End-user value of on-site domestic photovoltaic generation with different metering options in Sweden

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Abstract

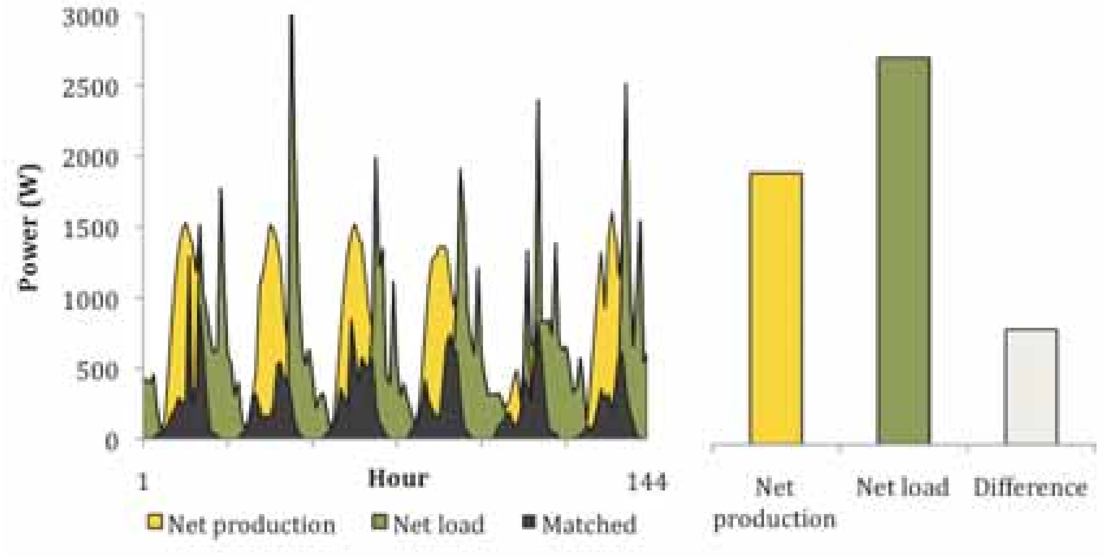
In Sweden the possibility for introducing net metering of on-site electricity production is currently being investigated by the government. In this paper we investigate if and how net metering improves the economics for small-scale photovoltaics (PV) in Swedish households, as compared to other metering alternatives. Data from both simulations and measurements are used to determine the degree of matching between production and demand at different billing periods for net metering. The results show that both the value of the produced PV electricity and the system sizes that are reasonable to install vary considerably between the different options. It is concluded that net metering would have a major impact on the value of on-site generation.

1. Introduction

Over the last couple of years the conditions for investing in photovoltaic (PV) systems in Sweden have gradually improved. Investment support to PV installations has been given in varying forms from 2005 and to complement these direct support schemes the Swedish government is currently investigating the possibility for introducing net metering for small-scale producers. This paper builds in part on an ongoing project that will supplement the governmental inquiry by investigating in more detail the effect of different metering alternatives (mainly different types of net metering as compared to the business-as-usual alternative or hourly metering) on the consequences for small-scale producers, power traders, grid companies and the state finances.

The concept of net metering is illustrated in Fig. 1. Typically, PV systems overproduce power during daytime, while there is a net demand during nights. With net metering the aggregated net production is subtracted from the net demand over a certain billing period, and the customer only pays for the difference.

The focus of this paper is net metering for residential end-users/producers in detached Swedish houses. The main questions asked are: How much will the production from a PV system be worth for such a small-scale producer with and without net metering and which are the optimal sizes of household-based PV systems with different metering options?



(a) (b)

Fig. 1. Schematic example of matching between PV power production and electricity load (a) and total balance between net production and net load (b) in a household. With net metering, the end-user only pays for the difference between net production and net load.

2. Methodology

Calculations of load matching and production value are done for one year with hourly power demand and PV production data. The studied metering and billing alternatives are:

A. Billing of net load (business-as-usual). Any surplus is submitted for free.

B. Hourly selling of net production to the market spot price.

C. Monthly net metering. Net production is subtracted from the net load each month.

D. Annual net metering. Net production is subtracted from the net load each year.

With net production at hour k denoted by $P_n(k)$, net demand by $L_n(k)$ and matched production and load by $M(k)$, the value of the production without net metering is:

$$C_p = C_s \sum_k P_n(k) + C_b \sum_k M(k)\,,\ k = 1,\ldots,8760 \tag{1}$$

where C_s and C_b are electricity selling and buying prices, respectively. In alternative A the selling price $C_s = 0$. Note that the matching part replaces purchased electricity and is worth the buying price, which is typically higher than the selling price. For monthly net metering (alternative C), total production during the billing period is subtracted from the total load, with the constraint that any period surplus cannot be sold:

$$C_{p,m} = C_b \left(\sum_{k=k_m}^{k_{m+1}-1} L_n(k) - \max\left[0, \sum_{k=k_m}^{k_{m+1}-1} L_n(k) - \sum_{k=k_m}^{k_{m+1}-1} P_n(k)\right]\right),\ m = 1,\ldots,12; \qquad C_p = \sum_{m=1}^{12} C_{p,m} \tag{2}$$

where k_m is the starting hourly index of each month. For annual net metering (alternative D) this value is evaluated for one year instead. The value can also be expressed per MWh total production:

$$\hat{C}_p = C_p \Big/ \sum_{k=1}^{8760} \left(P_n(k) + M(k)\right) \tag{3}$$

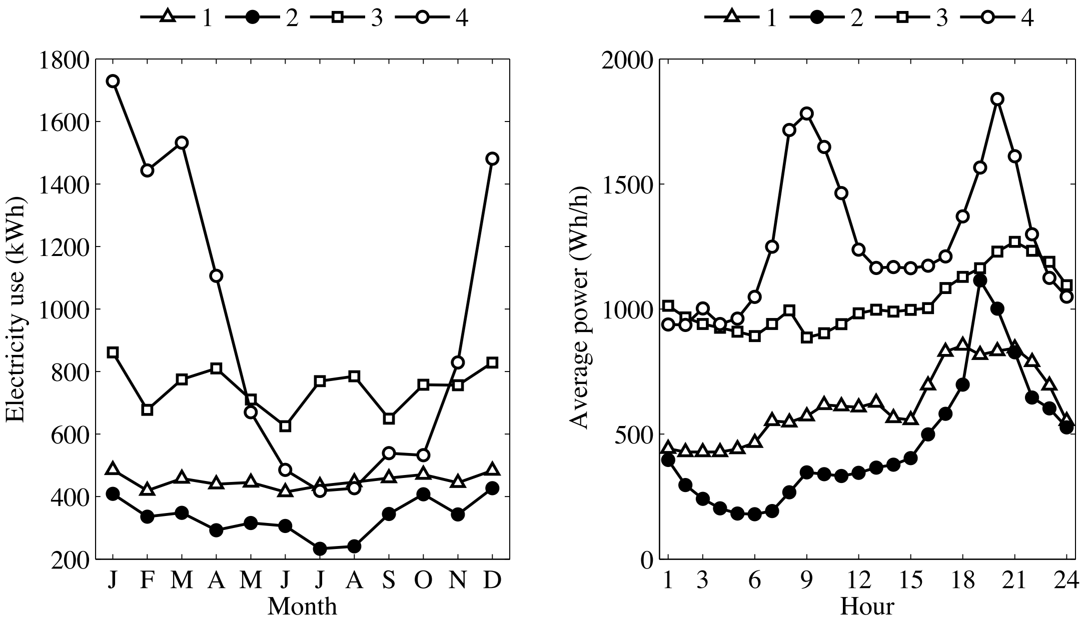
3. Data

3.1. Photovoltaic power production

PV production is modelled from irradiance data obtained from the Swedish Meteorological and Hydrological Institute (SMHI), covering beam and diffuse irradiation for Stockholm (59.35° N, 18.07° E), in 1999. Temperature data were obtained from a nearby meteorological station. For comparison with higher resolution simulations, minutely resolved irradiance data were also obtained for Stockholm. A model for simulating the power output of PV systems with specified tilt and azimuth angles from input beam and diffuse irradiance and temperature was applied to these data. The model is based on standard approaches in ref. [1]. The PV system output is determined in every time step k as:

$$P(k) = AI_T(k)\eta_c(I_T(k), T_a(k))\eta_{add} \tag{4}$$

where A is the surface area of the PV array, η_c is the conversion efficiency, set to 0.14 at standard test conditions (STC), I_T is the global in-plane irradiance, T_a is the ambient temperature and η_{add} represents further array losses and losses in additional equipment, such as inverters, set to 0.8. The conversion efficiency is dependent on the incident radiation and the measured ambient temperature. The model was applied to a standard roof tilt for detached houses (31°) and an orientation due south.



(a) (b)

Fig. 2. Load curves for the four households in the study; distribution of monthly totals (a) and average daily load curves calculated over the whole year (b).

3.2. Residential load profiles

Load data were obtained for four Swedish detached houses, in the following denoted households 1–4. The load of household 1 was constructed with the stochastic load model in ref. [3], which is representative of a typical Swedish household without electric heating. This simulation was done with a 1-min resolution and averaged to hourly data. Households 2–4 were obtained from the Swedish Energy Agency's recent measurement survey of household electricity [4] and are representative of different heating systems: district heating (2), natural gas (3) and direct electric heating with a heat pump (4). The differences in monthly total loads and daily load curves are shown in Fig. 2.

3.3. Electricity prices

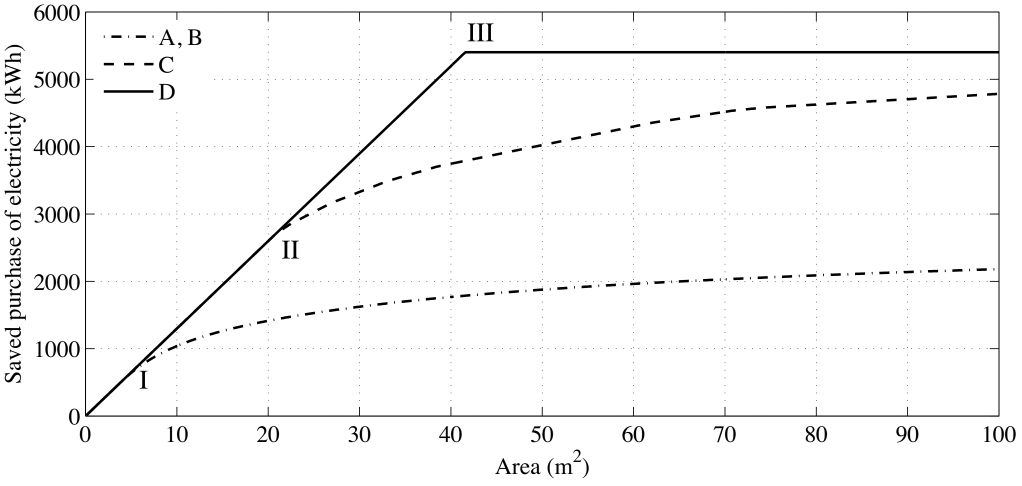
For residential customers there is a considerable difference between the price for bought electricity, which includes added costs and taxes, and sold electricity, which is normally the market spot price. Therefore, saving purchased electricity is worth more for the household than selling surplus electricity. In this study the selling price is set to C_s = 50 EUR/MWh and the buying price to C_b = 125 EUR/MWh, based on a typical price composition shown in Fig. 3.

Fig. 3. Typical composition of electricity buying and selling prices for a Swedish household (VAT = value added tax, GEC = green electricity certificate cost).

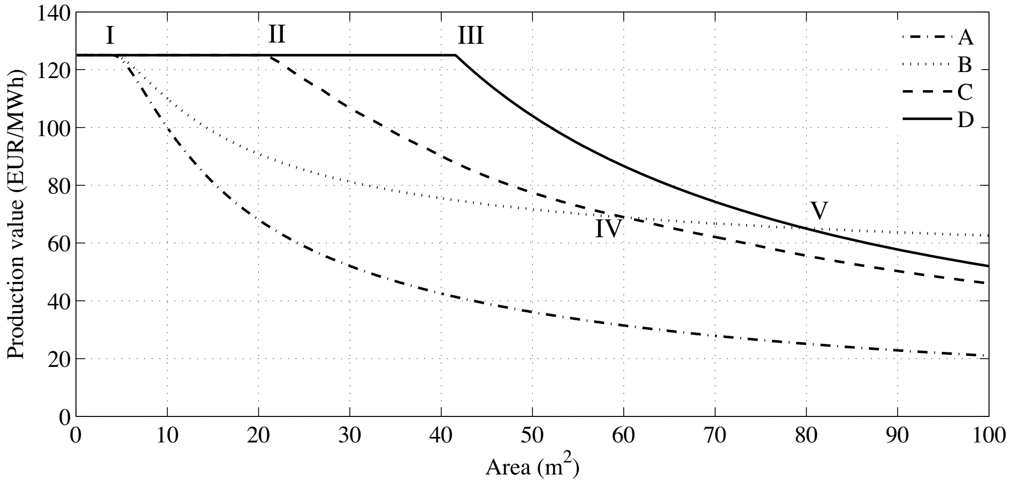
4. Results

4.1. Saved electricity purchase and production value

Fig. 4 shows the resulting saved electricity purchase and production value per produced MWh in household 1 as a function of PV system size, represented by the array area in m^2. The system size could also be expressed as system peak power, where 1 m^2 corresponds to 140 W_p. In (a) the three branching points I, II and III indicate at which system sizes a surplus starts to form. As a result, the savings level out for larger systems, as a larger fraction of the production is unmatched by the load. These branching points indicate the largest possible system sizes if the value per produced MWh is to be maximised. The production value is shown in (b), and it is clearly seen that the longer the net metering period, the larger the possible system size for which the value per MWh is equal to the buying price. For larger systems the value declines, eventually approaching zero for all metering alternatives except B (hourly sold surplus). This means that for sufficiently large systems, there will be two points of intersection with the C and D curves, beyond which hourly sale is more beneficial than net metering.

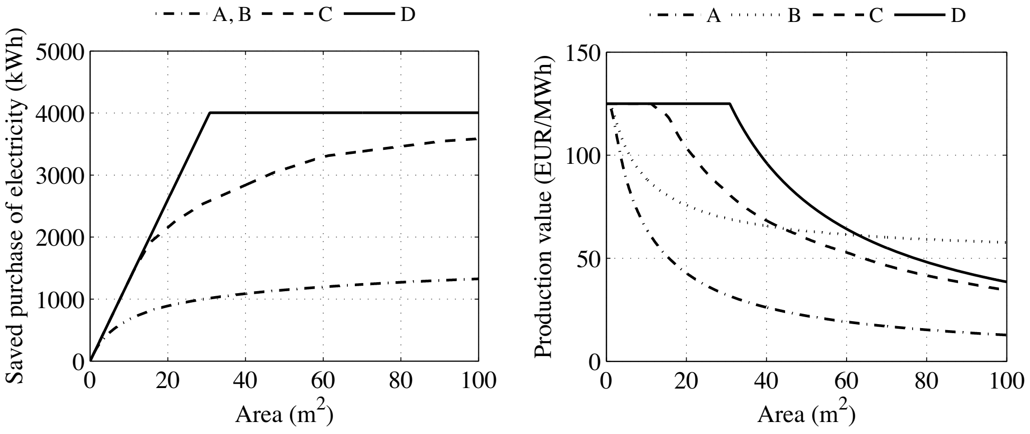


(a)

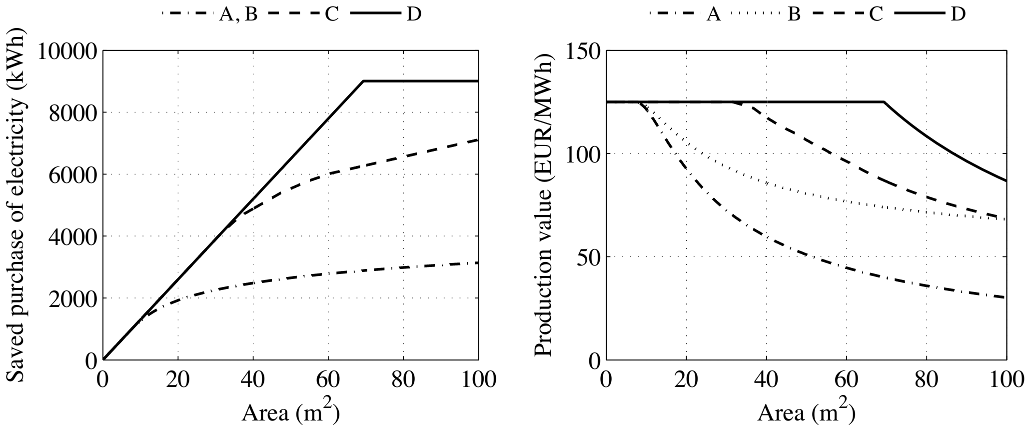


(b)

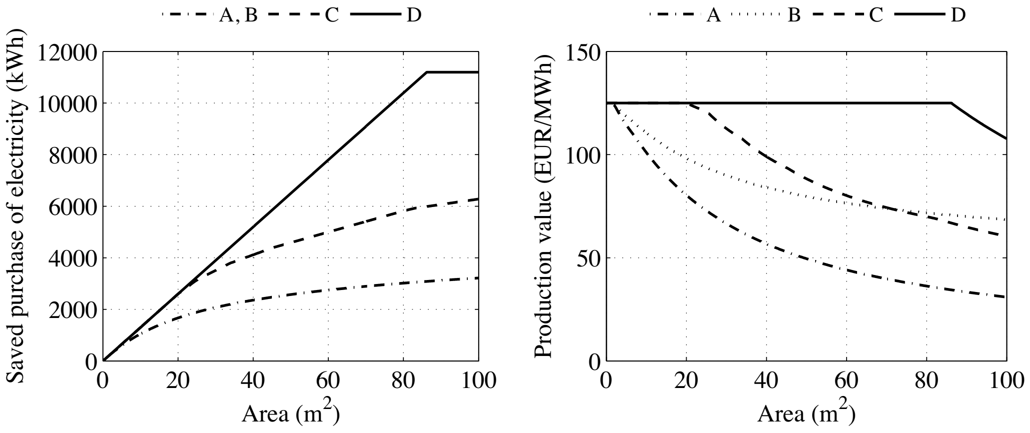
Fig. 4. Dependence of saved purchased electricity (a) and value of production (b) on the system size (represented by the PV array area) for household 1. Five points are indicated: I, II and III indicate the largest system sizes for which all produced electricity saves purchased electricity at hourly metering, monthly net metering and annual net metering, respectively. IV and V show for which system sizes hourly sold electricity makes the total production worth as much as monthly and annually net-metered production, respectively.



(a) Household 2



(b) Household 3



(c) Household 4

Fig. 5. Saved purchased electricity and value of production for households 2-4.

Figure 5 shows the same type of graphs for the other three, measured, households. There are two notable differences. Firstly, the load size determines which system size can be installed with maximised per-MWh values. With hourly and monthly metering, the largest systems can be installed in household 3, which has the highest day-time summer base load, while the houses with lower loads permit smaller systems. With annual net metering it is household 4, with the highest annual load, that permits the largest system size.

Secondly, the differences in load curves cause differences between the households in the relative improvement with the different metering alternatives. In all the three houses with non-electric heating (1-3), monthly net metering increases the saved purchased electricity from around 10-20 % of the total load at point I to about 50 % at point II. However, in household 4, which has direct electric heating, the monthly differences (cf. Fig. 2) cause a marked difference between monthly and annual net metering because of the seasonal mismatch with PV. In this case, point IV appears at a system size below that which gives annual balance between production and load, which means that hourly electricity sale is more beneficial than monthly net metering for this and larger system sizes.

Taken together, the results show that monthly net metering makes a considerable difference both for the end-user's production value and the maximum system sizes, more than doubling the latter compared to the business-as-usual situation. Annual net metering further doubles the possible system size, depending on the seasonal load distribution. It should be noted, though, that the largest systems in Figs. 4 and 5 are unlikely to be installed in detached houses because of the limited roof area.

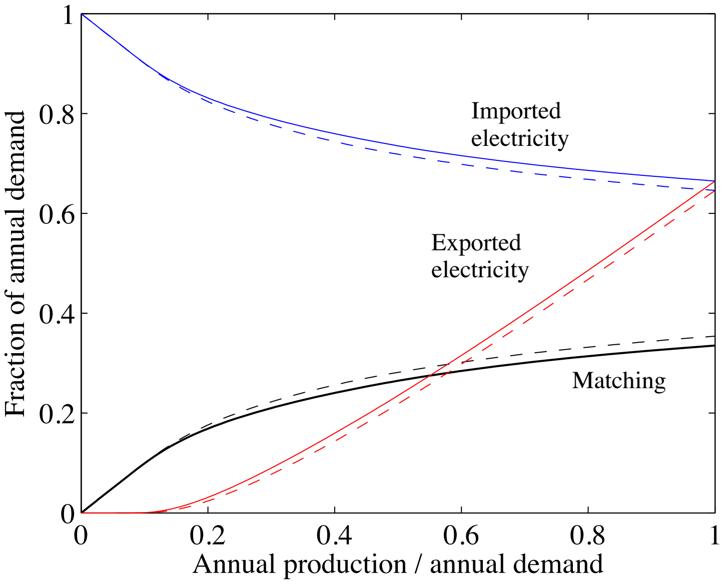


Fig. 6. Comparison between matched, exported and imported electricity calculated with minutely (solid lines) and hourly (dashed lines) resolution.

4.2. Dependence on time resolution

When evaluating metering alternatives A and B, the calculations above were done on hourly totals; however, in reality the matching in these cases is instantaneous and a higher resolution could be more realistic. To verify that hourly averages are sufficiently high-resolved, simulations were done on the original 1-min resolution data for household 1 and the 1-min resolution irradiance data. The results are summarised in Fig. 6 and show that for imported, exported and matched electricity, the differences in resolution give overall differences in the order of a few percent. This difference would have an insignificant impact on the above calculations.

5. Discussion

This analysis has been limited to detached houses. In further work the same approach will be applied to other end-users such as multi-family houses, offices and industries. The analysis is simplified in some respects. For example the buying and selling prices are constant. More detailed simulations involving hourly and seasonal market price variations could introduce further differences. As has been shown e.g. in ref. [5], the PV power production fluctuations coincide with spot prices on the Nordic electricity market to raise the production value compared to average values.

6. Conclusions

The main conclusion from the study is that net metering saves substantial amounts of purchased electricity compared to the business-as-usual situation. In effect, the system sizes that are reasonable to install are more than doubled with monthly net metering and several times larger with annual net metering. Without net metering, the system sizes that would be installed to maximise the production value would only cover a minor fraction of the annual demand.

Acknowledgments

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