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A prospective economic assessment of residential PV self-consumption with batteries and its systemic effects: The French case in 2030

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ABSTRACT

The coupling market dynamics of PV sector and Li-ion batteries enhances the economics of residential PV self-consumption. If residential PV self-consumption systems become economically competitive in the near future, end-users will be willing to switch to PV self-consumption instead of using power from the network. However, if this transition were to occur massively or suddenly, the national energy system would be faced with a radical change. Our study has shown that French residential PV systems combined with Li-ion batteries could become profitable for individual investors before 2030. The demand in the residential sector would thus be natural in the near future in France. However, massive PV integration raises new issues for electricity system stakeholders (e.g. profit losses for traditional power generators, grid management, and sub-optimisation of the power system). This study has shown that PV self-consumption with batteries has a smaller impact on the power system than full grid injection. It is also shown that rapid integration is more costly than the progressive option with regard to PV system integration. We thus recommend a regular and progressive policy when transitioning to PV self-consumption to allow enough time for stakeholders to adapt to the new market situation.

1. Introduction

The PV sector has demonstrated visible progress over the last decade, reaching more than 300 gigawatts (GW) of installed capacity in 2016 (IEA PVPS, 2002–2015; Solar Power Europe, 2017). The reduced cost of PV modules has helped enhance the economic competitiveness of PV systems. End-users have economic incentives to adapt the mode of PV electricity self-consumption so as to reduce their electricity bills compared with the conventional way of purchasing electricity from the grid.

If residential PV systems coupled with batteries become economically competitive with a high ratio of self-consumption in the near future, end-users will be willing to switch to the self-consumption of PV electricity instead of using power from the network. A rupture (or radical change) could impact the national power system if the transition of PV self-consumption in the residential sector occurs massively or suddenly. Such change will influence the interests of the electricity market stakeholders and can be problematic for the national energy system. Policymakers would therefore have to focus on an optimal mix of PV power to achieve a careful balance with the other energy technologies. This is why policymakers need to understand the timing of this transition in order to detect any changes and to anticipate any transformation.

In this context, this study sets out to forecast any radical changes in the residential sector and discuss the role of policy. The article first assesses the future economic attractiveness of French residential PV systems coupled with lithium-ion (Li-ion) batteries in 2030. It gives a late threshold date since the evaluation is based on the French case where the electricity tariffs are relatively low and the residential PV system prices are higher. We then conduct a sensitivity analysis based on the key parameters used to define the LCOE estimates. The possible systemic consequences of a massive shift toward this solution are subsequently explained. The systemic effects of integrating PV into the power system have also been analysed. The ultimate objective is to help policymakers forecast possible scenarios for PV self-consumption so they can prepare for the future transition with strategic actions. By way of conclusion, we discuss the policy implications and elaborate policy recommendations based on the results of this study.

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2. Research context

2.1. Solar PV energy in power systems according to IEA scenarios in 2030

The Paris Agreement defined the international climate objectives to keep the mean global temperature rise to well below 2 degrees above pre-industrial levels and to limit the temperature rise even further to 1.5 degrees above pre-industrial levels (UNFCCC, 2015).[1] Solar PV energy is highlighted as a solution making it possible to meet such objectives. According to the IEA hi-renewable (hi-Ren) scenario, 16% of the global electricity will be supplied by solar PV power by 2050. This study was based on two IEA energy scenarios (IEA, 2014a, 2014b) to estimate the PV system prices in 2030: 2DS and hi-Ren. The IEA 2 degree scenario (2DS) proposes a radical energy system transformation to reach a mean global temperature rise limited to 2 °C by 2100 (IEA, 2014b). Furthermore, the IEA hi-Ren scenario[2] suggests that even greater efforts are required to shift to a low-carbon energy system based on the larger integration of renewable energies.

Table 1 illustrates the IEA solar PV goals with respect to the PV installed capacity and PV electricity generation by 2030 and 2050. Supported by the political efforts of many countries aiming to reduce their carbon footprint or to increase their energy independence, the PV sector is currently on track to meet the 2DS target (IEA, 2016).

Table 1
IEA's solar PV targets for 2030 and 2050.

	Actual	2DS		Hi-Ren	
Year	2015	2030	2050	2030	2050
Installed PV capacity	227 GW	841 GW	2785 GW	1721 GW	4674 GW
PV electricity generation	285 TWh	1141 TWh	3824 TWh	2370 TWh	6300 TWh

2.2. Literature review of PV self-consumption

The self-consumption of photovoltaic power in buildings is becoming increasingly relevant in the context of the energy transition. Self-consumption refers to the direct use of PV electricity on the same site where it is produced, with a smaller amount of electricity fed into the grid. PV self-consumption can imply many different solutions, from stand-alone off-grid systems in rural regions to the local consumption of smart energy systems. Thus, the literature on self-consumption is diverse, encompassing a wide range of technologies and systems.

A combination of increasing grid power costs, decreasing PV system costs and reduced feed-in-tariffs (e.g. the German EEG, (EPIA, 2013)) provides enough economic incentive to encourage PV self-consumption (Merei et al., 2016; IEA-RETD, 2014). The concept of prosumers (producers and consumers) is important in defining the concept of PV self-consumption in electricity systems since customers become more proactive with respect to power consumption by installing solar PV panels and managing their energy bills. The power sector is transforming from the traditional centralized system to locally presuming systems (Lavrijssen and Carrillo Parra, 2017; Parag and Sovacool, 2016).

The ratio of self-consumption, which defines the rate between onsite consumption and the total production of the system installed on the site, is a very important factor for defining the economics of the PV self-consumption model. The degree of PV self-consumption differs according to the power consumption profile in buildings. Unlike industrial or commercial sectors, however, the degree of self-consumption is smaller in separate residential systems because of a low correlation between onsite consumption and PV system output (EPIA, 2013; Quoilin et al., 2016). Luthander et al. (2015) explained that the level of self-consumption can be increased through methods like demand-side management or coupling with storage technologies.

Kyriakopoulos and Arabatzis (2016) have described a range of energy storage technology choices available for power generation. Diouf and Pode (2015) indicated that lithium-ion batteries can be a promising technology in the context of renewable energies. Driven by the need for mobile devices, together with the emerging electrical vehicle (EV) markets, the lithium-ion (Li-ion) battery technology has shown remarkable progress. The capital costs of Li-ion batteries are expected to fall over the next few years (Deutsche Bank, 2016; Beetz, 2015). This possible cost reduction makes the large-scale deployment of PV systems in the residential sector a feasible solution. Merei et al. (2016) has shown the profitability of PV self-consumption for the commercial sector can be enhanced by combining it with batteries on the condition that the battery costs can be reduced to €200/kW h in the future. Regarding the residential sector, Braun et al. (2009) has shown in the French-German Sol-ion project that the use of the lithium-ion technology increases PV self-consumption without changing user consumption habits. They calculated that the system could become profitable if the cost of Li-ion batteries fell under €350/kWh.

More recently, Eusebio and Camus (2016) claimed that residential PV systems with battery back-up power reached grid parity in Portugal following the decrease in battery prices. In addition, Shah et al. (2015) mentioned the potential of using off-grid residential hybrid energy systems (solar PV, battery, and combined heat and power) to address the national energy transition and system integration. In addition, Yu (2017) analysed the socio-economic benefits of off-grid PV systems with batteries in less-developed regions like Africa and South East Asia. Some studies provided insight into optimal sizes of residential distributed batteries (Weniger et al., 2014; Huld et al., 2014; Partlin et al., 2015).

Various factors should be taken into account to explain the decision of customers to adopt renewable energy technologies (Luthra et al., 2015). Reddy and Painuly (2004) provided a set of barrier groups for the penetration of renewable technologies: lack of awareness, financial, market, technical, institutional and behavioural. Sen and Ganguly (2017) stated market failures, awareness, socio-cultural aspects, and policy as barriers of renewable energy development. Sommerfeld et al. (2017) indicated the importance of correctly understanding consumer behavioural patterns with respect to PV self-consumption to guarantee the accuracy of future PV policies. Social feasibility (Kimura and Suzuki, 2006; Sen and Ganguly, 2017) or individual desire for greater energy autonomy (IEA-RETD, 2014; Yu and Popiolek, 2015) should not be ignored when explaining the consumer decision-making process. For example, Tsantopoulos et al. (2014) analysed the attitude of citizens to installing photovoltaic systems. The study found that Greek citizens were sufficiently willing to invest in photovoltaic systems either residentially or on a plot of land, though their motivation was quite different according to their income level and education. However, the economic driver is one of the key aspects behind the decision of residential end-users to use PV self-consumption (Sommerfeld et al., 2017; Reddy and Painuly, 2004; IEA-RETD, 2014).

In addition, some studies highlighted the importance of a systemic approach to assessing the economics of PV systems with regard to PV integration (Keppler and Cometto, 2012; Hirth, 2014). For example, Keppler and Cometto (2012) provided comprehensive insight into the technical and economic aspects conditioning the high penetration of PV power.

In this context, this study aims to assess the economic feasibility of

[1] Articles 2 and 4.

[2] The scenario is a variant of the 2DS model, assuming the slower deployment of nuclear energy, the delayed introduction of carbon capture and storage (CCS) technologies and the more rapid deployment of renewables, notably solar and wind energies.