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A high-resolution determination of the technical potential for residential-roof-mounted photovoltaic systems in Germany

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Abstract

In Germany the introduction of a feed-in tariff for renewable energies in the year 2000 led to a massive increase in newly constructed photovoltaic (PV) plants reaching a total installed capacity of 35 GW_p as of November 30th, 2013. The distribution of these plants shows a large disparity between regions, which motivates investigations of regional potentials which earlier studies of Germany have not addressed in detail. This study presents a high-resolution calculation for the technical potential of residential-roof-mounted photovoltaic systems for each municipality in Germany. Electricity load curves for municipalities were generated based on the socio-economic structure and used to draw generalized conclusions about the relationship between the (potential) supply from PV and the local demand. The total German residential-roof-mounted technical PV potential was determined as 148 TWh/a with an installable capacity of 208 GW_p. About 30% of municipalities could become autonomous based on a yearly balance of PV electricity generation. If the daily and seasonal variations in demand and PV electricity generation were considered, only 53 of the 11,593 German municipalities could become autonomous, provided they installed a short-term storage system which would have to be sized around 57% of their daily electricity demand. Imposing the restriction that no feedback of electricity into the distribution network outside the municipality should occur, and assuming that no local storage exists, around 49% of the total technical potential, i.e. 103 GW_p could be installed (i.e. 90 GW_p additional potential since some municipalities already experience feedbacks into the distribution network). A validation of the results with municipal solar cadastres has shown that the discrepancy between them and the technical potential calculated in this study is quite consistently about 30%, which is assumed to be due to non-residential buildings not being considered here. The calculated technical potential is most sensitive to the assumptions on the module efficiency and the usable area of (slanted) roofs. A validation of building data assumptions as well as a comparison with other studies both show a good agreement.

Keywords: Photovoltaic potential; Roof-mounted; Demand-supply balance; Germany

1. Introduction

1.1. Motivation

Across Europe there are ambitious goals for the transformation of the energy system. As part of their

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sustainability strategy, in 2007 the member states of the European Union (EU) agreed on the following, so-called "20-20-20" targets for the year 2020 to make the transition to a more sustainable energy system: firstly, a reduction in greenhouse gas emissions by 20% compared to 1990, secondly 20% of primary energy from renewables and thirdly a 20% reduction in primary energy demand through energy efficiency (European Commission, 2010). Subsequently, in their Energy Concept of 2010, the German government set targets for renewable energies in gross electricity consumption of 35%, 50% and 80% by 2020, 2030 and 2050 respectively (German Federal Government, 2010). Significant progress has already been made towards these goals, so that in 2010 renewable energies had a share in gross electricity consumption of about 17% with 101.7 TWh generated electricity, of which 12% was generated by photovoltaic (PV) plants (BMU, 2011). By 2012 this share had already increased to 23% for all renewable energies with a share of 20% generated by photovoltaic plants (BDEW, 2013a).

This rapid development of renewable energy in general, and photovoltaic in particular, is largely due to the German Renewable Energy Act (EEG) (Federal Republic of Germany, 2009), which sets the energy-political framework and has stipulated the feed-in tariffs (FITs) for renewables in Germany since 2000. The relatively high FITs awarded to photovoltaic in recent years led to this technology not only establishing itself in just over a decade (62 MW_p in 2000 compared to 35 GW_p in 2013 (BDEW, 2013a); (BNetzA, 2013)), but also to a widespread scientific and political discussion about the law and the distribution of the associated large economic burden onto the end users. The FITs for photovoltaic electricity were drastically cut in recent years from around 40 ct/kWh in 2010 to about 13 ct/kWh in 2013 (Federal Republic of Germany, 2009). Amongst other things, this led to the rapid demise of the PV manufacturing sector in Germany in 2011 (BMWi, 2012), but has also focused renewed attention on the most economically efficient application of this technology. In particular, this concerns the distribution of the exploited potential compared to other, sometimes competing land uses.

In this regard, the utilization of residential buildings' roofs is a very attractive option for PV electricity generation, since there are currently no competing land uses for these areas (apart from solar thermal applications). The available area is usually determined via solar cadastres. For single municipalities however, the creation of a solar cadastre is a rather expensive undertaking. As they usually have no reliable estimate of the PV potential in their municipality, it is difficult for them to decide whether a solar cadastre in their specific case is worth the investment or not.

Large regional disparities are apparent in the distribution of PV plants in Germany. These could be attributed to many reasons such as climatic conditions (which have an impact on the economic conditions), differences in building stock and population density, as well as social factors such as available income and demography (Linder, 2013). However, in the past the balance between energy supply and demand has rarely been considered in decisions about PV installations. With the PV capacity reaching significant levels, that flaw could lead to major disparities between supply and demand, e.g. in rural areas where the electricity production from PV can exceed the total electricity demand significantly. An effective political control over future installations, e.g. by regionalization of subsidy schemes, is only possible with knowledge about the regional remaining potentials as well as the regionally specific abilities to use the generated electricity locally.

Since the extensive installation of photovoltaic plants has already led to problems with the electricity grid, in the future a more controlled approach should be chosen to prevent grid failures like in Italy in 2003 and in Northern Germany in 2006 (Fuhs, 2013; Henneaux et al., 2012). Already in 2011 suggestions for the recalibration of the inverters have been made (VDE FNN, 2011) and passed as a law in the System Stability Law in 2012 (German Federal Government, 2012) preventing the simultaneous shutdown of photovoltaic plants in cases of frequency irregularities in the distribution grid. Additionally, since the EEG 2012 a feed-in management (Federal Republic of Germany, 2009) has also been introduced, preventing generation peaks. However, additional installations especially in the residential sector which do not have to provide grid services and are connected to weak distribution grids will still aggravate this problem. The starting point for such a controlled approach for further photovoltaic installations is an analysis of the available and already exploited potential (Boemer et al., 2011).

1.2. Aims and objectives

It is the general aim of this paper to gain insights on regional technical potentials for roof-mounted photovoltaic systems across Germany and to explore their possible exploitation. The paper's specific objectives are to:

1. Develop a methodology for the assessment of the residential-roof-mounted photovoltaic potential over large (national) areas in a high resolution, which combines readily available statistical data with the powerful functions of a geographic information system (GIS).
2. Identify the remaining technical potential for future photovoltaic installations by comparing the calculated potential with actual installed capacities on a municipal level.
3. Identify areas where the PV capacity should and could be enhanced and areas where development should be stopped to enable a better matching of electricity supply and demand by comparing hourly photovoltaic electricity production with estimated local electricity load profiles.