Analysis of Potential Distribution and Size of Photovoltaic Systems on Rural Rooftops −
A contribution to an optimized local energy storage system with a remote sensing and GIS-based approach in Swabia, Germany

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1 Introduction

The present study as part of the joint research project "Smart-Power-Flow"[3] (at Reiner Lemoine Institute for Renewable Energies) focuses on modelling PV systems´ distribution on German rural communities. Although solar power energy systems in Germany has been increasing exponentially for the last 20 years (WRITH 2014), the majority of literature on PV potential has focus on rooftop PV systems on urban regions and a small number publications consider the typology of small rural communities. These areas although less populated as cities, are where highest PV potential in Germany is expected (DENA 2010) and at the same time where the availability of laserscan data is highly incomplete or not affordable for small administrations or projects. Several authors have used remote-sensed imagery to quantify the PV potential on regional scale but only few authors (KJELLSSON, E. 2000; BERGAMASCO, L. & ASINARI, P. 2011; JO, J. H. & OTANICAR, T. P. 2011) have attempted to use high-resolution images to quantify the suitable rooftop surface on building basis and none of them have addressed the particularities of rural communities.

The aim of the study is to create a methodology, which predicts the size and location of future photovoltaic systems on rooftops, based on generally accessible data and that is easily reproducible on a building scale for other rural villages. The methodology uses as inputs high-resolution aerial imagery, GIS building footprints from the Land-register map and the Bavarian database of photovoltaic systems. In addition, the method is tested using two types of images: a) official orthophotos from the Bavarian Land-survey Office and b) Google Earth™ orthophotos, to assess the accuracy of freely available data to the project. The results are compared with each other on the discussion section.

2 Methodology

To accurately quantify the available rooftop area for PV installation, high-resolution orthophotos from the Bavarian Land-survey Office and Google Earth™ images (both recorded RGB bands with 0.2 m and 0.4 m spatial resolution respectably) were processed identify suitable rooftop areas, roof obstructions and shadows. A Photovoltaic Calculator has been used to quantify the PV energy generation potential in the experimental study area. Finally, the prognosis step predicts the likely PV-expansion pathway based on each rooftop PV potential and the scenarios of the German Energy Agency. Figure 1 presents a

[3] Project funded by the Federal Ministry of Economics and Technology (BMWi) under grant agreement no. 0325522A.

flow diagram of the methodological approach used to model spatial distributed PV potential for rural communities. The experimental site location is the village of Freihalden (Jettingen-Scheppach) in the region of Swabia, Bavaria. The village was chosen among the 17 designated as critical in terms of electricity grid by the regional network operator, who is also partner of this study. Only 5% of buildings are blocks, 17% are two-family homes and the remaining 77% of them single houses. Freihalden presents a perfect settlement pattern characteristic of rural communities in Germany and Central Europe.

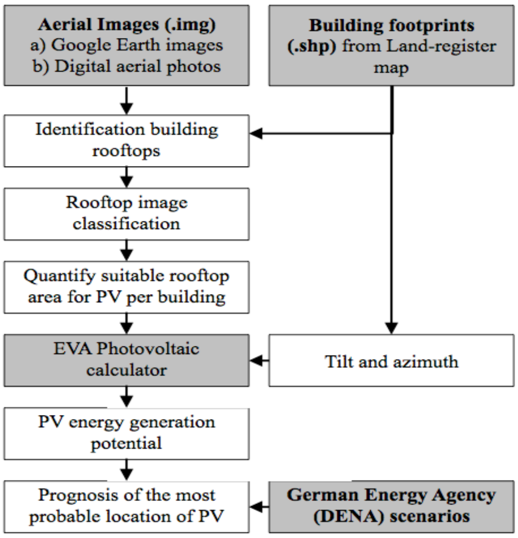

Figure 1: Methodology applied to estimate spatial distributed PV potential in rural communities.

2.1 Isolating building rooftops

First, the current status quo was analysed, cross-referencing the files from the Bavarian register of PV systems and the Land-register map. Bavarian Register of PV system offers free access throughout its webpage. These buildings were excluded from dataset in order to avoid assigning them as potential buildings in the future. Building rooftops were isolated cropping the images with building footprints from the Land-register map. Directly integrating the building footprint shapefile limits the subsequent pixel-based image analysis within the rooftop surface and thus excludes data from outside the building rooftop.

2.2 Suitable area computation

To identify the suitable areas per rooftop a Supervised image classification is conducted on the subset image of the building rooftops. Particularly the purpose is to identify four zones: (1) shadows, (2) obstructions, (3) suitable areas, (4) non-suitable areas. The extension of Semi-automatic Image Classification from QGIS was used to performe this step, seeking to build a methodology based on accessible data and open-source software. The output of the image classification analysis, shown in Figure 2, is converted to vector data and the potential suitable area is assigned to each building. Rooftop orientation and average slope are spatially joined to each rooftop.

Figure 2: Original orthophoto clipped by the building footprint (left) and classified output after supervised image classification [black=shadow, red=non suitable, green=suitable, pink=obstruction] (right)

2.3 PV energy calculation and prognosis expansion pathway

PV Calculator software has been used to quantify the PV energy generation potential in the study area. EVA is a tool created at the Reiner Lemoine Institute that is able to calculate energy production of PV systems and its financial analysis. Finally, the prognosis step predicts the likely PV-expansion pathway based on each rooftop PV potential and the scenarios of the German Energy Agency. The German Energy Agency in its Dena-Netzstudie II (2010) generated two scenarios for the expansion of PV and wind energy sources in Germany at municipal level with a horizon year of 2030. The scenarios are made to fulfil German national goals concerning the implantation of renewable energy sources in the electricity market. Each municipality is assigned to a category with an expansion factor – ranging from 0,7 to 5 – depending on the population density and the already existing solar plants in relation to German average. The prioritization of the buildings until fulfilling the DENA goal for Freihalden follows the criteria of the highest specific yield, namely the expected annual energy (kWh) by the installed capacity of the building (kW). The output of the method is stored in a database including the central coordinates of each building.

3 Results and discussion

Freihalden was found to have 43 buildings with already PV systems in its rooftops, which represented an already installed nominal power of 571 kWp. The classification of the Bavarian land-register orthophoto concluded that 82% of the buildings in the community have adequate areas with more than 10 m^2 suitable for PV, where as in the classification of the Google Earth™ orthophoto 78% of the buildings are considered to have adequate areas for PV. It was found that 39,6 - 40,1% of total rooftop area is considered suitable for PV. This number can be used a rule-of-thumb for future studies in the area. The total PV technical potential of Freihalden reaches the 3170 kWp. Individual building potential ranges from 1 potential kWp to 42 kWp and the specific yield varies from 980,1 to 763,1 kWp/kWh. From the 412 buildings composing the village, 98 of those with highest potential expected to install PV systems in the next 17 years in order to achieve the Bavarian renewable energy goals for 2030.

We conclude that for the same training areas, both images present almost the same suitable area — 39,5% and 40,1% —, which supports the classification procedure. It was found that the classification decreases its accuracy depending on the material of the roofs. In this way, red roofs have the highest accuracy. On the contrary, black and very dark roofs exhibit similar spectral signatures between suitable, non-suitable and shadow areas, ergo the classification delivered worse result. Overall the Bavarian land-register orthophoto presented a higher accuracy in all roof types (red roofs: 91%; grey roofs: 87%; black roofs: 76%) compared to the Google Earth™ image (red roofs: 88%; grey roofs: 82%; black roofs: 71%). As a consequence, the Bavarian land-register orthophoto has a weighted average accuracy of 89% while the Google Earth™ image has a weighted average accuracy of 84%. This can be explained due to the fact that Google Earth™ images have lower ground resolution and pixel depth. The average suitable area for PV in the village (40,1%) is consistent with the studies conducted for Germany by LÖDL et al. (2010), KERBER (2011) and the INTERNATIONAL ENERGY AGENCY (2002), — 44,8%, 40% and 40% respectively—, with the advantage that the PV potential per building is also calculated. If applied to another village, the quantity of suitable area will be adapted to the amount of obstructions existing in that village and to its roof configuration, making the methodology much more precise. On the other hand, supervised classification can hardly be automatized. Even if signatures for each class are stored and saved as separated files, it is likely that they cannot be applied to images that were taken under other weather conditions. This implies longer working times and specific remote sensing knowledge if the methodology is to be corrected applied. The prognosis expansion pathways were found to identify with the highest implementation potential from all buildings classified as suitable only small to medium size buildings, all facing south, in both images. South-facing buildings yield higher energy production than building facing south-east or south-west with similar suitable area, and hence are ranked higher according to the criteria of the highest specific yield. There is 430 kWp difference between the PV technical potential based on the Google Earth™ image classification in comparison to the Bavarian land-register orthophoto classification, which represents a 16% lower technical potential. The lower technical potential is a consequence of the fewer number of buildings identified in the Google Earth™ image classification in comparison to Bavarian land-register orthophoto classification.

4 Conclusion and outlook

We have proved that it is possible to use open-source software and freely available images to download from Google Earth™ and still be able to obtain significantly accurate results. Google Earth™ images are already processed images and have lower spatial and radiometric resolution. Nevertheless, accuracy assessments give reasonable good results. If future research is to be made following the approach of this study, steps can be implemented in order to improve the classification output. Segmentation of rooftops can also delivered meaningful improvements. Automatize the sequential steps, by writing a R or python code, would speed up the methodology. To improve the prognosis expansion pathway, the acquisition of extra data including social variables rise as an important requirement. Without additional data that can enlighten the situation when a person decides on installing a PV system, the expansion pathways may be observed only as an orientation.

References

BERGAMASCO, L. & ASINARI, P. (2011), Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: Further improvements by ortho-image analysis to Turin (Italy). Solar Energy 85(11), 2741–2756

DEUTSCHE ENERGIE-AGENTUR GMBH (2010), Dena-Netzstudie II . Integration erneuerbarer Energien in die deutsche Stromversorgung im Zeitraum 2015–2020 mit Ausblick 2025.

INTERNATIONAL ENERGY AGENCY (IEA) (2002), Potential for Building Integrated Photovoltaics. IEA-PVPS T7-4, Paris, 2002.

JO, J. H. & OTANICAR, T. P. (2011), A hierarchical methodology for the mesoscale assessment of building integrated roof solar energy systems. Renew. Energy, 36(11), 2992–3000.

KERBER, G. (2011), Aufnahmefähigkeit von Niederspannungsverteilnetzen für die Einspeisung aus Photovoltaikkleinanlagen. Technischen Universität München, 2011.

KJELLSSON, E. (2000), Potential for building integrated photovoltaics - A study for Sweden. IEA-PVPS Task, 2–4 p.

LÖDL, M., KERBER, G., WITZMANN, R., HOFFMANN, C. & METZGER, M. (2010), Abschätzung des Photovoltaik-Potentials auf Dachflächen in Deutschland. Proc. 11th Symposium Energieinnovation, Graz, Austria, 10-12 February 2010, 14 p.

WIRTH, H. (2014), Recent facts about photovoltaics in Germany. Frauhofer Institute for Solar Energy Systems ISE, Berlin, 5 p.