Advanced Solar Monitoring: Phase1 (ASM-1) Final Report

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Contents

1. Introduction

The increasing penetration of photovoltaic (PV) solar electricity gives rise to a number of simultaneous challenges. The need for balancing demand and supply on a local and/or regional scale may lead to advanced tariff setting systems that go hand in hand with advanced monitoring and forecasting of solar electricity generation. Moreover in order to design the right investment program for the electricity grid infrastructure advanced forecasting of future new installed capacity is needed. ASM-1 started in the year 2013 with a vision to deal with problems and opportunities arising in the PV market with the help of “Big Data”. A Big Data approach of large connected data sets can contribute in addressing these challenges. McKinsey and company demonstrated the advantages and the future of Big Data for different applications [1].

The key driving issues presently in the PV market are:

- Need for a transparent PV system supply market
- Understanding and forecasting of solar PV power as a spatio-temporal phenomenon: smooth supply - demand management
- Solar potential mapping

The underlying idea of using Big Data is that datasets that don’t make commercial sense individually could generate a value once combined with other datasets. In the present project phase we explored the advantage of using Big Data for local electricity demand and supply matching on a scale of 200.000 inhabitants. Also, combining all these data fits in with the overall trend in the solar industry of moving towards complete energy management. In addition, we performed a detailed study on the solar PV potential of rooftops by mapping and developing a model.

For this, we chose an area in The Netherlands defined by the Dutch postal codes 73 and 81. This area contains one medium size city Apeldoorn and rural area with villages like Vaassen, Epe and Heerde. Ultimately the aim of the analysis is to go down to the EAN (European Article Number) code level by which electricity connections are classified, which show the individual demand points but due to data constraints we have limited the research to the level of spatial resolution varying between household level to 4 digit postal code; as for temporal resolution we choose 1 hour.

The present study intends to present results on the following research questions:

1. How is local generation associated with local demand over time?
2. What is the solar PV potential in the city for residential sector?
3. What are possible strategies to fill in the cumulative supply-demand mismatch?
4. What are appropriate strategies for time resolved balancing?

The state of the art or the innovation lies in collecting and combining data from various sources on a scale that has not been attempted before in the solar energy sector. This would mean creating a value out of huge connected datasets which would have made less meaning when looked at individually [2]. The work carried out has been published in two different conference proceedings [2], [3].

2 Overview of PV monitoring systems

Small solar installations(rooftop or individual houses) need an effective way of monitoring. There are a large number of monitoring facilities available for these but there is still some work needed in the area of small scale solar monitoring. The market is now coming up with these small systems each with its own hardware for integrating the signals and a software interface. Below mentioned are some of the basic types of monitoring systems now in use.

1. Local monitoring by reading display of inverter

Most simple way to perform local monitoring is display available on inverter or on inverter control unit. Almost every grid-connected inverter is equipped with an LCD screen. Most important inverter and grid related parameters are available on LCD screen in such case. Values like PV array power, AC grid power, PV array current are usually available. For sophisticated monitoring and control purposes environmental data such as module temperature, ambient temperature, solar radiation, wind speed can also recorder through external sensors and then be available to the user. Some of these monitoring systems are developed by Fronius and SMA.

2. Meter reading
    - Smart meters
    - Online direct management:
        - web based services
            - Eneco (Toon)
            - Delta, Comfort Wijzer (Fifthplay)
            - Nuon (E-manager)
        - Other providers (**www.energieverbruiksmanagers.nl**)
            - Aurum (from 2014)
            - BeNext (iHome)
            - Enelogic P1
            - EnerGQ (i-Care Premium)
            - Greeniant (Greeniant)
            - Net2Grid (Smart Bridge / Smart Reader)
            - Plugwise (Smile P1)
            - Quby
            - Qurrent (Q-box)
            - Watch-E (Watch-E portal)

3. Remote monitoring

Remote control and communication between inverters can be realized with wireless connection (bluetooth or Wi-Fi), through RS485 interface or via grid (power line connection). However, it is important to highlight that different monitoring equipment and communication possibilities of different producers are not compatible. For system monitoring inverters and control equipment of the same producer must be used. The range of remote monitoring can reach up to 1200m and depending on the specifications of each system several inverters can be connected in chain and monitored at the same time. The most popular way of communication between the monitoring system and the inverter is Ethernet or internet. Older installations were using GSM network or dial up connections. One of the features that remote monitoring offers is the alert and system messages that can be sent to the user by SMS fax or email. Some of the Remote monitoring tools are:

- Solar log
- Sunny portal
- Rbee Solar
- PV Log

One of the most important parts of PV monitoring is the data logging. Data can be stored in inverters memory or in external units (data loggers). However, most of monitoring companies (such as Solar Log) but also inverter manufacturer companies (SMA, Mastervolt, PowerOne) also offer the possibility of hosting the data on their web server, therefore data loggers are not necessary anymore and the inverter has only a small amount of memory that is used for buffering. In that way data processing and storage is taking place on central units and then the information is available to the user through software applications.

3 I-REAL solar monitoring system

I-Real developed a working solar monitoring system based on the project requirements of the Advanced Solar Monitoring (ASM) project. In order to achieve a simple and effective way of monitoring, I-Real aimed at collecting data from existing infrastructure and devices. This means that a minimum of additional hardware is required which brings down the overall costs of installation. For sites where the device protocol is not applicable, the NRGhub can be applied as a local gateway (only if required)

Main development effort was the software structure and database architecture. As the system is designed for mass monitoring a GIS viewer is included, showing each site on a map. The user interface includes a graphical interface of the generation meter. Included in the database structure is an asset management module in order to capture maintenance data and research data files associated with each site.

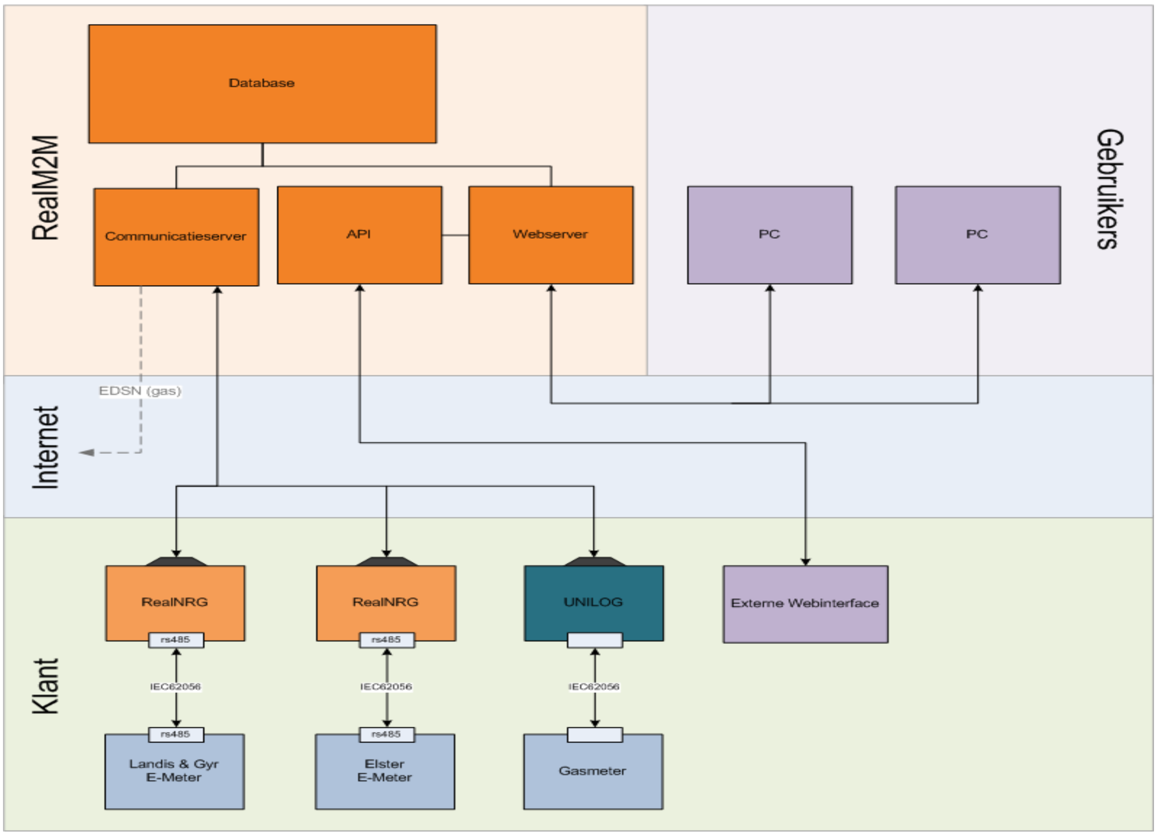


Figure 1: Framework of the solar monitoring system of I-Real

4 Aurum Europe display of sites with analogue and smart meter data

The majority (95%) of meters installed in residential Dutch meter cabinets are (still) analogue meters which cannot be read remotely. Aurum developed sensors which register every 10 second a measurement for electricity usage. These measurements are sent through a gateway in the house to a database. The central stored energy information can be displays or downloaded on different platforms.

In the period 1/6/2013 to 1/6/2014 we installed hardware for remote monitoring (10 second intervals) of residential electricity and gas consumption and in some individual cases Photo Voltaics production and feed-in as well as Heat consumption (Municiple Heating infrastructure)

Because of the variation in existing Gas en Electricity meter-cabinet configurations in the field, we used different solutions.

Initially we have used a sensor solution which measures 'pulses'. These sensors proved to be inadequate in some gas-related situations (Beta Units). For this we selected and adjusted another of our sensor solutions (creating 'meter profiles' instead of pulses by measuring per 200 ms instead of pulses)- Gamma units.

Currently we have 684 Beta sites installed. Currently we have approximately 150 Gamma units installed (rapidly expanding number - started in May 2014). In total we installed hardware on 684 + 150 sites.

146 residential dwellings (Beta) were in the designated area for the ASM pilot study (postal codes 73 and 81) of which 8 households effectively feed in electricity to the grid. The remainder of these sites are located elsewhere in The Netherlands.

Although these meter readings do not reside in our test location we use this data for profile extrapolation and benchmarking.

Table 1

Current installed base	Number of Residents / units
Number of installed	**684**
Number of incorrect measurements (upgrades)	118
Number to be replaced by later version	80
Number of correct installed and running	486
Data quality testing	4+ weeks
PV installations among respondents	3%

Although we uptime and monitor measuring quality of our 'live infrastructure' on a constant basis, we have specifically evaluated the functionality of the 684 Beta-sites in Q4 2013. On 118 sites we concluded that the volatility did not meet the expectancies and that the meter readings of these dwellings in our databases were of insufficient quality. Analysis showed that the reason was that specific mostly gas meters (but in some cases also electricity meters) do not work well with our Beta sensors. We have therefor selected Gamma configuration and adjusted these configurations for ASM-use in the field. Also the data communication and backend algorithms have been optimized.

5 Solar Potential measurement (top down)

Several top-down studies have been performed on solar PV potential in the Netherlands, sometimes in conjunction with potential studies for Europe [6,8,10]. De Noord *et al*. [10] summarize the early studies. An estimate done in 1987 mentioned total realistic roof area of 120 km^2, which corresponds to 24 GWp capacity, assuming a power density of 200 Wp/m^2 (20% PV system efficiency) [9]. Alsema and van Brummelen calculate a potential of 336 km^2 based on 116 km^2 building integrated PV (BIPV) and 220 km^2 ground-based PV (agricultural areas). They mention 70 GWp as total potential capacity. Corten and Bergsma have used a detailed inventory of roof and façade area to determine a technical potential of 667 km^2 (117 GWp) on roofs and 230 km^2 (41 GWp) on facades. De Noord *et al.* re-assessed these potential estimates and present the realistic potential of solar PV in the Netherlands to be 400 km^2 (80-120 GWp) for BIPV and 200 km^2 (40- 60 GWp) for GBPV.

A recent top-down study on solar potential was performed for 27 countries that made up the European Union in 2012 [5]. A method was developed using readily available statistical data on buildings from European databases to determine BIPV potential. Based on country-specific data on building characteristics and irradiation the BIPV technical potential in the EU-27 is 4978.5 km^2 (3180.5 km^2 on roofs and 1798 km^2 on facades) (see Fig. 2); for the Netherlands the total potential is 211.6 km^2 (141.5 km^2 roof and 70.5 km^2 façade). Another, earlier, European study [4] revealed total potential of 356 km^2, based on a total roof area potential of 259 km^2 (residential and non-residential buildings) and total façade area potential of 97 km^2.

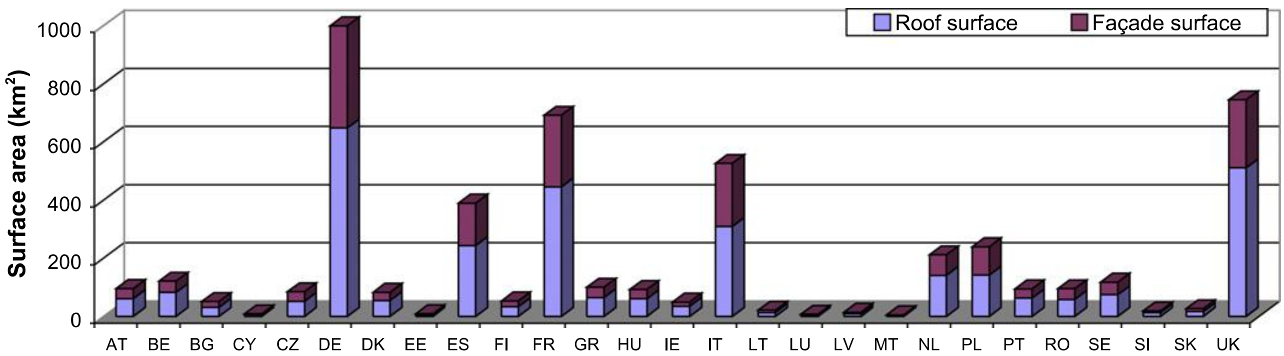


Figure 2: Calculated usable roof and façade area for BIPV for EU-27 countries [5]

In summary, present top-down estimates for BIPV potential in the Netherlands range between 200 and 400 km^2, or 40-80 GWp. Land based PV installations would perhaps add another 200 km^2. Total country potential thus ranges from 80-120 GWp.

At the end of 2013, the total amount of installed PV is estimated at 722 MWp [11]. It is predicted that in the year 2020 an amount of 4 GWp will be installed in the Netherlands [12]. With present annual growth rates, this may be a conservative estimate.

The top-down assessment should be validated using bottom-up assessments that now are possible, using tools such as Zonatlas [13], which are based on aerial photographs and satellite images.

6 Data Base setup

In order to get a bottom up study started we began by looking at different data sets that are available and could be used in the project. Since the backbone of the study is the Big Data approach, energy consumption, solar energy and PV capacity data are the most important datasets. Having all this huge amount of data with a spatial entity associated with it would mean much more in terms of visualization, analysis and the outputs. Therefore, a Geographical Information System (GIS) has been opted for handling the data analysis and presentation of results.

The next step was to create an interface for data transfer from different systems to a common database for data storage. Figure 3 shows the data format and structure adopted in the project. A detailed description of the type of data used in this research is given below. In addition the methods of acquisition of the data and the challenges with the data have also been discussed.

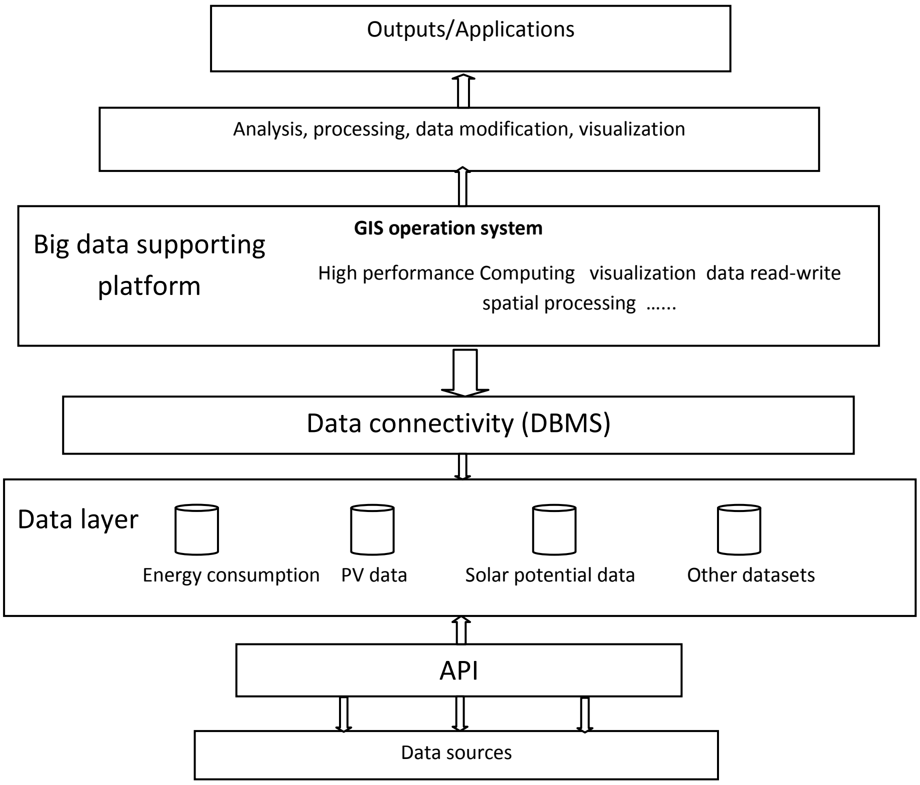


Figure 3: Data format collection and structure

We chose to set up an Application Programming Interface (API), which would interact among the systems and could access databases and transfer the required data. Then data analysis in terms of demand-supply mapping and study has been conducted. PV industry, consumers and utilities can make use of the results improving their business, increase efficiency of their systems. In short the following steps have been taken in order to make the Big Data database and analysis.

- Collect data and make meaningful conclusions
- Create clean and useable datasets
- Add spatial entity for visualization and analysis in GIS.

6.1 Energy consumption data

The companies involved in the project work on solutions for the balance between the generated renewable energy and the local consumption of energy. They also deliver products and services that help people understand and manage electricity usage. Therefore the energy consumption data for residential and industrial sectors in the pilot area was delivered by them. The challenge here was in integrating the data from different sources onto a common platform and format for analysis. In addition, the data amount was huge and accumulating by the hour. This also demands a strong and reliable method for collecting, storing, analysis and visualization of these huge databases.

6.2 PV generation data

Installed capacity of PV systems distributed over the Netherlands is provided by many companies freely or the data is published on the internet by some service providers. This data includes installations per postal code, average yield per month, capacity of the PV installation, in few cases the address of the PV installation, orientation of the panel etc. This data base is necessary to keep track of current installations and to manage future progress. The data has been acquired from PIR (production installation register) of Rijkswaterstaat (Ministry of Infrastructure and the Environment), AURUM and SOLAR CARE. Due to privacy issues acquiring this data was a difficult task. There was a mismatch in the level at which this data was available. Nevertheless, it has been made sure that the combined dataset was unique and realistic.

6.3 PV potential Data

Solar PV potential data was an important asset in the study. With this information we were able to locate areas suitable for PV installations on building roof tops. With this information it is also easy to identify buildings/ areas with high solar potential. Mapping this information also helps in management of existing and future PV installations especially for grid managers. Solar potential data has been generated with the help of AHN (*Actueel Hoogtebestand Nederland*), a digital elevation model (DEM) created from high resolution LiDAR data. The method to locate feasible PV sites has been adopted from a study by Chaves and Bahill [6]. The result is further used to estimate the potential for the study area and also extrapolate it for the Netherlands. The method is not discussed in detail here but results have been presented to discuss the PV potential [3]. The methodology and results obtained will be discussed in detail in the next section.

6.4 Other relevant data bases

In addition to the above databases the study also required information on buildings, geographic locations and electricity grid capacity and solar potential information. This information is available from different sources and bringing it all onto one database is a huge task. The necessary building information has been acquired from the Dutch Base Address Register (BAG) and the geographic locations through extensive use of Google maps and ArcGIS. A special challenge was to convert all the available data into a spatial database. A spatial database allows visualization in a GIS environment which aids in better analysis.

7 Solar PV Potential (bottom up)

7.1 Introduction

Photovoltaic (PV) solar energy in Europe has been increasing rapidly in the past few years. Technological developments and research efforts have brought PV in the renewable energy sector to a new level. Estimation of the actual potential of PV in the residential sector creates various business opportunities and would assist in policy making. In addition, consumers are also increasingly aware of how PV could benefit them, as in many countries retail grid parity is present [7]. Several top-down studies have been performed on solar PV potential in the Netherlands, sometimes in conjunction with potential studies for Europe [8–11]. Many studies also mention different capacities based on different top-down approaches [8], [9], [11]. De Noord et al. re assessed these potential estimates and presented the realistic potential of solar PV in the Netherlands to be 400 km2 (80-120 GWp) for building integrated PV (BIPV) and 200 km2 (40- 60 GWp) for ground-based PV (GBPV). The latest figure for PV potential is presented by Lemmens et al., at 150 GWp and is based on the present electricity consumption in the Netherlands of 120 TWh [12].

To summarize present top-down estimates for BIPV potential, in the Netherlands it ranges from 200-400 km2, or 40-80 GWp. Land based PV installations would perhaps add another 200 km2. Total country potential thus ranges from 80-120 GWp. At the end of 2014, the total amount of installed PV was estimated at 1.1 GWp [13]. It is predicted that in the year 2020 an amount of 4 GWp will be installed in the Netherlands [14]. With present annual growth rates, this may be a conservative estimate.

Since the top-down assessment values are difficult to rely upon these should be validated using bottom-up assessments that now are possible, using tools such as “Solar Atlas”, in Dutch Zonatlas [15], which are based on aerial photographs and solar irradiation. But determining the actual solar potential of BIPV using high-resolution data can be very challenging due to the complexity of the urban areas.

High resolution rooftop potential studies are relatively new and not much has been done in this area at rooftop level for estimating the technical and geographical potential for PV deployment. [16] estimated the technical potential of roof integrated PV systems using easily available data and stratified-samples of Geographical Information Systems (GIS) maps at a regional level. Based on this work, PV solar energy potential estimations at municipal to regional level was conducted in Italy with the help of global solar radiation maps taken from the Joint Research Centre of the European Commission [17]. Hofierka & Kaňuk proposed a methodology for PV potential estimation in urban areas based on the open source solar radiation tool r.sun (developed by (Šúri & Hofierka) [18]) and 3 D city model in GIS [19]. Furthermore, models to estimate solar potential on building rooftops using GIS and statistical approaches to create roof top solar radiation maps were also explored [20], [21]. Redweik et al. developed a model to calculate the solar energy potential of the buildings taking into account both the roofs and the facades using high resolution LiDAR (Laser Imaging Detection And Ranging) data and applied the model to the campus of university of Lisbon [22]. However, all the mentioned studies fall short in estimating the potential at individual rooftop level.

In the present study, we estimate the rooftop PV potential in Apeldoorn, a city in the Netherlands using high resolution LiDAR data and GIS techniques. Only roof integrated PV is addressed here. With the use of Solar Analyst [23] ArcGIS solar irradiation over large geographic areas is computed accounting for atmospheric effects, sun angle, elevation and effects of shadows by buildings, elevation and orientation. Classification of the solar irradiation map was done to differentiate between optimum and less optimum suitable sites. These were the basis of potential estimation, where further energy potential calculations are made taking into account the slope and orientation information. These estimations would help in looking at the trend of PV diffusion, create business opportunities and additionally provide an insight for policy implementations.

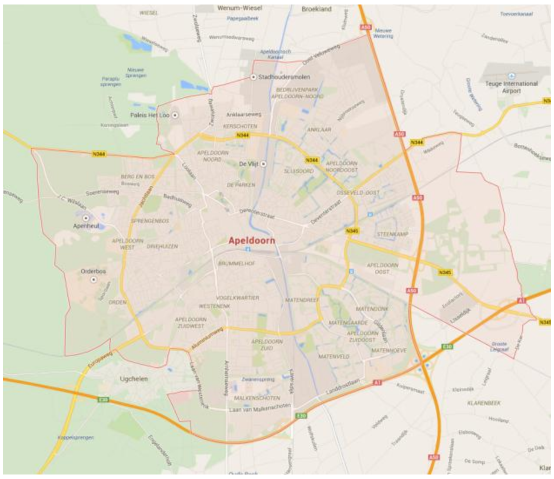


Figure 4: City of Apeldoorn which is taken as the study area in this research.

7.2 Method 1.

The area chosen for the study was the city of Apeldoorn (52° 13′ N, 5° 57′ E), in the Gelderland province of the Netherlands. For locating the potential PV sites and for calculating the PV potential a digital elevation model (DEM) derived from LiDAR data was used. This was obtained from Actueel Hoogtebestand Nederlands (AHN)[24]. This key input has a resolution of 50 cm (point spacing of 9 points per m^2, which is well suited for estimation of solar radiation at roof-tops. The study area chosen in shown in Figure 4. The city itself is at low elevation, while in the West one recognizes a hilly region called De Veluwe. Another important dataset was a vector file of the footprints of residential buildings in the study area. In this paper we focus on the residential sector. The recent building footprint layer was obtained from Basisregistratie Adressen en Gebouwen (BAG), which is a part of the government cadaster system.

The estimation of solar potential in this study was calculated in two steps. First, suitable locations for roof-top PV were singled out, and then potential estimation calculations were performed based on GIS data analysis. We specified some requirements in order to characterize suitable locations; and performed all the calculations using ArcGIS.

The criteria chosen for locating suitable PV sites were solar irradiation, slope and orientation. This has been adopted from the work of [6]. The Area Solar Radiation Tool of the ArcGIS Spatial Analyst automatically performs the solar irradiation calculation based on the model by [23]. This model takes DEM as the main input and other parameters relating to slope, shade and transmissivity of the atmosphere and calculates the solar irradiance during the time specified and produces an output image having pixel values in units of Wh/m^2.

The other inputs for the model were slope and orientation, which were also created by the Spatial Analyst tool in ArcGIS. All the three images were masked to show only residential buildings and were converted into binary raster images taking the following criteria:

- Feasible Slope: less than or equal to 38 degrees
- Feasible Solar Irradiation: greater than 70% of the annual maximum received in the area which has been taken at 600kWh/m^2 according to the modelled irradiance
- Feasible Orientation: (a) South facing and (b) other orientations.

South facing slopes have been considered as optimum while the other slopes have been taken as less optimum in this study. The binary rasters were then combined together to create a final binary image, which was then filtered to create a smooth and continuous image.

A raster to polygon tool was used to convert the suitable areas into a vector polygon layer. Attributes like area, potential capacity and power were then attached to these polygons. A value of 150Wp/m^2 has been taken as the PV power density that can be installed. Therefore, the final output has been classified as follows

- 0 : for unsuitable areas shown in red
- 1: partially suitable areas (with high solar irradiance and orientations other than south) shown in yellow and
- 2: optimally suited areas(high irradiation and south facing slopes) in green.

In addition, the production from the estimated capacity was determined using values determined by [25]. This study states that the annual production of a PV system in the Netherlands can be estimated at 875 kWh/kWp. Therefore, for optimum (south facing) oriented areas 950 kWh/kWp has been chosen and for other, less optimal orientations 750 kWh/kWp has been taken.

7.3 Method 2.

A slight variation from Method 1. explained above, this method classifies the irradiation map that has been generated using Area Solar Radiation tool of the ArcGIS Spatial Analyst. Since the intensity of irradiation instead of irradiation value at points of interest is taken into account the final calculations do not have error propagation. Since, the model already takes the shadows, slopes and orientations into account, additional use of these parameters to create binary rasters is only optional. To refine the previous method, a classification of rooftops has been performed. Flat or sloping roofs have been categorised to have different potential capacities.

In this method, the irradiation raster was classified into four categories

- <50%: areas receiving less than 50% of average annual irradiation in the region. These areas are categorised as unsuitable for PV.
- 50%-70%: areas receiving between 50-70% of the average annual irradiation. These are intermediate, i.e., specially E-W facing slopes and areas receiving sufficient amount of irradiation fall in this category.
- 70%-90%: These are the good regions for PV. Mostly south facing slopes receiving more than average irradiation are in this category. Rooftops receiving irradiation between 70-90% are categorised here.

- >90% : These are the best areas for PV siting. These are very ideal locations, meaning strictly south facing slopes receiving the greatest irradiation in the region, without shadow effects.

For these the capacity and production estimation values are 100Wp/m^2 for flat roofs and 1500Wp/m^2 for sloping roofs. The production estimation values are 0, 600, 750 and 900kWh/kWp respectively for the 4 categories. These values are shown clearly in Table 1 for both the methods.

7.4 Results

The results are explained in the following subsections. The first subsection shows the model inputs and in the second subsection binary outputs after the application of criteria of method 1 are shown. The third subsection shows the final output from both the methods, and addition of attributes and finally the potential estimations.

Table 2: Criteria and estimation values for Method 1 and 2

	GRID CODE	Feasibility	Legend	Potential Yield
Method 1 **150Wp/m^2**	0	Not Suitable		0/0
	1	Partial (2/3 criteria satisfied)		750kWh/kWp
	2	Suitable		950kWh/kWp
Method 2 **100Wp/m^2 flat roofs** **150Wp/m^2 sloping roofs**	0	<50%		0
	1	50-70%		600kWh/kWp
	2	70-90%		750kWh/kWp
	3	>90%		900kWh/kWp

7.4.1 Model Inputs

In this subsection the inputs taken in the model are displayed. Figure 5 (left image) shows the height map of the buildings. Figure 5 (right image) shows the annual solar radiation image in kWh/m2. The area receives an annual maximum irradiation of 960 kWh/m2 in a year according to the model-based calculations. Figure 6 shows the orientation image or the direction of the slope.

Figure 5: (Left) AHN height information derived for residential buildings. Height information is in meters. (Right) Solar Irradiation image derived for building by running the Solar Radiation tool. South facing slopes are seen to receive greater irradiation

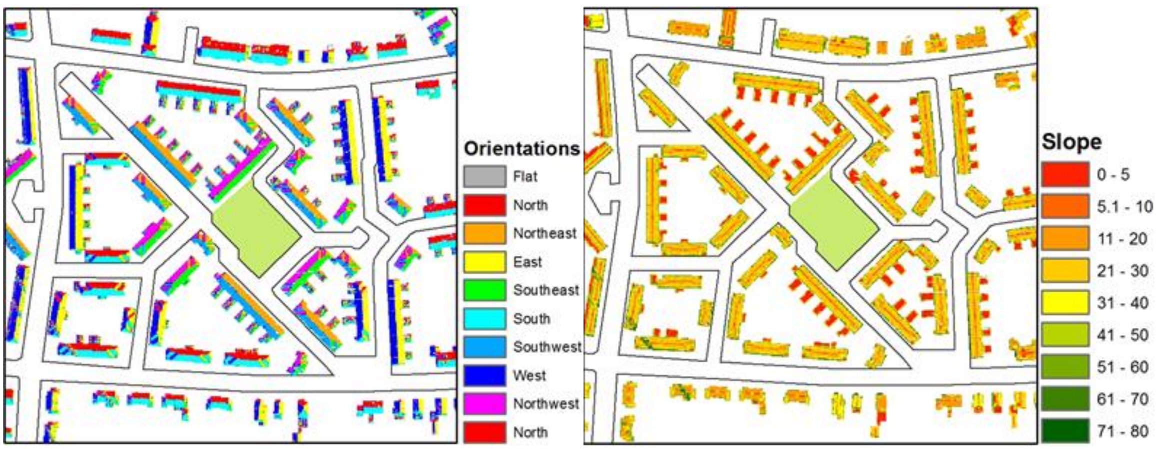


Figure 6: Left: Orientation image showing the direction of slope of the rooftops. Right: Slope image classified in classes to distinguish between flat and sloping roofs.

7.4.2 Binary outputs

Binary outputs after applying the mentioned criteria for slope, solar irradiation and orientation have been determined and are presented here. Figure 7 shows in green the optimum irradiation map of areas receiving greater than 600 kWh/m2 per year. We see that most of the building rooftops are selected along with a few roads or empty areas. The right image in Figure 7 shows the feasible slope areas in green, which are 38° and below. The white areas show unfeasible areas, which we can identify mostly as facades or vegetation. Images in Figure 8 are the optimum orientation map, which shows south facing slopes in green (left image) and other orientations image (right image).

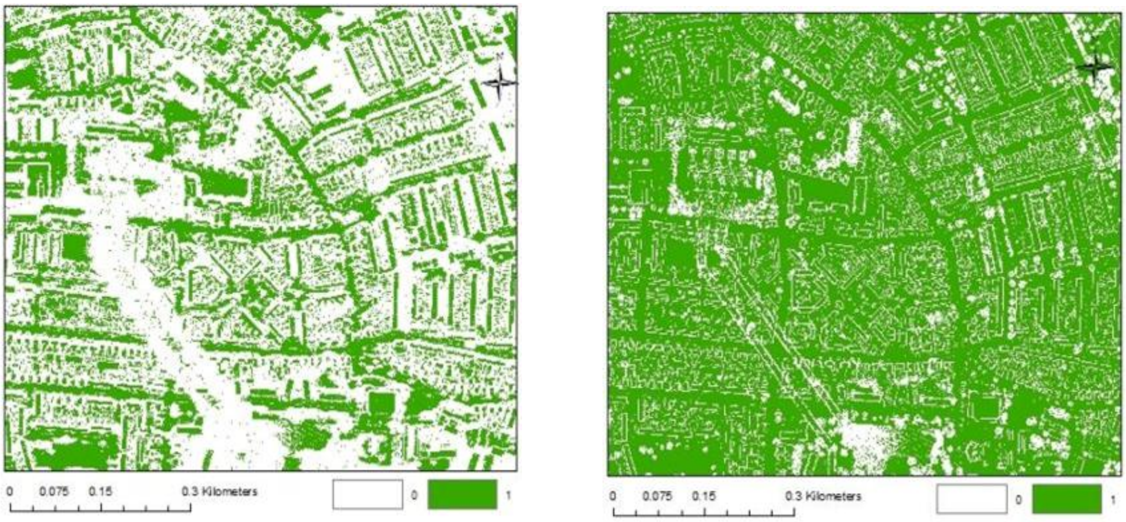


Figure 7: Optimum irradiation image (left) and feasible slope image (right).

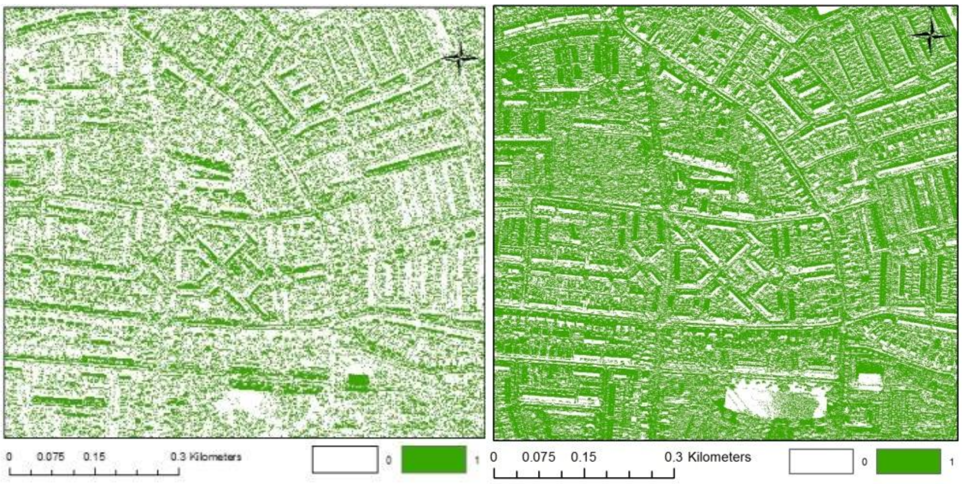


Figure 8: Optimum orientation image (left) showing south facing slopes and other orientations image (right)

7.4.3 Final outputs

Method 1

The final output is a polygon layer that shows 3 classes (Figure 9). Areas in green are optimally best suited locations for PV. These areas receive maximum amount of solar irradiation and have an optimum slope and south orientation. South facing slopes in the Northern hemisphere receive maximum amount of solar irradiation.

Figure 9: Final output showing the geographic potential of Apeldoorn city using Method 1. Gridcode 0 shows unfeasible areas, 1 represents partially suitable area and 2 shows best suits areas for the deployment of PV.

The areas in yellow are partially optimum or the other orientations, which still receive about more than 70% of the average solar irradiation in the region. These areas are suitable for PV but may not show high energy yields, as they do not receive maximum solar irradiation throughout the year.

The red areas are categorised as totally unsuitable. These regions receive either minimum amount of solar radiation or have unfeasible slopes (facades or steep slopes) or are either shaded from trees or nearby buildings.

The final output presented below is the result of a smoothing filter on a raster, which was then converted into a polygon shapefile. These polygons were then intersected with the building information from BAG so that the final output has address information along with the building properties as shown in Figure 10.

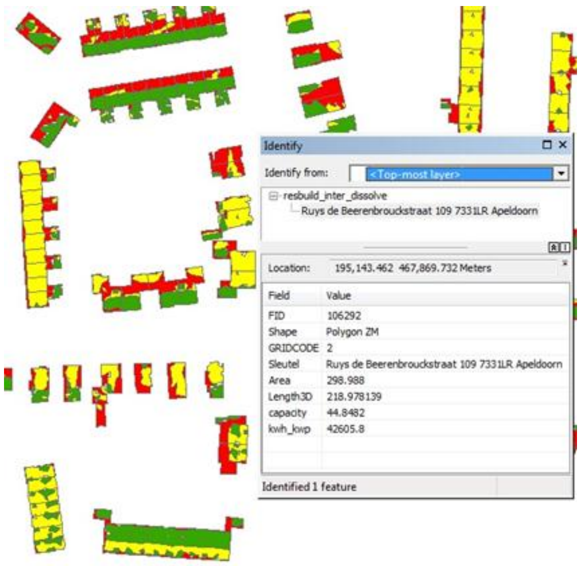


Figure 10: Final map with information on address, potential capacity and power.

Method 2

Figure 11: Final output of method 2 showing the PV rooftop potential in the city of Apeldoorn.

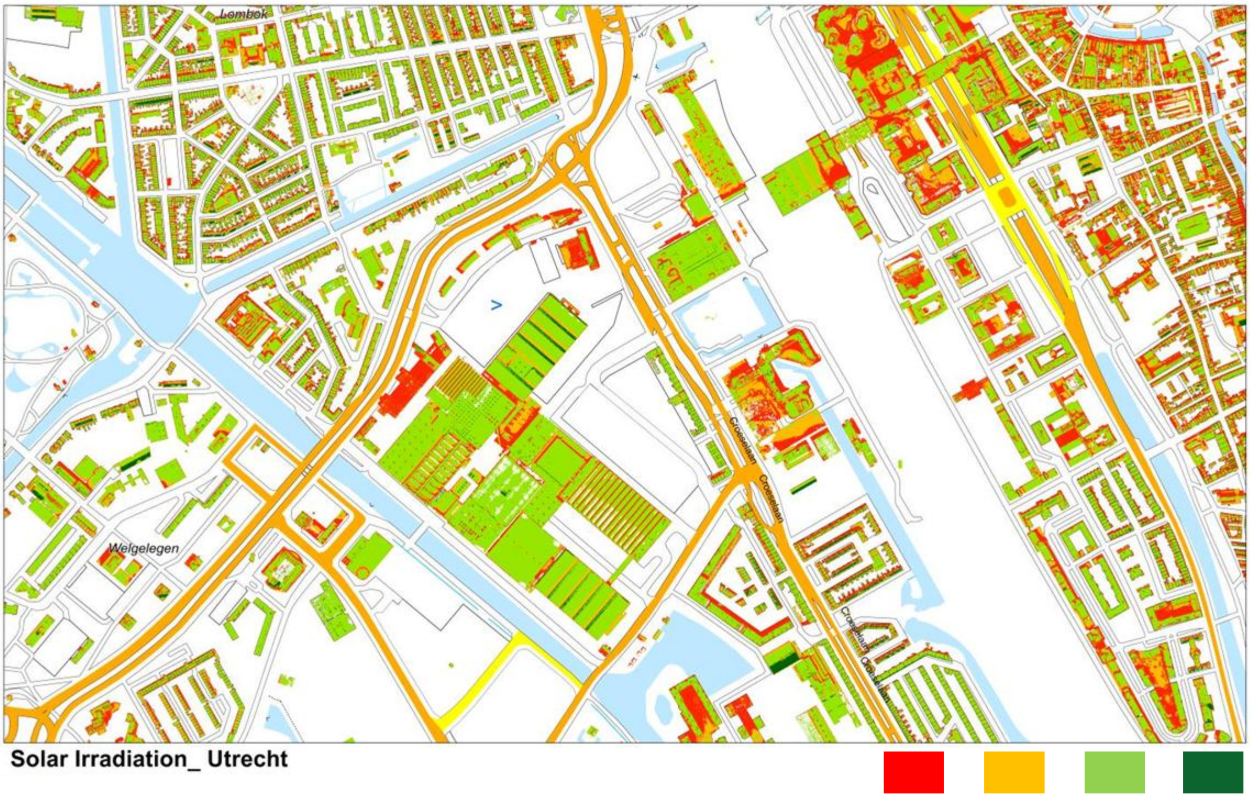
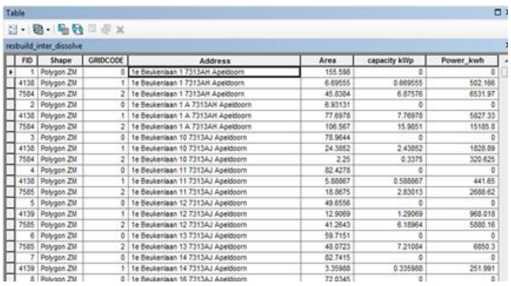


Figure 12: Final map of the city of Utrecht produced from Method 2

The output from Method 2 is displayed in Figure 10 and Figure 11. This method has been found to produce better results than Method 1 and is faster in processing. The additional use of slope and orientation parameters for refinement in Method 1, create strict rules to select only optimum areas, leaving behind areas which are partly suitable (eg. E-W facing slopes). Using this method we also created a PV potential map for the city of Utrecht which is shown in Figure 11. The interpretation of the colours is similar to Method 1, where red shows unsuitable areas, orange partially suitable, light green very suitable areas and dark green best suited areas.

Attaching Attribute Data

After the final output has been created, additional information regarding to building data and potential calculations has been attached to the final output table. Figure 13 shows a sample of the attribute table associated with the final map. Each record corresponds to an address and each address is further categorised based on the grid code, which is 0, 1 or 2 (Method 1) or 0,1,2 or 3 (Method 2) .



Table

resbuild_inter_dissolve

FID	Shape	GRIDCODE	Address	Area	capacity kWp	Power_kwh
1	Polygon ZM	0	1e Beukenlaan 1 7313AH Apeldoorn	155.598	0	0
4138	Polygon ZM	1	1e Beukenlaan 1 7313AH Apeldoorn	6.69555	0.669555	502.166
7584	Polygon ZM	2	1e Beukenlaan 1 7313AH Apeldoorn	45.8384	6.87576	6531.97
2	Polygon ZM	0	1e Beukenlaan 1 A 7313AH Apeldoorn	6.93131	0	0
4138	Polygon ZM	1	1e Beukenlaan 1 A 7313AH Apeldoorn	77.6978	7.76978	5827.33
7584	Polygon ZM	2	1e Beukenlaan 1 A 7313AH Apeldoorn	106.567	15.9851	15185.8
3	Polygon ZM	0	1e Beukenlaan 10 7313AJ Apeldoorn	78.9644	0	0
4138	Polygon ZM	1	1e Beukenlaan 10 7313AJ Apeldoorn	24.3852	2.43852	1828.89
7584	Polygon ZM	2	1e Beukenlaan 10 7313AJ Apeldoorn	2.25	0.3375	320.625
4	Polygon ZM	0	1e Beukenlaan 11 7313AJ Apeldoorn	82.4278	0	0
4138	Polygon ZM	1	1e Beukenlaan 11 7313AJ Apeldoorn	5.88867	0.588867	441.65
7585	Polygon ZM	2	1e Beukenlaan 11 7313AJ Apeldoorn	18.8675	2.83013	2688.62
5	Polygon ZM	0	1e Beukenlaan 12 7313AJ Apeldoorn	49.6556	0	0
4139	Polygon ZM	1	1e Beukenlaan 12 7313AJ Apeldoorn	12.9069	1.29069	968.018
7585	Polygon ZM	2	1e Beukenlaan 12 7313AJ Apeldoorn	41.2643	6.18964	5880.16
6	Polygon ZM	0	1e Beukenlaan 13 7313AJ Apeldoorn	59.7151	0	0
7585	Polygon ZM	2	1e Beukenlaan 13 7313AJ Apeldoorn	48.0723	7.21084	6850.3
7	Polygon ZM	0	1e Beukenlaan 14 7313AJ Apeldoorn	82.7415	0	0
4139	Polygon ZM	1	1e Beukenlaan 14 7313AJ Apeldoorn	3.35988	0.335988	251.991
8	Polygon ZM	0	1e Beukenlaan 16 7313AJ Apeldoorn	72.0345	0	0

Figure 13: Attribute table for the final output.

7.4.4 Potential estimations

Table 3: Potential estimations for the city of Apeldoorn for the 2 methods.

Apeldoorn	GRID CODE	Potential Capacity	Potential Yield	Total Area/Capacity/Yield
Method 1	0	Not Suitable	0	2.4 km^2
150Wp/m^2	1	99.9 MWp	74866.9 MWh	319 MWp
	2	220 MWp	209034.6 MWh	283.9 GWh
Method 2	0	Not Suitable	0	2.9 km^2
100Wp/m^2 flat roofs	1	158 MWp	94804 MWh	392.9 MWp
150Wp/m^2 sloping roofs	2	209.6 MWp	157215.9 MWh	274.8 GWh
	3	25.3 MWp	22801 MWh	

Table 2 shows the calculated PV potential estimations for the city of Apeldoorn. The table has been made using values presented in Table 1 and the area available under each grid code calculated from ArcGIS. All the calculations have been performed using scripting in ArcGIS. We can see that the potential capacity from Method 1 is smaller than Method 2 while the yield estimations are vice versa. This is because

- In Method 1 a constant rate of power density for capacity estimations has been chosen while in Method 2 differentiation between flat and sloping roofs has been made and different values of power density have been chosen.
- The above segregation determines which constant yield estimation value needs to be used for potential yield calculations.

8 Data layers and analysis

Figure 14: Initial database plan (left) and the GIS layers of data used in the project (right)

All the data gathered has been put in a database and a spatial entity has been attached to them to visualize and analyse the data in a GIS platform. In order to look in to the trends in the local generation and demand, electricity consumption data for 94 households with hourly resolution has been analysed along with electricity generation with the same resolution for one household. In addition, we also looked into monthly PV generation for 20 households and about 4 households with a daily resolution of electricity generation. The supply demand matching or mismatch has been analysed with the help of above mentioned data.

The total installed capacity in the area was found to be 17.55 MWp according to the data gathered from PIR Rijkwaterstaat. The area has 3828 PV installations. Figure 15 shows the map of the pilot area covering the Dutch postal codes 73 and 81. The map illustrates the total installed PV capacity per postal code in the area. Mapped locations of PV installations have also been displayed at postal code level.

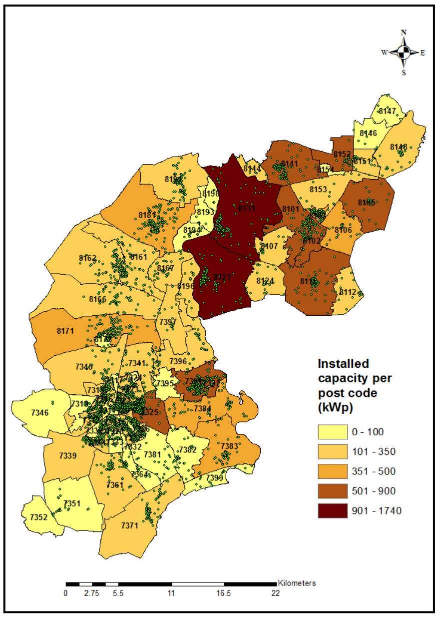


Figure 15: Map showing the total installed capacity per post code in the pilot area.

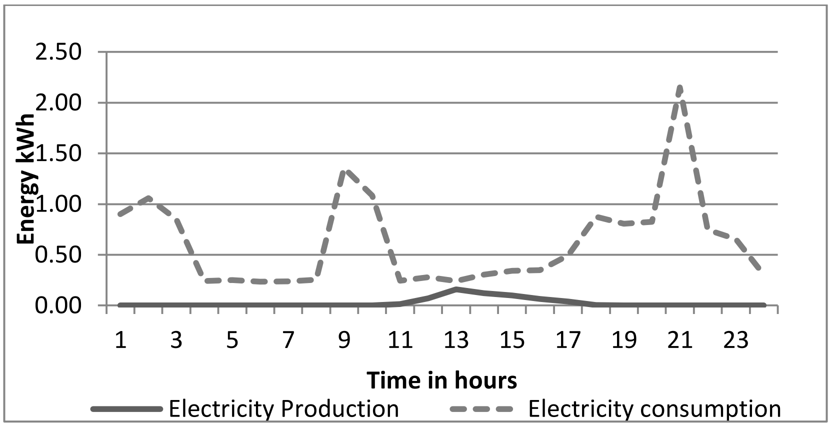


Figure 16. Energy consumption and production in hourly resolution on 12th December, 2013 for a household in Post Code 8131.

Figure 16 shows the electricity consumption and the production for a household in the pilot area with solar panels. The peaks in the consumption clearly indicate the use of a heavy appliance while the production line corresponds to the availability of sunlight which is the highest around mid-day for a day in December. A close look at these consumption patterns could give an insight into grid management.

Figure 17 shows the production pattern for 3 different capacity PV systems in the pilot area for the whole year. They follow a similar pattern but the amount of power generated differs due to the installed capacity.

Figure 1 shows a scenario: how much electricity could have been generated if a particular house had a PV system installed. The solid line shows consumption pattern for a household with annual electricity consumption for the year 2013, which was 4216 kWh. The dashed line shows the predicted generation if the household had a PV system of 2.25 kWp capacity. It would have generated about 1767.6 kWh, which is about 42% of the electricity consumed by the household.

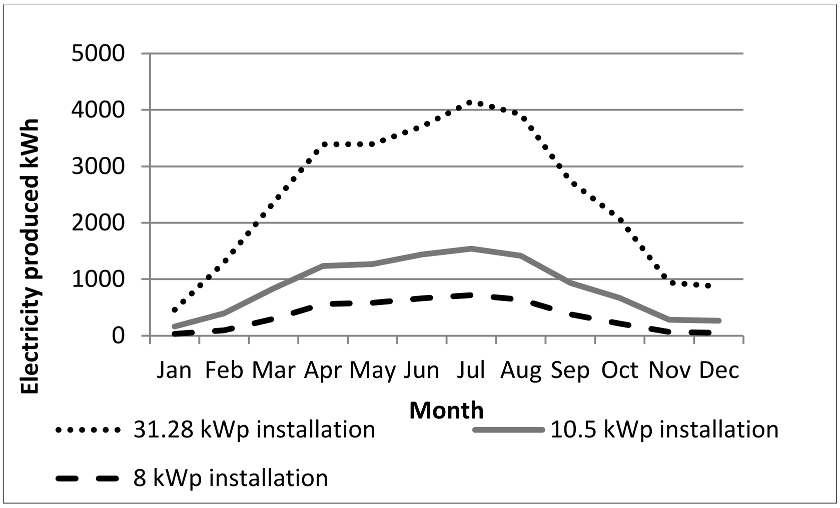


Figure 17: Comparison of 3 different capacity systems in the pilot area for the year 2013.

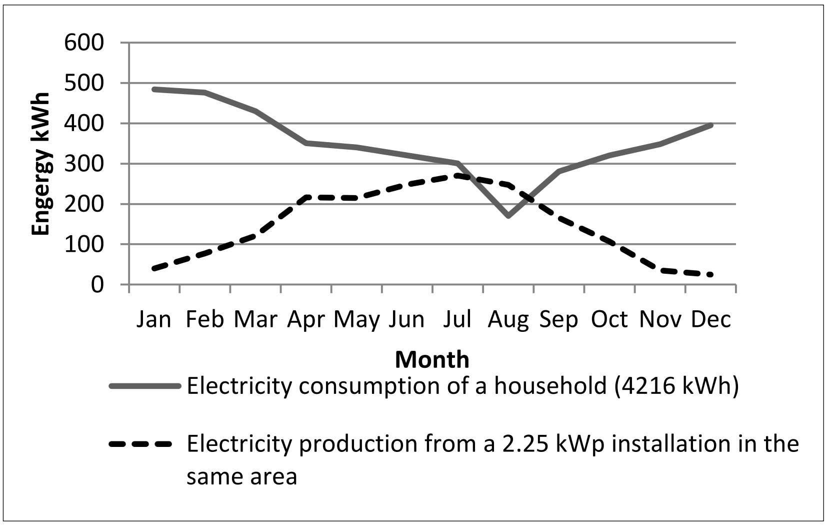


Figure 18: Scenario: if the household had a PV system.

9 Conclusions

We were able to bring data sets from different sources onto the same GIS base i.e. create BIG DATA. This helped us the arriving at the following conclusions. It was found that about 1.61% of the total electricity consumption is covered by PV in the pilot area for the domestic sector. Therefore, there is scope for filling this gap. Grid operators would have to keep track of all the ongoing installations and be able to manage the feed–in and the consumption and consumers will be able to understand and forecast the generation of solar power as a function of place and time which will enable smooth management of supply and demand

We performed a new analysis of PV potential based on the AHN elevation data. The calculations showed that the city of Apeldoorn has great PV potential in its residential sector. Based on an average electricity consumption of residential houses in Apeldoorn of 3500 kWh/yr, the potential electricity that could be generated would be able to cover the electricity demand of the city completely and even produce more. But proper measures have to be taken to sustain the grid at all times. Power generated from PV is greater in the summer compared to winter months where electricity consumption increases. This calls for proper energy management to store/sell the excess produced in the summer. Time resolved balancing will require a combination of demand steering (variable tariff setting) and storage.

9.1 Future Prospects

Creating value for different stakeholders be it consumers, network companies, policy makers, public and private organizations is a goal of any project. In this project we show the power of Big Data and how this could create a value to different stakeholders. If more data was available detailed analysis of supply-demand balancing could have been made. This could be done by creating a community that could share data or by volunteered geographic information (VGI) or crowdsourcing. Access to data on infrastructure, and operation maintenance data would lead to better monitoring and infrastructure optimization in planning and maintenance upcoming installations and present installations.

Appendix: Overview of national activities and projects related to the ASM project

The challenge as described in section 1 is being addressed from different angels and approaches. This section gives an overview of related activities and projects.

1. Portaal Zonnestroom

Framework	*TKI Solar*
Project period	*2013-2015*
Leader	*DNV KEMA*
Participants	*Univ Utrecht, Milieu Centraal, Stichting Monitoring Zonnestroom, Alliander*

The goals of the project are:

1. To create a complete, reliable and independent portal for information on PV for consumers and small businesses.
2. A model for financing options for PV for consumers and small businesses. This includes a model for the value of PV systems in case of selling before end of life (in case of moving to another house).

2. IPIN program (Innovatieprogramma intelligente netten)

Framework	*Started in 2010 as independent program under RVO, since 2012 part of the program of TKI Swithc2SmartGrids.*
Project period	*2010-2014, 12 pilots*
Leader	*RVO (TKI Smart Grids)*

New technologies and partnerships for smart grids.

2.1. PowerMatching City

Framework	*IPIN*
Project period	*2009-2014*
Leader	*DNV KEMA*
Partners	*TNO, Essent, Gasunie, Enexis, TU/e, TU/Delft*
Suppliers	*Nedap, NXP*

PowerMatching City is a living lab demonstration of the future energy system, located in Hoogkerk near Groningen in The Netherlands. In PowerMatching City the connected households have smart appliances that match their energy use in real time, depending on the available (renewable) generation, and offers trading possibilities.
PowerMatching City is, first and foremost, the European field trial to connect supply and demand of electricity and heat in an intelligent way (smart grids). Purpose of the ongoing project is to fully profit of characteristics of both centralized and renewable energy systems. Since 2009 this demonstration project has taken place in Hoogkerk, near Groningen. During the first phase 25 households participated. At the end of 2011 the second phase took off. Nowadays 42 households are taking part in Power Matching City, more clustered together than before.

2.2. INZET

Framework	*IPIN*
Project period	*2010-2014*
Leader	*Zeenergie (L. Godschalk)*

Partners *Greenchoice, Proxenergy, Alliander, municipality Zeewolde, province Flevoland*

INZET aims to provide the town of Zeewolde with locally produced renewable energy while experimenting with demand side management.

3. Amsterdam Smart City

Framework	*General platform*
Project period	*2009-2014*
Leader	*Municipality Amsterdam*
Partners	*Liander, KPN*
Connected	*70 partners*

Amsterdam Smart City (ASC) is a partnership with the goal to develop the Amsterdam Metropolitan Area into a smart city. Amsterdam Smart City has established Amsterdam as an urban living lab that offers businesses to test and demonstrate innovative products and services.
ASC connects the needs and wishes of users, residents, government and business. ASC essentially stimulates all parties to take action.
ASC provides new possibilities for testing technologies, products, services and approaches in various urban living labs in the region. All knowledge gained is widely shared, as it is believed that open and scalable innovation is the key to sustainable success.
Open infrastructures, open innovation, open knowledge and open data. This forms the basis for product and service innovations that can improve the quality of life.
One of the initiatives within ASC is about supply-demand balancing, initiated by Alliander.

4. Energie Data Hub

Framework	*-*
Project period	*2012 - ?*
Leader	*Get There*
Partners	*Municipality Groningen, Province Groningen, RUG*

Big data project for sustainable energy data and smart meter data. Storage and processing of big data. Use of the data for: balancing of demand and supply, energy savings and privacy protection.

5. Smart Energy Collective

Framework	*Cooperation platform*
Project period	*2009-2014*
Leader	*Alliander*
Partners	*ABB, BAM, Eneco, Stedin, Delta, KPN, Heijmans, IBM*

Ultimate goal is standardization of intelligent energy network architectures.
Development of a collective market for intelligent energy networks with sufficient size.
Connected to Stad van de Zon (Heerhugowaard)

6. Zonatlas

Framework *Private company*

Zonatlas is a Geo information based system that shows which roofs are suitable for solar energy generation. It includes a financial calculation tool for households. It is based on the AHN2 (Actueel Hoogtebestand Nederland) and calculation algorithms from Tetraeder.

7. PICO (Project Interactieve Communicatie- en Ontwerp tool)

Framework	*TKI EnerGO*
Project period	*mid 2013 – mid 2015*
Leader	*Geodan*
Partners	*TNO, Alliander, Ecofys, Esri, Waifer*

Dataplatform, tools and models (GIS based):
To facilitate policy- and investment decisions related to the energy transition on the level of a neighbourhood.

8. Simulation Globe

Framework	*Maps4Society*
Project period	
Leader	*Univ Utrecht*
Partners	*KNMI, RIVM, Witteveen & Bos, Van Oord, Deltares, TU Delft*

On-line simulation globes. Status unclear

9. EXE BV

Framework	*New found company by Alliander*

Complexity, rules and conflicting interests make that it is a challenge to define new business concepts. Therefore Alliander founded the emerging Business Area 'EXE b.v.': a BV inside Alliander that facilitates future business. EXE translates the future energy market to today. Slimme EnergieBeurs (SEB) is a product en trademark within EXE: electricity trading between consumers and prosumers, realized as a backoffice service for utilities.

10. Solar forecasting and smart grids

Framework	*TKI Switch2smartgrids*
Project period	*2013-2015*
Leader	*Ecofys*
Participants	*DNV KEMA, Univ Utrecht*

Ecofys, DNV KEMA and Utrecht University research how the integration of a large quantity of PV power can be achieved in a cost-effective way, and how solar power can be effectively connected to existing energy consumers based on Smart Grids and demand response. For this the project partners realize and validate the 'Solar Forecasting' prediction system, a tool that can better predict the performance of local PV installations. More accurate forecasting of PV production can be used to maintain a better balance between electricity demand and supply. Using Smart Grids and demand response the SF & SG project partners want to ensure that local and regional energy consumers can also directly use the solar power generated.

11. Smart grids: rendement voor iedereen

Framework	*Economic Board Utrecht*

Project period *2013-2015*
Leader *DNV KEMA*
Participants *Utrecht Sustainability institute, Univ Utrecht, Ecofys, Eemflow, Univ Applied Science Utrecht, Univ Groningen, Icasus, Lomboxnet, Stedin, Capgemini*

This project develops and tests a series of new and upscalable services and business for the electricity grid of the future. Testing is done in two smart grids of 100 households each in Amersfoort and Utrecht.

12. Urses projects

Framework *NWO financed research projects*
Submission *2013*
Project period *2014-2018*
Budget *6,5 million in 11 projects*

The goal of the Urses program (Uncertainty Reduction in Smart Energy Systems) is to contribute to reducing the uncertainty for actors in the energy system. The program wants to generate scientific knowledge and tools for smart energy systems. Insight is needed in the causes, the character and the effects of uncertainty from a societal and behavioral perspective.
List of Projects:

- Smart Regimes for Smart Grids – Dr. M.J. Arentsen, Universiteit Twente
- Stable and scalable decentralized power balancing systems using adaptive clustering – Prof. dr. F.M.T. Brazier, TU Delft
- Aquifer Thermal Energy Storage Smart Grids – Dr. T. Kevicky, TU Delft
- Distributed Intelligence for Smart Power routing and mATCHing – Prof. dr. ir. W.L. Kling, TU Eindhoven
- Smart Organisation of (SMART) Energy Systems – SO(S)ES – Dr. D.A. Loorbach, Erasmus Universiteit
- Car as Power Plant – Fuel cell cars creating a detachable decentralized multi-modal smart energy system – Dr. ir. Z. Lukszo, TU Delft
- ENergy-Based analysis and control of the grid: dealing with uncertainty and mARKets (ENBARK) – Prof. dr. C. De Persis, Rijksuniversiteit Groningen
- PMU Supported Frequency-Based Corrective Control of Future Power Systems – Dr. ir. M.S.E.E. Popov, TU Delft
- Emerging Energy Practices in the Smart Grid – Prof. dr. ir. G. Spaargaren, Wageningen Universiteit
- Realizing the smart grid: aligning consumer behaviour with technological opportunities – Prof. dr. L. Steg, Rijksuniversiteit Groningen
- Gaming beyond the Copper Plate: scheduling flexible consumption and decentralised generation within distribution constraints – Dr. M.M. de Weerdt, TU Delft

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