Applied Energy 204 (2017) 1–15

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

What drives the profitability of household PV investments, self-consumption and self-sufficiency?

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HIGHLIGHTS

- Simulation model to analyse profitability of household PV and storage investments.
- Consideration of technological, market-based, political and geographical drivers.
- Comparison of PV-based self-consumption and self-sufficiency in Germany and Ireland.
- Household electricity demand from grid may fall to 25% in Germany/35% in Ireland.
- Strong self-sufficiency incentives in Germany may lead to distributional challenges.

ARTICLE INFO

Article history:
Received 12 April 2017
Received in revised form 29 May 2017
Accepted 16 June 2017

Keywords:
Solar PV
Self-consumption
Self-sufficiency
Battery storage

ABSTRACT

Many countries introduced subsidy schemes that were successful in incentivising investments into residential solar PV. The resulting growth of the global PV market was accompanied by cost reductions for PV systems, reductions of PV subsidies and, often, increasing electricity retail prices. Along with decreasing costs for battery storages, these developments made self-consumption and self-sufficiency continuously more attractive. However, the profitability of PV-storage systems depends on many factors, including technological, political and geographical aspects. We present a simulation model to identify the most profitable sizes of PV and storage systems from a household perspective and explore what drives the profitability of self-consumption and self-sufficiency. We compare and contrast Germany and Ireland to account for regulatory and geographical differences. Our results show that PV-storage systems are generally profitable in Germany and that, after minor technology cost reductions, this result holds even in the absence of subsidies. In Ireland, such systems are not yet profitable but this may change soon with expected technology costs reductions. The share of electricity demand that will be required from the grid may be reduced to 25–35%. Implications for the electricity retail business and policy makers are discussed including distributional concerns and system efficiency considerations.

1. Introduction

Many countries worldwide have adopted policies to support the expansion of renewable energy sources (RES) aimed at reducing greenhouse gas emissions and combating climate change. The European Union (EU), for instance, aims for a 27% share of RES in final energy consumption by 2030 whereas more than two thirds of gross final European energy consumption shall be provided through RES by 2050, with a yet higher share for electricity [1].

While the support schemes adopted in different countries differ in nature (see Solangi et al. [2] or Steinhilber et al. [3] for overviews), they were very effective in incentivising investments into RES. As a result, the installed RES capacities have increased rapidly. The installed solar photovoltaic (PV) capacity, for instance, has reached more than 300 GW globally at the beginning of 2017 with around 70 GW having been installed in 2016 alone.[1] This strong growth of the PV market has led to strong cost reductions for new PV systems [4–6] and the cost reductions came along with reductions of the PV subsidies. The growth has also led to significant improvements of PV power converter technologies and control algorithms ensuring power quality of grid connected PV systems [7,8]

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[1] See e.g.: http://www.climateactionprogramme.org; http://www.solarserver.com/.

http://dx.doi.org/10.1016/j.apenergy.2017.06.055
0306-2619/

without affecting the above-mentioned cost reductions. At the same time, depending on how the different governments decided to levy the RES subsidies, electricity retail prices increased. As a result, solar PV has reached 'grid parity' in many countries in recent years [9–13]. This means that in these countries self-consumption of the electricity generated from PV became more attractive than feeding the electricity into the grid and getting paid the subsidy. Self-consumption, self-sufficiency and grid parity have sparked an increasing interest by researchers and consumers recently [14,15]. We use the terms self-consumption and self-sufficiency as described by Luthander et al. [15], who define $self\text{-}consumption = \frac{\text{self-consumed PV electricity}}{\text{total electricity generation from PV}}$ and $self\text{-}sufficiency = \frac{\text{self-consumed PV electricity}}{\text{total electricity demand}}$. Since battery storage costs also decreased strongly over recent years and storages can help to increase self-consumption and self-sufficiency, a growing share of the literature on self-consumption and self-sufficiency includes PV-storage systems [16–18]. In this context, Graebig et al. [19] found that self-sufficiency as a goal in its own right is as important for consumers as economic considerations in determining their interest in PV-storage systems. However, since their willingness to pay for self-sufficiency is not unlimited, the quantification of costs associated with different levels of self-sufficiency gains importance.

The statements by the EU [20] that consumers should be put at the heart of energy markets and that they should be empowered and become more active market participants (e.g., through distributed generation, demand response and self-consumption) can be interpreted as a clear support of so-called prosumers (i.e. consumers that are also producers). Prosumers are undoubtedly more active than traditional consumers and they have a natural interest in self-consumption. However, there are also critical views on self-consumption [9,21]. This criticism is not directed at the PV expansion and self-consumption as such but mainly raises distributional concerns under current regulation.

In order to explore how imminent the issues of self-consumption and self-sufficiency are in different countries, what levels of self-consumption and self-sufficiency can be expected, at what costs, and what the main drivers are, we compare and contrast two EU countries which differ strongly in terms of their solar energy policy as well as their geographical and meteorological conditions and solar PV potential. These are Germany and Ireland. This comparison makes an interesting case study as their overall targets for electricity generation from RES are similarly ambitious (Ireland pursues a 40% target for electricity from RES by 2020, Germany a 40–45% target by 2025), while the legislation around RES expansion, particularly in terms of support for solar PV differs substantially (see Section 2). In each country, we consider two household sizes and 100 individual load profiles within each household size. Using these load profiles, the techno-economic assessment is carried out with a simulation model implemented in MATLAB. We also use our model to quantify the costs associated with different levels of self-sufficiency. In an Irish context, research on residential PV is scant. While La Monaca & Ryan [22] analyse the impact of different support schemes for residential PV in Ireland, they do not include storage or a detailed driver analysis into their work. To our knowledge, our paper is the first to analyse drivers and costs of PV-based self-sufficiency in Ireland.

The remainder of this paper proceeds as follows. In Section 2, we summarise the regulatory framework in relation to solar PV support in Germany and Ireland and describe a selection of related work. In Section 3, we provide an overview of the input data for our analyses. In Section 4, we describe the simulation model used in this paper. In Section 5, we present the results before we discuss implications and limitations in Section 6. Section 7 concludes.

2. Renewable policy background and related work

With the introduction of the Renewable Energy Act ("EEG") in 2000, Germany provided attractive investment conditions for PV based on a feed-in tariff (FIT) scheme. As a result, the installed peak capacity of photovoltaic (PV) plants has significantly increased from 1 GW_p in 2004 to over 40 GW_p in 2016 [23]. Since 2009, the FIT for small PV plants (<10 kW_p) was reduced from 43 cent/kWh to 12.3 cent/kWh in 2016 [24] while the average price of turnkey PV systems (<100 kW_p) decreased from 4100 €/kW_p to 1130 €/kW_p over the same period of time [25]. RES support payments are levied on a per unit (kWh) basis in Germany. The per unit contribution to RES expansion increased from 1.33 cent/kWh in 2009 to 6.35 cent/kWh in 2016 leading, among other effects, to a residential electricity retail price increase from 21.4 cent/kWh to 27.7 cent/kWh which made self-consumption continuously more attractive altogether [26]. Since battery storages can help to increase PV self-consumption and, hence, profitability, up to 60% of the new installed PV systems in Germany are equipped with a battery storage system [27].

In Ireland, the support of RES was also based on a FIT scheme. The first Irish Renewable Energy Feed-in Tariff scheme (REFIT 1) was introduced in 2006. Unlike in Germany and many other countries, however, the Irish REFIT does not provide support for solar energy so far. Moreover, REFIT is levied by the Public Service Obligation (PSO), i.e. it is paid for on a per household rather than on a per unit basis. As a result, residential electricity retail prices (per kWh) have not increased to a similar extent; they amount to approximately 18 cent/kWh[2] which is much lower than in Germany. In addition, compared to Germany, the meteorological conditions are less favourable for PV. Altogether, it is therefore obvious that the investment conditions for PV in Ireland have not been attractive. Consequently, the installed peak capacity in the Republic of Ireland only totals around 2 MW_p by the end of 2016. However, the Irish government in their energy white paper released in December 2015 state that they envisage a diversification of renewable energy sources [28]. While onshore wind is planned to continue to make a significant contribution, it is debated whether the new scheme should also support solar PV.

Beyond these regulatory differences, however, there are many other parameters that drive the profitability of self-consumption. Assessing their impact is important to understand how imminent the issue is and what levels of self-consumption can be expected. The literature on grid parity, self-consumption and PV battery storage systems has grown rapidly in the recent past and many drivers have been analysed. Huijben & Verbong [29], Spertino et al. [30], Karakaya et al. [11] and Hagerman et al. [10], for instance, analyse different drivers of PV grid parity, including PV installation costs, electricity prices, meteorological conditions of different locations and their impact on solar power availability and the policy framework (e.g. the availability of a FIT or other relevant regulations). However, their research does not explicitly include storage systems. Hoppmann et al. [31] and Vieira et al. [17] include storages and explore the impact of storage cost as well electricity price variations. However, they do not explicitly account for geographical characteristics and their impact or the impact of varying electricity consumption levels and profiles. Nyholm et al. [32] use load data from around 2000 households taking into account geographical and demographic characteristics and their impact on the demand side of households to analyse to which extent batteries can increase self-consumption levels. However, they focus on the technical side of self-consumption without conducting a detailed analysis of economic drivers. Finally, Khalilpour & Vassallo [9,33] carry

[2] See: www.bonkers.ie.