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MATCHING PHOTOVOLTAICS GENERATION WITH COMMERCIAL LOAD PROFILES – CASE FROM CENTRAL SWEDEN

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ABSTRACT

Cities evolved to be major energy consumption centers. However, their potential to generate electricity from renewables is in most cases constrained to photovoltaics. Therefore, transforming them into sustainable and self-sufficient urban areas is a challenging task. In this preliminary study, we have investigated the match between photovoltaics (PV) generation and electrical load of five commercial buildings located in Sweden. First, the rooftop PV potential was assessed. Secondly, the optimization was performed aiming at reducing the energy flow between building/buildings and local electrical network. Results indicate that from the perspective of minimal power flow (for single buildings) optimal are PV system oriented to the southeast and southwest with a relatively small tilt angle of 15°.

Keywords: renewable energy sources, peak demand, rooftop photovoltaics, geographic information system-

1. INTRODUCTION

Making cities sustainable and energetically self-sufficient is a challenging task. Not only they are characterized by a very high-energy consumption per area but also their potential for generating environmentally friendly energy is strongly constrained. From the renewable energy sources, which can be utilized on large scale in high population density urban areas photovoltaics (PV) are the only promising technology. Their modular nature, high reliability and scalability makes them a perfect fit for undeveloped roofs areas in city centers.

Even if such systems are installed the individual owners not always can fully benefit from the potential of solar electricity. This results in most cases from a significant mismatch between PV generation and the electrical load (on a short- and long-term scale).

Considering above, in this study, we analyse the potential of rooftop PV that can be installed on commercial buildings in the northern part of Västerås (Sweden). Later we investigate the optimal installed capacity in PV which will minimize the energy flow within considered part of electrical grid.

2. DATA AND METHODS

For the purpose of this study, five commercial buildings located in the norther part of Västerås (Sweden) were considered. Their annual energy demand over the year 2017 ranged from 35.3 MWh to 103.9 MWh. An average hourly load ranging from 4.0 kWh to 11.9 kWh characterized the load. The aggregated load of five buildings is shown on Fig. 1.

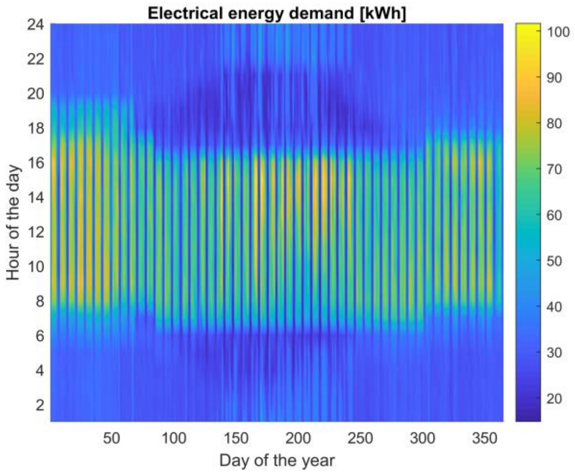

Fig 1 Spectrum of aggregated energy demand of six considered office buildings over the year 2017

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The theoretical available area for rooftop PV was estimated based on the following approach. For the city of Västerås, based on photogrammetric photographs, cloud of points was created, in which each point has X and Y coordinates and height (Z axis). The cloud of points is unclassified, there are no separate classes: for example, land, buildings, vegetation. Also the cloud of points is prepared as a regular grid with a resolution of 0.5 m. A digital elevation model (DEM) of roofs with 1 m spatial resolution was created on the basis of unclassified cloud of points and the outline of the shape of buildings (data relevance2016). Based on the DEM, a model and an exposition model of the roofs was created. Assuming the conditions for the shortest day of the year (December 23rd) and the geographical conditions of Västeras, for solar conditions at noon (vertical angle 7°), a shadows model of the roofs was created. Resulting (mean slope, majority exposition, shadow area) for roofs of selected buildings were exported to tabular form. Based on such information theoretical surface available for rooftop PV was estimated.

A typical PV module with a rated capacity of 200 W in standard testing conditions was considered in this study. Its dimensions are, height: 1.6 m and width: 1.0 m. The modules will be mounted with the longer side parallel to the roof surface. The temperature coefficient of the PV module of 0.475 %/°C and overall efficiency of the PV system of 90% were used in calculations.

The energy generation from PV system was calculated based on formula used by *inter allia* [1]. Whereas the irradiation on a surface different from horizontal (Fig 2) was estimated based on formula from [2]. Solar radiation data and temperature were downloaded from respectively [3] and [4].

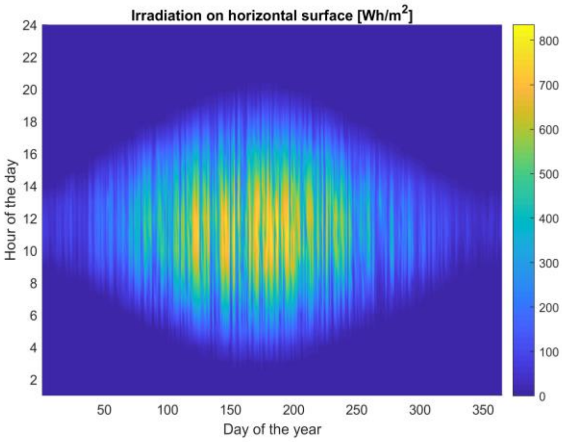

Fig 2 Spectrum of hourly irradiation on horizontal surface over the year 2017

3. RESULTS AND DISCUSSION

Since the roofs are almost flat (Fig. 3) it has been assumed that the PV modules will not be directly mounted on the roof and they will be installed in rows on a supportive structure. Therefore, it is mandatory to calculate the minimal spacing between the rows of PV modules (to overcome shadows). The method presented in [5] was used for that purpose and following potential installation angles were considered: 15°, 30°, 45° and 60°. The rows of PV modules can be installed with following azimuths: SE, S and SW. We have assumed that for a single roof only one azimuth can be chosen. The roof surface available for PV systems was considered a square (to enable easy calculation of the PV potential).

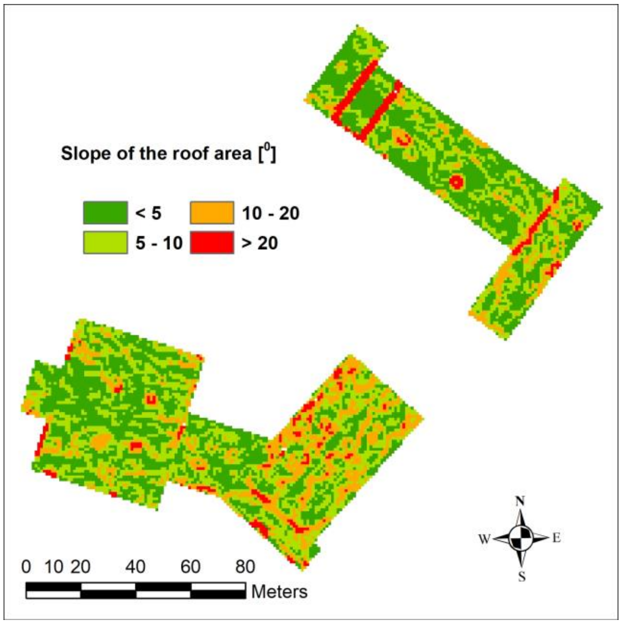

Fig 3 Slope of the two exemplar roofs

From the roof surface analysis we found that the potential area available for rooftop PV amounts in total to 18.6 thousands m^2. Considering the unavoidable mutual shading this area is further reduced to 13.3 thousands m^2. For four different (15°, 30°, 45° and 60°) potential tilt angles of PV modules we got the following average power densities for all roofs: 25.9, 12.9, 8.4 and 7.0 W/m^2. Various azimuths and tilts of PV modules result in different capacity factors of PV systems. These (based on the year 2017 data) ranged from 9.1% for modules facing southwest at 60° tilt and 11.8 for modules facing southeast at 45° tilt. The highest maximal capacity installed in PV generation would in theory amount to 290.4 kW and provide on an annual basis 304.7 MWh of electricity (which is just slightly above the aggregated energy demand of all buildings which was

288.6 MWh). Unfortunately, there is a significant mismatch between the demand and supply on an intrannual scale (Fig. 4). For given capacity of PV the five buildings energetic self-sufficiency reached 38.8% whereas the self-consumption from PV systems was 36.8%. Adding such PV increase the energy flow in the electricity grid from initial 288.6 MWh to 368.9 MWh on annual basis.

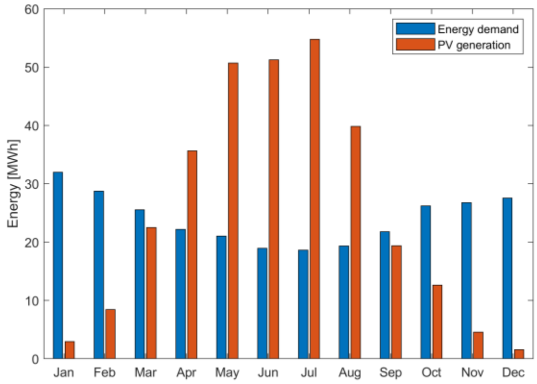

Fig 4 Mothly mismatch between PV generation (290 kW) and aggregated building demand

Considering the mismatch presented on Fig. 4 we have decided to perform a simple optimization, which aims at minimizing the energy flows occurring on the local electrical grid. We assume that the energy flow will be minimal when the sum of energy surpluses from the PV generation and the residual load from commercial buildings will be minimal [6]. This objective function is given in Eq. 1.

$$\min Z = \sum_{i=1}^{8760} \left(E_i^S + E_i^D\right) \qquad (1)$$

where: E_i^S – energy surplus from PV generation in kWh, E_i^D – residual load of the buildings after considering PV generation in kWh.

The optimization was divided into two stages. First, we have optimized the PV capacity on a building level (by considering that: systems can be installed in different configurations (azimuth and tilt angle) and the maximal system capacity is constrained by roof area and spacing between rows of PV modules. In the second state the optimization was conducted based on the aggregated load and cumulative potential of rooftop PV (by assuming that they are part of the same low-voltage local transmission network/are using the same transformer). The model was implemented and solved in MS Excel (Solver add-in, GRG method was selected with default settings). The decisions variables were non-negative and continuous. Later rounded to the closest integer value.

The optimization results for five (A1-A5) considered buildings are presented on Fig. 5. As can be observed from the perspective of selected objective function the optimal orientation of PV modules is either southwest or southeast. For such capacities of PV systems the energetic self-sufficiency of buildings ranges from 21% to 30%. In case of all buildings a relatively high self-consumption of PV generation was observed, around 80%. The overall energy flow for all buildings was reduced from 288.6 MWh to 238.7 MWh.

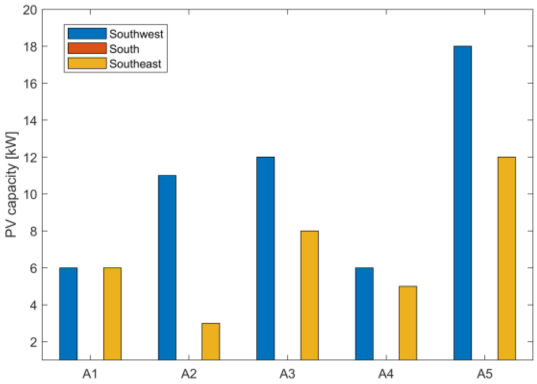

Fig 5 Capacity installed in PV generation for 5 considered buildings. All with a 15° tilt angle.

Once all buildings were considered as a larger system the results in terms of installed capacity distribution are quite different (Fig. 6). It was observed that the total energy flow was reduced to 231.9 MWh (6 MWh less than when optimized on individual level) and also the self-suffiency of all buildings raised to 83.0%.

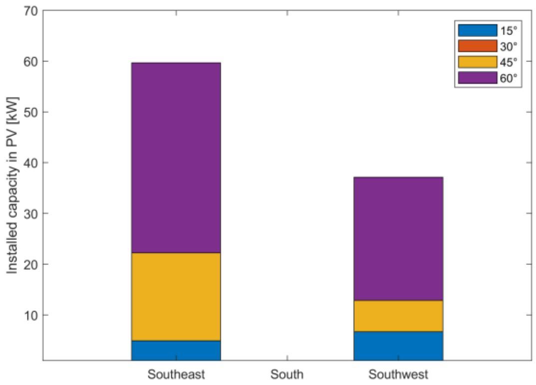

Fig 6 Capacity installed in PV generation.

For the considered objective and case study the PV generation has a limited impact on the maximal observed energy demand. For the capacity installed as on Fig. 6 or even the maximal capacity of 290.4 kW the reduction of maximal demand value is very low and amounts to 4.9 kWh.

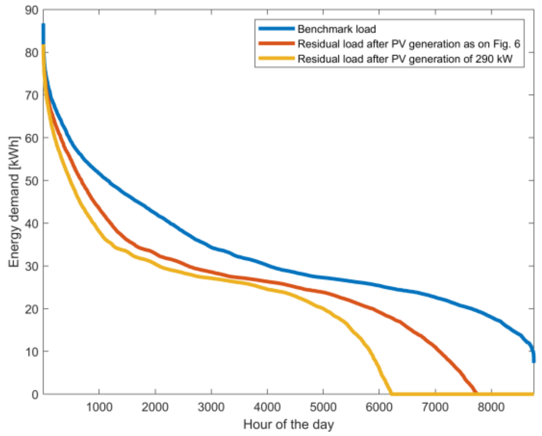

Fig 7 Load duration curves for three different scenarios

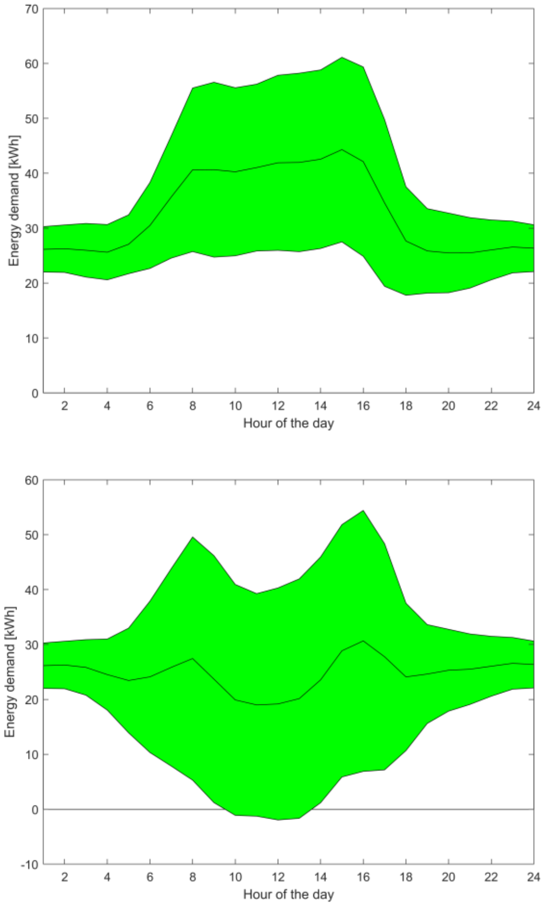

Fig 8 Typical base case (top) and residual (bottom)daily energy load profile after adding PV generation as on Fig 6

4. CONCLUSIONS

With the continuous price, decrease of PV technology and increasing electricity cost from the power grid a rapid growth of rooftop PV systems should be observed. This will be beneficial to the natural environment, will reduce the energy waste (transmission losses) but also increase the energy self-sufficiency of buildings/cities. However, existing significant mismatch between power generation from PV installation and the electrical load of the building makes the power flows unpredictable (both in terms of volume and direction) and harder to manage. The energy storage is an option although in many cases such solutions are economically not yet justified. Therefore, it is crucial to ensure that the design of PV systems on a city level should take into the consideration the local grid limitations, observed load profiles and rooftop PV potential. In this study we have focused on the last two and have shown that for limiting the power flow the most beneficial is not always the orientation of PV modules that ensures highest capacity factor. Further research in this area will consider the economic aspect of such solution and will be extended to a larger area (sample of buildings).

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