# Metering Solar Energy for Rental Flats

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***Abstract*—The recently published "Mieterstromgesetz", a German law regarding landlord supply of photovoltaic power to their tenants, aims to substantially increase the amount of photovoltaics installed on rental apartment buildings. This paper discusses the effect the different metering concepts foreseen in the law have on the energetic performance of landlord-to-tenant power supply.**

***Keywords: landlord-to-tenant power, metering concepts, simulation***

## I. Introduction

Avoiding the most dramatic consequences of climate change is one of the aims which the Paris agreement establishes. In order to limit the earth's temperature increase to less than $1.5\,^{\circ}\mathrm{C}$ above pre-industrial levels, the entire energy system needs to be decarbonised by 2040 [1]. Germany's energy system is steadily moving towards higher levels of renewables. In 2016, they already covered $31.7\,\%$ of the electric energy demand and $12.6\,\%$ of the primary energy demand. Photovoltaics (PV) supplied $6.4\,\%$ of the electricity demand in 2016 [2], however around $25\,\%$ is required for a successful and economically viable energy transition [3], [4]. Since future electricity demand will increase dramatically due to sector coupling, an enormous amount of additional PV capacity needs to be installed [1], [3], [4].

One big step towards increasing the amount of installed PV and tapping into currently unused roof surface area, is the expansion of PV to more urban multi-storey buildings which are often occupied by tenants. International examples of this are on-site mini power purchase agreements (PPAs) with tenants which were discussed in the UK in the context of social housing as early as 2003 to 2010 [5], [6]. The US National Renewable Energy Laboratory (NREL) addressed the topic in 2010 [7]. At the European level, the European Consumer Organisation (BEUC) provides an overview of exemplary practices to promote solar energy for tenants in various EU member states. E.g. Denmark set up netmetering, while the Netherlands granted an energy tax exemption for tenants, allowing them to benefit from self-consumed solar electricity provided by their landlord's PV unit [8]. Nevertheless, the report identifies self-consumed solar power for tenants as a blind spot of renewable energy policies in Europe, with tenant energy consumption at a financial disadvantage compared to self-consumption in owner-occupied houses [9].

In German energy law, landlord-to-tenant power is currently a hot topic and is discussed in several studies [10], [11], [12]. It is anticipated that the recently published landlord-to-tenant (L2T) power supply law "Mieterstromgesetz" [13] (MSG) in Germany will provide new incentives for house owners to supply their tenants with solar energy. However, the effectiveness of the new law depends very much on the details of its implementation. This paper therefore focuses on the simulation of tenant energy schemes in multi-storey buildings in order to determine whether the Mieterstromgesetz achieves its goal of supplying more affordable solar energy to tenants in cities. The paper first briefly describes the database and underlying assumptions. Secondly it presents the results of a baseline simulation, including the outcomes of various parameter variations. The final section discusses the results, focusing on a critical assessment of the effectiveness of the tenant energy law.

## II. Model description

The landlord-to-tenant power supply law is designed to end the discrimination of tenants regarding PV self consumption and enable them to benefit from the advantages of the energy transition (including cheaper and clean energy). Among other regulations, the law establishes an incentive in the form of a premium tariff for landlords to sell PV energy directly to tenants without passing through the grid. This premium tariff is added on top of the regular PPA-tariff and is valued between 2.2 up to $3.8\,\mathrm{ct/kWh}$, which increases the profitability of PV projects on multi-storey buildings. But it also sets a strict limit for the costs of electricity for the tenants from the landlord: the energy price may not exceed $90\,\%$ of the default provider tariff. The law furthermore defines that L2T power supply is only possible within the same building. As the regulator therefore does not aim to encourage district power supply, this will not be subject of this paper. Finally, it is important to note that if no public grid is utilised for direct usage of PV energy, no grid related fees become due. The German renewable energy act ("EEG") reallocation charge however has to be paid. Given the outlined framework, a PV system should aspire to as high a direct consumption within a building as possible to achieve the best economic output.

### A. Simulation model

The law will only increase PV installation if it is profitable for both tenants and landlords. Therefore, the landlords need to bill the tenants, for which in turn the tenants' level of PV consumption must be established. The most accurate solution would be a precise sub-second-measurement of all energy flows and then to charge the tenant appropriately. But since this kind of metering system is too expensive, the law allows for three different metering concepts which use meters with a much lower time resolution and/or avoid individually measured energy flows. The local distribution

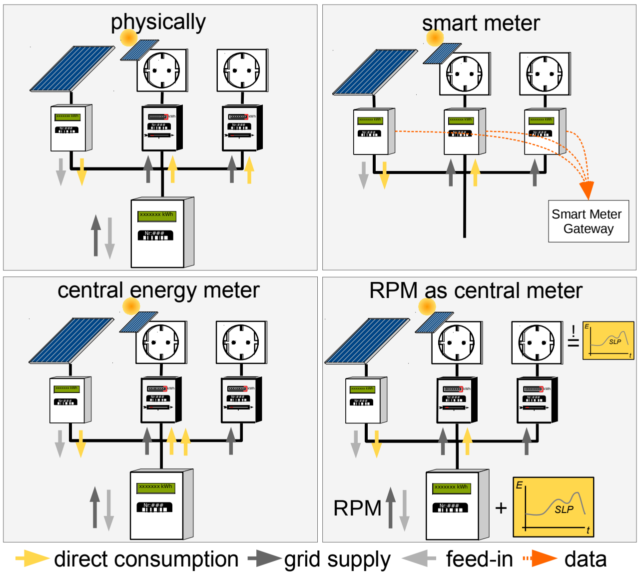


Fig. 1. Different metering concepts for PV landlord-to-tenant power supply.

system operator (DSO) has the authority to prescribe which model has to be used within the area of operation. While this does not impact the energy flows themselves, the measured quantities differ and therefore this affects the billing of the tenants.

This paper focuses on the economic impact of the different metering concepts. Integral to all metering concepts is a meter at the production unit to define the energy output (see Fig. 1). The three metering concepts which are described in the law to determine the directly consumed energy are:

1) smart meters at all energy producers and flats to allow assignment of directly consumed energy,
2) central bidirectional Ferraris meters at the house connection point or
3) central recorded power measurement (RPM) at the house connection point.

While in case 1 all energy flows are measured and thus can be billed precisely, some values have to be derived by calculations in cases 2 and 3.

The directly consumed energy $E_{\text{dir}}$ is the difference between the produced PV energy $E_{\text{PV}}$ and the energy fed into the grid $E_{\text{fi}}$. Additionally, the direct consumption is reduced by the energy demand of the PV clients $E_{\text{l,c}}$:

$$E_{\text{dir}} = \min(E_{\text{PV}} - E_{\text{fi}}, E_{\text{l,c}}) \tag{1}$$

Since the bidirectional Ferraris meter in case 2 only meters the cumulative energy consumption, it has been defined that all direct consumption is calculated at the PV in-house tariff. This simple estimation is quite common in Germany and is inspired by the rules for combined heat and power plant operators, which use the same approach. If only a few of the flats in a building are participating in the PPA, this metering concept tends to provide an overestimation of the directly consumed power.

In case 3, the aim of the recorded power measurement at the connection point is to obtain information about the PV production and the feed-in with a temporal resolution of typically 15 min. But since even in this case the percentage of directly consumed energy by the PV clients is not clear, it is defined that all non-clients (index: nc) have a standard load profile, $p_{\text{SLP}}$, scaled by their annual energy demand $E_{\text{l,nc}}$.

$$P_{\text{l,nc}}(t) = p_{\text{SLP}}(t) \cdot \sum E_{\text{l,nc}} \tag{2}$$

For this calculation PV power is defined as positive. The assumed artificial load $P_{\text{l,nc}}(t)$ of the non-clients is added to the RPM values to determine a virtual RPM $P^*_{\text{RPM}}$ in order to calculate the virtual feed-in $P^*_{\text{fi}}$. Because this calculation could lead to more PV feed-in than actually produced, it needs to be limited to the PV production.

$$P^*_{\text{RPM}}(t) = P_{\text{RPM}}(t) + P_{\text{l,nc}}(t) \tag{3}$$

$$P^*_{\text{fi}}(t) = \min(E_{\text{PV}}, \max(0, \sum P^*_{\text{RPM}}(t)\,\Delta t)) \tag{4}$$

### B. Economic evaluation

Besides the fixed cost for metering and billing $C_{\text{fix}}$, four variable items need to be accounted for separately. From the perspective of the PV system operator there are two factors contributing to costs and two contributing to the returns.

The first item is the energy drawn from the grid $E_{\text{gl}}$ at market costs, grid related fees, and taxes $c_{\text{gl}}$. The second item is the cost of generating the PV energy $E_{\text{PV}}$. This energy has a minimum cost equivalent to the feed-in tariff, since it could also have been fed into the grid. But the real cost might be higher. To calculate the real cost, the levelled costs of electricity (LCOE) including the margin of the provider $c_{\text{lcoe}}$ is needed and must then be compared to the feed-in tariff. The energy cost to the landlord is then the larger of the two. Additionally the directly consumed PV energy $E_{\text{dir}}$ is subject of the EEG reallocation charge $c_{\text{eeg}}$, which is reduced by the state premium granted by the landlord-to-tenant power supply law $r_{\text{ltp}}$.

$$C = c_{\text{gl}} \cdot E_{\text{gl}} + c_{\text{lcoe}} \cdot E_{\text{PV}} + (c_{\text{eeg}} - r_{\text{ltp}}) \cdot E_{\text{dir}} + C_{\text{fix}} \tag{5}$$

Third, contributing to the provider's returns, there is the energy fed into the grid remunerated at the rate of the feed-in tariff $r_{\text{fi}}$ according to the EEG. The fourth factor is the energy sold to the PV client $E_{\text{l,c}}$ for which the provider receives the rate of the respective mini PPA $r_{\text{PPA}}$, minus sales taxes $c_{\text{vat}}$.

$$R = r_{\text{fi}} \cdot E_{\text{fi}} + (r_{\text{PPA}} - c_{\text{vat}}) \cdot E_{\text{l,c}} \tag{6}$$

Based on the monitoring report of the German grid regulator [14], the parameters in Table I were used for the economic analysis in this paper.

TABLE I
ECONOMIC PARAMETERS

| | | |
|---|---|---|
| PV LCOE | 12.00 | ct / kWh |
| EEG reallocation charge | 6.35 | ct / kWh |
| grid fees | 6.62 | ct / kWh |
| mean electricity spot price | 3.51 | ct / kWh |
| electricity tax | 2.05 | ct / kWh |
| tariff of the default provider | 31.17 | ct / kWh |
| feed-in tariff (PV: 15 kW) | 12.08 | ct / kWh |
| landlord-to-tenant state funding | 3.58 | ct / kWh |
| fix costs (metering, billing, etc.) | 5.00 | € / year |
| VAT | 19 | % |

### C. Input Data and Assumptions

To help make the results of this paper reproducible, this section describes the data and the assumptions used for the calculations. For high accuracy all simulation were executed with a temporal resolution of 1-min mean values. The weather input data is a time series measured in Lindenberg (Brandenburg, Germany) by the Baseline Surface Radiation Network (BSRN) in 2004. The measured global and diffuse horizontal irradiation were calculated in the plane of array according to Klucher [15]. The ambient temperature is used to calculate PV power following Beyer et al [16] and Schmidt and Sauer for the inverter [17]. As surface we assume a flat roof with a mounting system tilted $15°$, facing East-West, as these are common in urban areas. Finally the annual PV energy yield is assumed to be $932\,\mathrm{kWh}$ per kW installed PV power.

While there are many measured load profiles for residential single family houses, load profiles for multi-storey buildings are considerably more rare - due to, among other things, the difficulty of getting all tenants to agree to a measurement. Furthermore the load simulation of those buildings is more sophisticated, as more variables need to be considered: i.e. the number of inhabitants varies within a broad range and different household set-ups from singles to extended families are found within individual buildings. In order to model this diversity adequately, the load profiles are synthesised using the behaviour-based load profile generator (bLPG) by Noah Pflugradt [18]. This tool simulates the behaviour of the tenants using a psychology based model of desires and then generates the load profile from the usage of facilities.

For this study three different types of households where selected. The first type is single person households, characterised by a relatively low load demand of $640\,\mathrm{kWh}$ to $2280\,\mathrm{kWh}$ and often with no more than the base load around noon. The second is pensioners, with a significant variation in annual demand from $680\,\mathrm{kWh}$ to $3580\,\mathrm{kWh}$ and load related activity throughout the whole day. And third there are families with between one and three children, a load demand between $1650$ and $5360\,\mathrm{kWh}$ and a diverse load behaviour. To make sure that the study applies to a wide range of house types with very different tenants, a library of 350 different household profiles was created, each representing a flat in a multi-storey building. Then houses were composed by randomly selecting profiles from the library. The share of singles, pensioners and families was chosen based on statistical data for Berlin [19]. The mean annual load demand per apartment in Berlin is $2300\,\mathrm{kWh}$ [20], [21].

As multi-storey buildings differ in size and number of flats, a building with $200\,\mathrm{m}^2$ ground area was chosen as study object, since this is representative for many buildings in Berlin. Due to micro-shading from chimneys or air-conditioning and/or roof shape it was assumed that only $100\,\mathrm{m}^2$ could be used for PV purposes, which results in a total installed power of $15\,\mathrm{kW}$. As the number of supplied flats varies within the analyses, the ratio of installed PV power per flat varies (see Fig. 2).

The bLPG was developed for the residential sector and single family buildings. To take the energy usage of the building infrastructure such as pumps, elevator and stair lights into account, a constant base load of $1\,\mathrm{kW}$ was added. It then was validated against other load profiles by comparing the average daily load with:

1) the German standard load profile (SLP),
2) a typical single house profile proposed by the German standard VDI 4655,
3) and a measurement of a real multi-storey building in Berlin.

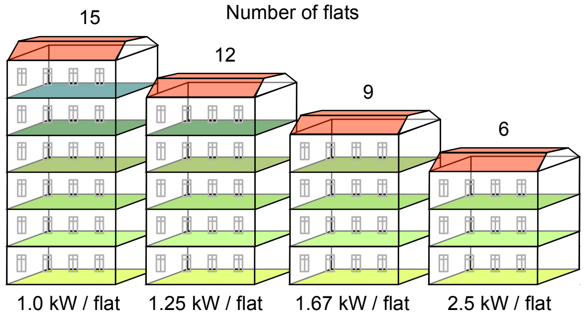


Fig. 2. Studied buildings and the number of flats in the building with $200\,\mathrm{m}^2$ ground area and specific installed PV power.

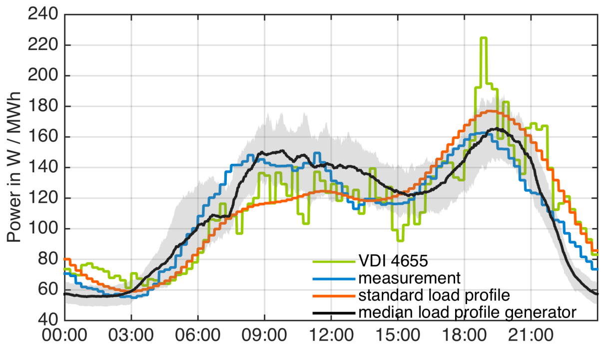


Fig. 3. Comparison between standard load profile, measured load profile and a load profile generated by the bLPG. Black: median of 100 buildings with 6 storeys. Grey area: min and max values.

As can be seen in Fig. 3, the profiles of the average daily load show similar characteristics, with an increasing load in the morning hours and a distinct load peak at evening.

Although the standard load profile and the artificial load of the VDI 4655 are very similar, the measurement and the load from the bLPG show a slightly diverging consumption pattern at morning and midday. On the one hand the curve of the bLPG shows higher load values during daytime while on the other hand lower values could be found at night. This is due to the different behaviour patterns and the much smaller sample size of the bLPG profiles. The standard load profile is based on a study of single family houses in West Germany in the 1980s, while the bLPG households are based on a survey in East Germany in 2010. In those 30 years the behaviour pattern and the electric devices changed significantly.

## III. Simulation Results

### A. Smart metering

In this section the results of the simulation analysis of the described landlord-tenant PV-project are shown. The simulation with smart meters serves as reference scenario,

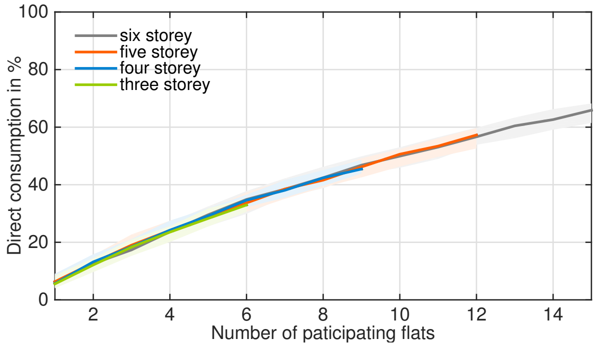


Fig. 4. Direct consumption over the number of participating flats for different buildings using a smart meter.

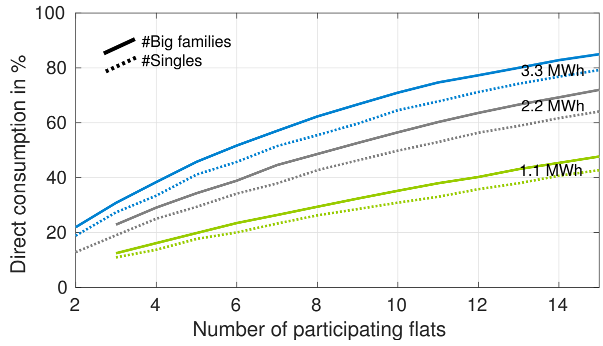


Fig. 6. Direct consumption over the number of participating flats for different load profiles and levels of annual demand using a smart meter.

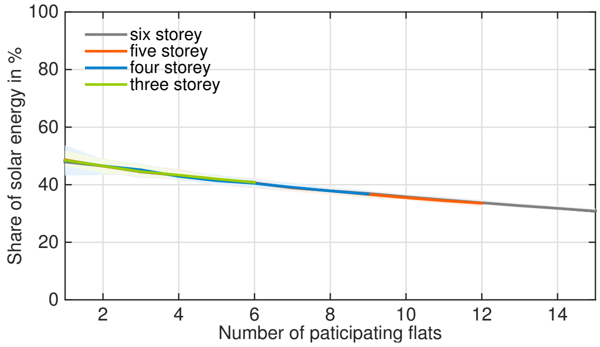


Fig. 5. Share of solar energy for the client above the number of participating flats for different buildings using a smart meter.

since they have the best accuracy due to the high time resolution.

With a given PV generator size, the share of directly consumed PV energy increases with the number of participants in the building. But the share of solar energy supply for a specific consumer decreases as the number of participating flats rises. In Fig. 4 the direct consumption is depicted over the number of participating flats for different buildings with smart meters. The line shows the median whereas the surrounding area marks the variation of $\pm 25\,\%$, due to different combinations of load profiles of the participating tenants. It is clearly visible that the direct consumption of this metering concept is independent of the building size. A maximum of about $70\,\%$ direct consumption is possible in the studied building as the number of participants reaches 15. Whereas with only three storeys, a maximum of $30\,\%$ could be achieved.

The share of solar energy for the tenants is shown in Fig. 5. This share is also influenced by the number of storeys. The solar share decreases from $50\,\%$ to $30\,\%$ as the produced energy is split to more flats of the higher buildings.

All in all, the size of the multi-storey building does not seem to have an impact. The number of participants and therefore the sum of tenant energy demand however does have a distinct influence. Therefore the demand of the clients was investigated more closely.

To determine the influence of the shape of the load profile, different load profiles were normalised to the same energy demand. In a second step, the annual energy demands were then varied. The results are shown in Fig. 6. From family profiles (solid lines) to singles' profiles (dotted lines) with the same annual energy demand, the direct consumption sinks slightly by roughly $\pm 2.5\,\%$ in all three cases. This difference however is negligible compared to the total influence of the annual energy demand. Halving the demand of $2.2\,\mathrm{MWh}$ per flat (grey) reduces the direct consumption absolutely by $10\,\%$ to $24\,\%$ (green). In the other direction, an additional demand of $1.1\,\mathrm{MWh}$ per flat consistently increased direct consumption by $13\,\%$ (blue).

The share of solar energy supply shows the opposite effect. It decreases when the annual demand rises, hence necessitating a higher share of grid energy supply. In general, single flats tend to have a slightly lower share of solar supply.

### *B. Central metering concepts*

The findings from the simulation with smart meters are now compared to results with central metering concepts. It has been shown that the number of storeys does not impact the energetic results of a solar project when smart metering is used. This changes if the concept of a central energy meter is applied.

With a central Ferraris meter the direct consumption of the whole building is measured. Thus, an increasing number of flats in the building (even if not a part of the L2T PPA) increases the maximum direct consumption.

In case 2, all direct consumption is allocated to the PV clients. Hence from a PV operator perspective it is not necessary to increase the number of participating flats when the energy demand of the clients reaches the sum of direct consumption of the multi-storey building. In Fig. 7 it is clearly shown that the share of direct consumption remains constant after a certain number of clients. Compared to the smart meter the share of direct consumption is overestimated until $100\,\%$ of the tenants are PV customers.

In case 3, the share of direct consumption is calculated by the usage of central RPM and standard load profiles (SLP). SLP are time series of electrical load for a sum of customers. About 100 households were needed to have the statistical distribution of the SLP. Hence it is not advisable to model the load of a single flat. When applied to the non-PV clients, the deviation of the real load profile from the assumed SLP affects the energy balance. This effect is stronger, if only a few flats use PV power. The negative deviation compared to accounting by smart meter can be see in Fig. 8.

It is quite clear that a calculation model with negative direct consumption should not be applied on those cases with

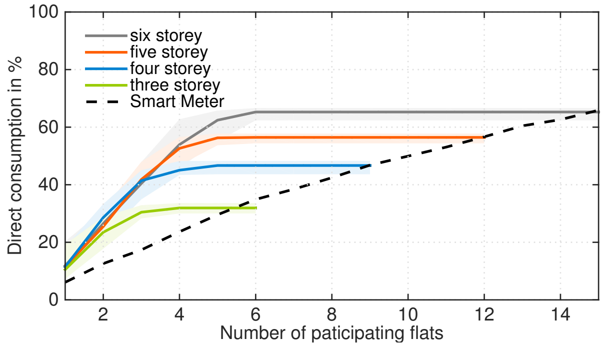


Fig. 7. Direct consumption over the number of participating flats for different buildings using a central energy meter.

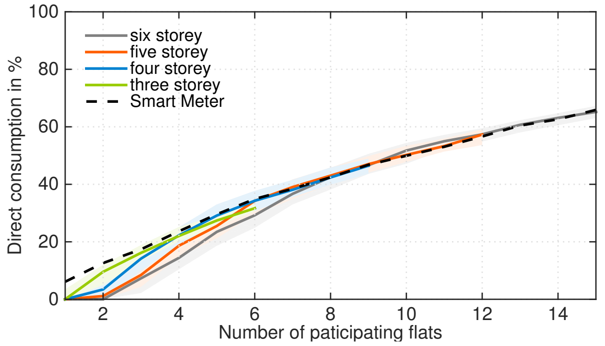


Fig. 8. Direct consumption above the number of participating flats for different buildings using a central RPM and SLP for calculation.

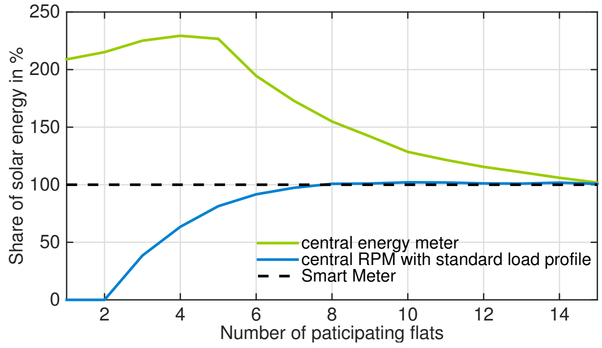


Fig. 9. Specific clients share of solar energy over the number of participating flats comparing the different metering concepts in the six storey building.

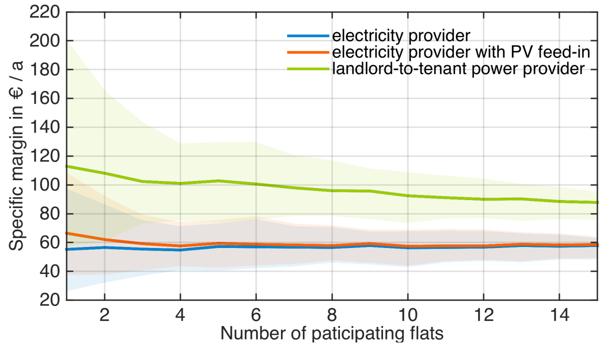


Fig. 10. Comparison of the specific margin for different business models for selling energy over the number of clients using a smart meter.

few PV costumers. The deviation decreases as the share of PV clients increases, because the share of SLP flats also decreases. The more inhabitants live in a building, the more PV costumers were needed to take any direct consumption into account. It can be concluded that, compared to the smart meter, the share of direct consumption is underestimated until 30 % to 50 % of the flats are supplied by the rooftop PV system.

Those findings can also be applied to the share of solar energy supply for the customers. A comparison of both central metering concepts to the smart meter is depicted in Fig. 9. Both metering concepts severely misestimate the solar share of the PPA clients. Projects with a central Ferraris meter will account a higher solar share than projects with central RPM. The former privileges the L2T PPA.

Additionally, the lower solar share measured by the central RPM leads to a higher demand of grid supply, and therefore increases the amount of grid related fees. This means that the RPM has an positive economic impact on the distribution system operator (DSO). Due to the face that the DSO prescribes the metering concept, a conflict of interests arises. This could be contrary to the mandatory duties.

### *C. Economic assessment*

So far it has been shown that the different metering concepts have an influence on the billed amounts of energy. To find out whether a PV project is profitable, a more detailed economic analysis is necessary. In order to reduce the number of parameters used, a reference case of a smart meter measured six storey building is assumed for the following analysis.

Firstly the L2T power purchase agreement is compared with classical power products. Therefore the specific annual balance per client is shown for three different business models for selling energy in Fig. 10. The blue curve shows the revenue obtained by an electricity provider buying energy at the stock-market. It is more or less constant over the range of participating flats. Thus the economic gain increases equally with the number of clients. This changes with a rooftop PV system feeding all energy into the grid, depicted as the orange curve. As the costs of the PV system are slightly below the feed-in tariff, a specific value is gained which is divided through the amount of costumers. Therefore the specific gain decreases with the number of participants. Third, the green curve shows the specific margin of an L2T power supply. It also decreases as the number of participating flats rises, because the share of directly consumed PV energy per client decreases. Hence more expensive grid energy is needed to meet the energy demand, which reduces the specific margin slightly.

As the energetic performance shows a distinct dependence on the metering concept, the specific margin can also be compared by the different meter, which was done in Fig. 11. As above, the green curve depicts the decreasing gain per flat with a smart meter which serves as reference value. While the RPM accounting with standard load profiles reduces the gain, the central Ferraris meter increases the margin. All curves converge if all flats use rooftop energy.

The implementation of L2T power supply is threatened when the specific margin is reduced by the metering concept. Therefore a central Ferraris meter is advantageous from

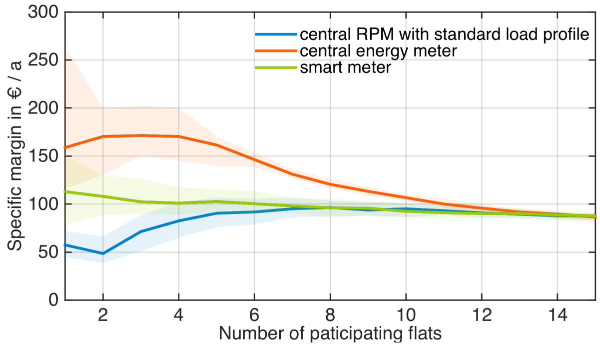


Fig. 11. Comparison of the specific margin for different metering concepts over the number of participating flats.

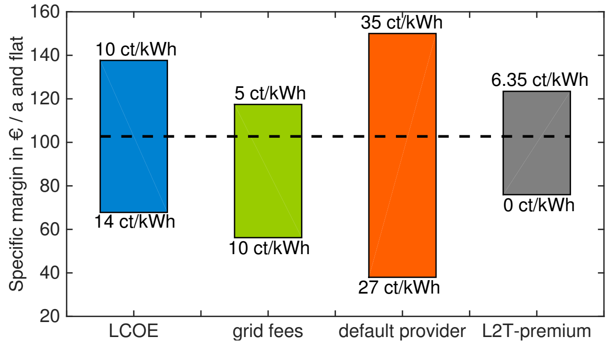


Fig. 12. Parameter variation of the economic base parameter using a smart meter with eight participating flats.

PV operators perspective, since the higher margin could be used as insurance against a low number of participants. On the other hand, the central Ferraris meter sets a decreasing incentive to increase the share of L2T PPA clients as the specific margin decreases. Furthermore, a higher margin increases the scope to compete with cheaper tariffs as the margin can be passed on to the tenants.

Finally the economic assumption needs to be validated. This is done for an example case in which it is assumed that eight flats are PV clients. The mean margin is depicted in Fig. 12. First, the LCOE is varied between $10\,\mathrm{ct/kWh}$ and $14\,\mathrm{ct/kWh}$. It can be seen that a difference of $2\,\mathrm{ct/kWh}$ of the LCOE reduces or increases the specific margin per flat by about 30 Euro per year. Since PV projects in cities are often negatively affected by micro shading and other cost-pushing effects, a reduced margin may be very common and pushes the curve towards usual wholesale prices. This underlines the cost pressure the projects face.

Secondly, the grid fees are taken to account. Grid fees in Germany vary between less than $5\,\mathrm{ct/kWh}$ in regions which have a small renewable share in the local energy mix as in southern Germany, and more than $10\,\mathrm{ct/kWh}$ within regions stressed by growing renewable feed-in as are found in north-east Germany. Those fees affect the economic evaluation in two ways. On the one hand, a higher grid fee increases the costs for energy drawn from the grid which affects the general costs of the tariffs. On the other, directly consumed energy is more valuable since grid related fees are avoided. If a non-varying tariff from the default provider is assumed as well as increased grid fees of $10\,\mathrm{ct/kWh}$, the margin is halved. On the contrary, lower grid fees are not as beneficial and only slightly raise the profit.

Thirdly, the effect of the default provider tariff is examined. As the landlord-to-tenant tariff is capped by $90\,\%$ of this tariff, a higher default provider price allows higher L2T margins. On the other hand, low prices bring the L2T power supply under considerable economic pressure.

Finally, the L2T premium shows only a slight impact on the economic results. Hence abandoning the premium seems to be an economical solution for distribution grids with low default provider tariffs.

Concluding the economic evaluation, the specific gain of an additional client is limited by the fact that available PV energy needs to be shared between all participating flats and more energy from the grid is needed to meet the demand. Nevertheless the total balance for the PV provider increases with more clients. Furthermore, it clearly emerged that the metering concept has a distinct impact on the economic performance, especially when there is a low share of participants. While a central Ferraris meter is beneficial for the PV operator and increases the margin for cheaper tariffs, a billing with RPM and standard load profiles affects the balance negatively. Finally it was shown that there is a regional impact on the margin. This was explained by the fact that higher grid fees and default provider tariffs make solar energy more competitive. On the other hand cheaper tariffs have an inhibitory effect.

## IV. Discussion and Conclusion

The Mieterstromgesetz aims for a supportive legal framework for landlord-to-tenant PV power supply. A special incentive has been incorporated to provide a better economic situation for these PPAs. This should lead to the expansion of PV from rural areas and single households to urban areas with multi-storey buildings.

The economic analysis showed some mayor impacting factors on the profitability of the L2T power supply. These are the metering system, the production costs, the grid fees and the default provider price.

The law leaves the choice of the metering concept open to the local distribution system operator. By choosing the central RPM concept, the amount of electricity demand drawn from the grid could be overestimated for small L2T projects. This would be beneficial for the DSO.

Urban PV projects have higher LCOE, because of the high cost of scaffolding. This decreases their profitability. The restriction of the L2T electricity price to $90\,\%$ of the price of the default local provider sets an additional limit to the possible income. Urban-only distribution grids have lower grid fees than rural grids and may have lower local provider tariffs. This makes solar energy less competitive in cities.

All of these local parameters cannot be influenced neither by the landlord, nor by the tenant. However they may well be decisive for the profitability of a given L2T PPA. The implementation of rooftop PV systems thus depends largely on the local framework. This means, that the Mieterstromgesetz could be insufficient to enforce the urban distribution of rooftop PV systems in Germany. The effectiveness of the federal incentive programme should therefore be observed closely, as it is in danger of failing its proposed aim.

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Figure 12 needs to be corrected, because grid fees also influence the default provider tariff, which was not implemented in the simulation on the first run.