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Economic potentials of community-shared solar plants from the utility-side of the meter – A Hungarian case

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ABSTRACT

Community-shared solar PV systems support the democratization with the efficiency of centralized systems. The paper highlights the economic competitiveness of this model in Hungary. Three options were elaborated by an Excel-based model. Analysis includes levelized costs and levelized savings calculations. Results indicate that new solutions have higher NPVs than traditional ones in Hungary. Sensitivity analyses highlight that net savings of community-financed business models are very sensitive concerning VAT and the capital investments of residential customers.

1. Introduction

Recent studies deal with the main technological, environmental, political and social benefits and barriers of decentralized PV systems as disruptive, system innovations (Bauknecht et al., 2020; Gao and Yuan, 2020; Dincer and Acar, 2018; Shum, 2017; Guerrero et al., 2010; Shum and Watanabe, 2009). These research surveys confirm that small-scale PV generation technologies not only affect the subsystem of power generation but also require and cause deep changes both along and in each single stages of the value creation process of the power industry. Furthermore, it is also stressed that in order to increase the penetration and diffusion of decentralized solutions, the physical, legal, political, institutional, organizational and market dimensions of the dominant technology regime of the power sector should be modified and altered (Ros et al., 2018; Adil and Ko, 2016; Deutsch, 2012; Markard and Truffer, 2006). To solve the problem of systemic fit and to meet the ambitious national renewable energy targets, environmental, social and economic analyses of centralized, large-scale PV systems as viable and sustaining alternatives have also come to the forefront (Rodríguez-Manotas et al., 2018; Guerin, 2017; Ahadi et al., 2014; Sanz et al., 2011; Dakkak et al., 2003), and the total installed capacity of centralized, utility-scale PV plants is on the rise (Wolfe, 2018; Bolinger et al., 2019). Moreover, several innovative business models and financing schemes have emerged worldwide and become available for both centralized and decentralized technological solutions.

Regarding the residential scale, besides the traditional decentralized customer-sited rooftop models with self-, utility- or public financing, the widespread diffusion of solar service models such as Solar Leasing, Solar Power Purchase Agreements, and Roof Rental offerings can be observed (Zhang, 2016; Huijben and Verbong, 2013). At the utility-scale, as a particular type of centralized PV system with the potential of democratization of the industry, a group of new business models has been developed called inter alia shared solar (Feldman et al. 2015; Augustine and McGavisk, 2016), community solar (Asmus, 2008, Funkhouser et al., 2015), community-shared solar (Coughlin et al., 2012; Chan et al., 2017), or community-owned (Sommerfeldt, 2015) PV plants. As PV market is booming worldwide (Zeitouny et al., 2018), a relatively rapid uptake of community-based solutions is also identified by Šahović and Pereira da Silva (2016) and Capellán-Pérez et al. (2020). By taking into account the ownership structures, community-shared PV models can be further divided into community-financed PV plants with traditional utility ownership structures and energy community-based PV plants with collective ownership structures. In the first case, new PV power generation capacities are established through the involvement of residential capital in such a way that instead of building their own PV capacities, residential customers with PV capacity-building intentions agree on a specific financing arrangement with the utility to support the centralized PV investments of the company and in turn, the capital investors receive a fixed amount of electricity over a predefined period of time. The generation of power from renewable resources is provided by local PV plants in renewable energy communities. The local communities partly or wholly own the plants with the participation of utilities. According to this business model, residential customers, local businesses and/or local municipalities buy

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power from the community-owned PV plant and utilize local energy supplemented with traditional power purchases managed by the utility. One of the key common benefits of community-shared solar PV systems is their ability to support democratization by allowing the integration of those residential and non-residential customers (e.g., flat owners, renters, those with shaded roofs) to PV-based power generation who do not have the necessary technical, legal, physical or financial conditions to establish their own decentralized systems. Between the two extremes of decentralized (e.g., small-scale rooftop) and centralized (e.g., traditional utility-scale) plants, community-shared PV systems aim to achieve cost savings at the national level, due to their efficiency and scale advantages, while providing utilities and energy companies the opportunity to access to new funding sources and define new value propositions for their customer base (DOE, 2010; Sommerfeldt, 2015; Dunlop and Roesch, 2016).

It is an evidence from the viewpoint of technology management and system innovation that to gain momentum, to threaten the position of centralized fossil and nuclear power plants as dominating technology paradigms for power generation, and to be ahead of other renewable-based solutions and modern fossil fuel-based technologies, PV-based power technologies need to demonstrate better performance in serving the traditional and the new - measured by well-known technical and economic performance metrics - and the new - evaluated by the new performance dimensions of environmental and social impacts – functions of the power sector (McHenry, 2012). The results of the functional competitions among the different technological groups and configurations have an impact on the choices and reactions of new and old market players, while in turn, their technological choices and behavior guide the functional development of technologies. Additionally, the development of the functional performances of different technology groups influences the evolution and the shift of the technology trajectory of power generation, and ultimately, the emergence of a new system configuration (Hofman and Elzen, 2010).

In general, small- and large-scale PV-based technologies are seen to perform better in serving the new functions of the power system by having relative sustainability advantages in terms of social and environmental impacts over traditional nuclear and fossil fuel-based solutions (Deutsch, 2018; Murphy et al., 2014). However, despite the continuous development efforts, the strong learning effects, and the remarkable cost reduction of PV generation that now exceeds nearly 75% over the last decade (IRENA, 2019), PV technologies in most of the cases without public support are still at a disadvantage in terms of economic performance compared to traditional ones, even though these performance gaps can vary from solution to solution, and from project to project, and the narrowing of the gap is a global phenomenon. Besides the use of traditional economic measures, such as net present value or internal rate of return, applicable to evaluate the economic performance or feasibility of different power projects, levelized cost of energy (LCOE) has become a widely accepted tool to assess the cost-effectiveness and the long term competitiveness of different power generation technologies (Ueckerdt et al., 2013). In this sense, based on the comparison of LCOEs of power generation technologies, it is possible to define the position of each technological solution in the traditional functional competition among incumbent and emerging technologies (Branker et al., 2011; Webb et al., 2017). Grid parity has become a measure to indicate the symbolic milestone when PV-based solutions will produce power for the same cost of traditional technologies (Orioli and di Gangi, 2017). Grid parity for rooftop PV models is defined as the threshold at which the grid-connected PV system supplies electricity to the end-user at the same price as grid-supplied electricity (Ramírez-Sagner et al., 2017). For utility-scale PV plants, it usually refers to the threshold at which the levelized cost of electricity generated by the centralized PV plant equals to LCOE of conventional power generation technologies or to the wholesale market price of power (Bhandari and Stadler, 2009). While some authors (Orioli and di Gangi, 2017; Hagerman et al., 2016; Bazilian et al., 2013; Breyer and Gerlach, 2013) indicate that PV-based technologies had already reached or those are close to reach grid parity in some counties or regions, other scholars (Nissen and Harfst, 2019; Benes and Augustin, 2016; Choi et al., 2015; Joskow, 2011) strive to draw the attention to the limitations and drawbacks of using LCOE-based technology comparisons by stressing that: i) detailed description of the methodological background and assumptions used by the different LCOE studies are usually missing, ii) access to credible data for the key characteristics of generation technologies is limited; iii) financing costs has a remarkable effect on the LCOE of PV plants, while current LCOE studies and calculations usually do not take into account the financial barriers and tax effects, iv) proper and transparent valuations of LCOE of solar plants can only be made on a locational basis; v) no perfect displacement exists between dispatchable and non-dispatchable generation, and between intermittent and continuous generation (capacity factors are variant).

Furthermore, different PV-based solutions represent a Schumpeterian “swarm of new entry” of competing technologies meaning that on the one hand, small- and large-scale PV technologies with emerging and distinct business models, physical and financial flows have their own grid parity points. On the other hand, the traditional functional performance of these solutions will influence which technology, if any, will lead to a new standard in a given national context.

Although many studies have been conducted on the availability and economic viability of different PV-based business models focusing on the inter-group competitions between traditional and PV-based power plants by examining the financial performance and functional competitiveness of a selected PV-based solution against its conventional competitors, the goal of this paper is to highlight the importance of intragroup competition by investigating the economic performance of traditional utility-scale PV parks and community-financed PV plants from the utility-side of the meter in the Hungarian context. There are hypothetical business models developed to fill the research gap and to contribute to other future works in other countries. The traditional functional competition between the business models was examined by using NPV and LCOE analyses. In order to handle some limitations associated with LCOE comparisons, tax effects were also integrated into the model, levelized cost savings of each solution were defined, and the uncertainty associated with the factors that have more influence in the profitability of these systems was assessed through one and two-way sensitivity analyses. Accordingly, the article is organized as follows. Section 2 outlines the actual status of the Hungarian PV market and future expectations, introduces and highlights the key assumptions of the business models, and discusses the methodology used to perform economic analyses. Section 3 presents the key findings of NPV, LCOE and LSOE calculations, and sensitivity analyses. Finally, a summary with concluding remarks are provided as useful information to potential investors and policy makers.

2. Model development and assumptions

2.1. Present status and key trends in the Hungarian PV market

Although the share of renewable electricity generation has been growing dramatically in the EU, until nowadays, Hungary has been somewhat lagging behind this trend, mainly due to the lack of experience and expertise related to renewable technologies, and the uncertainty around the introduction of the new feed-in tariff scheme, called METÁR. However, the total installed capacity of PV plants increased from 395.63 MW in 2017 to 1 340 MW in 2019, which represents an impressive percentage growth of 238.70% (MAVIR, 2020). It is also worth to mention that regarding the type of PV plants, small-scale residential PV systems have lost their dominance (due to their slowing growth rate) and licensed PV plants seem to take over the leading role in terms of new capacity installations (during the period 2017 and 2019, 661.99 MW of new utility-scale PV plants were installed). Despite the fact, that the number of RES cooperatives and energy communities is in its uptake especially in the field of energy efficiency in Hungary (Németh et al., 2020; Capellán-Pérez et al., 2020), literally no community-shared solar PV plant is in operation or expected to be built in the near future according to the official information. Currently, a hundred of SMEs and power retail companies offer to install and operate residential-scale rooftop PV systems for household or plan to enter the market with Solar Leasing services. 59.93 MW from the total power generation portfolio of the main market player was utility-scale PV plants in 2019, and the company is still planning to build approximately a total of 180 MW traditional, utility-owned PV plants by the end of 2020, due to the advantageous position of the country regarding solar radiation, sunshine duration and cloud cover, the continuous improvement of the technology accompanied by increasing efficiency and decreasing CAPEX and OPEX costs. The official forecasts of the Hungarian Transmission System Operator (MAVIR, 2019), the National Energy Strategy (NFM, 2012) and the National Energy and Climate Plan (ITM, 2020) indicate that the total installed capacity of solar power plants will be in the range of 1 663 - 4 000 MW by 2025, and can achieve 4 313 MW to 11 975 MW by 2040. The energy scenarios of ENTSO-E (2018) also assume that the share of PV-based power generation in the total annual power generation can reach 31.16% in the pessimistic, 37.17% in the real, and 57.53% in the optimistic case by 2040. All these mean that solar power is treated as the most important renewable energy source in the future. Based on the ambitious expectations and the investment plans of the Hungarian market players, this paper contributes to the existing knowledge base by examining whether the introduction of a new business model, i.e., the use of community-financed PV system, can contribute to the greening of the power generation portfolio of a potential utility company by providing an economically viable option for external financing.

2.2. Assumptions on the business model of community-financed PV plant

Economic comparison of utility-side benefits of the community-shared PV business model with the traditional utility-scale PV system was elaborated via a decision-analytic model using Microsoft Excel and Visual Basic Programming. Physical (solid arrows) and monetary (dotted arrows) flows defined for the business models of utility-scale and community-shared solar PV plants in the Hungarian context are presented in Fig. 1.

The traditional power utility business model (Fig. 1.) focuses on the generation of electricity based on large-scale PV plants developed and operated by the utility company. Residential customers in this model are supplied with power via the transmission and distribution grid by using intermediaries (such as TSOs, DSOs and retailers) and pay on a per-unit consumed basis (defined by the universal service price scheme applied for residential households) (Hall and Roelich, 2016). In the case of community financing, the PV system is installed and owned by the utility; however, the invested capital is provided by residential customers, and it equals the investment costs of unique roof-top PV systems installed by households with average annual power consumption profile. The utility can benefit from the difference between the investment costs of residential scale and centralized, utility-scale PV systems. It can sell the electricity produced by the PV plant to the transmission system operator who pays a guaranteed (feed-in) price and can sell the excess production in the wholesale market. These revenues should cover the operational costs of the plant, the system usage fees and charges, the purchase and supply of electricity to investors (with the associated residential system usage charges), and the VAT liabilities. Taking into account that the level of public VAT revenues may not be lower than the amount of revenue generated by the traditional retail power purchases, in this paper three types of community-shared PV plant options are investigated based on the VAT deduction entitlement of the utility: in Option 1 the utility is not eligible to reclaim VAT neither on the CAPEX nor on the OPEX costs of the project, while in Option 2 the utility is entitled to reclaim its VAT-payments on the CAPEX costs of the investment. In contrast, the utility is entitled to reclaim its VAT-payment both on CAPEX and OPEX costs in Option 3.

2.3. Methodology and data

Regarding the location of the projects, hypothetical PV plants were expected to be built in Szekszárd, which is situated in the southern part of the country, and can be characterized with balanced annual solar irradiation values (see Fig. 2). Annual total solar irradiation on a tilted plane (with an optimal angle of 35°) for the randomly selected location was defined by using long time series of 15-minutes data between 2004 and 2015. Global solar irradiation data was provided by the HelioClim-3 database (SodaPro, 2020).

The analysis of the economic viability of PV-based business models requires a careful examination of heterogeneous parameters. In order to build realistic models, legislative and engineering issues and preconditions

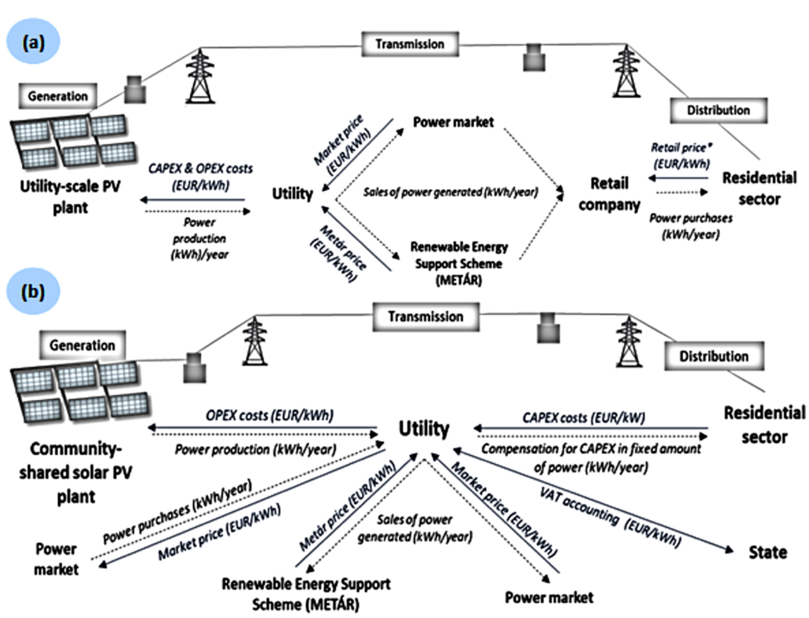

Fig. 1. Schematic representation of traditional utility-scale PV (a) and community-financed solar PV (b) business models.

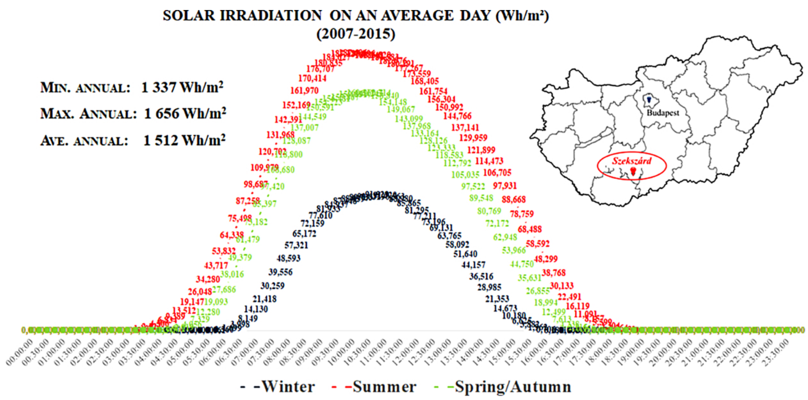

Fig. 2. Location and annual solar irradiation of the site.

were explored, cost and price data used in the models were derived from official databases, forecasts of the industry representatives and available market surveys. Key model variables determining the costs and the cash-in and outflows of the utility were defined, calculated and, if it was necessary, estimated for the engineering and technical attributes of the PV plants (e.g. size of the plant, performance rate and degradation, land requirements), the capital expenditures (e.g. investment costs, connection charges, reinvestment cost of inverter), the operational expenditures (e.g. costs of operation and maintenance, transmission and distribution fees and charges, wholesale market prices), and for the revenue streams (e.g. rate and of feed-in tariff, wholesale market prices) valid for the different business models. Assumptions were also made on the timing of the project, and on the key general and macroeconomic premises (e.g. discount rate, tax rate, exchange rate). The input parameters, abbreviations and assumptions of the calculations and the source of data are summarized in the Appendix A, in Table A1. Electricity production of traditional utility-scale and community-financed PV systems were defined according to Šúri et al. (2007). For each PV business model options expressions of net present value, levelized cost of electricity and levelized savings of electricity were defined based on the country-specific regulations and option-specific cash-in and outflows. The economic calculations were performed with three different WACC levels to determine the feasibility and economic potentials of the proposed financial structures.

3. Results and discussion

Results of the economic analyses of the different PV systems (Table 1.) show that due to the high LCOEs, NPVs of the traditional utility-scale power plant calculated with three different WACC levels are negative under baseline conditions, indicating that the realization of the project without investment support should be rejected by the utility. In contrast, if VAT entitlement of the company is not considered, community-financed options have the same level of LCOE values, which decrease as the WACC increases and lower than the LCOE values of the traditional utility-scale PV plant. If VAT-entitlement of the utility is taken into account, changes in the LCOE confirm that as the major generation cost for solar PV plants are the upfront cost and the cost of financing the initial investment, LCOEs are very dependent on the financing and taxation methods available. The higher LCOEs of community-financed solar PV with Option 1 are misleading in the sense that the initial investment costs (CAPEX) of these projects are covered by the individual contributions of residential customers leading to a favorable situation in which the NPVs of the option is positive. NPVs of community-financed solar PV Options gradually improve with the increase of the discount rate, and under baseline conditions, according to the NPV principle, all options can be accepted by the utility.

Taking the cost-reducing potentials of technology development and learning effect into account, these findings on the LCOE of traditional large-scale PV plants are in line with the results of previous reviews using somehow different but country-specific assumptions. IEA-NEA (2015) estimates that LCOEs of PV-based power plants in Hungary will be in the range of 149.18 EUR_{2015}/MWh to 224.15 EUR_{2015}/MWh by 2030 and REKK (2018) forecasts that LCOEs of large-scale PV plants achieve 52.65 EUR_{2018}/MWh by 2025. Although a direct comparison of levelized costs of the hypothetical PV-based business models with the LCOEs of conventional power generation technologies cannot be performed because of the differences in the initial assumptions in the calculations used by the country-specific surveys, it should be concluded that wholesale grid parity will not be achieved in the starting year, due to the fact that expected average prices for baseload and peakload products traded on the Hungarian Power Exchange is 55.54 EUR_{2021}/MWh and 68.22 EUR_{2021}/MWh respectively.

Fig. 3 compares the levelized unit savings of electricity generation, i.e., the net present value of the unit-savings of electrical energy over the design lifetime, of the different financing schemes. LSOE analyses suggest that the benefits realized over the 25 years of operation of the community-financed solar PV systems can be enhanced significantly by the reclaim of VAT-payments on the CAPEX and OPEX costs of the

Table 1
Results of LCOE and NPV analysis at different WACC levels.

PV Plant and Option type	Life-cycle cost of PV plant (cent EUR_{2021}/kWh)			Net Present Value (EUR)**		
	WACC *5.83%*	WACC *6.04%*	WACC *7.00%*	WACC *5.83%*	WACC *6.04%*	WACC *7.00%*
Traditional utility-scale power plant	14.15**	14.35**	15.29**	−2 778 395	−2 825 380	−3 025 820
Community-financed PV plant Option 1*	10.26*	10.22*	10.04*	586 656	680 168	1 066 038
Real LCOE**	16.15**	16.16**	16.21**			
Community-financed PV plant Option 2*	10.26*	10.22*	10.04*	2 891 644	2 979 765	3 335 724
Real LCOE**	11.90**	11.83**	11.55**			
Community-financed PV plant Option 3*	10.26*	10.22*	10.04*	3 732 563	3 790 773	4 029 463
Real LCOE**	10.26**	10.22**	10.04**			

Notes: Values were calculated without taxes and * excluding VAT or ** including VAT.

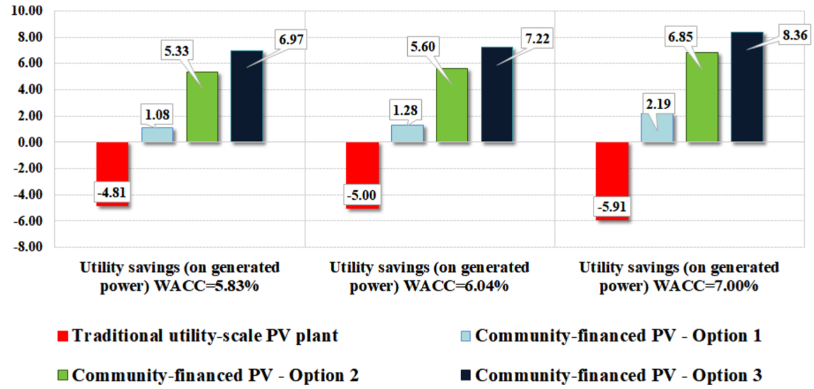

Fig. 3. Levelized unit savings (LSOE) without VAT payment/refund (cent EUR/kWh).

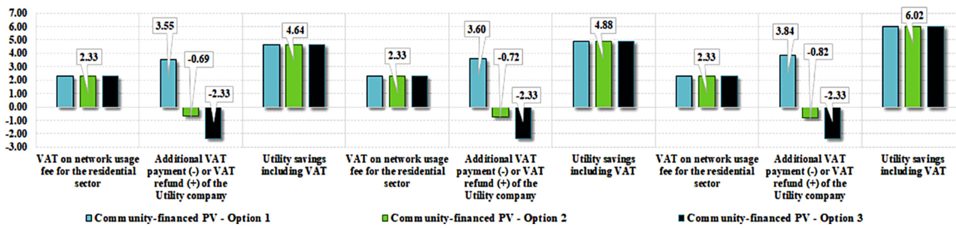

Fig. 4. Levelized unit savings (LSOE) after VAT payment/refund (EUR/kWh).

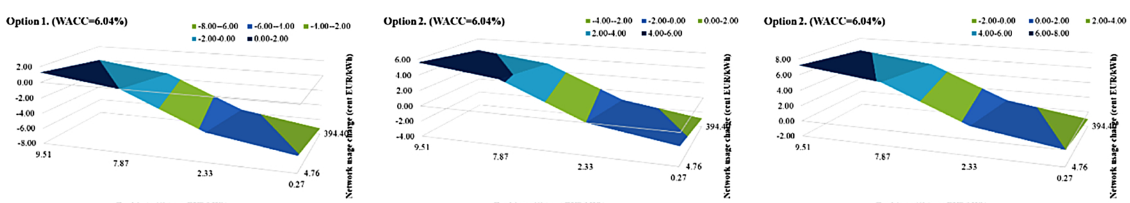

Fig. 5. Sensitivity analysis of LSOE to Feed-in tariff and network usage charge (cent EUR/kWh).

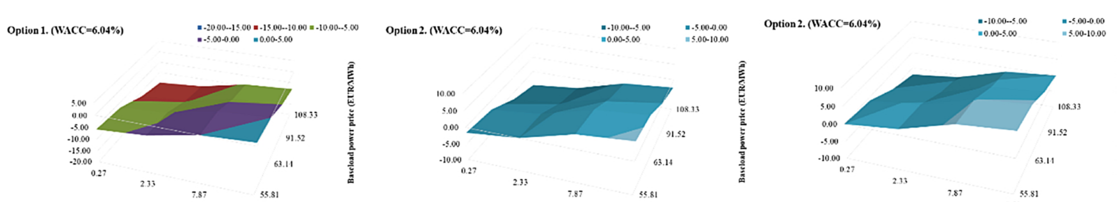

Fig. 6. Sensitivity analysis of LSOE to Feed-in tariff and baseload power price (cent EUR/kWh).

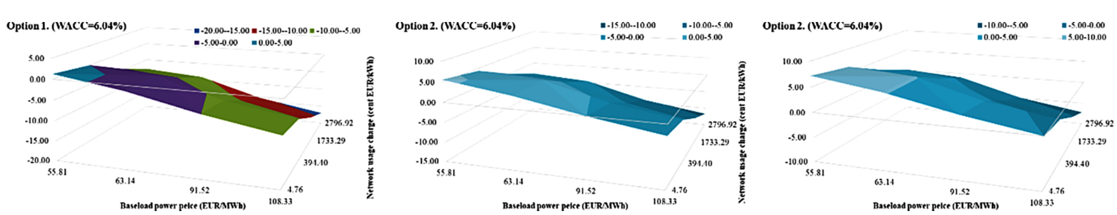

Fig. 7. Sensitivity analysis of LSOE to Baseload power and network usage charge (cent EUR/kWh).

project. At WACC level of 6.04%, the total life-cycle benefits of community-financed solar PV plant Option 3 is more than 5.64 times higher than in the case of Option 1. However, taking into account the requirement that the level of public VAT revenues may not be lower than the amount of revenue generated by the traditional retail power purchases of residential customers, the utility would be able to reclaim 3.60 cents EUR/kWh in the case of Option 1, 0.72 cents EUR/kWh in the case of Option 2, and in Option 3 has a 2.33 cents EUR/kWh VAT payment obligation (corresponding to the VAT paid on the system usage charge by residential customers), which result in the same level of benefit (4.89 cents EUR/kWh) achieved by the three options (Fig. 4).

In order to highlight the sensitivity of the business models of community-financed PV plants to the modification of the initial assumptions, one-way and two-way sensitivity analyses were performed. Sensitivity analyses at 6.04% of WACC, investigate the effects of the key influential exogenous variables on the savings realized by the utility, i.e., the purchase price of the new feed-in tariff ($I_{METÁR}$), the yearly price of baseload electricity traded in the Hungarian Derivative Energy Market from the Year 2022 (C_{MARKET}), and the network usage charge (C_{RSC}) from the year 2022 that the utility has to pay for transporting the

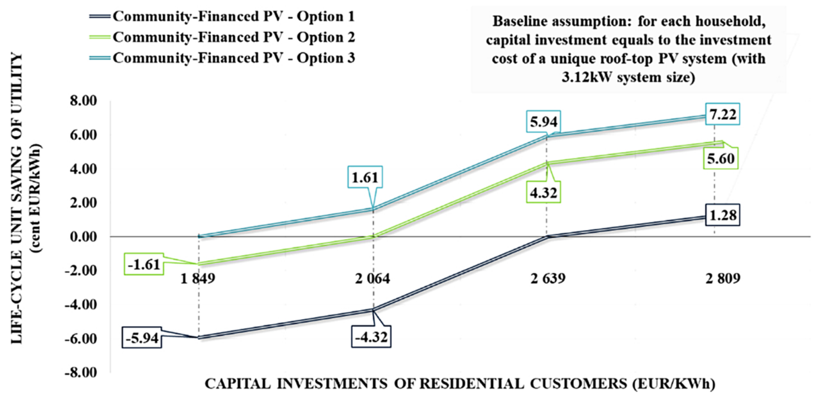

Fig. 8. Sensitivity analysis of LSOE to the capital investments of households.

fixed amount of electricity to its investors. As Figs. 5, 6 and 7 illustrate, by using a conservative approach and assuming the decline in the renewable support mechanism (i.e., lower feed-in tariffs), the increase in the HUDEX baseload price (C_{MARKET}) and in the network usage charge (C_{RSC}) after 2022, levelized unit savings of electricity generation of the different community-shared PV systems will decrease. Regarding the value of feed-in tariff, LSOE turns to a negative range at 0.226 cents EUR/kWh in the case of Option 3, at 2.33 cents EUR/kWh in the case of Option 2, and at 7.87 cents EUR/kWh in the case of Option 1. If HUDEX baseload electricity price (C_{MARKET}) rises to a higher level than 63.16 EUR/MWh Option 1 become unprofitable without VAT refund, for prices above 91.52 EUR/MWh the LSOE of Option 2 and above 108.33 EUR/MWh the LSOE of Option 3 turns into negative. If network usage charge for residential customers (C_{RSC}) continues to increase and exceeds 4.76 cents EUR/kWh after 2022, levelized unit savings of all options remain positive.

Two-way sensitivity analyses also suggest that in those cases in which pairwise critical parameters follow an unfavorable trend, unit-savings can be realized on each community-financed solar PV capacity investment options, however, in a decreasing manner. It can be concluded for all variables of the analyzes that life-cycle unit savings of Option 1 are more sensitive to variations in the input variables compared to Option 2 and Option 3. While in the case of Option 2, more than the half of the LSOE values are in the positive range and Option 3 of community-shared solar PV capacity investment provides unit-savings even in the worst-case scenarios, these options assume that the utility is entitled to VAT deduction for CAPEX, and for CAPEX & OPEX, respectively.

In addition to the external factors beyond the control of the utility, it is worth to investigate the sensitivity of levelized unit savings to the modification of the capital investments made by residential customers, since the feasibility of community-financed PV projects depends primarily on the ability of the company to attract a sufficient number of investors. Indeed, the attractiveness of participating in a community-financed PV project for residential customers is determined by its opportunity cost. Consequently, the availability of and the access to different PV technologies and business models, and the opportunity for customers to exercise their freedom of choice could allow them to have a higher bargaining power than utilities in setting the conditions for the cooperation.

If VAT deduction entitlement is available (Fig. 8.), Option 2 and Option 3 can give more room for maneuver for the utility to offer a lucrative business opportunity by adjusting the amount of the expected capital investments of residential customers to provide higher levelized unit savings for households than competing solutions, while also maintaining its profitability.

4. Conclusions and open research questions

Notable theoretical and empirical research efforts have been made on providing an accurate framework for the investigation of the diffusion, availability, economic viability and functional competitiveness of different types of PV technologies in the last few years, while commercial interest in the different PV-based business models has also been growing rapidly. This paper draws attention to the fact that the viability and competitiveness of a PV-based technological solution are context-driven and should not be determined independently of the business model being used. In this sense, market players should not only select and measure the competitiveness of a given technological solution against its incumbent or emerging competitors, but they should also consider and evaluate the windows of opportunity regarding the different business models opened up by the particular technology to make their final choice. Therefore, functional competition between small and large-scale PV-based technologies is affected by the appearance of new theoretical and business concepts on ownership modes and financing issues. Indeed, grid parity will probably be achieved in specific situations depending on the resource availability, the scale of the plant, the efficiency and cost improvements of the technology, the increase of the market prices and the form of ownership and financing.

The research concept of this paper aims to explore the economic benefits of community-financed solar PV plants from the utility side of the meter. Key findings suggest that the investment options of community-financed PV model available for a utility represent economically viable alternatives with significantly lower real LCOE and higher NPV compared to the traditional centralized PV investments in the Hungarian market. Although VAT deduction entitlement of the utility influences the financing of the investment, in accordance with the principle associated with the level of public VAT revenues, the same level of benefit can be achieved by the modeled options. Sensitivity analyses highlight that even if the critical exogenous variables move in an unfavorable direction, community-financed PV systems with VAT deduction entitlement can guarantee positive levelized unit-savings for the company. However, there are several options available to customers to pay for green power; thus, utilities have to find the target market with an appropriate size where the point of the uniqueness of community financed PV plants is valued by the households.

There are several limitations to this study. Any decision model requires the simplification of the reality and assumptions of likely scenarios may not capture all the influential factors and their potential modifications in the future. Furthermore, data came from a variety of secondary sources and some official data publicly available was not the latest. Despite the use of MS Visual Basic Programing, further research is also needed to construct a dynamic system model supporting real-time modifications of parameters. Supplementary research should focus on the integration of power storage technologies and the environmental and social impacts of PV technologies as new functionalities into the model.

Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A. Assumptions and variables

Table A1
Input parameters, assumptions and data sources.

Input parameters and abbreviation	Value (unit)	Assumptions and source	
Year of investment	2020	Own assumption	
Starting year of operation	2021		
Solar irradiation (S_{IR})	1 337 Wh/m^2	Minimal annual irradiation data for Szekszárd, Helio-Clim-3 database (2004-2015) (SodaPro, 2020)	
System size (S_{sys})	4 000 kW	Own assumption	
Performance ratio (PR)	82.00%	Own assumptions based on industry benchmark*	
Performance ratio degradation (PRD)	0,20 %points/year		
Starting year of PRD	4 Year		
Lifetime (n)	25 Year		
Investment costs of PV system (C_{sys})	1 260 EUR_{2020}/kW	Average, based on industry benchmark*	
Specific Land requirements	6.185 m^2/kW	Own calculation	
Land multiplier	2	Own assumption on the site coverage (50.00%)	
Land requirements (L_{size})	4.9480 ha	Own calculation	
Investment costs of land (C_{land})	167 677 EUR_{2020}/ha	Average, based on market data	
Reinvestment cost of inverter (C_{INV})	88.20 EUR_{2020}/kW	Own assumption based on industry benchmark*	
Network connection charges (C_{Con})	17 291 EUR_{2020}	Own calculation based on Hungarian Energy and Public Utility Regulatory Authority (HEA) Directive 15/2016 (XII. 20.) for overhead lines: ((3 000(m)-125(m))*(13.05 EUR_{2019}/m)*50.00%	
O&M costs of PV system ($C_{O\&M}$)	20.00 EUR_{2019}/kWh	Average, based on industry benchmark*	
Transmission system usage fee (C_{USC})	0.0060 EUR_{2019}/kWh	Hungarian Energy and Public Utility Regulatory Authority (HEA) Directive 15/2016 (XII. 20.)	
Regulation surcharge (C_{RS})	0.00043 EUR_{2019}/kWh	Available data on average METAR system regulation surcharges (01.01.2019-31.12.2019) provided by HEA (2020a, b, c) dataset	
Annual power consumption of residential customers	3 500 kWh	Own assumption	
PV rooftop system size	3.12 kW		
Investment costs of Rooftop PV systems (System size: 3.12 kW)	2 809 EUR/kW	Average, based on industry benchmark* and market data	
Invested capital by residential investors (INV_{RES})	9 814 560 EUR_{2020}	Own assumption based on industry benchmark*	
Feed-in tariff ($I_{METÁR,2020}$)	0.1002 EUR_{2019}/kWh	HEA (2020a, b, c) dataset	
Feed-in tariff ($I_{METÁR,2020}$)	0.1002 EUR_{2019}/kWh		
Feed-in tariff period	185 months	HEA Directive 13/2017 (XI.8.)	
Feed-in tariff annual volume limit ($PP_{METÁR}$)	1 100 kW h/kW		
Market price of power purchases (Average base load price) (C_{MARKET})	58.10 EUR_{2020}/MWh 55.50 EUR_{2021}/MWh 55.80 EUR_{2022}/MWh	Own calculation based on HUDEX (2019) dataset (01.01.2019-31.12.2019).	HUDEX BL2019 Y + 1 HUDEX BL2019 Y + 2 HUDEX BL2019 Y + 3
Market price of electricity sales (Average peak load price) (I_{MARKET})	70.10 EUR_{2020}/MWh 68,20 EUR_{2021}/MWh 69.30 EUR_{2022}/MWh		HUDEX PL2018 Y + 1 HUDEX PL2019 Y + 2 HUDEX PL2019 Y + 3
Power agreement (P_{CONT})	4 279 360 kW h/year	A fixed amount of power transferred to residential investors for 25 years	
Network use charges for residential customers (C_{RSC})	0,0449 EUR_{2019}/kWh	HEA (2020a, b, c) dataset	
Inflation rate (r_{inf})	from 2021: 3.30%	Hungarian National Bank HNB (2020a, b), (all costs increase with inflation)	
WACC (real)	5.83%, 6.04%, 7.00%	Own assumptions, 6.04% specified to PV projects in Hungary by 2025 (REKK, 2018)	
VAT	27%	HNB (2020a, b)	
EUR-HUF exchange rate	333.99	Average, based on the HNB dataset (01.01.2020-01.02.2020)	

* Benchmark data are based on Reich et al. (2012), Peter et al. (2016), Šúri et al. (2007) and REKK (2018).

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