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Economics of small wind turbines in urban settings: An empirical investigation for Germany

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ABSTRACT

In this paper we investigate the location-specific attractiveness of small wind turbines (SWT) for private households. In order to assess the economic viability of an investment in SWT, we analyze a set of scenarios that incorporate different types of SWT, various storage system options, support schemes, and specific urban surroundings for the case of Germany. As urban structures substantially influence local wind speeds, and hence the potential energy yield of a turbine, the location of SWT in the urban area is crucial for their economic feasibility. We find that SWT today are only profitable under very favorable conditions, the most important parameters being prevailing wind speeds and the location's degree of urbanization. In most cases, the coupling of the SWT to a storage system is crucial for cost-effectiveness. A feed-in tariff system specifically adapted to SWT technology is found to be an important driver of diffusion. Further research needs are identified in the field of long-term performance and yield projections for SWT. Based on the findings from our study, significant SWT diffusion can only be expected, if at all, in coastal suburban and rural areas.

1. Introduction

In the context of the ongoing political debate on global climate change and the international agreement to limit the global warming to a temperature increase of max. 2 °C, the German government set ambitious energy and climate goals in its energy concept in 2010. The energy and climate targets determined in the energy concept aim at a reduction of CO_2 emissions by 40% by 2020 (compared to the level of 1990), and even by 80–95% by 2050. Besides the increase of energy efficiency, a key measure to achieve the climate goals is the support of renewable energy sources (RES).[1] In particular, this includes the stepwise increase of the share of RES in primary energy generation to 35%. In the year 2013, this share was already at about 24% [1]. However, despite increasing shares of RES, there are different obstacles and challenges that could jeopardize a further successful energy transition in Germany. These particularly refer to the cost of the grid expansion and restructuring, the integration of off-shore wind farms, both from a technical and an environmental perspective, the increasing shortage of suitable land for RES development, and a decreasing social acceptance of RES, such as on-shore wind power. However, tackling the complex challenge of meeting climate goals requires the consideration and contribution of various renewable energy technologies, in particular also small-scale generation units.

From the perspective of large-scale investors, mature renewable energy technologies, such as on- and off-shore wind power, solar (thermal) power plants, hydro power and biomass plants are the most important investment options. Due to the feed-in tariffs provided by the EEG support scheme [2] and the associated feed-in guarantee for the generated electricity, these technologies are often attractive and low-risk long-term investments.

But also small investors, such as private households, can play an important role in Germany's energy transition. Firstly, environmental awareness is increasing and many households are interested in a sustainable and CO_2-free electricity supply, which is also reflected in their willingness-to-pay for sustainable energy technologies [3]. Secondly, private households are financially contributing to the expansion of RES through a fixed rate per kWh,[2] which implies increasing long-term costs that have to be paid for the energy

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[1] In this case, RES essentially contain relatively mature energy technologies, such as on- and off-shore wind power, solar (thermal) power, hydro power and biomass power plants.

[2] Since October 2014 the levy imposed on households is 6.24 €-ct/kWh [4], raised from the previous level of 5.27 €-ct/kWh. In 2014, the burden imposed on electricity consumers was around €20 bn.

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transition. Therefore, actively supporting climate protection and decreasing their own electricity bill are valid incentives for households to invest in RES [5]. In this context, private households have the incentive to become "prosumer", i.e. producer and consumer of energy at the same time. So far, however, in the private household sector in Germany, only investments in photovoltaics (PV) and to some extent in biomass plants have turned out to be economically feasible.

Besides PV and biomass facilities, barely considered investment options for households to generate electricity are small wind turbines (SWT). SWT are characterized by a small installed capacity (typically around 1–10 kW) as well as a hub height of up to around 30 m, and can either be free-standing or roof-mounted. Roof-mounted SWT in particular could be an investment option for private households in urban areas.

The market for SWT is still small, but growing steadily. The German Federal SWT Association (Bundesverband Kleinwindanlagen, BVKW) expects an increase in the number of installed SWT of up to 700,000 units in Germany by 2020 [6]. In comparison, the number of installed SWT in the UK is expected to increase to about 600,000 units in the same period of time [7]. The World Wind Energy Association (WWEA) published the first worldwide market study of SWT in 2012. China was identified as the country with the largest number of SWT (450,000 units), followed by the United States with around 140,000 units. Most of these SWT are not grid-connected but running in off-grid (island) systems, particularly in rural areas of China, where SWT have been used for local electricity generation or water pumps since the early 1980s. According to the WWEA study, there were around 520,000 units installed in 2009 worldwide, a number which grew in 2010 by 26% to about 650,000 [8]. An increased importance of SWT is also expected for developing countries in the context of rural electrification projects [9].

SWT exhibit several advantages. They offer the possibility of an independent electricity supply or, alternatively, receiving feed-in payments from feeding the generated electricity into the grid. Transmission costs are negligible due to the spatial proximity between supplier and consumer. From a technical perspective, the manufacturing processes of SWT are well-known and proven. Therefore, SWT are characterized by a high degree of technical reliability, which is advantageous regarding supply and planning reliability [10].[3] Despite some similarities between large-scale turbines and SWT, there are considerable differences with respect to the economic feasibility, which calls for a separate investigation of SWT economics [5]. The development potential of this technology is still impaired by a lack of technological standards, non-transparent regulatory frameworks, and a lack of reliable wind power prediction tools, particularly with respect to the economic feasibility.

Recent literature on SWT is still particularly focused on technical aspects of this energy technology. This includes the assessment of life-cycle costs [11], energy-related amortization calculations, and the evaluation of the CO_2-saving potential [12]. Other publications investigate the optimal installation position of roof-mounted turbines by means of wind tunnel tests [13] or the change of wind speeds in areas with higher building density [14]. Recent technical studies focused on blade design and cut-in wind speeds [15], aerodynamic noise [16], and the impact of ambient turbulence on turbine performance [17]. First attempts to estimate yield expectations for SWT have been conducted by Kühn [18], Richter [19], and Sunderland and Conlon [20], among others. Reference studies or long-term field tests on the performance of SWT in urban areas are very limited in numbers. The Warwick Wind Trials study, conducted in the UK during 2007–2008, provides some results on SWT performance in urban areas, indicating that an increase in the degree of building density leads to a decrease in the generated energy yield [21]. More recently, Abohela et al. [22] specifically investigated the effect of roof shape, wind direction, height of buildings and the surrounding urban environment on the energy yield and positioning of roof-mounted SWT. A first evaluation of the economic feasibility of SWT was recently undertaken by Bortolini et al. [23]. They compared the performance and viability of SWT in five European countries by means of a net present value (NPV) approach. The estimation of the cash flows considers several technical parameters, such as performance curves and costs, as well as national factors, such as wind speed distribution and incentive schemes. The wind speed and the national incentive schemes were found to be the most important determinants of economic feasibility. The employed wind speed data provide average wind conditions on a country level, which are measured at 50 m above ground. However, a particular adaptation of wind speeds to the conditions in different regions within the countries, or even at different building heights, is not incorporated.

In this paper, we investigate the potential investment in SWT for private households dependent on the location under varying urban conditions. The economic feasibility of SWT, and therefore the investment decision of households in this technology, essentially depends on three factors: (1) the technical design of the turbine with regard to size and type; (2) the economic and regulatory framework with respect to the support scheme; and (3) spatial aspects, such as the wind speed in the context of the urbanization level, particularly with regard to building heights and density. Especially the potential location of SWT in the urban area is crucial for the economic feasibility evaluation, as urban structures substantially influence local wind speeds, and, therefore, the potential energy yield of a turbine [24]. In order to assess the profitability of an investment in this technology from the perspective of a private household, we model various investment scenarios that incorporate different types of SWT, various storage system options that can be coupled, support schemes, bank loans, and in particular the specific characteristics of urban locations. In addition, we investigate the impact of the introduction of a modified feed-in tariff system that is better adapted to SWT than the existing tariffs for large wind turbines are. However, the main focus of this empirical study is the assessment of definite investment decisions in SWT in view of varying conditions caused by different urban settings.

Since, to our knowledge, there is no comprehensive economic feasibility evaluation for SWT under urban conditions available as yet, this paper aims at providing a better empirical understanding of the economic potentials of SWT technology, also trying to identify key factors for the private household's investment decisions. Particularly, the creation of a spatial context through the incorporation of different urban scenarios, which represent diverse urban conditions and structures, is a key challenge for economic feasibility analyses that focus on SWT diffusion potential in cities. Thus, the spatial context incorporated here is a new aspect of research. Furthermore, considering different SWT types with regard to design (horizontal or vertical axis) and output level as well as the various options of coupling to different storage types capture the latest technological developments on the market for SWT. Additional merit is created through specifically investigating economic feasibility in respect of the support scheme in place, as well as alternative policy measures.

The remainder of this paper is structured as follows. In section 2, we introduce the three SWT reference turbines considered and some peculiarities of SWT. Section 3 introduces the methodology and the parameters considered for the prediction of yields and revenues. The procedure is then applied to selected locations as an

[3] SWT have a high degree of reliability compared to large-scale, multi-MW wind turbines.