Increasing residential self-consumption of PV energy by DSM

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Abstract:

Since 2012, the feed-in remuneration for newly installed PV systems is smaller than the energy costs in Germany. Therefore, maximizing self-consumption of residential PV systems is profitable. Demand Side Management (DSM) measures can support this by adjustment of the household's energy consumption pattern by shifting the time of operation of suitable household appliances. This paper investigates both the potential savings and the increased self-consumption rate which can be achieved by DSM. Furthermore, the effects on user behavior are presented. The analyses are based on the total power consumption of 565 households as well as load profiles and operation times of dishwashers, washing machines and dryers.

Keywords: PV system, residential self-consumption, Demand Side Management, Smart Meter

1 Introduction

In 2012, grid parity for German private households has been reached. [1] Since then, feed-in remuneration of photovoltaics (PV) is smaller than the cost of energy from the grid for newly installed systems. This means that it is financially rewarding to consume as much self-produced PV energy as possible. The difference between energy costs and feed-in remuneration can be seen as savings. Several options, like battery storage or DSM can be used to increase the self-consumption rate. This paper focuses on DSM, which means a temporally adjustment of the household's energy demand. With DSM, the operation of certain appliances is delayed. This can be achieved manually or with some kind of energy management system which coordinates the starting times automatically after the device has been set to "ready". Simulations of these DSM measures based on real consumption data can be applied in order to quantify the effects on customer behavior and on possible savings.

Similar analyses have already been performed: "*Simulations of daily load scheduling were performed to match on-site PV power generation and recent (2008-2012) hourly electricity market prices, using a set of high-resolution (10 min) appliance load profiles from 200 monitored Swedish households. (…) The maximum economic benefit over the studied years was 20 EUR per year and household."* [2] The main result of these investigations is "(…) *that there is an overall low potential for improved self-consumption through optimal scheduling of the studied appliances, at least with the current Swedish market conditions."* [2] The author also mentions the dependence on the market conditions.

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2 Methods

The evaluation of these DSM measures is based on time-resolved power consumption data for 565 German households. Load profiles and operation times of relevant appliances (dishwasher, washing machine and dryer) are identified by disaggregation of the total load. [3] Every household is assumed to already have a PV system, so acquisition costs are not considered. PV generation is computationally simulated based on radiation and temperature [4]. User behavior and effects on monetary savings and self-consumption rates are investigated for three different sizes of the PV system (3 kW, 5 kW and 7 kW) and three different maximum shifting intervals (3 h, 5 h and 8 h). For comparison, another scenario is analyzed which not only allows postponing the operation times but also shifting to an earlier point in time.

The self-consumption rate of PV energy depends on both PV production and household demand. It has to be taken into account that as soon as a device is shifted to another time, this also affects the rate during the original operation time.

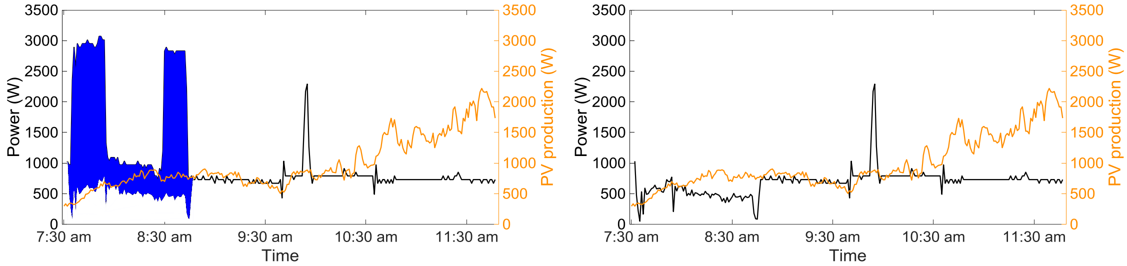

Figure 1: *Total power consumption with (left) and without (right) appliance load profile*

Figure 1 (left) shows the shifting interval of three hours for a recognized dishwasher. The total power consumption is drawn in black, whereas the appliance's load profile is represented by the blue area. PV production of the relevant day is shown on the secondary axis. Removing the blue parts leads to the consumption pattern depicted in Figure 1 (right). After that, every possible position of the load profile within the allowed shifting interval is examined regarding a possible increase of self-consumption. In this example, a delay to boundary of the interval (cf. Figure 2) leads to the best results and therefore the operation time is adjusted.

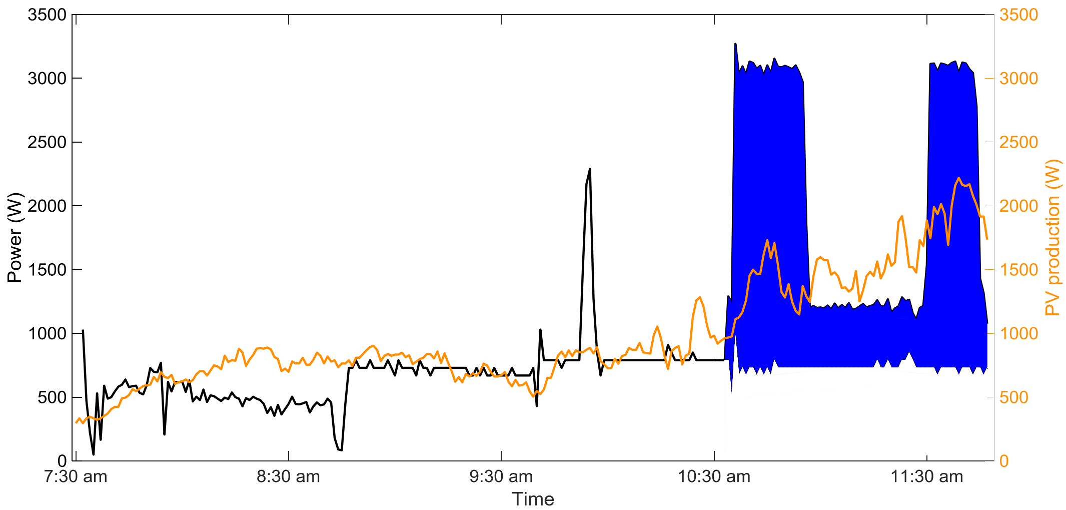

Figure 2: *Total power consumption with delayed appliance*

This is iteratively repeated for every recognized appliance in the consumption data. For combined occurrences of washing machine and dryer, these appliances are also shifted as a group. In order to quantify the effect of these DSM measures, the increase of self-consumption is calculated. Additionally, the monetary savings are determined. For these computations, the feed-in remuneration is set to 0.1231 EUR/kWh which is equivalent to the value for PV systems which have been installed until May 2016. [1] The average energy price in the relevant region is 0.2643 EUR/kWh, which yields potential savings of 0.1412 EUR/kWh.

3 Results

The described method results in a change in user behavior. This can be visualized via average operation probability for different types of days. Figure 3 shows these probabilities for dishwashers for nine types of days: working day, Saturday and Sunday for three different seasons where “transition” includes both spring and fall. The blue bars show the normalized probability for starting the dishwasher during the relevant interval. Since it’s a probability, it does not represent the absolute number or frequency of uses. It can be seen that during working days of all seasons, most of the dishwashers are used during the evenings. Weekend days evince an additional peak around noon.

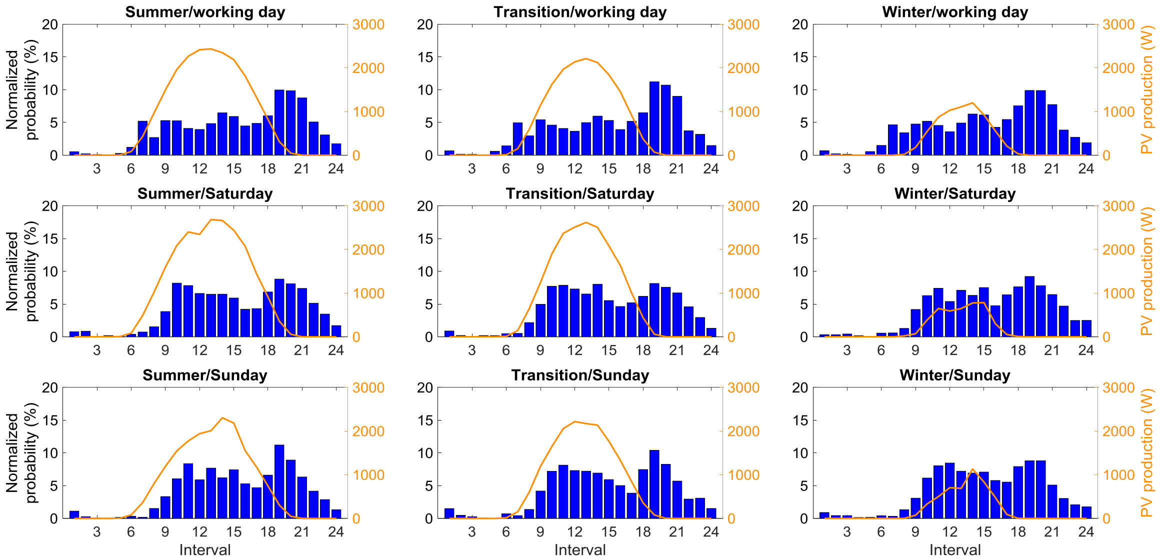

Figure 3: *User behavior – dishwashers – 5 kW*

PV generation for a PV plant with a peak power of 5 kW is displayed on the second axis. As expected, summer days have significantly higher values than winter days. It also shows that the typical user behavior does not fit the PV curve, leaving potential for optimization.

The adjusted user behavior according to the described algorithm is depicted in Figure 4. The usage pattern for all types of days significantly changed. The small peak in the mornings of workdays disappeared, since the operation is shifted to times of higher PV generation around noon. Similar, but smaller, changes occur for weekends. Due to decreasing PV generation in the afternoon, this part of the days remains almost unchanged, since postponing does not yield increased self-consumption. However, the shifting interval of 8 h is an exception here, as it allows postponing from the evening to the next morning.

Figure 5 shows the probabilities of the enhanced scenario with shifting in both directions. Similarly to the previous results, usage from the morning is delayed to noon. Additionally, afternoon and evening are also shifted to the time around noon, which results in a probability distribution which resembles the PV generation curve.

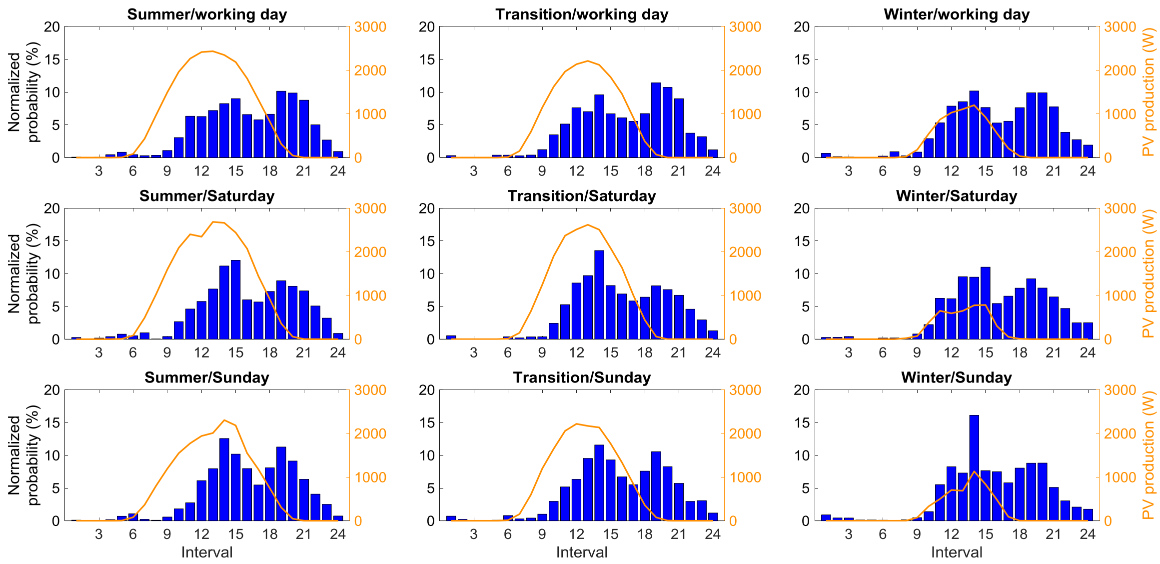

Figure 4: *User behavior shifted by 5 h – dishwashers – 5 kW*

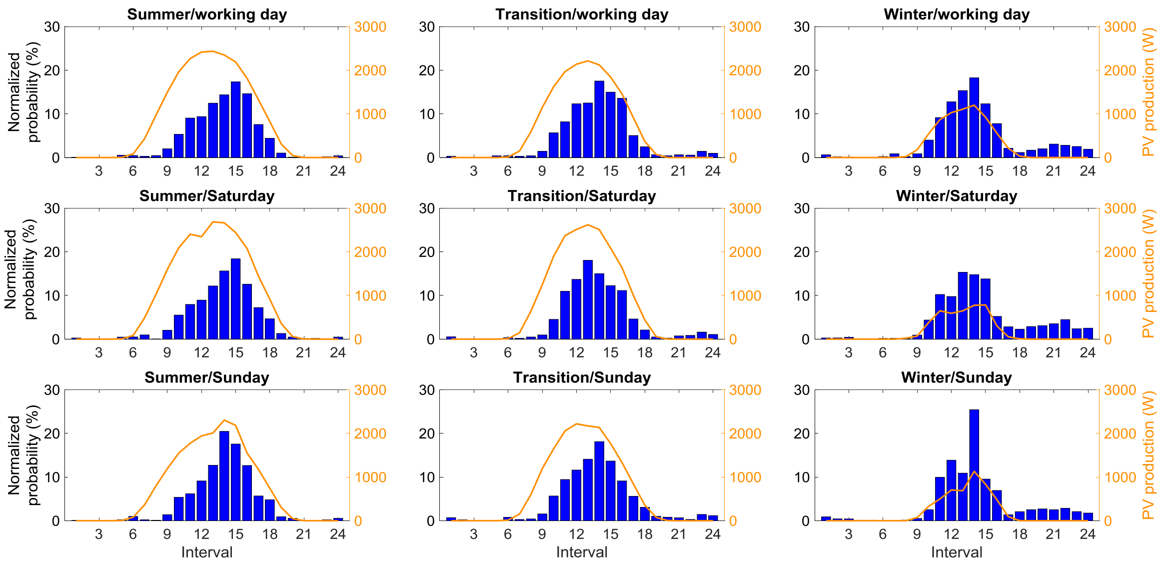

Figure 5: *User behavior shifted by 5 h in both directions – dishwashers – 5 kW*

Due to lower PV production during the winter season some late uses remain at their original point of times because other appliances already consume the whole PV energy. The lower PV production is also the reason why the uses during the winter interval are concentrated on fewer hours compared to the other two seasons. Because of the additional option of shifting devices in two directions, only a few appliances are postponed to the next day like it happened for the eight-hour delay scenario.

Without a financial incentive, this simulated load shifting is unlikely to actually happen. [5] Therefore, the potential savings for every household are calculated in the next step. Figure 6 shows the results, summed over all three types of appliances, in a boxplot. As expected from the probability distributions, shifting in both directions leads to significantly higher values, since the evening peak can also be shifted. But still these values are on average rather small, so it is questionable whether this current market setting is enough motivation for this rather massive change in behavior. Most values are below 20 € per annum, which is also confirmed by literature [2].

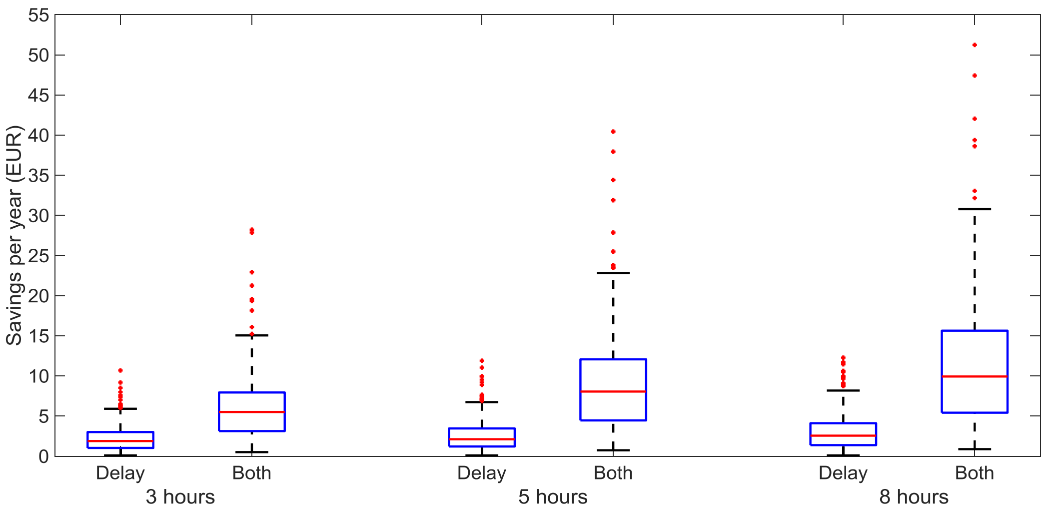

Figure 6: *Distribution of yearly savings for both scenarios*

In Table 1, the average saving potential is listed numerically. The table shows a kind of saturation effect which can't be seen in the boxplot. For the scenario where appliances only can be postponed, the values for an installed peak power of 5 kW are always larger than for 7 kW, which seems counterintuitive, but can be explained with the full coverage of the household's demand over an extended period of time, which leaves no potential for optimization by load shifting.

Table 1: *Average saving potential for both scenarios*

Peak power	3 h		5 h		8 h	
	Delay	Both	Delay	Both	Delay	Both
3 kW	2.12 €	5.11 €	2.49 €	7.64 €	2.83 €	9.70 €
5 kW	2.27 €	6.11 €	2.64 €	9.00 €	3.08 €	11.22 €
7 kW	2.18 €	6.41 €	2.53 €	9.38 €	3.04 €	11.59 €

For the enhanced scenario with shifting devices in both directions the potential savings are higher for larger installed peak power. Because of the additional possibilities, the impact of the described effect is smaller. Nevertheless, the difference of savings between 5 kW and 7 kW is smaller than between 3 kW and 5 kW.

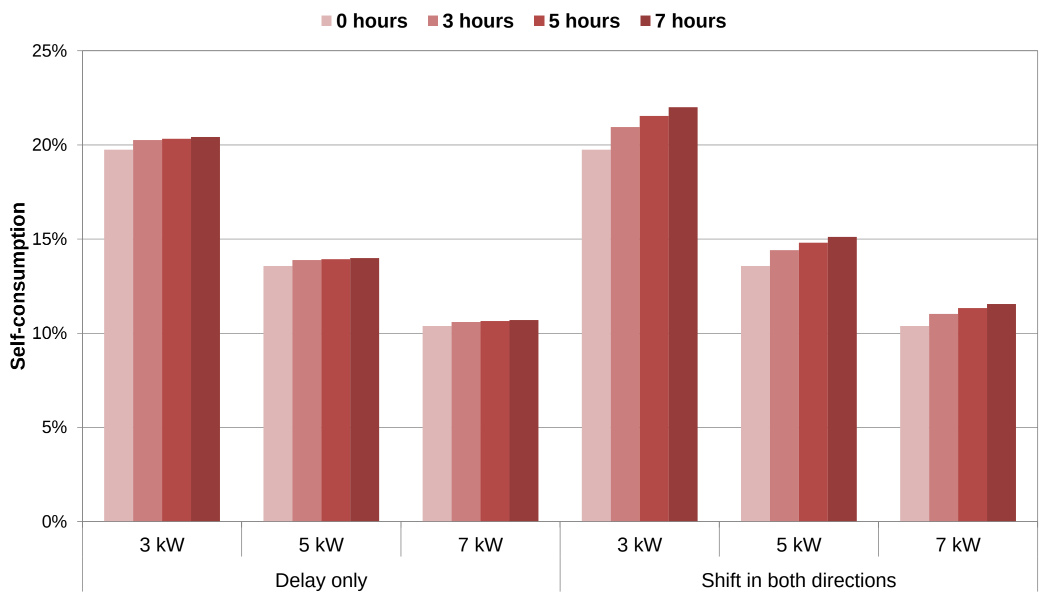

Figure 7: *Increased self-consumption rate with DSM*

The last subject of investigation is the rate of self-consumption. It is defined as the sum of directly consumed PV energy divided by the whole PV generation. [6] The results for both scenarios are depicted in Figure 7. The initial values are lower than comparable studies suggest [4]. This can be explained by the fact that the sample's mean consumption is only about 2 200 kWh, which is significantly less than average.

For higher peak power, the self-consumption rate is smaller, since the amount that can be consumed directly is defined by the household load, and therefore excess production reduces this rate. As already observed, shifting in both directions offers larger possibilities for increasing self-consumption, but an increase occurs for all configurations.

4 Conclusion

The described algorithm yields plausible simulation results. The calculations show that residential DSM with dishwashers, washing machines and dryers is a suitable method to increase the self-consumed energy from PV systems. The amount of increase strongly depends on the assumptions of allowed and accepted shifting: higher shifting intervals correspond with higher increase, and so does shifting in both directions compared to only postponing the time of operation. The increased self-consumption rate results in monetary savings for the household. These savings are rather small and account for only about 3 % of total energy costs of the respective households. Therefore, this might not pose a large enough incentive for actual changes in customer behavior in today's market setting. But due to constantly decreasing feed-in remuneration and the fact that PV systems which are older than 20 years won't get any feed-in remuneration, the amount of money which can be saved per additional self-consumed kWh is going to rise [1].

The presented method is also suitable to evaluate flexible tariffs as subject of investigation. This allows to quantify the effects of new tariff structures on customer behavior, and consequently on grid load, purchase prices and GHG emissions [7].

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