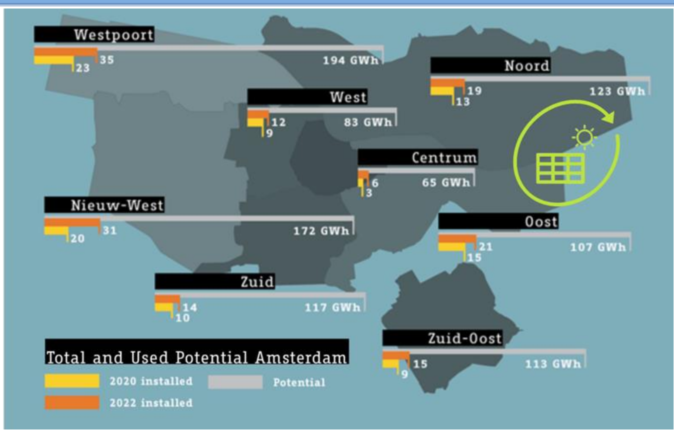
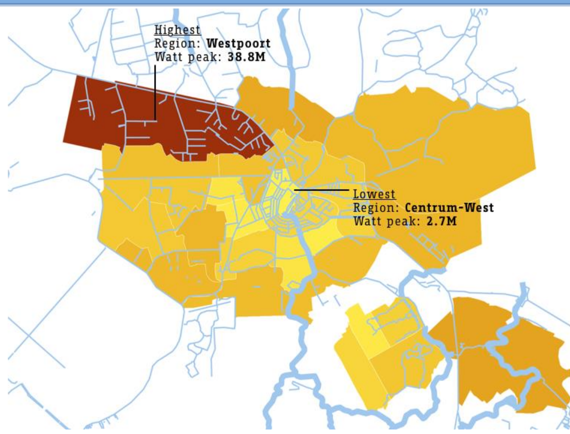
simply positive

D6.2. Semi-annually visualization of PV installations progress per neighbourhood based on the Focus District in Amsterdam including a PV development strategy showing unused potential

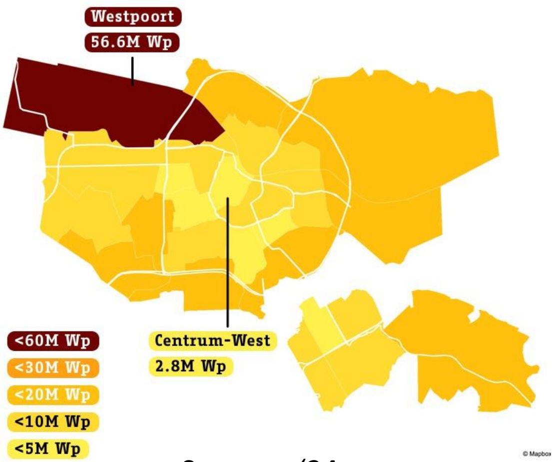
2023-2024



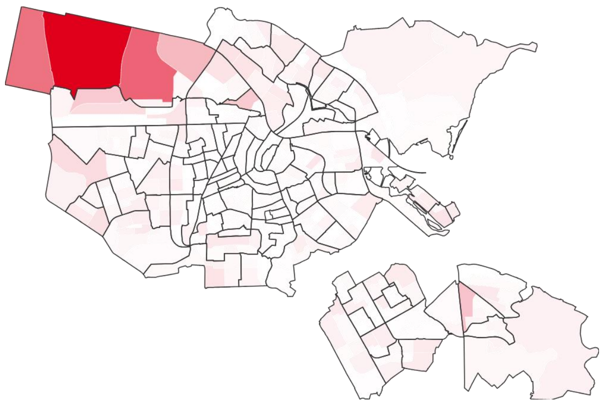
Summer ‘23



Winter ‘23



Summer ‘24



Winter ‘24

SONNENPLATZ Großschönau · Città di Settimo Torinese · AMS Amsterdam Institute for Advanced Metropolitan Solutions · TU Delft · PV Works · denkstatt create sustainable value · FH Technikum Wien University of Applied Sciences · Reșița

Leader: PV Works

Dissemination Level

PU	Public	X
CO	Confidential	

History

Version	Description	Lead author	Date
V1	First Template	PVW	May 2023
V2	Draft Semi-Annual Report	PVW	June 2023
V3	Review	PVW, SON	July 2023
V4	Final 1st Semi-Annual Report	PVW	July 2023
V5	Draft Semi-Annual Report V.2	PVW	December 2023
V6	Updated Draft Semi-Annual Report V.2	PVW	January 2024
V7	Updated Draft Semi-Annual Report V.3	PVW	July 2024
V8	Updated Draft Semi-Annual Report V.4 (final)	PVW	December 2024

Disclaimer

This project has been developed in the framework of the PED Program, which is implemented by the Joint Programming Initiative Urban Europe and SET Plan Action 3.2. *The Austrian part is supported by the Austrian Ministry of Climate Action, Environment, Energy, Mobility, Innovation, and Technology (BMK); the Romanian part is supported by a grant of the Ministry of Research, Innovation and Digitization CNCS/CCCDI – UEFISCDI, project number PED-JPI-SIMPLY POSITIVE, contracts number 325/2022 and 326/2022, within PNCDI III; the Dutch part is supported by the RVO (the Netherlands Enterprise Agency), reference number ERANETPED-02767306; and the Italian part is supported by a grant of the Ministry of Education and Merit - Department for Higher Education and Research, project number PED_00042, from the Fund for Investment in Scientific and Technological Research (FIRST/FAR) and/or Special Accounting Account no. 5944.*

Executive Summary

A prioritization strategy for cities will be developed to facilitate the installation of PV systems across their urban fabric and to raise awareness of the PV energy yield potential. Several factors will be taken into consideration in developing the strategy:

a) economical (feed-in tariffs, LCOE and RoIe of urban PV systems),

b) energetical (known or computed bottlenecks in mid-low voltage distribution grid), prioritization of PVT over PV regarding the heat transition,

c) architectural (status of building permits, planned constructions, etc.), and

d) governance (ownerships, collective projects).

The strategy will be based on the data from the city of Amsterdam with focus on replicability and usability for all other SIMPLY POSITIVE focus districts.

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List of Abbreviations and Acronyms

AC	Alternating Current
AHN	Algemeen Hoogtebestand Nederland (in Dutch)
BAG	Basisregistratie Adressen en Gebouwen (in Dutch)
DC	Direct Current
DNI	Direct Normal Irradiance
DHI	Diffuse Horizontal Irradiance
DSO	Distribution system operator
DSM	Digital Surface Model
FD	Focus District
GHI	Global Horizontal Irradiance
LCOE	Levelized Costs of Electricity
LiDAR	Light Detection and Ranging
PDOK	Publieke Documentatie Op de Kaart (in Dutch)
PV	Photovoltaic
PVT	Photovoltaic Thermal
RoI	Return on Investment
SCF	Sun Coverage Factor
SVF	Sky View Factor
WP	Work Package
Wp	Watt Peak

Table of Contents

1. Introduction

1.1. Purpose of the document

In this document, the available annual data on the installed capacity of photovoltaic (PV) systems is retrieved for the city of Amsterdam per district to present the progress in PV installations. Also, the rooftop PV energy yield potential is calculated and compared with future targets of the city. In addition, results from research and interviews on PV adoption barriers and common challenges and solutions between cities will be presented.

1.2. Relation to other project activities

A study to estimate the rooftop PV energy yield potential in Amsterdam was carried out by the TU Delft and the AMS Institute. The project resulted in a realistic quantification of solar PV potential on Amsterdam rooftops and a comparison with the actual PV installations. In such a modelling framework, further developed at PV Works, height data of the terrain are used to digitally construct the urban fabric; recognize rooftops with respect to cadastre data; automatically place PV modules on rooftops; and accurately compute the PV systems' energy yield up to the AC-side for every considered building. All this is accomplished with a pace of 2.4 buildings/second. These data are already used by the city of Amsterdam to engage citizens and plan in time PV installations with accelerated permit certifications. The city of Amsterdam supports the Simply Positive project.

1.3. Structure of the document

In Chapter 2 of the document the methodology for retrieving the amount of existing PV systems and the model used for calculating the rooftop PV potential is presented. Chapter 3 obtains the results and discussion on semi-annual progress of PV installations in Amsterdam. Chapter 4 contains the results and discussion on the calculated PV energy yield potential taking limiting factors into account. Finally, the conclusions are given in Chapter 5.

2. Methodology

2.1. Inventory of existing PV systems in Amsterdam

2.1.1. Annual detection of PV systems from aerial imagery

The municipality detects the installed solar panels from aerial photos of the buildings and makes this information available. The detection is carried out by a collaboration between Amsterdam and *Reader,* a company specialized in automatic detection. The high-resolution aerial photos are made publicly available [1] every year up to a resolution of 8 cm. An example of an aerial image with installed PV modules is presented in Figure 1. In addition to the most recent 2024 aerial images, they also share the aerial photos from 2016 till 2023. This enables us to determine when and where the installations have been placed. From matching the PV energy yield per year and making the comparison between the two following years we have found out that the peak power of modules installed each following year increases as shown in Table 1.

Table 1 - PV Module peak power

Installation year	Module Peak power
Year	**Peak power (Wp)**
2024	435
2023	410
2022	384
2021	330
2020	315
2019	305
2018	295
2017	256
2016	252

Figure 1 - Existing PV on aerial imagery

2.1.2. Quarterly increase in PV systems connected to electricity network.

The data of PV systems connected to the electricity network is collected by the distribution system operator (DSO) Liander [2] which is active in all districts of Amsterdam. This dataset consists only of PV systems that are connected to the low-voltage grid. The data of individual PV systems are aggregated per Amsterdam neighbourhoods to meet privacy regulations. Neighbourhoods with less than 5 connections are not included in districts but are added to a separate section (in Table 3 called *Others*). In total there are 342 neighbourhoods in Amsterdam with PV systems connected to the low-voltage grid, which are brought under 8 districts.

2.2. Potential PV systems

2.2.1. Input Data

LiDAR Height data

In 2020 and 2021 new height data was retrieved by Algemeen Hoogtebestand Nederland (AHN4) and made available on their website *AHN viewer* [3]. The point cloud has an average resolution of 25 cm, but for the sake of quick analysis this data is converted into a digital surface model with a grid size of 50 cm. This raster data comes in tiles of 2.5 by 1.25 km which means the data must be processed per districts in Amsterdam.

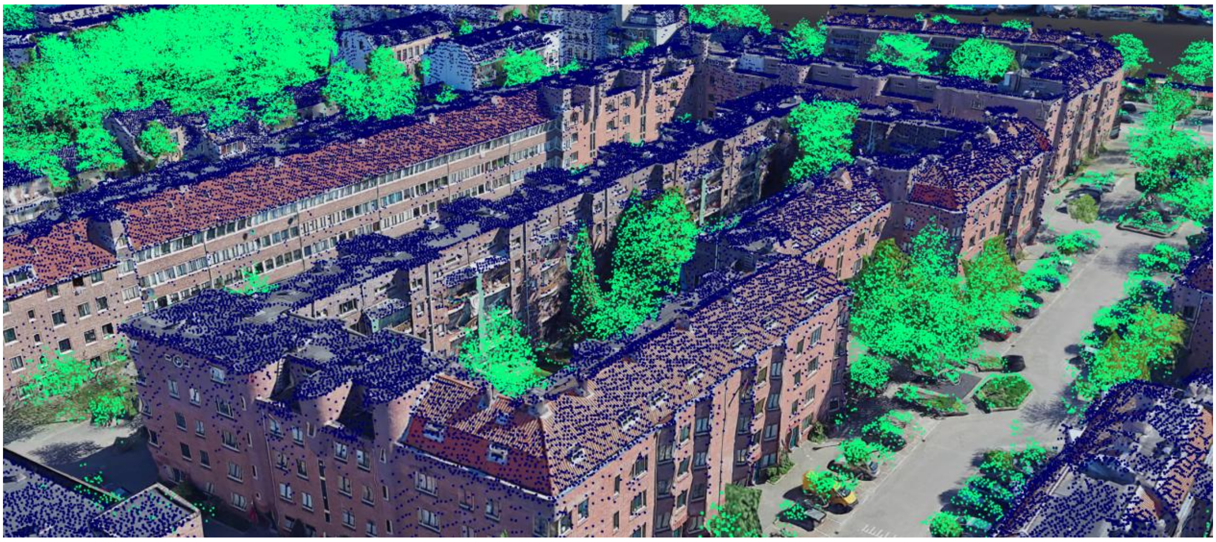

Figure 2 - LiDAR Point cloud visualized on a 3D building block in Amsterdam

BAG cadastre building data

The so-called BAG data (Basisregistratie Adressen en Gebouwen) was collected on the 6th of June 2023 from the Cadastre [4], including 545,288 addresses for 194,380 buildings across the city of Amsterdam. For each building, the projected footprint of the building is a 2D polygon described in X and Y coordinates as shown in Figure 3.

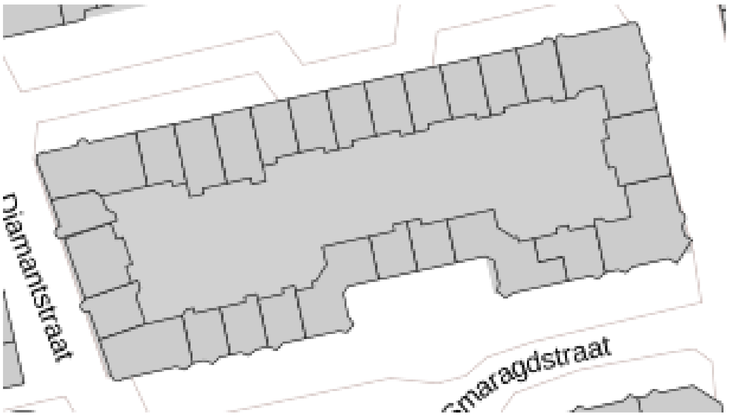

Figure 3 - BAG cadastre building footprints for a building block in Amsterdam

Climate Data

Hourly meteorological data is collected from weather stations in and around the city of Amsterdam and they are used to determine a weather pattern for an average year. Several years of historical weather data are used by software programs like METEONORM to create an array of 8760 hours with a typical weather pattern for each day. The required parameters for calculating the time-dependent solar irradiance on a module are solar position polar coordinates azimuth and elevation in degrees, Global horizontal irradiance (GHI), Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI), ambient temperature and windspeed.

PV Module Data

Standard rectangular PV modules are fitted on the available roof area. The dimensions of the module as well as the mounting height are input parameters. Furthermore, the characteristics of the module such as the efficiency under standard test conditions (STC), open circuit voltage, short circuit current, number of cells in series, ideality factor and temperature coefficient are required for calculating the energy yield. These characteristics are commonly found in the datasheet of the PV module. Also, the overall reflective index, back and front emissivity and ground albedo are taken into account. A summary of the parameters of the PV module panel used in our study is given in Table 2.

Table 2 - BAG cadastre building footprints for a building block in Amsterdam

PV Module parameters	
Parameter	**Value**
Module length (m)	1.669
Module width (m)	0.996
Efficiency at STC (%)	19.6
Open circuit voltage (V)	41.08
Number of cells in series	120
Ideality factor (-)	1.2
Temperature coefficient (%/*C)	-0.027
Ground albedo (-)	0.2
Reflective index (-)	0.1
Top emissivity (-)	0.2
Back emissivity (-)	0.89

2.2.2. Skyline-based model

Figure 4 details our modelling framework to evaluate the PV deployment for a particular site. We start with LiDAR data which are readily available in the Netherlands. In this step, we consider only points that are classified as buildings. Using these points, we detect planar surfaces that are large enough to fit a PV array. Non-curved surfaces larger than 10 m^2 are selected for PV module installations.

A heuristic layout algorithm is used to fit as many modules as possible in different orientations on the selected surfaces. For flat rooftops, modules are placed facing south with a tilt angle of 13 degrees and a row spacing of 0.7 meter, or east-west with 10 degrees tilt. On sloped rooftops, both the portrait and landscape orientation of modules are assessed.

The surrounding horizon is scanned for each module of the array. In this case we use every Lidar point, including, for example, trees. The horizon scan is used as an input for our skyline-based approach to calculate the energy yield. In this approach we apply the sky-view factor (SVF), sun-coverage factor (SCF), ground albedo, and module tilt and azimuth to make a quick estimation of the annual PV energy yield.

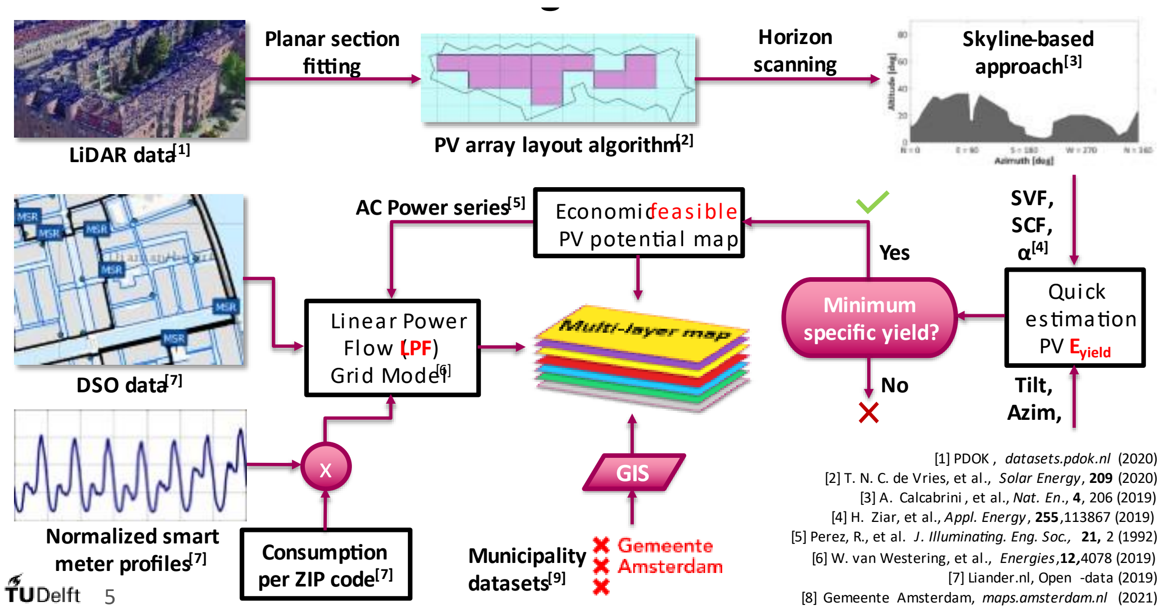

Figure 4 - Modelling framework for the assessment of PV energy yield

After obtaining the annual PV energy yield per module we check whether the performance of the module is cost-effective. A performance threshold of 650 kWh/kW_p is used to filter out poor performing modules. When the module performance is lower 650 kWh/kW_p the spot is not considered as suitable for PV module installation. Conversely, we consider the spot cost-effective for which we continue to calculate a yearly AC power output. The AC power output is an input for a linear power flow model, designed to calculate bus-line voltages for grid networks. The result of this model indicates parts of the grid that could lead to voltage problems.

Figure 5 shows how flat surfaces are successfully detected and geometry sticking out-of-plane is ignored. This means that there are gaps in the detected surface where, for example, a dormer was placed at the roof.

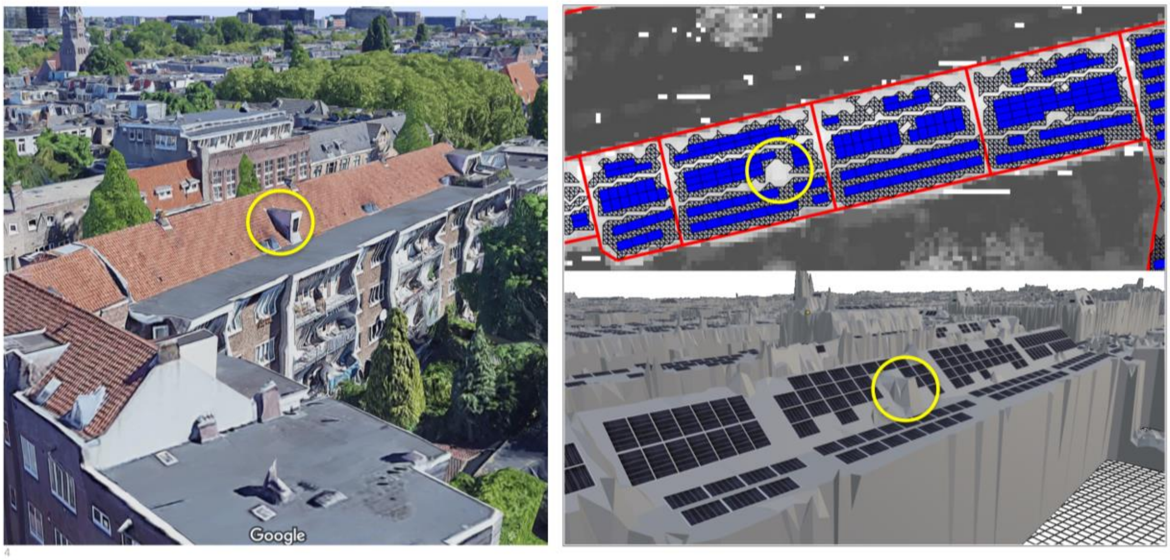

Figure 5 - Detection of available roof space and fitting of PV modules in multiple orientations

2.2.3. Improved methodology

A new app has been developed in python to improve upon the lessons learned from the previous MATLAB code and extend the framework with python's broad capabilities.

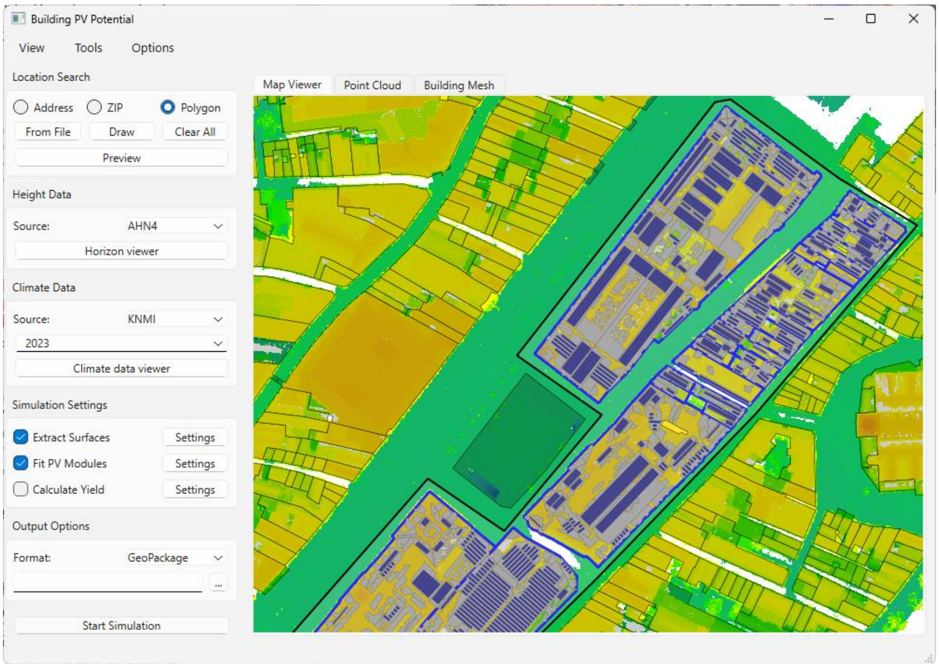

Figure 6 – New tool developed in Python using the PyQt6 package

The skyline-based approach had to be adapted for the more complex PV-T calculations, which require an hourly incident irradiation profile for a full year. This means meteorological data is now used for each PV module to calculate the DC output power for each hour and the annual yield is obtained by integration, instead of creating climate coefficients.

Roof polygons

The methodology for the detection of roof points and conversion to polygons has been improved to create a more complete roof shape. The edges are snapped to the adjacency lines of neighbouring polygons to create a seamless roof mesh, as can be seen in the images below.

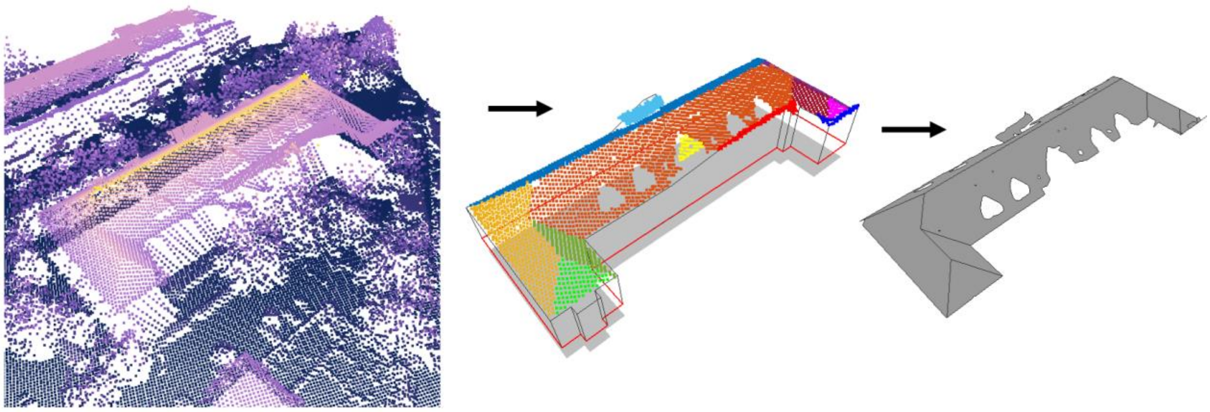

Figure 7 – Process from point cloud to detected planar clusters of points to simplified polygons

Module fitting

To take into account the choice of more aesthetically pleasing module layouts, new algorithms have been developed to remove panels from the maximum. In an iterative process an erosion function is used to erase sticking-out panels from the edges of a group. Alternatively, the choice can be made to have strictly rectangular groups of panels within a roof section. Depending on the shape of the roof and size of the panels, this process can remove many panels from being further processed.

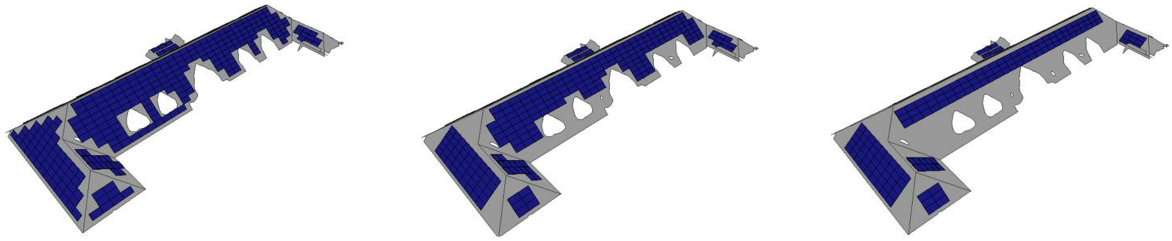

Figure 8 – Different choices of module layout methods. First the maximum possible on the left, then eroded in the middle and strictly rectangular on the right

Horizon profile

The horizon scanning approach has been sped up by resampling the height data based on distance. This means nearby points are unchanged, but points far away from the module have been removed at random before doing any further processing. This means a much larger search radius can be used.

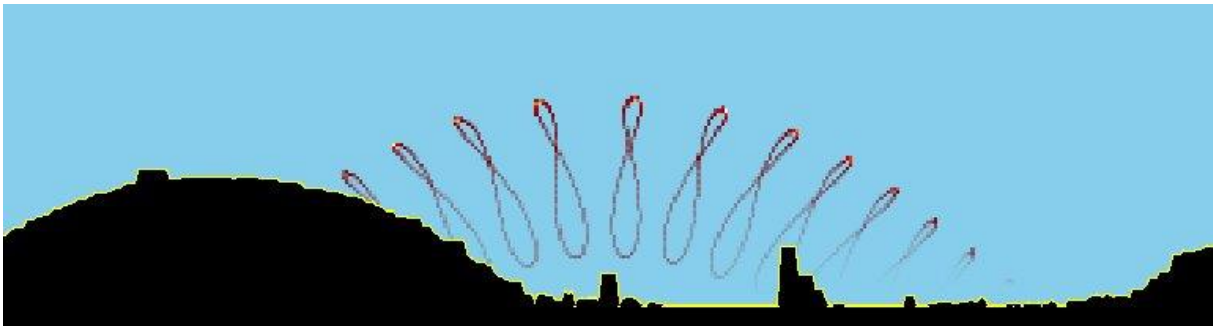

Figure 9 – Skyline profile generated by horizon scanning algorithm in yellow, with the solar position shown for a full year in the background

2.3. Potential PVT systems

In this work we also look at the heat energy potential, by considering that the installed module can also be a PVT module. The used models are explained in detail in deliverable D4.1. To simplify the annual simulation process across the districts, unique coefficients are obtained and used directly after calculating the incident irradiance. This approach characterizes thermal and electrical performance as functions of operational conditions, including fluid inlet temperature, ambient temperature, and solar radiation. The electrical coefficient is 10.0 and the electrical coefficient is 0.33. The electrical and thermal efficiency are 0.195 and 0.47, respectively.

2.4. Compared research on other Dutch cities

In the context of the Simply Positive Project, AMS Institute conducted research and interviews with municipalities and their responsible program managers in energy-related departments.

The scope of the research was to explore hindering and aiding factors for solar panel adoption on rooftops in cities, comparing five major Dutch cities: Rotterdam, Den Haag, Amsterdam, Utrecht, and Eindhoven.

With a focus on the interview conducted with the program manager of Solar Energy at the City of Amsterdam, a summary of the PV installation challenges and initiatives is provided.

In the context of Amsterdam's efforts to adapt and expand solar panel usage and RES, the challenges outlined during the interview with the program manager for solar in Amsterdam's

Sustainability Department reveal a complex interplay of regulatory, financial, and technical issues.

Projects are frequently delayed by ownership issues, which make it challenging to reach an agreement for installations, especially in buildings with mixed ownership. Furthermore, Amsterdam is dependent on national regulations and does not have direct authority to require solar installations. Another significant obstacle is money, particularly for housing firms that require insulation and other repairs at the same time. Regulations that now prioritize land usage over rooftop solar systems further impede growth. The incorporation of more sophisticated solar systems, such as energy storage, is limited by capacity concerns with the local grid operator, LIANDER. Other challenges include cultural and aesthetic considerations, especially in historic districts. Adoption is further slowed by technical constraints, such as the older rooftops' ability to support weight.

Limited solar adoption is a result of low association participation among small homeowners and unclear incentives for energy storage devices. Uncertainties around energy pricing also affect the economic appeal of solar installations. Finally, Amsterdam's varied architecture and building types make it difficult to scale pilot projects and uptake, while there is still a lack of good public awareness and communication on the advantages of solar energy.

The initiatives and proposed improvements for enhancing solar panel adaptation and RES in Amsterdam reflect a strategic and integrated approach to address the challenges previously outlined. These initiatives focus on fostering innovation, streamlining processes, and enhancing collaboration among stakeholders.

Amsterdam has launched several programs to encourage the use of solar energy. Housing associations receive subsidies, and €4 million from the climate fund is used to increase renters' access to solar. Through building assessments, financial aid, and stakeholder participation, the city promotes the use of solar energy. To lessen the financial strain on communities, Amsterdam is also looking into creative finance solutions that involve collaborations with banks and installation companies. The city is advocating for national policy reforms to strengthen local solar mandates to get past regulatory obstacles. To make it easier to install solar panels on historic structures, building codes are being modified. In addition, to store solar energy in EV batteries, efforts are being made to integrate solar with EVs. Local energy management is being tested through pilot programs like FlexPower.

While neighborhood-focused strategies reduce procedures, energy cooperatives enable locals to share the benefits of solar energy. Startups creating sustainable and lightweight solar solutions can find support in the "Startup in Residence" initiative. Multifunctional rooftop projects encourage combination usage, such as green roofs and rainwater collecting alongside solar panels, while public awareness efforts seek to increase knowledge of the advantages of solar energy.

3. Semi-annual development of the installed PV capacity

3.1. PV systems connected to DSO in the past period.

The PV related data provided by the DSO was not available for every three months of the past period. Instead, a datasheet is made available at the end of each year, which was used for the analysis in this project. In total there are 25892 PV systems connected to the low-voltage grid in the city of Amsterdam, with a total installed capacity of 80177 kW. The overview of installations per district is presented in Table 3. Note, these are only small (household) PV systems connected to the low-voltage grid. Some PV systems installed on large buildings can be connected directly to the medium-voltage network and are not considered in our analysis. It means that the data presented in this report could underestimate the real situation in the city of Amsterdam.

Table 3 - PV systems connected to the DSO

	PV systems connected to low-voltage grid	
District	**Number of connections**	**Grid installed capacity (kW)**
Centrum	604	2179
Nieuw-West	6982	20067
Noord	4200	14374
Oost	5631	16759
West	2206	6186
Westpoort	214	776
Zuid	2536	7238
Zuidoost	2997	9864
Others	522	2734

3.2. Latest results of aerial detection of PV systems

The aerial images for the 2023 and 2024 reports on the detection of all existing PV system using aerial images were created in spring and the results were made available in June and November, respectively. The data from the latest report is shown in Table 4. The Centrum district of Amsterdam has the smallest number of new PV modules, which can be expected from the densely populated city centre with many historical buildings. The most modules in 2024 were installed in Westpoort district that are clustered in 214 separate PV systems.

Table 4 - Latest information on detected existing PV systems (update October 2024)

	Detected in 2024				
District	**Buildings**	**PV Systems**	**Total number of Panels**	**New Panels 2024**	**Cumulative Installed Capacity (kW)**
Centrum	16437	864	31839	5985	11345

Nieuw-West	36451	7300	170700	26226	60926
Noord	35171	5287	109757	13765	39508
Oost	22723	4110	104863	10156	36615
Weesp	14322	3354	57602	11926	20873
West	21238	1526	55499	3870	18845
Westpoort	2695	214	181281	31450	64881
Zuid	27995	2326	73529	6330	25892
Zuidoost	19895	4041	79731	8974	29211
Total	**196927**	**29022**	**864801**	**118682**	**308096**

3.3. Progress of installed PV per district

Table 5 presents 8 years of PV installation history in the districts of Amsterdam. The year columns show the cumulative installed capacity in kW and the column next to it shows the annual growth rate percentage in that year with respect to the previous year (numbers are shown in blue colour). Westpoort district has experienced the fastest growth in PV installations, going from the smallest amount of installed PV capacity in 2016 to the largest one in 2024.

Westpoort is the industrial district in Amsterdam, meaning that the growth mainly comes from very large installations.

Table 5 - Progress of installed PV capacity per district in Amsterdam (update October 2024)

	Cumulative installed capacity (kW) & annual growth rate (%)															
District	**2016**	**2017**	**+%**	**2018**	**+%**	**2019**	**+%**	**2020**	**+%**	**2021**	**+%**	**2022**	**+%**	**2023**	**+%**	**2024**	**+%**
Centrum	796	1184	49%	1847	56%	2593	40%	3776	46%	5826	54%	7045	21%	8829	25%	11345	29%
Nieuw-West	3551	4978	40%	7810	57%	13600	74%	23005	69%	29871	30%	37370	25%	49826	33%	60926	22%
Noord	3493	5183	48%	6931	34%	9664	39%	14660	52%	18271	25%	23465	28%	34676	48%	39508	14%
Oost	3287	5374	63%	7138	33%	11422	60%	16633	46%	20237	22%	24657	22%	32302	31%	36615	13%
Weesp	1469	2264	54%	2748	21%	4265	55%	7191	69%	10077	40%	12116	20%	15956	32%	20873	31%
West	2440	2886	18%	4115	43%	6565	60%	10176	55%	11898	17%	13640	15%	17620	29%	18845	7%
Westpoort	130	308	138%	3317	976%	8788	165%	26697	204%	31261	17%	41941	34%	55505	32%	64881	17%
Zuid	2741	4120	50%	5337	30%	7475	40%	11400	53%	13018	14%	16737	29%	23061	38%	25892	12%
Zuidoost	3228	4420	37%	5535	25%	8446	53%	9984	18%	12580	26%	16601	32%	25183	52%	29211	16%
Total	**17906**	**26296**	**47%**	**39242**	**49%**	**64373**	**64%**	**113538**	**76%**	**140459**	**24%**	**176972**	**26%**	**237774**	**34%**	**278885**	**17%**

3.4. Visualisations of PV systems installed

Some visualizations are provided in this document to help understanding the general situation in Amsterdam and in each district. These visualizations relate to available data in Autumn 2024 by aerial photos, coming from 2024.

In Figure 10 it is possible to see the total installed power in watt peak in 2024, divided in the different districts of Amsterdam. As explained in the previous section (3.3), Westpoort has the largest amount of installed PV capacity with a value of 64.9 MW_p, while the lowest value is attributed to the Centrum district (11.3 MW_p). Overall, Amsterdam rooftops hold upwards of 295MW worth of solar panels. While the industrial area of Westpoort accounts for the 23% of the total, it is noticeable that closer to the city center the installations are less. Moreover, outer areas like Weesp, Noord-Oost and Buitenveldert contribute roughly twice the whole amount of the city center.

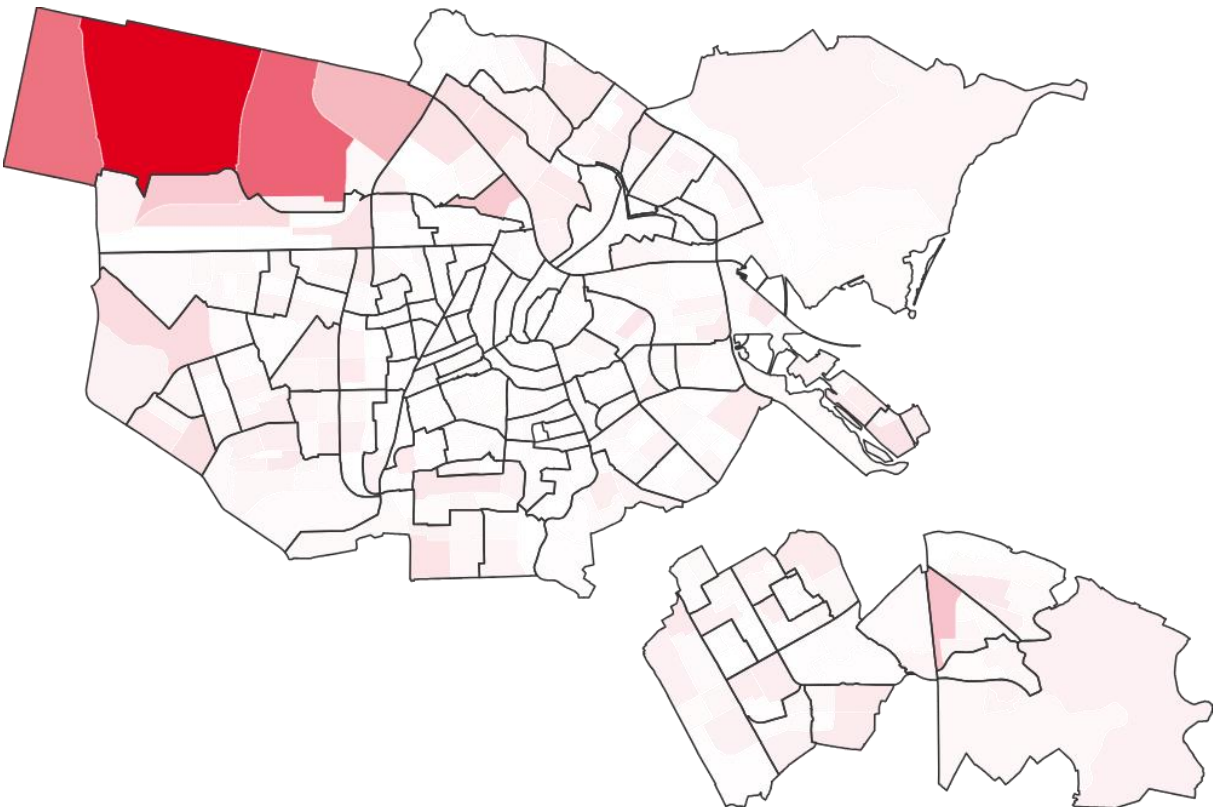

Figure 10 – Total watt peaks installed per different areas in Amsterdam

Building on this, in Figure 11 it is possible to see the timeline of watt peak from rooftop solar panels installed between 2016 and 2024. Increasing PV panels have been installed, reaching 1.12 PJ of installed capacity. Still, this covers only the 16% of the total potential, and only the 7% of the total demand of electricity in Amsterdam. On the other hand, it is interesting to notice that only with rooftop potential, the city can cover nearly half of its electrical demand.

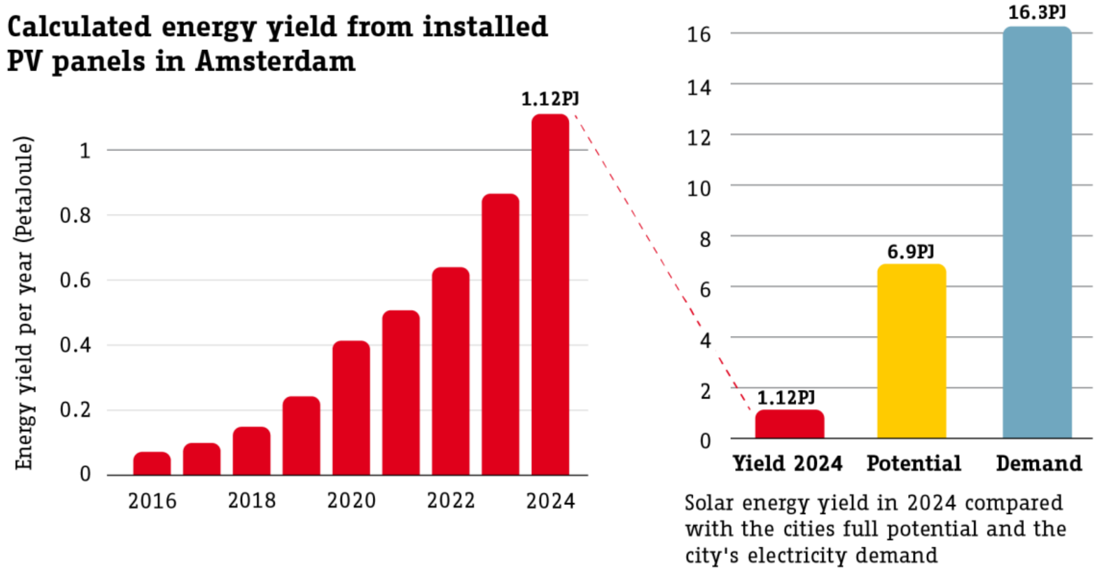

Figure 11 – Installed PV panels in Amsterdam since 2016 till 2024, compared with total potential and demand.

4. Calculated Rooftop PV Potential

4.1. Maximum possible installed capacity

As explained in Chapter 2, we used the skyline-based model approach to calculate the annual energy yield of modules placed on the suitable roofs of Amsterdam buildings. The results of the roof assessment, number of installed modules and the annual energy yield are displayed in Table 6.

Table 6 - PV Potential of the districts in Amsterdam

	Building Info			Potential			
District	Buildings	Building area (km^2)	Roof area (km^2)	PV systems*	Modules	Capacity (MW)	Annual Yield** (GWh)
Centrum	16452	2.76	2.26	11898	388253	128.1	121.8
Nieuw-West	36638	4.71	2.99	21801	889098	293.4	289.5
Noord	35285	3.22	2.94	19898	809039	267.0	263.9
Oost	22820	3.29	2.57	15168	676605	223.3	220.4
West	21304	2.70	2.17	14725	554169	182.9	180.6
Westpoort	2749	3.39	2.72	1888	893814	295.0	302.8
Zuid	28046	3.82	3.11	19609	745271	245.9	237.3
Zuidoost	19971	2.69	2.31	11409	679089	224.1	220.0
Total	**183265**	**26.57**	**21.07**	**116396**	**5635338**	**1859.7**	**1836.1**

*PV system consists at least of 4 PV modules
**The annual energy yield is calculated for a typical meteorological year

4.2. Limiting factors for PV implementation

The results presented in Table 6 were calculated taking several limiting factors into account that do not currently allow placing PV modules. The limiting factors are related to the existence of green roofs or terraces, monumental buildings, water management works and grid congestion.

In parallel to the technical methodology, social studies have been. The research aimed to understand what the barriers to adopting PV systems are, based on data collected among Amsterdam's citizens.

The spatial distribution of PV installations in Amsterdam reveals clear patterns of success, barriers, and opportunities for intervention through clustered PV adoptions observed. Visualization of the main findings can be seen in Figure 11. Hotspots and high-high clusters, concentrated in specific neighborhoods, showcase areas of high adoption driven by (presumably) favorable socio-economic/demographic and infrastructural conditions. Conversely, cold spots and low-low clusters, particularly in Centrum, West, and Zuid, highlight significant barriers such as urban density, physical constraints, and lagging adoption in commercial/work and multi-apartment buildings. Outliers, including high-low and low-high clusters, reveal unique localized patterns where successes can be scaled or specific barriers addressed. Furthermore, demographic insights indicate that younger populations under 35, single-person and single-parent households, and families without children require focused support, as do lagging districts such as Zuid and Centrum. Collectively, the distribution of PV installations reflects a clustered pattern influenced by urban structure, socio-economic conditions, and existing policies, underscoring the need for targeted, context-specific interventions to ensure equitable and widespread PV adoption across Amsterdam.

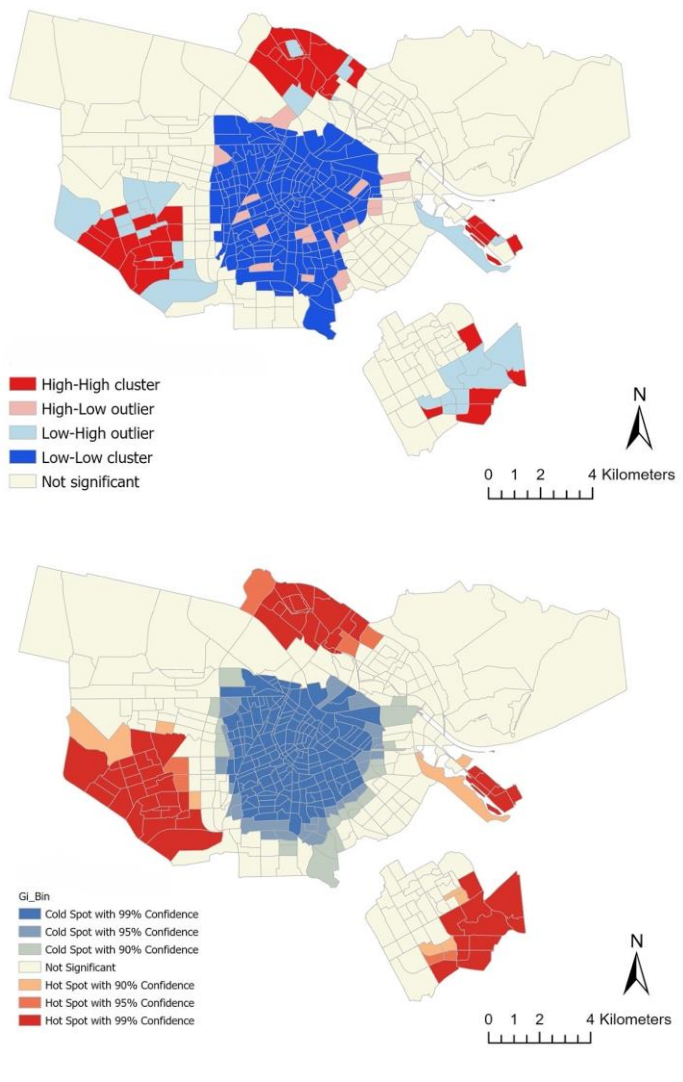

Figure 12 - Spots (above) and clusters (below) in Amsterdam based on PV adoption

Identification of correlation of building functions, properties, value, ownership can indicate a pattern in adoption of PV panels. Together with an overview of contemporary policy (result 6.4), this can lead to new insights for more effective support mechanisms or to identify troubling regulations.

NOTE: the following results are updated only till 2023, but still relevant for considerations

To start, it is interesting to focus on building functions. In figure 13, a timeline from 2016 till 2023 grouped by building function, is presented. It is evident that residential buildings are predominant in the provision of electricity through rooftop solar panels, leading with 127MW$_p$ in 2023, roughly half of the total provision, while functions like Sports, Commercial and Education provide together only 17 MW$_p$ in 2023. This data is expected as residential buildings are the 80% of all the buildings in Amsterdam. Moreover, it is relevant to notice that in 2019 residential and industrial received a clear bump. Might be interesting understand the policies adopted in that period and the successful strategies. Comparing the total with the average it is possible to highlight important factors, indeed the residential watt peak installed is the lowest, contributing with less than 1KW$_p$. This suggests further analysis and exploration of the reasons behind. Education and industrial buildings contribute on average the most watt peak, partly explained by their relatively large rooftop areas. Comparatively, commercial rooftops offer a lot of room for more solar panels. Even though the residential sector provides most of the space for PV installation, still it can be exploited even more, due to the enormous number of residential buildings in the city of Amsterdam.

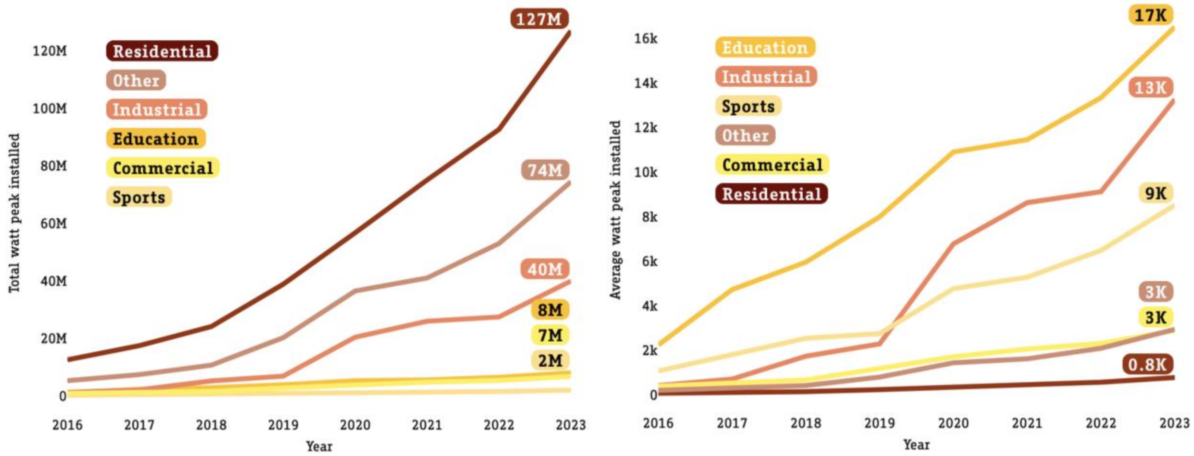

Figure 13 – Timeline of total (left) and average (right) watt peak from rooftop solar panels from 2016 till 2023, grouped by building function

In figure 13, a specific analysis of the total watt peak installed in 2024 on residential buildings is provided. This map highlights that closer to the city center there is less watt peak installed, questioning whether it is because of older buildings and their policies, or for other reasons.

The best-performing areas are along the city outer ring, where also newer buildings are present. This visualisation opens conversations to understand the causes behind a scarcity of watt peak on residential rooftops in the inner parts of Amsterdam.

Figure 14 – Total watt peak from residential rooftop solar panels in 2024, grouped by neighbourhood

To support the analysis of the situation, we decided to consider further different features related to housing and PV installation. Understanding the distribution of average watt peak based on the building construction year (figure 15) outlines the trend of new buildings to have more PV installations. Buildings from 2019 and 2020 alone account for 38MW_p. Moreover, buildings constructed in 1900 also jump out, contributing with 5.4MW_p, a unique amount for pre-war buildings. The bottom right corner of the graph shows there are still many modern buildings without solar panels, requiring for more attention.

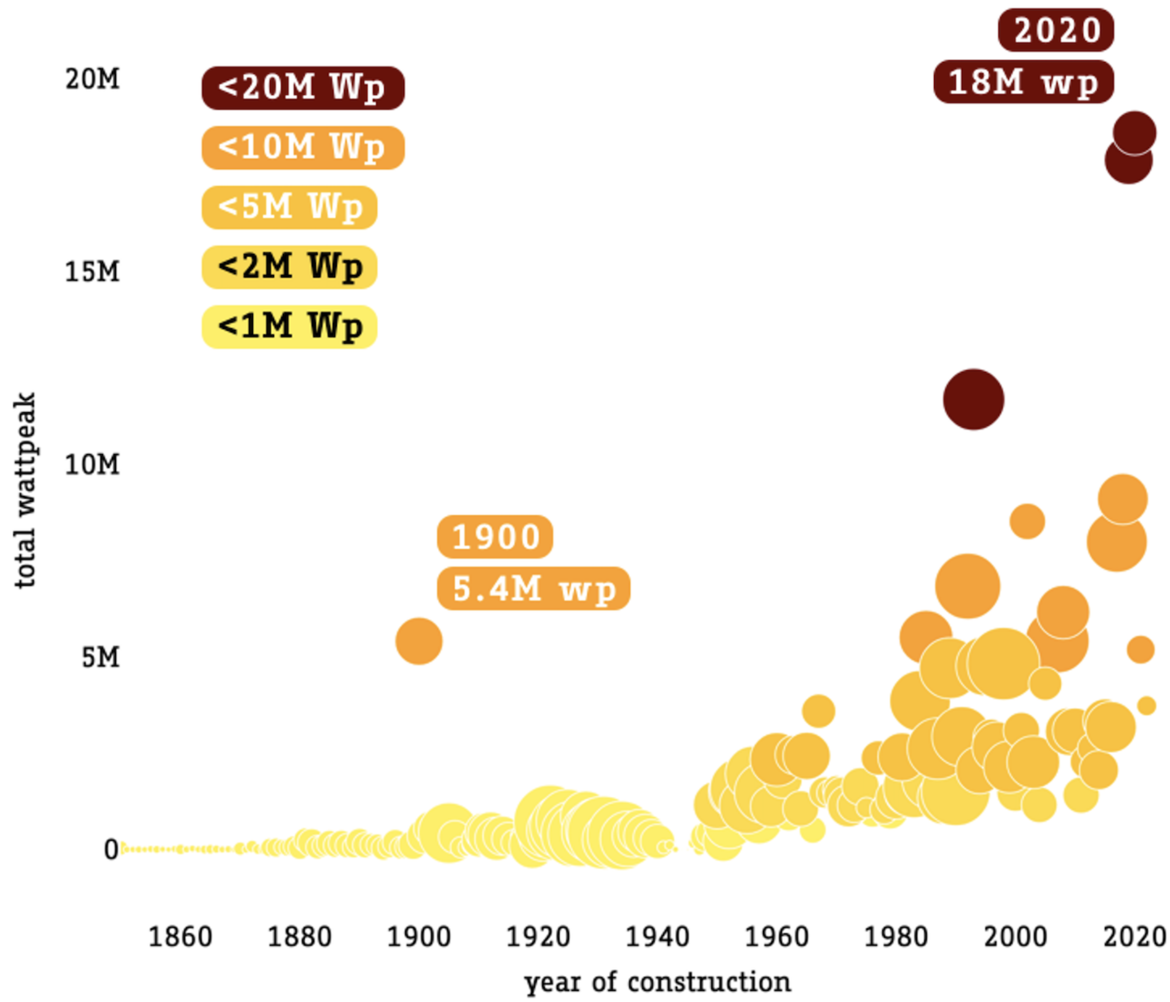

Figure 15 – Total watt peak from rooftop solar panels in 2023, grouped by building construction year

Adding on this, the timeline for protected and non-protected buildings (figure 16) highlights the importance of finding solutions dealing with restriction policies on monumental buildings. Buildings with monumental status have not taken part in the recent sprawl of solar panels. While protected buildings make up 16% of the city's potential, they only account for 8% of its current total solar watt peak. On the other hand, as per June 2024, the city of Amsterdam announced a lesser strict regulation of monuments for energy solutions. This will become effective in a new plan for sustainable heritage in Fall 2024 (*Meer Erfgoed Duurzaam Maken Door Minder Regels*, 2024).

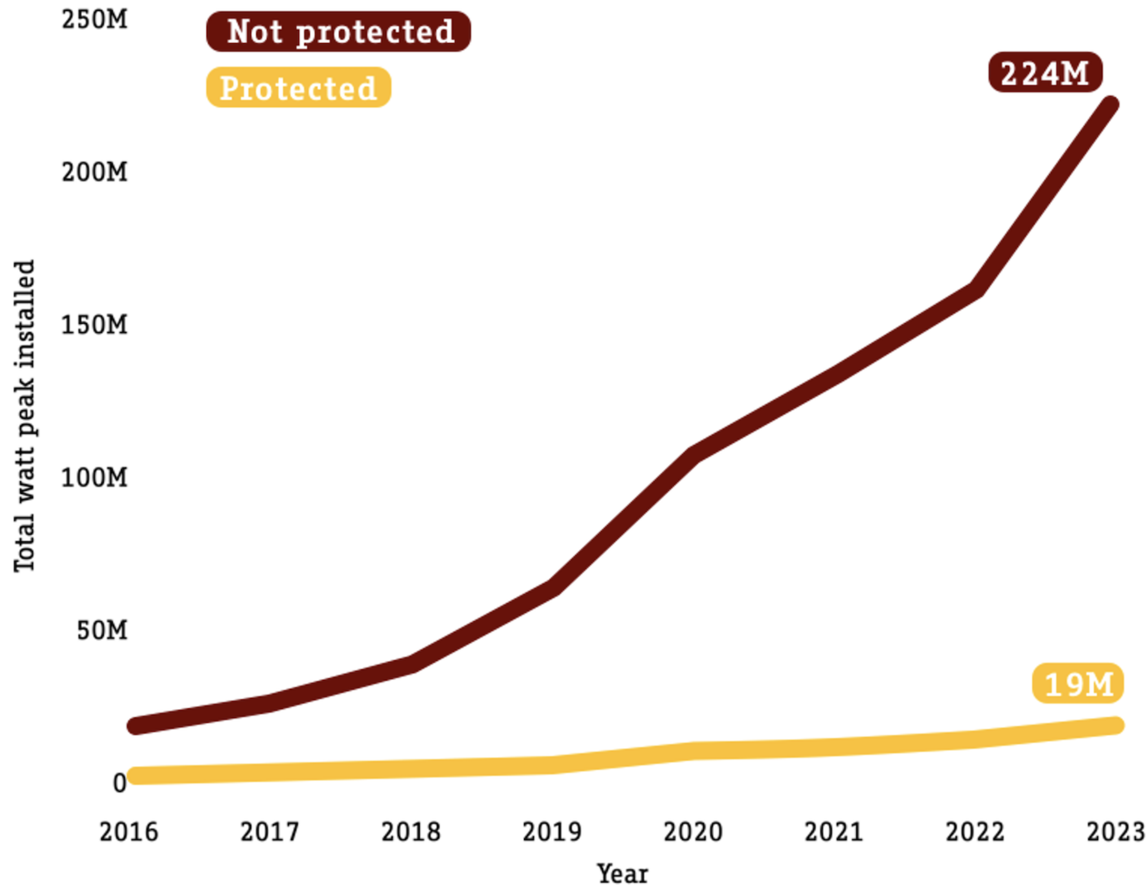

Figure 16 – Timeline of watt peak from rooftop solar panels, grouped by monumental status

To conclude, analysing the ownership of the property gave interesting output, seeing how the difference between owner occupation and rental is not relevant, giving some useful insights for the research (figure 17). Moreover, the difference between the presence or not of housing association does not show significant variations, displaying only a little advantage for buildings with house associations that installed slightly more PV systems on their rooftops (figure 18).

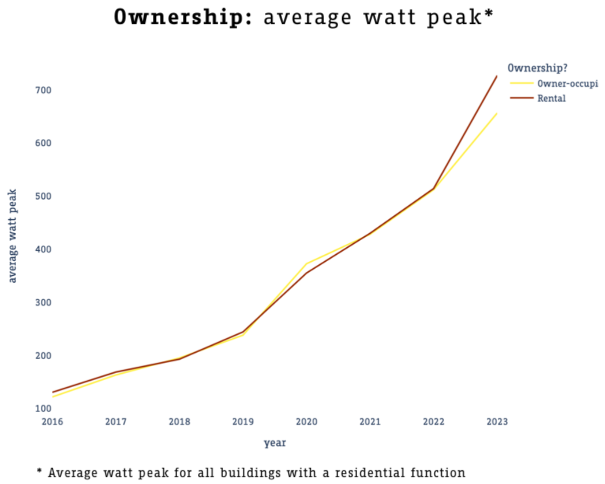

Figure 17 – Average watt peak related to the ownership of the building

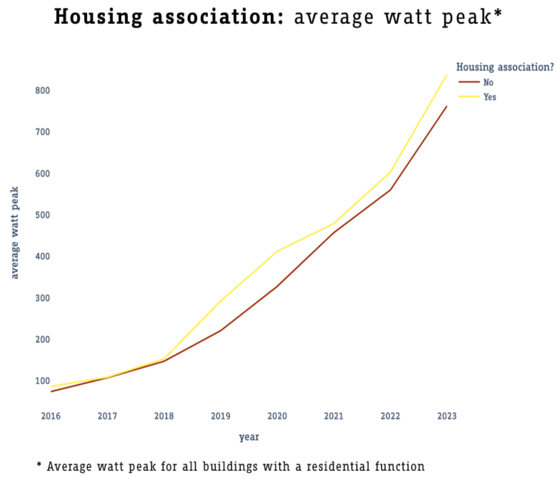

Figure 18 – Average watt peak related to the ownership of a housing association

In figure 19, 20 and 21 we want to consider limiting factors in residential buildings, starting from the relation between their energy label and the average watt peak installed, showing that a good energy label is not strictly related to a high average watt peak installation, even though the trend line has a positive slope. On the other hand, it is interesting to notice the impact of PV installation on property values, which even if a high average watt peak installation might raise the value of a property, it is not a determinant factor on its price. To conclude with figure 21, a logical positive slope trend line shows how the bigger the building, the bigger the power installed on it.

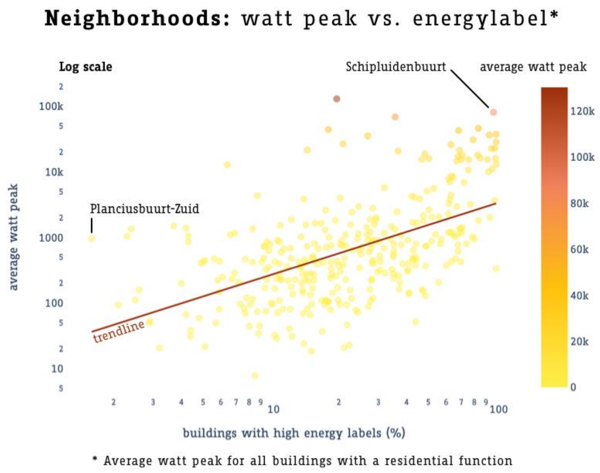

Figure 19 – Average watt peak compared to the building energy label

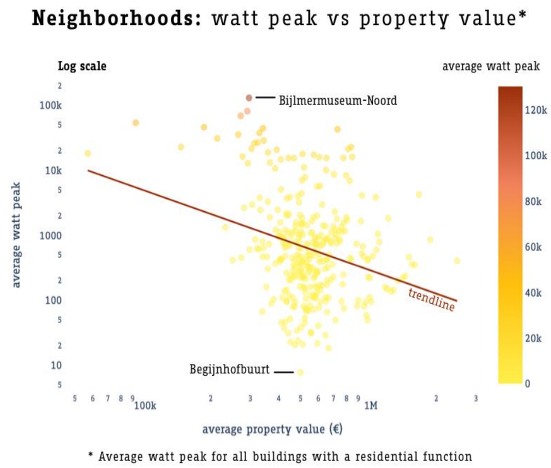

Figure 20 – Watt peak compared with property value

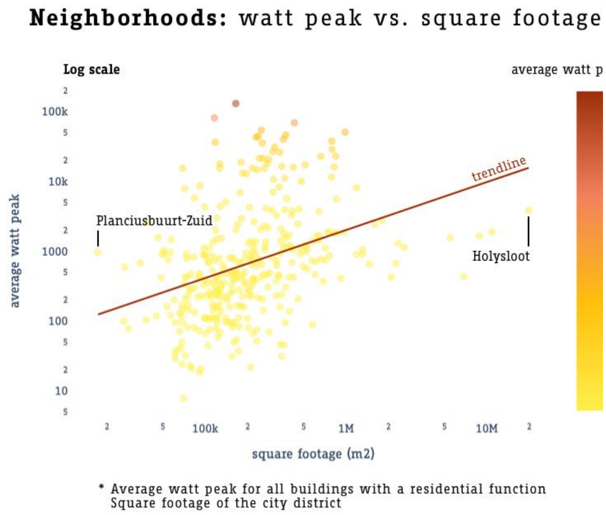

Figure 21 – Building size (presented in square meters) versus PV uptake (in average watt peak)

4.3. Comparison with new methodology

The new methodology shows a significant increase in the calculated potential for all districts. We can see a 73% increase in installed capacity, which is mainly due to better detection of roof surfaces. Also, the orientation of the surfaces is more accurate, meaning more panels can be fitted in the available surfaces. The calculated yield is 89% higher than the previously calculated potential. The yield is calculated with meteorological data of the past 10 years. It could be seen that the measured solar irradiation has been increasing over the last years, adding to the disproportional increase of the yield.

Table 7 - New and Old PV Potential in Amsterdam

	Potential			
	Modules	**Capacity (MW)**	**Annual Yield (GWh)**	**Performance (kWh/kWp)**
2021 Simulation	3255567	1074	974	907
2024 Simulation	5635338	1860	1836	987

4.4. Visualisations of potential PV systems installed

One more visualization is presented in Figure 22 to show the potential power installable in each district of Amsterdam. Currently, 278.9 MW_p is installed, meaning the city is only at 15% of its total solar potential, which is 1859.7MW_p. It shows how actually the district of Westpoort despite its high values in the previous figures, still has a good amount of installable watt peak.

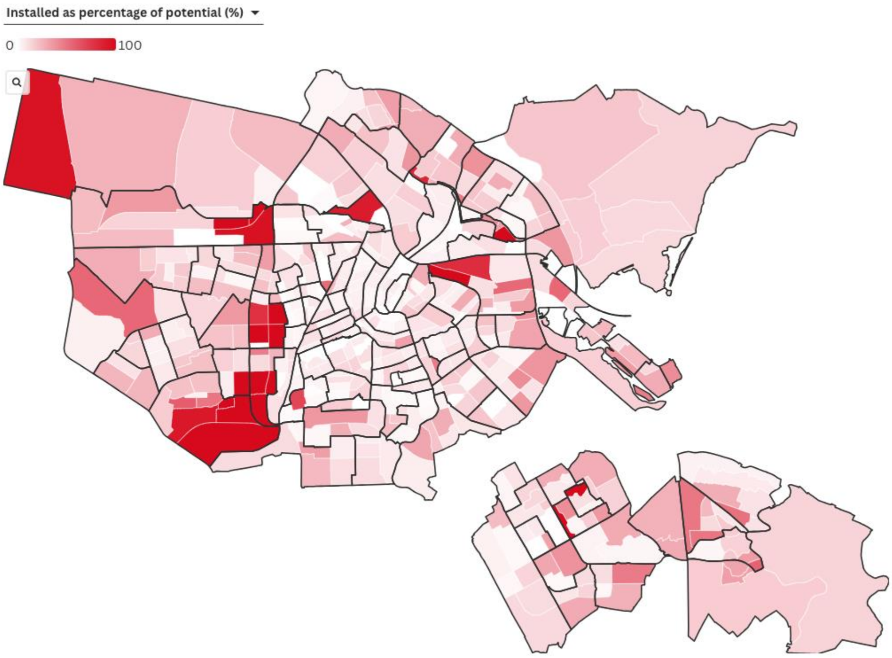

Figure 22 – Potential of watt peak from rooftop solar panels in 2024, grouped by city region

4.5. Visualisations of potential PVT systems

Important considerations have to be made on PVT opportunities in the city. As shown in Figure 23, PVT systems give the opportunity to get closer to a natural gas-free Amsterdam. With a PVT system, thermal energy is provided, creating better conditions and improving the efficiency of electrical energy generation in the photovoltaic part of the system. Exploiting the full potential of Amsterdam's rooftops, using innovative PVT system, it is possible to cover almost half of the total energy demand Amsterdam requires yearly.

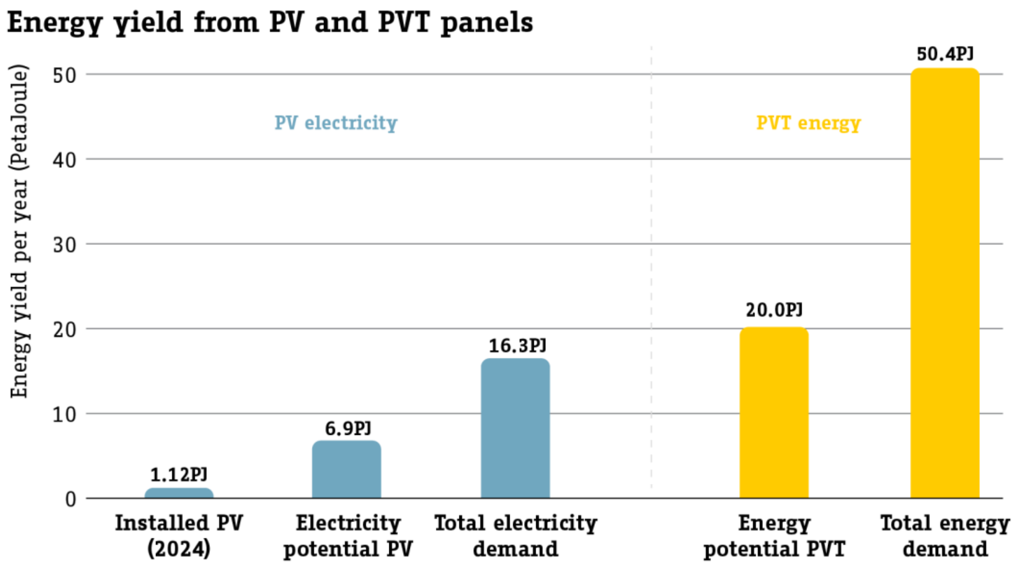

Figure 23 - Energy Yield from PV and PVT panels in Amsterdam

5. Conclusions

This document contains an overview of installed capacity of photovoltaic (PV) systems in the city of Amsterdam per district. It also reports on the rooftop PV energy yield potential and the actual electricity generation of installed PV systems. Moreover, it adds with the last findings on PVT for the city, showing how its efficiency can help the transition towards Amsterdam natural gas-free by 2040.

The approach of calculating the PV(T) energy yield potential of building rooftops in Amsterdam is described in the document. Through the cooperation of the AMS institute, TU Delft and PV Works, the city of Amsterdam has an accurate information about the PV(T) energy yield potential of the city.

With new data, there is a big opportunity to include more analysis in the visualisations due to a deeper understanding of the barriers for adoption of PV(T) for Amsterdam, analysing hotspots and clusters in the city. Merging the knowledge and data regarding policy, with technological and social barriers, it is possible to identify the gaps to optimise the implementation of PV systems on rooftops.

Sources

[1] High resolution arial imagery can be accessed via https://www.pdok.nl/introductie/-/article/pdok-luchtfoto-rgb-open-

[2] Open Data of Liander for new PV connections. https://www.liander.nl/partners/datadiensten/open-data/data

[3] Height data retrieved from algemeen hoogtebestand Nederland, https://www.ahn.nl/open-data

[4] Bag Cadaster data from bag viewer, https://bagviewer.kadaster.nl/lvbag/bag-viewer/

[5] Meer erfgoed duurzaam maken door minder regels. (2024, June 13). Gemeente Amsterdam. Retrieved July 20, 2024, from https://www.amsterdam.nl/nieuws/nieuwsoverzicht/erfgoed-duurzaam-maken/

simply positive