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Research article

Economic and regulatory feasibility of solar PV in the Austrian multi-apartment housing sector

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Abstract: Austria established energy policy targets to decarbonize the housing sector with an increasing usage of low carbon electricity. Solar photovoltaic (PV) is one of the technologies being used to reach this target. Currently, the deployment of PV in the multi-apartment building sector is supported by subsidies. Taking into account the available potential and the policy goals for large-scale PV deployment in the residential sector in Austria, this paper investigates the economic feasibility of PV generation in multi-apartment buildings in the absence of subsidies. It also looks at the necessary regulatory conditions for implementation of economically feasible business models for PV generation in multi-apartment buildings. The empirical data for current research came from case studies of three actual projects, which were implemented by stakeholders with practical experience and knowledge in residential PV.

Keywords: photovoltaic; levelized costs of electricity; decentralized energy generation; building sector; business models

1. Introduction

Climate change mitigation policy calls for significant reductions of greenhouse gas (GHG) emissions to avoid potentially catastrophic risks of climate change [1]. To achieve this, emissions should be reduced by 50% globally and by 80% in industrialised countries by 2050 [2]. The building sector, together with the energy-generation, transport, and industry sectors, is a major source of GHG emissions and is responsible for 40% of energy consumption in the European Union (EU) [3].

Austria was among the first European countries to ratify the Paris Agreement in July 2016 and is currently developing an integrated energy and climate strategy that is consistent with it. The Paris Agreement speaks about an increase in global temperature at above 2 ℃ comparatively to the pre-industrial level. It also calls for the need that each country should prepare a national climate action plan to achieve this target.

The building sector accounts for 40% of global and European energy consumption. To stay within the 2 ℃ target, the GHG intensity of buildings needs to be reduced significantly [4], which is recognised by the European and Austrian decision-makers. At the European level, the EU Parliament in 2010 approved the Energy Performance of Buildings Directive 2010/31/EU, which requires European countries to increase the number of nearly zero-energy buildings and to encourage deployment of zero-energy buildings [5]. In Austria, the building sector accounts for 12% of GHG emissions [6]. The European climate change mitigation process requires a radical change in the energy performance of buildings. In line with this, Austria established ambitious targets to reduce its GHG emissions by 36% by 2030, compared to the EU target of 30% [7].

Currently two possible options for decarbonisation of the housing sector exist: i) the use of low carbon electricity, generated from renewable energy sources (RES); and ii) the implementation of measures to increase energy efficiency. The housing sector is related to all three areas of the energy transition towards a greater share of RES—electricity generation, heating, and mobility. Thus, on one side, the housing sector can become a producer of renewable energy, while on the other, it has enormous potential for reducing the existing level of energy consumption through different energy efficiency measures [8].

In terms of electricity generation, volumes of installed solar capacities are growing steadily worldwide. In line with this international tendency, the number of installed PV capacities in Austria also increased significantly during the last decade. For instance, in 2014 the volume of installed PV capacity reached 77 MWp, which is ten times higher than in 2010 [9]. The main drivers of this development were different types of subsidies, including feed-in tariffs and housing subsidies, as well as support from local and regional governments. However, the majority of these measures targeted single-family homes. There are still several policy barriers to implementing PV generation options in multi-apartment houses.

The economic feasibility of implementing PV solutions in multi-apartment buildings is another barrier. It is affected by the relatively small size comparatively to typically larger-scale PV installations. The size of PV systems can influence the profitability of individual investments and have an impact on the total costs of reaching PV electricity generation targets in the residential sector.

In Austria, most of PV installations are supported by national or regional subsidies, which have different forms, such as feed-in-tariffs, quotas, etc. to make renewable energies competitive in terms of prices with fossil fuels. However, there is also discussion about the removal of subsidies. Therefore, the question appears whether medium-scale PV generation required for multi-apartment buildings is economically feasible in the absence of subsidies and with non-renewable energy prices at their currently low level.

A detailed assessment of PV electricity generation in multi-apartment buildings in Austria must include a comprehensive economic feasibility study. There are several studies that focus mainly on the technological aspects of PV; however, there is a lack of economic assessments, particularly in the multi-apartment building sector. Estimations regarding the economic feasibility of different PV configurations in the context of multi-apartment houses is needed to further develop business models. Moreover, a comprehensive economic investigation can be a powerful instrument to support national policy decisions.

This paper thus aims to address two research questions: i) Is PV electricity generation in the multi-apartment building sector feasible even in the absence of subsidies? ii) What regulatory conditions are needed for the implementation of economically feasible business models for PV generation in multi-apartment buildings?

In this research, we assume that self-consumption models for PV on buildings provide an option to decouple economic performance from policy support such as feed-in tariffs or subsidies. Feasible business models to better utilise locally generated renewable energy are expected to constitute a tipping point for the Energy Transition ("*Energiewende*") in Austria. Until now, generated electricity could be used only by the property owner directly or be fed into the public grid. To make better use of decentralised energy generation, new strategies and models need to be found. Such models would enable the sale of electricity through micro-grids to tenants, shared owners, or commercial renters on the same or neighbouring developments.

2. Background

2.1. Renewable energies and energy-efficiency policy for the building sector in Austria

As a member country of the European Union, Austria is covered by the European energy policy, such as the EU roadmap for renewable energies and the EU Directive on Energy Performance of Buildings. The EU roadmap, published in 2011, requires reduction of GHG emissions by at least 80% by 2050 through a significant increase in the share of renewable energy sources (RES) [10]. The EU 2030 policy framework for climate and energy requires an increase in the share of RES to at least 27% of the EU's energy consumption by 2030 [11].

According to Austria's energy strategy, the share of renewable energies in total electricity production should be increased from 75% in 2005 to 80% in 2020. The Austria Energy Strategy also states that the largest potential for PV is through integration into buildings [12].

In their work, [13] make assumptions about the maximum possible technical potential capacity/activity for Austria. Their assumptions are based on the maximum yearly electricity production provided by RES 2020 [14]. The JRC–EU–TIMES model is then calibrated for 2005 and validated for 2010 and 2015. According to these assumptions Austria has PV potentials for 13.4 GW by 2020, which corresponds to 12.9 TWh. In reality, PV in Austria is expected to achieve a cumulated installed capacity of 1200 MW by 2020 [15].

Estimations of available roof areas were provided by [16]. Based on the detailed solar potential cadastre, which currently exists only for the Austrian province of Vorarlberg [17], [13] performed regression analysis to predict the available roof areas for the whole of Austria. According to their results, the total available roof top area is 902 km^2. The share of roof area where PV is technically feasible, represents an average of around 27% of that area [13]. This would mean that altogether 241 km^2 of roof area in Austria is feasible for PV production.

2.2. *Deployment of PV in building sector*

PV is a promising technology for low carbon electricity because of its economic potential [18]. Recently, PV experienced a massive reduction in cost due to the decline in the costs of components and large-scale deployment in different parts of the world. During the period 2006–2011, the global PV capacity underwent an average annual growth rate of 56% and reached a 100 GW volume in 2011 [19]. The costs of PV modules declined by more than 50% and the installed cost of roof-mounted systems by more than 20% [20]. This decrease in PV prices was made possible by the decline in factory-gate prices for crystalline-silicon PV modules [21]. There are also projections that PV will reach grid parity with retail electricity prices in several countries in the near future [22]. However, these cost reductions were driven mainly by subsidies such as feed-in-tariffs and production tax credits and rebates [23].

If PV is deployed on buildings, the levelized costs of electricity (LCOE) from PV can compete with electricity retail prices rather than with LCOE from other energy sources. In this case, a PV system can directly supply the building electricity demand. Such a process is also known as PV self-consumption. Some authors regard PV self-consumption as a core driver for PV economic rooftop performance, which can become an alternative to subsidised feed-in-tariffs [24].

Several studies investigated deployment of PV in general. For instance, [25] analyzed factors influencing the costs of PV, such as weighted average cost of capital (WACC) and developed a global map of PV costs, accounting for differences in solar irradiance and WACC in order to calculate LCOE for PV systems in 143 countries [25]. These results suggest that WACC has a significant impact on LCOE and that policies are needed to de-risk low carbon investment. The need for de-risking policies for solar projects is also highlighted by [26].

A significantly lower number of studies were conducted on PV self-consumption in the building sector. The majority of these studies were on single-family homes [24,27,28]. There are also some studies on PV self-consumption at universities [27] or at the district level [28]. In addition, the existing studies focus mainly on technological aspects of PV self-consumption.

Several research works have been written on the costs of PV generation for the residential sector. [13] model the costs for Austrian PV generation based on the large energy system model for 28 EU member countries, called JRC–TIMES–EU. [29] conducted an analysis of the relationship between the PV array and inverter size for different module technologies and found that the inverter efficiency curve is crucial for the sizing of PV systems. [30] estimates the profit-maximising size of residential PV systems for more than 800 households in Austria. These estimates include various electricity tariffs, subsidy schemes, and investment costs of PV systems in the size range of 1–20 kWp of installed capacity. The authors find that significant inefficiencies occur as a result of incentives to install relatively small PV systems. Deployment of larger PV systems in the residential sector will allow the costs to be decreased. For instance, an increase of minimum system sizes to 10 kWp would reduce the total investment costs by 10% [31].

In their study on economic potentials of PV self-consumption for large buildings [24] analyse the economic performance of rooftop PV self-consumption in terms of investment attractiveness and internal rate of return (IRR) of PV systems. The research design includes three case studies on both residential and office buildings in Berlin (Germany), Bern (Switzerland) and Vienna (Austria). For those projects, the average PV self-consumption rate was around 80% with an IRR of 13%. However, this only occurred where there were very high retail prices and low investment costs—the most important drivers for profitability of PV investments and even more important than the level of solar irradiance. This study also suggests that multi-apartment buildings provide a combination of key drivers for economic implementation, such as low ratio of PV output to electric demand and an inherent temporal match of PV output to electricity demand. It can thus be a starting point for large-scale deployment of PV on rooftops.

The study of [24] also identifies barriers to deployment of rooftop PV, such as adverse incentives, uncertainties regarding risks, and access to capital. An important adverse incentive is the so-called tenant-landlord dilemma, where a building owner has to bear the investment costs of energy-efficiency measures but cannot reap the profits, as these are appropriated by the tenant. For example, in Austria there is no legal provision for increasing rents after thermal refurbishment of a building. The separation of costs and benefits reduces the willingness of landlords to invest. Tenants are also unable to invest because the rooftop does not belong to them. Such barriers can be addressed by regulatory innovations for shared investments and by new business models. The second barrier is risk uncertainty, given that as PV investment costs occur immediately but have a long repayment period, positive cash flows depend on how electricity tariffs and the grid tariff structure develop. The third barrier is the lack of opportunities to raise debt capital. These two last barriers can also be addressed with the help of innovative financing models.

In Austria, new construction and refurbishment is supported by object-related subsidies provided by provincial governments to housing developers with subsidiary subject-side subsidies. These subsidies are allocated to all tenures in multi-apartment housing, and the majority of the population are targeted by the housing policy measures due to a unitary approach in housing policy in Austria. Despite having a high share of subsidised housing, Austria spends only around 0.7% of GDP on housing subsidies [32]. The housing subsidies schemes have continuously included support for deployment of RES systems in addition to feed-in tariffs, which are primarily dedicated to large-scale PV installations. However, deployment of RES is driven not only by subsidies but also by implementation of new building codes; these have Total Energy Efficiency and Primary Energy Consumption as main indicators, which additionally consider on-site production of renewable energy.

The Austrian government currently subsidises rooftop PV systems through an administratively determined feed-in tariff or co-funding of investment. However, this support is provided on the basis of the "first come–first served" principle. Currently there is much debate about how cost-efficient it is to allocate subsidies to deploy rooftop PV systems [33]. For instance, policy makers may have difficulties in identifying an appropriate level and duration of the feed-in tariff, as they would need to take a view on future market development and technological progress [34]. There are also concerns about the economic efficiency of subsidy allocation in cases where there is no competition at all [35]. Concerns about the "first come–first served" principle are also connected with the absence of regulations to govern the decision-making process. PV subsidies are also awarded within minutes after the opening of the application procedure, which shows how high the demand is for them [36].

It also seems that even though the prices for PV have decreased, investment in PV systems in Austria is still a subject of subsidisation. Currently, around 98% of all installed PV systems in Austria are subject to some kind of public co-funding [31].

3. Methodology

3.1. Economic feasibility calculations

The concept of levelized cost of electricity (LCOE) is one of the most commonly used definitions for economic evaluations of PV systems. It allows PV to be compared with other power technologies and for considering grid parity for emerging technologies such as PV [37]. LCOE calculations also consider all the costs of a system and account for the quantity of electricity the system generates over its lifetime. This approach is also frequently used to compare different electricity generation options according to different technologies or sites.

In this research, we apply the LCOE concept to compare different configurations and sizes of PV systems with each other in multi-apartment blocks in order to understand the economic competitiveness of these systems. A range of configurations was therefore determined as follows (see Table 1).

Table 1. Defined configurations for the economic feasibility of PV systems in multi-apartment buildings.

Criteria	Range
PV configuration	Single PV system per apartment
	Joint PV system per building
Building standard	New building
	Old building
Building size	10 … 150 apartments per building
Installed PV capacity	0.25 … 3 kWp per apartment

The main criterion is the availability to each apartment in the house of its own PV system, including panel, construction, cabling, inverter etc. Other criteria are:

(1) size of the building (between 10 and 150 apartments per building),

(2) building standards (new or old building). We assume that this criterion is especially relevant for definition of LCOE and for the costs for building services, as implementation of PV systems in existing buildings is more expensive than integration of PV into new housing [38],

(3) PV capacity with basic configuration for each apartment ranging between 0.25 and 3 kWp.

We apply a well-established methodology to calculate LCOE. The following formula is used to calculate the LCOE for the defined PV configurations in multi-apartment buildings:

$$LCOE = \frac{\sum_{t=0}^{T}(I_t+O_t)/(1+r)^t}{\sum_{t=0}^{T} S_t(1-d)^t/(1+r)^t} \quad (1)$$

where T = Life of the project
t = year t
I_t = Initial investment cost of the system for t
O_t = Operation and maintenance cost for t
r = Discount rate
S_t = Rated energy output for t
d = Degradation rate

As shown in Eq 1 there are essential assumptions for calculating the LCOE of PV systems, such as system lifetime, discount rate, energy output, and degradation of the PV panel.

Based on existing scientific sources we make the following assumptions:

(1) Lifespan of 25 years for the system. We make this assumption according to the majority of studies dealing with LCOE calculations of PV [18,25,39]: a lifespan of 40 years or more has yet to be demonstrated [21],
(2) Discount rate, which depends on lifespan, circumstances, and location, and is applied to discount both costs and energy output over the lifespan of the PV system. We apply the weighted average cost of capital (WACC) methodology developed in several studies and adapted by [25] to determine the discount rate for several PV configurations. Thus, the WACC represents the cost of capital or the financing cost, considering the proportional weight of equity and debt,
(3) Share of equity and debt of 30–70% in line with the sources for Austria like [40],
(4) Rate on equity of 3% and a debt interest rate of 6% in line with the sources on varying costs of capital across countries and impacts of governmental policies, access to capital, financial risk, and inflation rate [41].

Based on the assumptions on the share of equity and debt, and the respective interest rates we calculate the WACC at 3.9% for Austria. We use this result, which corresponds to the discount rate, as the default value for all PV configurations.

Varying solar irradiation is another important component for LCOE calculations, as the energy output of a PV system is location-specific and determines LCOE calculations. It is calculated by the installed capacity of the PV system in kWp multiplied by the capacity factor in kWh/kWp. For Austria, a value of 1037 kWh/kWp (location Vienna, c-Si panel, optimised orientation) was calculated on the basis of PVGIS tool (Photovoltaic Geographical Information System).

Furthermore, the energy yield of PV panels over the lifespan depends on how much the initial energy output declines year by year, which is defined by an assumed degradation rate of 0.5% per year [18]. This is an empirical value for crystalline-silicon modules based on monitoring data and arises due to signs of wear. Reasons therefore are crystalline changes in the semiconductor material, as well as contaminated solar cells, shading effects or signs of aging of other elements of the solar modules.

Similar to energy output, investment costs and operation and maintenance costs vary according to location, installed capacity, complexity, operation, and other circumstances, such as building integration, etc. [37]. According to Eq 1 the initial investment cost of the PV system has to be considered in the period t = 0, whereas costs of operation and maintenance will occur in all periods over the lifespan until t = T. Corresponding to [21] the operation and maintenance costs are assumed at a rate of 1% of the initial investment. The overall investment cost covers investments for module, inverter, and building integration (cabling, etc.).

The dataset used for the investment cost items is generated on the basis of national data [31]. These data are calculated without subsidies based on a 2016 price level and on input from real estate experts and building promoters.

Based on these data and assumptions we develop scenarios for 20-, 50-, and 100-apartment buildings and for installed capacity of 0.3, 0.6, 1.4, and 2.8 kWp per apartment, which reflects the capacity required for a PV total cover ratio (relation of PV generation to yearly demand for electricity) of 10, 20, 50, and 100%.

3.2. Case study method

The current legal framework in Austria allows utilisation of locally generated electricity in the common parts of multi-apartment buildings. Nevertheless, the local electricity usage and the basic load are so low that ensuring direct provision to individual apartment owners and tenants with small units is a prerequisite.

In the framework of this study we analyze economic feasibility and barriers for implementation of PV electricity generation in three case studies:

(1) *Neubau Grünes Wohnen* (green housing new construction),
(2) *Pauschaler Nutzungsvertrag* (all-in usage contract),
(3) *Kaufmännisch-bilanzielle Weitergabe der PV-Erträge an Haushalte* (unbilled PV revenue allocation to households).

These case studies were developed within the project “StromBIZ” which researched business models for decentralised electricity generation and distribution in Austria targeted at delivering PV electricity to individual apartments within multi-apartment buildings. For all three case studies, the main issue was to concurrently reach economic, legal, and technical practicability while fulfilling certain aspects of consumer protection and housing legislation. The first two case studies are in line with currently existing legislation in Austria. The third requires an adaptation of the legal framework, as described below.

3.2.1. Case study “green housing new construction”

The model represents newly constructed housing in urban areas around Vienna. According to this model, PV electricity-generation panels are located in common areas such as on the rooftops. This case study assumes that the PV panel itself is rented to the apartment tenants, in contrast with models of PV electricity where power is sold direct to households (impossible under the current legal framework). Therefore, each apartment rents its own PV panels on the rooftop of the house.

Typical projects for this model include houses with 60 to 150 apartments and the total living space between 4,500 and 12,000 m^2 in size. As PV generation is integrated during the planning phase of these projects, all the technical requirements for PV generation are present during the construction planning itself.

From the financing point of view, the model is applicable to both privately financed and subsidised new construction. Project developers are motivated to apply this model: i) to contribute to climate change mitigation and the deployment of renewable energy sources; and ii) to position the company as environmental friendly in the market place.

The case study was applied to a recently constructed building in the 11^{th} District of Vienna by the project developer, "Building Development Network Fleissner and Partner GmbH". The pilot project name is "*Wohn-Oase-Simmering*", the word *Oase* (oasis) indicating that it has an ecological orientation. The building has 87 apartments. From the technical side, the deployment of PV panels on the rooftops was facilitated by a new 2015 construction regulation abolishing the need for emergency chimneys, which were previously a required construction element. The new regulation allows for additional space on the roofs for PV panels. The project foresees 2–3 panels per apartment to be managed by the owner of the house. An important element of this model is that the electricity is not sold to the tenant but that the tenant rents the PV panel from the house owner.

3.2.2. Case study "All-in usage contract"

This case study was applied to a student hall of residence built in 2011 in the 22^{nd} district of Vienna. It has 329 places for students, including one- or two-roomed apartments with communal kitchens and other extensive community areas, such as rooms for parties, sauna, fitness, and music. Altogether the project covers 8,100 m^2, including apartments, common areas, and some office space. Legally, student halls in Austria are treated similarly to hotels. Unlike apartments, the individual households are not required to have separate electricity meters. In this form of tenancy, all-in rents can be charged, including energy and all other utilities. Monthly payments are forecast for six months and after this period adjusted accordingly if energy consumption has been lower or higher than expected. The short-term risks of changing electricity prices and consumption are covered by the operator of the student hall. These provisions make it easy to integrate on-site production of PV electricity.

3.2.3. Case study "Unbilled PV-revenue allocation to households"

The project "StromBIZ" was a case study that examined how to maximise the technical, economic, and legal feasibility of direct delivery of PV electricity to households in multi-apartment buildings with a minimum of legal changes.

To explain this model some specifics of property law and electricity law in Austria must be discussed. All supply lines (electricity, gas, IT) within a building are owned by the building owner and not by the utility provider or transmission system operator (TSO). The TSO has responsibility for the operational reliability of the supply lines up to the apartment door. The supply lines between the plot boundary and the apartment door therefore have a hybrid legal character.

The model requires the access point between the public grid and the joint customer grid within the building to be legally defined. This will usually mean one residential building, but in bigger estates it may mean all the apartments accessible from one stairwell. However, for technical reasons the access point should be within the lowest network level (in Austria: level 7). By using a joint customer grid it should be possible to allocate the electricity produced by the PV facility to any of the customers on the same circuit. In such a constellation, electricity is distributed without using the public grid and therefore with no grid service fee and almost no taxes. As it competes with electricity from the public grid, this type of PV-self-consumption permits a higher load tariff, which allows the PV investment to be amortised over a reasonable time period.

Both the PV facility and all participating apartments require smart meters with 15-minute measuring. Meter reading and allocation of PV electricity is a new service which will need to be developed and applied (e.g., by TSOs) and thus to be paid for.

The model requires no changes in the existing system of network levels and balance groups. According to EU legislation, individual choice of the electricity provider is allowed (whereas there is no free choice as to the TSO). The model even addresses concerns on data privacy, as installation of a smart meter may be refused by a householder. Such a household would simply be excluded from allocation of PV electricity.

Different business models may be applied. The model shows high potential for PV facilities to be installed and financed as part of new construction or major renovations of existing buildings. Amortisation of the PV investment will occur through annuity payments on construction or renovation costs. It will thus be part of the rent payment. In return the tenants will be allocated free electricity through different schemes. One scheme is to use a fixed formula according to the size of the dwelling, as this is also the key for annuity payments. Another scheme is to charge according to the real demand of the dwellings.

The model also allows for business situations where third-party investors install and operate PV facilities and enter into contracts with individual households in the same building.

4. Results

4.1. Economic feasibility

Based on the methodology, described in section 3.1., Figure 1 shows the results of the specific investment costs of single PV systems per apartment in a new apartment building, illustrating the share of several cost components for the selected PV configurations in buildings with 20, 50, and 100 apartments and an installed capacity of 0.3, 0.6, 1.4, and 2.8 kWp per apartment. The overall investment cost covers investments for panel, inverter, and building implementation and is generated on the basis of Austrian data [31] without subsidies, based on a 2016 price level. The shown scenarios in terms of installed capacity (0.3–2.8 kWp), reflects the capacity required for a PV total cover ratio of 10–100%.

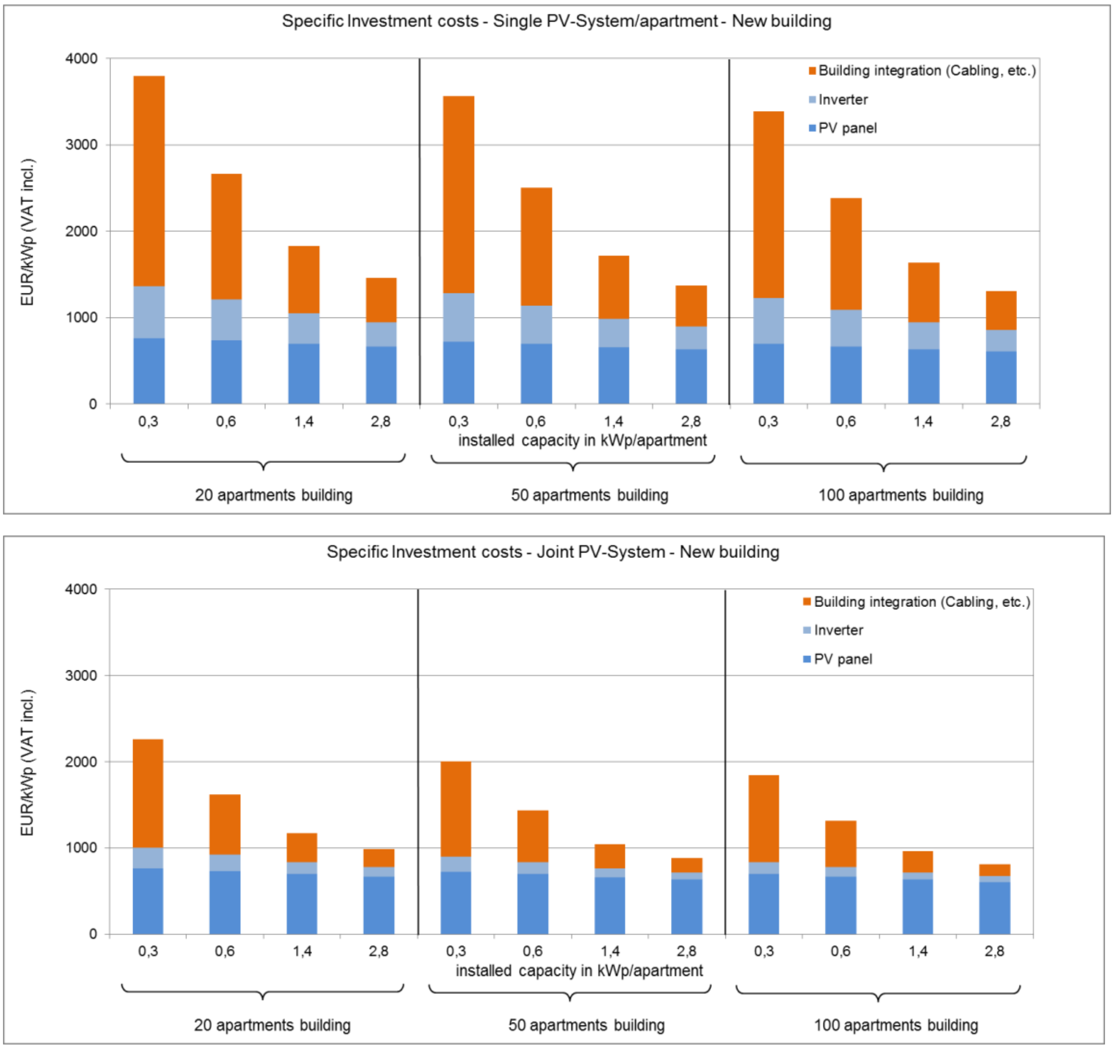

Figure 1. Specific investment costs of single PV systems per apartment and joint PV systems in new buildings.

The results show that there are four factors that significantly influence the costs of PV systems. These factors are single or joint ownership of PV systems, size of the building in terms of the number of dwellings, the installed capacity, and the age of the building.

First, single PV systems per each apartment in a new building (case study "green housing new construction") have the highest costs, namely, €3,800/kWp. Another factor driving the costs is the size of the building, with costs varying between €3,800/kWp for a 20-apartment building (0.3 kWp/apartment) and €1,300/kWp for a 100-apartment building (2.8 kWp/apartment).

Second, PV systems, which are owned jointly (both the other case studies), have significantly lower costs ranging between €2,300/kWp (20-apartment building: 0.3 kWp/apartment) and €800/kWp (100-apartment building: 2.8 kWp/apartment). As shown, the specific costs are determined by the ownership of PV systems. While the system configuration single PV system need to be equipped with an inverter per PV system and integrated in the building separately, a jointly owned PV system which can be seen as one large PV system requires one (larger) inverter and a less complex building implementation than single systems. Thus, the specific costs for the inverter and the building integration is much lower than for the single systems.

Third, the results show that the lower the installed capacity, the higher the share of specific costs for building integration, as several cost items, such as cabling, meter adaptions, data management, and billing have to be considered anyway, independently of the installed capacity. Thus, the share of the costs for building integration declines in accordance with a higher PV capacity per apartment. Furthermore, the costs for integrating the PV system into a building are higher for single PV systems than for joint systems because of higher expenditures for connections, cabling, etc. For both main categories, single and joint PV systems, the costs for the PV panel remain at the same level, declining just a little with higher PV capacity and larger building size. This decline is due to economy of scale. The same applies to the costs for inverters, but in contrast to the module costs, the inverter costs for single PV systems are significantly higher due to the fact that each single PV system requires an inverter. Both for building implementation and inverters, a reduction rate of 5% is assumed by doubling the building size. This reduction can be considered as a kind of quantity discount.

Fourth, implementation in newly constructed or modernised buildings plays a significant role. Old buildings require much higher expenditure for integration of PV facilities, since a supplementary installation of PV in existing buildings could be very complex, including adaptions to the building. In new buildings PV is a fixed component within the entire building design and therefore less effort must be made. In terms of the cost for building integration it is assumed to apply the same cost for all existing buildings, independently of the age of the building, therefore existing or old buildings need not to be specified in more detail. These additional costs compared to newly constructed buildings are estimated at 30% [38]. These costs result in about 10% higher overall costs for PV electricity systems in old buildings than in newly constructed buildings.

The following results of LCOE calculations facilitate comparison between several PV configurations in multi-apartment buildings.

LCOE calculations for single PV systems in new multi-apartment buildings (Figure 2 show the dependence on the number of apartments per building and the installed capacity per apartment. According to the calculated investment costs (Figure 2), the lowest installed PV capacity (0.3 to 0.5 kWp/apartment) results in LCOE ranging between €0.24/kWh up to €0.32 cent/kWh. It also shows a strong cost regression by higher installed capacities and a weak economy of scale in terms of apartments per building. In summary, more than 50% of the assessed configurations result in LCOE of below €0.15/kWh.

The LCOE for joint PV configurations is significantly lower than for single PV systems. Joint ownership of PV systems leads to up to 90% reduction in LCOE (Figure 3. More than 75% of all joint PV systems investigated have an LCOE below €0.12/kWh. A significantly high share of joint PV systems have an LCOE of between €0.6 and €0.8/kWh, especially those PV systems with an installed capacity >1 kWp per apartment on large buildings. The calculations for old buildings show an LCOE that is about 10% higher than that of newly built houses, which is due to higher cost for building integration, such as cabling, construction, meter adaption, etc.

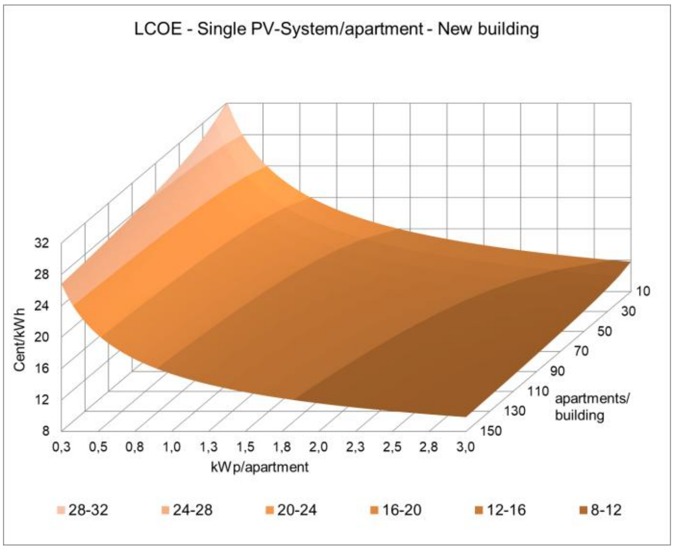

Figure 2. LCOE of single PV systems per apartment in new buildings.

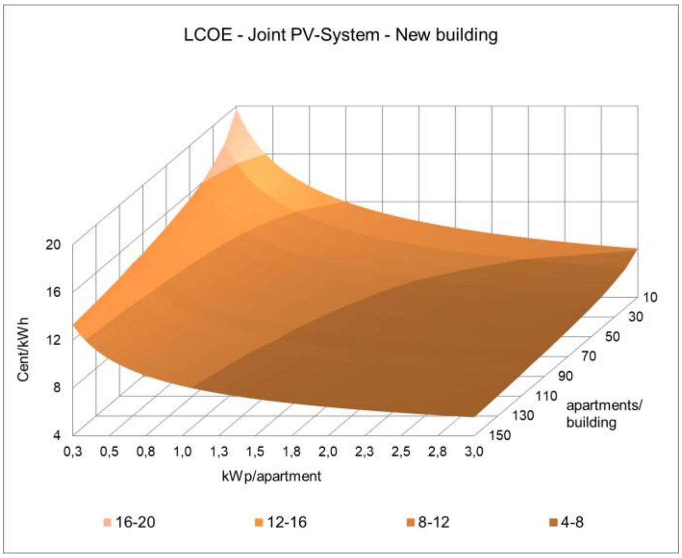

Figure 3. LCOE of joint PV systems in new buildings.

Figure 4 shows the results of sensitivity analysis on effects of parameters such as costs of capital (WACC) on the LCOE. Here, the parameter investment costs have the deepest impact on LCOE. These results show the significant impact of WACC on LCOE, namely, that the higher investment costs for PV systems are, the higher the LCOE is. Furthermore, the sensitivity analysis shows that the size of a building has lower effects on LCOE than the installed capacity.

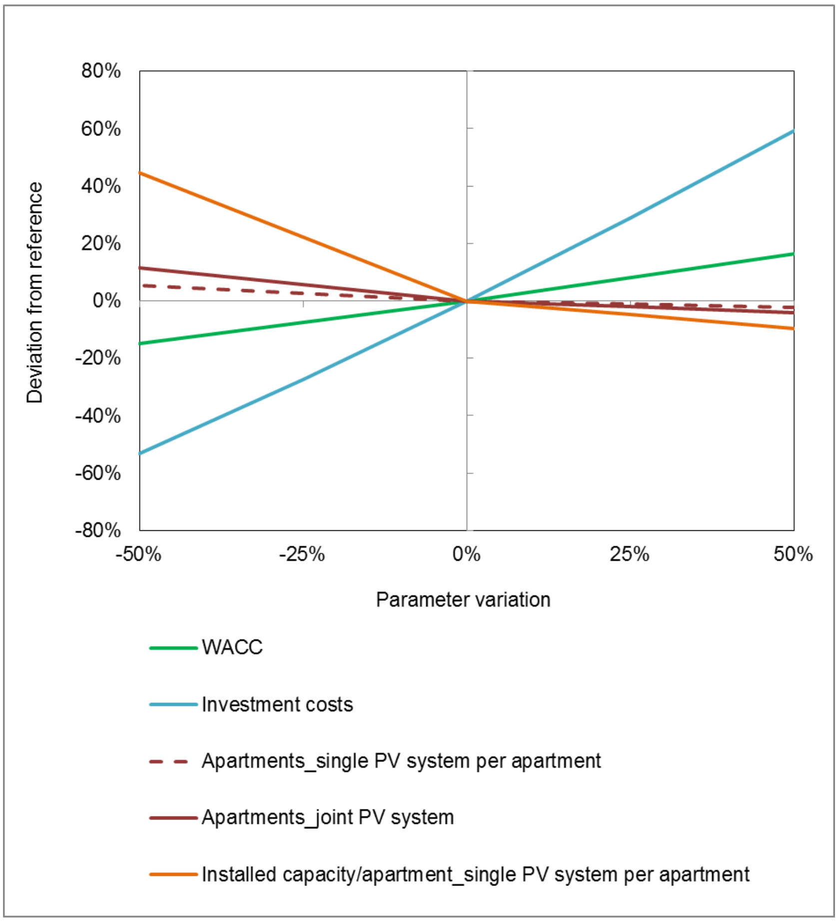

Figure 4. Sensitivity analysis of LCOE of PV systems in multi-apartment buildings.

4.2. Barriers in implementation

4.2.1. Technical barriers

The above-mentioned case studies showed the technical feasibility of PV generation in multi-apartment housing. However, a few issues arise, which are connected with ongoing innovations in PV technologies and control techniques.

One planning aspect deserves particular attention. This is the limited amount of space on roofs of urban multi-apartment buildings. Upscale top-floor apartments often have large roof terraces. In subsidised buildings or student halls the roof is often reserved for common use, such as gardening or recreation facilities. Air conditioning requires external devices, which are mostly allocated on the top of the building. Chimneys and ventilation shafts produce shadows and scattered open space that limits the potential for PV installations.

On the buildings assessed in the case studies, the possible PV installations would only be able to produce around 20% of the total annual electricity consumption of all apartments and common parts, and in many cases much less. This may change if technical innovation produces more efficient PV panels than those of today (below 20%). Future technical developments may also make integrating PV panels into building facades economically feasible. For now, however, there is only enough available roof space in high-density urban areas to cater to the energy demand of individual apartments. Another technical aspect especially related to multi-apartment building refers to the building integration of PV systems. Compared to single family houses the cabling, meter adaptions, data management, and billing is much more complex, which is due to longer distances within the building (cabling) and many parties you have to dealing with (data management, billing).

4.2.2. Economic barriers

In terms of the economic feasibility of on-site energy production, the level of self-consumption is even more important than the size of the PV facility and is essential for short amortisation periods. A medium-size facility can be more economic than a large one, if production and on-site consumption are consistent. In this respect, housing and PV electricity production do not have a very good fit. The load curve of the residential sector has peaks in the morning and particularly in the evening; it is much higher in winter than in summer. In contrast to the load curve, the production curve of PV is similar to a parabola with its maximum at noon in winter and a couple of hours later in summer. In a yearly perspective, the peak of the PV production is reached in summer, whereas in winter only 20–30% of the maximum is generated. The combination of different household profiles may improve the conformance of the curves, but only to a limited extent.

Grocery stores provide a very suitable consumption curve given that they stock refrigerated products. Supplying a supermarket on the ground floor of a residential building with PV electricity from the roof is a promising business scenario. Food retailers are in keen competition and focus their marketing on “green” topics. However, the big players benefit from extremely low tariffs. A few of them have even become electricity suppliers themselves. The possible cost benefits of local solutions are therefore very low and these could work only with very simple and low-risk solutions. The model of renting the panels in parallel with the premises, as described in the case study, “green housing new construction” might work if there is good will from all the parties involved. Suitable consumption curves are also given for office buildings.

A high level of self-consumption can be achieved with small capacities of about 20–30% of annual electricity consumption. There are potentials, especially in the area of base load coverage. This coincides with the availability of roof space on typical urban buildings.

This quantity seems low, but given the short amortisation time of joint PV systems, it is regarded as a rational contribution to the “*Energiewende*”. The level of self-consumption may significantly improve if the costs of electricity storage continue to go down. E-mobility will have a great impact on the economy of PV electricity generation in housing, particularly as the residential sector will play an important role in building a loading infrastructure for e-cars.

One regulatory barrier that had strongly impaired the economy of PV investments in multi-apartment construction was eliminated in late 2016. This was the use of “energy need for heating” as an indicator to regulate thermal minimum requirements in Austrian housing subsidy schemes. This indicator addresses only the building envelope. The EU Energy Performance of Buildings Directive [5] focuses on the indicator “energy performance factor”, which also considers on-site production of renewable energy, implying a strong incentive in subsidised new construction to apply slightly thinner thermal insulation and instead install PV units on the roof. The economic feasibility of PV electricity distribution would seem to be crucial if this regulatory opportunity is to be seized. This change is highly relevant, as housing subsidies impact some 60% of multi-apartment new construction in Austria [20].

The economy of PV electricity generation in urban areas is expected to be boosted as technologies are unrolled to increase the efficiency of PV panels and economically integrate them into building facades.

4.2.3. Legal barriers

Whereas PV electricity generation on single family houses works adequately, this has not been so in the multi-apartment sector. Major obstacles to implementation can be found in the legal regulations on electricity and housing. There is evidence of an appropriate legal and regulatory framework for PV electricity generation on single-family houses, but this framework is not appropriate for the multi-apartment sector. The regulatory framework contains major barriers to PV deployment in this sector.

In fact, it is the non-integration of the two spheres of legal regulations that have prevented a roll-out of PV in the large-scale residential sector. Electricity legislation and housing legislation come under the authority of different ministries. There are hardly any legal experts covering both spheres. For a very long time—since electrification of the housing stock a century ago—there has been no real need to bridge those two fields of regulation.

Of all the case studies described, only the "all-in usage contract" can be implemented without constraints under the current legal framework. It seems meaningful that homes for students are not subject to housing legislation but are treated similarly to hotels. This provides an insight into the self-contained character of housing legislation. For decades, housing legislation has been characterised by only moderate innovation with an excessive focus on customer rights. Issues of urban development, real estate markets, and ecological sustainability have been hardly alluded to.

Even the case study "green housing new construction" proves to be not feasible, partly because of its economy risks, and partly because of legal restrictions. Renting out the PV panels instead of selling electricity seems like a bright idea for beating restrictive electricity regulations—the PV-panel owner in this case is neither a producer nor a distributor of electricity, and can thus avoid all the obligations such designations would incur. It was developed as a contractual leasehold model outside the sphere of housing law. But in the end, no waiver of termination of this leasehold contract would stand up to Consumer Protection Laws (*Konsumentenschutzgesetz*-KSchG, BGBl. Nr. 140/1979). This conclusion causes a prohibitive economic risk to any housing developer.

An evaluation of the legal feasibility of implementing the three cases showed that under the current regulatory framework in Austria, only the "all-in usage" contract case can be implemented without constraints.

The evaluation showed that the case cannot be implemented under the current legal framework because of the existing deficiencies. The case involves the model where the house owner rents PV panels to the tenants, instead of selling electricity. This may be one way of overcoming the existing restrictive electricity regulations. The model was developed as a contractual leasehold model outside the sphere of housing law. However, current Consumer Protection Law does not allow a waiver for termination of the leasehold contract. This creates a significant economic risk for revenues to housing projects already developed.

On the other hand, the case study “Unbilled PV-revenue allocation to households”, as described above, presents a cost-efficient solution with only minor changes to the Electricity Act of 2010 (*Elektrizitätswirtschafts-und-organisationsgesetz*-ElWOG, BGBl. I Nr. 112/2008). In fact, this model has had a strong impact on the current legal reform. The draft Green Electricity Act (*Ökostromgesetz*), published for legal review in early 2017 and expected to enter into force in the second quarter of 2017, also includes a reform of the Electricity Act, which, in terms of both functionality and reasoning, follows many of the provisions of the case study “Unbilled PV-revenue allocation to households”.

5. Conclusion

We summarise all identified barriers in the table below.

Table 2. Technical, economic and regulatory barriers.

Barriers	Green housing new construction	All-in usage contract	Unbilled PV-revenue allocation to households
Technical	Inadequate space on roofs, conflicting uses		
Economic	Poor economic performance; risk of premature dismissal of PV panels	Sufficient performance, but small market	Good performance
Regulatory	Absence of enforcement mechanisms for landlords in case of termination of lease contracts	None	Moderate legal reform required

Our results allowed four factors to be identified that influence the economic feasibility of PV generation in multiple-apartment housing. These factors are single or joint ownership of PV systems, size of the building in terms of the number of dwellings, the installed capacities and the age of the building. The results also show that jointly owned PV systems allow reduction of the LCOE to €0.06–€0.08/kWh. This makes PV generation competitive with fossil fuels even in the absence of subsidies.

However, there are many barriers to implementation for solutions such as jointly owned PV systems. Technical barriers are availability of space on rooftops of urban multi-apartment buildings. Economic barriers are a low level of self-consumption due to a mismatch of the PV load curve and the consumption curve of private households. This results in only moderate capacities of annual electricity consumption. But those barriers may diminish, if electricity storage and e-mobility further develop. A massive barrier used to be the Austrian housing subsidy schemes, as they have favoured measures on the building envelope instead of local generation of renewable energy. But this barrier was recently removed.

But the main barriers are seen in the regulatory and legal framework in Austria. To date, virtually no model of allocation of PV electricity to households in multi-apartment buildings works. The only case study without legal barriers are student halls of residence. The main barriers appear in electricity regulations, as any business entity running a joint PV facility is classified as an energy producer and distributor and hampered by prohibitive obligations.

The most significant regulatory driver is the development of the Green Electricity Act, which was published for legal review at the beginning of 2017. The law includes a reform of the Electricity Act of 2010 (ElWOG), which is the main regulatory body for PV utilisation. The law is expected to enter into force during the second quarter of 2017. It aims to facilitate innovation in PV utilisation as it will be open to the largest possible number of business applications. One will be PV installation in the course of new construction or major renovation projects and refinancing with allocation of free electricity to households, as described in the case study "Unbilled PV-revenue allocation to households". Other applications will include existing or new kinds of service providers to invest in PV and contract to households.

However, the current reform of the Electricity Act will not be the end of the road in terms of tapping the full potential of PV in multi-apartment housing. Enabling joint PV facilities will create a new market. New very promising technologies on market allocation of energy services are appearing and will require further smart regulation. Besides regulatory and legal framework reforms, further research is needed on newly emerging technologies to facilitate the deployment of PV generation. The blockchain technology is a prospective breakthrough technology, which may create quite new perspectives in allocating and contracting of locally produced renewable energy. The international community recognises the actuality of this technology and the first global summit on blockchain technology in the energy sector, EventHorizon, was conducted in Vienna in February 2017 (www.eventhorizon2017.com). However, implementation of this technology would require further development of the regulatory and legal framework.

There are still plenty of unresolved issues with respect to housing law. All areas of housing management, maintenance, major renovation, use of common areas, financing, and quorum rules are strongly regulated. Even worse, regulations differ among the different sectors of the housing stock. Past experience suggests that the necessary reform steps will be more easily implemented in the Limited Profit Housing Act (*Wohnungsgemeinnützigkeitsgesetz*-WGG, BGBl. Nr. 139/1979), which mainly applies to subsidised housing, than in the field of condominium housing (*Wohnungseigentumsgesetz*-WEG, BGBl. I Nr. 114/2002) or rental housing (*Mietrechtsgesetz*–MRG, BGBl. Nr. 520/1981). Unfortunately, housing has become one of the most awkward and reform-adverse fields of Austrian federal policy in the past two decades. The long-standing government coalition between the centre-left (SPÖ) and centre-right (ÖVP) hold opposing ideological positions on housing dating back to the early 20th century. As they are dependent on quite different clienteles no compromise seems possible. Further investigation is needed to see whether a small reform with a few technical regulations be enough or whether some of the core positions of the governing parties can be shifted.

Developments during the last couple of months have been positive in terms of creating a suitable framework for deployment of PV generation in multi-apartment housing. The models developed in the "StromBIZ" project have had a positive impact and inspired recent reforms in the legal system. The Austrian Research Promotion Agency (FFG) ran a detailed information campaign, as it does for all its research programs, and this reached a major part of its stakeholders, thus impacting policy makers. An important way of overcoming barriers is to put across challenges and differences in simple language. This allows complexity to be simplified and the interconnections between various different relevant aspects—technical, economic, and legal—to be better understood.

The most significant regulatory driver was the development of the Green Electricity Act, which was published for legal review at the beginning of 2017. The law, which includes reforms to the Electricity Act 2010, is expected to enter into force during the second quarter of 2017. The law will facilitate innovation in PV utilisation for business applications.

However, the current reform of the Electricity Act will not be the end of the road in terms of tapping the full potential of PV in multi-apartment housing. Further reforms of the housing law are also necessary. For instance, there are currently plenty of unresolved issues such as the reforms needed for implementation of the Limited Profit Housing Act (WGG). This act mainly applies to subsidised housing and does not include condominium housing (WEG) or rental housing (MRG).

According to the Austrian government programme from 2017, Austria's electricity production shall be entirely covered by renewable energies by 2030. This is only feasible through a highly ambitious implementation programme for PV installations.

The 2017 amendment of the Austrian Electricity Sector Act of 2010, §16a (ElWOG) laid the legal foundation for PV installations in multi-party residential buildings, thus allowing for the development of models for the supply with PV electricity. High levels of self-sufficiency are now possible and allow for economic feasibility. But due to existing uncertainties, a large-scale implementation was not yet observed. Contract design of the models is complex, and therefore one of the hurdles.

In June 2018, the Government presented an "integrated Climate and Energy Strategy". In addition to electricity sector regulations it stipulates a reform of housing legislation to advance PV rollout. It announces a "100,000 roofs PV programme". An existing tax on medium to large scale PV facilities shall be cancelled.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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