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Profitability of Solar Photovoltaic Rooftop Systems in Buildings with Medium Sized Loads

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Abstract

In Sweden, it is generally most feasible to install solar photovoltaics (PV) primarily for self-consumption, as long as there either is a large enough load when the sun shines or that over-generation is generously compensated. Currently there are two support schemes for PV: a capital subsidy and a tax rebate for grid feed-ins. However, the latter is not available for systems above 100A, thus making self-consumption highly important for these systems. This paper studies the profitability of systems connected to loads from 100 to 700 MWh, most of them above 100A. In particular, it compares multi-family buildings to other building types. Analyses were based on measured electricity use matched to simulated PV yield and current market conditions. Calculations were conducted with and without consideration of existing roofs. In general, the supply points in multi-family buildings had less favorable load profiles than the ones in other buildings, which resulted in lower self-sufficiencies as well as relatively lower profitability and smaller system sizes. The support schemes turned out to be crucial for the profitability in most cases, but not all. For supply points in other building types with loads above 300 MWh profitable systems were found also without a subsidy. Taking areas and orientations of existing roofs into consideration drastically decreased the share of profitable systems.

Keywords: *solar photovoltaics, buildings, profitability, support schemes, Sweden, self-consumption*

1. Introduction

Sweden has a small but growing solar photovoltaic (PV) market with a majority of installations made on buildings (Lindahl, 2015). As in the rest of the world, system prices has decreased drastically the last few years, but due to low electricity prices, PV system investments are generally still in need of financial support to reach profitability. Sweden has an REC (Renewable Energy Certificates) system in place since 2003 and since 2009 there is also a direct capital subsidy program available for all PV installations connected to the grid. After a few years of discussions about a support scheme based on net billing, a tax rebate system for renewable electricity generated in small plants was introduced in 2015. A tax rebate of 0.60 SEK is achieved per kilowatt-hour electricity fed into the grid up to an equivalent amount that is bought from the grid during one calendar year. The tax rebate is only available for systems with a main fuse size of maximum 100A. After years of falling prices and with the new support scheme in place, the relevance of the investment subsidy has been questioned and there are ongoing discussions about the appropriate subsidy level for the near future.

The effects of current market conditions and support schemes were previously examined by the authors of this paper in an economic feasibility study of solar PV systems in Swedish multi-family buildings. Economic analyses were then conducted for 108 electricity supply points with loads ranging from 0 to 370 MWh and fuse sizes from 16 to 250A. The study has been presented in the article “Economic feasibility of solar photovoltaic rooftop systems in a complex setting: A Swedish case study” submitted to Energy earlier this year. Today, it is generally most feasible to install solar PV primarily for the purpose of self-consumption, as long as there either is a large enough load during hours with high insolation (in Sweden mainly daytime April – September) or over-generation of PV electricity is generously compensated. However, it was shown that the

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profitability of a PV system is highly affected by both building specific parameters and load characteristics.

In this paper, the profitability analysis was expanded to comprise also other types of buildings and it focuses on electricity supply points with medium sized loads (100 – 700 MWh). Most of the studied supply points have main fuses above 100A, and are therefore not entitled to the tax rebate described above. The paper examines the importance of an investment subsidy under different circumstances and aims to show how the profitability as well as self-sufficiency of a PV system is affected by the size of the load and load profile. In particular, the results of multi-family buildings are compared to the results of other buildings. Moreover, the influence and potential limitations of existing roofs were studied.

2. Method

Economic analyses were conducted for 35 PV systems based on measured electricity use matched to simulated PV electricity generation. For each of the electricity loads a PV system was sized according to highest system profitability. First, the analyses were carried out for optimally oriented systems (oriented to give a high annual yield) and thereafter consideration was taken to the slopes and orientations of existing roofs.

The method used in this paper has previously been used and described in the article "Economic feasibility of solar photovoltaic rooftop systems in a complex setting: A Swedish case study" (Haegermark, Kovacs and Dalenbäck), which was submitted to Energy 2016. Therefore, a condensed version of the methodology description is given below along with input data used in this study.

This study comprises 22 electricity supply points in multi-family buildings and 13 supply points in buildings with other types of activities (e.g. office, museum and warehouse). It was limited to supply points with yearly electricity loads between 100 and 1000 MWh and the main fuse sizes range from 80A to 750A. Some of the supply points only include electricity for facility management, while others include all electricity use within the building (e.g. electricity for facility management and household electricity).

The buildings are all situated in Gothenburg, Sweden (57° 42' N, 11° 58' E). Measured data of electricity use were collected from a database owned by the local grid company (Göteborg Energi Nät AB) with the consent of the property owners. Hourly data from 2014 were used in all cases but one. For the last supply point, data from 2013 were used.

The electricity use in each of the electricity supply points was matched to simulated electricity generation from a fictive PV system on an hourly basis. Solar electricity generation was achieved from simulations in Polysun with a poly-crystalline PV system and local climate data. A summary of the input parameters used for the simulations are shown in Table 1.

Table 1 Summary of input parameters for simulations in Polysun

Input parameter	Value	Unit
Weather data	Gothenburg	n/a
Module	Yingli YL205P	n/a
Module type	Polycrystalline	n/a
Module nominal peak power	250	W
Efficiency at STC (standard test conditions)	15.3	%
Module area	1.633m^2 (1.65m*0.99m)	m^2
Soiling losses	2	%
Cable losses	2	%
Module mismatch	1	%
Inverter	Sunny Tripower STP 25000TL-30	n/a
Inverter efficiency	93.5	%
Performance ratio	88	%
Degradation	0	%
Module orientation (base case)	0 (south)	°
Module tilt (base case)	45	°

The PV system sizes were decided according to highest system profitability. For this, net present value (NPV) (eq. 1) was used as the decisive financial metric. The NPV approach is considered appropriate when choosing between mutually exclusive investments (Berk and DeMarzo, 2014). It includes all future cash flows, considers time value of money and recognizes the size of the project.

$$\mathrm{NPV} = \mathrm{PV(benefits)} - \mathrm{PV(costs)} = \mathrm{PV(all\ project\ cash\ flows)} = \sum_{n=0}^{N} (C_n / (1+r)^n) \qquad \text{(eq. 1)}$$

C= cash flow (positive or negative)
n= year of cash flow
N= total number of years of cash flows
r= discount rate

Table 2: Summary of input parameters for economic calculations. The table presents all cash flows excluding VAT.

	Input parameter	Value	Source
PV system parameters	Lifespan of PV system	30 years	
	Salvage value	0 SEK	
	Degradation of PV modules	0.5%/year	Jordan and Kurtz, 2013
General	Real discount rate	4%	
	VAT	25%	
Investment costs	PV system incl. BoS and installation (year 0)	$I_0 = 11000 + 3200 \times P^{(-0,0033\times P)}$ (where P=peak power)	Assumptions based on Lindahl, 2015
	Meter for green certificates (year 0)	4800 SEK	
	Inverter replacement incl. installation (year 15)	15% of investment	
Annual costs	Operation and maintenance costs	0.75% of investment	Keating et al., 2015
	Grid metering fee	1500 SEK	Göteborg Energi, 2015a
	Metering fee for green certificates	Sold certificates up to 1000 SEK: 0.2 x income Sold certificates above 1000 SEK: 0.1 x income	Egen el, 2015
Value of self-consumed electricity	Green certificate trading (first 15 years)	0.20 SEK/kWh for 15 years	Energimyndigheten, 2015
	Avoided spot price	0.29 SEK/kWh (Nord Pool Spot price for SE3 2014) first year and increasing with 2.4% per year	Nord Pool Spot, 2015. Spot price assumed based on Lindahl, 2015
	Avoided grid fee	0.07 SEK/kWh	Göteborg Energi, 2015b
	Avoided energy tax	0.29 SEK/kWh	Lindahl, 2015
	Avoided green certificate fee (excl. VAT)	0.03 SEK/kWh	
	Avoided trading surcharge (excl. VAT)	0.05 SEK/kWh	
Value of sold electricity	Green certificate trading (first 15 years)	0.20 SEK/kWh for 15 years	Energimyndigheten, 2015
	Selling price	0.29 SEK/kWh (Nord Pool Spot average price for SE3 2014) and increasing with 2,4% per year	Nord Pool Spot, 2015. Sales at spot price was assumed based on Lindahl, 2015.
	Grid benefit compensation	0.037 SEK/kWh	Göteborg Energi, 2015a
Economic incentive	Investment subsidy	20% of PV system cost (maximum 800 000 SEK)	Assumption based on current subsidy (Lindahl, 2015)

The profitability was calculated from the perspective of a building owner. The costs include the initial investment, a replacement of the inverter, operation and maintenance costs, and other additional costs associated with the PV electricity generation. The basic benefits include cash inflows from sold electricity, tradeable green certificates, and savings from reduced electricity purchases from the grid. Calculations were performed with and without PV-specific benefits currently available in Sweden, that is, investment subsidy and tax rebate. All economic input parameters were chosen to reflect current market conditions.

A summary of the economic parameters used in the base case is given in Table 2. In addition, the following sensitivity analyses were conducted:

No subsidy. The current capital subsidy is available for all grid-connected PV systems. However, due to a discrepancy between supply and demand, the waiting period before a subsidy request is granted can be very long. Moreover, the subsidy scheme is today only planned to continue until 2019 and the level for upcoming years has not yet been decided. For these reasons, profitability was also calculated without a subsidy.

Value-added tax: The owners of multi-family buildings, which mainly have private customers, are generally not allowed to deduct value-added tax (VAT) from their expenses. Hence, in the base case scenarios VAT was added to all costs for these buildings. Economic calculations for buildings other than multi-family houses were conducted without value-added tax (VAT). This difference between multi-family buildings and other buildings is one of the factors that affects the system profitability. Hence, additional calculations without VAT were carried out for the multi-family buildings in the scenario with 20% subsidy in order to separate this effect from the influence of other parameters.

Tax rebate for systems ≤ 100A: There is today no plan for how long the current tax rebate program will be in place and it was therefore not included in the base case scenario. However, a sensitivity analysis including a tax rebate of 0.60 SEK/kWh during the first 10 and 30 years respectively was carried out for systems with a main fuses of 100A or less. The tax rebate is received for solar electricity fed into the grid up to a maximum of 30 MWh. However, it does not apply for more than the amount of electricity that is bought from the grid.

Discount rate: Besides the costs benefits associated with the installation of a PV system, the profitability of the investment will also vary with the chosen discount rate. In the base case scenario in this study a discount rate of 4 is used. For the systems in multi-family buildings, results from the base case were compared to scenarios with no subsidy, but a discount rate of 2 and 3 respectively.

Roof-tops: Initially, the study focuses on how the profitability of a PV system is affected by the size and type of electric load as well as current support measures. Calculations in the base case scenarios are therefore performed without consideration of the size and orientation of available rooftop areas. Instead, the economic analyses are based on a PV system oriented towards the south with a 45° slope, which gives a high yearly energy output per kilowatt peak. As a sensitivity analysis, the characteristics of existing roofs were included in the economic calculations, and reductions of PV generation and profitability due to less beneficial system orientations were determined.

3. Results

The results presented below are based on data from 35 real electricity supply points, all with unique load profiles. Some main characteristics of these loads are displayed in Figure 1. Figure 1a shows the load factor (highest hourly electricity use to yearly electricity use) as a function of yearly electricity use. Here, no difference can be seen between the supply points in multi-family buildings and other buildings. Figure 1b on the other hand, shows a divergence in how large share of the electricity use that coincide with hours of sunshine. Especially, the share of load that occurs during daytime is generally lower in multi-family buildings than in other buildings.

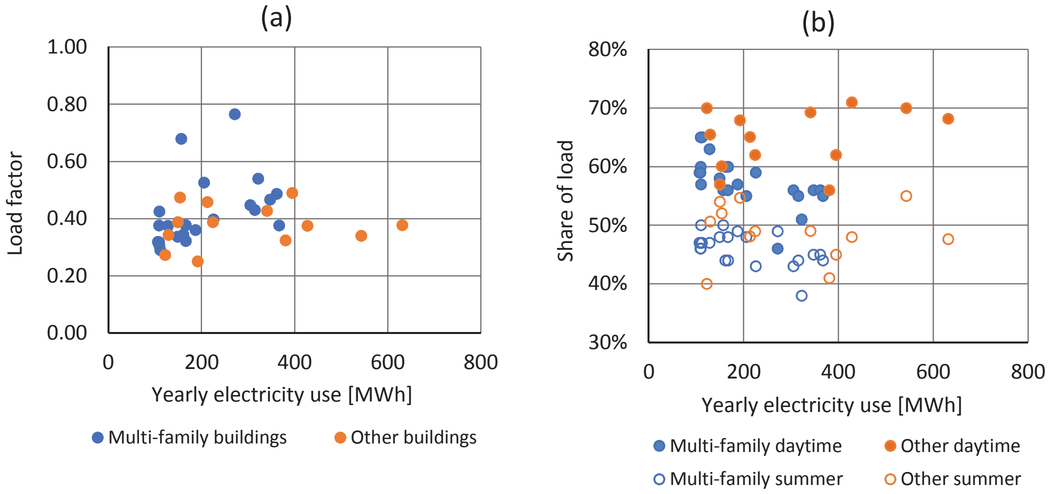

Fig.1: Characteristics of the studied electricity loads. Figure (a) shows the highest measured hourly energy as a function of yearly electricity use. Figure (b) shows the share of the load that occurs during daytime (07h-18h) and summer half-year (April – September) respectively as a function of yearly electricity use.

3.1 Profitability and sizing

This section gives the results from economic analyses with and without a capital subsidy of 20%. The highest achieved profitability (in NPV) for PV systems connected to each of the studied electricity supply points are shown in figure 2, while figure 3 shows the corresponding system sizes.

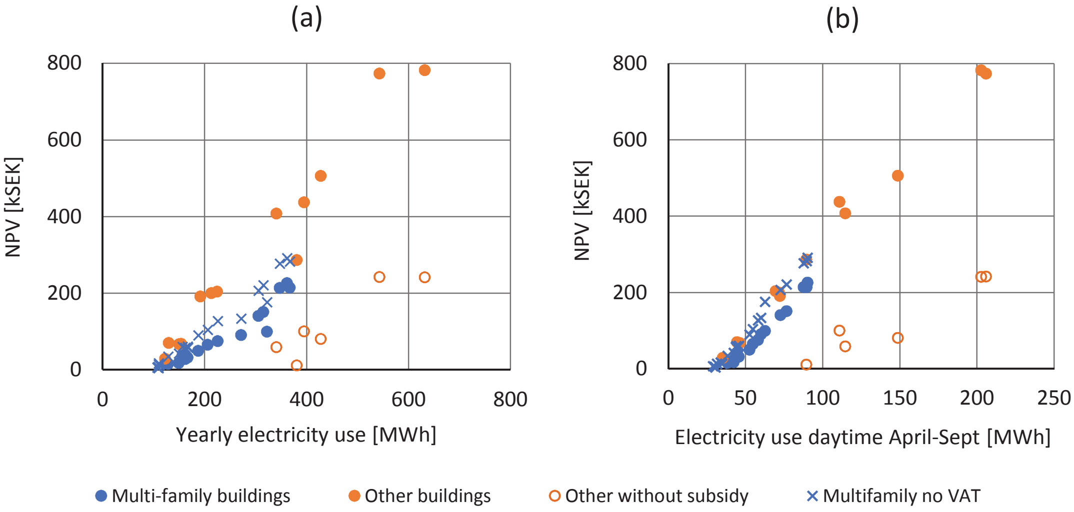

Fig. 2: The highest net present values (NPV) for PV systems connected to the studied electricity supply points. Profitability is shown as a function of (a) early electricity use and (b) electricity use during daytime (07h-18h) April – September. For multi-family buildings, the results are all with subsidy but with and without VAT. For systems in other buildings, results are shown with and without subsidy. Only systems with positive NPVs are included.

In relation to yearly electricity use, PV systems in multi-family buildings results in lower net present values (figure 2a) and lower system sizes (figure 3a) compared to the systems in other buildings. This can partly be explained by the fact that the profitability in multi-family buildings was calculated with VAT added to all cost. However, also when excluding VAT for the cost (as for other buildings), the results show lower values for multi-family buildings. It can be seen that excluding VAT makes the largest difference on optimal system size, while there is only a small increase in system profitability.

Comparing NPV or system size to the part of electricity load that occurs during daytime April through September (figures 2b and 3b) shows even stronger correlations than when comparing to the yearly load. Also, now there is no difference between multi-family buildings calculated without VAT and other buildings, indicating that the previous gap was due to differences in the load profiles (figure 1b).

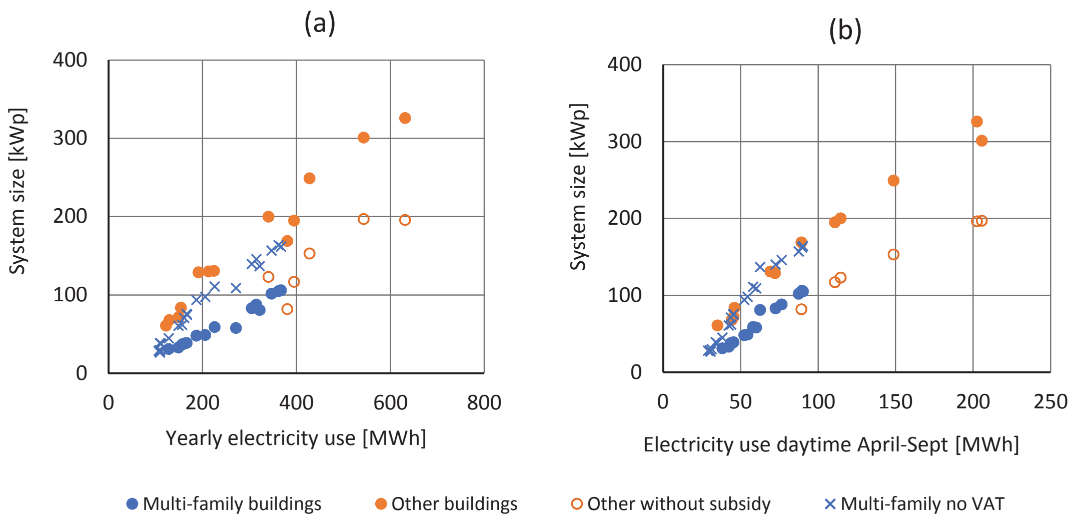

Fig. 3: Solar PV system sizes that results in the highest net present values (NPV) as a function of (a) total early electricity use and (b) electricity use that occurs during daytime (07h-18h) April – September. For multi-family buildings, the results are all with subsidy but with and without VAT. For systems in other buildings the results are shown with and without subsidy. Only systems with positive NPVs are included.

Without an investment subsidy no profitable system sizes were found for supply points in multifamily buildings, but for half of the supply points in other buildings. It can be seen that a daytime summer load of about 90 MWh, or yearly loads above 300 MWh, was required for the PV systems in other buildings to reach profitability. Regarding the supply points in multifamily buildings with yearly loads above 300 MWh, system sizes around 60 kW were close to being profitable.

3.2 Self-sufficiency and grid feed-ins

In this section, the share of the yearly electricity load that is covered by solar electricity, so called self-sufficiency, as well as solar electricity grid feed-ins are shown for the system sizes previously displayed in figure 3.

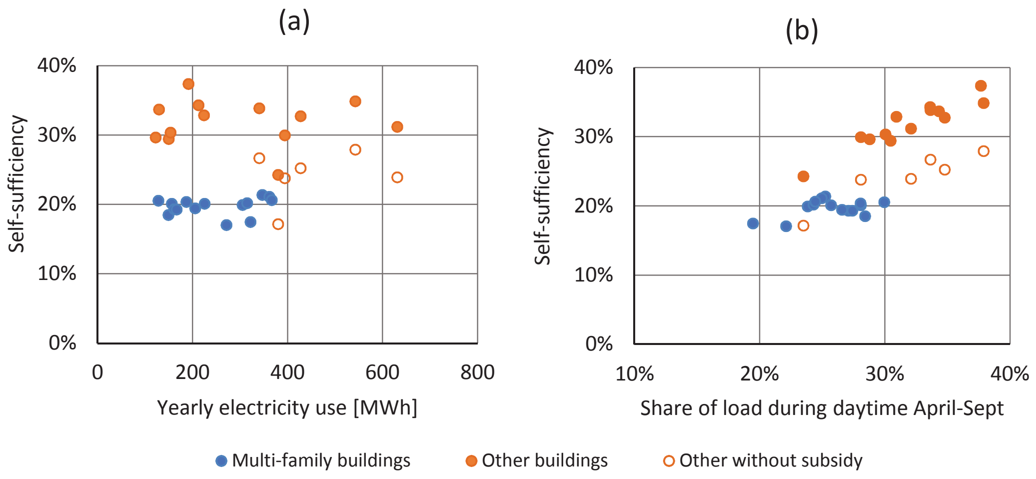

Fig. 4: Self-sufficiency (self-consumed solar electricity to total electricity use) as a function of (a) yearly electricity use and (b) share of the load that occurs during daytime (7h-18h) April-September.

Figure 4 shows that the PV systems optimally sized for supply points in multi-family buildings all result in a self-sufficiency around 20 %, while for the systems in other buildings it varies from above 20 to almost 40 %. For buildings other than multi-family houses, figure 4b shows a trend with increasing self-sufficiency with increase share of electricity load during daytime from April through September.

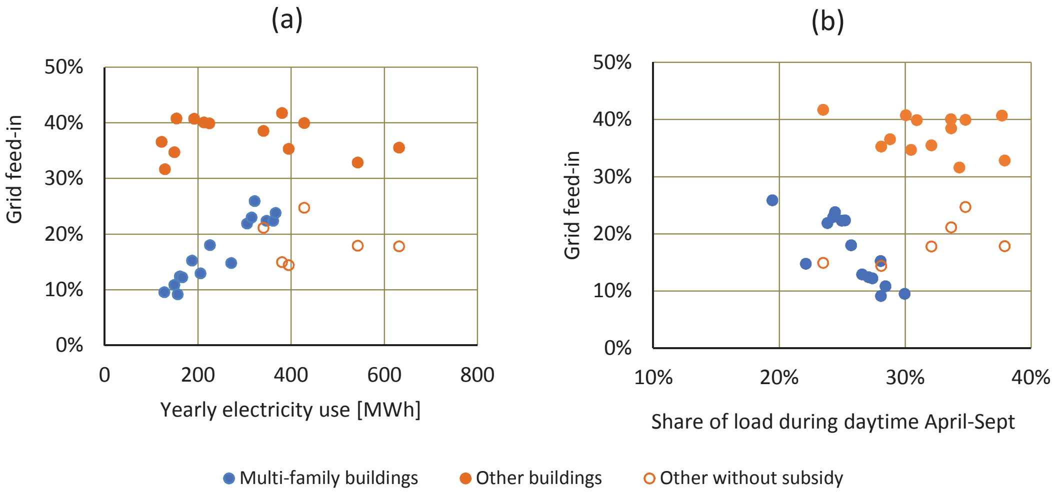

Fig. 5: Grid feed-in (over-generation of solar electricity to total solar electricity generation) as a function of (a) yearly electricity use and (b) share of the load that occurs during daytime (7h-18h) April-September.

Figure 5 shows the share of electricity that is fed to the grid, thus over-generation of solar electricity. The grid-feed-ins are about 10-25 % for systems in multi-family buildings and as much as 30-40 % for systems in other buildings (with subsidy) (figure 5). For multi-family buildings, the grid feed-ins increases with increased yearly use (figure 5a), but decreases with increased share of the load that occurs during daytime April through September. The same trends cannot be seen for other buildings.

3.3 Tax rebate

Eight of the electricity supply points in multi-family buildings and one of the supply points in other buildings have a main fuse smaller or equal to 100A, which makes them entitled to a tax rebate based on solar electricity fed to the grid (see section 2). Optimal system sizes for scenarios with 20% subsidy and tax rebate during 0, 10 and 30 years respectively are shown in figure 6.

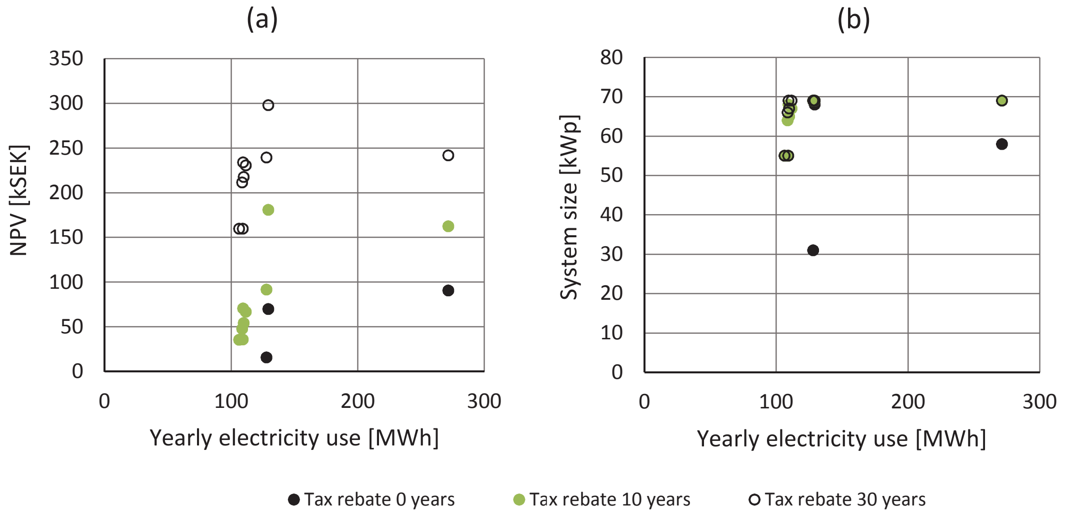

Fig. 6: Diagrams showing (a) maximum net present values (NPVs) and (b) corresponding system sizes for electricity supply points ≤ 100A, when the economic analyses are carried out with an investment subsidy as well as a tax rebate during 0, 10 or 30 years. Only systems with positive NPVs are included.

Only considering an investment subsidy, and no tax rebate, profitable PV systems were found for three of the supply points within this group (≤ 100A). With a tax rebate during 10 or 30 years on the other hand, all of the systems were profitable. As seen in figure 6, these two scenarios resulted in similar optimal system sizes, but with higher NPVs when including the tax rebate during a longer period of time.

3.4 Discount rate

A sensitivity analysis of the discount rate was carried out for all supply points in multifamily buildings. Figure 7 displays the resulting optimal system sizes and corresponding NPVs.

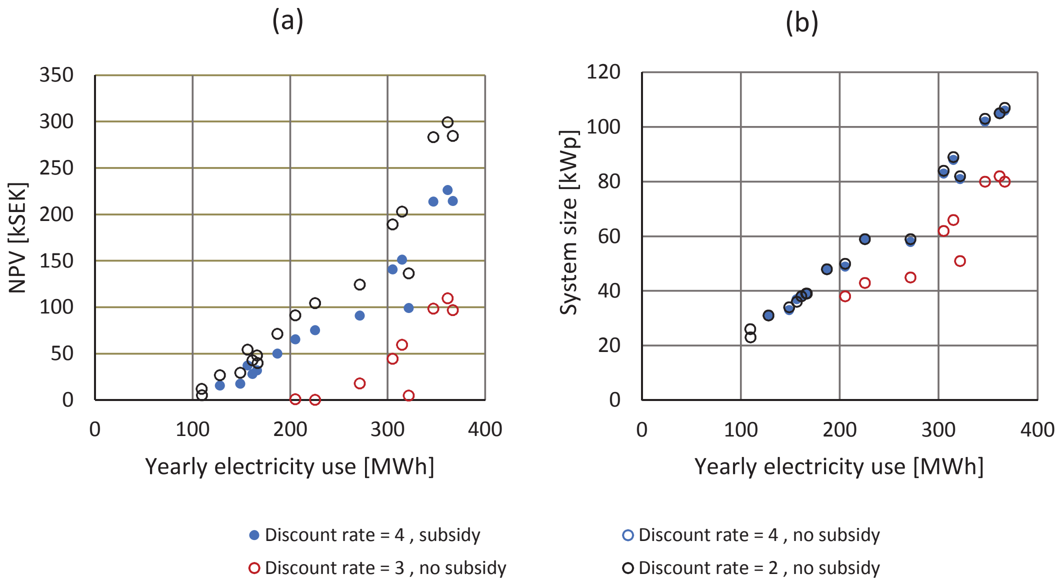

Fig. 7: Diagrams showing (a) maximum net present values (NPVs) and (b) corresponding system sizes for electricity supply points in multifamily buildings for economic analyses based on different discount rates. Only systems with positive NPVs are included.

Using a discount rate of 4 (base base), there were no profitable systems when the subsidy was excluded from the analysis. Accepting a discount rate of 3 would result in 9 profitable systems and with a discount rate of 2, twice as many are profitable. Moreover, figure 7 shows that with a discount rate of 2, the optimal same system sizes are the same as with a discount rate of 4 and a subsidy. However, the corresponding NPVs are higher in the former case.

3.4 Existing roofs

The results shown in previous sections were all were based on PV systems oriented to give a high yearly output and with an unrestricted system size. Since this is not often the circumstances in reality, this section explores the available areas offered by existing roofs and their effect on system profitability.

Figure 8 shows the optimal PV system sizes as well as the practically possible system sizes after consideration has been taken to available roof areas. The previously calculated PV system sizes for supply points in multi-family buildings (section 3.1) were generally small enough to fit the available roof areas. Only 3 out of 22 systems would have to be reduced (if sized with both subsidy and tax rebate). On the contrary, the systems sized for electricity loads in other building types were generally too large. When assuming a 15 degree module slope on flat roofs, all but one of these systems had to be downsized, 40% of them as much as 5 times or more. This is a result of relatively larger system sizes in combination with generally higher electricity use per floor area for these supply points, compared to the ones in multi-family buildings. Also, a large share of these buildings have a very small usable roof area relative to the floor area.

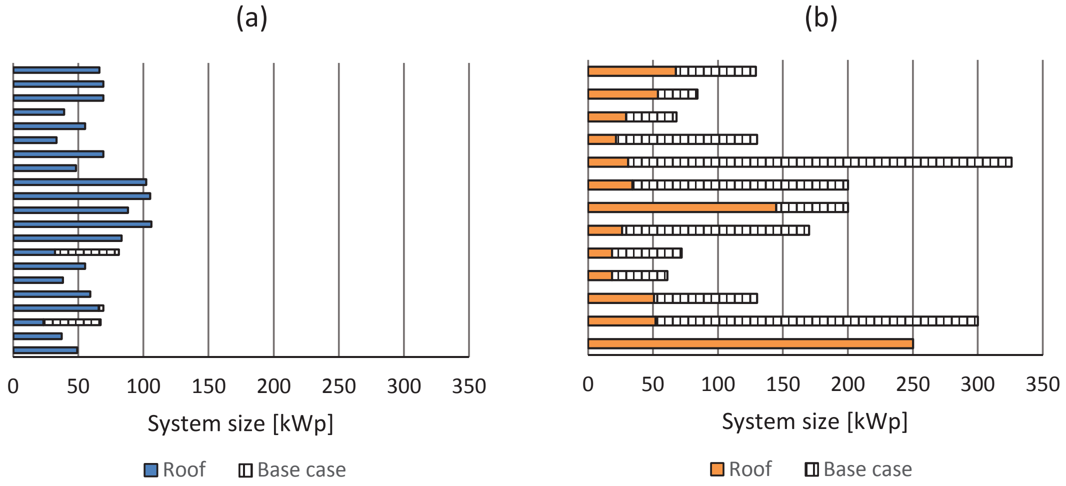

Fig. 8: System sizes before (base case) and after considering available roof areas in (a) multi-family buildings and (b) other buildings.

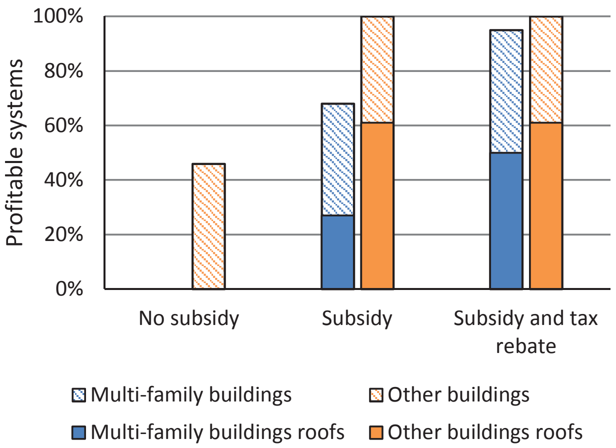

Fig. 9: Share of profitable PV systems in multi-family buildings and other buildings respectively before and after consideration of existing roofs. The results are shown for three different support scheme scenarios.

Reduced system sizes as well as adjustments of the module orientation to the slopes and directions of existing roofs affect the profitability of the PV systems. The shares of profitable systems before and after consideration of existing roofs are shown for different scenarios in figure 9. With a 20% investment subsidy, the number of profitable systems (positive NPVs) in multi-family buildings decreased from 15 to 6 and in other buildings from 13 to 8.

4. Conclusions

In general, the share of electricity use during hours of sunshine is lower for the studied multi-family buildings, compared to the buildings with other types of activities, thus giving them a disadvantage when matched to the electricity generation from a solar PV system. The effects of this difference can be seen as a lower self-sufficiency, as well as relatively lower profitability and smaller system sizes for supply points in multi-family buildings, compared to other buildings.

The currently available support schemes for solar PV in Sweden – an investment subsidy and a tax rebate based on net billing – turned out to be crucial for the profitability of a PV system investment in most of the studied buildings, but not all. Without any of the two, no profitable system sizes were found for the supply points in multi-family buildings. Among the supply points in other building types on the other hand, the ones with a yearly electricity use above 300 MWh resulted in profitable systems also without additional financial support. With an investment subsidy of 20 %, more than half of the systems in multi-family buildings were profitable and all of the systems in other buildings. A fourth of the studied supply points had a main fuse smaller than or equal to 100A and were thereby also qualified for the tax rebate program. How much this would influence the profitability depends on the number of years that the program will be in place, which at this point is unknown. However, it was shown that with a subsidy, an additional tax rebate during either 10 or 30 years resulted in similar optimal system sizes. Taking the areas, slopes and directions of existing roofs into consideration drastically decreased the number of profitable systems both among the multi-family buildings and other buildings.

The economically optimal self-sufficiency (electricity use covered by solar electricity) was around 20 % for multi-family buildings and from 24 % up to almost 40 % for other buildings. Self-sufficiency was shown to be linked to the share of load that occurs during daytime April-September, rather than the size of the yearly load.

5. References

Berk, J., DeMarzo, P., 2014. Corporate Finance, third ed. Pearson Education Limited, Edinburgh Gate.

Egen el, 2015. Elcertifikatmätaren kan nu fås trådlös [Online], Available at: http://egenel.etc.se/ [Accessed Nov 2015] Energimyndigheten, 2015

Göteborg Energi, 2015a. Ersättningar och avgifter för produktion av el 2015 [Online], Available at: http://www.goteborgenergi.se/ [Accessed Nov 2015]

Göteborg Energi, 2015b. Elnätspriser i Göteborg 2015 [Online] Available at: http://www.goteborgenergi.se/ [Accessed Nov 2015]

Jordan, D.C., Kurtz, S.R., 2013. Photovoltaic Degradation Rates — an Analytical Review 12–29. doi:10.1002/pip

Keating, T.J., Walker, A. and Ardani, K., 2015. SAPC Best Practices in PV Operations and Maintenance Version 1.0. National Renewable Energy Laboratory, Golden, CO. Available at: http://www.nrel.gov/

Lindahl, J., 2015. National Survey Report of PV Power Applications in SWEDEN 2014. Available at: http://www.iea-pvps.org/

Nord Pool Spot, 2015. Elspot prices SE3 2014 [Online] Available at: http://www.nordpoolspot.com/ [Accessed Nov 2015