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Beyond the sun—Socioeconomic drivers of the adoption of small-scale photovoltaic installations in Germany

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ABSTRACT

The share of solar energy in German electricity supply has increased rapidly in recent years. This is due to guaranteed feed-in tariffs in conjunction with decreasing prices for solar panels. However, little is known on geographical factors, settlement structure, neighborhood effects or the crucial role of middle actors for the spatial distribution of photovoltaics. The presented study addresses these issues by accounting for more than 820,000 small-scale installations (≤16 kWp) registered between 1991 and 2012.

It turns out that the installed capacity (and generated supply) from small-scale installations clearly varies among German counties. Based on econometric analysis, this can partly be explained by differences in solar radiation. However, other factors, such as house density, homeownership, per-capita income and neighborhood effects seem to be equally or even more important. In contrast, households' ecological attitude hardly affects the investment decisions.

1. Introduction

Despite a vivid debate on the so-called *Energiewende*, which denotes the switch towards clean energy, Germany's energy supply still depends strongly on fossil and nuclear energy sources. The corresponding shares range from 77% for electricity supply to 90% and 95% for heating and fuels respectively [8]. In order to reduce the dependency on fossil and nuclear energy sources and to continuously increase the share of renewable sources, policy established the *Renewable Energy Sources Act* (EEG). Looking, for example, at electricity supply, the EEG seeks to increase the share of renewable sources from about 23% in 2012 to 50% by no later than 2030 [7]. To achieve this target, the EEG grants priority to renewable energy sources and guarantees comparatively high feed-in tariffs. Since Germany's share of power supply from renewable energy has continuously increased in recent years, the instrument has indeed proved to be effective. This is in line with the findings of other studies, which consider feed-in tariffs as a particularly suitable instrument to foster the adoption of renewable energy [49].

The group of producers is manifold and encloses large energy suppliers, farmers and private households. Though installations of farmers and large energy suppliers account for about 77% of total capacity, social acceptance of renewable energy and the commitment of private households can be considered a crucial factor of a successful energy turnaround [52,57]. This can be achieved, if the generation of electricity becomes a part of civil society, either by the establishment of citizen energy holdings or by making private households small-scale producers [16,23]. While holdings are of particular relevance for major projects (e.g., wind farms), the latter relates to the residential adoption of solar energy.

The large number of small-scale installations points to the increasing popularity of this instrument. However, with a maturing renewable energy sector (accompanied by decreasing feed-in tariffs) other market shaping factors gain in importance. These include but are not limited to region-specific as well as socio-technical aspects that influence the enduring success of the energy turnaround and the establishment of a low carbon society [53]. In this context, our focus is on geographical factors, settlement structure, neighborhood effects and the crucial role of middle actors as main agents of the energy turnaround [41].

The presented study addresses these issues for about 400 German counties. For this purpose, the analyzed sample comprises all installations with a capacity up to 16 kWp that have been attached to or on top of private houses between 1991 and 2012.[1]

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[1] The 16 kWp frontier relates to the size of larger private houses' roofs [37].

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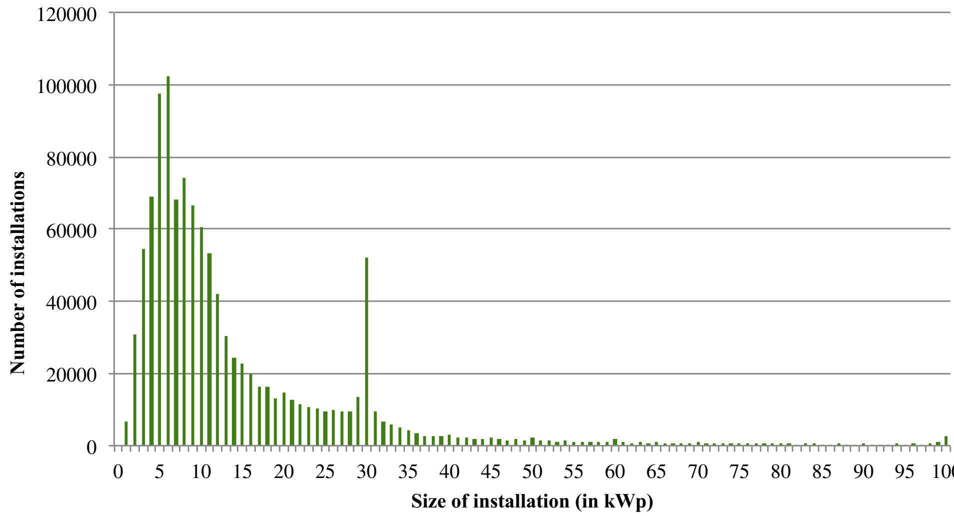

Fig. 1. Distribution of photovoltaic installations (≤100 kWp) in Germany, accumulated number of installations between 1991 and 2012.
Source: Own calculations and illustration based on data from Refs. [11,19].

The paper is organized as follows: Section 2 briefly describes recent trends of photovoltaics in Germany and gives a first idea on the installations' spatial distribution. Section 3 discusses corresponding literature and derives the main hypotheses. Formulation and application of a general and a spatial regression model follows in Section 4. The paper closes with a brief discussion of policy implications in Section 5.

2. Recent trends and spatial distribution

2.1. Electricity supply from renewable energy sources

The energy turnaround traces back to the early nineties when Germany adopted the *Law on Feeding Electricity into the Grid* that forced major network operators (owned by major electricity suppliers) to feed in electricity from renewable sources into the main grid and to guarantee fixed tariffs for a period of 20 years [46]. Main beneficiaries of this regulation were small wind farms, whose installed capacity increased rapidly.

At the same time, guaranteed tariffs turned out to be too low in terms of photovoltaic installations. As a consequence the first amendment to the act (named EEG thereafter) in the year 2000 included the so-called 100,000-roof-program established by *Kreditanstalt für Wiederaufbau* (KfW). The success was remarkable. Due to the highly subsidized feed-in tariffs, which by far exceeded compensations for electricity supply from any other source, the target had already been reached at the end of 2003.

When subsidization phased out with the end of the program, a new amendment in 2004 significantly increased guaranteed compensations (to be paid by the network operators) and capacity from photovoltaic installations continued to grow rapidly. Though guaranteed tariffs decreased with the amendment in 2009, the positive trend has remained rather stable and even strengthened recently. This can partly be explained by clear cost reductions of installations from about 5000 €/kW in 2006 to 1800 €/kW in 2013 [56].

As a consequence, total capacity from photovoltaics continuously increased from close to zero in 1991 via 1100 MWp in the year 2004 (shortly after the 100,000-roof-program) to about 32,600 MWp in 2011. The extended capacity corresponds to an increase in produced electricity from about 550 GWh in 2004 to 28,000 GWh in 2012. Thus, electricity supply from photovoltaics accounts for about 20% of electricity from renewables and 6% of total supply.

2.2. Spatial distribution of small-scale installations

The strong extension in capacity and produced electricity is carried by a rather heterogeneous group of producers that encloses operators of large solar parks, farmers and manufacturers with relatively large roofs as well as private households.

Fig. 1 shows the distribution of photovoltaic installations ≤100 kWp by size of installation.[2] More than 820,000 small-scale installations up to 16 kWp (71% all photovoltaic installations) account for about one fourth of total capacity (23.0%) and produced supply (23.2%). The residential adoption of photovoltaic technology can therefore be considered an important mosaic on the way to a low carbon society.

In order to receive guaranteed feed-in tariffs, each installation must be reported under the specification of zip code and installed capacity to the *Bundesnetzagentur*.[3] Thus, the corresponding capacity can be reassigned to one of the German counties (NUTS 3). It turns out that accumulated capacities and accordingly power supply related to small-scale installations are distributed across the country but slightly concentrate in southern Germany. This is in line with the findings of a comparative study among Germany's Federal States according to which about two fifth of the overall capacity is installed in the southern states of Bavaria and Baden-Württemberg [9]. In addition these states are most successful in exploiting the existing potential of solar energy [21].

Fig.2 illustrates the distribution of small-scale installations for the years 2004 (shortly after the 100,000-roof program) and 2012.

3. Corresponding literature and main hypotheses

Guaranteed feed-in tariffs defined by the EEG hold for any region in Germany. Differences in the regional distribution of small-scale installations shall therefore be mostly independent from national regulation. Instead differences in the regions' cumulated installed capacity (and subsequently generated supply) are likely to be

[2] Peaks between 4 and 9 kWp can most likely be explained by the physical construction of town, twin and single-family houses. The peak at 30 kWp derives from an obligatory test of grid compatibility for installations >30 kWp. Farmers and entrepreneurs seem to avoid this test, even if roofs would principally allow for larger installations.

[3] The Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway.