Economic Feasibility of Solar Panels in Amsterdam

Assessing and validating the potential of roof top solar panels in the city of Amsterdam

VU University Amsterdam

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Source: Stam, Diependaal, & Van 't Hull, 2013

Abstract

One of the aims of the Dutch national government is to stimulate renewable energy in order to create a green and diversified energy system. Solar energy is a vital part of this transition and necessary to be able to achieve the targets. In this context, the municipality of Amsterdam aims to reduce its dependency on fossil fuels and large international energy companies. Solar panels are often proposed as financially attractive using questionable assumptions, such as netting being possible the entire lifetime of solar panels or a 4% increase in energy price per year. In this thesis the solar potential of roof top solar panels is assessed and validated in order to determine the economic feasibility for the city of Amsterdam

The Klein and Theilacker (1981) model, the KT model, is set up to assess solar potential in the city of Amsterdam, because of its compatibility with the available data and its claimed high accuracy. In order to determine the economic feasibility of roof top solar panels a net present value analysis is performed that allows to explore the relative importance of different aspects that influence energy production and its revenues. Furthermore, the return on investment, payback time and levelized cost of electricity allow for assessing the risks related to investing in solar panels. Observed energy production data from solar panel systems in Amsterdam is used to validate the KT model, which is then used to assess the performance of the Zonatlas, because of its importance to decision making.

The cost-benefit analysis indicates that solar panel systems prices decrease from €2.06/Wp for a 4 solar panel system to €1.39/Wp for a 24 solar panel system under the assumption that netting remains possible during the economic lifetime of solar panels. The optimal conditions for energy production in the city of Amsterdam are a southward orientation and a slope of 33°, but if the slope is adjusted every month, the annual energy output of a solar panel increases by 3.23%.

The net present value for the roof tops in Amsterdam ranges from €0.09/Wp - €3.49/Wp, where the maximum is reached in optimal conditions. The orientation is more dominant than the slope in influencing the economic feasibility and if the solar panel is not facing south, it is better to install the solar panel relatively flat. Roof parts with a relatively low net present value, such as roof parts with a northward orientation or a steep slope (>35°), are very sensitive to a change in costs or energy price. Northward oriented roof parts are least sensitive to a change in solar radiation, since more optimal oriented solar panels are more efficient in converting solar radiation. Roof parts with relatively steep slopes (>35°) are more sensitive to a change in any of the factors, including solar radiation, than more gentle slopes.

The validation shows that the KT model deviates strongly from the observed energy production data from one year to the next year and between months. Further research is required to gain more insight in the causes of this deviation. The Zonatlas predicts less output than the KT model, which is partly explained by the fact that the Zonatlas detects steeper slopes than the roof top data set. For further research it is recommended to extend the validation analysis by including more observed energy production data and to increase the number of roof parts in the roof top data set in order to generate more robust results.

Preface

This research has been done in the context of a master thesis for my master Earth Sciences, specialization Earth Sciences & Economics, at the VU University Amsterdam. A personal aim of this thesis was to challenge my scientific skills of conducting an academic research. This project has been a great learning experience.

Special thanks go to my VU supervisor Eric Koomen, who has been of great value throughout this research. His comments and ideas have enhanced the quality of this thesis. Steven Fruijtier of Geodan, a geo-ICT company in Amsterdam, has been very kind to provide me with roof top data. I also want to thank Sanne Hettinga for her time and help with getting this thesis started. At last my gratitude goes out to Pieter van Beukering for being my second assessor.

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1. Introduction

In this chapter an introduction into this thesis is given, followed by the research questions. Furthermore, a short description of the method and a reading guide are presented. This chapter ends with an introduction into solar potential modelling.

1.1 Introduction

One of the aims of the Dutch national government is to stimulate renewable energy in order to create a green and diversified energy system, which is agreed upon in *Het Energieakkoord voor Duurzame Groei* (SER, 2013). Solar energy is a vital part of this transition and necessary to be able to achieve the targets. In this context, the municipality of Amsterdam aims to reduce its dependency on fossil fuels and large international energy companies (Stam, Diependaal & Van 't Hull, 2013). According to the municipality 11 km2 of suitable roof space is available for solar panels in the city of Amsterdam. This is sufficient to supply power to 330.000 households (Stam, Diependaal & Van 't Hull, 2013). The goal is to increase the installed capacity of 9 MW in 2013 to 160 MW in 2020 and up to 1000 MW in 2040. The municipality of Amsterdam acknowledges that meeting this goal depends on the willingness of citizens and businesses to invest in solar panels. An important factor for citizens and businesses whether to invest in solar panels is the financial attractiveness. Although other motives also play a role, such as saving the environment or being less dependent on big energy companies, the financial motives often are leading (Van Der Lelij & Visscher, 2013). The municipality of Amsterdam stimulates solar energy by informing citizens and businesses about solar energy, providing financing methods, searching for public roofs for solar projects and integrating solar energy carefully in the city to maintain public support (Stam, Diependaal & Van 't Hull, 2013).

In order to increase the integration of solar power in the city of Amsterdam the solar potential has to be fully utilized. The solar potential is defined as the expected generated energy by solar panels in kWh/year, in the city of Amsterdam. In order to maximize the use of this potential, it is essential to exploit the optimal conditions for roof top solar panels, specifically for Amsterdam. However, the literature is inconsistent about the optimal roof slope (Siderea, 2014, Stichting Monitoring Zonnestroom, 2015, Van Sark, 2014, www.zonatlas.nl, 2015d & www.essent.nl, n.d.(b)). Many institutes and companies that sell solar panels propose solar energy as financially attractive, based on questionable assumptions, such as a 4%/year increase in energy price and netting being possible during the whole lifetime of solar panels (Bontenbal, 2014, www.eneco.nl, 2015a). A 4%/year increase in energy price makes sense based on long-term historic observations (CBS, PBL & Wageningen UR, 2015 & CBS, 2015), but recent developments cause energy prices to drop, such as lower solar energy costs (Carr, 2012), a surplus of green energy in Germany and interlinking of the European energy market (www.pricewise.nl, 2015), a decreasing energy demand (Rooijers, Schepers, Van Gerwen & Van Der Veen, 2014), and decentralized energy production (Randall, 2015). The regulation of netting will be evaluated in 2017 and possibly reduced in 2020 (TK 2013/2014, 29 023, no. 175). A reduction in netting negatively influences the financial attractiveness of solar panels. It is therefore important to identify which factors have the highest impact on the economic feasibility of solar panels in Amsterdam in order to assess potential risks involved in the investment. This thesis, therefore, aims to establish a method that allows to explore the relative importance of the different aspects that influence energy production and its revenues. Therewith, it helps to increase the share of solar power in the city of Amsterdam.

1.2 Research Questions

The motivation for this research originates from a small research performed by Geodan, a geo-ICT company in Amsterdam. A new roof detection method was tested by comparing it to the Zonatlas. The Zonatlas is an online application that determines the economic feasibility of roof top solar panels in 230 municipalities in the Netherlands, which is also referred to by the municipality of Amsterdam to be used by citizens and businesses (www.amsterdam.nl, 2015). The comparison revealed large differences between the detection method and the Zonatlas. Since this application is already widely used by policy makers, households and housing corporations it is of great importance to decision making (www.zonatlas.nl, 2015a). Therefore, one of the objectives of this thesis is to validate the Zonatlas using a self-constructed solar potential model, based on scientific literature, and observed energy production data. In order to do this, it is necessary to determine the optimal conditions for roof top solar panels, specifically for the city of Amsterdam, to achieve the highest energy production. Based on the established solar potential model, it is also possible to assess the relative importance of the different conditions that influence the economic feasibility of roof-top solar panels in Amsterdam.

The following research question is leading in this thesis:

> *How to assess the economic feasibility of roof top solar panels in a spatially explicit modelling approach for the city of Amsterdam?*

This main question is answered through the following sub-questions:

> *How to assess solar potential for roof top solar panels in Amsterdam?*
>
> *What are the current costs and benefits of roof top solar panels?*

Using the method developed to answer the above questions it is then possible to answer the following questions related to finding the optimal location of solar panels:

> *What are the optimal conditions for roof top solar panels to achieve the highest energy production?*
>
> *Which factors have the highest impact on the profitability of roof top solar panels?*

In order to validate the assessment of the economic feasibility the following question is also answered:

> *How does the performance of the solar potential model relate to observed energy production data and the Zonatlas?*

Solar potential is dependent on the position on the Earth with respect to the Sun. Therefore, solar potential has spatial variation. The research questions above are applied specifically to the city of Amsterdam.

1.3 Reading Guide

In this section the structure of this research is highlighted. For every chapter a short description of the applied method is given. Section 1.4 contains an introduction in the development of solar potential modelling and reviews several solar potential models.

Chapter 2 describes the methods used to execute this research. The solar potential model is divided into its components in order to explain the workflow of the model. Furthermore, the economic assessment is explained. The net present value analysis, payback time, return on investment and levelized cost of electricity concepts are exemplified. These economic methods give a full understanding of the economic feasibility of solar panels on different locations. This chapter ends with a description of the validation methods that are used to assess the performance of the solar potential model.

In Chapter 3 the results are presented and illustrated. First, the implementation of the solar potential model for the study case, the city of Amsterdam, is discussed. Secondly, the costs and benefits of roof top solar panels are given, based on the Dutch market. Thereafter, the optimal roof op conditions are determined to fully utilize the solar potential of the roofs. Furthermore, the roof top data set is described, followed by the outcomes of the solar potential model of Klein and Theilacker (1981). Based on these results the economic feasibility is determined using the economic methods described in Chapter 2. The net present value expressed per Watt peak is the main component of the economic assessment, since most other sources express the economic value of solar panels this way (Milieu Centraal, 2015a & Van Sark et al., 2014). The net present value per Watt peak is also used in the sensitivity analysis, which examines the effect of a change in the energy price, costs or incoming solar radiation on the economic feasibility of solar panels. In the factor analysis the relative impact of these factors are given. This chapter concludes with a validation of the solar potential model using observed energy production data from a small sample of solar panel systems in Amsterdam. The solar potential model is then used to validate the Zonatlas.

Throughout Chapter 3 the results are briefly discussed. Chapter 4 contains an extensive discussion of the methods and main findings of this research. The limitations and assumptions of the methods are addressed. The main findings are compared with scientific literature and recommendations for further research are given. Chapter 5 presents the main conclusions of this research.

1.4 Solar Potential Modelling

In order to assess the solar potential on roofs in Amsterdam, it is necessary to have a solar potential model that is able to take the effect of the slope of the roof and the orientation, or surface azimuth slope, of the roof into account. Duffie and Beckman (2013) have collected multiple models and have laid down the fundamentals of solar potential modelling in their book "Solar Engineering of Thermal Processes". The authors describe the equations that calculate the incoming solar radiation per month on every possible roof slope and orientation. Also other authors have reviewed the accuracy and usefulness of these models, such as Guymard (2008), Jahkrani, Samo, Rigit & Kamboh (2013), Dervisi & Mahdavi (2012) and Freitas, Catita, Redweik & Brito (2014). In this section an introduction into solar potential models is given. Also the development of these models through time is highlighted.

1.4.1 Introduction

Solar potential models are designed to calculate the incoming solar radiation on solar panels. These models make use of the incoming solar radiation that is measured by weather stations on a horizontal surface. Solar panels are typically installed at an angle. Solar potential models convert the incoming solar radiation on a horizontal surface into incoming solar radiation on a sloped surface. Solar radiation consists of three main parts: Beam, diffuse and reflected radiation. Beam radiation is the radiation from the sun that is directly collected by the surface of the solar panel. Diffuse radiation is scattered through the atmosphere by particles and clouds. The direction from which the diffuse radiation is received, from a solar panel point of view, is dependent on the atmospheric clarity and cloudiness. These are both highly variable during the day, but can be estimated by using the clearness index (see Section 2.1.2.4). Reflected radiation has to do with the albedo of the surrounding surfaces that reflect some of the solar radiation back into the direction of a solar panel (see Section 3.1.2). Every solar potential model has its own way of taking into account the slope and orientation of solar panels and of modelling how incoming solar beams are scattered by the atmosphere and reflected by the ground (Duffie & Beckman, 2013).

In general, solar potential models can be divided into two types based on the input data. Hourly models use meteorological data of average incoming solar radiation per day. The distribution per hour is estimated accordingly. Monthly models use the monthly average incoming solar radiation and assume that each day has the same incoming solar radiation. Since, monthly average data is recorded by the Royal Dutch Meteorological Institute (KNMI, n.d.(a)) for a long period for the city of Amsterdam, this type of model is used in this research. However, hourly models in general have a higher accuracy, but also require more specific less widely available data (Duffie & Beckman, 2013). Over the years multiple variations of solar potential models have been developed. There is no agreement among the scientific community that one model performs best (Jahkrani et al., 2013 & Freitas et al., 2014). It is often pointed out that the accuracy of the model is largely determined by the study area, the slope and orientation of solar panels, and the months or seasons that are examined.

1.4.2 Development

Both hourly and monthly models are discussed in this section, since the development of these models contains many similarities and overlap. Hottel & Woertz (1942) were one of the first to include beam and diffuse radiation into one model. Isotropic models assume that all diffuse radiation is isotropic, meaning that the diffuse radiation received on a solar panel is equal from all directions. This is also one of the assumptions of the Hottel & Woertz (1942) model. In 1963 Liu & Jordan extended this model by including reflected radiation from the ground, which is caused by the albedo effect. Those two models require hourly data, but Liu & Jordan (1962) have also computed a monthly isotropic model, which is improved by Klein (1977). A big disadvantage of this model however, is that it is unable to deal with different orientations (Duffy & Beckman, 2013).

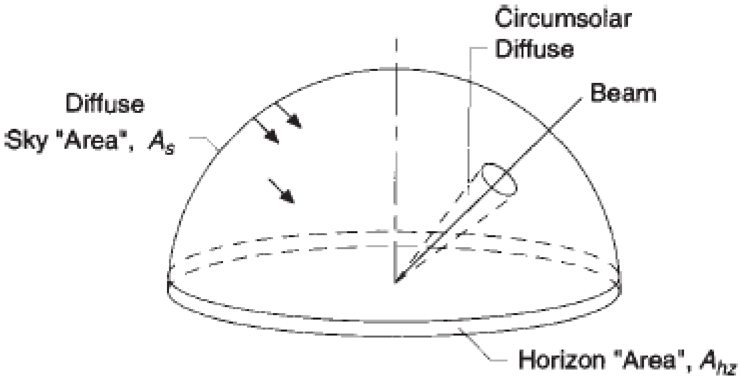


Figure 1 Three parts of diffuse radiation. Source: Perez et al. (1988).

Anisotropic models are more accurate and more complex than isotropic models, because the diffuse radiation is no longer assumed to be only isotropic. Besides, isotropic diffuse radiation, which is received uniformly from the entire sky dome (see Figure 1), also circumsolar and horizontal brightening diffuse radiation are taken into account (Perez, Stewart, Seals & Guertin, 1988). Circumsolar diffuse radiation encloses the beam radiation and is the result of forward scattering of solar radiation. Horizon brightening is mainly concentrated around the horizon.

Hay & Davies (1980) have developed a partly anisotropic model without horizontal brightening. Klucher (1979) had already proposed that this factor has to be part of any anisotropic model and developed a term to correct for horizontal brightening. In 1990 Reindl, Beckman & Duffie were able to include the horizontal brightening factor into the model. From that point on, it became known as the HDKR (Hay, Davies, Klucher, Reindl) model.

Perez, Ineichen, Seals, Michalsky & Stewart (1990) also include circumsolar diffuse radiation and horizontal brightening into a single model. Noorian, Moradil & Kamali (2008) compare 12 models for a case study in Karaj, Iran, including among others the HDKR and the Perez, et al. (1990) model, showing that the Perez, et al. (1990) model performs best, but also the HDKR model was among the best models. Also Guymard (2008) shows that by examining 10 models with and without ideal input data and conditions, the Perez model has the highest accuracy with ideal conditions and input data. With suboptimal input data the HDKR model is one of the best performing models.

However, Ivanova (2013 & 2014) states, after a detailed analysis of obstructed environments, that it is questionable to introduce horizontal brightening in urban environments as often this type of diffuse radiation is blocked by buildings and other urban structures. Duffie & Beckman (2013) also highlight that it is very impractical to calculate diffuse reflections in urban environments, because of changing reflections of solar radiation on buildings, trees and other objects.

Besides Liu & Jordan (1962) also Klein & Theilacker (1981), also known as the KT model, have developed a monthly isotropic model. The KT model is valid for every surface orientation, slope and latitude. Duffie & Beckman (2013) recommend the KT model, especially for sloped surfaces with a more than 15° southward orientation, because of its accuracy. In general, sloped surfaces to the east and west inhibit larger uncertainties in estimated radiation than southward sloped surfaces, due to the fact that early and late in the day instrumental errors may be more present when incoming solar radiation is measured by weather stations. This is caused by a relatively larger air mass and less certain atmospheric transmission (Duffie & Beckman, 2013). Because if its claimed high accuracy and the availability of monthly data for the city of Amsterdam (KNMI, n.d.(a)), the KT model is used in this research.

2. Method

In this section the methods used in this research are described. First, the method to set up the solar potential model is explained, including all the basic concepts. This is followed by the methods belonging to the economic assessment. This section concludes with a description of how the solar potential model and the Zonatlas are validated.

2.1 Solar Potential Modelling

In this section the solar potential model, the Klein and Theilacker model (1981), also known as KT model, is further explained. First the workflow of the KT model is described using a flowchart. Secondly, some concepts are discussed, such as the extra-terrestrial radiation, mean day of the month, declination, solar hour angle and clearness index, all of which are an essential part of solar potential modelling. In the last two sections the solar potential model is further elaborated in order to calculate the expected generated output of a solar panel.

2.1.1 Flowchart

In order to give an overview of how the KT model works, a flow diagram is given in Figure 2. Four blocks of variables are input to calculate the generated output per configuration of solar panels on a roof part in kWh/month. All twelve months are summed up and in the end the generated output is calculated for 25 consecutive years, which is the economic lifetime of a solar panel. The roof top data set contains information about the roof slope, orientation and surface area of the roof parts. The basic concepts of solar potential modelling are given in Section 2.1.2. Some factors are either location specific or solar panel specific. The efficiency, performance ratio, surface area and degradation rate of solar panels are specific characteristics and differ between solar panels. These components are described in Sections 2.1.4 and 3.1.3. The location specific variables are unique for Amsterdam, such as the latitude, incoming solar radiation on a horizontal surface, albedo effect and the optimal roof slope. These factors are described in Sections 3.1.1, 3.1.2 and 3.3. The equations belonging to the KT model are given in Section 2.1.3 and the final results in Section 3.4.2.

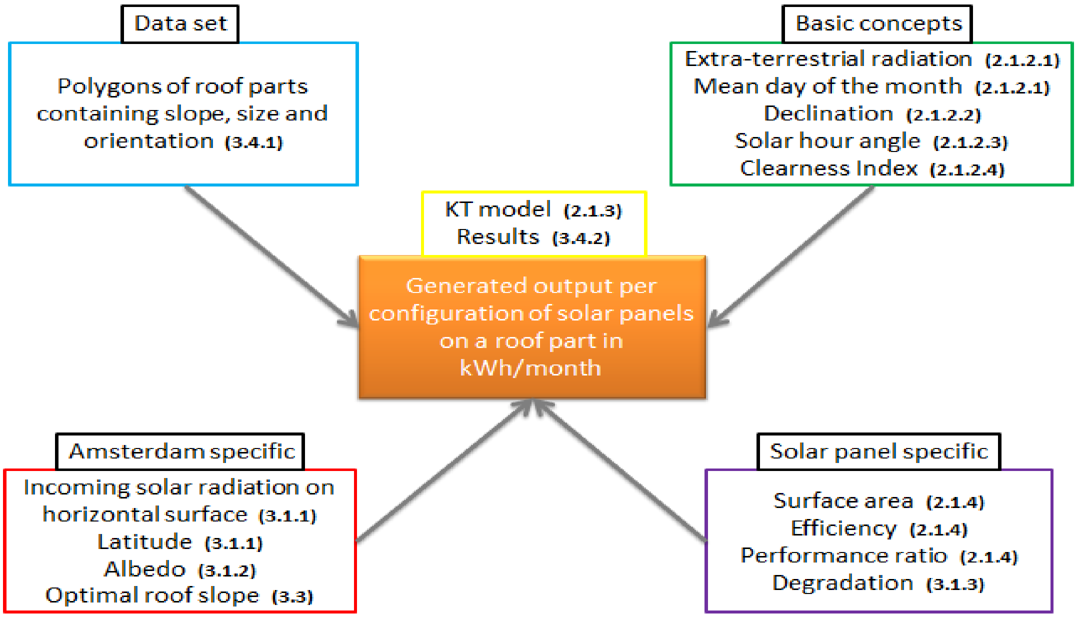


Figure 2 Flowchart of the KT model. In brackets the corresponding section.

2.1.2 Concepts of Solar Potential Modelling

In this section the concepts of extra-terrestrial radiation, mean day of the month, declination, solar hour angle and clearness index are discussed. These concepts are essential for understanding solar potential modelling.

2.1.2.1 Extra-Terrestrial Radiation and Mean Day of the Month

The solar constant, 1367 $\mathrm{W/m^2}$, is the energy from the sun received on a surface perpendicular to the direction of propagation of the radiation at mean Earth-Sun distance outside the atmosphere (Duffie & Beckman, 2013). Due to the eccentricity of the Earth's orbit the mean Earth-Sun distance, which is 1.495 x 10^{11} meters, varies by 1.7% during a year (see Figure 3). This variation in distance leads to a variation in influx of 3.3% of the extra-terrestrial radiation. Figure 4 shows the monthly variation in extra-terrestrial radiation, which is lower on the northern hemisphere in summer, because the Sun-Earth distance is greater.

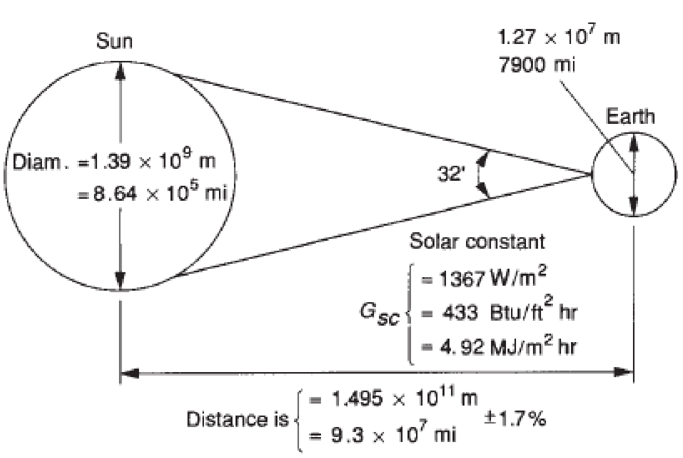


Figure 3 The relationships between the Sun and the Earth. Source: Duffy & Beckman (2013)

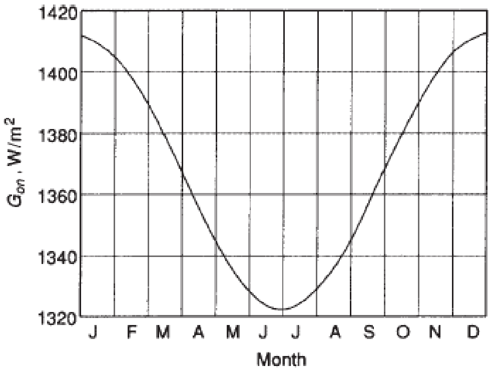


Figure 4 Extra-terrestrial radiation variation per month. Source: Duffy & Beckman (2013)

The extra-terrestrial radiation on a horizontal surface can be calculated using Equation (1). It is the solar radiation that would strike the Earth if there was no atmosphere scattering the solar radiation.

$$H_0 = \left(\frac{24*3600G_{sc}}{\pi} * \left(1+0.033\cos\frac{360n}{365}\right) * \left(\cos\varphi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\varphi\sin\delta\right)\right)/1000000 \qquad (1)$$

Where:

H_0 is the extra-terrestrial radiation in $\mathrm{MJ/m^2}$
G_{sc} is the solar constant 1367 $\mathrm{W/m^2}$
n is day of the year
φ is the latitude
δ is the declination
ω_s is the sunset hour angle

Due to the monthly variation of the extra-terrestrial radiation, the mean day of the month is not always the 15th or 16th day of the month (see Table 1). Klein (1977) has determined the mean day of the month by selecting for each month the day which is closest to the monthly mean value of incoming extra-terrestrial radiation. Using always the 15th or 16th day of the month leads to errors in the calculation of incoming solar radiation, especially in June and December. Table 1 gives the mean day of the month for each month by adding all days of the previous months to the mean day of the particular month. The declination and sunset hour angle are explained in Sections 2.1.2.2 and 2.1.2.3.

2.1.2.2 Declination

The declination, δ, is the angular position of the Sun when she is above the local meridian with respect to the plane of the equator. In other words, it is the angle between the Sun and the plane of the equator when the Sun reaches its highest point in the sky. It is a result of the tilt of the Earth and therefore variable between -23.45° and 23.45°. The declination can be calculated by Equation (2) (Spencer, 1971). The average monthly declination for Schiphol is shown in Table 1.

$$\delta = \left(\frac{180}{\pi}\right) * (0.006918 - 0.399912\cos \mathrm{X} + 0.070257\sin \mathrm{X} - 0.006758\cos 2\mathrm{X} + 0.000907\sin 2\mathrm{X} - 0.002697\cos 3\mathrm{X} + 0.00148\sin 3\mathrm{X}) \tag{2}$$

Where:

$$X = (n-1) * \left(\frac{360}{365}\right) \tag{3}$$

2.1.2.3 Solar Hour Angle

The solar hour angle, ω, is the angular displacement of the Sun either east or west of the local meridian due to the fact that the Earth rotates on its axis at 15° per hour. On horizontal surfaces the angle of incidence, θ_z, which is the angle of the beam radiation from the Sun, is between -90° and 90° when the Sun is above the horizon and exactly above the local meridian at 0° (see Figure 5). Equation (4) can be solved by setting $\theta_z = 90°$ (Duffie & Beckman, 2013):

$$\cos\theta_z = \cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta \tag{4}$$

Where:

θ_z is the angle of incidence on a horizontal surface
φ is the latitude
δ is the declination
ω is the solar hour angle

Equation (4), with $\theta_z = 9°0$, can be rewritten into:

$$\omega_s = cos^{-1}(-\tan\varphi * \tan\delta) \tag{5}$$

Where:

ω_s is the sunset hour angle
φ is the latitude
δ is the declination

With $\theta_z = 90°$, the solar hour angle has turned into the sunset hour angle, because if the angle of incidence is 90° it is possible to calculate the angle at which the Sun sets for a horizontal surface by using Equation (5). The sunrise hour angle is the negative of the sunset hour angle. As can be seen in Equation (5), the sunset hour angle is dependent on the declination and the latitude. Because of the tilt of the Earth, on the northern hemisphere days are longer in summer than in winter. As a result, the angles at which the Sun sets or rises are much larger in summer, because the Sun rises earlier and sets later. Table 1 shows the sunset hour angle for horizontal surfaces per month.

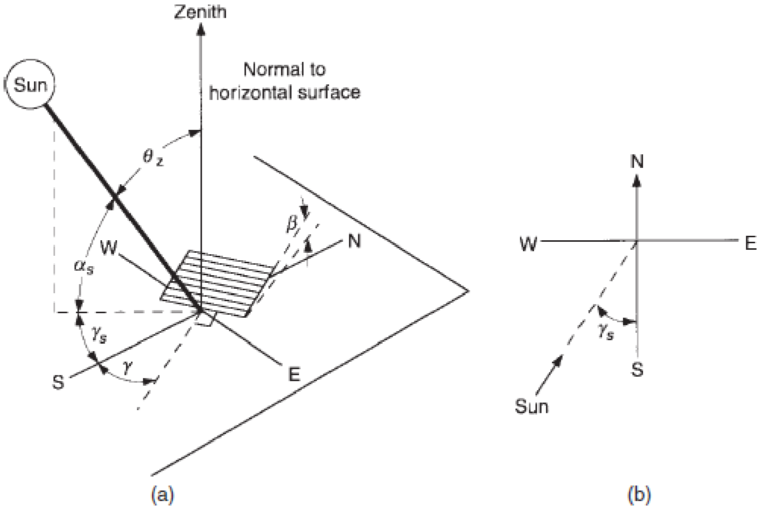


Figure 5 Relationships between a solar panel and the Sun. θ_z = the angle of incidence on a horizontal surface β = slope of the solar panel. γ = orientation of the solar panel. Source: Duffie & Beckman, 2013.

2.1.2.4 Clearness Index

In Section 1.4.1 the three components of solar radiation are explained. One of the components is the diffuse radiation. It is necessary to know which fraction of the total solar radiation is diffuse, since beam and diffuse radiation have a different amount of energy. The amount of diffuse radiation depends on atmospheric clarity and cloudiness, which can be estimated using the monthly average clearness index. It is the ratio (see Equation (6)) between the monthly average daily radiation on a horizontal surface and the monthly average daily extra-terrestrial radiation (Liu & Jordan, 1960), which is constant as is described in Section 2.1.2.1 (see Equation (1)). This ratio gives the fraction of the extra-terrestrial solar radiation that has been scattered, before it reaches the Earth's surface.

$$\bar{K}_T = \frac{\bar{H}}{H_0} \tag{6}$$

Where:
$\bar{H}$ is the monthly average daily radiation on a horizontal surface
H_0 is the monthly average daily extra-terrestrial radiation

The monthly average clearness index, $\bar{K}_T$, is used to determine the fraction of the total radiation, $\bar{H}$, that is diffuse. The ratio $\frac{\bar{H}_d}{\bar{H}}$ is plotted as a function of $\bar{K}_T$ to come up with a correlation. $\bar{H}_d$ is the monthly average diffuse radiation. This correlation method is not fully satisfactory and the resulting correlations vary by different authors (see Figure 6). The differences may be caused by instrumental errors, seasons, air mass and other weather variables (Duffie & Beckman, 2013).

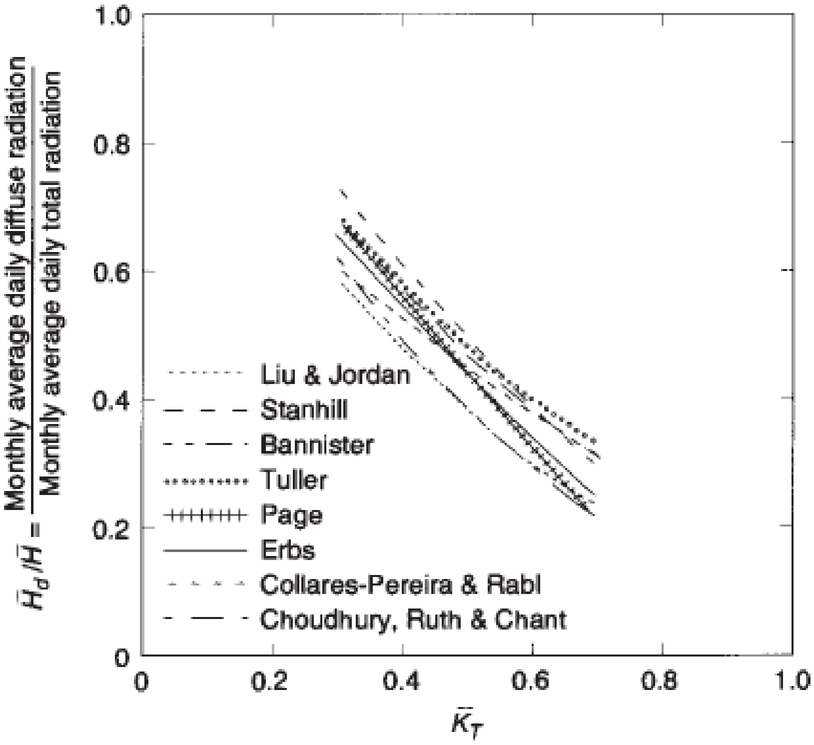


Figure 6 Correlations between the fraction of the incoming solar radiation that is diffuse and the clearness index. Source: Klein & Duffie (1978)

The correlation found by Erbs, Klein & Duffie (1982) is recommended by Duffie & Beckman (2013) and also one of the most widely used, such as by NASA in their Surface Meteorology and Solar Energy program that uses satellite measurements to estimate total beam and diffuse solar radiation (Stackhouse, 2006). It should be noted, however, that Erbs et al. (1982) have examined only four study sites in the USA. How applicable these correlations are to the Netherlands is uncertain, but studies for other locations have been performed. Dervisi & Mahdavi (2012) have computed a model comparison with eight different correlation models for Vienna, Austria. The Erbs model showed the best results. Erbs et al. (1982) also compared their correlation with data from Highett in Australia and the model of Orgill & Hollands (1977). The agreement of the results was within a few percent. A study by Ahwide, Spena & El-Kafrawy (2013) for Tripoli, Libya reveals that Erbs model has the best fit.

Erbs et al. (1982) have found a seasonal dependence in the correlation between the fraction that is diffuse and the clearness index (see Figure 6). Erbs et al. (1982) claim that during winter dust and moisture are lower and thus less solar radiation is diffused. This is highly questionable for the Netherlands, since Dutch winters are usually wet, but Velds (1992) found satisfactory results for the Netherlands when using Erbs correlation. The correlation is valid for a long-term average of 0.3 ≤ $\bar{K}_T$ ≤ 0.8. Winter and other seasons are divided by sunset solar angle and not by months. Equation (7) represents winter, when the sun does not get higher at the sky than 81.4°. Accordingly, winter in Amsterdam is from October up to and including February (see Table 1). Equation (8) is for all other months.

$$\omega_s \leq 81.4° \qquad \frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^{\ 2} - 2.137\bar{K}_T^{\ 3} \tag{7}$$

$$\omega_s \geq 81.4° \qquad \frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^{\ 2} - 1.821\bar{K}_T^{\ 3} \tag{8}$$

2.1.3 Klein and Theilacker Model

The model developed by Klein & Theilacker (1981), the KT model, is elaborated in this section. For a run of the KT model with example data, the reader is referred to Appendix II. The model calculates the long-term geometric conversion factor in order to convert the total solar radiation from a horizontal surface to a sloped surface (see Equation (9)).

$$\overline{H}_T = \overline{H} * \overline{R} \tag{9}$$

Where:
$\overline{H}_T$ is the total monthly daily average solar radiation on a sloped surface
$\overline{H}$ is the long-term monthly daily average solar radiation on a horizontal surface
$\overline{R}$ is the long-term geometric conversion factor

The long term geometric conversion factor, $\overline{R}$, in Equation (9), consists of different components (see Equation (10)). The Erbs coefficient (see Section 2.1.2.4) and the albedo (see Section 3.1.2) are corrected by $\left(\frac{1+cos\,\beta}{2}\right)$ and $\left(\frac{1-cos\,\beta}{2}\right)$. These terms are view factors of a solar panel. A solar panel can only collect incoming solar radiation that is in the cone of sight of the solar panel.

$$\overline{R} = D + \frac{\overline{H}_d}{\overline{H}}\left(\frac{1+cos\,\beta}{2}\right) + \rho_g\left(\frac{1-cos\,\beta}{2}\right) \tag{10}$$

Where:
ρ_g is the albedo
$\frac{\overline{H}_d}{\overline{H}}$ is the diffuse fraction based on the Erbs correlation

$$D = \begin{cases} \max\left(0, G\ (\omega_{ss}, \omega_{sr})\right) & if\ \omega_{ss} \geq \omega_{sr} \\ \max(0, [G\ (\omega_{ss}, -\omega_s) +\ G(\omega_s, \omega_{sr})]) & if\ \omega_{sr} > \omega_{ss} \end{cases} \tag{11}$$

ω_{ss} is the sunset hour angle on a sloped surface
ω_{sr} is the sunrise hour angle on a sloped surface
G is the solar irradiance

$$G(\omega_1, \omega_2) = \frac{1}{2d}\left[\left(\frac{bA}{2} - a'B\right)(\omega_1 - \omega_2)\frac{\pi}{180} + (a'A - bB)(\sin\omega_1 - \sin\omega_2) - a'C(\cos\omega_1 - \cos\omega_2) + \frac{bA}{2}(\sin\omega_1\cos\omega_1 - \sin\omega_2\cos\omega_2) + \frac{bC}{2}(sin^2\omega_1 - sin^2\omega_2)\right] \tag{12}$$

$$a' = a - \frac{\mathrm{\overline{H}_d}}{\mathrm{\overline{H}}} \tag{13}$$

$$a = 0.409 + 0.5016\sin(\omega_s - 60) \tag{14a}$$

$$b = 0.6609 - 0.4767\sin(\omega_s - 60) \tag{14b}$$

$$d = \sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s \tag{15}$$

Equation (11) has a built in precaution, a max term, that ensures that no negative solar irradiance is used in the model. *G*, Equation (12), is the solar irradiance, which is the rate at which radiant energy is incident on a surface per unit area of surface. It is possible that Equation (12) is negative in some rare cases on high latitudes and/or north-facing slopes. The max term ensures that the solar irradiance is non-negative.

Equations (14) are the Collares-Pereira and Rabl (1979) coefficients. These coefficients are conversion factors from monthly average radiation to long-term daily average radiation. This corrects for the fact solar radiation varies greatly from day to day, due to constant changing of atmospheric conditions. These conversion factors are used in Equations (12) and (13) to determine solar irradiance.

ω_{sr} and ω_{ss} are the sunrise and sunset hour angles on a sloped surface. These hour angles are calculated using the hour angles on a horizontal surface (see Section 2.1.2.3). Whether ω_{sr} or ω_{ss} is ω_1 or ω_2 in Equation (12), depends on which of the two, ω_{sr} or ω_{ss}, is larger. This is expressed in the two if-statements in Equation (11), which determines how *G*, and thus *D*, is calculated (see max term in Equation (11)). ω_{sr} and ω_{ss} are determined by Equations (16).

$$|\omega_{sr}| = \min\left[\omega_s, cos^{-1}\frac{AB+C\sqrt{A^2-B^2+C^2}}{A^2+C^2}\right] \tag{16a}$$

$$\omega_{sr} = \begin{cases} -|\omega_{sr}| & if\ (A > 0\ and\ B > 0)\ or\ (A \geq B) \\ +|\omega_{sr}| & else \end{cases} \tag{16b}$$

$$|\omega_{ss}| = \min\left[\omega_s, cos^{-1}\frac{AB-C\sqrt{A^2-B^2+C^2}}{A^2+C^2}\right] \tag{16c}$$

$$\omega_{ss} = \begin{cases} +|\omega_{ss}| & if\ (A > 0\ and\ B > 0)\ or\ (A \geq B) \\ -|\omega_{ss}| & else \end{cases} \tag{16d}$$

$$A = \cos\beta + \tan\varphi\cos\gamma\sin\beta \tag{17a}$$

$$B = \cos\omega_s\cos\beta + \tan\delta\sin\beta\cos\gamma \tag{17b}$$

$$C = \frac{\sin\beta\sin\gamma}{\cos\varphi} \tag{17c}$$

Equations (16) have two if-statements, because on northwards oriented sloped surfaces, the Sun may rise and set twice a day. In the early morning solar radiation reaches the solar panel, but as the Sun orbits from east to west via south, solar radiation is unable to reach the northwards oriented sloped solar panel when the Sun is at south. Thus, the Sun has set in the point of view of the solar panel. As the sun follows its path east, it reaches the solar panel again. So the sun has risen again and it sets again at the end of the day. It depends on the slope and orientation of the solar panel, whether this happens or not.

In Equations (17) the latitude, solar panel slope, solar panel orientation, declination and solar hour angle are taken into account. Equations (17) affect Equations (9 – 16) and show that a change in the orientation, for example, effects total solar radiation collected by a solar panel.

2.1.4 Surface Area, Efficiency and Performance Ratio

In this section the final steps of calculating the energy output of solar panels are given. $\overline{H}_T$ of Equation (9), which is the total monthly daily average solar radiation on a sloped surface in MJ/m^2, is multiplied by the available space on a roof for solar panels, the efficiency of a solar panel, *r*, and a performance ratio, *PR*, which is a correction factor for any kind of losses, such as converting to electricity via inverters, temperature losses, snow, shadings, weak radiation and cable losses. The efficiency of modern commercial solar PV panels range between 15 and 20% (Twidell & Weir, 2006 & Milieu Centraal, n.d.). The performance ratio is around 0.85 for current commercial solar panels (Fraunhofer, 2014). Equation (18) shows these last steps (www.photovoltaic-software.com, 2015).

$$E = A * r * PR * \overline{H}_T \tag{18}$$

Where:
E is the energy output (in MJ/day)
A is the total surface area of the solar panels on a roof (in m^2)
r is the efficiency of the solar panel
PR is the performance ratio
$\overline{H}_T$ is the annual radiation (in MJ/m^2)

Multiplying *E* by the amount of days per month gives the monthly average solar radiation on the available surface area of a solar panel on a roof. Summing all months gives the total solar panel energy output per year in MJ. The results are shown in Section 3.4.2.

2.2 Economic Methods

In this section the economic methods are elucidated. First, the net present value method is discussed. Secondly, the return on investment, payback time and levelized cost of electricity are explained. These economic methods are used to determine the economic feasibility of solar panels.

2.2.1 Net Present Value

The economic feasibility of solar panels is often expressed in net present value (NPV) per Watt peak (Milieu Centraal, 2015a & Van Sark et al., 2014). This arises the possibility to compare the outcomes with the literature. A net present value analysis takes current and future cash flows into account. This is essential for solar panels, since a large investment upfront is required while the benefits and maintenance costs are generated every year. Solar panels save money by producing electricity. The maintenance costs are mainly the replacement of the inverter after 10 – 15 years. Van Sark et al. (2014) argue that this cost corresponds to about 1% of the investment costs per year. So, every year 1% from the total solar panel system costs is taken to resemble maintenance costs. After 25 years, the lifetime of solar panels, all maintenance costs are covered, which include replacement of the inverter, replacing faulty wiring and other small parts, and possible cleaning costs to keep the solar panels operating at its maximum. A net present value analysis discounts all future costs and benefits into current prices based on a discount rate. The discount rate determines the value of money in the future. A high discount rate gives a low value to future money and vice versa. Equation (19) shows the net present value formula in its general form.

$$NPV(i,N) = -R_0 + \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \tag{19}$$

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

R_t is defined as the difference between the benefits and costs per year, taking into account maintenance costs of 1% of the investment costs per year and an annual increase of the electricity price by 2% (see Section 3.2.2.1). The discount rate is set at 3%, which is, among other discount rates, also used by Van Sark et al. (2014). For government investments the discount rate has to be 5.5% and consists of a risk premium and a return on the capital market of 2.5%, which a government usually acquires, if it would invest in the capital market (www.mkba-informatie.nl, n.d.). In this case however, solar panels are bought by citizens and not a government. The interest rate citizens get from a savings account by a bank is currently at highest 1.5% per year and 10 year deposits yield an interest rate of 2.35% (www.spaarrente.nl, 2015). The guarantees given by manufacturers that the peak capacity of solar panels is still 80% after 25 years lowers the risks associated with this investment (www.essent.nl(a), n.d. & www.powergroup.nl, n.d.). Therefore, a low risk premium is chosen of around 1%. Together with the interest rate citizens acquire, the discount rate is 3%.

2.2.2 Return on Investment, Payback Time and Levelized Cost of Electricity

In this section other methods that help determine the economic feasibility of solar panels are described. The return on investment, also known as rate of return, is the interest rate that is earned when the investment in solar panels is made. Households can also put money in a savings account or deposit to earn an interest rate and this allows for a comparison with the return on investment. This gives an indication whether solar panels are a profitable investment. The return on investment can be calculated using the net present value. The return on investment expresses the profit on the investment over time as a proportion of the investment. Dividing the return on investment by the lifetime of solar panels gives the return on investment per year. The return on investment (ROI) is defined by Equation (20).

$$ROI = \frac{NPV}{Initial\ investment} \tag{20}$$

One of the factors that determine whether investments are made in solar panels by households is the payback time. It is important to know how long it takes to earn the investment back. The payback time is calculated by dividing the total costs after 25 years by the total savings after 25 years and multiplying this difference by 25. The outcome is rounded up in order to be as conservative as possible. Unlike a net present value analysis, the intertemporal flow of money is not taken into account and therefore the payback time method lacks accuracy. The error usually remains within ± 1 year, because in this case a stable increase of the energy price is assumed (Kenniscentrum InfoMil, n.d.).

The levelized cost of electricity is an economic assessment of the total build costs of a power source and its operating costs divided by the output during its lifetime. The levelized cost of electricity (LCOE) is expressed by Equation (21) (EPIA, 2011).

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{21}$$

Where:
I_t are the investment costs in year *t*
M_t are the maintenance costs in year *t*
E_t is the annual produced electricity in year *t*
r is the discount rate.
n is the lifetime of the solar panels

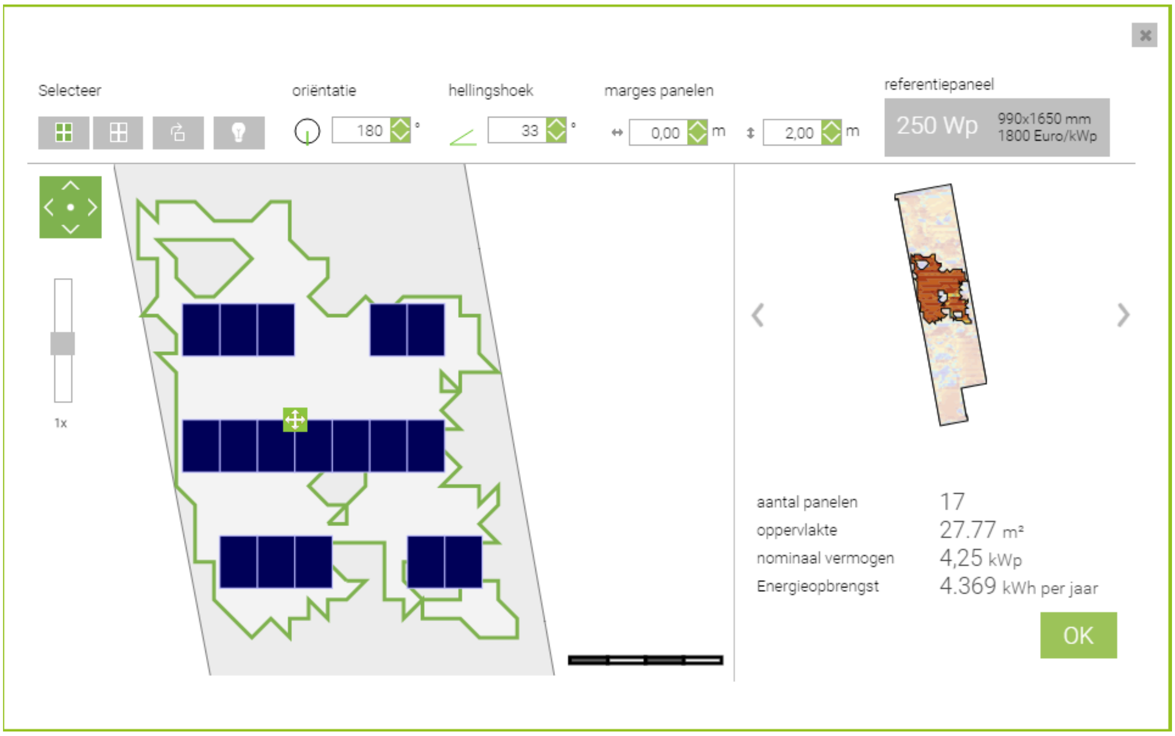
The levelized cost of electricity is expressed in €/kWh and is often used to compare different energy sources. In this case it is used to compare the consumer electricity price of €0.23/kWh with the price of generating solar electricity. This gives an indication whether electricity from solar panels is cheaper than energy from the grid. All these economic methods combined provide a good overview of the economic feasibility of solar panels.

2.3 Validation Methods

In this section the validation methods are illustrated. Observed energy production data from solar panels in Amsterdam is used to validate the Klein & Theilacker model (1981), the KT model. The Zonatlas is already briefly described in Section 1.2, but is further elaborated in this section.

Observed energy production data is extracted from www.zonnestroomopbrengst.eu (2015). In total 23 different solar panel systems located in Amsterdam are registered and maintained on the website. Detailed descriptions per solar panel system are available and contain information about the type of solar panel, roof slope, orientation and the amount of installed Watt peak. These characteristics are input for the KT model in order to control for differences between solar panel installations, such as efficiency of solar panels. The generated output per month per solar panel system, which is available on the website, from 2010 – 2014 is used to validate the KT model. The validation data is corrected for deviations in solar radiation with respect to the long-term average.

The Zonatlas has been launched to support the sustainable energy transition and to assist households, policymakers and housing corporations in investing in solar panels (www.klimaatverbond.nl, n.d.). The Zonatlas allows for manually adjusting the settings, such as type of solar panel, energy consumption, etc.. The Zonatlas considers a roof to be flat if the slope is below 10°. Automatically, the Zonatlas changes the slope of the flat roofs to 40° degrees, which is assumed to be the optimal slope. Manually, this is changed into the optimal slope determined in Section 3.3. The efficiency and degradation rate of a solar panel are 15% and 0.1% respectively in the Zonatlas. These rates set at 16% and 0.5%, which are used in this analysis (see Sections 2.1.4 and 3.1.3). Figure 7 shows the optimization window of the Zonatlas. It gives information about the solar panels, such as orientation, slope, total amount, surface area, Watt peak and generated output. The amount of solar panels is adjusted until the available roof space is optimally utilized, with enough space between the solar panels, which is only necessary on flat roofs.



oriëntatie 180°

hellingshoek 33°

marges panelen ↔ 0,00 m ↕ 2,00 m

referentiepaneel 250 Wp 990x1650 mm 1800 Euro/kWp

aantal panelen	17
oppervlakte	27.77 m²
nominaal vermogen	4,25 kWp
Energieopbrengst	4.369 kWh per jaar

Figure 7 The optimization panel of the Zonatlas to optimize the amount of solar panels. Source www.zonatlas.nl, 2015

The orientation of roof parts in the Zonatlas is adjusted to match the orientation compass card of the KT model, because north is 180° in the KT model and 0° in the Zonatlas. The deviation of the Zonatlas compared to the KT model is determined by subtracting the smallest, in absolute value, orientation of the two from the other orientation. This results in a deviation that is always positive, but lacks meaning whether the difference is clockwise or counter-clockwise on the compass card. The slopes of the roof parts are compared by subtracting the values found in the Zonatlas from the values in the roof top data set. Thus, a negative value means that the value in the Zonatlas is larger.

The roof top data set described in Section 3.4.1 contains BAG identification numbers. For in total 300 roof parts these numbers are inserted at bagviewer.kadaster.nl (2015) to find the corresponding addresses, since the Zonatlas only works with addresses. Many times the amount of roof parts per building and the size of the roof parts differ between the Zonatlas and the roof top data set. The Zonatlas often only takes the most suitable roof part per building and classifies the other parts as unsuitable. Therefore, the amount of solar panels per roof parts differs. To avoid comparing two solar panel systems of different sizes, the amount of solar panels calculated in these research, based on the roof top data set, is used and the Zonatlas is adjusted accordingly. This makes it possible to compare the expected generated energy output per roof part.

Addresses of the solar panel systems of the observed energy production data are unknown, because of privacy issues, and since the Zonatlas only works with addresses, it is impossible to compare the observed energy data to the Zonatlas. Therefore, the KT model is used in combination with the roof top data set, of which the locations are known, to validate the Zonatlas. The observed energy production data is only used to validate the KT model.

3 Results

In this section the results are presented. The results are achieved using the methods described in Chapter 2. First, the solar potential model is implemented in the city of Amsterdam. Secondly, the costs and benefits of solar panels are determined based on the Dutch market. In the next section the optimal roof top conditions are given. Furthermore, the outcomes of the solar potential model are highlighted and the economic feasibility of roof top solar panels in Amsterdam is determined using a net present value analysis and other economic methods. Thereafter, the sensitivity analysis examines the effect of a change in one of the variables on the economic feasibility of solar panels. This chapter concludes with a validation analysis of the Klein & Theilacker model (1981), also known as the KT model, and the Zonatlas.

3.1 Solar Potential in Amsterdam

In this section the solar potential model is implemented for the city of Amsterdam and the outcomes are given. The KT model described in Section 2.1 is implemented in Excel to be able to perform calculations. In this section the albedo effect and degradation of solar panels over time, which are specific for the city of Amsterdam and determine the performance of the model, are described.

3.1.1 Monthly Average Daily Radiation and Latitude

As stated before, a solar potential model converts the incoming solar radiation on a horizontal surface into incoming solar radiation on a sloped surface. The Royal Netherlands Meteorological Institute (KNMI) measures the incoming solar radiation on a horizontal surface and presents this data per month. The closest weather station of the KNMI near Amsterdam is located at Schiphol international airport, which is approximately 10 kilometres away from the city centre of Amsterdam. The latitude of Schiphol is 52.3 degrees North, which is the same as Amsterdam (52.4 in northern Amsterdam). The available period for this weather station is 1990 – 2010. The monthly average radiation data from the KNMI is given in the second column of Table 1. The KT model works with monthly average daily radiation, which is $\overline{H}$ and is given in the third column of Table 1. It is calculated by dividing the monthly average radiation by the number of days in a month.

Table 1 Monthly average radiation on a horizontal surface between 1990-2010 in MJ/m^2 at Schiphol airport (KNMI, n.d.(a)). $\overline{\mathrm{H}}$ = monthly average daily radiation. Source mean day of the month: Klein, 1977. *n* = day of the year. δ = declination. ω_s = sunset hour angle.

	Monthly radiation in MJ/m^2	$\overline{H}$	Mean day of the month	n	δ	ω_s
Jan	72.67	2.34	17 Jan	17	-20.90	60.39
Feb	128.67	4.60	16 Feb	47	-12.61	73.18
Mar	267.00	8.61	16 Mar	75	-2.04	87.36
Apr	428.89	14.30	15 Apr	105	9.48	102.48
May	569.68	18.38	15 May	135	18.67	115.93
June	572.83	19.09	11 June	162	23.04	123.38
July	570.49	18.40	17 July	198	21.35	120.37
Aug	476.99	15.39	16 Aug	228	13.99	108.80
Sep	306.86	10.23	15 Sep	258	3.34	94.33
Oct	185.26	5.98	15 Oct	288	-8.22	79.23
Nov	81.47	2.72	14 Nov	318	-18.04	65.08
Dec	53.01	1.71	10 Dec	344	-22.84	56.98
Year	**3717.68**	--	--	--	--	--

3.1.2 Albedo

The albedo is the fraction of the incoming solar radiation that is reflected. The albedo factor is used to calculate the reflection of the surface around solar panels. The albedo affects the amount of radiation on the solar panel. A higher albedo means more incoming radiation is reflected by the surface and may be collected by a solar panel. Figure 8 shows the albedo in cities (Ramírez & Muñoz, 2012). It is obvious that the albedo of a city varies by the materials used in a city. Typically, the albedo of materials increases with age because the colours fade away over time (Ramírez & Muñoz, 2012). The predominant building materials in Amsterdam are bricks and stones, often also for roads, but also numerous trees are present in Amsterdam. Spangmyr (2010) has determined the albedo for mid-latitude snow-free cities between 0.10 and 0.27. Therefore, the albedo for Amsterdam is set at 0.20.

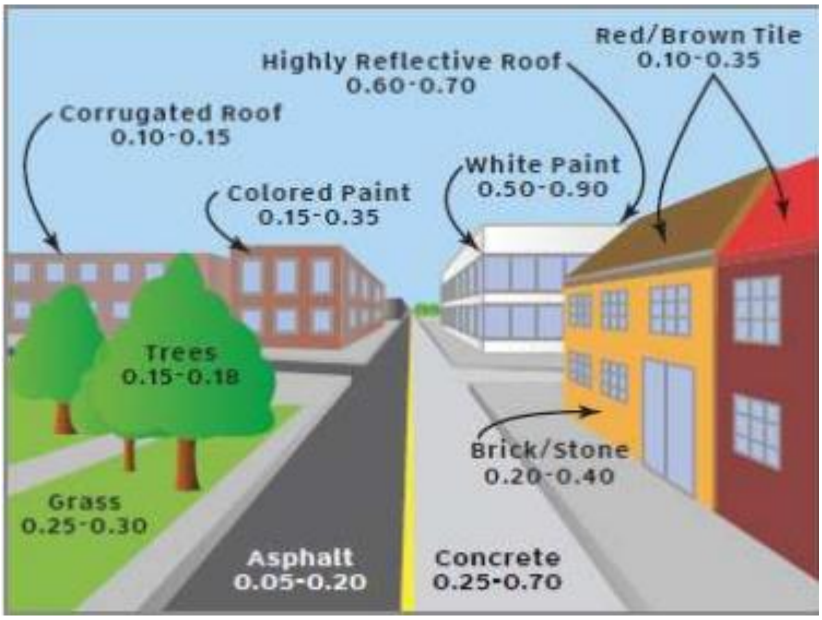


Figure 8 The albedo factor in cities. Source: Ramírez & Muñoz, 2012.

3.1.3 Degradation of Solar Panels

Manufacturers of solar panels often give guarantees that solar panels still have a peak capacity of 80% after 20-25 years (www.essent.nl(a), n.d. & www.powergroup.nl, n.d). Jordan & Kurtz (2012) have computed an extensive review of almost 2000 degradation rates over the last 40 years published in the literature. The median value in their analysis is 0.5%/year. This seems to be consistent with the guarantees given by manufacturers, as after 25 years with a rate of 0.5%/year solar panels have a peak capacity of 88%. With a decrease of 0.85%/year the peak capacity is 80% after 25 years. In this analysis a degradation rate of 0.5% year is taken.

3.2 Costs and Benefits of Solar Panels

In this section the costs and benefits of solar panels are given in order to assess the economic feasibility of solar panels. These costs and benefits are input for the economic assessments performed in Section 3.4. Throughout this research a reference panel of 250 Watt peak (Wp) with a size of 990 mm x 1650 mm is used. For every roof surface the maximum amount of solar panels is calculated. www.zonatlas.nl (2015d), Milieu Centraal (2015a), which is an independent knowledge institute, and www.comparemysolar.nl (2015) use the same type of reference panel.

3.2.1 Costs

In this section the costs of solar panel modules, inverters, installation and complete solar panel systems are specified. The cost are expressed per Watt Peak (Wp) in order to be able to compare the costs of solar panel systems with a different rated power.

3.2.1.1 Solar Panels

Van Sark, Rutten & Cace (2014) performed between 2011 and 2014 every three to four months a complete analysis of the Dutch solar panel market, specifying the costs for solar panels, inverters and installation separately. Unfortunately, the most recent market analysis dates back from April 2014. Van Sark et al. (2014) have determined the price of solar panels, after examining 879 solar panels, to be €1.09/Wp on average. 50% of the solar panels has a price lower than €1.10/Wp. This is without inverter and installation costs.

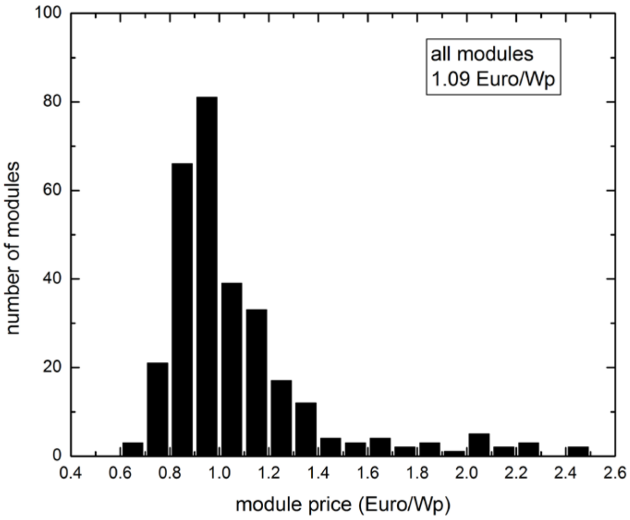


Figure 9 Price of solar panel modules in €/Wp. The average is €1.09/Wp. Source: Van Sark et al. (2014)

According to Van Sark et al. (2014) there is no relationship between costs of a solar panel and its rated power. The costs depend for a large part on the origin of a solar panel, as Chinese manufacturers are able to set prices that are 19% lower than similar solar panels from other countries. As can be seen in Figure 9, the range in prices is very large. From a consumer perspective it is not attractive to buy solar panels that cost more than around 1.00 €/Wp, because there are almost 200 other solar panels that are cheaper. There are many solar panels available in the price range 0.80 €/Wp - 1.00 Wp (see Figure 9).

3.2.1.2 Inverters

Van Sark et al. (2014) have also examined more than 700 inverters that are available on the Dutch market. This device inverts the direct current (DC) of a solar panel into an alternating current (AC) in order to be able to use the generated energy or to deliver it back to the grid. Large inverters have a lower price per Wp than small inverters, but the purchase price of small inverters is lower. The price ranges between €0.10/Wp and €0.90/Wp (see Figure 10). The lifetime of an inverter is around 12 years, but solar panels can last up to 25 years (www.essent.nl(a), n.d. & www.powergroup.nl, n.d). An inverter has to be replaced once during the lifetime of solar panels.

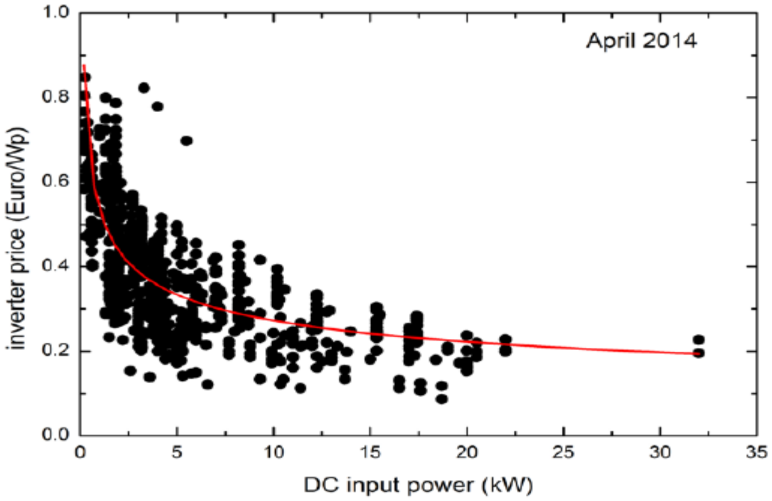


Figure 10 Price of inverters in €/Wp arranged per DC input power. Source: Van Sark et al. (2014)

3.2.1.3 Installation

Installation costs vary between €0.20/Wp and €0.80/Wp (Van Sark et al., 2014). This is a very wide range and the average is around €0.40/Wp. Installation costs drop with larger solar panel systems. Stichting Sun4Ever (2015) compares installation costs of solar panel systems. However, they do not take other costs into account such as small materials, wires and other installation materials, which are often included in the installation costs, such as in the analysis of Van Sark et al. (2014). Installers of solar panels are very unclear about what is included in the installation costs and therefore it is not possible to compare installation costs. According to Milieu Centraal (2015a) the installation costs resemble about 20 – 25% of the investment costs.

3.2.1.4 Solar Panel Systems

In this section the costs of solar panels, inverters and installation are combined, as often solar panel systems are offered as a package for a single price. The costs for complete solar panel systems are used for further analysis in this research, as more data is available for complete solar panel systems. The maintenance costs are not dealt with in this section, but are included in the net present value analysis (see Section 3.4.3). Figure 11 shows the development of solar panel system prices since 2006. The costs have decreased by 60% in 9 years. The costs of solar panel systems are estimated at €1.03/Wp for large installations above 100 kWp by ECN, which is the National Energy Research Centre (Lensink & Van Zuijlen, 2014). However, in this analysis the focus is on solar panels on roofs of individual houses.

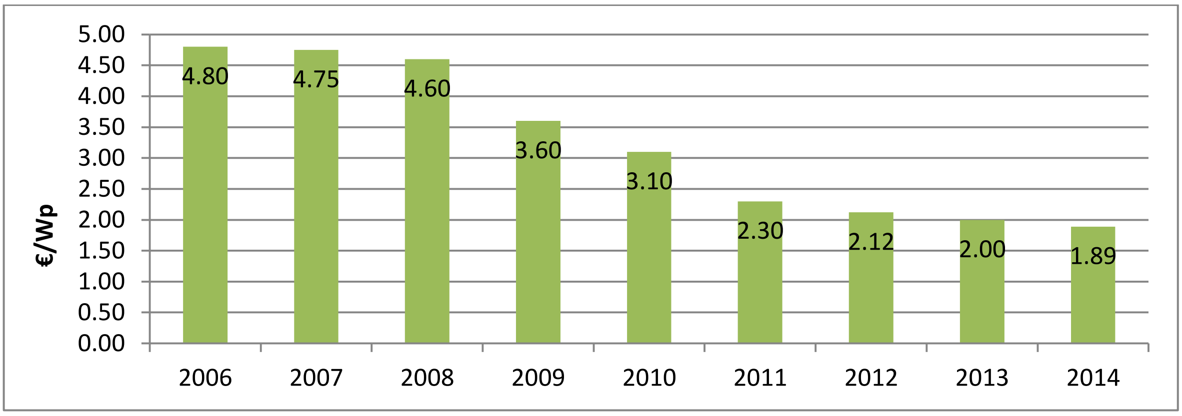


Figure 11 Development of solar panel system prices in €/Wp in the Netherlands 2006-2014. Source: Milieu Centraal (2015a)

Other sources that provide information about costs of solar panel systems are included in a regression analysis (see Figure 12). Around 90 different solar panel systems of different sizes have been found. Those solar panel systems are either offered by energy companies or other installers of solar panel systems, or are given on comparison websites. Also the results found by Van Sark et al. (2014) and Milieu Centraal (2015a) are included in the regression. A complete list is given in Appendix III. The Zonatlas is left out of the regression, because of its simple calculation method (www.zonatlas.nl, 2015c). In the Zonatlas the maintenance and insurance cost are set at €24/Wp per year with a 2% inflation rate. There is no discount factor and the annual energy price increase is 4% per year. It does not take into account that the total size of the solar panel system matters and assumes a standard price of €1.80/Wp (see Table 2) (www.zonatlas.nl, 2015c).

Table 2 Comparison of solar panel system prices in €/Wp. The regression ranges from 4 to 24 solar panels.

Number of solar panels	Van Sark et al. (2014)	Milieucentraal (2015a)	Zonatlas (2015)	Regression
3	2.85	2.87	1.80	-
10	1.83	1.89	1.80	1.68
20	1.58	1.65	1.80	1.44

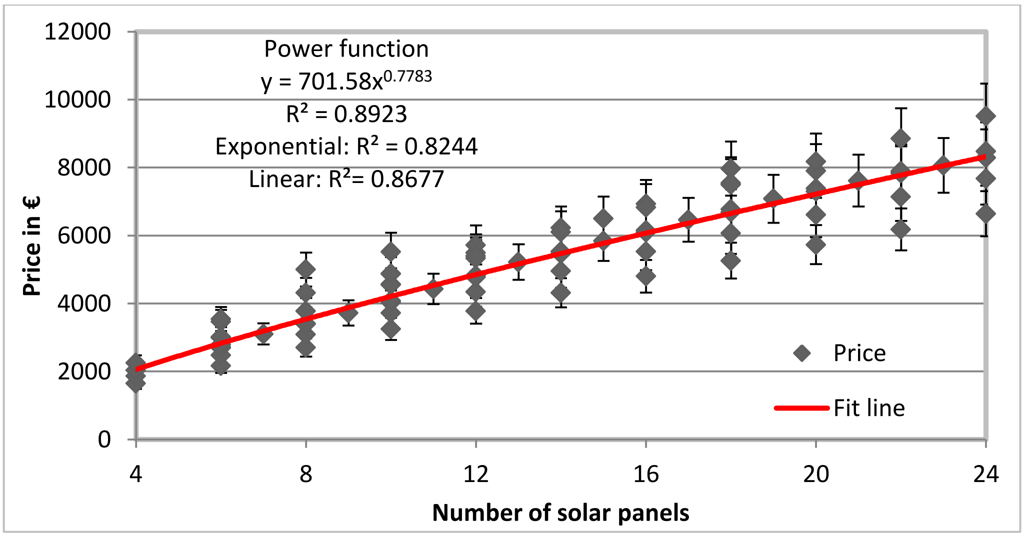


Figure 12 Regression analysis with prices of solar panel systems

Only solar panel systems with a size between 4 and 24 solar panels are taken into account in the regression. On the smallest roof in the roof top data set, 4 solar panels can be placed (see Section 3.4.1). There is no sufficient data available for solar panel systems larger than 24 solar panels. Therefore, on roofs that are able to store more than 24 solar panels, some parts of the roof are empty as the maximum amount per roof is set at 24 solar panels. The solar panels differ per provider, because companies deliver solar panels from different manufacturers. The solar panels are mono-crystalline and the amount of Wp is always around 250. The most providers offer solar panel systems in standard configurations of 3, 6, 8, 12, 16, etc.. The regression is performed to calculate the costs of solar panels with different configurations.

Figure 12 shows that the regression is best fitted with a power function. Other types of fit lines have quite similar R^2, but the power function fit line resembles the relationship between the costs and the size of a solar system the best. It is supported by the literature and Figure 13 that the costs decrease with an increasing number of solar panels (see Table 2, Van Sark et al., 2014 & Milieu Centraal, 2015a). In Figure 12 error bars of 10% are displayed, because solar panel installations often require custom work and therefore the costs may vary. In Figure 13 the costs in Figure 12 are expressed per Wp. Figure 13 shows that the costs of a solar panel system decrease with every additional solar panel. One should also notice that the decrease slows down if the number of solar panels increases. The marginal costs of solar panel systems are decreasing with a decreasing rate.

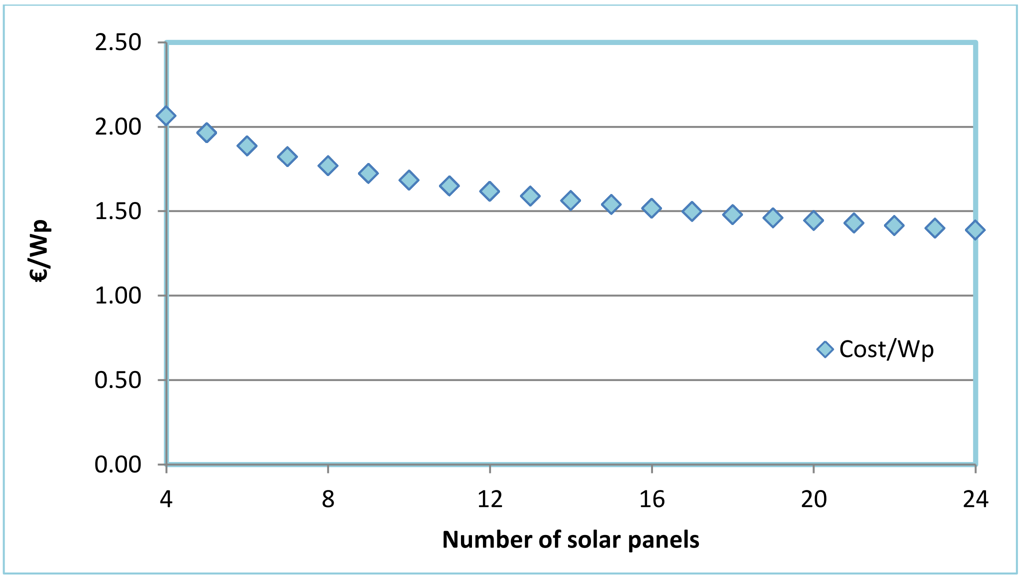


Figure 13 Costs of solar panel systems expressed in €/Wp based on the regression

Milieu Centraal (2015a) has expressed the costs per Wp for three solar panel system sizes, which has also been done by Van Sark et al. (2014). Table 2 shows that the costs decrease with size. The results of the regression are 0.15 – 0.20 €/Wp lower than Van Sark et al. (2014) and Milieu Centraal (2015a). This has two reasons. The first reason is that Van Sark et al. (2014) have done their analysis in April 2014 and Milieu Centraal (2015a) claims that their prices are valid for 2014. The regression is computed a year later and, as is also shown by Milieu Centraal (2015a) in Figure 11, the prices of solar panel systems decrease every year. The second reason is that in the regression only solar panels of 250 Wp are taken into account, while Van Sark et al. (2014) and Milieu Centraal (2015a) also consider other solar panels, which have a different price per Wp.

3.2.2 Benefits

In this section the benefits of solar panels are expressed in savings per year. Also the regulations netting and VAT return are discussed.

3.2.2.1 Savings

The benefits of solar panel systems are expressed in savings per year, because the energy bill is lower every year if solar panels are installed. The reasoning behind this is that if buying energy from the grid is very cheap, it is not profitable to invest in self-produced energy and vice versa. The savings are determined by multiplying the generated output by the current average energy price of € 0.23/kWh (Milieu Centraal, 2015b). The economic lifetime of solar panels is 25 years and therefore it is necessary to take the expected development of the energy price into account. A lot of disagreement exists about the development of the energy price in the future. Many companies that sell solar panels assume a price increase of 3% or even 4.5% per year (Bontenbal, 2014 & www.eneco.nl, 2015a). Eventually after 25 years, the energy price has risen to € 0.50/kWh. The question is whether this is realistic. Recent developments, given in Section 1.1, might cause the energy price to drop (Carr, 2012, www.pricewise.nl, 2015, Rooijers, et al., 2014 & Randall, 2015). Figure 14 shows that the consumer price index of energy in the Netherlands is the same in 2015 as in 2009, and is decreasing (CBS, PBL & Wageningen UR, 2015). CBS (2015) and ECN (2014) point out that the transaction price of energy in 2015, taxes and VAT included, is the same as it was in 2007 (see Figure 15). Projections of the wholesale price of energy show that the price might decrease from € 0.0436/kWh in 2015 to € 0.0379/kWh in 2019 (Bontenbal, 2014 & www.powerhouse.nl, 2015).

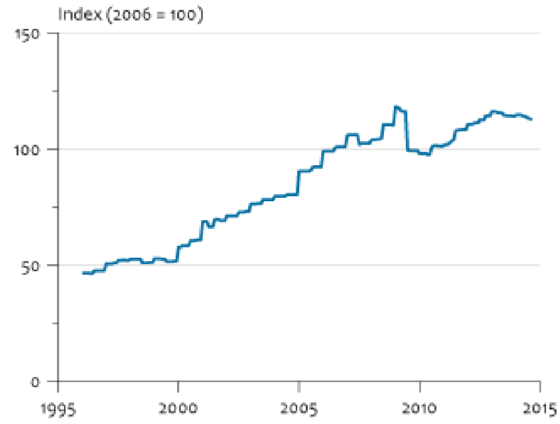


Figure 14 Consumer price index energy in the Netherlands. Source: CBS, PBL & Wageningen UR, 2015

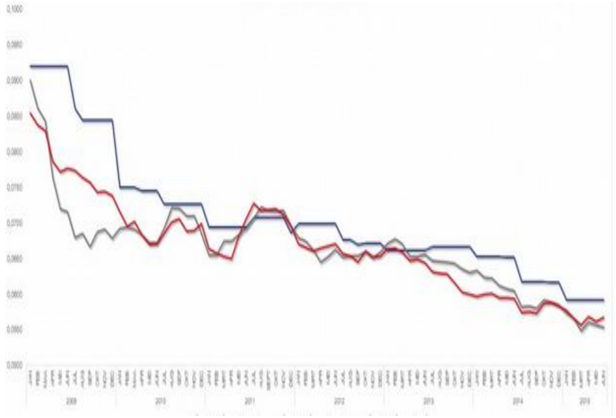


Figure 15 Decrease in energy transaction price between 2009 and 2015 in the Netherlands from €0.093/kWh to €0.0436/kWh. Source: www.pricewise.nl, 2015

Energy taxes have increased in recent years due to the VAT increase from 19% to 21% and the introduction of additional taxes to finance sustainable energy projects (Bontenbal, 2014). Vethman & Gerdes (2011) had projected in 2011 an energy price of € 0.23/kWh in 2015, which is indeed the case. They also foresee an energy price of € 0.29/kWh in 2040. This is an increase of 26% with respect to 2015 and an increase of around 1%/year. They have based their analysis on policies existing in 2011 and energy taxes have increased more than Vethman & Gerdes (2011) had projected. Therefore, in this analysis an annual increase of the energy price of 2% is taken, which results in an energy price of € 0.38/kWh at the end of the lifetime of solar panels in 2040. This is an increase of 61% with respect to 2015. The 2% increase per year is also in line with the long term inflation (CBS, 2014).

Figure 16 shows the savings, of not having to buy energy from the grid, of the roof tops in the roof top data set after 25 years expressed in €/Wp. It is very clear that there is a maximum in the amount of savings per Wp in this model, which is a saving of €7.10/Wp. This is for the optimal locations and since it is expressed per Wp, the maximum saving per Wp is the same for every configuration of solar panels. Graphs showing the relationship between savings and orientation and slope are not included, since the graphs have the same shape as the graphs in Section 3.4.2.

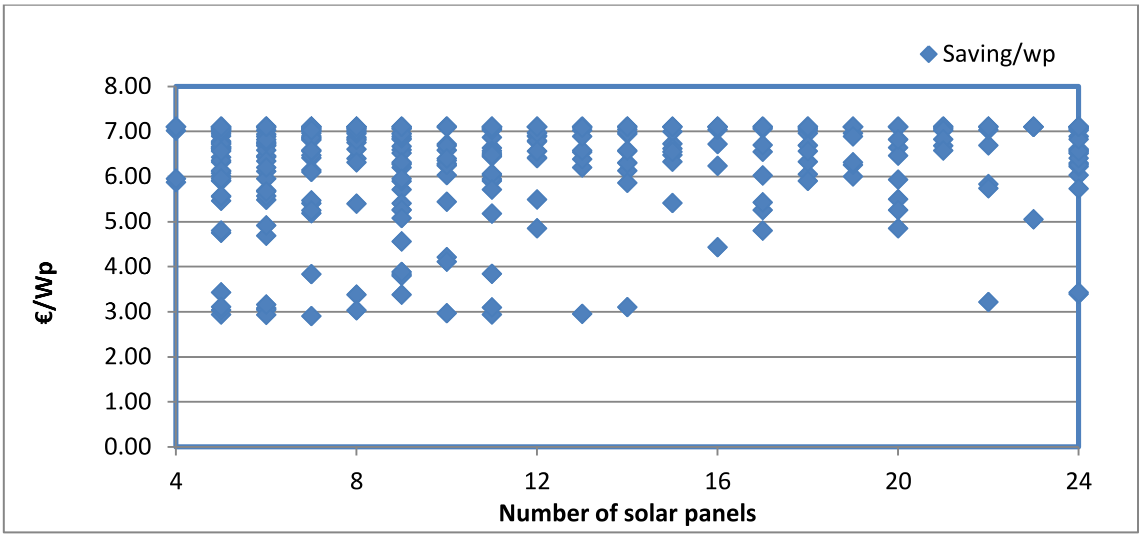


Figure 16 The savings per roof surface after 25 years expressed in €/Wp

3.2.2.2 Netting

Electricity produced by solar panels can be either consumed directly by a household or delivered back to the energy grid. Unlimited amounts of electricity can be delivered back to the grid by the household. However, only for the amount of electricity a household buys from an energy company, a compensation of € 0,23/kWh has to be paid by the energy company to the household (www.consuwijzer.nl, 2015). Any electricity delivered back above that maximum has to be compensated for by the energy company by at least € 0,08/kWh, but some energy companies give a higher compensation (www.consuwijzer.nl, 2015 & www.eneco.nl, 2015b). This legislation is called netting and makes solar panels economically more attractive. In this research it is however not possible to take this regulation into account, since it requires knowledge of the consumption of electricity per household, the amount of energy a household has delivered back to the grid and the amount of electricity an energy company has delivered to the household. This is privacy sensitive information and not accessible. The energy consumption cannot be accurately estimated by taking the surface area of a building, because multiple households can be present in one building. This is especially the case in the city of Amsterdam.

3.2.2.3 VAT Return

It is possible for households to get a VAT return on the investment in solar panels (Belastingdienst, n.d.). Because of a verdict by the Court of Justice of the European Union at June 20th 2013, residents that have solar panels installed are seen by the law as entrepreneurs. Therefore, these residents have the right to reclaim the VAT on their bought solar panel system. This is a considerable saving on the purchase price. The VAT return saves € 350 for a 4 solar panel system and up to € 1450 for a 24 solar panel system. It is unknown how long this regulation will last, since the ministers of the countries of the European Union are considering adjustments (Milieu Centraal, n.d.).

3.3 Optimal Roof Top Conditions

In this section the optimal roof slope is determined. This is important, because on flat roofs solar panels are installed on a frame, which can be set into the optimal slope. For flat roofs the orientation is not important, because the frame can be mounted in any direction and therefore the orientation is always optimal, which is south based on Figure 18. In order to determine the optimal roof slope, the expected energy output of a solar panel system is calculated considering a flat roof and multiple solar panel slopes in a southward orientation. The results are shown in Table 3.

Table 3 Energy output per month in kWh for a flat roof with 24 solar panels. The degrees represent different slopes of a solar panel. The last columns give the optimal degree per month and the corresponding output

	0°	10°	20°	30°	32°	33°	34°	35°	38°	40°	Optimal degree	
											Month	Output
Jan	107.8	134.0	157.6	177.7	181.2	182.9	184.6	186.3	190.9	193.8	68°	213.7
Feb	189.3	220.7	247.6	269.2	272.8	274.6	276.2	277.8	282.3	284.9	59°	296.9
Mar	392.0	433.1	465.5	488.1	491.4	492.9	494.3	495.6	498.8	500.4	46°	502.5
Apr	632.9	672.6	698.6	701.0	710.5	710.5	710.4	710.1	708.3	706.4	33°	710.5
May	847.7	871.7	879.7	870.7	866.8	864.6	862.3	859.8	851.2	844.7	20°	879.7
June	856.2	867.0	863.2	843.9	838.3	835.1	831.9	828.5	817.4	809.3	12°	867.5
July	851.2	866.8	867.1	851.6	846.6	843.8	840.9	837.8	827.7	820.2	15°	868.9
Aug	706.5	737.3	753.8	755.2	753.7	752.7	751.6	750.3	745.5	741.5	26°	756.5
Sep	451.2	486.7	512.5	527.8	529.5	530.2	530.8	531.3	532.1	532.1	39°	532.1
Oct	272.0	309.9	341.4	365.7	369.7	371.5	373.3	374.9	379.5	382.1	54°	390.6
Nov	120.4	141.7	160.3	175.7	178.3	179.5	180.8	181.9	185.2	187.2	62°	198.0
Dec	78.9	96.7	112.8	126.5	128.9	130.0	131.2	132.3	135.4	137.4	68°	150.8
Year	**5506.1**	**5838.1**	**6059.9**	**6161.9**	**6167.5**	**6168.4**	**6168.1**	**6166.5**	**6154.2**	**6139.8**	**--**	**6367.7**

Table 3 shows that the optimal slope is 33° for the city of Amsterdam, because it has the highest output for the whole year. The differences with similar slopes are very small. A roof with a slope of 40° results in a decrease in energy output of only 0.46% with respect to the optimal slope. If the solar panels are installed with the optimal slope instead of laying down flat, the increase in energy output is 12%. Siderea (2014), which is an energy consultancy company, has determined an increase in energy output by 11%, only in their model the optimal slope is 30°. Stichting Monitoring Zonnestroom (2015) has set the optimal slope at 38°. Van Sark (2014) assumes an optimal slope of 40°. Also the Zonatlas assumes an optimal slope of 40° (www.zonatlas.nl, 2015d). An energy company talks about an optimal roof slope of 36° (www.essent.nl, n.d.(b)). The optimal slope of 33° is different than other sources, but there is inconsistency about the optimal slope in the literature.

The energy output per month in Table 3 indicates that the optimal slope differs per month. This makes sense, since the position of the Sun with respect to the Earth differs every month. A higher solar panel slope gives a higher energy output in winter, while a lower slope gives a higher output in summer. It also explains why solar tracking systems exist, which raise the energy output of solar panels (Mousazadeh, et al., 2009 & Poulek & Libra, 2007). Therefore, the optimal roof slope is determined for every month and also the corresponding energy output is calculated. The results are shown in the last two columns of Table 3. The optimal roof slope is very steep in winter and almost flat in summer. In December and January the optimal roof slope is the same at 68°. An optimal roof slope per month results in an increase in energy output of 3.23% with respect to a slope of 33°.

3.4 Economic Feasibility of Roof Tops in Amsterdam

In this section the solar potential of roof tops in Amsterdam is given. Furthermore, the economic feasibility of these roof tops is assessed by executing multiple economic methods on a roof top data set. This section starts with a description of the roof top data set. Secondly, the solar potential of the roof tops according to the KT model is given. Thereafter, a net present value analysis is performed to assess the economic feasibility of the roof tops. The economic assessment is further extended by determining the return on investment, payback time and levelized cost of electricity.

3.4.1 Roof Top Data Set

In this section a description of the roof top data set containing the roof parts is given, including an explanation of the manipulations. The roof top data set is provided by Geodan BV, Amsterdam and contains 500 random buildings in Amsterdam from the BAG (Basisregistratie Adressen en Gebouwen) in Shapefile format. Every building has a unique building identification number. Geodan has applied a special algorithm in order to determine the angle of the roof, based on the AHN2 (Algemeen Hoogtebestand Nederland), and the orientation of the roof. Height measurement in the point cloud of the AHN2 are clustered based on the mathematic convex hull principle. Points between certain height values form a convex set, if the minimum size requirements are met. A convex hull is an imaginary polygon connecting the outer points in a convex set. The algorithm defines when certain combinations of points have to be seen as flat or sloped roofs. Each convex set becomes a roof part.

Using ArcGIS software, the surface area of the roof parts is calculated. A correction factor of 0.8 is used to account for possible errors and to account for the fact that solar panels require some distance from the edge of the roof. Moreover, a certain distance is required between solar panels in order to prevent shades on other solar panels. Several spatial operations are executed to improve the accuracy of the roof top data set. All roofs with a slope below 5° are treated as flat roofs and are given the optimal roof slope and optimal orientation, since on flat roofs solar panels are installed on a frame with the optimal slope, facing the optimal orientation. Every roof part is also classified in one of the 28 classes of Appendix I, based on the slope and orientation, in order to be able to visualize the data. Figure 17 shows an example of multiple roof parts on a single building in Amsterdam. It shows that roof parts can have various shapes and sizes.

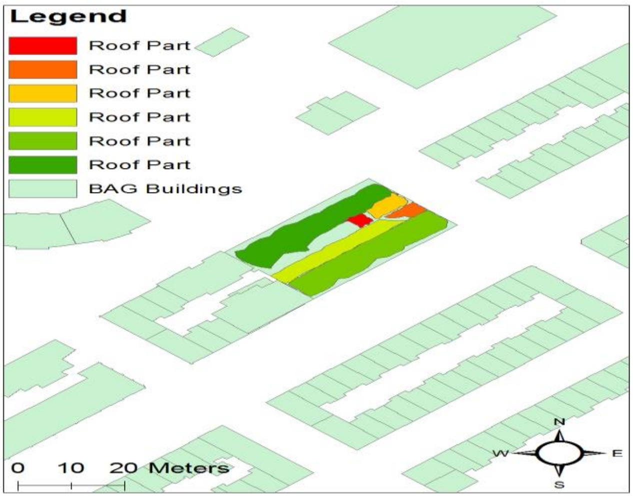


Figure 17 Example of a roof with all its roof parts in colours. The light blue buildings are from the BAG, but are not present in the roof top data set

3.4.2 Results per Orientation and Slope

In this section the outcome of the KT model is presented and given for every orientation and slope, specifically for the roof parts in the city of Amsterdam. Figure 18 shows the output per roof part, each with one solar panel installed, after 25 years in kWh in relation to the orientation. The highest outputs are between 0-60° and 300-360°. One should take into account that 0° represents south in this analysis. If a solar panel is facing north, the generated output is around 60% lower than a southward oriented solar panel. The orientation to the east or west lowers the output by 10%.

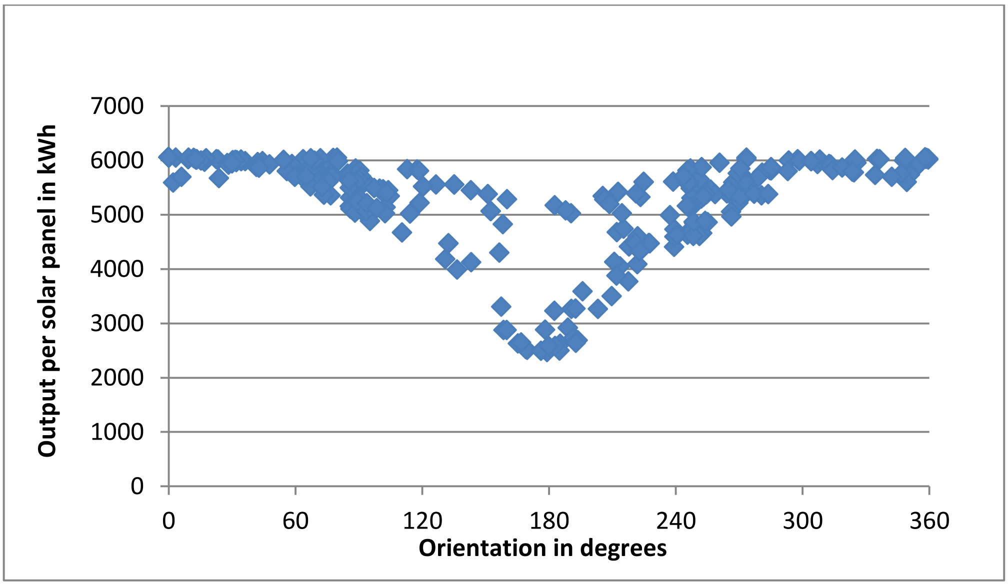


Figure 18 Output per roof part in kWh after 25 years for every orientation.
Per roof part just one solar panel is taken for an equal comparison.

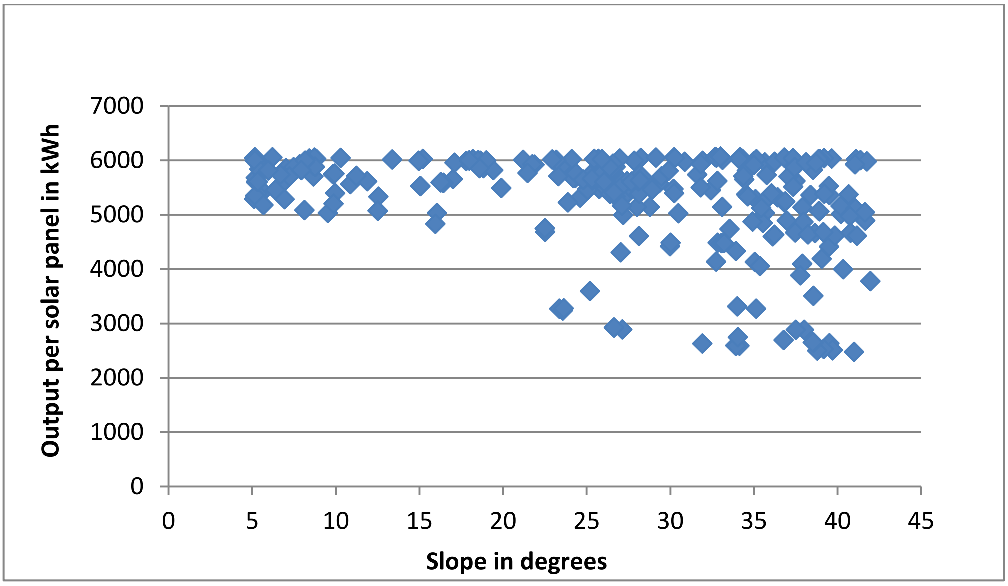


Figure 19 Output per roof part in kWh after 25 years for every slope.
Per roof part just one solar panel is taken for an equal comparison.

The relationship between the slope of a solar panel and the generated output is given in Figure 19. There is a clear cut-off point at 5°, because roofs with a slope lower than 5° are treated as flat. Roof frames can be mounted on roofs with a small slope. All flat roofs have maximum energy output, because of a southward orientation and optimal slope of 33°. The dots in Figures 18 and 19 give a somewhat distorted picture in terms of number of roofs with the same slope. For example, there are a lot of flat roofs, which have a slope of 33° and an orientation of 0°, but this is not clearly visible in Figures 18 and 19. The maximum energy output produced by a solar panel on a flat roof is 6054 kWh after 25 years. The maximum energy output on other slopes is only slightly lower (see Figure 19).

The main reason why in Figure 19 some solar panels have a much lower output, is because the orientation of those solar panels is not optimal. As is determined in Section 3.3, a slope of 0° results in a 12% lower output compared to a slope of 33°. Thus, if the solar panels are all facing south the range in energy output would be between 5300 kWh and 6054 kWh. Since some solar panels produce much less than 5300 kWh, the orientation must play a major role. It is likely that the slope and orientation enforce each other. A relatively steep slope, >20°, combined with an orientation far from south results in outputs way below 5000 kWh, because the Sun reaches the solar panels less frequent and at a non-optimal angle. The solar panels used in this analysis have a peak capacity of 250 Watt peak (Wp). On the best locations, optimal slope and facing south, a single solar panel produces 242 kWh/year.

3.4.3 Net Present Value

In this section the net present value (NPV) is determined, based on the costs and benefits given in Sections 3.2, to assess the economic feasibility of the roof tops in Amsterdam. The method of how to determine the economic feasibility of solar panels using a net present value analysis is described in Section 2.2.1. The net present value and the relation to the slope, orientation and amount of Wp are highlighted. This section ends with categorizing the roof top data set into classes based on their orientation and slope to be able to determine the net present value for certain combinations of orientations and slopes.

3.4.3.1 NPV per Wp, Slope and Orientation

For every roof top in the roof top data set the net present value is determined. Figure 20 shows the NPV expressed per Wp. In general a larger solar panel system results in a higher NPV per solar panel. Larger solar panel systems are thus a more secure investment and give higher benefits. In the current configuration all roofs yield a positive net present value, which means that it is a profitable investment. However, some roof parts show a very low net present value, for example of only €0.09/Wp. This particular roof part, with an orientation of 185° and a slope of 40°, has space for five solar panels and thus a total net present value of 5 * 250 Wp * €0.09/Wp = €112.50. This means that after 25 years, with a discount rate of 3%, the investment and maintenance costs are covered, and an additional €112.50 is earned. Considering the uncertainties, for example in output and energy price, this is not a secure investment. The roof with the highest net present value of €3.49/Wp has 24 solar panels and thus a total net present value of € 20,940. This is a considerable profit after 25 years.

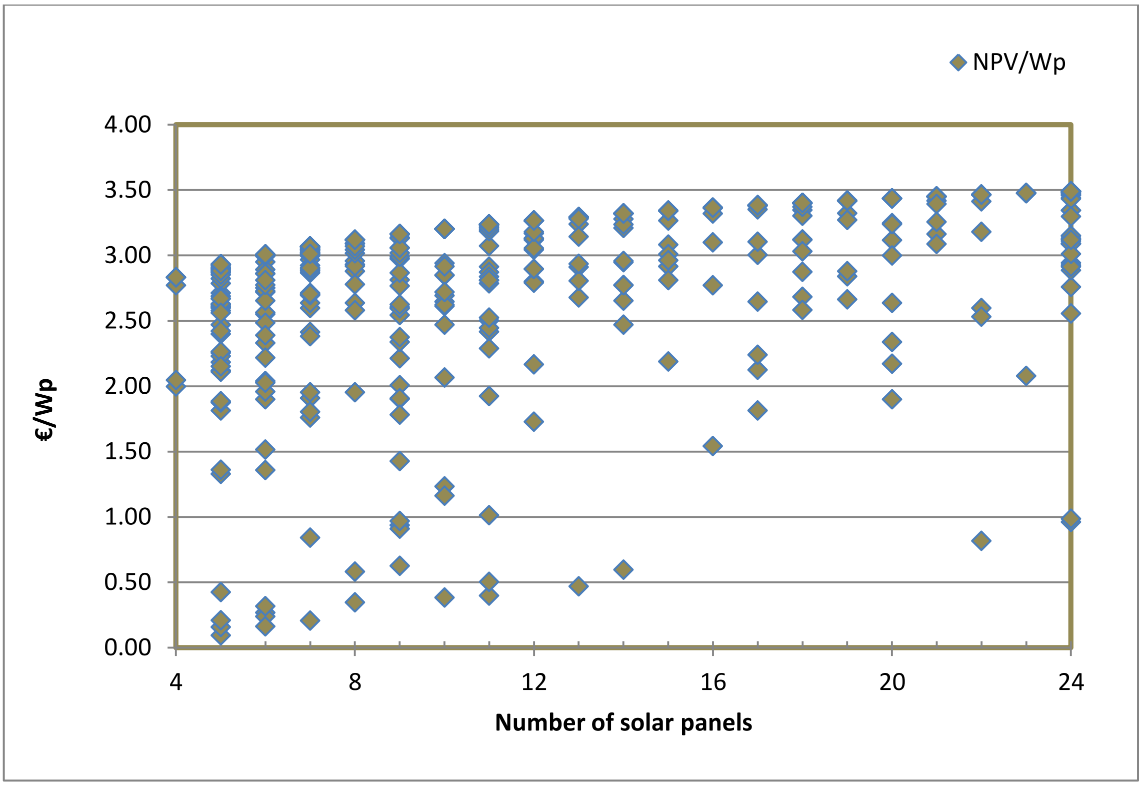


Figure 20 Net present value expressed in €/Wp for every roof part

Figures 21 and 22 show the relationship between the NPV and the slope and the orientation respectively. The outcome is quite similar to Figures 18 and 19 in Section 3.4.2. Figure 21 shows that the orientation is one of the main factors determining the NPV. A sharp decreases in NPV occurs when the orientation is more than 60° away from south. This is strongly correlated to Figure 18. However, the effect is much larger since the best location has a NPV that is almost 3800% higher than the NPV at the worst location. Roof parts facing south have a NPV that is around 25% higher than eastward and westward facing roof parts, which is again higher a higher difference than in Figure 18. Especially a northward orientation is not favourable for solar panels. Note that in Figure 21 flat roofs are visible by the large number of dots at 0°. In Figure 22 a relatively steep slope and a 'bad' orientation lead to a very low NPV. Also the amount of solar panels plays a role, as is shown in Figure 13, because larger systems have lower costs per Wp. Note that in Figure 22 the flat roofs are visible by the large number of dots at 33°.

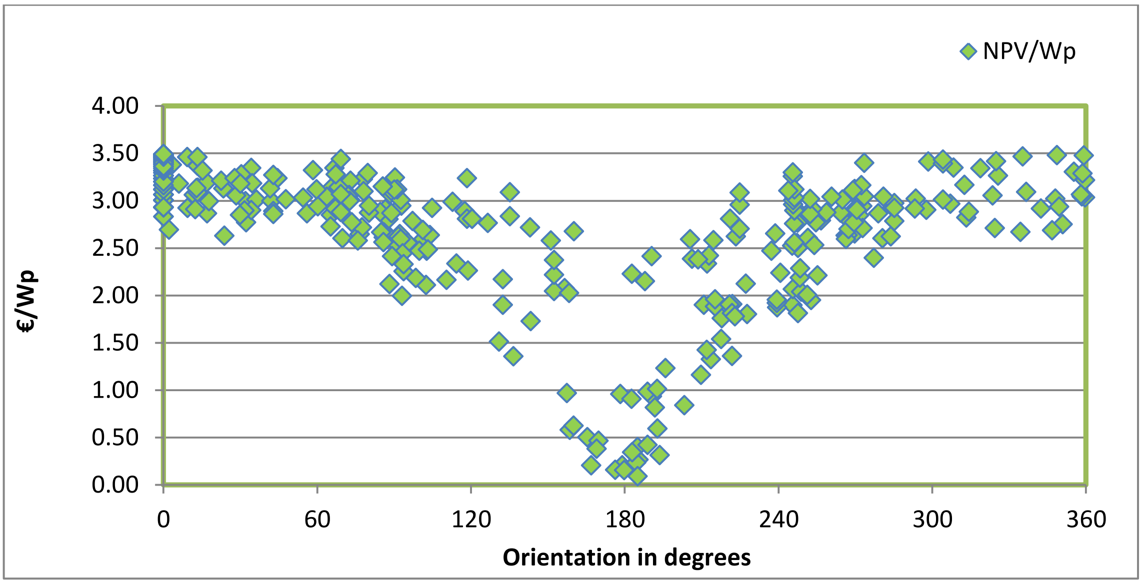


Figure 21 Relationship between NPV in €/Wp and the orientation of a roof part

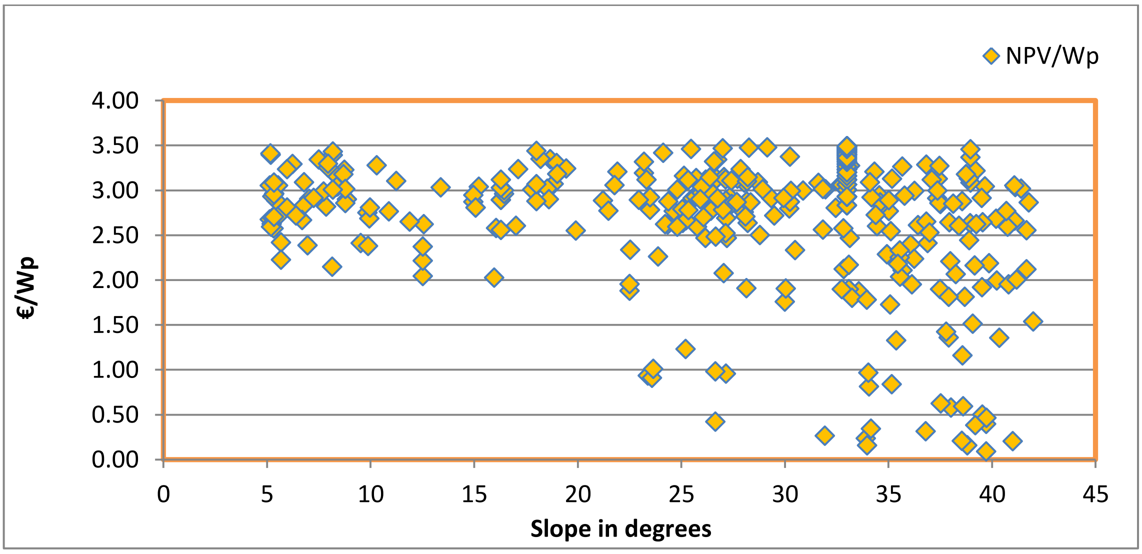


Figure 22 Relationship between NPV in €/Wp and the slope of a roof part

3.4.3.2 NPV per Slope-Orientation Class

The aim in this section is to visualize the combined effect of the orientation and slope on the NPV. This way the effect, of these factors combined, on the profitability of solar panels becomes clear. Because the roofs in the roof top data set have all possible combinations of orientation and slope, classes are computed based on the orientation and slope. Figures 18 and 19 in Section 3.4.2 link the orientation and slope to the output. Based on Figures 18 and 19 a division in so-called slope-orientation classes is made. It is for example very clear in Figure 18 that the output between an orientation of 0° and 60° remains relatively constant. After 60° it starts declining. Therefore the orientation is divided into seven slope-orientation classes shown in green rectangles in Figure 23. Per orientation class four slope classes are defined. These slope classes are between 5-15°, 15-25°, 25-35° and 35-45°. This makes a total of 28 slope-orientation classes and a full list is given in Appendix I.

Figure 23 shows the NPV per slope-orientation class and there are a few patterns that stand out. The most striking one is a low NPV when the orientation is between 150° and 210° (class 13-16), which are the slope-orientation classes with a northward orientation, since 180° is north. It is not surprising that the NPV of class 13 is relatively high compared to classes 14, 15 and 16. The slope of class 13 is between 5° and 15° and because the orientation is north, it has a higher accessibility for the Sun than a relatively steep slope, especially in summer when the sun is high in the sky. A slope between 15° and 25° (class 14) results in a reduction of 53% in NPV with respect to class 13. This is quite significant. Classes 15 and 16 are even lower, because the combination of a northward orientation and a relatively steep slope (>25°) allows for very little sunlight to be collected by the solar panels, resulting in a very low NPV.

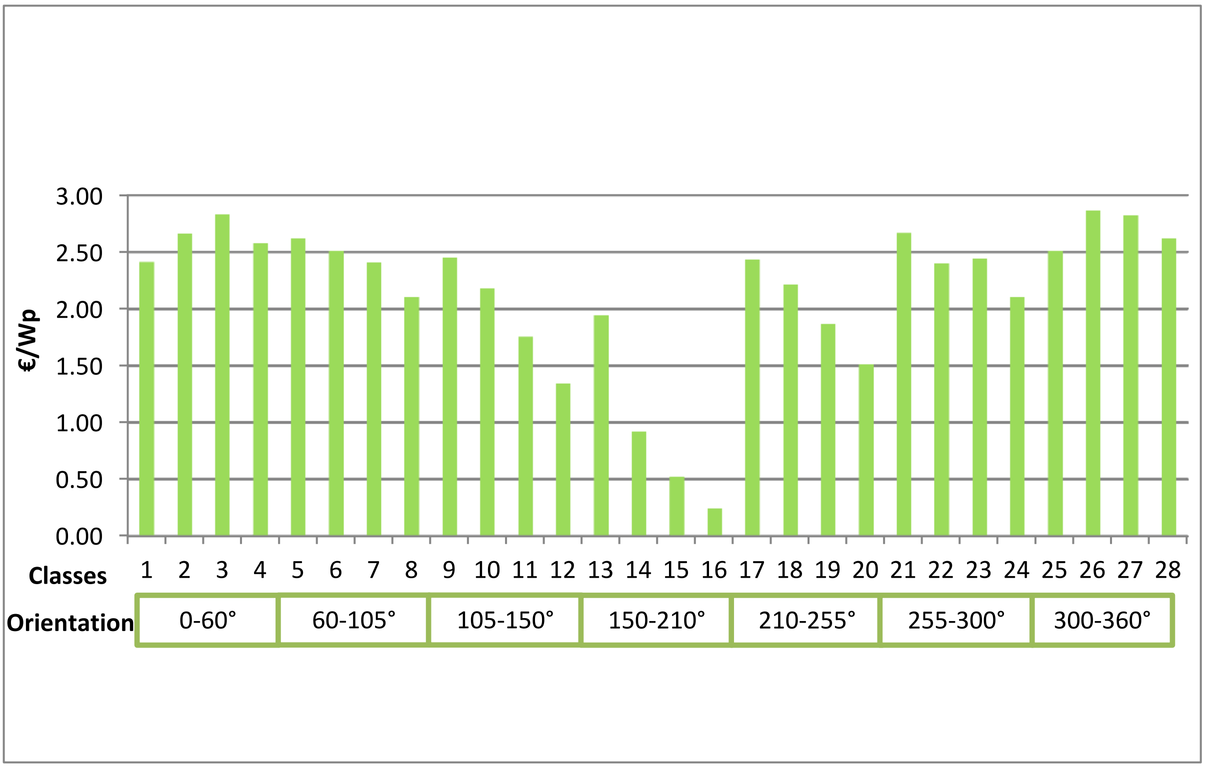


Figure 23 NPV per slope-orientation class. Every orientation class, given in the green rectangles, has four different slope classes See for a full list of the slope-orientation classes Appendix III.

Besides the slope-orientation classes with an orientation between 0-60° and 300-360°, which are the optimal orientation classes, the pattern is that the flattest slope has the highest NPV (see Figure 23). Per non-optimal orientation class the first bar is the highest (classes 5, 9, 13, 17 and 21), followed by the second bar, third bar and fourth bar (except for classes 22 and 23, which are the other way round). This suggests that if a solar panel is not southward oriented, it is better to install a solar panel relatively flat, since the first bar of every orientation class, which has always a slope between 5-15°, is highest. The conclusion is that the optimal slope of 33° (see Section 3.3) is only valid for a solar panel with a southward orientation. In the literature many studies have determined only the optimal roof slope for southward facing solar panels and not for other orientations (Siraki & Pillay, 2012; Hussein, Ahmad & El-Ghetany, 2004; Mehleri, Zervas, Sarimveis, Palyvos & Markatos, 2010). However, Christensen & Barker (2001) have taken into account that the optimal roof slope changes with orientation and have determined the optimal slope and orientation for locations in the United States.

Class 3 contains, among other roofs, all flat roofs in the roof top data set, since these roofs have an orientation of 0° and a slope of 33°. Class 3 should have the highest NPV, since the flat roofs inhibit the optimal conditions. However, it has the second highest NPV, because class 26 has a NPV of €2.87/Wp, which is €0.04/Wp higher than class 3. Class 27 is only €0.01/Wp lower than class 3, so 3 classes are very similar. Class 26 has the highest NPV, because the slope-orientation class sizes and the sizes of the roof parts are unequal. Some roofs can host large solar systems of 24 solar panels, which have a higher NPV per Wp than smaller solar systems (see Figure 13). Class 26 only contains 3 roof parts and these roof parts have space for 17, 18 and 21 solar panels respectively, which are relatively large solar panels systems. Class 27 only has 5 records, but contains solar panel systems of 7 and 8 solar panels and 3 records of solar panel systems with 24 solar panels. Class 3 contains 459 roof shapes, because all flat roofs are in this class. Thus, also very small solar panel systems of 4 solar panels are in this class, which lowers the average NPV of class 3.

3.4.4 Other Economic Assessments

In this section the economic assessment is extended by calculating the return on investment, payback time and levelized cost of electricity. The return on investment is determined to be able to compare the economic performance of the roof tops with interest rates on deposits and savings accounts by banks. The payback time gives the amount of years it takes to earn the investment back. The levelized cost of electricity is used to determine grid parity, that is that the costs of solar energy are lower than or equal to the price of electricity from the national grid.

3.4.4.1 Return on Investment

In this section the return on investment is determined to identify whether solar panels are a good investment compared to the interest rates on saving accounts and deposits. Only 2% of the roof parts in the roof top data set of Amsterdam have an annual return on investment below 1.5% per year. That is below the interest rate of a savings account (see Section 2.2.1). Therefore, these roof parts can be considered as a risky investment, since the current interest rate on a savings account generates more money. Some deposits have higher interest rates (see Section 2.2.1) than the next 2% percent (see Figure 24). So, 96% of the roof parts has an attractive return on investment per year. 38% of the roof parts have a very profitable return on investment of more than 9% per year.

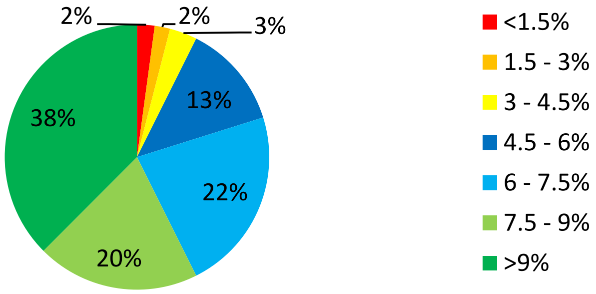


Figure 24 Return on investment per year of the investment in solar panels per roof part.

3.4.4.2 Payback Time

The payback time gives the amount of years it takes, before the investment costs are earned back. The accuracy of this method is typically ± 1 year. A payback time of 7 years means that the payback time is between 6 and 7 years. The return on investment of Section 3.4.4.1 has been linked to the payback time in Table 4. Per category of return on investment per year, the most common payback time in that category is taken as the payback time for that category. The roof parts with a higher return on investment, more than 3%, than interest rates on savings accounts and deposits, have a payback time of 10 years or less, with an accuracy of ± 1 year.

Table 4 The return on investment per year and the payback time per roof part

Return on investment per year	Number of roof parts	Percentage of roof parts per category	Payback time
<1.5%	16	2%	>14
1.5 - 3%	14	2%	11 -- 13
3 - 4.5%	25	3%	9 -- 10
4.5 - 6%	95	13%	8
6 - 7.5%	167	22%	7
7.5 - 9%	148	20%	6
>9%	279	38%	6

Figure 25 shows the payback time in relation to the number of solar panels. Of the 744 roof parts, 388 roof parts have a payback time of six years, which is the minimum in the roof top data set. Only 64 roof parts have a payback time of 9 years or higher. There is 1 roof that has a payback time of 18 years. This particular roof part, with an orientation of 185° and a slope of 40°, is the roof part with the lowest NPV in Section 3.4.3.1, due to the combination of a northward orientation and a relatively steep slope. All roofs that have a payback time of 11 years or longer have an orientation between 157° and 221°. This is a range between 23° west of north and 41° degrees east of north, which shows that northward oriented roof parts have a lower financial attractiveness.

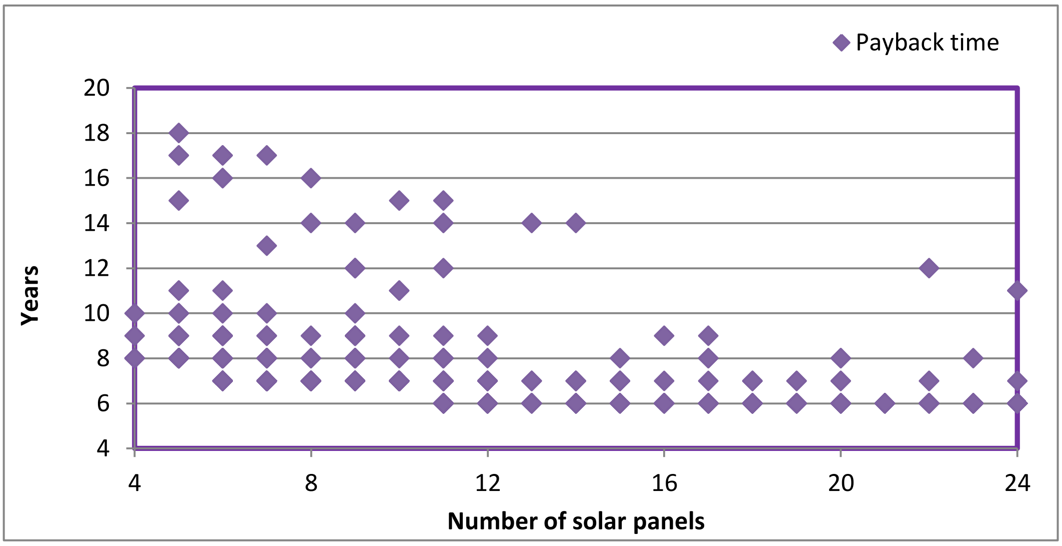


Figure 25 Payback time of the investment in solar panels per roof part

3.4.4.3 Levelized Cost of Electricity and Grid Parity

An energy source is competitive and financially attractive when grid parity occurs. Grid parity implies that the levelized cost of electricity (LCOE) is equal to or lower than the current price of electricity, when buying it from energy companies. Thus, grid parity is a necessary condition in order to be less dependent on large international energy companies, which is a target of the municipality of Amsterdam (Stam, Diependaal & Van 't Hull, 2013). For Dutch households the current average energy price charged by energy companies is €0.23/kWh (Milieu Centraal, 2015b). Thus, grid parity is reached if the levelized cost of solar panel electricity is equal to or below €0.23/kWh. In the roof top data set 32 roof parts have a levelized cost of more than €0.23/kWh. Those are the roof parts with a long payback time and a low NPV. For 712 roof parts grid parity is reached, which means that it is cheaper to produce electricity with solar panels than buying electricity from energy companies. The best locations have a levelized cost of electricity of €0.12/kWh.

The main differences between the NPV and LCOE is that a NPV analysis does not discount the investment costs and takes an annual increase of energy price into account (see Equations 19 and 21). Therefore, it is possible that even if grid parity does not occur, the net present value is positive. In other words, it may be cheaper to buy electricity from energy companies according to the LCOE, while the NPV is positive, which indicates that it is a profitable investment. In the roof top data set grid parity does not occur if the NPV is €1.41/Wp or lower. So, all roof parts with a NPV higher than €1.41/Wp produce solar electricity that is cheaper than buying energy from energy companies. An increase in energy price or a decrease in costs makes solar panels more attractive and increases the NPV of roof parts. In that case, grid parity occurs on more roof parts.

3.5 Sensitivity Analysis

In this section the energy price, costs and incoming solar radiation are adjusted to account for the variability in these factors. This helps assessing the risks related to investing in solar panels. First, the energy price is increased or decreased per year based on expected developments in the future. Secondly, the costs of solar panels are changed. Thereafter, the incoming solar radiation is varied based on long-term variations in the Netherlands. This section concludes assessing the relative effect of the aforementioned factors in a factor analysis. The figures in this section make use of the slope-orientation classes (see Section 3.4.3.2). Appendix I contains a list of all slope-orientation classes.

3.5.1 Energy Price

In determining the benefits of solar panels in Section 3.2.2.1, an annual increase of the energy price of 2% is taken into account. This is in line with the long term inflation (CBS, 2014), but a conservative estimate compared to some companies (Bontenbal, 2014 & www.eneco.nl, 2015a). The development of energy prices is very hard to predict for the next 25 years. The energy price consists for about 70% of taxes and the tax on energy has almost doubled between 2004 and 2014 (Bontenbal, 2014). It is therefore likely that energy taxes will rise in the future. Other factors that might increase the energy price are geopolitical unrest and depletion of fossil fuels.

The costs of energy itself decrease in the next few years (Bontenbal, 2014 & www.powerhouse.nl, 2015). The future developments described in Section 1.1 also cause the energy price to drop. Better insulated buildings and more energy efficient devices may reduce energy demand and thus the energy price, as the energy use per household is already decreasing (ECN, 2014). This makes the prediction very uncertain. Therefore, a wide range of developments of the energy price is considered. In total seven scenarios are shown in Figure 26, ranging from an annual decrease of 2% per year to an annual increase of 5% per year.

Figure 26 shows the effect of the energy price on the NPV. The bars represent the change in NPV of the corresponding energy price development, compared to the situation used in Section 3.4.3, which is the reference situation and has an annual energy price increase of 2%. That is why the 2% increase in energy price is not displayed in Figure 26. For example, the NPV of class 1 changes by 66% if the energy prices rises annually by 5% instead of 2%. So, the green bar consists also of all the lower bars. The colours represent the difference with the previous scenario.

Classes with a very low NPV, which either have a northward orientation or a steep slope (>35°) (see Figure 23), are more sensitive to a change in energy price than other classes (see Figure 26). Especially, classes 14, 15 and 16 are very sensitive. These classes have a northward orientation and thus very little sunlight can be collected by solar panels on these roof parts. Classes 15 and 16 even have a negative NPV if the energy price decreases by 2% per year (not visible in Figure 26). Class 16 also is negative by a 1% fall per year. The NPV of class 16 falls by 156% if the energy price goes down by 2% per year. On the other hand, a 5% increase instead of 2%, results in a 193% increase in NPV in class 16. The other classes are quite similar to each other. The classes with the highest NPV in Figure 23, classes 3, 26 and 27, are least sensitive to a change in energy price.

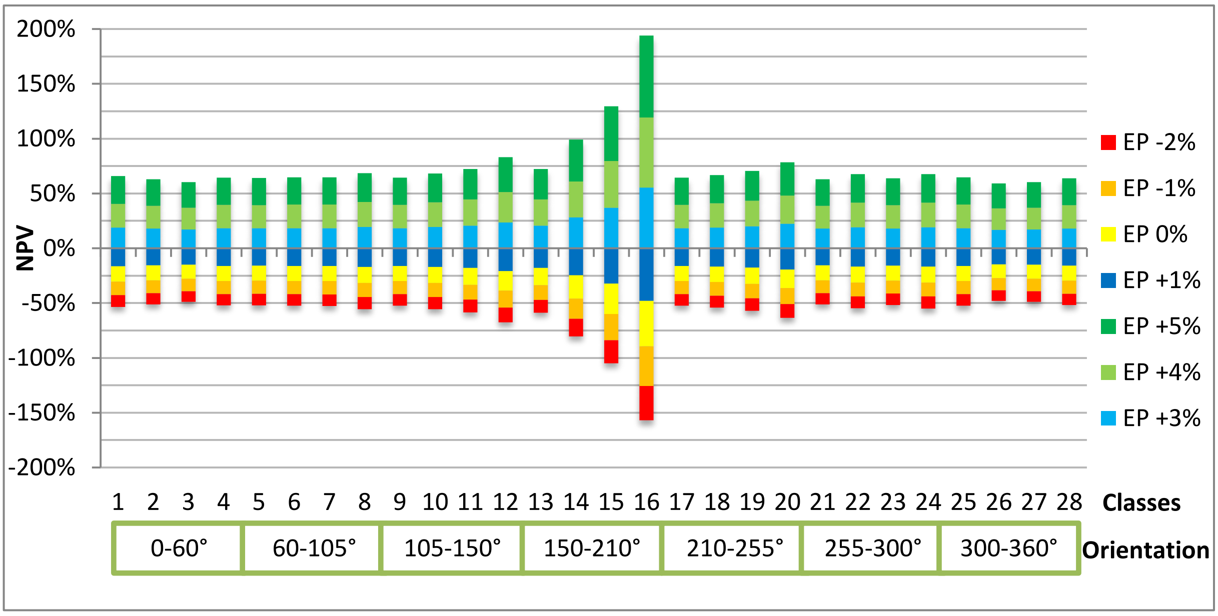


Figure 26 Change in NPV by different developments of the energy price per year. EP = energy price increase per year for 25 years. The roofs are categorized in 28 classes based on their orientation and slope. Every orientation, given in the green rectangles, has four different slope classes. See for a full list of the classes Appendix I.

The rate of change is not constant within a class. For example, in class 1 the effect of a change in energy price in scenario EP+3% with respect to the reference scenario is 19 percent points. The change in EP+4% scenario with respect to EP+3% scenario is 22 percent points. Comparing EP+5% and EP+4% gives a 25 percent points increase. This can be seen in Figure 26, as above 0% every upper bar is larger than every lower bar. The larger the increase in energy price, the bigger the effect on the NPV compared to the previous scenario. The NPV increases with an increasing rate.

A lower energy price, in scenarios EP+1%, EP+0%, EP-1% and EP-2%, results in lower savings and a lower NPV. Examining the NPV in the aforementioned way reveals a decreasing rate of the effect, namely -16, -14, -12 and -11 percent points in class 1. The NPV falls with a decreasing rate. A decreasing energy price can also be regarded as an abolition of the netting regulation. There is determined that the netting regulation will be evaluated in 2017 and possibly reduced from 2020 (TK 2013/2014, 29 023, no. 175). If this regulation ends, the benefits of solar panels will be lower, since the compensation of €0.08/kWh is much lower than the current energy price of €0.23/kWh (see Section 3.2.2.2).

3.5.2 Costs

In this section the costs are adjusted in order to mimic an increase or decrease in costs. As was shown in Figure 11 the costs of solar panel systems have decreased in the last decade. In the preceding decades costs of solar panels were even higher. Carr (2012) used data of historical solar panel prices from Bloomberg, New Energy Finance to visualize this law in relation to the price development of solar panels and called it the Swanson-effect (see Figure 27), after Richard Swanson founder of a large solar power company in the US. Richard Swanson applied the learning or experience curve onto the development of the solar energy market (Swanson, 2006). Swanson's Law states that the price of solar panels drops by 20% for every doubling of the cumulative shipping volume. So, if the production grows, the price drops. Figure 27 shows the so-called Swanson-effect. In 2013 the price of solar panel modules was more than 100 times lower than in 1977.

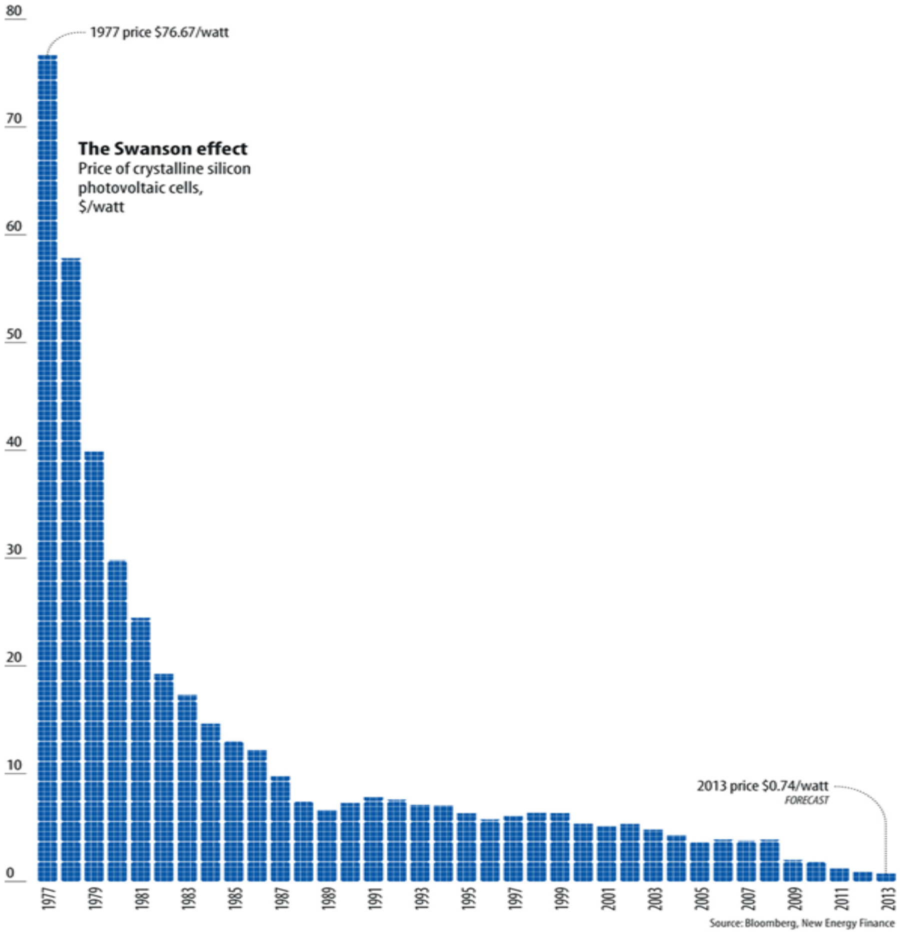


Figure 27 The Swanson Effect. The decrease in the costs of solar panels between 1977 and 2013. Source: Carr, 2012

Schaeffer et al. (2004) have made projections for future solar panel prices in the Netherlands (see Figure 28). Because the analysis has been done in 2004, one can see that scenario A, blue line, is the best prediction for the period between 2004 and 2014, since the price of solar panel systems is €1,89/Wp in 2014 (see Figure 11). Thus, during this period the learning rate was 30%, which means that the costs decreased by 30% for every doubling of the cumulative shipping volume, and that the annual increase of shipping volume was 20%, which is the same as the previous decades (Schaeffer et al., 2004).

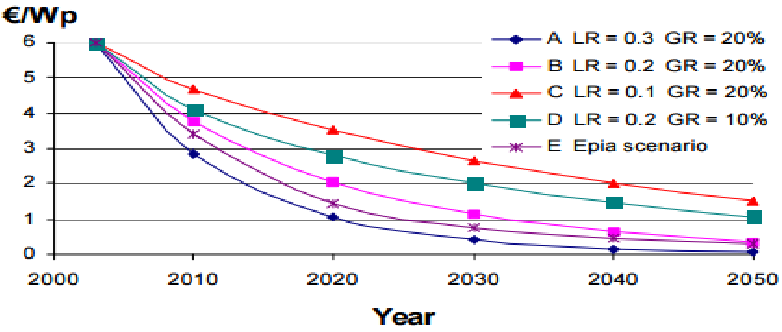


Figure 28 Future projections of the development of solar panel prices. LR = learning rate. GR = growth rate of annual shippings. Epia = scenario by Greenpeace and Epia. Source: Schaeffer et al. (2004) & Greenpeace & EPIA (2008)

Based on the aforementioned sources a range of cost changes between +10% and -50%, by steps of 10% is chosen. Although prices have decreased in the last decades and the projections assume further decreasing prices, also an increase of the costs by 10% is taken into account. Future predictions always have uncertainties and for completeness the cost rise by 10% is added. A decrease in costs, by for example 30%, means that as well as the investment costs as the maintenance costs fall by 30%, since the maintenance costs are linked to the investment costs in this analysis (see Section 2.2.1).

The results are given in Figure 29, which looks the same as Figure 26. Again the northward oriented roofs are the most sensitive and a change in costs has the smallest effect on classes with the highest NPV (classes 3, 26 and 27). Rising the costs by 10% decreases the NPV by 5 - 10%, except for classes 14 - 16. The NPV in these classes drops by 14%, 21% and 37% respectively. The high sensitivity of the northward oriented roof parts might be caused by the fact that the NPV is relatively low. The average costs per generated kWh is relatively high. So, a decrease in costs has a large influence on the NPV. This might also apply to Figure 26. At every 10% cost change the rate of change in the NPV is the same within a class. For example, with every fall in costs by 10% in class 1, the net present value increases by 6%. Every class has a constant rate of change. This is different with respect to the effect of the energy price in Section 3.5.1.

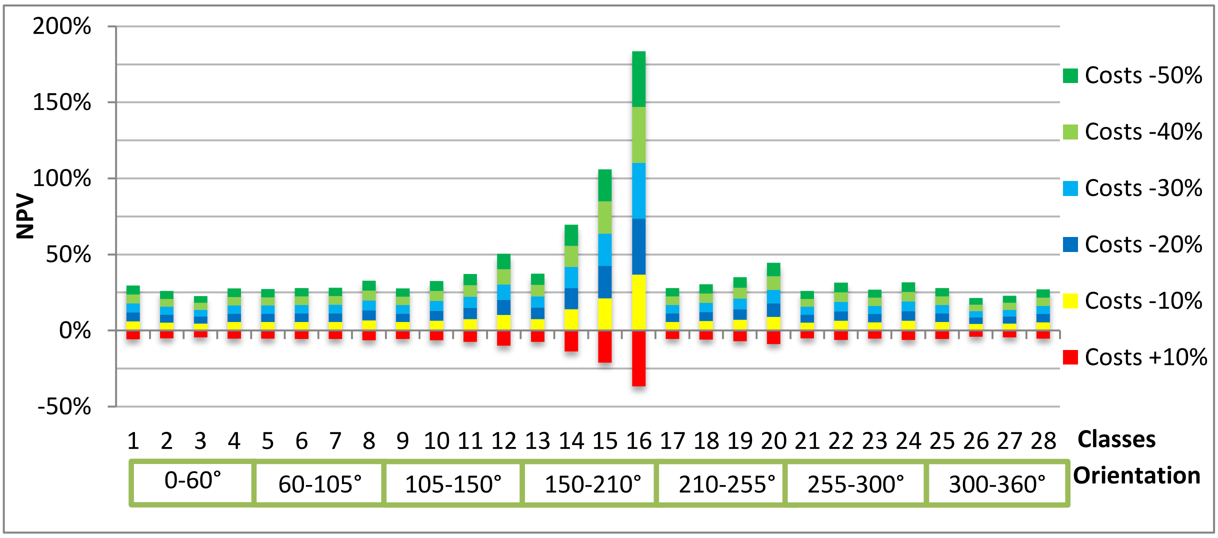


Figure 29 Change in NPV by different developments of the costs. The roofs are categorized in 28 classes based on their orientation and slope. Every orientation, given in the green rectangles, has four different slope classes. See for a full list of the classes Appendix I.

3.5.3 Solar Radiation

The solar radiation data used in this analysis is an average for Schiphol airport for the period 1990-2010. Every year the solar radiation differs from this average. For instance, 2014 was a relatively sunny year with 4% more sunshine than the average (Stichting Monitoring Zonnestroom, 2015). Solar radiation data per month or year for Schiphol is online available from 2010 (KNMI, n.d.(b)). For the national weather station in De Bilt the period 1958 – 1990 is available (Velds, 1992). The year with the lowest solar irradiance is 1988, with a solar irradiance of 8% lower than the average. 1959 had the largest deviation of 13% more solar irradiance than the average. Valkenburg in South-Holland shows similar deviations in the period 1988 – 2014 (www.polderpv.nl, 2015). The years 1998 and 2003 stand out with the lowest and highest solar irradiance of -10% and +9% respectively.

Based on these long-term measurements, scenarios are set up with a maximum deviation of 15% (see Figure 30). For almost every class the results are similar, except for classes 14 -16. The increase or decrease in NPV is between 25% and 30% in the best and worst case scenario (SR +15% & SR - 15%). Classes, 14, 15 and 16 are the least sensitive to a change in solar radiation and this is opposite to Figures 26 and 29. This is because solar panels with a more optimal orientation are more efficient to convert the extra solar radiation into usable electricity.

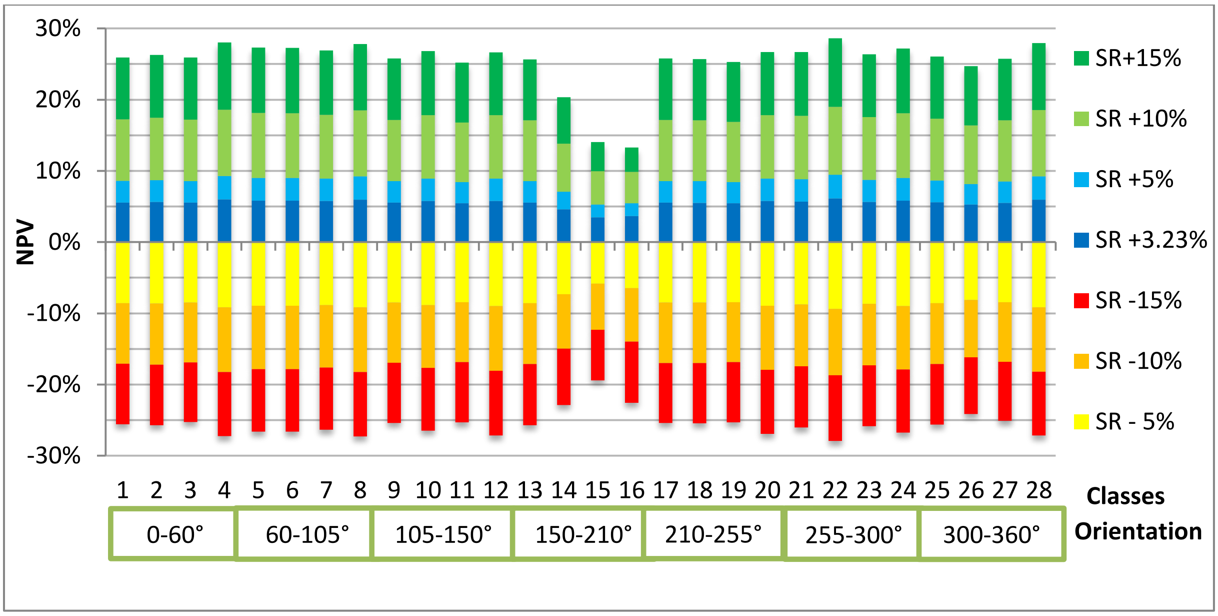


Figure 30 Change in NPV by different developments of incoming solar radiation. SR = incoming solar radiation. The roofs are categorized in 28 classes based on their orientation and slope. Every orientation, given in the green rectangles, has four different slope classes. See for a full list of the classes Appendix III.

Also a SR +3.23% scenario is included, because that is the amount the incoming solar radiation increases if the angle of the installation frame on flat roofs is optimized for every month (see Section 3.3). Thus instead of the optimal roof slope of 33° for the whole year, the roof slope is optimized per month. The additional energy output of 3.23% results in an increase in NPV of 5% or 6%, except for classes 15 and 16, which have an increase of 3% and 4% respectively. Optimizing the slope of the solar panels every month requires a special installation system, which enables the alteration of the solar panel slope automatically. This increases the investment costs as well as the maintenance costs and this is reflected upon in the discussion in Chapter 4.

3.5.4 Factor Analysis

In this section the factors that are adjusted in Sections 3.5.1, 3.5.2 and 3.5.3 are compared for their sensitivity. The costs, energy price and solar radiation are decreased and increased by 50% in order to compare the relative effect on the NPV per Wp. This is valuable for assessing the risks connected to investing in solar panels.

The increase or decrease of the energy price by 50% means that the energy price after 25 years has been decreased by 50% with respect to the starting year. In order to reach a 50% increase the energy price has to rise annually by 1.6%, but in the reference scenario the energy price already increases by 2% per year. So, the energy price increases by 3.6% per year, starting from €0.23/kWh. In order to acquire a 50% decrease the energy price has to go down annually by 2.8%. This means that the energy price decreases by 0.8% per year. It is graphically not appealing to visualize 28 different classes and therefore the average of the whole roof top data set is taken. This decreases accuracy with respect to the NPV, but the relative effect between the different factors is fairly accurate.

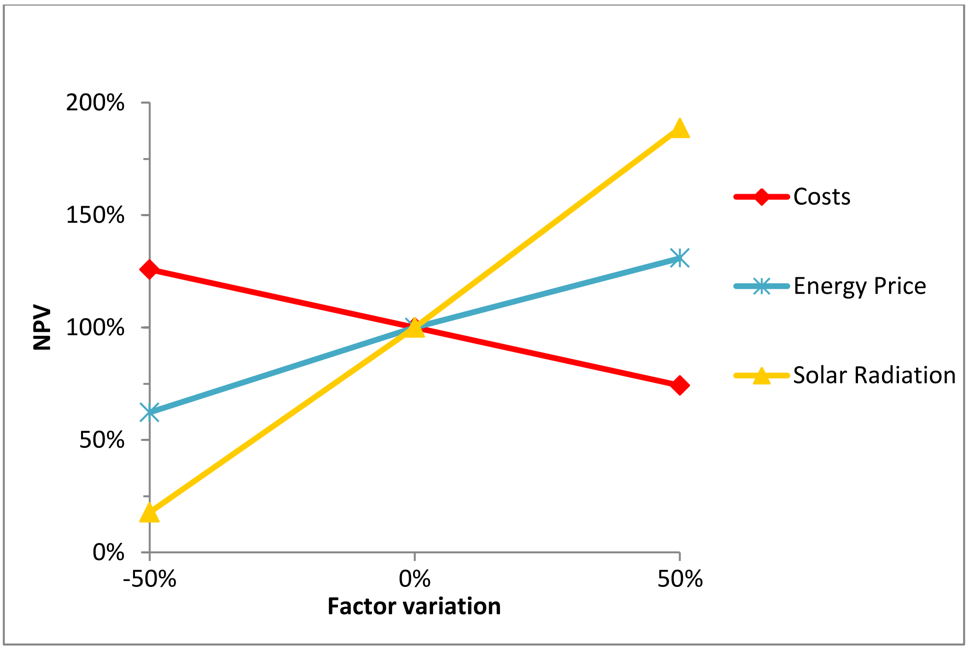


Figure 31 Relative effect of the different factors on the average NPV.

It becomes clear from Figure 31 that incoming solar radiation is the most important factor. A 50% decrease in solar radiation results in a 82% change in the average NPV. The increase is even 89% by a 50% rise. The average NPV changes more than the incoming solar radiation. An increase of the energy price by 50% decreases the average NPV by 31%, while a decrease of 50% lowers the average NPV by 38%. Those two factors only affect the benefits and not the costs. The fact that all roof parts have a positive NPV (see Section 3.4.3), which means that benefits are higher than costs, explains the relatively high sensitivity, especially of the incoming solar radiation, as the benefits outweigh the costs. A change in costs by 50% leads to a smaller change of the average NPV of only 26%. Only the costs have the same positive and negative change, because it is the only factor with a linear relationship.

3.6 Validation

In this section the performance of the solar potential model, the KT model, is assessed by comparing the energy output with observed energy production data. Furthermore, the KT model is used to assess the performance of the Zonatlas. First, the validation of the KT model using observed energy production data of a small sample of solar panel systems in Amsterdam is given. Secondly, the performance of the Zonatlas is assessed using the KT model. The validation methods used in this section are described in Section 2.3. The data is available in Appendices IV and V.

3.6.1 Observed Energy Production Data

In this section the solar potential model, the KT model, is validated using measured energy production data from 23 solar panel systems in Amsterdam between 2010 and 2014. The observed energy production data is retrieved from www.zonnestroomopbrengst.eu (2015) and is listed in Appendix IV. Table 5 gives the amount of solar panel systems that have a complete record for that particular year. Not every solar panel system has a record for each year, because not all solar panel systems existed in 2010 or people started using the website later. Also, some people stopped using the website before 2014. Broken solar panels or construction work on roofs are the cause of months with no output. Only years with complete records for all twelve months are taken into account.

Table 5 Number of solar panel systems with a complete record for that year.
Source: www.zonnestroomopbrengst.eu (2015).

Solar Panel Systems				
2010	**2011**	**2012**	**2013**	**2014**
4	6	12	17	17

The results of the validation are shown in Figures 32 and 33. A positive deviation means that the KT model predicts a lower energy output than the observed energy production data indicates. In Figure 32, this is the case for January, February and March. April and May have an alternating positive and negative deviation. For the remaining months, the KT model overestimates the energy output. As is mentioned in Section 2.3, all observed energy production data is corrected per month for anomalies with respect to the long term average solar radiation, because the KT model uses the long term data.

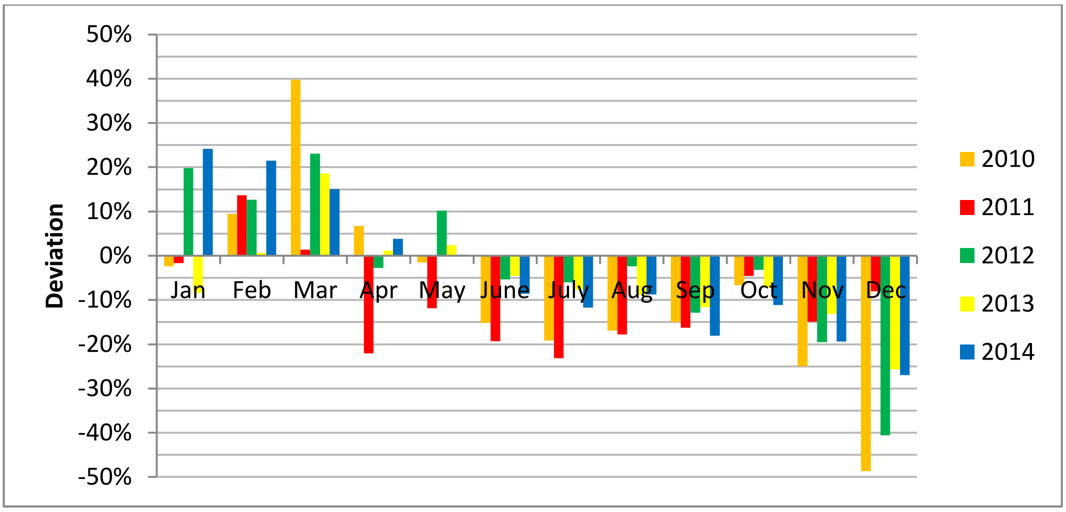


Figure 32 Validation of the KT model in percentages using observed energy production data. A negative deviation means that the KT model predicts a higher solar energy output than is generated by the solar panels.
Source: www.zonnestroomopbrengst.eu (2015).

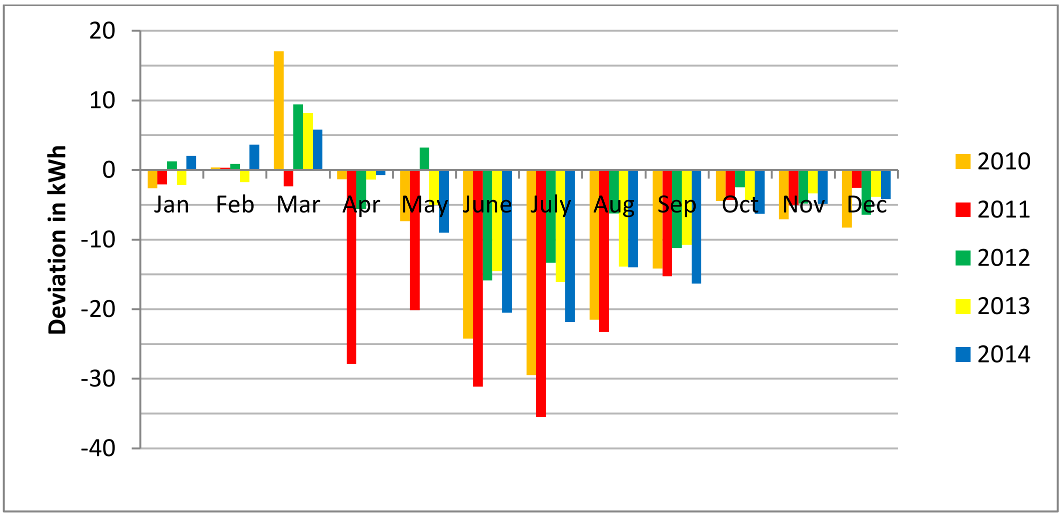


Figure 33 Validation of the KT model in absolute value using observed energy production data. A negative deviation means that the KT model predicts a higher solar energy output than is generated by the solar panels. Source: www.zonnestroomopbrengst.eu (2015).

Figure 33 shows the results of the validation in absolute value, instead of percentages (see Figure 32). The deviation is relatively small in absolute value from October until February, but in those months the amount of generated energy is also relatively small. That is why the deviation in percentages is relatively large for some months in this period. The specific distribution of positive and negative deviation in Figures 32 and 33 could not be explained. It remains puzzling why January, February and March have a positive deviation and the other months a negative deviation. The difference in amount of deviation per month is also caused by unknown factors. In the discussion in Chapter 4 it is explored what might cause the differences between the KT model and the observed energy production data.

3.6.2 Zonatlas

In this section the performance of the Zonatlas is assessed by using the KT model. First, 300 roof parts of the roof top data set are compared to the roof parts in the Zonatlas for the solar potential. Additionally, the orientation and slope are assessed to identify any differences between the roof top data set and the Zonatlas. All the data is listed in Appendix V. In total 148 of the 300 assessed roof parts in the roof top data set do not exist in the Zonatlas. This occurred because of various reasons, such as no accurate height data available in the Zonatlas or less suitable roof parts according to the Zonatlas or not identified roof parts by the Zonatlas. For a list of all roof parts that could not be compared, see Appendix V-3.

3.6.2.1 Energy Output

In this section the expected energy output of solar panels in kWh in year 1 is compared between the KT model and the Zonatlas. The results are shown in the last column of Table 6 for the slope-orientation classes of which at least two records are found in the Zonatlas. In 2 out of the 10 classes the values are negative, which means that the Zonatlas predicts a higher energy output than the KT model. As is explained in Section 2.3, the solar panel systems that are compared have the same size in the Zonatlas as in the roof top data set, to be able to make an equal comparison. So, the deviation is not caused by a difference in size.

Table 6 Comparison results. The classes with at least two records in the Zonatlas are shown. The deviation is the average per class. Classes 6 and 21 have large deviations due to detection errors.

Roof Top Data Set			Zonatlas	Deviation of Zonatlas Compared to Roof Top Data Set			
Class	Orientation	Slope	Count	Orientation in degrees	Slope in degrees	Roof Area in m2	Solar Radiation in kWh
2	0 - 60°	15 - 25°	2	0.93	-2.29	-13.56	115.39
3	0 - 60°	25 - 35°	107	1.13	-0.50	8.08	93.83
4	0 - 60°	35 - 45°	2	2.50	-8.36	-10.63	59.94
6	60 - 105°	15 - 25°	6	20.67	-11.77	-10.95	513.61
7	60 - 105°	25 - 35°	11	1.63	-4.60	5.16	616.06
19	210 - 255°	25 - 35°	2	3.00	-2.15	-10.45	-168.32
21	255 - 300°	5 - 15°	2	86.51	-26.19	-4.53	-33.95
23	255 - 300°	25 - 35°	7	1.28	-3.57	0.99	847.64
27	300 - 360°	25 - 35°	2	0.54	-13.79	15.44	179.39
28	300 - 360°	35 - 45°	4	1.33	-13.49	-9.16	128.75

The energy output of solar panel systems in this comparison range between 1000 and 6000 kWh for the first year, with a majority of the solar panel systems above 4000 kWh. Classes 6, 7 and 23 have a positive deviation of more than 500 kWh. These classes have a west (classes 6 and 7) or east orientation (class 23). Taking 4000 kWh as the average output, shows that the KT model predicts 12.5% more output than the Zonatlas. Unfortunately, roofs with a northward orientation could not be assessed, since the Zonatlas marks those roofs as unsuitable.

Six classes, almost all with a south orientation (±60°), have a deviation between 50 and 200 kWh. This is a deviation between 1.25% and 5%, assuming 4000 kWh as the average. The fact that class 3, with the most records, has a deviation of below 100 kWh, shows that the prediction of energy output is close to that of the Zonatlas for southward orientations. Table 11 in Appendix V-1 shows no large differences with Table 6, except for class 3, which has a lower deviation by 20 kWh due to the removal of errors in roof detection.

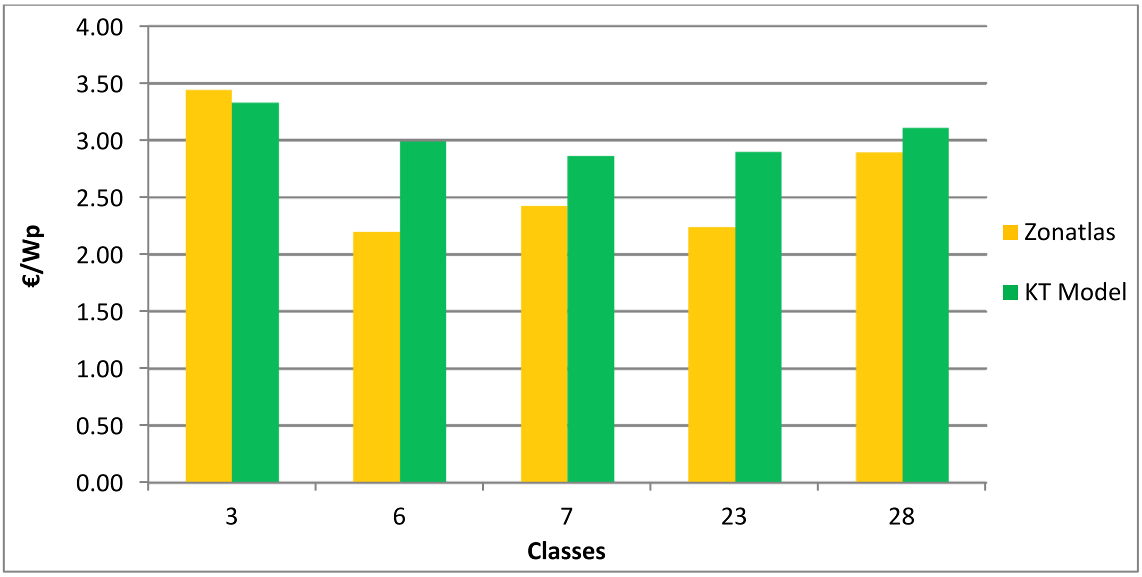


Figure 34 NPV based on the energy output predicted by the Zonatlas and the roof top data set. The economic method used in this research is applied to the Zonatlas. So, the economic method of the Zonatlas is not used.

Figure 34 shows the NPV of the roof parts based on the predicted energy output by the Zonatlas and the KT model. Only the classes with more than two records are taken into account. The economic method used in this research is applied to the Zonatlas, so the economic method of the Zonatlas is not used. Classes 6, 7 and 23 are consistent with Table 6. The Zonatlas predicts less solar radiation on the roof parts in those classes and thus also the NPV is lower. The large deviation in solar radiation is reflected in the large gap in net present value. Also class 28 is consistent with a much smaller solar radiation deviation and thus a smaller difference in NPV. The NPV in class 3 is almost the same in the roof top data set as in the Zonatlas. However, the Zonatlas has a higher NPV, while according to Table 6 the Zonatlas predicts less solar radiation. Although the differences are small, it could not be explained why Figure 34 and Table 6 contradict each other for class 3.

3.6.2.2 Orientation and Slope

In this section the orientation and slope of the Zonatlas and the roof top data set are assessed in order to identify if it is the cause of differences in energy output. If the orientation and slope differ, it has an effect on the deviation in energy output found in Section 3.6.2.1.

The orientation of the roof parts in the roof top data set is compared with the orientation given in the Zonatlas. The results are shown in the fifth column of Table 6. In general the results show that the roof top data set and the Zonatlas almost generate the same orientation for the roof parts. Except for two classes, the average deviation is within 3° degrees, which is very small. Of the 152 compared roof parts only 8 roof parts have a deviation higher than 3° degrees, namely between 4° and 9°. On a 0 - 360° scale this is a deviation of 1.1% - 2.5%. In Appendix V-1 Table 11 is included which is the same as Table 6, but without roof detection errors. Some roof parts are identified by the Zonatlas as flat, while the roof top data set regards them as sloped or vice versa. This happens 14 times and is the main source of the large deviations in classes 6 and 21. The slopes of three roofs fall between 5° and 10°, which leads to a flat roof in the Zonatlas, since the Zonatlas considers roofs with a slope of up to 10° as flat, but leads to a sloped roof in the roof data set, because 5° degrees is the limit for flat roofs. Table 11 shows a decrease in deviation in class 3 from 1.13° to 0.05°, which is expected. Class 4 decreases by 1°, but class 6 has the largest decrease from over 20° to below 5°.

Figure 33 Complex roofs in Amsterdam Source: Google Maps

The results of the slope analysis are given in the sixth column of Table 6 and is the average deviation per slope-orientation class. A minus sign means that the average slope in the Zonatlas is larger than the average slope in the roof top data set for that particular class. It stands out that all classes have steeper slopes in the Zonatlas than in the roof top data set. Class 3 contains, among other roof parts, the flat roofs and thus only a small deviation is to be expected. Of the classes that have more than two records in the Zonatlas, the deviation is more than 10°, except for classes 7 and 23. This is a very large deviation, especially for class 6 that only has slopes between 15° and 25°. An average deviation of -11.77° in class 6 is a deviation between 50% and 84%. Classes 7 and 23 have a deviation below 5°, and as is shown in Section 3.3, this results in a deviation in energy output of the solar panels of only a few percent. Although the average deviations of the slopes are larger than the average deviations of the orientations, the effect on the energy output is smaller, since the orientation has a larger effect on the output (see Section 3.4.2). Table 11 shows no large differences with Table 6 for the slopes. The differences in roof slopes partly occurs, because of the detection of different roof parts. An example is given in Figure 33. These complex roofs have multiple roof slopes, which also differ from the front and back. The Zonatlas identifies the lower steep parts of the roofs (slope >50°), while the roof top data set sees the upper less steep parts of the roofs (slope <20°) as the most suitable in this particular case (see Figure 33). This detection of different roof parts happens on more occasions, but it does not explain the deviation in the average slope per class completely.

4. Discussion

In this section the methods used in this research and the main findings are discussed. Scientific literature is reviewed as much as possible to reflect on the conclusions in this thesis. First, the assumptions and limitations of the methods are discussed. Secondly, the main findings are critically assessed using scientific literature.

4.1 Methods

In this section the methods are discussed. The solar potential model of Klein and Theilacker (1981) makes use of monthly daily average radiation data instead of hourly data. The advantage is that this type of data is widely available and the amount of calculations and the computing time is limited. The main disadvantage is that this model has a lower accuracy than models that use hourly data. The KT model is recommended by Duffie & Beckman (2013), especially for orientations more than 15° from south, which is often the case when modelling roofs. It should be noted that there is no agreement among the scientific community that one model performs best, because it is often dependent on the available type of data, season, location and climate (Jahkrani et al., 2013 & Freitas et al., 2014)

A large uncertainty in the KT model is the calculation of the clearness index (see Section 2.2.2.4). The correlation method developed by Erbs et al. (1982) is applicable to the United States, where on certain locations winters are dryer and/or have less dust in the air than summers. However, Velds (1992) found good results using the Erbs coefficient in the Netherlands. Also other authors found the best results using the Erbs coefficient (Dervisi & Mahdavi, 2012; Ahwide, Spena & El-Kafrawy, 2013). Still, the Erbs coefficient remains a large uncertainty in the solar potential model and could possibly be improved by finding another way of calculating the clearness index.

The economic assessment is performed with the most recent data available. Most data is from 2014, since no data for the year 2015 is already available. The main assumption in the economic assessment is that all of the produced solar energy is either consumed directly by the household or delivered back to the grid for a price of €0.23/kWh. The ratio consumed/delivered back is unknown and this ratio is different for every household. Also the energy consumption of every household is unknown, because it is privacy sensitive information. However, this information is required since the maximum that can be delivered back for €0.23/kWh depends on the energy consumption of the household. Therefore, this assumption had to be made, but a consequence is that larger solar panel systems are always more profitable than smaller solar panel systems, since there is no limit to netting. This should be taken into account when interpreting the results. In the near future the netting regulation is likely to be changed (TK 2013/2014, 29 023, no. 175). Therefore, the economic assessment is designed for quick adaptation of developments in costs and benefits of solar panels.

The validation analysis has shown that improvement of the solar potential model is necessary, especially for non-south orientations. In order to generate more robust results and to be able to provide more conclusions, it is recommended for future research to conduct the analysis in this thesis with a larger data set. 744 individual roof parts do not allow for much variation, since almost half of the roof parts are flat. Some of the 28 compiled slope-orientation classes only have a few records, which makes the results vulnerable to outliers or errors. The presented method of how to assess the economic feasibility of roof top solar panels in the city of Amsterdam can be applied to any city in the world by adjusting the location specific parameters.

4.2 Results

In this section the main results are discussed. First, the validation and the outcome of the solar potential model are reviewed and compared to other sources. Thereafter, other findings related to the optimal conditions and the sensitivity analysis are critically assessed.

The validation of the KT model using observed energy production data from solar panel systems in Amsterdam has shown a pattern that arises many questions (see Section 3.6.1). The deviation between the observed energy production data and the Zonatlas is large and variable per month and per year, despite that the KT model is corrected for anomalies with respect to long-term solar radiation and for specific characteristics of each type of solar panel in the observed energy production data set. The fact that the KT model underestimates January, February and March could not be explained as being the result of winter, since the KT model regards October – February as winter months (see Section 2.1.2.4). The KT model overestimates summer months, which might be caused by shadows, since the effect of shadows may be larger in summer. If shadows occur in summer, more energy output is missed compared to winter. However, this contradicts with the large negative deviations in November and December. Another possible reason of the deviation in summer is the performance of inverters. In the Netherlands often medium conditions for solar panels occur. That is why inverters are used that are very good in low and medium conditions, but not so good on hot and sunny days, which leads to a lower energy output in spring and summer (www.zonnepanelen.net, 2015). Especially, 2010 and 2011 have a high deviation throughout the year. This might be caused by developments in the technology of solar panels. The KT model might not work well with older solar panels. Maybe the validation is improved if shadows are taken into account in the KT model using a realistic 3D rendering of the city of Amsterdam. Another method that might enhance the performance of the KT model is controlling for ambient temperature, since solar panels perform better with lower temperatures (Mohammadi, n.d), which might explain the deviation in summer months. It still remains uncertain why the KT model and the observed energy production have this variability. Further research is required to gain more insight.

Because the validation shows that the solar potential model, the KT model, lacks accuracy, the outcomes of the KT model are compared with other sources to be able to reflect on the lack of accuracy for the city of Amsterdam. In 2014 a new prefix for the energy output per kWp is determined for solar panels in the Netherlands (Van Sark, 2014). This is 875 kWh/kWp and is acquired by monitoring solar systems. The prefix resembles what a typical solar panel in the Netherlands generates on average per kWp. For the best locations it can be as high as more than 1000 kWh/kWp (Van Sark, 2014). The average for the Netherlands for optimal locations is determined by Van Sark (2014) at around 940 kWh/kWp. In this determination an optimal location is a solar panel facing south with a slope of 40° (Van Sark, 2014). The KT model shows that at optimal locations solar panels generate 969 kWh/kWp, which is very close to 940 kWh/kWp. The average of the roof top data set of 744 roof parts is 918 kWh/kWp, which is within 5% of the prefix of 875 kWh/kWp, determined by Van Sark (2014). This shows that the average overall outcome of the KT model is close to the prefix.

Other sources that can be used to compare the outcomes of the KT model are the solar radiation charts given in Figures 36 and 37. Solar radiation charts display in percentages how much of the maximum output can be achieved with a certain orientation and slope. According to Figure 36 a slope of 0°, which is the middle of the circle, gives an energy output of around 85% of that of the optimum. This is a decrease of 15%, while Siderea (2014) claims that it is only 11%. In Section 3.3 is determined that it is 12% according to the KT model. Figure 37, is based on Uccle in Belgium, which has a different latitude. Figure 37 gives a decrease of around 13%. The KT model is within a few percent of the other sources. According to Figures 36 and 37 the incoming radiation on solar panels with a slope of 33° facing eastwards or westwards is around 18% lower. Figure 10, which shows the outcome of the KT model (see Section 3.4.2), gives a decrease of around 10%. This is a 8 percent point deviation for solar panels with an eastward or westward orientation.

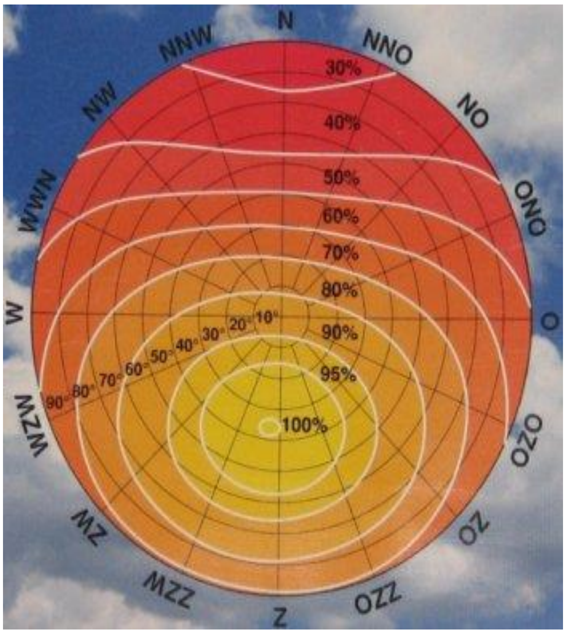


Figure 34 The radiation chart developed by Ecofys. The degrees represent the slope of the solar panel. The percentages are the energy output with respect to the optimum. Source: www.olino.org, n.d.

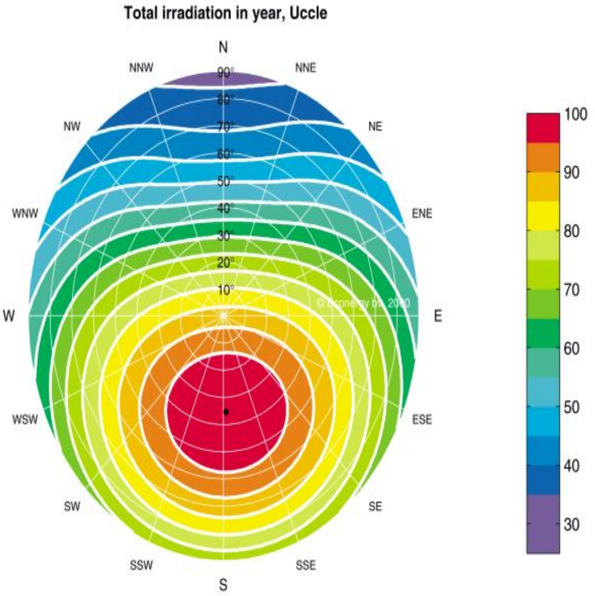


Figure 35 Radiation chart for Uccle in Belgium in percentages of the maximum. Source: http://www.energiebewust.info, n.d.

One of the main findings is that orientation is more dominant than slope in determining the solar potential. The literature is very rare about this subject. www.solstats.com (2015) confirms that the orientation has a larger effect on the solar potential for London, England. Also the effect of orientation and slope on the energy output of solar panels is consistent with the findings in this research. Tian, Davies-Colley, Gong & Thorrold (2001) show graphs that indicate that the orientation and slope have the same effect on the energy output for locations in New Zealand. More conclusive literature could not be found and since London is more similar to Amsterdam than New Zealand, it is likely that the orientation indeed plays a larger role than the slope.

The optimal conditions show that the energy output of solar panels increases if the slope of the solar panels is adjusted every month. This raises the question whether it is more profitable to install solar tracking systems. In the newest designs of tracking systems the solar cells themselves are the sensors that detect the intensity of the sun rays (Rizk & Chaiko, 2008). The solar panel adjusts itself automatically through the day. Solar tracking systems use up to 3% of the additional generated energy to power the tracking device (Mousazadeh, et al., 2009). In this analysis the solar panel slope is only adjusted per month. However, additional energy can be gained by adjusting the slope and orientation of the solar panel throughout the day. According to Poulek & Libra (2007) energy output can be increased by 40%, but this can be highly variable from day to day, depending on the weather conditions (www.helmholz.us, n.d.). Mousazadeh, et al. (2009) have reviewed multiple solar tracking systems and finds energy gains between 10% and 100%, depending on weather conditions and type of solar tracking system technology.

The question is whether the additional energy gain outweighs the extra investment and maintenance costs and the decreased reliability of the solar system. According to Poulek & Libra (2007) a 5 kWp solar panel tracking system is about €2700 more expensive than a regular solar panel system. 20 solar panels of 250 Wp are mounted on one tracking device. However, this is only applicable on very large flat roofs and is more suitable for ground-mounted solar panels. Smaller tracking systems of 4 solar panels are in the range of a €1000 (www.solar-motors.com, 2015). Maintenance costs are higher, since the tracking motor has to be replaced every 8 years. The back-up battery lasts no longer than 5 years. Under the optimal conditions for a solar panel system of 8 solar panels, which requires two tracking systems, an increase in energy output by 40% raises the net present value from €3.12/Wp to €4.00/Wp. The benefits outweigh the costs and solar tracking systems may enhance the economic feasibility of solar panels, taking into account higher investment and maintenance costs and decreased reliability.

The outcomes of the sensitivity analysis could not be verified by scientific literature. No sources could be found that have performed a sensitivity analysis on solar panels in order to quantify the effect of different aspects of solar panels on the economic feasibility, especially for city of Amsterdam. The results of the sensitivity analysis indicate that there might be a geographic aspect determining the effect on teconomic feasibility, since roofs with relatively low solar potential, and thus high average costs per kWh, are very sensitive to a change in one of the factors. This can be translated to other cities. It might be the case that cities with a lower solar potential than Amsterdam have a much higher sensitivity. Further research is recommended to increase the scientific knowledge of the performance of solar panels in different scenarios.

5. Conclusion

In this section the main conclusions of this research are presented. The solar potential of roof top solar panels is assessed and validated in order to determine the economic feasibility for the city of Amsterdam. In this thesis the following research question was leading: *How to assess the economic feasibility of roof top solar panels in a spatially explicit modelling approach for the city of Amsterdam?*

In this thesis the Klein and Theilacker (1981) model, the KT model, is set up to assess solar potential in the city of Amsterdam, because of its compatibility with the available data and its claimed high accuracy. In order to determine the economic feasibility of roof top solar panels a net present value analysis is performed that allows to explore the relative importance of different aspects that influence energy production and its revenues. Observed energy production data from solar panel systems in Amsterdam is used to validate the KT model, which is then used to assess the performance of the Zonatlas, because of its importance to decision making.

The current costs and benefits of roof top solar panels are determined by analysing the Dutch solar panel market. Many solar panels are available in the price range of 0.80 €/Wp - 1.00 Wp (Watt peak). Inverters have a large price variation, since larger inverters are cheaper per Wp, and range between 0.10 and 0.90 €/Wp. The installation costs vary between 0.20 and 0.80 $€/W_p$ with an average of 0.40 $€/W_p$. Assessing the costs of 90 solar panel systems reveals prices that range between €2.06/Wp for a 4 solar panel system and €1.39/Wp for a 24 solar panel system, which are 0.15 – 0.20 €/Wp lower than Van Sark et al. (2014) and Milieu Centraal (2015a). The prices of complete solar panel systems decrease per Wp under the assumption that netting remains possible during the economic lifetime of solar panels.

The optimal conditions for energy production in the city of Amsterdam are determined to achieve the highest energy production. The literature is inconsistent with respect to the optimal slope for solar panels (Siderea, 2014, Stichting Monitoring Zonnestroom, 2015, Van Sark, 2014, www.zonatlas.nl, 2015d & www.essent.nl, n.d.(b)). A southward orientation and a slope of 33° give the highest energy output according to the KT model. The energy output of solar panels decreases by 12% if the solar panels are installed flat instead of at the optimal slope of 33°. An eastward or westward orientation decreases the energy output by 10%. North facing solar panels generate 60% less energy. Since the position of the Earth relative to the Sun changes throughout a year, the optimal slope is different every month. The optimal slope ranges from 68° in December and January to 12° in June. If the slope is adjusted every month, the annual energy output of the solar panels increases by 3.23%, whereas Sun tracker systems can increase energy production by more than 40% Poulek & Libra (2007). Adjusting the slope per month increases the net present value by 3-6%.

In order to assess the economic feasibility of roof top solar panels the net present value of roof parts in the city of Amsterdam is determined. Furthermore, the return on investment, payback time and levelized cost of electricity allow for assessing the risks related to investing in solar panels. The net present value for the roof tops in Amsterdam ranges from €0.09/Wp - €3.49/Wp, where the maximum is reached in optimal conditions. Northward facing solar panels have a relatively low net present value. The orientation is more dominant than the slope in influencing the economic feasibility. If the solar panel is not facing south, it is better to install the solar panel relatively flat. In these conditions the highest net present value is reached with a slope of 5°-15°. The return on investment is for 96% of the roof parts more than 3% per year, which is higher than interest rates of saving accounts and deposits. 58% of the roof parts have a return on investment of more than 6% per year. The payback time is in optimal conditions 6 years. Only 64 roof parts have a payback time of more than 9 years and the least suitable roof has a payback time of 18 years. The levelized cost of electricity method is used to determine whether grid parity occurs, which is the case when solar panel electricity costs equal to or less than €0.23/kWh. Grid parity occurs for 712 out of the 744 roof parts. These roof parts have a net present value, which is higher than €1.41/Wp. In optimal conditions the levelized cost of electricity is €0.12/kWh.

To identify the factors that have the highest impact on the profitability of roof top solar panels in Amsterdam, a sensitivity analysis has been performed. The results indicate that roof parts with a relatively low net present value, such as roof parts with a northward orientation or a steep slope (>35°), are very sensitive to a change in costs or energy price, because the average costs per generated kWh is relatively high. Northward oriented roof parts are least sensitive to a change in solar radiation, since more optimal oriented solar panels are more efficient in converting solar radiation. Roof parts with relatively steep slopes (>35°) are more sensitive to a change in any of the factors, including solar radiation, than more gentle slopes. If the netting regulation is reduced, especially northern faced and steep roof parts decrease in economic attractiveness. The solar radiation has the highest effect on the economic feasibility, followed by the energy price and costs.

Observed energy production data from solar panel systems in Amsterdam is used to validate the KT model, which is then used to assess the performance of the Zonatlas. The validation shows that the KT model deviates strongly from the observed energy production data from one year to the next year and between months. Further research is required to gain more insight in the causes of this deviation. The validation of the Zonatlas using the KT model shows that the Zonatlas predicts for southwards oriented roof parts (±60°) up to 5% less energy output than the KT model. For west and east orientations the KT model forecast around 12.5% more energy output. In order to identify the cause of this deviation the slope and orientation detection are compared between the roof top data set and the Zonatlas. The orientation deviation is on average within 3°, but the Zonatlas detects much steeper slopes, which explains partly why the Zonatlas predicts less energy output, since steeper slopes have a lower solar potential. It is recommended to extend the validation analysis by including more observed energy production data and to increase the number of roof parts in the roof top data set in order to generate more robust results.

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Appendix

The appendix contains additional information and data that is used in this research. Appendix I includes a table of the division of roof parts in classes by orientation and slope. Appendix II is a workflow of the KT model using example data. In Appendix III all the solar panel systems are listed with the costs and source. Appendix IV contains the validation data. Appendix V shows the comparison data between the roof top data set and the Zonatlas.

Appendix I Slope-Orientation Classes

Table 7 Division of roof top data set by orientation and slope

Division of Roof Parts		
Orientation	Slope	Class Number
0-60°	5-15°	1
0-60°	15-25°	2
0-60°	25-35°	3
0-60°	35-45°	4
60-105°	5-15°	5
60-105°	15-25°	6
60-105°	25-35°	7
60-105°	35-45°	8
105-150°	5-15°	9
105-150°	15-25°	10
105-150°	25-35°	11
105-150°	35-45°	12
150-210°	5-15°	13
150-210°	15-25°	14
150-210°	25-35°	15
150-210°	35-45°	16
210-255°	5-15°	17
210-255°	15-25°	18
210-255°	25-35°	19
210-255°	35-45°	20
255-300°	5-15°	21
255-300°	15-25°	22
255-300°	25-35°	23
255-300°	35-45°	24
300-360°	5-15°	25
300-360°	15-25°	26
300-360°	25-35°	27
300-360°	35-45°	28

Appendix II Example of Workflow of KT Model

As an example, the focus is on a random roof with a slope of 30° and an orientation of -20°, which means it faces 20° east from south. The calculations are done for January. In this section the reader is often referred to Section 2.1.3, since this appendix is an example of the model presented in that section.

The ultimate goal is to be able to calculate Equation 9 from Section 2.1.3, which is shown again below, since the interest is for $\overline{H}_T$.

$$\overline{H}_T = \overline{H} * \overline{R} \tag{9}$$

Where:
$\overline{H}_T$ is the total monthly daily average solar radiation on a sloped surface
$\overline{H}$ is the long-term monthly daily average solar radiation on an horizontal surface
$\overline{R}$ is the long-term geometric factor

$\overline{H}$ is already known from Table 1 (see Section 3.1.1) and is 2.344 MJ/m^2. So, only $\overline{R}$ needs to be calculated. It is more convenient to work backwards through Equations 9 – 17, since all the variables in Equations 17 are known. *A*, *B* and *C* are shown in Equations 22. As is mentioned in Section 3.1.1, the latitude, φ, is 52.3. The sunset hour angle, ω_s, and the declination, δ, for January are given in Table 1.

$$A = \cos 30 + \tan 52.3 \cos(-20) \sin 30 = 1.474 \tag{22a}$$

$$B = \cos 60.39 \cos 30 + \tan(-20.90) \sin 30 \cos(-20) = 0.248 \tag{22b}$$

$$C = \frac{\sin 30 \sin(-20)}{\cos 52.3} = -0.280 \tag{22c}$$

Knowing *A*, *B* and *C*, allows for calculation of ω_{sr} and ω_{ss} using Equations 16 from Section 2.1.3. The terms $cos^{-1}\frac{AB+C\sqrt{A^2-B^2+C^2}}{A^2+C^2}$ and $cos^{-1}\frac{AB-C\sqrt{A^2-B^2+C^2}}{A^2+C^2}$ are calculated using the outcomes of Equations 22 (see Equations 23).

$$|\omega_{sr}| = \min[60.39, 91.21] \tag{23}$$

$$\omega_{sr} = \begin{cases} -|\omega_{sr}| & if\ (1.474 > 0\ and\ 0.248 > 0)\ or\ (1.474 \geq 0.248) \\ +|\omega_{sr}| & else \end{cases} \tag{23}$$

$$|\omega_{ss}| = \min[60.39, 69.72] \tag{23}$$

$$\omega_{ss} = \begin{cases} +|\omega_{ss}| & if\ (1.474 > 0\ and\ 0.248 > 0)\ or\ (1.474 \geq 0.248) \\ -|\omega_{ss}| & else \end{cases} \tag{23}$$

Thus $\omega_{sr} = -60.39$ and $\omega_{ss} = 60.39$. Coincidently, ω_{sr} is the negative of ω_{ss}. However, this does not have to be the case for other latitudes, slopes, orientations or months. In order to calculate G, Equation 12, *a'*, *a*, *b*, and *d* from Equation 13 – 15 have to be known first. *a*, *b*, and *d* are given in Equations 24 and 25.

$$a = 0.409 + 0.5016 \sin(60.39 - 60) = 0.412 \tag{24}$$

$$b = 0.6609 - 0.4767 \sin(60.39 - 60) = 0.658 \tag{24}$$

$$d = \sin 60.39 - \frac{60.39\pi}{180} \cos 60.39 = 0.349 \tag{25}$$

Determining a' requires the ratio $\frac{\overline{\mathrm{H}}_{\mathrm{d}}}{\overline{\mathrm{H}}}$ (see Equation 13). This ratio is given in Equations 7 and 8, but needs $\overline{K}_T$ of Equation 6. $\overline{K}_T$ is the ratio of $\frac{\overline{H}}{\overline{H_0}}$. $\overline{H}$ is the long-term monthly daily average radiation on an horizontal surface, for January in this case, which is 2.344 $\mathrm{MJ/m^2}$ (see Table 1). The extra-terrestrial radiation, H_0 (see Section 2.1.2.1), is computed in Equation 26, with the solar constant of 1367 $\mathrm{W/m^2}$ and the mean day of the month, $n = 17$, from Table 1.

$$H_0 = \frac{\left(\frac{(24*3600*1367)}{\pi}*\left(1+0.033\cos\frac{(360*17)}{365}\right)*\left(\cos 52.3 \cos -20.90 \sin 60.39+\frac{60.39\pi}{180}\sin 52.3 \sin -20.90\right)\right)}{1000000} = 7.725 \tag{26}$$

Thus $\overline{K}_T$ becomes:

$$\overline{K}_T = \frac{2.344}{7.725} = 0.303 \tag{27}$$

Because it is January and thus $\omega_s \leq 81.4°$ ($\omega_s = 60.39$), Equation 7 is used, which is the Erbs coefficient for the winter. It is valid to use the Erbs coefficient, because $0.3 \leq \overline{K}_T \leq 0.8$, which is a condition that has to be met (see Section 2.1.2.4).

$$\frac{\overline{H}_d}{\overline{H}} = 1.391 - (3.560 * 0.303) + (4.189 * (0.303)^2) - (2.137 * (0.303)^3) = 0.638 \tag{28}$$

Knowing the $\frac{\overline{H}_d}{\overline{H}}$ ratio and knowing a from Equation 24 enables the calculation of a':

$$a' = 0.412 - 0.638 = -0.225 \tag{29}$$

Now all the required variables to calculate, *G*, have been determined. Because $\omega_{ss} > \omega_{sr}$ ($60.39 > -60.39$) the upper max term in Equation 11 applies, which means that $\omega_{ss} = \omega_1$ and $\omega_{sr} = \omega_2$ in Equation 12. *G* is calculated in Equation 30.

$$\begin{aligned}
G(60.39,-60.39) = {} & \frac{1}{(2*0.349)} * \Bigg[\bigg(\Big(\frac{(0.658*1.474)}{2} - (-0.225 * 0.248)\Big) * (60.39 - -60.39) * \frac{\pi}{180}\bigg) + \\
& \Big(\big((-0.225 * 1.474) - (0.658 * 0.248)\big) * (\sin 60.39 - \sin(-60.39))\Big) - \big((-0.225 * -0.280) * \\
& (\cos 60.39 - \cos(-60.39))\big) + \\
& \Big(\frac{(0.658*1.474)}{2} * (\sin 60.39 \cos 60.39 - \sin(-60.39)\cos(-60.39))\Big) + \Big(\frac{(0.658*-0.280)}{2} * \big(sin^2 60.39 - \\
& sin^2(-60.39)\big)\Big)\Bigg] = 1.000
\end{aligned} \tag{30}$$

G > 0, so all the variables are calculated that are required for Equation 10, which gives the geometric factor $\overline{R}$.

$$\overline{R} = 1.000 + 0.638\left(\frac{1+cos\,30}{2}\right) + 0.2\left(\frac{1-cos\,30}{2}\right) = 1.609 \tag{31}$$

Completing Equation 9 results in:

$$\overline{H}_T = 2.344 * 1.609 = 3.767 \text{ MJ/m}^2 \quad (32)$$

The last steps of calculating the energy production of solar panels on roofs are multiplying $\overline{H}_T$ of Equation 32, which is the total monthly daily average solar radiation on a sloped surface in MJ/m^2, by the available space on the roof for solar panels, the efficiency of the solar panel, *r*, and the performance ratio, *PR*. Assuming an available roof space of 20 m^2 and an efficiency of the solar panel of 16%:

$$E(MJ) = 20 * 0.16 * 0.85 * 3.767 = 10.246 \text{ MJ/day} \quad (33)$$

Equation 33 shows the monthly daily average energy output of 20 m^2 solar panels in January on a roof that is sloped at a slope of 30° and has an orientation of 20° east from south. Multiplying the outcome of Equation 33 by 31, the number of days in January, reveals the monthly average energy output of the solar panels for January. This has been done in Equation 34, in which also the MJ are converted to kWh.

$$E(kWh) = \frac{10.246*31}{3.6} = 88.229\ kWh \quad (34)$$

These calculations, from Equations 22 - 34, give the monthly average solar radiation on roofs that have all possible combinations of slopes and orientations. This example has been done for January but can be easily done for every month with the use of Table 1 (see Section 3.1.1).

Appendix III List of Solar Panel System Costs

Table 8 List of costs of solar panel systems

Number of solar panels	Module costs	Installation costs	Total	Source
3	1200	500	1700	http://www.zonne-energie-feitjes.nl/zonnepanelen/kosten-zonnepanelen/
3	-	-	2138	Van Sark et al
3	-	-	2100	http://www.milieucentraal.nl/energie-besparen/zonnepanelen/zonnepanelen-kopen/kosten-en-baten-van-zonnepanelen/
4	1200	450	1650	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
4	1416	450	1866	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
4	1584	450	2034	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
4	1800	450	2250	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
6	-	-	3465	http://www.eon.nl/thuis/nl/zonnepanelen/onze-zonneproducten/comfort.html
6	-	-	3000	http://www.milieucentraal.nl/energie-besparen/zonnepanelen/zonnepanelen-kopen/kosten-en-baten-van-zonnepanelen/
6	1700	470	2170	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
6	2006	470	2476	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
6	2244	470	2714	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
6	2550	470	3020	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
6	2000	700	2700	http://www.zonne-energie-feitjes.nl/zonnepanelen/kosten-zonnepanelen/
6	-	391	3545	https://www.zonnepaneleneneco.nl/zonnepanelen-gratis-geinstalleerd/#prijstabel
6	-	-	2792	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
7	-	-	3103	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
8	-	-	3413	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
8	-	545	4319	https://www.zonnepaneleneneco.nl/zonnepanelen-gratis-geinstalleerd/#prijstabel
8	2150	557	2707	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
8	2537	557	3094	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
8	2838	557	3395	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
8	3225	557	3782	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html

8	4000	1000	5000	http://www.zonne-energie-feitjes.nl/zonnepanelen/kosten-zonnepanelen/
9	-	-	3723	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
10	-	-	4575	Van Sark et al
10	-	-	4033	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
10	-	-	4875	http://www.nuon.nl/zonnepanelen/prijs.jsp
10	-	--	5525	http://www.nuon.nl/zonnepanelen/prijs.jsp
10	2600	652	3252	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
10	3068	652	3720	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
10	3432	652	4084	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
10	3900	652	4552	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
10	-	618	4879	https://www.zonnepaneleneneco.nl/zonnepanelen-gratis-geinstalleerd/#prijstabel
11	-	-	4429	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
12	-	-	4824	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
12	-	695	5489	https://www.zonnepaneleneneco.nl/zonnepanelen-gratis-geinstalleerd/#prijstabel
12	-	-	5723	http://www.eon.nl/thuis/nl/zonnepanelen/onze-zonneproducten/comfort.html
12	3100	684	3784	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
12	3658	684	4342	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
12	4092	684	4776	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
12	4650	684	5334	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
12	-	-	5400	http://www.milieucentraal.nl/energie-besparen/zonnepanelen/zonnepanelen-kopen/kosten-en-baten-van-zonnepanelen/
13	-	-	5219	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
14	-	-	5529	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
14	-	553	6229	https://www.zonnepaneleneneco.nl/zonnepanelen-gratis-geinstalleerd/#prijstabel
14	3575	742	4317	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
14	4219	742	4961	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
14	4719	742	5461	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
14	5363	742	6105	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
15	5500	1000	6500	https://www.bespaarbazaar.nl/kenniscentrum/financieel/prijszonnepanelen/
15	-	-	5840	https://www.essent.nl/content/Images/124941_Essent%20prijsli

				jst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
16	-	-	6150	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
16	-	904	6939	https://www.zonnepaneleneneco.nl/zonnepanelen-gratis-geinstalleerd/#prijstabel
16	4050	753	4803	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
16	4779	753	5532	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
16	5346	753	6099	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
16	6075	753	6828	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
17	-	-	6460	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
18	-	-	6770	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
18	-	1032	7549	https://www.zonnepaneleneneco.nl/zonnepanelen-gratis-geinstalleerd/#prijstabel
18	-	-	7970	http://www.eon.nl/thuis/nl/zonnepanelen/onze-zonneproducten/design.html
18	4475	787	5262	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
18	5281	787	6068	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
18	5907	787	6694	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
18	6713	787	7500	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
19	-	-	7081	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
20	-	-	7900	Van Sark et al
20	-	-	7391	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
20	4900	832	5732	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
20	5782	832	6614	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
20	6468	832	7300	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
20	7350	832	8182	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
21	-	-	7616	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
22	-	-	7841	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
22	5350	832	6182	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
22	6313	832	7145	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
22	7062	832	7894	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
22	8025	832	8857	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
23	-	-	8067	https://www.essent.nl/content/Images/124941_Essent%20prijsli

				jst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
24	-	-	8292	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
24	5750	891	6641	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_A.html
24	6785	891	7676	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_B.html
24	7590	891	8481	http://www.zonnepanelen-installateurs.info/Zonnepanelen_set_C.html
24	8625	891	9516	http://www.zonnepanelen-installateurs.info/zonnepanelen_set_D.html
25	-	-	8517	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
26	-	-	8742	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
27	-	-	8968	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
28	-	-	9193	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
29	-	-	9418	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf
30	-	-	9643	https://www.essent.nl/content/Images/124941_Essent%20prijslijst%20SpaarPanelen%20255%20Wp%20Mono%20Black.pdf

Appendix IV Validation Data

Appendix IV-1 shows the 23 solar panel systems with characteristics located in Amsterdam, used for validation. Appendix IV-2 gives the energy output of those solar panel systems per year.

Appendix IV-1 Solar Panel Systems with Characteristics

Table 9 List of solar panel systems with characteristics, used for validation of solar potential model. Source: www.zonnestroomopbrengst.eu, 2015

#	Postal code	Start	Slope	Orien-tation	Watt Peak	Number of Solar Panels	Efficiency %	Size Solar Panel (m2)	Type of Solar Panel
1	1011VH	2011	15	160	390	2	15.3	1.28	IBC Solar MonoSol 195MS
2	1015GL	2012	25	180	3335	11	18.4	1.63	Sunpower SPR 300 WHT D
3	1018DR	2012	20	180	1440	6	15.1	1.62	CEEG SST (Shanghai) CSUN245-60M
4	1018DZ	2012	10	163	14750	90	15.4	1.63	Suntech Power STP250S-20/Wd
5	1019KR	2013	30	180	6760	26	15.8	1.64	Aleo Solar S18K260
6	1052EP	2012	15	170	15120	63	14.6	1.64	Aleo Solar S_19 240W
7	1054ZT	2010	13	180	600	3	13.6	1.47	Suntech Power STP200-18/Ub
8	1060	2009	10	225	3600	21	14	1.47	Suntech Power STP200-18/Ub
9	1064	2011	15	180	2310	9	14.4	1.94	Suntech Power STP280-24/Vd
10	1065B	2009	35	180	3240	18	13.5	1.30	Sharp NT-180U1 180 watt 24v
11	1066	2011	25	180	1260	6	14.2	1.47	Suntech Power STP210-18/Ud
12	1066	2011	36	180	1380	6	14	1.64	Aleo Solar S_18 230W
13	1086VJ	2012	20	220	6000	25	14.6	1.64	Aleo Solar S_19 240W
14	1087	2009	35	180	600	3	13.6	1.47	Suntech Power STP200-18/Ub
15	1087	2012	15	220	11520	48	14.6	1.64	Aleo Solar S_19 240Wp
16	1087DP	2011	20	220	10810	47	14	1.64	Aleo Solar S_18 230W
17	1091	2009	10	180	600	3	13.6	1.47	Suntech Power STP200-18/Ub
18	1091	2010	10	90	600	3	13.6	1.47	Suntech Power STP200-18/Ub
19	1091	2010	10	270	600	3	13.6	1.47	Suntech Power STP200-18/Ub
20	1092BR	2012	10	157	12750	51	15.4	1.63	Suntech Power STP250S-20/Wd
21	1096AK	2012	15	155	4800	20	14.6	1.64	Aleo Solar S_19 240W
22	1099BS	2011	25	180	13440	48	14.4	1.94	Suntech Power STP280-24/Vb
23	1112AP	2013	15	220	30000	120	15.2	1.64	Aleo Solar S_18 250W

Appendix IV-2 Energy Output per Year of Solar Panel Systems

Table 10 All 23 solar panel systems with the energy output per year between 2010-2014, used for validation of solar potential model. The validation data is corrected for anomalies with respect to the long-term average solar radiation. All numbers are in kWh/kWp. Source: www.zonnestroomopbrengst.eu, 2015

# 1	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	8.97	9.23	8.72	-	-	8.68	8.04	9.28	12.89	-	-	-32.66%	-37.61%	-28.03%
Feb	-	-	20.26	17.18	21.03	-	-	16.43	15.67	20.49	26.92	-	-	-38.98%	-41.81%	-23.91%
Mar	-	-	60.26	58.46	69.74	-	-	53.04	55.39	50.67	54.97	-	-	-3.52%	0.77%	-7.82%
Apr	-	-	75.64	96.15	87.44	-	-	84.79	90.52	89.66	98.33	-	-	-13.76%	-7.94%	-8.81%
May	-	-	112.82	100.51	108.21	-	-	114.74	114.39	113.85	135.26	-	-	-15.17%	-15.43%	-15.83%
June	-	-	99.23	110.77	112.05	-	-	109.59	111.90	106.34	146.40	-	-	-25.14%	-23.57%	-27.36%
July	-	-	107.69	122.82	111.79	-	-	112.69	111.08	109.73	142.17	-	-	-20.74%	-21.87%	-22.82%
Aug	-	-	107.44	106.15	90.26	-	-	97.98	91.91	92.72	116.44	-	-	-15.86%	-21.07%	-20.37%
Sep	-	-	70.77	60.77	75.90	-	-	61.51	59.75	60.04	75.15	-	-	-18.15%	-20.49%	-20.11%
Oct	-	-	30.77	30.77	30.00	-	-	31.31	30.81	30.37	41.92	-	-	-25.31%	-26.50%	-27.57%
Nov	-	-	11.28	10.26	12.31	-	-	10.79	10.95	9.81	18.97	-	-	-43.13%	-42.29%	-48.28%
Dec	-	-	3.59	6.92	4.87	-	-	3.73	5.35	4.50	11.90	-	-	-68.69%	-55.00%	-62.15%
Year	**-**	**-**	**708.72**	**729.99**	**732.32**	**-**	**-**	**705.28**	**705.78**	**697.46**	**881.35**	**-**	**-**	**-**	**-**	**-**

# 2	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014		2010	2011	2012	2013	2014
Jan	-	-	19.21	24.04	18.12	-	-	18.59	20.95	19.28	10.54	-	-	76.49%	98.89%	83.04%
Feb	-	-	43.31	44.54	38.45	-	-	35.12	40.62	37.45	20.26	-	-	73.35%	100.48%	84.87%
Mar	-	-	74.88	77.73	98.80	-	-	65.91	73.65	71.79	46.81	-	-	40.79%	57.35%	53.36%
Apr	-	-	79.91	117.87	105.61	-	-	89.58	110.97	108.29	93.08	-	-	-3.76%	19.22%	16.35%
May	-	-	122.04	118.89	125.58	-	-	124.11	135.31	132.12	82.60	-	-	50.26%	63.82%	59.96%
June	-	-	104.23	127.48	130.04	-	-	115.12	128.78	123.42	95.31	-	-	20.78%	35.12%	29.49%
July	-	-	114.45	143.71	128.16	-	-	119.76	129.98	125.80	98.10	-	-	22.09%	32.50%	28.24%
Aug	-	-	117.97	132.31	108.33	-	-	107.58	114.55	111.28	88.12	-	-	22.09%	30.00%	26.29%
Sep	-	-	86.50	74.07	94.36	-	-	75.19	72.83	74.64	81.16	-	-	-7.36%	-10.27%	-8.04%
Oct	-	-	51.84	49.79	46.91	-	-	52.75	49.86	47.48	43.62	-	-	20.94%	14.31%	8.86%
Nov	-	-	26.65	22.43	17.88	-	-	25.50	23.94	14.25	21.94	-	-	16.19%	9.08%	-35.05%
Dec	-	-	13.94	22.62	14.40	-	-	14.47	17.50	13.32	14.80	-	-	-2.25%	18.26%	-10.04%
Year	**-**	**-**	**854.93**	**955.48**	**926.64**	**-**	**-**	**843.67**	**918.94**	**879.13**	**696.32**	**-**	**-**	**-**	**-**	**-**

# 3	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	3.16	-	-	-	-	2.75	-	11.01	-	-	-	-74.98%	-
Feb	-	-	-	10.35	-	-	-	-	9.44	-	22.66	-	-	-	-58.35%	-
Mar	-	-	-	48.40	-	-	-	-	45.86	-	50.91	-	-	-	-9.91%	-
Apr	-	-	-	84.72	-	-	-	-	79.76	-	96.71	-	-	-	-17.53%	-

May	-	-	-	88.89	-	-	-	-	101.17	-	76.68	-	-	-	31.93%	-
June	-	-	-	99.93	-	-	-	-	100.95	-	87.14	-	-	-	15.85%	-
July	-	-	-	113.61	-	-	-	-	102.75	-	88.13	-	-	-	16.59%	-
Aug	-	-	-	97.66	-	-	-	-	84.55	-	122.79	-	-	-	-31.14%	-
Sep	-	-	-	45.76	-	-	-	-	44.99	-	78.30	-	-	-	-42.54%	-
Oct	-	-	-	18.23	-	-	-	-	18.26	-	42.00	-	-	-	-56.54%	-
Nov	-	-	-	3.79	-	-	-	-	4.04	-	19.43	-	-	-	-79.18%	-
Dec	-	-	-	2.92	-	-	-	-	2.26	-	13.04	-	-	-	-82.68%	-
Year	**-**	**-**	**-**	**617.42**	**-**	**-**	**-**	**-**	**596.79**	**-**	**708.81**	**-**	**-**	**-**	**-**	**-**

# 4	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	9.04	12.90	-	-	-	7.88	13.73	21.77	-	-	-	-63.80%	-36.93%
Feb	-	-	-	26.35	30.31	-	-	-	24.03	29.53	44.06	-	-	-	-45.46%	-32.99%
Mar	-	-	-	69.56	79.96	-	-	-	65.91	58.10	87.28	-	-	-	-24.48%	-33.44%
Apr	-	-	-	108.03	62.05	-	-	-	101.71	63.63	152.27	-	-	-	-33.21%	-58.21%
May	-	-	-	113.07	72.66	-	-	-	128.69	76.45	204.88	-	-	-	-37.19%	-62.69%
June	-	-	-	125.49	77.63	-	-	-	126.77	73.68	218.44	-	-	-	-41.97%	-66.27%
July	-	-	-	137.90	117.00	-	-	-	124.72	114.84	210.69	-	-	-	-40.80%	-45.49%
Aug	-	-	-	125.19	94.99	-	-	-	108.39	97.58	172.44	-	-	-	-37.14%	-43.41%
Sep	-	-	-	72.76	77.26	-	-	-	71.54	61.11	111.37	-	-	-	-35.76%	-45.13%
Oct	-	-	-	43.30	36.67	-	-	-	43.36	37.12	62.48	-	-	-	-30.60%	-40.59%
Nov	-	-	-	17.13	18.94	-	-	-	18.28	15.10	28.05	-	-	-	-34.83%	-46.17%
Dec	-	-	-	11.55	6.74	-	-	-	8.94	6.23	17.42	-	-	-	-48.70%	-64.23%
Year	**-**	**-**	**-**	**859.37**	**687.11**	**-**	**-**	**-**	**830.21**	**647.08**	**1331.15**	**-**	**-**	**-**	**-**	**-**

# 5	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	-	20.63	-	-	-	-	21.96	10.46	-	-	-	-	109.82%
Feb	-	-	-	-	40.68	-	-	-	-	39.63	20.82	-	-	-	-	90.30%
Mar	-	-	-	-	102.96	-	-	-	-	74.81	44.97	-	-	-	-	66.37%
Apr	-	-	-	-	111.83	-	-	-	-	114.67	67.35	-	-	-	-	70.25%
May	-	-	-	-	130.26	-	-	-	-	137.05	93.35	-	-	-	-	46.81%
June	-	-	-	-	138.21	-	-	-	-	131.17	109.29	-	-	-	-	20.02%
July	-	-	-	-	137.13	-	-	-	-	134.60	114.33	-	-	-	-	17.74%
Aug	-	-	-	-	111.16	-	-	-	-	114.19	103.97	-	-	-	-	9.82%
Sep	-	-	-	-	90.9	-	-	-	-	71.90	89.00	-	-	-	-	-19.21%
Oct	-	-	-	-	52.89	-	-	-	-	53.54	49.35	-	-	-	-	8.48%
Nov	-	-	-	-	31.15	-	-	-	-	24.83	25.91	-	-	-	-	-4.17%
Dec	-	-	-	-	15.88	-	-	-	-	14.68	17.55	-	-	-	-	-16.32%
Year	**-**	**-**	**-**	**-**	**983.68**	**-**	**-**	**-**	**-**	**933.02**	**746.36**	**-**	**-**	**-**	**-**	**-**

# 6	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	18.38	18.66	-	-	-	16.02	19.86	11.73	-	-	-	36.61%	69.35%
Feb	-	-	-	37.63	40.30	-	-	-	34.32	39.26	25.40	-	-	-	35.12%	54.58%
Mar	-	-	-	83.98	102.41	-	-	-	79.58	74.41	53.10	-	-	-	49.87%	40.14%
Apr	-	-	-	127.26	115.54	-	-	-	119.81	118.47	96.13	-	-	-	24.64%	23.25%
May	-	-	-	126.53	135.18	-	-	-	144.01	142.22	133.53	-	-	-	7.85%	6.51%
June	-	-	-	135.19	143.72	-	-	-	136.57	136.40	145.20	-	-	-	-5.95%	-6.06%
July	-	-	-	149.59	138.57	-	-	-	135.30	136.02	140.81	-	-	-	-3.92%	-3.41%
Aug	-	-	-	137.94	119.87	-	-	-	119.43	123.13	114.59	-	-	-	4.22%	7.45%
Sep	-	-	-	85.86	100.20	-	-	-	84.42	79.26	73.39	-	-	-	15.02%	7.99%
Oct	-	-	-	54.14	51.30	-	-	-	54.22	51.93	40.22	-	-	-	34.81%	29.12%
Nov	-	-	-	22.93	29.24	-	-	-	24.47	23.31	18.04	-	-	-	35.62%	29.18%
Dec	-	-	-	18.20	14.39	-	-	-	14.08	13.31	11.23	-	-	-	25.46%	18.54%
Year	**-**	**-**	**-**	**997.63**	**1009.38**	**-**	**-**	**-**	**962.21**	**957.57**	**863.37**	**-**	**-**	**-**	**-**	**-**

# 7	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	15.34	-	-	-	-	14.85	-	-	-	11.88	-	24.96%	-	-	-
Feb	-	26.89	-	-	-	-	32.05	-	-	-	25.86	-	23.93%	-	-	-
Mar	-	100.07	-	-	-	-	79.08	-	-	-	53.81	-	46.96%	-	-	-
Apr	-	133.49	-	-	-	-	106.07	-	-	-	96.69	-	9.69%	-	-	-
May	-	133.84	-	-	-	-	127.19	-	-	-	133.15	-	-4.48%	-	-	-
June	-	118.64	-	-	-	-	122.75	-	-	-	143.83	-	-14.66%	-	-	-
July	-	107.89	-	-	-	-	120.46	-	-	-	139.06	-	-13.37%	-	-	-
Aug	-	97.18	-	-	-	-	111.03	-	-	-	113.08	-	-1.81%	-	-	-
Sep	-	89.73	-	-	-	-	87.93	-	-	-	72.29	-	21.65%	-	-	-
Oct	-	72.04	-	-	-	-	65.53	-	-	-	39.42	-	66.24%	-	-	-
Nov	-	43.24	-	-	-	-	31.28	-	-	-	17.48	-	78.96%	-	-	-
Dec	-	23.11	-	-	-	-	21.37	-	-	-	10.72	-	99.29%	-	-	-
Year	**-**	**961.46**	**-**	**-**	**-**	**-**	**919.59**	**-**	**-**	**-**	**857.26**	**-**	**-**	**-**	**-**	**-**

# 8	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	3.75	7.33	12.67	9.72	10.48	3.47	7.09	12.26	8.47	11.15	20.58	-83.11%	-65.52%	-40.40%	-58.83%	-45.80%
Feb	20.42	16.67	26.00	19.17	22.86	25.45	19.87	21.08	17.48	22.27	39.47	-35.53%	-49.66%	-46.58%	-55.70%	-43.58%
Mar	70.83	59	58.33	55.56	64.20	68.18	46.63	51.34	52.65	46.65	75.45	-9.64%	-38.20%	-31.96%	-30.22%	-38.17%
Apr	95.83	96.67	74.33	96.39	81.93	74.13	76.81	83.32	90.75	84.01	129.35	-42.69%	-40.62%	-35.58%	-29.84%	-35.05%
May	108.75	121.67	117.33	106.03	108.75	119.00	115.62	119.32	120.67	114.42	170.73	-30.30%	-32.28%	-30.11%	-29.32%	-32.98%
June	136.25	107.67	114.00	120.49	122.64	120.04	111.40	125.91	121.72	116.39	179.72	-33.21%	-38.02%	-29.94%	-32.28%	-35.24%
July	120.42	94.33	124.00	127.92	113.69	107.44	105.32	129.76	115.70	111.60	173.88	-38.21%	-39.43%	-25.37%	-33.46%	-35.82%
Aug	104.58	89.33	125.67	111.57	94.71	116.20	102.06	114.60	96.60	97.29	144.23	-19.43%	-29.23%	-20.54%	-33.02%	-32.54%
Sep	61.67	57.67	86.00	60.41	60.99	65.66	56.52	74.75	59.40	48.24	94.30	-30.37%	-40.07%	-20.73%	-37.01%	-48.84%

Oct	37.08	36.67	40.00	32.58	23.00	35.73	33.36	40.70	32.63	23.28	54.76	-34.76%	-39.09%	-25.67%	-40.43%	-57.49%
Nov	14.58	16.00	16.33	13.01	14.22	15.20	11.58	15.62	13.88	11.33	24.73	-38.54%	-53.20%	-36.83%	-43.86%	-54.17%
Dec	5	7.67	7.33	8.63	7.17	4.81	7.09	7.61	6.68	6.63	15.70	-69.35%	-54.82%	-51.54%	-57.46%	-57.77%
Year	**779.16**	**710.68**	**801.99**	**761.48**	**724.64**	**755.30**	**693.34**	**796.28**	**736.62**	**693.26**	**1122.90**	**-**	**-**	**-**	**-**	**-**

# 9	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	13.91	10.09	13.89	-	-	13.46	8.79	14.78	12.20	-	-	10.32%	-27.94%	21.13%
Feb	-	-	30.95	29.96	32.71	-	-	25.10	27.32	31.86	26.95	-	-	-6.88%	1.38%	18.23%
Mar	-	-	82.59	77.29	94.04	-	-	72.69	73.24	68.33	57.29	-	-	26.88%	27.83%	19.26%
Apr	-	-	95.32	120.57	103.86	-	-	106.85	113.51	106.50	104.48	-	-	2.27%	8.64%	1.93%
May	-	-	133.95	120.95	96.46	-	-	136.23	137.65	101.49	145.55	-	-	-6.41%	-5.42%	-30.27%
June	-	-	120.97	132.30	123.87	-	-	133.60	133.65	117.56	83.40	-	-	60.19%	60.24%	40.96%
July	-	-	127.82	146.10	96.14	-	-	133.76	132.14	94.37	153.54	-	-	-12.88%	-13.94%	-38.54%
Aug	-	-	126.45	133.41	111.69	-	-	115.31	115.51	114.73	124.80	-	-	-7.60%	-7.45%	-8.07%
Sep	-	-	91.54	80.00	92.71	-	-	79.57	78.66	73.33	79.64	-	-	-0.09%	-1.23%	-7.92%
Oct	-	-	50.41	41.10	34.72	-	-	51.30	41.16	35.14	43.14	-	-	18.90%	-4.60%	-18.54%
Nov	-	-	17.70	15.42	21.37	-	-	16.93	16.46	17.03	19.18	-	-	-11.73%	-14.22%	-11.21%
Dec	-	-	8.41	10.10	9.13	-	-	8.73	7.82	8.44	12.02	-	-	-27.40%	-35.00%	-29.78%
Year	**-**	**-**	**900.02**	**917.29**	**830.59**	**-**	**-**	**893.53**	**885.90**	**783.57**	**862.21**	**-**	**-**	**-**	**-**	**-**

# 10	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	9.26	16.05	15.43	10.80	16.98	8.58	15.54	14.94	9.41	18.07	10.38	-17.31%	49.72%	43.93%	-9.28%	74.15%
Feb	21.6	44.75	24.69	32.41	30.86	26.92	53.33	20.02	29.56	30.06	21.49	25.25%	148.16%	-6.84%	37.53%	39.88%
Mar	75.62	72.53	74.07	67.90	75.62	72.79	57.32	65.19	64.34	54.94	43.69	66.60%	31.19%	49.22%	47.26%	25.76%
Apr	129.63	115.74	77.16	104.94	84.88	100.28	91.96	86.50	98.80	87.04	74.67	34.30%	23.17%	15.84%	32.32%	16.57%
May	108.02	131.17	123.46	108.02	115.74	118.20	124.65	125.56	122.94	121.77	106.04	11.47%	17.55%	18.41%	15.94%	14.84%
June	131.17	117.28	98.77	108.02	115.74	115.56	121.34	109.09	109.12	109.85	125.79	-8.13%	-3.54%	-13.28%	-13.25%	-12.68%
July	129.63	95.68	104.94	129.63	106.48	115.65	106.83	109.81	117.24	104.52	133.48	-13.35%	-19.96%	-17.73%	-12.16%	-21.69%
Aug	87.96	84.88	108.02	104.94	84.88	97.73	96.98	98.51	90.86	87.19	122.69	-20.34%	-20.95%	-19.71%	-25.94%	-28.93%
Sep	66.36	70.99	74.07	57.10	70.99	70.65	69.57	64.38	56.14	56.15	92.26	-23.42%	-24.60%	-30.22%	-39.15%	-39.14%
Oct	46.3	55.56	38.58	43.21	40.12	44.62	50.54	39.26	43.27	40.61	58.67	-23.96%	-13.86%	-33.09%	-26.25%	-30.79%
Nov	16.98	21.60	18.52	13.89	16.98	17.70	15.63	17.72	14.82	13.53	30.59	-42.13%	-48.92%	-42.08%	-51.54%	-55.75%
Dec	5.56	12.35	7.72	13.89	12.35	5.35	11.42	8.01	10.75	11.42	20.79	-74.26%	-45.07%	-61.46%	-48.30%	-45.07%
Year	**828.09**	**838.58**	**765.43**	**794.75**	**771.62**	**794.03**	**815.10**	**758.98**	**767.25**	**735.16**	**840.53**	**-**	**-**	**-**	**-**	**-**

# 11	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	13.17	-	-	-	-	12.75	-	-	10.59	-	-	20.42%	-	-
Feb	-	-	43.28	-	-	-	-	35.10	-	-	20.36	-	-	72.40%	-	-
Mar	-	-	83.37	-	-	-	-	73.38	-	-	47.04	-	-	56.01%	-	-

Apr	-	-	92.57	-	-	-	-	103.77	-	-	93.52	-	-	10.96%	-	-
May	-	-	130.67	-	-	-	-	132.89	-	-	83.00	-	-	60.12%	-	-
June	-	-	113.41	-	-	-	-	125.26	-	-	95.77	-	-	30.79%	-	-
July	-	-	124.02	-	-	-	-	129.78	-	-	98.57	-	-	31.66%	-	-
Aug	-	-	126.40	-	-	-	-	115.27	-	-	88.54	-	-	30.19%	-	-
Sep	-	-	91.73	-	-	-	-	79.73	-	-	81.55	-	-	-2.23%	-	-
Oct	-	-	50.43	-	-	-	-	51.32	-	-	43.83	-	-	17.09%	-	-
Nov	-	-	16.46	-	-	-	-	15.75	-	-	22.05	-	-	-28.58%	-	-
Dec	-	-	5.74	-	-	-	-	5.96	-	-	14.87	-	-	-59.94%	-	-
Year	**-**	**-**	**891.25**	**-**	**-**	**-**	**-**	**880.94**	**-**	**-**	**699.67**	**-**	**-**	**-**	**-**	**-**

# 12	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	19.58	-	-	-	-	18.95	-	-	10.27	-	-	84.55%	-	-
Feb	-	-	36.79	-	-	-	-	29.83	-	-	21.45	-	-	39.07%	-	-
Mar	-	-	84.26	-	-	-	-	74.16	-	-	43.61	-	-	70.04%	-	-
Apr	-	-	92.09	-	-	-	-	103.23	-	-	75.61	-	-	36.52%	-	-
May	-	-	127.92	-	-	-	-	130.09	-	-	107.88	-	-	20.59%	-	-
June	-	-	108.22	-	-	-	-	119.52	-	-	128.29	-	-	-6.84%	-	-
July	-	-	119.93	-	-	-	-	125.50	-	-	136.49	-	-	-8.05%	-	-
Aug	-	-	125.17	-	-	-	-	114.15	-	-	125.69	-	-	-9.19%	-	-
Sep	-	-	90.89	-	-	-	-	79.00	-	-	94.55	-	-	-16.44%	-	-
Oct	-	-	50.17	-	-	-	-	51.05	-	-	60.19	-	-	-15.19%	-	-
Nov	-	-	23.87	-	-	-	-	22.84	-	-	31.34	-	-	-27.14%	-	-
Dec	-	-	8.57	-	-	-	-	8.89	-	-	21.32	-	-	-58.27%	-	-
Year	**-**	**-**	**887.46**	**-**	**-**	**-**	**-**	**877.22**	**-**	**-**	**856.70**	**-**	**-**	**-**	**-**	**-**

# 13	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	20.59	17.10	-	-	-	17.95	18.20	13.97	-	-	-	28.49%	30.30%
Feb	-	-	-	35.44	37.00	-	-	-	32.32	36.04	28.71	-	-	-	12.58%	25.55%
Mar	-	-	-	85.76	99.27	-	-	-	81.26	72.13	58.18	-	-	-	39.68%	23.98%
Apr	-	-	-	124.07	111.04	-	-	-	116.81	113.86	104.32	-	-	-	11.97%	9.14%
May	-	-	-	122.39	137.12	-	-	-	139.29	144.26	143.64	-	-	-	-3.02%	0.44%
June	-	-	-	134.66	144.45	-	-	-	136.03	137.09	156.09	-	-	-	-12.85%	-12.17%
July	-	-	-	152.34	143.52	-	-	-	137.78	140.88	153.48	-	-	-	-10.23%	-8.21%
Aug	-	-	-	138.65	110.67	-	-	-	120.04	113.68	128.07	-	-	-	-6.27%	-11.23%
Sep	-	-	-	83.86	101.32	-	-	-	82.46	80.14	84.24	-	-	-	-2.12%	-4.86%
Oct	-	-	-	51.74	50.21	-	-	-	51.81	50.82	48.53	-	-	-	6.76%	4.72%
Nov	-	-	-	20.52	26.63	-	-	-	21.90	21.23	22.29	-	-	-	-1.75%	-4.76%
Dec	-	-	-	15.31	11.74	-	-	-	11.85	10.86	14.25	-	-	-	-16.85%	-23.80%
Year	**-**	**-**	**-**	**985.33**	**990.07**	**-**	**-**	**-**	**949.50**	**939.20**	**955.76**	**-**	**-**	**-**	**-**	**-**

# 14	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	25.27	-	-	-	-	23.42	-	-	-	-	10.32	126.89%	-	-	-	-
Feb	26.18	-	-	-	-	32.62	-	-	-	-	21.37	52.63%	-	-	-	-
Mar	83.5	-	-	-	-	80.37	-	-	-	-	43.46	84.95%	-	-	-	-
Apr	137.38	-	-	-	-	106.27	-	-	-	-	74.27	43.10%	-	-	-	-
May	120	-	-	-	-	131.31	-	-	-	-	105.47	24.50%	-	-	-	-
June	137.72	-	-	-	-	121.33	-	-	-	-	125.12	-3.03%	-	-	-	-
July	124.63	-	-	-	-	111.19	-	-	-	-	132.76	-16.24%	-	-	-	-
Aug	88.28	-	-	-	-	98.09	-	-	-	-	122.03	-19.62%	-	-	-	-
Sep	77.17	-	-	-	-	82.16	-	-	-	-	91.77	-10.47%	-	-	-	-
Oct	68.67	-	-	-	-	66.17	-	-	-	-	58.36	13.39%	-	-	-	-
Nov	23.57	-	-	-	-	24.57	-	-	-	-	30.43	-19.23%	-	-	-	-
Dec	18.67	-	-	-	-	17.97	-	-	-	-	20.68	-13.11%	-	-	-	-
Year	**931.04**	**-**	**-**	**-**	**-**	**895.48**	**-**	**-**	**-**	**-**	**836.01**	**-**	**-**	**-**	**-**	**-**

# 15	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	22.76	18.71	-	-	-	19.84	19.91	15.23	-	-	-	30.21%	30.70%
Feb	-	-	-	33.80	37.76	-	-	-	30.82	36.78	30.32	-	-	-	1.68%	21.33%
Mar	-	-	-	84.43	97.25	-	-	-	80.00	70.66	59.72	-	-	-	33.96%	18.32%
Apr	-	-	-	121.16	108.73	-	-	-	114.07	111.49	104.70	-	-	-	8.94%	6.48%
May	-	-	-	122.16	135.72	-	-	-	139.03	142.79	141.20	-	-	-	-1.53%	1.13%
June	-	-	-	131.49	144.74	-	-	-	132.83	137.37	151.00	-	-	-	-12.03%	-9.03%
July	-	-	-	152.70	122.26	-	-	-	138.11	120.01	147.04	-	-	-	-6.08%	-18.39%
Aug	-	-	-	136.73	109.70	-	-	-	118.38	112.69	121.98	-	-	-	-2.95%	-7.62%
Sep	-	-	-	82.80	98.43	-	-	-	81.41	77.86	79.75	-	-	-	2.09%	-2.37%
Oct	-	-	-	28.75	49.54	-	-	-	28.79	50.14	45.87	-	-	-	-37.24%	9.31%
Nov	-	-	-	21.78	28.13	-	-	-	23.24	22.42	20.83	-	-	-	11.57%	7.64%
Dec	-	-	-	18.69	14.87	-	-	-	14.46	13.75	13.22	-	-	-	9.43%	4.04%
Year	**-**	**-**	**-**	**957.25**	**965.84**	**-**	**-**	**-**	**920.99**	**915.88**	**930.87**	**-**	**-**	**-**	**-**	**-**

# 16	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	21.10	18.46	18.01	-	-	20.42	16.09	19.17	13.98	-	-	46.14%	15.13%	37.15%
Feb	-	-	46.19	33.28	37.01	-	-	37.46	30.35	36.05	28.73	-	-	30.39%	5.65%	25.50%
Mar	-	-	86.04	83.81	97.31	-	-	75.73	79.42	70.70	58.21	-	-	30.09%	36.42%	21.46%
Apr	-	-	91.62	120.78	107.80	-	-	102.70	113.71	110.54	104.38	-	-	-1.61%	8.93%	5.89%
May	-	-	139.68	114.40	133.64	-	-	142.05	130.20	140.60	143.72	-	-	-1.16%	-9.41%	-2.17%
June	-	-	58.07	132.84	140.04	-	-	64.14	134.19	132.91	156.18	-	-	-58.94%	-14.08%	-14.90%
July	-	-	107.53	152.61	139.59	-	-	112.52	138.03	137.02	153.58	-	-	-26.73%	-10.12%	-10.78%
Aug	-	-	134.37	138.91	107.52	-	-	122.54	120.27	110.45	128.15	-	-	-4.38%	-6.15%	-13.81%
Sep	-	-	94.84	82.66	98.05	-	-	82.43	81.28	77.56	84.29	-	-	-2.20%	-3.57%	-7.99%

Oct	-	-	54.87	52.00	48.59	-	-	55.84	52.07	49.18	48.56	-	-	14.99%	7.24%	1.29%
Nov	-	-	23.74	21.83	18.81	-	-	22.71	23.30	14.99	22.30	-	-	1.84%	4.46%	-32.77%
Dec	-	-	11.04	18.94	13.76	-	-	11.46	14.66	12.72	14.26	-	-	-19.62%	2.80%	-10.75%
Year	**-**	**-**	**869.09**	**970.52**	**960.13**	**-**	**-**	**850.00**	**933.55**	**911.90**	**956.32**	**-**	**-**	**-**	**-**	**-**

# 17	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	9.03	18.70	16.32	9.50	9.50	8.37	18.10	15.80	8.28	10.11	13.10	-36.15%	38.12%	20.54%	-36.81%	-22.85%
Feb	21.15	25.2	36.30	32.78	30.62	26.36	30.03	29.44	29.89	29.83	27.56	-4.37%	8.96%	6.80%	8.46%	8.22%
Mar	67.77	77.53	68.42	56.90	81.07	65.23	61.27	60.22	53.92	58.90	55.68	17.16%	10.05%	8.16%	-3.16%	5.80%
Apr	116.83	82.9	79.82	102.68	96.97	90.38	65.87	89.48	96.67	99.43	98.01	-7.79%	-32.79%	-8.70%	-1.37%	1.45%
May	107.02	128.47	120.23	106.38	114.42	117.10	122.08	122.27	121.07	120.38	132.78	-11.80%	-8.05%	-7.91%	-8.82%	-9.34%
June	134.73	117.83	104.35	119.00	121.93	118.70	121.91	115.25	120.21	115.72	142.01	-16.42%	-14.15%	-18.84%	-15.35%	-18.51%
July	139.78	103.42	113.97	131.38	118.35	124.71	115.47	119.26	118.83	116.17	136.84	-8.87%	-15.62%	-12.85%	-13.17%	-15.11%
Aug	92.05	89.12	114.57	118.62	98.97	102.28	101.82	104.48	102.70	101.67	111.50	-8.27%	-8.68%	-6.30%	-7.89%	-8.82%
Sep	70.25	70.45	73.55	71.33	82.02	74.80	69.04	63.93	70.14	64.88	71.59	4.49%	-3.56%	-10.70%	-2.03%	-9.37%
Oct	48.73	48.23	37.45	43.03	40.83	46.96	43.87	38.11	43.09	41.33	39.52	18.81%	11.00%	-3.58%	9.02%	4.56%
Nov	16.85	25.25	17.07	17.90	21.42	17.57	18.27	16.33	19.10	17.07	17.55	0.08%	4.06%	-6.97%	8.82%	-2.73%
Dec	6.9	13.48	8.48	15.57	10.55	6.64	12.47	8.80	12.05	9.76	10.71	-37.98%	16.41%	-17.81%	12.51%	-8.90%
Year	**831.09**	**800.58**	**790.53**	**825.07**	**826.65**	**799.08**	**780.20**	**783.36**	**795.95**	**785.25**	**856.85**	**-**	**-**	**-**	**-**	**-**

# 18	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	15.03	13.82	13.82	13.82	-	14.55	13.38	12.05	14.71	20.92	-	-30.47%	-36.07%	-42.43%	-29.71%
Feb	-	24.13	31.1	28.45	27.32	-	28.76	25.22	25.94	26.61	38.30	-	-24.92%	-34.15%	-32.26%	-30.51%
Mar	-	70.18	63.83	53.37	73.02	-	55.46	56.18	50.57	53.06	70.79	-	-21.66%	-20.64%	-28.56%	-25.05%
Apr	-	84.22	80.45	99.67	95.15	-	66.92	90.18	93.83	97.57	119.01	-	-43.77%	-24.22%	-21.15%	-18.02%
May	-	130.28	124.17	108.85	116.18	-	123.80	126.28	123.88	122.23	153.77	-	-19.49%	-17.88%	-19.43%	-20.51%
June	-	122.67	109.2	123.53	126.28	-	126.92	120.61	124.79	119.85	159.62	-	-20.49%	-24.44%	-21.82%	-24.91%
July	-	107.85	117.72	135.73	121.07	-	120.42	123.19	122.76	118.84	154.95	-	-22.29%	-20.50%	-20.77%	-23.31%
Aug	-	90.33	116.37	117.78	98.8	-	103.21	106.12	101.97	101.49	130.50	-	-20.91%	-18.68%	-21.86%	-22.23%
Sep	-	66.63	71.93	68.08	77.22	-	65.30	62.52	66.94	61.08	86.60	-	-24.60%	-27.81%	-22.70%	-29.47%
Oct	-	41.43	38.75	38.88	36.7	-	37.69	39.43	38.93	37.15	52.05	-	-27.60%	-24.24%	-25.20%	-28.63%
Nov	-	20.42	16.6	15.85	17.27	-	14.77	15.88	16.91	13.77	23.66	-	-37.57%	-32.89%	-28.52%	-41.83%
Dec	-	10.95	8.32	11.90	8.35	-	10.13	8.64	9.21	7.72	15.33	-	-33.97%	-43.69%	-39.95%	-49.65%
Year	**-**	**784.12**	**792.26**	**815.91**	**811.18**	**-**	**767.91**	**787.62**	**787.80**	**774.07**	**1025.51**	**-**	**-**	**-**	**-**	**-**

# 19	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	15.83	14.18	14.18	14.18	-	15.32	13.73	12.36	15.09	20.92	-	-26.77%	-34.40%	-40.93%	-27.88%
Feb	-	24.27	32.08	29.30	28.5	-	28.92	26.01	26.72	27.76	38.30	-	-24.48%	-32.08%	-30.23%	-27.51%
Mar	-	71.45	62.9	53.78	75.38	-	56.46	55.36	50.96	54.77	70.79	-	-20.24%	-21.80%	-28.01%	-22.63%
Apr	-	77.93	75.82	99.43	93.57	-	61.92	84.99	93.61	95.95	119.01	-	-47.97%	-28.58%	-21.34%	-19.38%

May	-	122.25	115.85	104.38	111.08	-	116.17	117.82	118.80	116.87	153.77	-	-24.45%	-23.38%	-22.74%	-24.00%
June	-	115.55	104.85	119.25	119.28	-	119.55	115.80	120.46	113.21	159.62	-	-25.10%	-27.45%	-24.53%	-29.08%
July	-	99.93	113.75	129.93	115.97	-	111.58	119.03	117.52	113.83	154.95	-	-27.99%	-23.18%	-24.16%	-26.54%
Aug	-	85.53	108.9	115.75	94.2	-	97.72	99.31	100.22	96.77	130.50	-	-25.12%	-23.90%	-23.20%	-25.85%
Sep	-	65	71.65	67.12	76.48	-	63.70	62.28	66.00	60.49	86.60	-	-26.45%	-28.09%	-23.79%	-30.15%
Oct	-	43.55	39.5	39.30	37.43	-	39.61	40.20	39.36	37.89	52.05	-	-23.89%	-22.78%	-24.39%	-27.21%
Nov	-	21.98	17.4	16.52	18.17	-	15.90	16.65	17.63	14.48	23.66	-	-32.80%	-29.66%	-25.50%	-38.80%
Dec	-	11.57	8.43	13.22	8.68	-	10.70	8.75	10.23	8.03	15.33	-	-30.23%	-42.94%	-33.29%	-47.66%
Year	**-**	**754.84**	**765.31**	**802.16**	**792.92**	**-**	**737.57**	**759.92**	**773.85**	**755.13**	**1025.51**	**-**	**-**	**-**	**-**	**-**

# 20	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	13.04	-	-	-	-	11.37	-	14.87	-	-	-	-23.57%	-
Feb	-	-	-	30.53	-	-	-	-	27.84	-	29.67	-	-	-	-6.15%	-
Mar	-	-	-	78.58	-	-	-	-	74.46	-	58.24	-	-	-	27.84%	-
Apr	-	-	-	117.13	-	-	-	-	110.27	-	101.17	-	-	-	9.00%	-
May	-	-	-	120.33	-	-	-	-	136.95	-	135.54	-	-	-	1.04%	-
June	-	-	-	133.35	-	-	-	-	134.71	-	144.15	-	-	-	-6.55%	-
July	-	-	-	148.15	-	-	-	-	133.99	-	139.13	-	-	-	-3.69%	-
Aug	-	-	-	133.10	-	-	-	-	115.24	-	114.21	-	-	-	0.90%	-
Sep	-	-	-	81.05	-	-	-	-	79.69	-	73.98	-	-	-	7.72%	-
Oct	-	-	-	49.56	-	-	-	-	49.63	-	41.84	-	-	-	18.61%	-
Nov	-	-	-	20.53	-	-	-	-	21.91	-	18.84	-	-	-	16.29%	-
Dec	-	-	-	5.52	-	-	-	-	4.27	-	11.77	-	-	-	-63.72%	-
Year	**-**	**-**	**-**	**930.87**	**-**	**-**	**-**	**-**	**900.33**	**-**	**883.41**	**-**	**-**	**-**	**-**	**-**

# 21	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	18.46	16.89	-	-	-	16.09	17.98	13.43	-	-	-	19.82%	33.86%
Feb	-	-	-	32.71	36.18	-	-	-	29.83	35.24	27.65	-	-	-	7.90%	27.48%
Mar	-	-	-	81.13	94.38	-	-	-	76.88	68.58	55.86	-	-	-	37.62%	22.76%
Apr	-	-	-	119.13	111.39	-	-	-	112.16	114.22	99.35	-	-	-	12.89%	14.97%
May	-	-	-	121.13	130.94	-	-	-	137.86	137.76	135.95	-	-	-	1.41%	1.33%
June	-	-	-	134.40	139.21	-	-	-	135.77	132.12	146.71	-	-	-	-7.46%	-9.94%
July	-	-	-	147.06	133.04	-	-	-	133.01	130.59	142.58	-	-	-	-6.71%	-8.41%
Aug	-	-	-	134.33	112.94	-	-	-	116.30	116.02	117.18	-	-	-	-0.75%	-0.99%
Sep	-	-	-	82.76	96.69	-	-	-	81.37	76.48	75.91	-	-	-	7.20%	0.75%
Oct	-	-	-	50.65	46.71	-	-	-	50.72	47.28	42.71	-	-	-	18.76%	10.70%
Nov	-	-	-	19.44	25.71	-	-	-	20.75	20.49	19.37	-	-	-	7.12%	5.82%
Dec	-	-	-	16.17	12.4	-	-	-	12.51	11.47	12.18	-	-	-	2.70%	-5.89%
Year	**-**	**-**	**-**	**957.37**	**956.48**	**-**	**-**	**-**	**923.24**	**908.22**	**888.87**	**-**	**-**	**-**	**-**	**-**

# 22	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	19.61	17.53	17.94	-	-	18.98	15.28	19.09	10.63	-	-	78.64%	43.80%	79.69%
Feb	-	-	49.14	38.15	43.17	-	-	39.85	34.79	42.05	20.43	-	-	95.01%	70.26%	105.80%
Mar	-	-	92.84	90.51	107.82	-	-	81.71	85.76	78.34	47.21	-	-	73.08%	81.66%	65.94%
Apr	-	-	98.62	114.93	117.92	-	-	110.55	108.20	120.91	93.87	-	-	17.77%	15.26%	28.81%
May	-	-	143.34	124.72	133.05	-	-	145.78	141.95	139.98	83.31	-	-	74.99%	70.39%	68.03%
June	-	-	112.17	136.37	139.96	-	-	123.89	137.76	132.83	96.12	-	-	28.88%	43.31%	38.19%
July	-	-	134.4	154.86	141.59	-	-	140.64	140.06	138.98	98.94	-	-	42.15%	41.57%	40.48%
Aug	-	-	141.75	143.59	117.85	-	-	129.27	124.32	121.06	88.87	-	-	45.45%	39.89%	36.22%
Sep	-	-	103.39	92.36	98.06	-	-	89.87	90.81	77.56	81.86	-	-	9.78%	10.94%	-5.25%
Oct	-	-	60.51	60.56	55.45	-	-	61.57	60.64	56.13	43.99	-	-	39.97%	37.86%	27.59%
Nov	-	-	24.67	21.83	28.41	-	-	23.60	23.30	22.65	22.13	-	-	6.64%	5.26%	2.32%
Dec	-	-	9.56	14.19	10.14	-	-	9.92	10.98	9.38	14.93	-	-	-33.53%	-26.45%	-37.19%
Year	**-**	**-**	**990.00**	**1009.60**	**1011.36**	**-**	**-**	**975.63**	**973.86**	**958.97**	**702.29**	**-**	**-**	**-**	**-**	**-**

# 23	Validation Data					Correction Validation Data					KT Model	Deviation validation data with respect to KT model				
	2010	**2011**	**2012**	**2013**	**2014**	**2010**	**2011**	**2012**	**2013**	**2014**		**2010**	**2011**	**2012**	**2013**	**2014**
Jan	-	-	-	-	18.95	-	-	-	-	20.17	15.23	-	-	-	-	32.45%
Feb	-	-	-	-	37.96	-	-	-	-	36.98	30.30	-	-	-	-	22.04%
Mar	-	-	-	-	98.12	-	-	-	-	71.29	59.69	-	-	-	-	19.44%
Apr	-	-	-	-	111.73	-	-	-	-	114.57	104.65	-	-	-	-	9.48%
May	-	-	-	-	136.59	-	-	-	-	143.71	141.12	-	-	-	-	1.83%
June	-	-	-	-	144.40	-	-	-	-	137.05	150.92	-	-	-	-	-9.19%
July	-	-	-	-	139.78	-	-	-	-	137.20	146.96	-	-	-	-	-6.64%
Aug	-	-	-	-	113.48	-	-	-	-	116.57	121.92	-	-	-	-	-4.38%
Sep	-	-	-	-	61.68	-	-	-	-	48.79	79.70	-	-	-	-	-38.79%
Oct	-	-	-	-	16.93	-	-	-	-	17.14	45.85	-	-	-	-	-62.62%
Nov	-	-	-	-	26.40	-	-	-	-	21.04	20.82	-	-	-	-	1.07%
Dec	-	-	-	-	12.51	-	-	-	-	11.57	13.21	-	-	-	-	-12.42%
Year	**-**	**-**	**-**	**-**	**918.53**	**-**	**-**	**-**	**-**	**876.07**	**930.36**	**-**	**-**	**-**	**-**	**-**

Appendix V Comparison Roof Top Data Set and Zonatlas

Appendix V-1 lists an additional table that does not include detection errors between the Zonatlas and the detection method of the roof top data set. Appendix V-2 shows all the roof parts that have a match in the Zonatlas. Appendix V-3 gives all the roof parts that do not exist in the Zonatlas for various reasons.

Appendix V-1 Detection Errors not Included

Table 11 Comparison roof top data set and Zonatlas with the average deviation per class. In this table the detection errors whether roofs are flat or sloped are deleted in order to see the impact of those errors on the outcomes.

Roof Top Data Set			Zonatlas	Deviation of Zonatlas Compared to Roof Top Data Set			
Class	Orientation	Slope	Count	Orientation in degrees	Slope in degrees	Roof Area in m2	Solar Radiation in kWh
2	0-60°	15-25°	2	0.93	-2.29	-13.56	115.39
3	0-60°	25-35°	100	0.05	-0.39	8.35	72.45
4	0-60°	35-45°	2	1.67	-8.36	-10.63	59.94
6	60-105°	15-25°	2	8.00	-22.94	1.05	588.62
7	60-105°	25-35°	6	1.59	-5.62	10.35	727.47
23	255-300°	25-35°	7	1.28	-3.57	0.99	847.64
27	300-360°	25-35°	2	0.54	-13.79	15.44	179.39
28	300-360°	35-45°	4	1.33	-13.49	-9.16	128.75

Appendix V-2 Matched Roof Parts

Table 12 List of roof parts that have a match in the Zonatlas

Building Identification Number	Roof Top Data Set						Zonatlas						Difference of Zonatlas with Roof Top Data Set			
	Class	Roof Surface Area (m2)	Slope (degrees)	Orientation (degrees)	Num-ber of Solar Panels	Energy Output Solar Panels Year 1 (kWh/ year)	Slope (degrees)	Orientation (degrees)	Roof surface area (m2)	Energy Output Solar Panels Year 1 (kWh/ year)	Energy Output Solar Panels Year 1 Optimal (kWh/ year)	Num-ber of Solar Panels	Slope (degrees)	Orientation (degrees)	Roof Surface Area (m2)	Energy Output Solar Panels Year 1 (kWh/ year)
0363100012061296	15	13.95	31.93	185.35	6	668.38	38	184	23.20	2605	1563	10	-6	1	-9	-894.62
0363100012061376a	3	72.90	33.00	0.00	24	6168.41	33	180	157.60	10446	6268	40	0	0	-71	-99.19
0363100012061376b	3	65.77	33.00	0.00	24	6168.41										
0363100012061598b	3	29.34	33.00	0.00	14	3598.24	33	180	25.3	1564	3649	6	0	0	4	-51.09
0363100012062232a	2	10.84	21.22	32.35	5	1274.03	24	213	41.6	4607	1212	19	-3	1	-31	61.66
0363100012062398	21	37.69	5.18	273.52	18	4624.11	33	180	35.60	2065	4646	8	-28	86	2	-22.14
0363100012063980a	18	12.97	19.91	247.19	6	1397.16	33	180	27.10	1576	1576	6	-13	113	-14	-178.84
0363100012063980b	17	15.23	7.04	247.05	7	1738.60	20	252	16.60	1421	1421	7	-13	5	-1	317.60
0363100012064975	3	28.20	33.00	0.00	13	3341.22	33	180	24.10	1277	3320	5	0	0	4	21.02
0363100012065390b	3	73.60	33.00	0.00	24	6168.41	33	180	65.50	3780	5670	16	0	0	8	498.41
0363100012065512	3	70.73	33.00	0.00	24	6168.41	33	180	53.40	3449	6367	13	0	0	17	-198.98
0363100012065973	3	47.33	33.00	0.00	23	5911.39	33	180	39.60	2219	5671	9	0	0	8	240.61
0363100012065995	3	48.73	33.00	0.00	23	5911.39	33	180	45.80	2930	6126	11	0	0	3	-214.97
0363100012066038	3	58.22	33.00	0.00	24	6168.41	33	180	56.00	3703	5925	15	0	0	2	243.61
0363100012066553	3	122.88	33.00	0.00	24	6168.41	33	180	108.90	6210	6210	24	0	0	14	-41.59
0363100012069076	3	47.63	33.00	0.00	23	5911.39	33	180	13.07	2105	6052	8	0	0	35	-140.48
0363100012069316	3	30.44	33.00	0.00	14	3598.24	33	180	28.90	1332	3730	5	0	0	2	-131.36
0363100012069513a	23	82.53	28.03	268.81	24	5655.84	32	88	91.80	4464	4464	24	-4	1	-9	1191.84
0363100012069513b	7	76.65	27.71	88.31	24	5710.85	32	268	65.30	4472	4472	24	-4	0	11	1238.85
0363100012069787a	7	26.01	26.71	65.37	12	2997.84	30	246	27.50	1742	2613	8	-3	1	-1	384.84
0363100012070305	3	55.57	33.00	0.00	24	6168.41	33	180	47.60	2861	5722	12	0	0	8	446.41
0363100012071320a	3	10.55	33.00	0.00	5	1285.09	33	180	27.00	1271	1271	5	0	0	-16	14.09
0363100012071438	3	52.60	33.00	0.00	24	6168.41	33	180	50.00	3377	6234	13	0	0	3	-66.05
0363100012071644	3	40.22	33.00	0.00	19	4883.32	33	180	33.40	2551	4847	10	0	0	7	36.42
0363100012072195	3	54.88	33.00	0.00	24	6168.41	33	180	46.60	2536	6086	10	0	0	8	82.01
0363100012072260	3	50.01	33.00	0.00	24	6168.41	33	180	45.10	3014	6028	12	0	0	5	140.41
0363100012072490	3	41.21	33.00	0.00	20	5140.34	33	180	40.60	1987	4968	8	0	0	1	172.84
0363100012072653b	3	11.47	33.00	0.00	5	1285.09	33	180	28.30	2123	3450	8	0	0	1	-108.65
0363100012072653c	3	17.80	33.00	0.00	8	2056.14										
0363100012072922a	20	14.00	37.49	245.49	6	1189.19	50	245	21.60	1276	1276	6	-13	0	-8	-86.81
0363100012072922b	16	16.50	38.02	158.54	8	976.56	49	156	25.70	2234	1986	9	-11	3	-9	-1009.22
0363100012072922c	16	19.31	37.52	160.09	9	1098.99	49	160	23.40	1486	2229	6	-11	0	-4	-1130.01
0363100012073980a	3	19.01	33.00	0.00	9	2313.15	33	180	25.80	1234	2221	5	0	0	-7	91.95
0363100012074829b	7	30.72	31.62	69.55	15	3649.16	54	248	17.7	767	2876	4	-22	2	13	772.91
0363100012075779a	3	15.40	33.00	0.00	7	1799.12	33.00	180.00	27.80	1608	1876	6	0	0	-12	-76.88

0363100012075887	3	46.55	33.00	0.00	22	5654.38	33.00	180.00	82.00	5630.00	5898	21	0	0	-35	-243.72
0363100012076630	3	40.34	33.00	0.00	19	4883.32	33.00	180.00	35.7	1937.00	4600	8.00	0	0	5	282.95
0363100012076909	3	74.55	33.00	0.00	24	6168.41	33.00	180.00	66.20	3675.00	6300	14	0	0	8	-131.59
0363100012077571	6	10.24	24.22	91.67	5	1203.44	27	89	18.10	1321	944	7	-3	3	-8	259.87
0363100012078179b	21	15.16	8.43	273.46	7	1791.73	33	180	26.30	1575	1838	6	-25	87	-11	-45.77
0363100012078503	3	71.51	33.00	0.00	24	6168.41	33.00	180.00	60.40	3203.00	5491	14.00	0	0	11	677.55
0363100012078514b	3	51.92	33.00	0.00	24	6168.41	33.00	180.00	33.97	2228.00	5941	9	0	0	18	227.08
0363100012078565b	3	66.09	33.00	0.00	24	6168.41	33.00	180.00	42.00	2044.00	6132	8.00	0	0	24	36.41
0363100012079311	3	48.89	33.00	0.00	23	5911.39	33.00	180.00	42.30	2345.00	5394	10.00	0	0	7	517.89
0363100012079390	3	46.81	33.00	0.00	22	5654.38	33.00	180.00	40.6	2075.00	5706	8	0	0	6	-51.87
0363100012079413a	7	16.32	25.77	101.52	7	1624.21	29	104	17.40	1186	1384	6	-3	2	-1	240.54
0363100012080292	4	10.10	35.02	32.33	4	1015.03	43	209	11.90	735	980	3	-8	3	-2	35.03
0363100012081455c	3	218.75	33.00	0.00	24	6168.41	33.00	180.00	172.00	5965.00	5965	24.00	0	0	47	203.41
0363100012081533b	3	21.80	33.00	0.00	10	2570.17	33.00	180.00	48.60	3495.00	2496	14	0	0	-27	73.74
0363100012081533c	3	66.79	33.00	0.00	24	6168.41	33.00	180.00	52.70	3731.00	5970	15	0	0	14	198.81
0363100012081533d	3	61.61	33.00	0.00	24	6168.41	33.00	180.00	63.70	3364.00	6210	13.00	0	0	-2	-42.05
0363100012081818	3	43.27	33.00	0.00	21	5397.36	33.00	180.00	37.40	1484.00	5194	6.00	0	0	6	203.36
0363100012082537c	3	66.87	33.00	0.00	24	6168.41	57.00	136.00	48.80	4223.00	5334	19	-24	44	18	834.09
0363100012082560b	3	47.93	33.00	0.00	23	5911.39	33	180	43.20	2238	5719	9	0	0	5	192.06
0363100012082671	3	59.75	33.00	0.00	24	6168.41	33.00	180.00	48.40	2799	6107	11	0	0	11	61.50
0363100012082763	3	149.42	33.00	0.00	24	6168.41	33.00	180.00	97.6	6055.00	6055	24	0	0	52	113.41
0363100012082866	3	68.01	33.00	0.00	24	6168.41	33.00	180.00	57.80	3207.00	5921	13	0	0	10	247.79
0363100012082905b	5	24.44	8.74	77.88	11	2823.16	33	180	23.00	1011	2780	4	-24	78	1	42.91
0363100012083212a	16	16.20	41.00	179.10	7	734.72	58	180	39.7	3388	3388	14	-17	0	-9	-865.49
0363100012083212b	28	14.95	41.12	359.64	7	1787.79										
0363100012084048a	27	83.25	28.26	359.11	24	6153.05	32.00	178.00	64.10	5884.00	5884	24.00	-4	1	19	269.05
0363100012084258	6	15.64	15.22	63.72	7	1790.14	54	253	16.60	964	1350	5	-39	9	-1	440.54
0363100012084287b	28	31.16	35.67	325.63	15	3794.67	44	147	32.70	2854	3568	12	-8	1	-2	227.17
0363100012084904	3	48.17	33.00	0.00	23	5911.39	33.00	180.00	43.10	2350.00	6006	9	0	0	5	-94.16
0363100012085122	3	43.56	33.00	0.00	21	5397.36	33.00	180.00	39.9	1856.00	5568	7	0	0	4	-170.64
0363100012085495b	3	58.44	33.00	0.00	24	6168.41	33.00	180.00	50.90	3116.00	6232	12.00	0	0	8	-63.59
0363100012086068b	7	28.56	29.34	86.59	13	3076.96	37	269	22.80	1862	2421	10	-8	2	6	656.36
0363100012086842	3	37.34	33.00	0.00	18	4626.31	33.00	180.00	38.50	1775.00	4564	7	0	0	-1	62.02
0363100012087607a	3	123.92	33.00	0.00	24	6168.41	33.00	180.00	105.30	6197.00	6197	24.00	0	0	19	-28.59
0363100012088209b	3	35.92	30.24	3.33	17	4365.17	39.00	182.00	13.90	962.00	4089	4.00	-9	1	22	276.67
0363100012088331	3	36.45	33.00	0.00	17	4369.29	33.00	180.00	36.50	2408.00	4548	9.00	0	0	0	-179.15
0363100012088727	3	38.46	33.00	0.00	18	4626.31	33.00	180.00	32.90	1558.00	4674	6.00	0	0	6	-47.69
0363100012088754	3	22.74	33.00	0.00	11	2827.19	33.00	180.00	23.10	1414.00	2592	6.00	0	0	0	234.85
0363100012089068b	7	25.63	26.17	68.63	12	2990.00	16	244	17.70	411	2466	2	10	5	8	524.00
0363100012089268	3	64.36	33.00	0.00	24	6168.41	33.00	180.00	53.60	2591.00	6218	10.00	0	0	11	-49.99
0363100012089493	3	41.85	33.00	0.00	20	5140.34	33.00	180.00	38.80	2014.00	5035	8.00	0	0	3	105.34
0363100012089814	3	50.08	33.00	0.00	24	6168.41	33.00	180.00	37.60	3124.00	6248	12.00	0	0	12	-79.59
0363100012090108	3	65.45	33.00	0.00	24	6168.41	33.00	180.00	61.00	3672.00	6295	14.00	0	0	4	-126.45
0363100012090146	3	691.90	33.00	0.00	24	6168.41	33.00	180.00	608.20	6366.00	6366	24.00	0	0	84	-197.59
0363100012090401	3	84.57	33.00	0.00	24	6168.41	33.00	180.00	66.00	4578.00	6104	18.00	0	0	19	64.41

0363100012090820b	3	25.52	33.00	0.00	12	3084.20	21	90	21.80	1957	2348	10	12	2	4	735.80
0363100012091827b	6	28.67	21.91	72.93	14	3517.45	29	260	25.60	1589	2781	8	-7	7	3	736.70
0363100012092017	3	26.90	27.86	44.45	13	3303.44	54	225	34.90	3149	2924	14	-26	1	-8	379.37
0363100012093739b	23	90.74	27.14	269.75	24	5701.38	31	88	89.50	4492	4492	24	-4	-88	1	1209.38
0363100012093867c	3	125.66	33.00	0.00	24	6168.41	56.00	186.00	71.7	5960.00	5960	24.00	-23	6	54	208.41
0363100012093939	3	12.46	33.00	0.00	6	1542.10	33.00	180.00	27.10	1520.00	1520	6.00	0	0	-15	22.10
0363100012094752	3	101.15	33.00	0.00	24	6168.41	33.00	180.00	99.10	5760.00	6010	23	0	0	2	157.97
0363100012095271a	8	21.46	39.54	76.64	10	2274.73	51	170	44.5	4283	5259.13	17	-11	87	0	-1755.14
0363100012095271b	16	23.33	39.54	165.41	11	1229.26										
0363100012095271c	3	61.38	33.00	0.00	24	6168.41	33.00	180.00	44.70	2224.00	5931	9	0	0	17	237.74
0363100012095914a	3	24.52	33.00	0.00	12	3084.20	33.00	180.00	26.00	1225.00	2940	5	0	0	-1	144.20
0363100012096589a	3	46.30	33.00	0.00	22	5654.38	33.00	180.00	49.50	3097.00	5678	12.00	0	0	-3	-23.46
0363100012096617a	3	24.01	33.00	0.00	11	2827.19	33.00	180.00	25.00	1285.00	2827	5.00	0	0	-1	0.19
0363100012097052a	3	11.46	33.00	0.00	5	1285.09	33.00	180.00	135.00	6180	6180	24	0	0.00	-20	-11.59
0363100012097052b	3	16.47	33.00	0.00	8	2056.14										
0363100012097052c	3	87.03	33.00	0.00	24	6168.41										
0363100012097126	3	51.26	33.00	0.00	24	6168.41	52.00	185.00	16.6	970.00	5820	4	-19	5	35	348.41
0363100012097494b	28	15.29	41.39	348.02	7	1781.94	58.00	166.00	36.8	4098.00	1687	17	-17	4	-22	94.53
0363100012097511a	3	23.51	33.00	0.00	11	2827.19	33.00	180.00	24.70	1259.00	2770	5.00	0	0	-1	57.39
0363100012097857a	28	16.09	39.66	358.46	7	1791.52	60	177	39.90	4194	1727	17	-20	1	-24	64.58
0363100012098105a	7	30.07	26.21	92.80	14	3321.77	30	93	34.70	3098	2711	16	-4	0	-5	611.02
0363100012098105b	23	44.45	25.13	272.39	21	5077.85	29	86	42.90	3433	4005	18	-4	6	2	1072.68
0363100012099768d	3	233.08	33.00	0.00	24	6168.41	33	180	67.20	4369	6168	17	0	0	166	0.41
0363100012099851	3	28.23	33.00	0.00	13	3341.22	33	180	26.20	1522	3298	6	0	0	2	43.56
0363100012100088a	24	20.24	38.40	280.63	9	2046.21	43	105	17.80	946	1703	5	-5	2	2	343.41
0363100012101170	3	175.83	33.00	0.00	24	6168.41	33.00	180.00	146.80	5968.00	5968	24.00	0	0	29	200.41
0363100012101250a	3	12.62	33.00	0.00	6	1542.10	33	180	30.2	1537	3979	6	0	0	4	133.61
0363100012101250b	3	21.12	33.00	0.00	10	2570.17										
0363100012101250c	3	37.60	33.00	0.00	18	4626.31	33.00	180.00	30.8	1526.00	4578	6.00	0	0	7	48.31
0363100012101601a	7	83.42	28.70	89.34	24	5661.02	33	269	65.80	4505	4505	24	-4	0	18	1156.02
0363100012101601b	23	76.87	27.41	269.15	24	5682.98	30	90	65.00	4506	4506	24	-3	1	12	1176.98
0363100012101656c	3	966.58	33.00	0.00	24	6168.41	33.00	180.00	929.10	5957.00	5957	24	0	0	37	211.41
0363100012102727	3	33.71	33.00	0.00	16	4112.27	33.00	180.00	33.30	1582.00	4219	6.00	0	0	0	-106.39
0363100012103277a	3	65.54	33.00	0.00	24	6189.14	33.00	180.00	60.70	3714.00	5942	15.00	0	0	5	246.74
0363100012103730a	3	18.90	25.71	13.36	9	2300.87	28	195	18.8	1577	2028	7	-2	2	0	273.30
0363100012103851b	2	24.44	23.19	16.87	11	2802.82	25	196	20.80	1676	2634	7	-2	1	4	169.11
0363100012103992a	6	16.81	24.37	84.66	8	1954.08	33	180	82.9	3831	4070	15	-9	85	-48	147.20
0363100012103992b	6	18.52	21.78	72.43	9	2263.40										
0363100012103992c	3	50.13	33.00	0.00	24	6168.41	33	180	82.90	4087	6131	16	0	0	-33	37.91
0363100012105627	3	41.30	33.00	0.00	20	5140.34	33.00	180.00	39.20	2315.00	5144	9.00	0	0	2	-4.10
0363100012105722a	7	97.25	26.74	66.77	24	5983.85	33	246	71.70	5196	5196	24	-6	-246	26	787.85
0363100012106407	3	75.74	33.00	0.00	24	6168.41	33.00	180.00	56.70	3230.00	5537	14.00	0	0	19	631.27
0363100012106479b	4	14.34	36.26	32.02	7	1772.79	45	212	33.80	3617	1688	15	-9	-212	-19	84.86
0363100012107573b	27	57.72	29.15	348.67	24	6156.02	53	169	46.00	5308	6066	21	-24	-169	12	89.74
0363100012107759b	3	54.30	33.00	0.00	24	6168.41	33.00	180.00	42.40	2533.00	6079	10.00	0	0	12	89.21

0363100012108107b	23	20.21	25.98	285.18	9	2222.94	29	105	16.10	1021	1838	5	-3	0	4	385.14
0363100012109407a	7	12.04	25.22	85.01	5	1215.41	28	90	20.60	1545	966	8	-3	5	-9	249.79
0363100012109407b	23	16.88	25.35	268.03	8	1911.93	29	88	19.20	1331	1521	7	-4	0	-2	390.78
0363100012110291	7	11.51	26.17	99.81	5	1163.09	29	99	20.20	1412	1009	7	-3	1	-9	154.51
0363100012110393	3	37.38	33.00	0.00	18	4626.31	33	180	32.40	1958	4406	8	0	0	5	220.81
0363100012110939a	3	22.15	33.00	0.00	10	2570.17	33	180	22.20	1073	2683	4	0	0	0	-112.33
0363100012111662	19	11.22	33.56	239.46	5	1004.38	36	239	21.60	1768	1105	8	-2	0	-10	-100.62
0363100012111957	3	11.62	33.00	0.00	5	1285.09	40.00	181.00	24.2	2277.00	1265	9	-7	1	-13	20.09
0363100012112792b	3	29.83	33.00	0.00	14	3598.24	58	169	31.1	3221	3469	13	-25	11	-1	129.47
0363100012113358	3	188.52	33.00	0.00	24	6168.41	33.00	180.00	138.8	5947.00	5947	24.00	0	0	50	221.41
0363100012113573	3	58.67	33.00	0.00	24	6168.41	33.00	180.00	62.8	3609.00	6187	14	0	0	-4	-18.45
0363100012113736	3	108.71	33.00	0.00	24	6168.41	33.00	180.00	102.2	6084	6084	24	0	0	7	84.41
0363100012113737b	28	22.58	39.20	359.60	11	2816.99	51.00	178.00	24.7	1980.00	2723	8	-12	2	-2	94.49
0363100012113761	3	47.11	33.00	0.00	23	5911.39	33.00	180.00	36.60	2004.00	5762	8.00	0	0	11	149.89
0363100012113793b	23	26.28	25.99	280.99	12	2941.65	30.00	100.00	26.5	2435	2435	12	-4	1	0	506.65
0363100012113917	19	15.17	28.14	222.04	7	1368.26	30.00	228.00	25.7	2521.00	1604	11	-2	6	-11	-236.02
0363100012114493	6	41.67	19.44	90.33	20	4940.01	21.00	90.00	43.10	3165.00	3956	16.00	-2	0	-1	983.76
0363100012114855	3	37.08	33.00	0.00	18	4626.31	33.00	180.00	33.60	1982.00	4460	8	0	0	3	166.81
0363100012115432	3	99.19	33.00	0.00	24	6168.41	33.00	180.00	68.10	3721.00	6379	14.00	0	0	31	-210.45
0363100012115863a	3	25.14	33.00	0.00	12	3084.20	33.00	180.00	26.00	1032.00	3096	4.00	0	0	-1	-11.80
0363100012116369a	3	55.11	33.00	0.00	24	6168.41	33.00	180.00	45.90	1735.00	5949	7	0	0	9	219.84
0363100012118065	3	58.51	33.00	0.00	24	6168.41	33.00	180.00	51.10	3110.00	6220	12	0	0	7	-51.59
0363100012118355	3	21.70	33.00	0.00	10	2570.17	60.00	138.00	35.8	3237.00	2158	15	-27	42	-14	412.17
0363100012118462	3	59.93	33.00	0.00	24	6168.41	33.00	180.00	46.1	2332.00	6219	9	0	0	14	-50.26
0363100012118540	3	66.97	33.00	0.00	24	6168.41	33.00	180.00	55	3332.00	6151	13	0	0	12	17.02
0363100012120335	3	10.18	33.00	0.00	4	1028.07	33.00	180.00	41.30	2283.00	1015	9	0	0	-31	13.40
0363100012122133	3	30.34	33.00	0.00	14	3598.24	33.00	180.00	32.80	1458.00	3402	6.00	0	0	-2	196.24
0363100012122213b	3	30.43	33.00	0.00	14	3598.24	33.00	180.00	35.7	2155	3771	8	0	0	-5	-173.01
0363100012122685	3	44.66	33.00	0.00	21	5397.36	33.00	180.00	35.70	2333.00	5444	9	0	0	9	-46.31
0363100012123546b	3	82.98	33.00	0.00	24	6168.41	33.00	180.00	58.5	2676.00	5839	11	0	0	24	329.86
0363100012124738	3	42.51	33.00	0.00	20	5140.34	33.00	180.00	35.70	2316.00	5147	9	0	0	7	-6.33
0363100012125222	3	46.19	33.00	0.00	22	5654.38	33.00	180.00	44.70	3061.00	5612	12.00	0	0	1	42.54

Appendix V-3 Non-existing Roof Parts

Table 13 List of roof parts that do not exist in the Zonatlas

Building Identification Number	Roof Top Data set						Zonatlas
	Class	Roof Surface Area (m2)	Slope	Orien-tation	Number of Solar Panels	Energy Output Solar Panels Year 1 (kWh/year)	
0363100012061598a	3	15.64	33.00	0.00	7	1799.12	Not Identified
0363100012062069a	23	20.05	26.49	269.75	9	2146.26	Less Suitable
0363100012062069b	3	20.64	33.00	0.00	10	2570.17	
0363100012062232b	18	41.56	22.53	212.17	20	3973.67	Not Identified
0363100012063486a	3	21.15	33.00	0.00	10	2570.17	Less Suitable
0363100012063486b	3	23.97	33.00	0.00	11	2827.19	
0363100012064034	3	14.17	33.00	0.00	6	1542.10	Less Suitable
0363100012064776a	8	21.00	36.43	85.96	10	2257.39	Less Suitable
0363100012064776b	24	29.78	36.83	269.72	14	3102.13	
0363100012065390a	8	10.05	40.22	93.04	4	850.20	Not Identified
0363100012067566	3	15.95	33.00	0.00	7	1799.12	Less Suitable
0363100012069406	3	63.10	33.00	0.00	24	6168.41	No Accurate Height Data
0363100012069689	3	58.10	33.00	0.00	24	6168.41	No Accurate Height Data
0363100012069787b	18	32.83	24.63	247.49	16	3607.65	Not Identified
0363100012071320b	9	19.42	10.88	126.62	9	2123.61	Not Identified
0363100012071320c	3	23.60	33.00	0.00	11	2827.19	
0363100012071598a	6	11.29	24.34	91.51	5	1203.14	No Accurate Height Data
0363100012071598b	23	24.44	25.54	270.02	11	2639.15	
0363100012072653a	3	10.73	33.00	0.00	5	1285.09	Not Identified
0363100012072861	9	15.71	5.45	117.62	7	1732.73	No Accurate Height Data
0363100012073980b	3	37.63	33.00	0.00	18	4626.31	Not Identified
0363100012074434a	25	10.92	5.54	324.46	5	1227.36	Less Suitable
0363100012074434b	3	31.29	33.00	0.00	15	3855.26	
0363100012074814a	8	36.07	37.93	92.25	17	3703.00	Less Suitable
0363100012074814b	23	65.35	34.55	272.71	24	5471.53	
0363100012074829a	20	11.22	38.68	247.60	5	988.13	Not Identified
0363100012075779b	3	33.34	33.00	0.00	16	4112.27	Not Identified
0363100012075929	2	38.32	18.68	34.29	18	4574.31	Less Suitable
0363100012077268	3	43.74	33.00	0.00	21	5397.36	No Accurate Height Data
0363100012078179a	18	11.54	17.02	251.46	5	1199.26	Not Identified
0363100012078514a	3	12.60	33.00	0.00	6	1542.10	Not Identified
0363100012078565a	3	12.89	33.00	0.00	6	1542.10	Not Identified
0363100012079164a	8	37.37	40.20	85.83	18	3940.20	Less Suitable
0363100012079164b	24	42.32	38.94	266.26	20	4290.76	
0363100012079413b	23	17.83	25.70	284.60	8	1976.30	Not Identified
0363100012079533a	3	29.94	33.00	0.00	14	3598.24	No Accurate Height Data

0363100012079533b	3	39.72	33.00	0.00	19	4883.32	
0363100012079533c	3	76.15	33.00	0.00	24	6168.41	
0363100012081455a	3	14.13	33.00	0.00	6	1542.10	Not Identified
0363100012081455b	3	36.58	33.00	0.00	17	4369.29	
0363100012081533a	25	14.20	9.84	350.93	6	1461.44	Not Identified
0363100012081533e	3	108.34	33.00	0.00	24	6168.41	Not Identified
0363100012081533f	3	89.26	33.00	0.00	24	6168.41	
0363100012082537a	21	11.87	8.86	297.70	5	1277.74	Not Identified
0363100012082537b	12	13.50	40.35	136.55	6	1016.04	
0363100012082560a	13	27.70	5.14	160.18	13	2916.47	Not Identified
0363100012082563	3	58.26	33.00	0.00	24	6168.41	No Accurate Height Data
0363100012082783a	3	20.76	33.00	0.00	10	2570.17	Less Suitable
0363100012082783b	3	26.92	33.00	0.00	13	3341.22	
0363100012082882	3	33.31	33.00	0.00	16	4112.27	Less Suitable
0363100012082905a	6	15.02	17.80	72.84	7	1777.46	Not Identified
0363100012083407a	3	140.25	33.00	0.00	24	6168.41	No Accurate Height Data
0363100012083847b	3	53.57	33.00	0.00	24	6168.41	
0363100012084048b	15	73.99	27.16	178.29	24	2940.49	Not Identified
0363100012084139	3	14.80	33.00	0.00	7	1799.12	No Accurate Height Data
0363100012084287a	12	24.63	35.08	143.25	12	2103.04	Not suitable
0363100012084312a	3	18.82	33.00	0.00	9	2313.15	Less Suitable
0363100012084312b	3	19.68	33.00	0.00	9	2313.15	
0363100012085495a	3	17.42	33.00	0.00	8	2056.14	Not Identified
0363100012086068a	23	26.11	30.21	268.65	12	2786.50	Not Identified
0363100012087501a	3	16.30	33.00	0.00	7	1799.12	Less Suitable
0363100012087501b	3	23.78	33.00	0.00	11	2827.19	
0363100012088067b	3	29.79	33.00	0.00	14	3598.24	Not Identified
0363100012088067c	3	34.25	33.00	0.00	16	4112.27	
0363100012088209a	15	13.81	33.91	184.53	6	659.40	Not Identified
0363100012088691	7	52.30	27.34	104.80	24	5447.43	No Accurate Height Data
0363100012089013a	3	20.23	33.00	0.00	9	2313.15	Less Suitable
0363100012089013b	3	22.99	33.00	0.00	11	2827.19	
0363100012089068a	19	24.29	28.79	247.57	11	2398.55	Not Identified
0363100012090134	26	43.49	24.13	324.90	21	5362.80	Less Suitable
0363100012090820a	6	23.71	18.84	88.49	11	2732.44	Not Identified
0363100012091827a	23	25.36	25.05	256.58	12	2781.41	Not Identified
0363100012093048a	7	27.57	32.45	87.85	13	3003.92	Less Suitable
0363100012093048b	23	37.35	30.25	264.26	18	4121.50	
0363100012093739a	7	100.01	27.06	88.13	24	5734.83	Not Identified
0363100012093867a	16	10.53	39.72	185.00	5	530.77	Not Identified
0363100012093867b	16	22.66	39.72	185.00	11	1167.69	
0363100012094117	23	15.51	28.21	266.93	7	1638.98	No Accurate Height Data
0363100012094996a	3	15.53	33.00	0.00	7	1799.12	Less Suitable
0363100012094996b	3	15.87	33.00	0.00	7	1799.12	
0363100012094996c	3	14.63	33.00	0.00	7	1799.12	

0363100012095571d	3	10.29	33.00	0.00	5	1285.09	Not Identified
0363100012095914b	3	44.99	33.00	0.00	22	5654.38	Not Identified
0363100012096589b	3	54.86	33.00	0.00	24	6168.41	Not Identified
0363100012096617b	3	38.32	33.00	0.00	18	4626.31	Not Identified
0363100012097494a	3	13.78	33.00	0.00	6	1542.10	Not Identified
0363100012097494b	3	14.28	33.00	0.00	6	1542.10	
0363100012097494c	3	15.19	33.00	0.00	7	1799.12	
0363100012097494d	16	28.28	39.72	169.77	13	1387.89	
0363100012097511b	3	28.04	33.00	0.00	13	3341.22	Not Identified
0363100012097857b	8	39.34	41.09	86.11	19	4121.71	Not Identified
0363100012097857c	24	46.25	40.75	266.36	22	4639.93	
0363100012097857d	3	133.81	33.00	0.00	24	6168.41	
0363100012099392a	3	17.23	33.00	0.00	8	2056.14	Less Suitable
0363100012099392b	3	22.15	33.00	0.00	10	2570.17	
0363100012099768a	3	11.23	33.00	0.00	5	1285.09	Not Identified
0363100012099768b	3	24.74	33.00	0.00	12	3084.20	
0363100012099768c	26	38.17	18.98	355.29	18	4533.25	
0363100012100088b	7	22.23	33.13	102.76	10	2181.52	Not Identified
0363100012101010a	3	10.59	33.00	0.00	5	1285.09	No Accurate Height Data
0363100012101010b	3	28.00	33.00	0.00	13	3341.22	
0363100012101656a	3	12.92	33.00	0.00	6	1542.10	Not Identified
0363100012101656b	3	21.28	33.00	0.00	10	2570.17	
0363100012101656d	3	208.98	33.00	0.00	24	6168.41	Not Identified
0363100012101885	3	178.54	33.00	0.00	24	6168.41	Building demolished
0363100012102992a	3	21.16	33.00	0.00	10	2570.17	Less Suitable
0363100012102992b	3	23.80	33.00	0.00	11	2827.19	
0363100012103730b	15	21.57	25.21	195.93	10	1522.93	Not Identified
0363100012103851a	14	19.80	23.38	190.68	9	1248.19	Not Identified
0363100012105722b	19	86.79	28.02	246.05	24	5236.27	Not Identified
0363100012106479a	20	11.98	35.38	213.67	5	859.30	Not Identified
0363100012107573a	16	21.25	39.19	169.07	10	1071.71	Not Identified
0363100012107759a	3	13.09	33.00	0.00	6	1542.10	Not Identified
0363100012108107a	7	18.34	25.07	103.91	8	1851.14	Not Identified
0363100012110615	3	43.74	33.00	0.00	21	5397.36	No Accurate Height Data
0363100012110939b	3	29.88	33.00	0.00	14	3598.24	Not Identified
0363100012111440	3	67.48	33.00	0.00	24	6168.41	No Accurate Height Data
0363100012111705a	25	14.41	5.35	307.12	7	1762.31	Less Suitable
0363100012111705b	3	24.84	33.00	0.00	12	3084.20	
0363100012112792a	3	20.52	33.00	0.00	10	2570.17	Not Identified
0363100012113352a	3	27.08	33.00	0.00	13	3341.22	No Accurate Height Data
0363100012113352b	3	28.72	33.00	0.00	14	3598.24	
0363100012113737a	16	13.76	38.80	176.31	6	634.75	Not Identified
0363100012113793a	7	20.97	27.18	101.24	10	2299.66	Not Identified
0363100012115125	3	93.82	33.00	0.00	24	6168.41	No Adress Available
0363100012115863b	3	43.24	33.00	0.00	21	5397.36	Not Identified

0363100012116369b	3	55.11	33.00	0.00	24	6168.41	Not Identified
0363100012116938a	3	18.11	33.00	0.00	8	2056.14	Less Suitable
0363100012116938b	26	36.60	18.21	308.29	17	4340.29	
0363100012117031	3	24.32	33.00	0.00	11	2827.19	No Accurate Height Data
0363100012118857	3	35.75	33.00	0.00	17	4369.29	No Accurate Height Data
0363100012119474	8	18.76	35.11	91.02	9	2017.26	No Accurate Height Data
0363100012119738	3	18.84	33.00	0.00	9	2313.15	No Accurate Height Data
0363100012120002a	3	10.21	33.00	0.00	5	1285.09	Less Suitable
0363100012120002b	3	15.56	33.00	0.00	7	1799.12	
0363100012120002c	3	20.42	33.00	0.00	9	2313.15	
0363100012120002d	3	25.40	33.00	0.00	12	3084.20	
0363100012120002e	5	28.40	6.23	79.72	13	3340.58	
0363100012120002f	23	39.01	34.66	270.73	19	4299.68	
0363100012120002g	8	58.45	41.67	95.38	24	4976.53	
0363100012122213a	3	11.81	33.00	0.00	5	1285.09	Not Identified
0363100012122213c	3	125.94	33.00	0.00	24	6168.41	Not Identified
0363100012123546a	25	25.25	8.35	312.60	12	3021.53	Not Identified
0363100012124182	3	48.65	33.00	0.00	23	5911.39	No Accurate Height Data