Assessment of the Photovoltaic Energy Potential in Distribution Grids

Marianne Zeyringer (1)(2)(3)

(1) Institute for Sustainable Economic Development, University of Natural Resources and Life Sciences (BOKU), 1180 Vienna, Austria

(2) Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands

(3) Institute for Energy and Transport, European Commission, Directorate- General Joint Research Centre, Westerduinweg 3, The Netherlands

Abstract:

Under the Renewable Energy Directive (European Commission, 2009a) Austria has to increase its share of renewable energy in the gross final energy consumption from 24.4% to 34% by 2020 (European Commission, 2009b), implying an increase of distributed, variable generation. Electricity demand varies spatially and temporally and resource supply and demand can be located far apart from each other. One possibility to bring supply closer to demand and to use the local renewable energy potential is to install rooftop photovoltaic systems (PV). A high integration rate of distributed photovoltaic systems may can frequency, voltage and power quality problems (Abu-Sharkh et al., 2006). We propose a methodology to spatially and temporally analyse the reverse load for Austria. First, we use measured load profiles for households and simulate stochastic load profiles using standardized ones for commercial comsumers. In a second step we combine the generated load profiles with hourly data on solar irradiation for the same period to determine the net demand load profiles per km^2. We find that (excluding night hours) on average in 0.5% of the hours the supply exceeds the demand. When excluding commercial consumers, it increases on average to 16%. This result suggests favoring PV deployment in areas with a high share of commercial consumers.

Keywords: load profile, distributed photovoltaic systems, spatially explicit

1 Introduction

The European Commission through the implementation of the Renewable Energy Directive (European Commission, 2009) set the target to increase the share of renewable energy in the gross final energy consumption from 8.5% in 2005 to 20% in 2020. Austria has to increase its share of renewable energy generation from 24.4% to 34% by 2020 (European Commission, 2009b). Assuming low expansion potential for hydropower in Austria implies an increase in distributed, variable generation. Electricity demand varies spatially and temporally and resource supply and demand can be located far apart from each other. One possibility to bring supply closer to demand and to use the local renewable energy potential is to install rooftop photovoltaic systems (PV). However, a high integration rate of distributed photovoltaic systems may can frequency, voltage and power quality problems. (Abu-Sharkh et al., 2006)

This article proposes a methodology to illustrate the spatial and temporal distribution of overproduction. Due to data availability we apply the proposed methodology to the case of Austria. For each km2 we prepare hourly solar output time series and bootstrap depending on its building composition from a pool of measured household load profiles. For businesses we simulate stochastic load profiles using standardized load profiles and construct the residuals from the measured households load profiles. We combine the generated load profiles with hourly data on solar irradiation to find the number of hours of reverse load in each grid cell.

This article contributes to recent scientific literature on analyzing a large scale implementation of distributed PV as done by Paatero and Lund, 2007; Widén et al., 2010 and Fekete et al., 2012. Others authors evaluate measure to allow a high integration such as grid reinforcements, storage facilities and meters enabling load control (Schroeder, 2011) (Quiggin et al., 2012) (Abu-Sharkh et al., 2006) (Komiyama et al., 2013) (Mulder et al., 2010)

This paper contributes to recent literature by analyzing spatially and temporally net load profiles and the resulting reverse flows, which cause problems concerning voltage rise. Differently, to other studies we use spatially explicit data on the consumers for an entire country and measured household load profiles. Different to most other studies, we also model the load profiles of commercial consumers.

The paper is structured as follows: In the next section, we describe the data used. In the third part we explain the methodology to generate the household and commercial load profiles aswell as the PV generation load. Section four provides the results and the last section we present a discussion and further outlook.

2 Data and Methodology

Figure 1 gives an overview on the data and the steps of the methodology which will be described in more detail in the following sections:

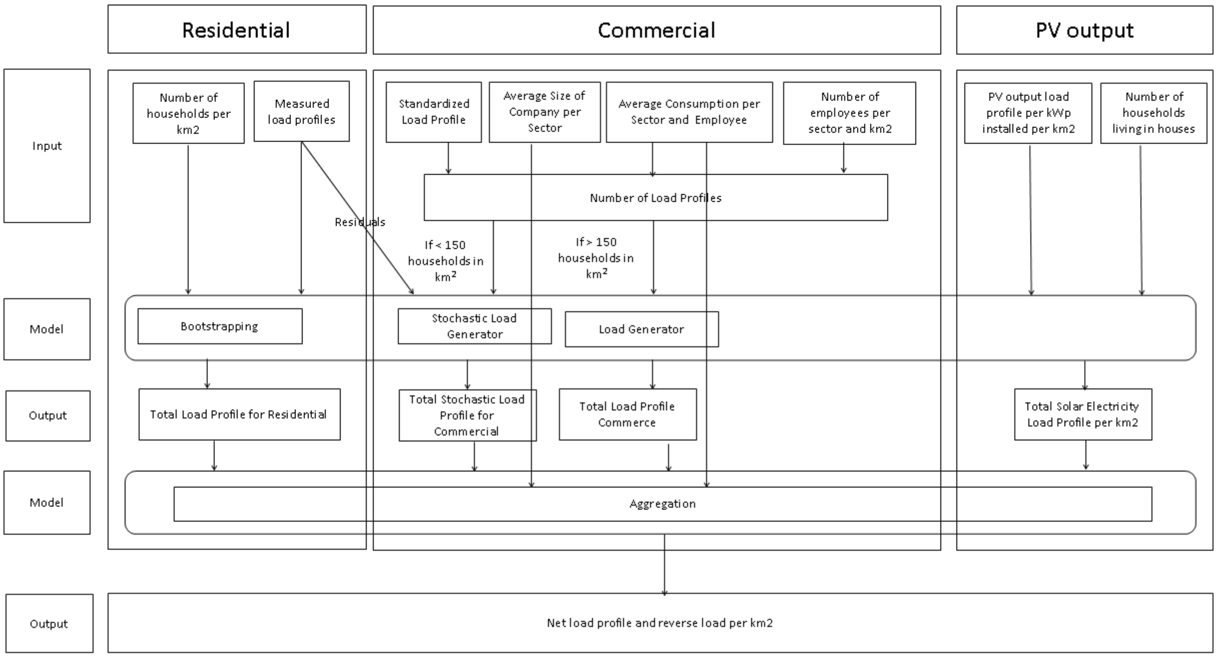

Figure 1 Overview of the data and methodology

2.1 Data

We use the MGI Lambert Raster R1000 to allocate the data to grid cells of 1km2.

We take the number of households from the Austrian statistical office's buildings- and dwellings census (Statistik Austria, 2012). This dataset includes the buildings per house type. For the calculation of the PV production potential we use the information on the households living in 1 or 2 apartment buildings, for the demand load profiles we use all house types.

The Austrian statistical office issued a workplace assessment in 2001, that provides information on all companies located within Austria such as the number of employees and the type of sector according to OENACE1995[1] by square kilometer (Statistik Austria, 2001).

For the load profiles the data source differs between the household and the commercial load profiles. For households we are using 800 measured household load profiles (Energieinstitut Linz et al., 2012). These were measured between April 2010 and April 2011 with a time resolution of 15 minutes. The measurements were conducted in 33 municipalities in Upper Austria ranging from 524 to 191,107 households. In order to represent the single loads we use the standardized load profile for commerce general provided by VDEW (Verband der Elektrizitätswirtschaft, now BDEW- Bundesverband der Energie- und Wasserwirtschaft e.V.) (Bundesverband der Energie- und Wasserwirtschaft e.V, 2000). The load profiles are normalized for annual electricity consumption of 1000 kWh and are used for consumer groups with less than 100.000 kWh of annual electricity consumption or a power rating smaller than 50kW (Wirtschaftskammer Österreich, 2012). They have been built for three day

[1] The OENACE categories are based on the NACE (Statistical Classification of Economic Activities in the European Community), a system set up by the European Commission to classify economic sectors (Statistik Austria, 1995).

types, i.e. weekday Saturday and Sunday and three different seasons i.e. summer from May 15 until September 14, the interim periods from March 21 until May 14 and from September 15 until October 31, and winter from November 1 until March 10 (Bundesverband der Energie- und Wasserwirtschaft e.V, 2000). The load profiles are normalized for an annual electricity consumption of 1000 kWh. Thus we use the yearly consumption per sector from the Nation Energy Accounts (Statistik Austria, 2008b).

For the PV output per hour we are using data from April 2010 to March 2010 with a time resolution of one hour and a spatial resolution of 1'30''. In the underlying calculations it is assumed that PV modules with crystalline silicon cells used and that they are mounted on free-standing racks. This means that they can be on top of building but not integrated into the building structure. In the calculation behind the data it is assumed that the buildings face south at the local optimum angle. The algorithm underlying the calculations can be found in (Šúri and Hofierka, 2004) and the calculation of the optimum angle in (Šúri et al., 2005). The hourly solar radiation data is from the Climate Monitoring Satellite Application Facility (Mueller et al., 2009) and temperature data are from the ECMWF ERA-interim reanalysis (European Centre for Medium-Range Weather Forecasts (ECMWF), n.d.). Huld et al., (2011) model the effects of temperature and irradiance on the PV performance. We use their results, the hourly PV output from the system described in this paragraph.

2.2 Methodology

The solar data is available from 5am to 7pm. Thus, we exclude the data between 8pm and 4am from the demand load profiles as PV can not contribute to this demand. The standardized load profiles exist for three different days in three seasons. We copy the days so as to reproduce one year. As the PV output data is in hourly time steps we convert the 15 minutes resolution of the demand load profiles to hours.

With our model we calculate aggregated load profiles for household and small- scale commercial consumers by using real data to recreate a realistic scenario. For households we look at the household data per grid cell. If the number is higher than 150 households a mean load profile gives a good approximation of reality.

$$X_i = P_i \cdot \langle L \rangle$$

where *X* is the aggregated load for grid *i*, *P* is the number of inhabitants in grid *i* and <*L*> is the mean load of the measured load profiles. If the number of inhabitants is lower than 150 people we want to capture some of the individual volatility in electricity usage. For this we pick randomly as many load profiles as there are inhabitants from the pool of measured household load profiles $X_1, X_2, \ldots, X_n$ (with n = 800). We are using the bootstrapping method which was introduced by B. Efron (1979). Secondly, we add them up for the aggregated load.

$$X_i = \sum_{n=1}^{P_i} L_{r_n}$$

where *X* is the load for grid *i*, *P* is the number of inhabitants in this grid, *L* is a randomly chosen load profile from our pool of load profiles, *r* is a random index of the load profile chosen.

For commercial consumers the situation different. We do not have measured load profiles; we create the dynamics of a variable electricity consumption via residuals. First, we exclude all consumers in the grid cells belonging to sections A to D of the OENACE criteria[2] assuming they are not connected to the low voltage distribution grid but to the medium voltage or high voltage grid. We also exclude sections D (construction) and section G (transport and communication) as they are mobile energy consumers or not connected to the low voltage distribution grid. The workplace assessment dataset does not give us the number of companies, only the number of employees. Thus, we use the average number of employees per enterprise in every section to arrive at the number of load profiles simulated in every grid cell. For grid cells where the number of employees is below the average number we simulate a single load profile. First we assume that the residuals of the small commercial units behave similar to the measured household load profiles. We calculate the residuals matrix, which is the distance for each time step of the measured load profile to the mean of that load profile. This is calculated by

$$R_i = C_i - \langle C \rangle$$

where *R* is the the residuals matrix, *C* is the matrix of load profiles, and <*C*> is the mean load profile. This generates a residuals matrix that keeps the difference for each data point. Our model then looks at the number of employees in each grid cell, picks that number of standardized load profiles but randomizes them by adding a randomly chosen residual load profile from our set.

$$Y_i = E_i \cdot S + \sum_{n=1}^{E_i} R_{r_n}$$

where *Y* is the commercial load profile matrix, *E* is the number of employees in the grid, *S* is the standardized load profile, *R* is a randomly chosen residual profile, *r* is a random index.

The matrices *X* and *Y,* containing the entire aggregated load profile data per grid and time step gets added up for the total aggregated load.

We assume that each household living in a building with one or two flats installs 1kWp on the roof. Thus, we multiply the PV output for each grid cell with the number of building of the type having one or two flats.

In a last step we add the aggregated load profiles to the PV output time series to get as a result the net load profile from April 2010 to April 2011.

3 Results

When excluding night hours on average in 0.5% of the hours PV supply exceeds demand. If we only take the load of the households on average in 16.1% of the hours the supply is higher than demand. Figure 2 shows the spatial distribution of the percentage of hours where PV supply exceeds demand in the West of Austria when only including households.

[2] OENACE Criteria: Section A: mining and quarrying, Section B: manufacturing ,Section C: energy and water supply, Section D: construction, Section E: wholesale and retail trade, Section F: accommodation and food service activities ,Section G: transport and communication, Section H: financial and insurance activities, Section I: real estate activities, Section J: public administration and social security

Comparing Figure 2 with Figure 3 shows that the overproduction is not highest in the most densely populated areas (e.g. Innsbruck) but in the more rural areas. The number of commercial units will probably be higher in areas where there are also larger apartment buildings.

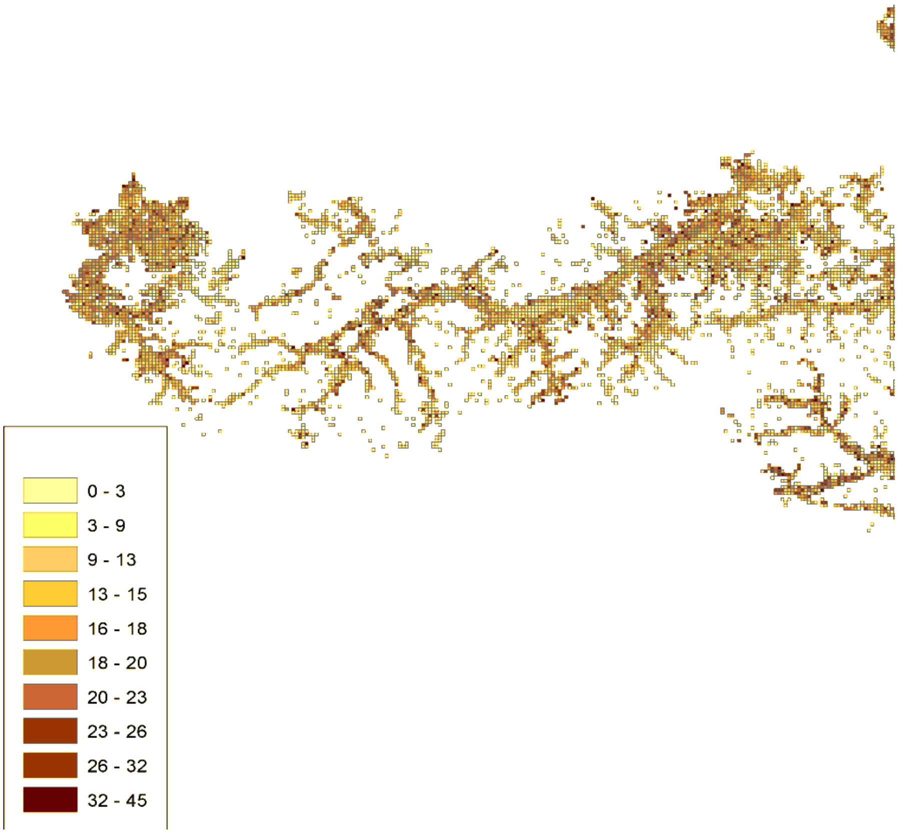

Figure 2 Percentage of hours where PV supply exceeds demand in Western Austria when only including households

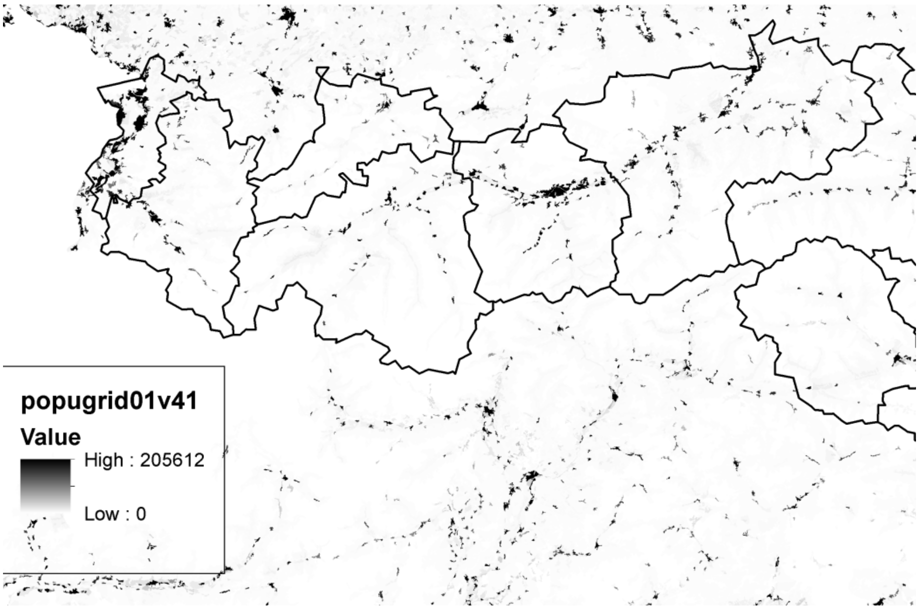

Figure 3 Population distribution

Figure 4 shows the percentage of grid cells where production exceeds demand over time when excluding commercial consumers. In July, the month with the highest PV production, in 27% of the hours demand exceeds supply. In December, the month with the lowest PV production, in 4% of the grid cells demand exceeds PV supply.

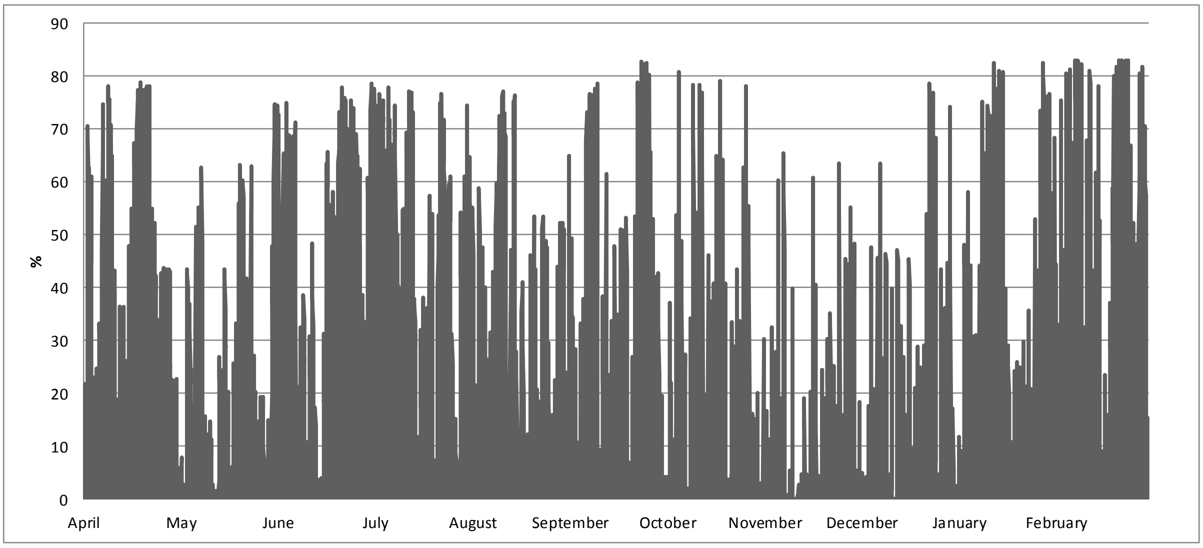

Figure 4 Percentage of grid cells over one year where production exceeds demand Austria when only including households

4 Conclusions and further research

The methodology allows modeling the spatial and temporal distribution of reverse flows by taking into consideration the unique consumer composition of the area. It shows that in case each building with one or two flats installs solar PV in the size of 1KWp, the reverse load flows for areas on average is not significant; different to locations with a low number of commercial units. This study suggests that in distribution grid sections with a high number of single family houses and a low number of commercial units forward planning is necessary. The average overproduction is low when considering commercial consumers. It would therefore be advantageous to support the implementation of rooftop PV in those areas. Our methodology is easily replicable to other regions and can serve as input data into other models studying the potential of distributed photovoltaic energy either in energy systems or distribution grid models. The research can be improved by calculating the photovoltaic output based on the available rooftop area. This will allow also studying areas with a higher share of commercial consumers. Further, the pool of household load profiles can be divided into different subsets. This would allow bootstrapping depending on the composition of the grid cell. For commercial units the research can be expanded by using different standardized load profiles depending on the sector the employees are working in the respective cell.

Acknowledgements

The authors wish to thank Dr. Horst Steinmüller and Dr. Andrea Kollmann from the Energy Institute Linz for granting us access to the measured household load profiles. We want to thank Prof. Andrés M. Alonso Fernández (Universidad Carlos III de Madrid) and Ricardo

Bolado Lavin (EC-JRC, Insitute for Energy and Transport) for their valuable advice on the methodology. This article has been supported by funds of the Oesterreichische Nationalbank (Anniversary Fund, project number: 14168).

Literature

Abu-Sharkh, S., Arnold, R.J., Kohler, J., Li, R., Markvart, T., Ross, J.N., Steemers, K., Wilson, P., Yao, R., 2006. Can microgrids make a major contribution to UK energy supply? Renewable and Sustainable Energy Reviews 10, 78–127.

Bundesverband der Energie- und Wasserwirtschaft e.V, 2000. VDEW Lastprofile- Step by Step, VDEW Materialien.

Energieinstitut Linz, Kollmann, A., Steinmueller, H., 2012. Datensatz anonymisierte Lastprofile. Linz, Oberösterreich.

European Commission, 2009a. Directive 2009/28/EC of the European parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC".

European Commission, 2009b. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union.

Fekete, K., Klaic, Z., Majdandzic, L., 2012. Expansion of the residential photovoltaic systems and its harmonic impact on the distribution grid. Renewable Energy 43, 140–148.

Komiyama, R., Shibata, S., Nakamura, Y., Fujii, Y., 2013. Analysis of possible introduction of PV systems considering output power fluctuations and battery technology, employing an optimal power generation mix model. Electrical Engineering in Japan 182, 9–19.

Mulder, G., Ridder, F.D., Six, D., 2010. Electricity storage for grid-connected household dwellings with PV panels. Solar Energy 84, 1284–1293.

Paatero, J.V., Lund, P.D., 2007. Effects of large-scale photovoltaic power integration on electricity distribution networks. Renewable Energy 32, 216–234.

Quiggin, D., Cornell, S., Tierney, M., Buswell, R., 2012. A simulation and optimisation study: Towards a decentralised microgrid, using real world fluctuation data. Energy 41, 549–559.

Schroeder, A., 2011. Modeling storage and demand management in power distribution grids. Applied Energy 88, 4700–4712.

Statistik Austria, 2012. Building and dwelling census 2012.

Widén, J., Wäckelgård, E., Paatero, J., Lund, P., 2010. Impacts of distributed photovoltaics on network voltages: Stochastic simulations of three Swedish low-voltage distribution grids. Electric Power Systems Research 80, 1562–1571.

Wirtschaftskammer Österreich, 2012. Standardisierte Lastprofile [WWW Document]. URL http://portal.wko.at/wk/format_detail.wk?AngID=1&StID=292071&DstID=0