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Solar photovoltaic self-consumption in the UK residential sector: New estimates from a smart grid demonstration project

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ABSTRACT

The economic incentive to install a solar photovoltaics ('PV') system depends increasingly on using PV generation on-site ('self-consumption') rather than receiving payments from generating solar energy and exporting it to the grid. There is, however, remarkably little empirical evidence on self-consumption. This paper begins to address this gap by analysing one-minute electricity monitoring data for 302 households that participated in a UK smart grid demonstration project. We calculate annual self-consumption levels and find that they are 855 kWh/year per household on average, or 45% of PV generation. We conduct a simple regression analysis to estimate self-consumption and use the results to show that self-consumption for an average UK household with electricity demand of 4000 kWh/year and 2.9 kWp PV system would be 966 ± 38 kWh/year, equivalent to a 24% reduction in average annual electricity demand from the grid. Our methodology can be readily applied to measure and predict self-consumption in other solar markets as well, which has increasingly important implications for valuing solar investments, setting feed-in tariffs, and examining the impacts of PV on networks and retail sales.

1. Introduction

Addressing climate change and reducing greenhouse gas emissions will require a rapid transition to electricity systems that are sustainable, affordable, and secure (Edenhofer et al., 2014; Pfeiffer et al., 2016). Solar photovoltaics ("PV") will almost certainly play a major role as a provider of zero carbon electricity (Carbon Tracker and Grantham Institute, 2017; Taylor et al., 2015). In the UK specifically, it has the highest level of public support of all low-carbon electricity generation technologies (BEIS, 2017a) and is expected to be the cheapest form of electricity generation by 2025, alongside onshore wind (Fig. 1). As of April 2017, over 12 GW of solar photovoltaics had been deployed, of which roughly 2.5 GW comes from small < 4 kW units associated with homes and small businesses and a further 4 GW from 4 kW to 5 MW arrays. (BEIS, 2017b). The trend is clear: solar PV is set to make a major contribution to UK electricity supply, and a substantial proportion of solar capacity will be highly-distributed.

Nonetheless, PV adoption in the UK residential sector has fallen dramatically from its peak rate of more than 55,000 installations per month in November 2011 to 2000–3000 per month in early 2017 (Fig. 2). This is at least partially in response to reductions in the government subsidy for residential PV – the feed-in tariff. The UK feed-in tariff has two components: a 'generation rate', which is a payment for each kWh generated by the PV (regardless of whether it is exported or used within the home), and an 'export rate', which is a payment for each kWh exported to the grid. Since its inception in April 2010, the UK government has progressively lowered the generation rate to reflect PV's falling capital costs (although the export rate has risen very slightly) (Fig. 2).[1]

Historically, the export rate has been low relative to the typical retail price of residential electricity (the 'import rate'). Because of this, in theory, households with PV benefit from shifting load from hours when they face import tariffs to hours when their PV is generating.[2] In other words, households with PV benefit from maximizing consumption of their own system's generation (i.e., 'self-consumption') when the export rate is lower than the import rate. The reverse is true if the export rate exceeds the import rate: households with PV would benefit from minimising self-consumption. Furthermore, the decline of the

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[1] Note the peaks in installations immediately before each drop in the generation rate. This reflects consumers rushing to adopt solar before an anticipated subsidy drop and suggests the subsidy levels at least partially impacted installation rates.

[2] A summary of typical feed-in tariff and metering configurations in the UK and other countries and how they incentivise different types of demand response behaviour can be found in McKenna and Thomson (2013, 2014).

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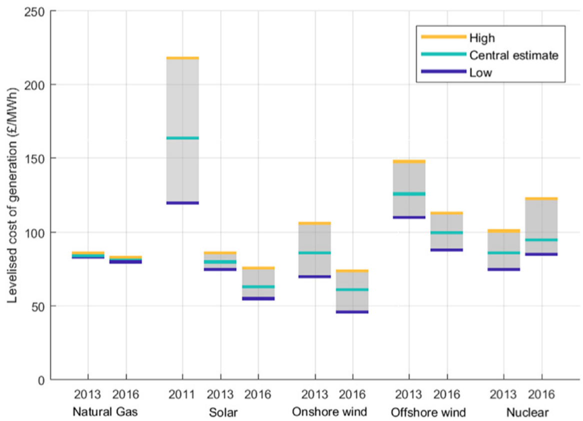

Fig. 1. Forecasts of comparable costs of electricity generation in Britain for 2025. Dates show year forecasts were published. Data from (Arup, 2011; BEIS, 2016a; DECC, 2013).

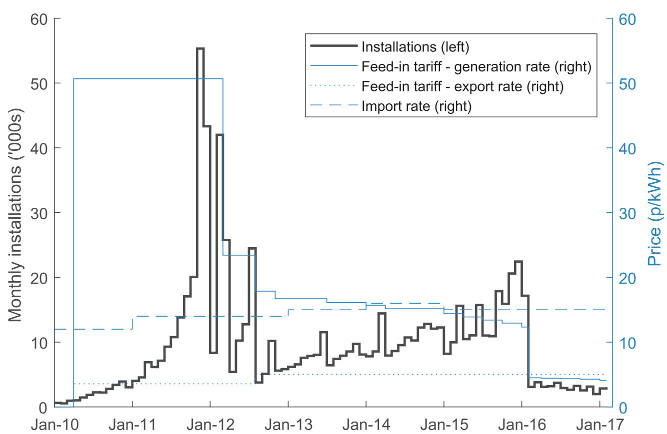

Fig. 2. Trends in deployment and feed-in tariff for residential PV in the UK. Typical residential import rate (retail price of electricity) also shown. Monthly installations from (BEIS, 2017c), feed-in tariff rates from (Ofgem, 2017) and import rates from (BEIS, 2017d; DECC, 2016).

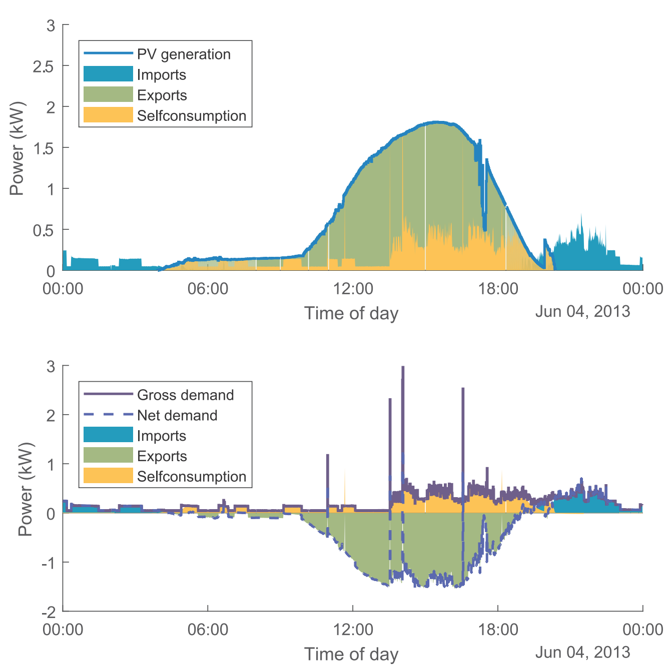

Fig. 3. Electrical power flows for a summer day for an example residential household with PV in UK. Data from (CLNR, 2017).

generation feed-in tariff rate has made maximizing self-consumption even more important—as the FiT historically played a significant role in determining solar investment payback, electricity bill savings (achieved through self-consumption) make up an increasing proportion of the overall returns to solar investment. Fig. 3 illustrates the relevant power flows for understanding self-consumption.

As noted, households with PV in general have a strong incentive to maximise self-consumption when import rates exceed export rates because of the electricity bill savings accrued when load is shifted from times of the day when it would otherwise face import tariff rates. However, households with PV in the UK have an even stronger incentive to self-consume due to a lack of smart metering for exports.[3] Exports are not directly measured but rather 'deemed' to be 50% of generation. As such, the financial benefit from exporting solar power to the grid (which should be excess generation as a function of the household's consumption *and* solar generation) is strictly a function of solar generation only (and the static 50% export assumption). Until smart meters are rolled out with the capacity to measure imports and exports in near-real-time, and dynamic pricing and half-hourly settlement are established, any electricity produced by domestic PV and used within the home is essentially free (zero marginal cost).[4]

As feed-in tariffs decrease and self-consumption plays a more important role in the economics of PV, potential PV adopters face greater uncertainty about the expected return on their investment, as this depends not only on estimating PV generation but also self-consumption. Therefore, estimating and predicting PV self-consumption can help potential adopters make informed judgements about their potential return on investment by reducing the amount of electricity they import from the grid.

Estimating self-consumption and predicting the resulting electricity bill savings are also critical for policymakers, as electricity bill savings estimates are often used to calculate the appropriate feed-in tariff rate to achieve PV deployment targets (DECC, 2015a). This is a particularly timely topic in the face of retail electricity price increases and regulatory changes. For example, in 2015, the UK government consulted on a review of the feed-in tariff scheme to ensure that deployment and spending were brought under control, and that generators were 'not making excessive returns on their investments' (DECC, 2015b). The review included an assessment and call for further evidence on the government's assumed self-consumption rate of 50% (relative to PV generation) for residential systems. The response to the consultation concluded there was 'little usable evidence' (DECC, 2015a, p. 31), despite over 800k residential PV systems in the UK (BEIS, 2017c). Based on the limited evidence available, the range of self-consumption rates was assumed to be 25–45% and a deliberately high value of 45% was chosen to 'encourage those installations that make most use of the renewable electricity generated' (DECC, 2015a, p. 31). There are also other markets around the world where self-consumption is becoming the main economic driver for solar, such as in Germany, France, and Spain (Labastida, 2017).

Lastly, self-consumption is also important for examining how increasing penetration of intermittent renewable electricity impacts electricity grids and for predicting retail sales. The challenge of balancing supply and demand of electricity on the high-voltage grid in real-time has been made more difficult as the growing volume of PV generation is connected to the distribution network and its output is effectively invisible to the system operator. Difficulties in forecasting PV generation mean there are real risks of periods with too much

[3] To be clear, we are not referring to a lack of smart meters in the general population, but a lack of consumers with PV registered for FiTs that are recorded as having metered exports rather than deemed exports.

[4] If half-hourly settlement and smart metering are introduced, the picture becomes more complicated, but still there will be an incentive to self-consume as long as import rates are higher than export rates, and assuming there is no opportunity cost of shifting load to different times of the day.