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A Multi-layer Modelling Framework for Techno-Socio-Economical Penetration of Photovoltaics

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***Abstract*—Urban areas rely on the wide implementation of X-Integrated Photovoltaic (X-IPV) systems to provide green electricity for the sustainable electrification. In this research, a modelling framework to accurately predicting their output energy yield and asses their impact on the low voltage distribution grid has been developed. This tool can compute a densely populated urban area at a pace of 2.5 seconds per building. In this contribution, we present the results of a pilot project executed in a Dutch neighborhood of 4873 separate roof owners located in the city of Amsterdam, the Netherlands.**

Keywords—X-IPV, PV energy yield, framework, low voltage, grid impact

I. INTRODUCTION

In recent years, many GIS (geographic information system) based approaches have been carried out using an irradiance-based approach to calculate the received solar irradiation on rooftops using digital elevation models (DEM). Most studies, stop after finding suitable roof sections on buildings [1-3].

In this research, a modelling framework is described, taking only the raw geographic maps as input, to generate a photovoltaic (PV) potential map for large regions in urban areas. The framework consists of a roof section detection approach [4], photovoltaic (PV) module layout algorithm [4] and DC energy yield estimation using a skyline-based approach [5]. Furthermore, a power series is calculated using standard irradiance-based models, with sky illumination as derived with Perez's model [6]. This power series is fed into a linear power flow model (LPF) created for extremely large electrical networks [7] to quickly asses voltage problems in the investigated area. The resulting geospatial maps can be used in GIS software where other city maps about the buildings (such as historic building, buildings with special permit requirements, water managements roofs, green roofs, etc.) can be overlaid, creating a multi-layer map

II. METHODOLOGY

With the Light Detection and Ranging method (LiDAR), a remote sensor is used to measure the distance to the scanned surface. The obtained point-cloud can then be converted to digital surface model (DSM) and digital terrain model (DTM). In the Netherlands, the most recent available files are AHN3 (Actueel Hoogtebestand Nederland), which are available for the whole country. The building footprints are retrieved from BAG (Basisregistratie Adressen en Gebouwen) and is used to clip the height data. A variation to the RANSAC method [8] is used to identify flat planes within a building cut-out of the point cloud.

To find the optimal layout of PV modules on an identified roof section, a simple, yet effective panel fitting algorithm is used to allocate PV modules inside the perimeters of each section of the roof [4]. This includes not placing PV modules in certain "no go" points in the section. This "no go" area could be there because of a dormer, chimney, or object causing the DSM to have an outlier point in the point cloud used to form the section.

Instead of having to calculate the potential energy yield of various points on the rooftop, the module center points can be used as input points for the skyline-based approach [5] developed recently at our group. This will give a specific yield and any module not surpassing the constraint of 650 kWh/kWp will be removed from further calculations, as they are deemed unfit to earn themselves back within at least 10 years.

The GPS coordinates and orientation of each remaining module are saved and for each cluster of buildings a power series is derived. Grid topology and consumption data provided by the local distribution system operator (DSO) Liander was provided, along with a simplified approach to quickly calculate the impact on the grid [7]. Originally, this approach was created to calculate a voltage drop due to the consumption. Only minor changes where necessary to make it fit to calculate the overvoltage due to high PV penetration levels.

III. RESULTS & DISCUSSION

The approach was first tested for the neighborhood De Pijp in the south district of Amsterdam. The region includes 4873 separate building footprints. In Figure 1, the results show a bubble diagram where the size of each circle represents the total amount of modules per building. The bigger buildings in this area can fit up to 1000 modules. Buildings that could not fit 3 or more modules were excluded from the final results, because they do not have a viable business case. However, they are still printed in the results map, but due to their miniscule size compared to the bigger ones, are hardly visible.

Figure 2 shows the results from the linear power flow grid model. The color of the buildings represents the derived overvoltage per unit compared to the nominal voltage of 400 V. The blue labels with "MSR" represent the medium voltage spaces, which contain the medium voltage transformers. It can be seen that the south most region in this neighborhood has some building blocks that surpass the limit of 1.1 p.u. This simulation was run on a summer's day at noon, which is the worst-case scenario, so it is not representative for the whole year. However, the grid voltage is not allowed to surpass the limits even for a short amount of time.

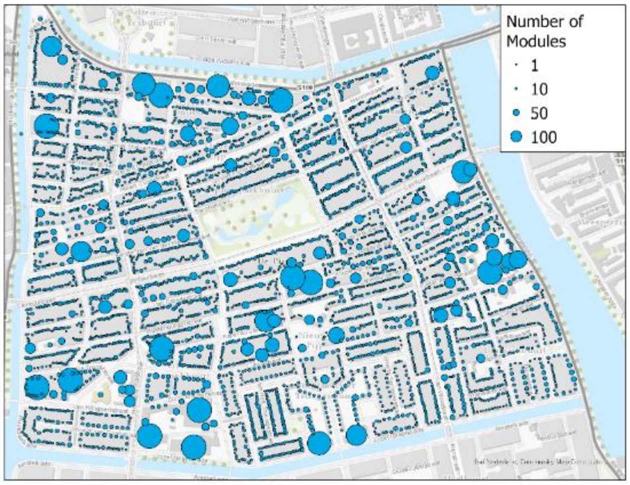

Fig. 1. Geospatialmap of massively distributed PV systems in *De Pijp* neighborhood in Amsterdam (the Netherlands)

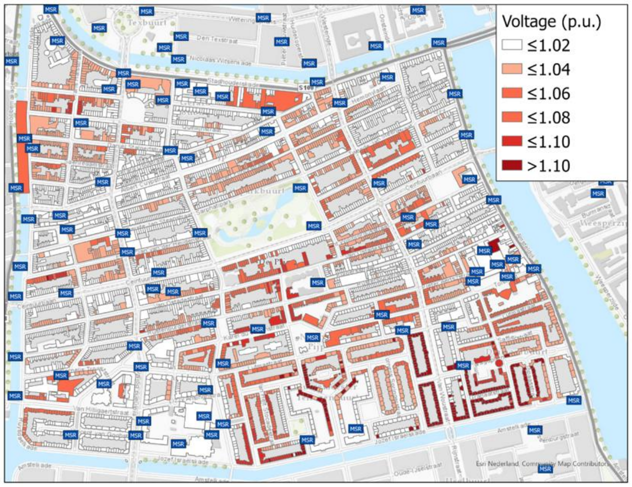

Fig. 2. Voltage disturbance simulation in the same urban area in case of 100% PV penetration at a summer's day at noon.

Fig. 3. Geospatial multi-layer map consisting of the PV potential, green roof area, water management bottlenecks, historic buildings and voltage problems.

Finally, several maps such as the ones shown in Figures 1 and 2 can be overlaid to obtain a comprehensive multi-layer map, as shown in Figure 3. It it contains severals layers of information, interaction and effects between map layers can be detected easily. This enables municipality decision makers for example to get an overview about all the relevant housing information that could be limiting the penetration of PV modules in the investigated area.

IV. CONCLUSIONS

In this contribution a modeling framework is described, which is developed to assess the PV potential of dense urban areas in a multi-layer geospatial map. In this approach, unnecessary steps are skipped, such as creating a full 3D building model, to ensure fast computation. This allows the simulation to be subjected along a lot of different scenarios, such as multiple panel properties and layouts. For a region with 4873 roof owners, the complete simulation from input data to amount of PV modules per building, took just 32 minutes. Using our skyline-based approach, no compromises had to be made that harmed the accuracy of the PV energy yield estimations. Furthermore, a linear power flow grid model was used to pinpoint low-voltage grid problems.

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