821	0,011785703	-523,003	0
OM cost total system	-5894,02448	49,50018582	-119,071	0
Replacement inverter/MLPN	244,012646	4,175716648	58,43611	0
Self_consumption	18754,3293	61,77407431	303,5955	0
% Rest Value of BIPV systen	58,345771	49,41002562	1,180849	0,2377

Table 22: Regression statistics of the NPV of a BIPV tiles solution under net metering scenario 3.

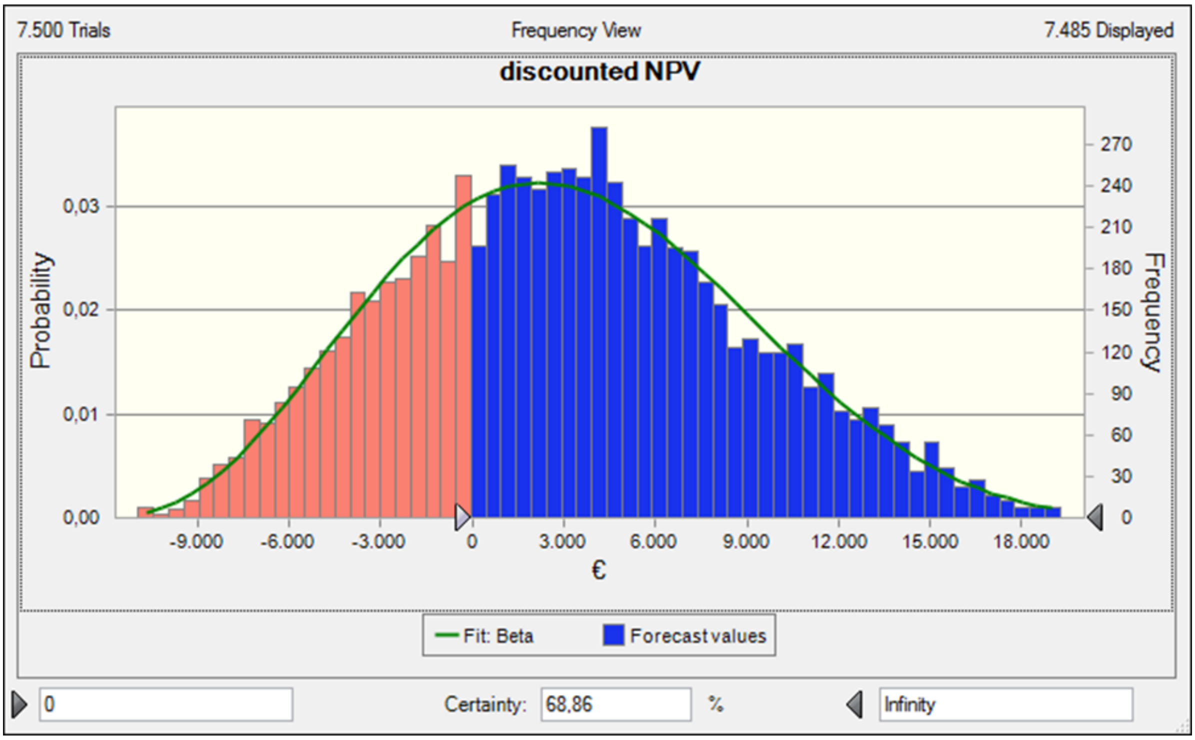


Figure 45: % with a positive NPV of a BIPV tiles solution under net metering scenario 1.

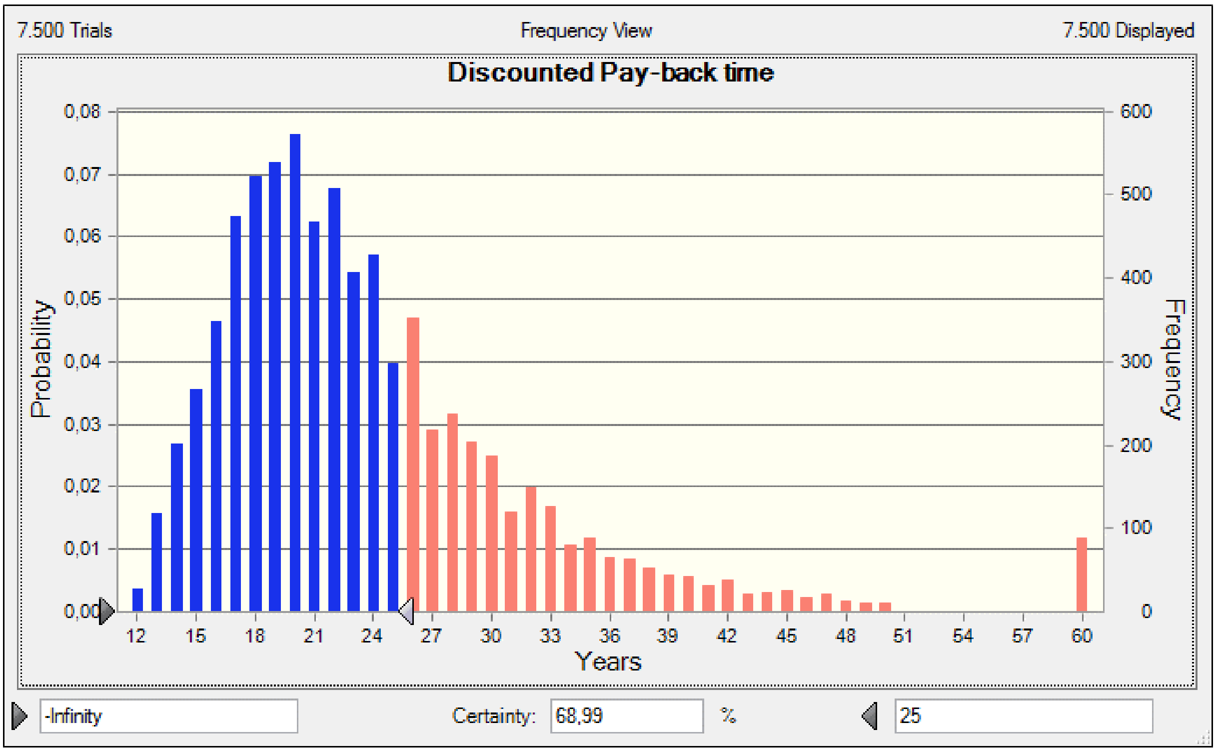
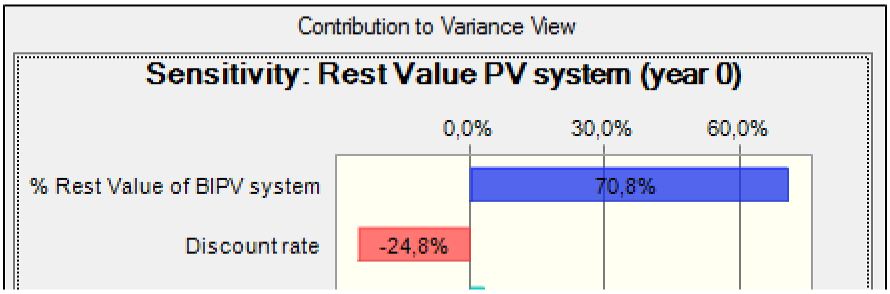


Figure 46: The discounted payback period of a BIPV tiles roofing solution under net metering scenario 1.

Discounted Salvage Value (DSV)



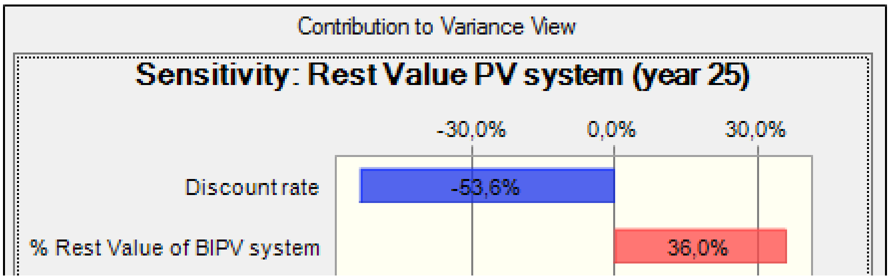


Figure 47: Contribution to variance of the DSV in year 0 and 25. A BIPV in-roof solution under net metering scenario 1.

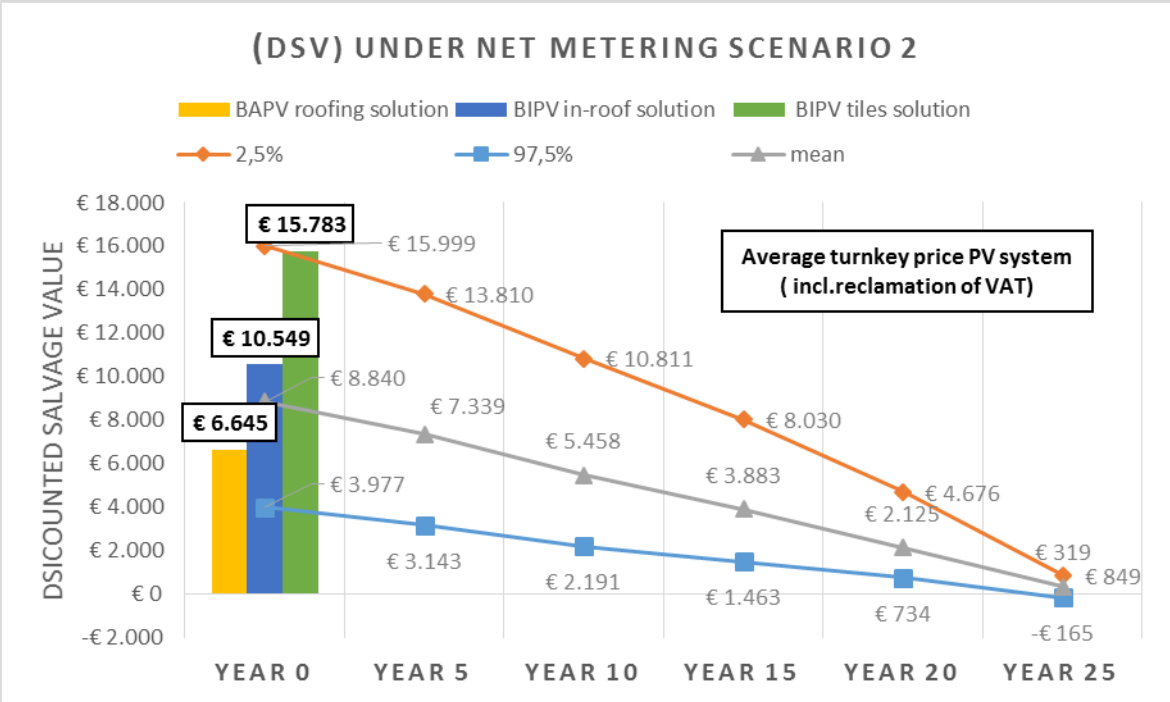


Figure 48: Discounted Salvage Value (DSV) under net metering scenario 2.

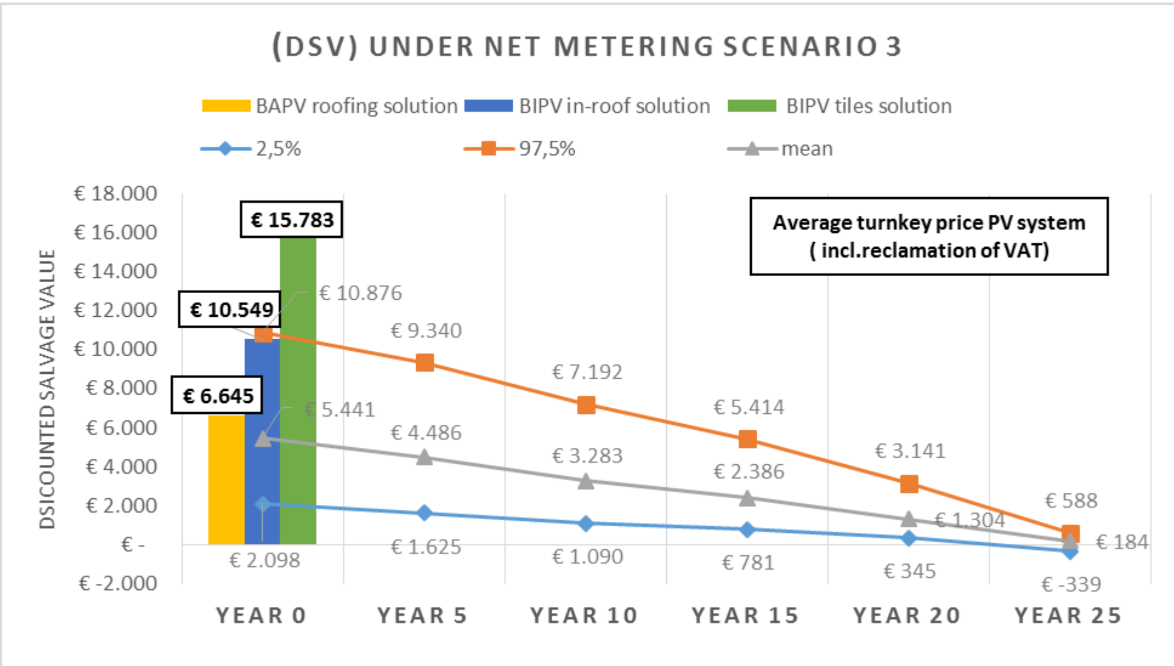


Figure 49: Discounted Salvage Value (DSV) under net metering scenario 3.

V. Results benchmark for the “aesthetic energy roof”

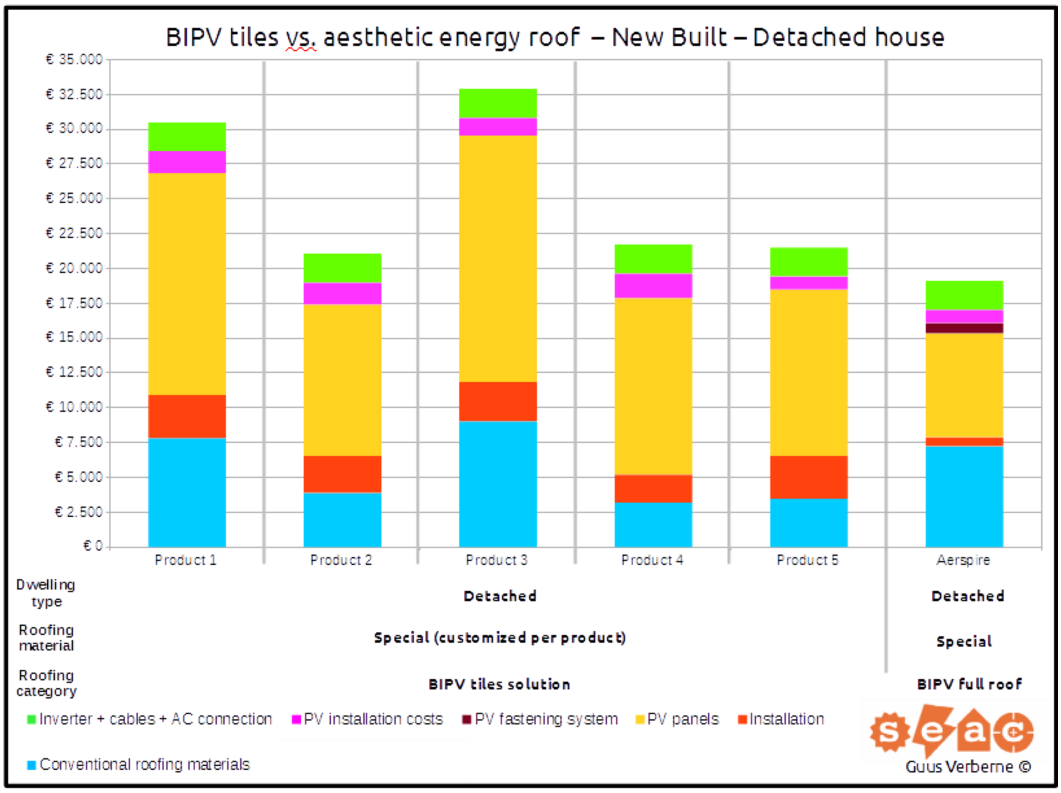


Figure 50: Turnkey prices BIPV tiles solution vs. the aesthetic energy roof for a detached house

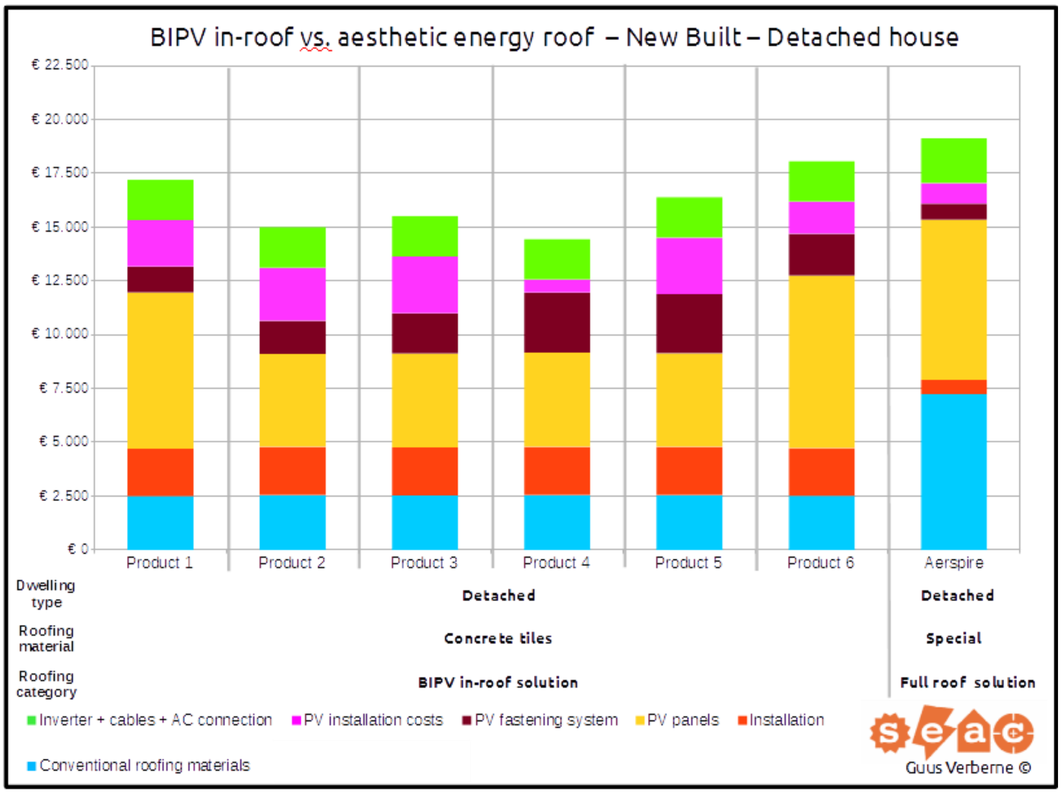
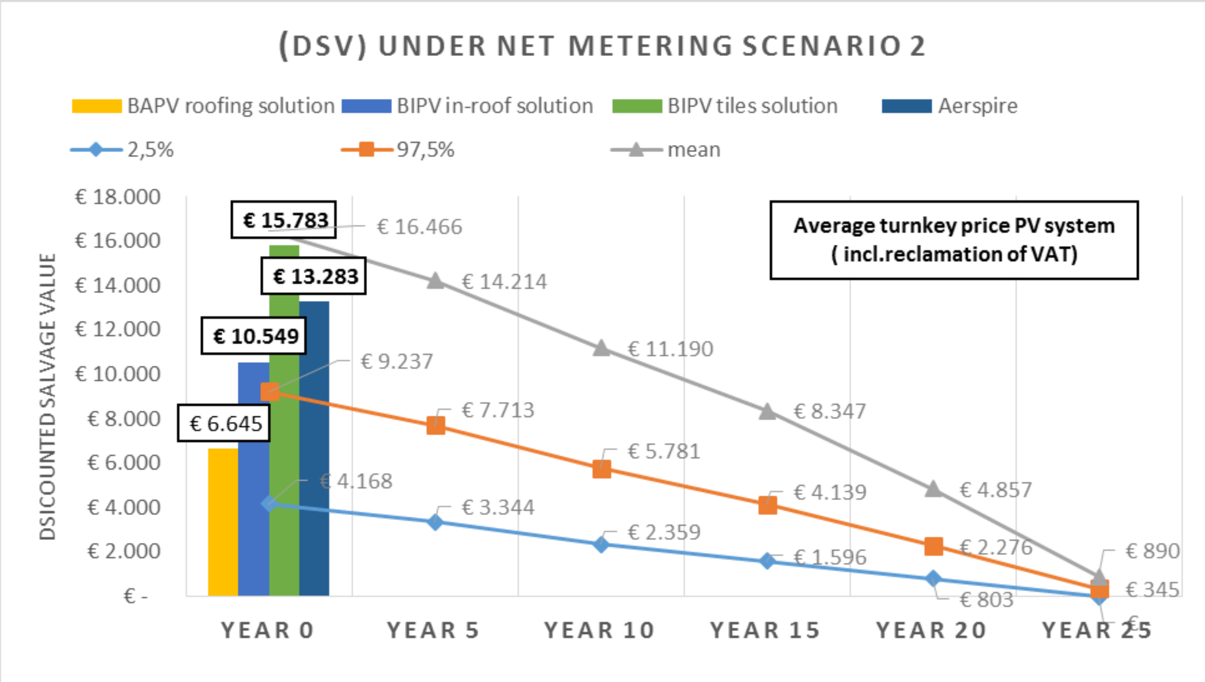


Figure 51: Turnkey prices BIPV in-roof solution vs. the aesthetic energy roof for a detached house.

VI. Results net metering scenarios “aesthetic energy roof”



Techno-economic model

Input variable	Roofing solution	Distribution	Range	
Technical parameters				
Installed Power	All	Fixed	5,1 kWp	
Annual yield	All	Fixed	880 kWh/a	Ratio
Module integration	BIPV AER integration	Fixed	0.98 (862,5 kWh/a)	Ratio
Degradation factor	AER	Fixed	0,2% per year	
CAPEX				
Investment costs total system, excl. inverter (excl. VAT)	AER	Fixed	€ 2624 per kWp	Min - Max
Investment cost inverter/MLPM	All	Fixed	€ 206 per kWh	
Installation and insurance cost (insurance not included)	AER	Fixed	€ 176,5 per kWp	Min - Max
Avoided costs	AER	Fixed (Concrete tiles)	€ 6535	
Economic lifetime	All	fixed	25 years	
OPEX				
Operation and Maintenance (OM)	All	Uniform Distribution	0 - 0,5%	Min – Max

Replacement inverter	All	Discrete Uniform Distribution	10 – 15	Min – Max
Electricity related parameters				
Total electricity consumption	All	Fixed	4488 kWh	
Self-consumption	All	Uniform Distribution	10% – 50 %	Min – Max
Electricity consumption price	All	Fixed	0,23 €/kWh	
Remuneration for electricity sales	Net metering scenario 1	Fixed	0,23 €/kWh (equal to electricity consumption price)	
	Net metering scenario 2	Fixed	0,159 €/kWh	
	Net metering scenario 3	Fixed	0,068 €/kWh (III)	
Electricity price change	All	Normal Distribution	2,8% (plus) (van de Water, 2014)	Std.Dev. 0,5
Additional economic and financial parameters				
The Value Added Tax (VAT)	BIPV	Fixed	14% (chapter 6.4)	
Monetary inflation	All	Normal Distribution	1,76%	Std.Dev. 0,5
The discount rate	All	Uniform Distribution	0% - 5%	Min – Max
% of salvage value for the BIPV system	All	Uniform Distribution	25% - 75%	Min – Max

Table 23: Parameters for the aesthetic energy roof under net metering scenario 1, 2 and 3.

Aesthetic energy roof as a roofing solution

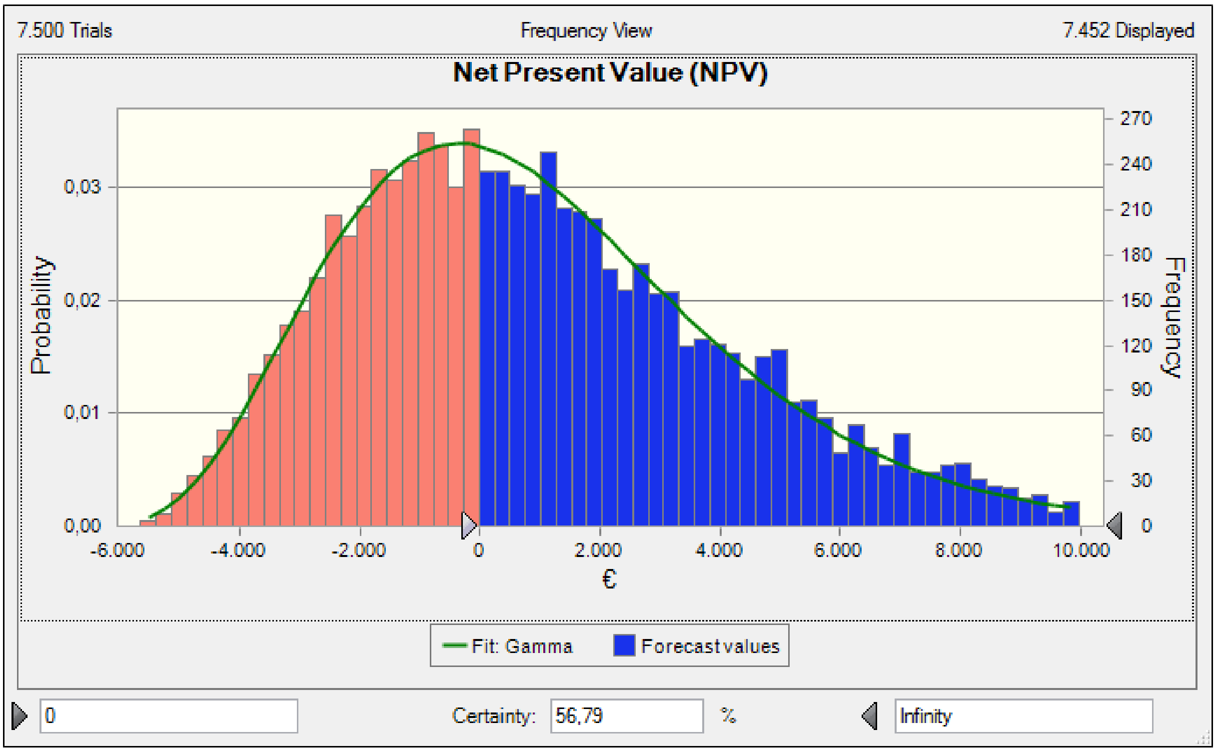


Figure 52: % with a positive NPV for the aesthetic energy roof, under net metering scenario 3.

SUMMARY OUTPUT - NPV - Aesthetic Energy Roof - Net metering scenario 1				
Regression Statistics				
Multiple R	0,989010578			
R Square	0,978141923			
Adjusted R Square	0,978124421			
Standard Error	704,8107878			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	6	1,66568E+11	2,78E+10	55884,89
Residual	7493	3722209542	496758,2	
Total	7499	1,7029E+11		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	10574,74229	88,74262374	119,1619	0
Discount rate	-3007,550595	5,651531882	-532,166	0
Electricity price change	3344,597407	16,35590745	204,4886	0
Inflation over inverter/MLPM	-355,5636874	16,37210079	-21,7177	1,8E-101
OM cost total system	-3880,813929	56,2038906	-69,0488	0
Replacement inverter/MLPM	248,2584121	4,794929323	51,7752	0

Table 24: Regression statistics of the NPV of the aesthetic energy roof under net metering scenario 1.

SUMMARY OUTPUT - NPV - Aesthetic Energy Roof - Net metering scenario 3.				
Regression Statistics				
Multiple R	0,982215844			
R Square	0,964747965			
Adjusted R Square	0,964715028			
Standard Error	602,5295941			
Observations	7500			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	7	74436202723	1,06E+10	29290,68
Residual	7492	2719910003	363041,9	
Total	7499	77156112726		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-7732,452641	77,35115319	-99,9656	0
Discount rate	-1376,79042	4,780742953	-287,987	0
Electricity price change	1737,717007	13,93588891	124,6937	0
Inflation over inverter/MLPM	-360,69413	13,93688236	-25,8805	1,6E-141
OM cost total system	-3801,980273	48,17284868	-78,9237	0
Replacement inverter/MLPM	251,9169365	4,092298685	61,55879	0
Self_consumption	19045,83991	60,05499133	317,14	0

Table 25: Regression statistics of the NPV of the aesthetic energy roof under net metering scenario 3.

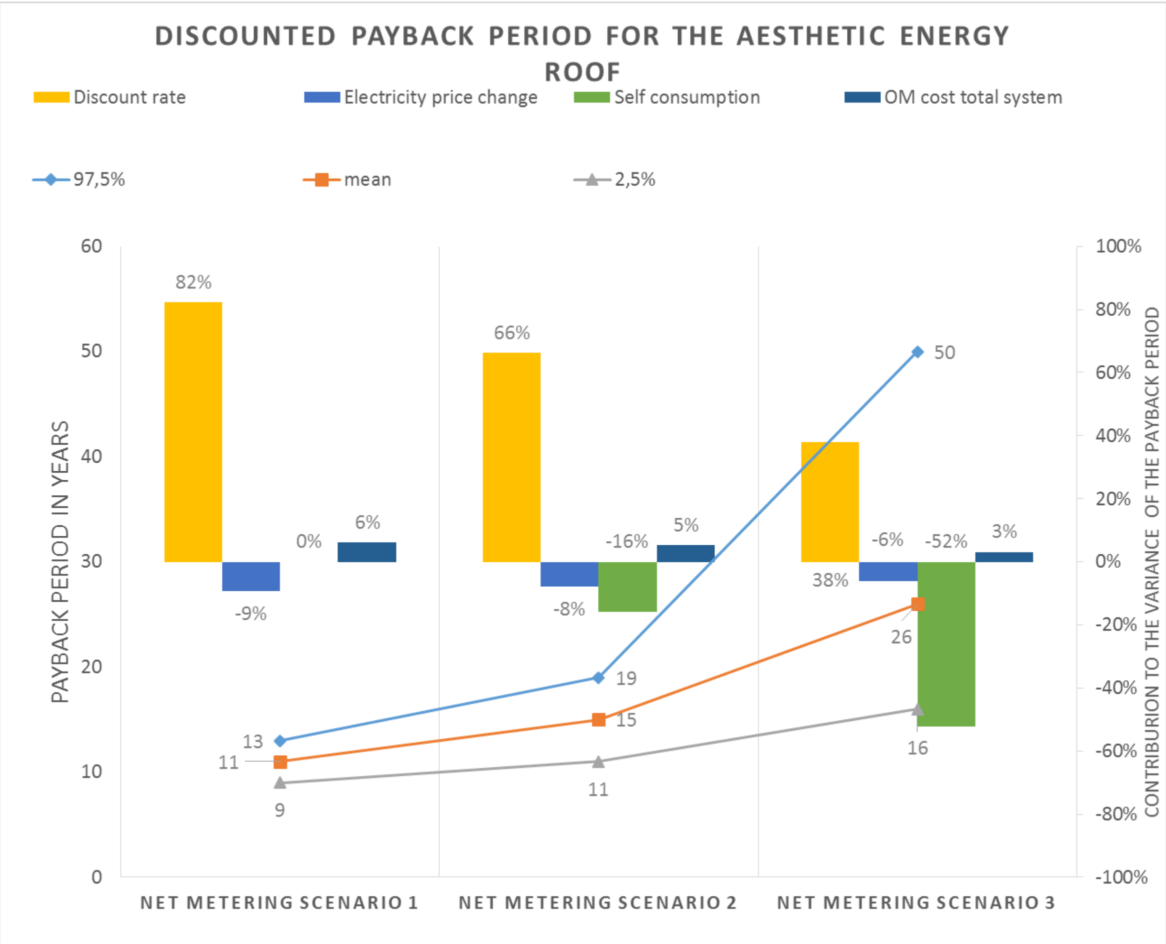


Figure 53: Discounted payback period for the aesthetic energy roof.