

Here Comes the Sun: A Prototypical GIS-based 4-dimensional Rooftop Solar Potential Analysis to Support the Energy Turnaround

Michael Roth¹, Christian Tilk²

¹Nürtingen-Geislingen University; School of Landscape Architecture, Environmental and Urban Planning; Department of Landscape Planning, especially Landscape Informatics; Nuertingen/Germany · michael.roth@hfwu.de

²Nürtingen-Geislingen University; School of Landscape Architecture, Environmental and Urban Planning; CAD and GIS Laboratory; Nuertingen/Germany

Abstract: To achieve the ambitious renewable energy (RE) targets in Germany, future decentralized RE investments and installations, such as rooftop photovoltaics (PV) are necessary, despite the decreasing feed-in tariffs. To stimulate additional building owners to install new PV panels, we have developed a prototypical GIS-based 4-dimensional solar potential analysis based on high resolution digital surface models, generated using structure from motion analysis based on aerial photography. Using the city of Nürtingen as a case study, we calculated rooftop insolation with a very high spatial and temporal resolution. By overlaying PV generation profiles with standardized electricity demand profiles for different user types, we can give accurate and valid estimations of the economic profitability of photovoltaic installations. This information shall support the local realization of the energy turnaround, but also can be used in planning support systems following the principles of Geodesign.

Keywords: Structure from motion, online GIS; landscape assessment, renewable energy, planning support system

1 Introduction

Responding to limited fossil fuels, and to reduce CO₂ emissions, renewable energy is heavily promoted throughout Europe (ROTH 2015). Wind and solar power are the main sources of renewable energy production in many European countries. Whereas large wind farms and solar parks face strong public opposition due to their impacts on landscape quality (VAN DER HORST 2007, BOSCH & PEYKE 2011), protected species and human health, photovoltaic panels on rooftops are socially well accepted. In Germany, in 2015 around 30 % of the electricity were generated from renewables, with around 6 % of the total electricity production generated from photovoltaics (FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY 2016). Since the German Renewable Energies Act entered into force in 2000, high subsidies by a feed-in tariff guaranteed for 20 years stimulated many private house owners, public institutions, and companies to install rooftop PV panels. These subsidies started with more than 50 cent/kWh in 2001 and have dropped to 12 cent/kWh today. After the massive growth rates in roof mounted PV from 2010 to 2012, in the last 3 years, with the decreasing feed-in tariff and panel prices being more or less stable today, the installations of new PV panels have massively decreased (FRAUNHOFER INSTITUT FÜR SOLARE ENERGIESYSTEME 2015). Until 2025, Germany wants to produce 40 to 45 % of its electricity from renewables, and 10 years later in 2035 between 55 and 60 % (FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY 2016). This will only be possible with new decentralized rooftop photovoltaics, especially as this source of energy is available throughout Germany and does not rely on new high voltage powerlines, as offshore wind energy does.

In our paper, we describe the development of a prototypical GIS-based 4-dimensional rooftop solar potential analysis. This tool was developed to communicate accurate potentials for electricity generation from roof-mounted PV panels and link this information with economic information such as the share of potential own consumption to give valid estimates of profitability of new investments in renewable energy. The overall goal behind this project is to stimulate additional building owners to install new PV panels by communicating that despite the generally decreasing revenue caused by decreasing feed-in tariffs, with a certain share of self-consumption and when using optimal roof areas, the investment in decentralized solar energy still makes sense. On a higher level, we hope that with our tool we can contribute to support the energy turnaround from fossil and nuclear energy to renewable.

2 Data and Methods

To calculate accurate and spatio-temporally high-resolution insolation data, accurate and high-resolution digital surface models (DSM) are required. We used a set of overlapping plane-based aerial photographs obtained from the city of Nürtingen as primary datasource. These photographs were taken on a clear day from 1,500 m height with a resolution of 200 megapixel per image and a ground resolution of around 5 cm. Using structure-from-motion approaches and AGISOFT's Photoscan software, we were able to calculate a 10 cm resolution digital surface model including buildings and vegetation (as the photographs were taken in summer). Vegetation is very important for insolation analysis, as shadows on roofs caused by large trees in urban areas might significantly limit the productivity of PV panels. In addition to the DSM, we used accurate building footprints which are available as vector data. Figure 1 shows a rendering of the surface model, textures were also generated using AGISOFT Photoscan.



Fig. 1: Rendering of the high-res digital surface model used as main input to the solar potential analysis

Using Esri's ArcGIS, insolation was calculated for these high-resolution digital surface models for intervals of 15 minutes throughout the year. This very high temporal resolution is necessary to obtain not only the yearly sum of insolation, but be able to estimate the share of own consumption of the electricity generated, based on daily production and consumption profiles, which also vary throughout the year. The Spatial Analyst's solar radiation analysis tool computes direct and diffuse radiation based on methods from the hemispherical viewshed algorithm developed by RICH et al. (RICH et al. 1994) and further developed by FU & RICH (2000, 2002).

Insolation was then aggregated for individual subareas of roofs. Roofs of individual buildings were divided into subareas homogenous in aspect and slope, e. g. parts of a saddle roof facing different cardinal directions. Subsequently, timelines of 15-minute intervals throughout the year were exported into statistical software (we used SPSS) to further process and analyse the data.

To calculate potential shares of self-consumption of the electricity produced, we used the so-called standard usage profiles provided by the German Association of Energy and Water Industries (data source: EWE 2014). These usage profiles exist for different user types such as private households, farms, general commerce, energy-intense commerce such as bakeries, etc. In each of those standard usage profile, the average electricity consumption is given for 15-minute intervals also throughout the year, to account for the fluctuation during the day, week and year. Figure 2 shows the standard usage profile for private households. This curve can be adapted to whatever the overall energy usage of a household is, thus there are no units on the y-axis.

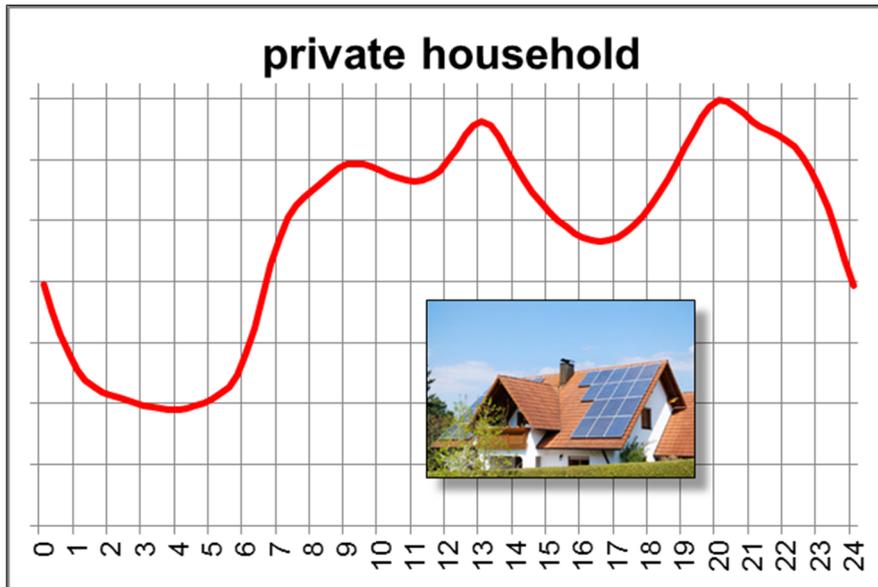


Fig. 2: Standardized electricity demand profile for a private household over the course of a day (midnight to midnight)

3 Results

The following figure 3 illustrates exemplary results of the insolation analysis described above. In the left column of images, the actual insolation for one 15-minute interval is shown for the subareas of roofs for three days in the year (March 20th, June 20th, September 20th). In the second column, the two different electricity generation profiles for two subareas for the three dates mentioned are given: The curve rising earlier in the day represents an east-south-east facing subarea, the one rising later one facing south-south-west.

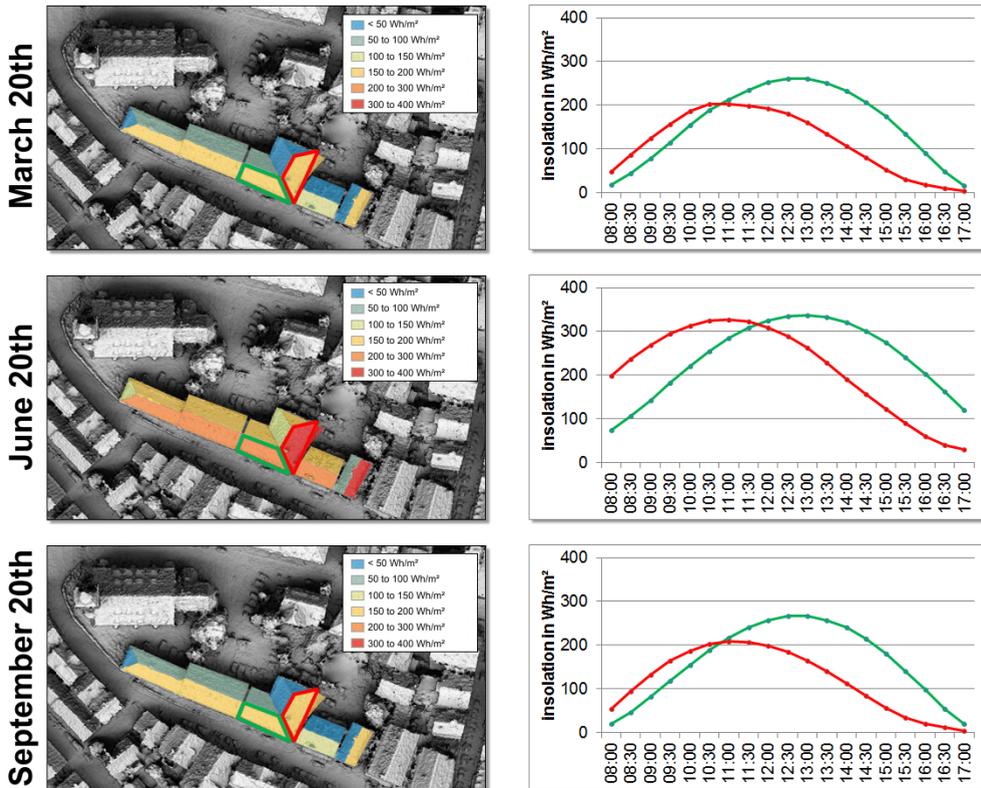


Fig. 3: Results of the insolation analysis for three different days in the year and for selected subareas of rooftops

The basic idea of our 4-dimensional solar potential analysis was to overlay rooftop PV-potentials with usage profiles to estimate the potential of self-consumption. Figure 4 shows clearly that a hypothetical commerce such as a barber can yield a far higher revenue using the same hypothetical PV installation than a private household in the same building, due to 93 % of self-consumption as compared to 72 % of self-consumption.

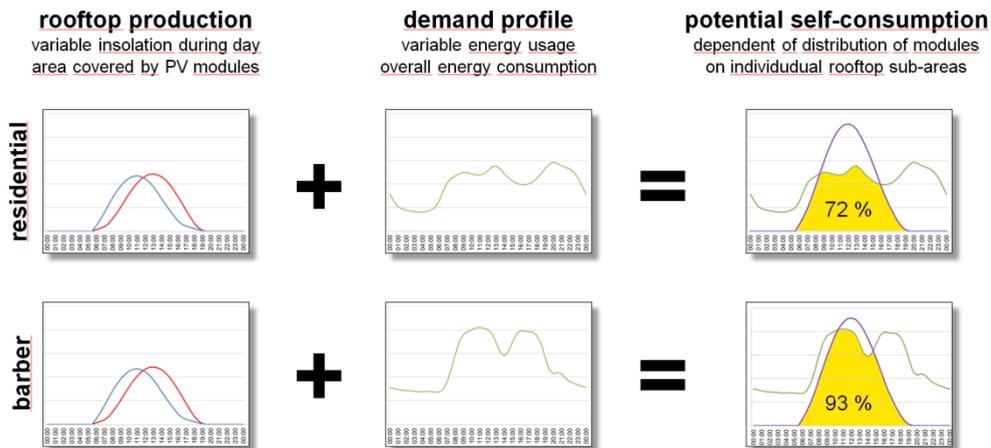


Fig. 4: Different potentials for electricity self-consumption based on different demand profiles

4 Discussion

In addition to existing solar potential analyses (e. g. LUBW 2012, KLÄRLE 2012), our approach does not only assess the overall yearly incoming solar radiation potential for each building, but has the following advantages: (a) Because of the high resolution of 10 cm and the full inclusion of accurate vegetation surfaces (unlike LIDAR based DSMs), we can very effectively and accurately calculate shadowing caused by rooftop structures and trees. (b) The high temporal resolution allows generating solar power generation profiles specific for each building and/or part of its roof. Consequently, building electricity generation can be overlaid with standardized electricity demand profiles for different user types such as private households, offices, commerce, etc. (e. g. BDEW 2014) or individual electricity use profiles (e. g. based on smart metering data) and thus, a very accurate and valid estimation of own electricity consumption can be estimated. As own consumption replaces buying electricity from the provider for around 25 ct per kWh, the economic benefit is twice as high for each kWh self-consumed than it is for feeding into the grid. In the future, electricity storage in building installed battery storage systems (cf. JOHANN & MADLENER 2014) or using electro cars (cf. DALLINGER & WIETSCHER 2012) will become very important, and a valid and accurate estimation of potential electricity generation and spatio-temporal usage patterns is a necessary basis for assessing the profitability of such solutions.

As our prototypical tool uses only data that basically is available state-wide and can be run on PC hardware and software, the transferability to other municipalities or regions is easily possible.

In regions where professional high-resolution aerial images are not available, UAV-based photography can be used to generate the basis for photogrammetric DSM generation, which subsequently can be used as a valid input to insolation analysis as has been demonstrated by SZABÓ et al. (2016), at least for smaller areas that can be covered with a UAV.

5 Conclusion and Outlook

By communicating the results of our analysis to the general public using an online GIS system, we hope to trigger future PV panel installations that help to support the energy turnaround and realize national, federal state and municipal renewable energy goals. This will require a solid communication strategy and the embedding of our information system into a wider strategy of public information about renewable energy, also taking various stakeholders, such as the municipal administration, environmental NGOs, energy providers, local trade and craft companies, etc. aboard. The city of Nürtingen has positive experiences with this, as already in 2010 a first web-based solar potential information system calculation overall yearly potentials has been released, two years before the federal state of Baden-Württemberg released the state-wide system. We are confident, that with the new system we can link to this tradition of pioneering.

Besides the main target group of building-owners, the tool can also be relevant for urban planning, landscape and environmental planning when developing energy strategies for the future. First interest has also already been shown by local businesses dealing with the generation and storage of renewable energy, which might use the tool as a basis for efficiently addressing potential customers.

A very interesting potential of our tool, which we want to investigate in the near future is the link to a planning support system approach. Planning support systems can be defined as "... geoinformation technology-based instruments that incorporate a suite of components that collectively support some specific parts of a unique professional planning task" (GEERTMAN 2008, p. 217). They serve a collaboration and communication function for planners and authorities in planning processes (PELZER et al. 2014), in different phases of the planning (KANTERS & WALL 2016), but also provide valuable information to stakeholders involved in and individuals affected by planning decisions, especially in relation to energy and climate change (OUHAJOU et al. 2015). Online tools and apps for communicating solar potentials and matching available rooftops with available capital for installations of PV panels exist (LUBW 2016), but still lack the precision and accuracy of the model we developed and are poorly used by the general public.

In an additional step, these planning support systems can be complemented following principles of geodesign (STEINITZ 2012), by joining additional evaluation and impact models such as rooftop visibility models, visual landscape quality models, and visual impact models to the solar potential analysis. By linking representation models (photogrammetry-based DSM) with process models (insolation model), evaluation models (economic profitability of rooftop PV), change models (agent-based models of user behaviour) and impact models (e. g. visual impact analysis of rooftop PV), mitigating landscape energy conflicts early in the planning process might become possible.

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