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Quantifying self-consumption linked to solar home battery systems: Statistical analysis and economic assessment ☆

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HIGHLIGHTS

- PV self-consumption with or without battery is evaluated for many households in EU.
- Self-sufficiency cannot exceed 80% without excessively oversizing the system.
- A simple equation is proposed to compute self-consumption from PV and battery sizes.
- Economic optimizations indicate that further decreases in battery costs are required.

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ABSTRACT

The recent development of new and innovative home battery systems has been seen by many as a catalyst for a solar energy revolution, and has created high expectations in the sector. Many observers have predicted an uptake of combined PV/battery units which could ultimately disconnect from the grid and lead to autonomous homes or micro-grids. However, most of the comments in social media, blogs or press articles lack proper cost evaluation and realistic simulations. We aim to bridge this gap by simulating self-consumption in various EU countries, for various household profiles, with or without battery. Results indicate that (1) self-consumption is a non-linear, almost asymptotic function of PV and battery sizes. Achieving 100% self-consumption (i.e. allowing for full off-grid operation) is not realistic for the studied countries without excessively oversizing the PV system and/or the battery; (2) although falling fast, the cost of domestic Li-Ion storage is most likely still too high for a large-scale market uptake in Europe; (3) home battery profitability and future uptake depend mainly on the indirect subsidies for self-consumption provided by the structure of retail prices; (4) the self-sufficiency rate varies widely between households. For a given household, the volume of self-consumption cannot be predicted in a deterministic way. Along with these results, this study also provides a database of synthetic household profiles, a simulation tool for the prediction of self-consumption and a method for the optimal sizing of such systems.

1. Introduction

The recent development and marketing of new home battery systems, combined with significant price reductions, have been seen by many as a catalyst for a solar energy revolution and have created high expectations in the sector. Significant uptake of combined photovoltaic (PV)/battery units is now seen as a possible future, which would lead to increased decentralised generation and higher self-consumption levels. In addition, if current cost reduction trends persist, it is predicted that these systems could ultimately disconnect from the grid and lead to autonomous homes or micro-grids.

At present, however, solar home battery systems are not in themselves economically viable in most EU countries: rooftop PV panels still require subsidies in the form of feed-in-tariffs, green certificates or favourable net metering schemes [1,2]. The benefits of battery systems are closely linked to higher levels of self-consumption and thus to exemptions from taxes and grid fees on the self-consumed part [2]. Increased self-consumption also raises concerns as regards the sharing of grid costs, taxes and levies: it

☆ The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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tends to reallocate costs from some prosumers who can afford the necessary investment to consumers who depend fully on the grid. The fact that the latter bear a higher proportion of non-energy-related costs is unfair and unsustainable [3].

The typical installation considered in this paper is depicted in Fig. 1: it consists of a DC-coupled PV and battery system, covering part of the household consumption and feeding excess electricity to the grid. Although the scope of the study is limited to single households, the proposed approach could easily be extended to public or commercial buildings, or to micro-grids comprising several households.

In order to provide reliable profitability indicators, we have to assess the volume of self-consumption made possible by a standalone PV system or the combination of a PV system with a home battery. A common simplification consists in assuming a fixed number of charging cycles over the lifetime of the battery. This is a convenient hypothesis, since it makes it easy to calculate the levelised cost of stored energy: if the lifetime is 10 years, a total of 3650 full daily cycles is assumed, which, once multiplied by the battery capacity and divided by the annualised investment, gives the levelised cost of stored kWh. As we demonstrate, however, this approach is erroneous, because the number of full equivalent cycles is usually less than one per day, and is highly dependent on battery capacity: a small battery tends to perform almost one full cycle every day, while a large battery presents much more limited average charge/discharge cycles.

The economic viability of PV combined with battery storage was evaluated in 2014 in the German context [5]. The authors concluded that, for an economically rational household, investments in battery storage are already profitable for small residential PV systems. However, the cost assumption for the battery system was very low (EUR 171/kWh + EUR 172/kW); a Bloomberg market survey from January 2016 indicates that the 2015 cost for batteries should be taken as being around USD 1250/kWh [6]. Other studies, such as [7], find that PV is profitable under current German regulations, but that batteries still need to become significantly cheaper if they are to be economically viable.

Truong et al. [8] analyses the profitability of a particular home battery brand in the case of Germany. They conclude that these systems require subsidies and increasing retails price of electricity to be economically viable. In [9], the economics of PV/battery systems is evaluated for the case of a supermarket. The results indicate that PV alone is profitable, with an optimum installed capacity around 200% of the peak load. However, the only scenario in which a battery is profitable is the one in which it costs decreases down to 200/kWh.

Studies on solar home batteries focus, *inter alia*, on systems' peak-shaving capabilities: if the maximum power that can be exchanged with the grid is limited, power curtailment can be significantly reduced by using a battery and an appropriate charging strategy. However, this also decreases the self-consumption rate (SCR) [10,11].

Various studies also focus on quantifying self-consumption with respect to system design. For example [12], shows that, depending on the battery size (0–32 kWh), the self-sufficiency rate (SSR) varies from 30% to 66% in winter and 48–99% in summer. Truong et al. [8] obtains similar results for a German houshold, in which a 7 kWh battery increases SSR from 38% to 65%. However, this effect decreases in time due to battery degradation. Weniger et al. [7] shows that self sufficiency of roughly 54% is achievable with a battery system of 1 kWh per MWh of yearly consumption and a PV system of 1 kWp/MWh. For SSRs above 70%, the PV and battery systems become prohibitively large.

To increase self-consumption, an alternative to battery storage is demand side management (DSM) through load shifting. This option has also been considered in previous studies, with very variable results. In [13], DSM only increases self-consumption by 7% and the system does not seem economically viable. Constrastingly, in [14], DSM increases SSR from 30.9% to 56.9%, and this figure goes up to 76% if a battery is added to the system.

Because consumption and production profiles directly affect SSR, the quality of the input data is key when evaluating self-consumption. Household consumption profiles are often available as aggregates, obtained by averaging the profiles of different households or daily profiles over a given time period (e.g. one month) [15]. This approach neglects the fast and wide variations in consumption. It can therefore bias the analysis: Kastel and Gilory-Scott [16] shows that the error between aggregated and original curves varies between 10% and 15% for the computation of self-consumption. To overcome this, we considered only high time-resolution, disaggregated household consumption profiles. Contrary to most previous studies, we also aim to simulate a high number of profiles so as to provide statistically-significant self-consumption indicators.

The final goal is to develop a simple tool (in the form of an equation) to quantify self consumption as a function of the installed PV and battery sizes. This kind of information is key for researchers or policy makers willing to evaluate the impacts (e.g. financial) of the deployment of such technologies. Because of its computational efficiency, it can also be used for the optimal sizing of such systems in a large number of possible configurations and cost assumptions.

We propose the following general approach:

1. A database of household 15-min electricity consumption profiles is gathered for the following countries: Belgium, Spain, Germany, Denmark, Hungary, Italy, Romania, France and the United Kingdom. These are simulated in conjunction with a PV generation model and a simple battery model. Irradiation and temperature profiles are obtained from typical meteorological year datasets;
2. The volume of self-consumption is derived as a function of the relative sizes of the yearly demand, PV generation and battery capacity. This analysis is carried out for all household profiles, the number of which is deemed sufficient to derive statistically significant SCR and SSR values; and

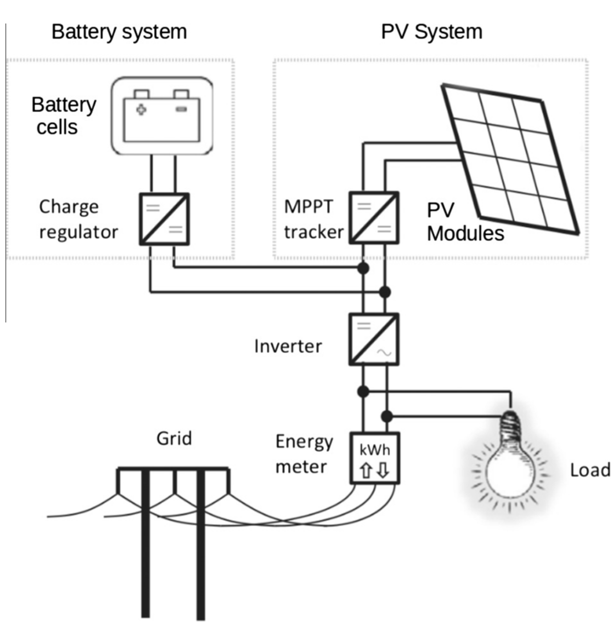

Fig. 1. Conceptual scheme of the considered DC-coupled system. Adapted from [4].