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Levelized profits for residential PV-battery systems and the role of regulatory and fiscal aspects in Germany

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Abstract

Background The levelized cost of electricity (LCOE), expressing the price per unit that a technology must receive over its lifetime to break even, is a useful indicator, but insufficient for a comprehensive investment appraisal of PV-battery (PV-BES) projects. For household PV-BES systems, aimed at prosumers in the German context, our paper seeks to look at the revenue side in addition to the costs side of the investment decision. We extend the LROE (levelized revenue of electricity) to consider the impact of different fiscal options available to households seeking to install PV-BES systems. From this, we calculate the levelized profit of electricity (LPOE), linking the cost-focused and revenue-focused perspectives of prosumers facing investment options. We calculate the LPOE for six different fiscal options available to prosumers, four household types with different socio-economic characteristics and for different sizes of PV-BES systems.

Results In terms of preliminary results, we identify the most advantageous fiscal option and the drivers of LPOE in relation to PV-BES systems in Germany. We find that the switching from the standard to small business tax setup is the optimal fiscal option for all households and all technology combinations, but the optimal income tax decision depends on the present value of revenues compared to tax deductibles. The LPOE is particularly sensitive to changes in CAPEX and retail electricity prices, with the FiT rate, VAT rate and Income Tax rate being somewhat influential. From an LPOE perspective, self-consumption is incentivized through lower FiT rates and higher electricity prices, whereas the abolition of the EEG contribution and low FiT rate adversely affect the LPOE of different options. Stand-alone PV remains the most attractive option, with bundles with storage showing weaker profitability performance.

Conclusions LPOE complements the LCOE and LROE indicators and offers a comprehensive investment analysis, integrating fiscal considerations. Moreover, it offers greater guidance as to the relative attractiveness of different technology configurations and technology sizing. Mechanisms could be implemented to enhance the profitability of residential PV-BES systems in line with energy policy objectives.

Keywords Levelized Cost of Electricity, Levelized Profit of Electricity, PV-BES, Prosumers, Fiscal regimes, Investment analysis

Background

The Levelized Cost of Electricity (LCOE) is a simple and commonly used metric for evaluating the economic attractiveness of power generation technologies in terms of cost. It is defined as " … a techno-economic parameter used to evaluate the cost of a kilowatt-hour of energy produced from a selected power plant." [1]

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Besides scientific institutions, manufacturers [2] consultancies [3] and international organizations such as IRENA [4], IEA [5], and IAEA [6] use the indicator for cost assessments. IRENA confirms that '… the analysis of costs can be very detailed, but for comparison purposes and transparency, the approach used... is a simplified one that focuses on the core cost metrics for which good data are readily available. This allows greater scrutiny of the underlying data and assumptions, improves transparency and confidence in the analysis while facilitating the comparison of costs by country or region for the same technologies, enabling the identification of the key drivers in any cost differences' [4]. It reinforces the approach as '... relatively simplistic, given the fact that the model needs to be applied to a wide range of technologies in different countries and regions. This has the advantage, however, of producing a transparent and easy-to-understand analysis' [4].

The literature on cost analysis of energy technologies based on LCOE is vast. A random selection of recent publications comprises studies on wind power [7], small wind turbines [8], wave energy [9], concentrated solar power [10] energy storage and renewable technologies [11], carbon capture and utilization [12], power to methane [13], hydrogen [14], biomass technologies [15] and utility-scale PV [16]. The LCOE approach is also used to analyse the cost of household photovoltaic (PV) systems, either as stand-alone PV systems [17] or integrated with battery storage of electricity (BES) [18].

Nevertheless, the widespread use of the LCOE concept cannot overcome its general disadvantage, namely, that it is an insufficient metric for investment appraisal. Therefore, the cost side of the technology needs to be compared with the revenue side. In contrast to LCOE, the Levelized Revenue of Electricity (LROE) focuses on the financial return of an investment in energy technologies. Glenk and Reichelstein use the LROE indicator for system level considerations, highlighting that "Investment …is … economically profitable if and only if the LROE exceeds the LCOE." [19]. The Levelized Profit of Electricity indicator (LPOE) extends the LROE and is defined as the difference between LROE and LCOE. These concepts only recently gained prominence for wind [20] and photovoltaic projects [21]. Whereas [21] rely on conventional cost aspects, ignoring financial and tax effects, [22] explicitly considers tax effects from tax credits and depreciation, however, ignores further detailed analysis with respect to regulatory options. From a prosumer's perspective, focusing on PV and BES systems, different options may exist in relation to the choice of tax regimes for value added tax (VAT) and income tax (IT). Therefore, we not only propose to go beyond the LCOE concept to consider the revenue side explicitly. In addition, for a thorough investigation of profitability which also addresses fiscal aspects for prosumers, we include the impact of different fiscal options for the treatment of value added tax (VAT) and income tax (IT) and their interdependencies in the analysis.

There can also be non-pecuniary factors motivating prosumer adoption of PV-BES systems. Vögele et al. [23] combine the LCOE concept with a socio-economic analysis in an integrated approach to study the diffusion of residential PV in Germany. While evaluating the techno-economic data relating to parameters such as PV, battery prices and rates for feed-in tariffs, they consider the role of wider cultural and attitudinal factors. For households, they find a clear trade-off between LCOE and self-sufficiency—for instance, households aiming to reach a high DSS (degree of self-sufficiency) of 90% or more face a much steeper LCOE [23]. This highlights that, beyond cost and return considerations, wider socio-economic factors, e.g., self-sufficiency,[1] may drive technology deployment as well.

This paper aims to address the prosumer's financial perspective on PV and BES technologies' adoption, highlighting profitability by the LPOE concept as difference between LCOE and LROE, and uses the approach for household PV-BES systems configurations for four household types. Specifically, it aims to:

(i) Develop and present an LPOE concept integrating fiscal and regulatory aspects of PV-BES differentiating VAT and IT options for prosumers
(ii) Calculate the LPOE (€/kWh) of PV-BES systems for four different households, characterised by varying electricity demand and load profiles
(iii) Identify factors that are particularly relevant for this profitability
(iv) Take the German context as of 2022 as an example.

Our approach provides a comprehensive picture of prosumers' economic gain from different configurations of household energy system and how this gain is influenced by VAT and IT options. This understanding can help policy makers to design regulations which incentivise prosumers to adopt household energy systems that maximise their contribution to (i) sustainability and (ii) energy security goals.

[1] In our analysis we use self-consumption as indicator for the financial analysis. Self-consumption reduces the electricity bill which must be paid and forms the basis for Value Added Tax on self-consumption to be paid by the prosumer. Often, self-sufficiency is analysed also. Self-sufficiency is defined as the share of own (PV-BES-based) electricity production of the household electricity demand. As self-sufficiency is a non-monetary indicator, we do not use it for this analysis.

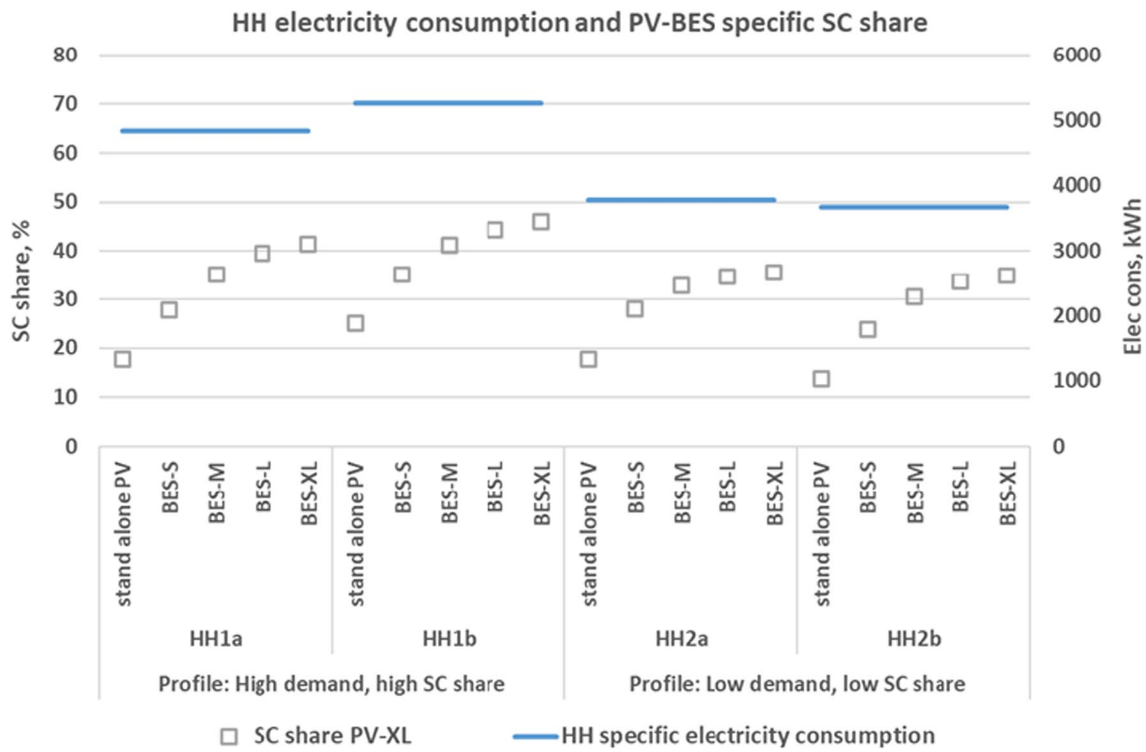

Fig. 1 Yearly electricity demand per household type and PV-BES specific self-consumption share (from [24])

Methods

Socioeconomics, finance, costs and technology

To consider household heterogeneity with regard to electricity consumption, we focus on four household (HH) types:

- HH1a: 4-person household with 2 employed adults and 2 children
- HH1b: 4-person household with 1 employed adult, 1 adult at home and 2 children
- HH2a: 2-person household with 2 retired adults
- HH2b: 2-person household with 2 employed adults.

With the chosen socio-economic structure, we aimed for a fair characterization of potential technology adopters, namely, owner-occupiers of (semi-) detached houses. Input data on electricity load and technical parameters of the PV-BES simulations were based on [24] and are presented in section 2 of the Additional file 1 (see Table S1). Figure 1 shows such values of PV-BES-specific self-consumption shares, as well as the values of yearly electricity consumption for each household type. Parameters relating to the fixed feed-in tariff, the cost of electricity purchases in addition to VAT and income tax are given in section 2 of the Additional file 1 (see Table S2). Finally, cost parameters (i.e., CAPEX and OPEX) of each PV-BES system considered in this study are reported in Table S3 in section 2 of the Additional file 1.

Modelling and financial metrics: basic LCOE, extended LCOE, LROE & LPOE

Details relating to the operation of the system as a stand-alone PV system or a coupled PV-BES system are given in section 3 of the Additional file 1.

The extended LCOE, LROE and LPOE are built upon the basic LCOE (without tax considerations). The tax implications of the VAT & IT regime configurations for both costs and revenues are accounted for within the extended LCOE metric. The extended LROE and LPOE are calculated from the LCOE resulting from the six possible configurations, with the LPOE being the difference between the LROE and LCOE for the particular configurations. The LCOE, LROE and LPOE are also subjected to a sensitivity assessment. Details on the calculations, on LCOE and LPOE tax-related components (Additional file 1: see Tables S4, S5 and S6) and on the sensitivity assessment can be found in sections 4, 5 and 6 of Additional file 1.[2]

[2] The LPOE calculations are based on a spreadsheet (Excel). The technical parameters (electricity demand, PV generation, self-consumption levels and BES degradation for the different PV-BES combinations and households), which are input parameters for the LPOE calculations, are derived from the PV-BES technical simulations conducted by Aniello et al. [24].

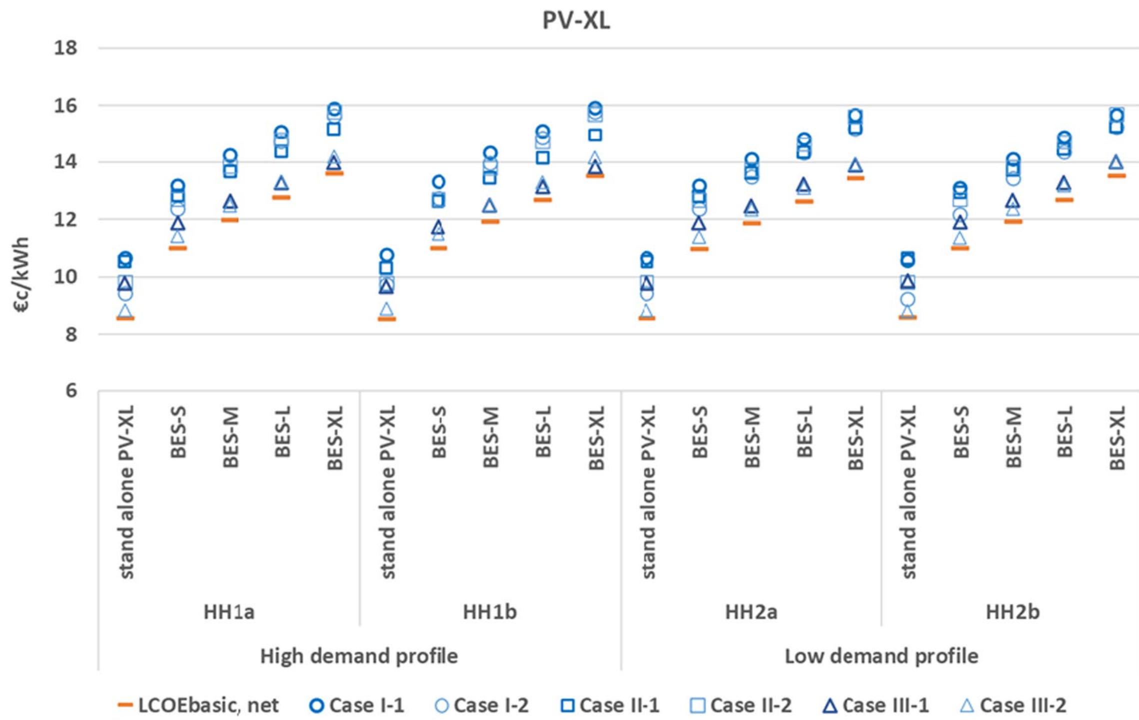

Fig. 2 $LCOE_{basic,net}$ and $LCOE_{total}$ for PV-XL and BES under different VAT and IT treatment

Results

Economic metrics for PV-XL and BES

Figure 2 shows the $LCOE_{total}$ results for stand-alone PV[3] systems and those with BES[4] for the six VAT/IT treatment options. For all households and technology combinations with comparably low levels of investment, case III-2 exhibits the lowest $LCOE_{total}$; however, it is increasing with larger BES capacities due to higher CAPEX. In the case of technology combinations with comparably high levels of investment, case III-1 proves better. Both cases apply for a change of the VAT treatment after 5 years, enabling the prosumer to take advantage of VAT settlement for investment cost at the beginning and to avoid VAT payment on self-consumption after year 5. In addition, case III-2 opts for the IT exemption from the beginning, therefore, avoiding paying IT on profits. This option is preferred if the real present value of the tax deductibles is smaller than the real present value of the revenues; this holds irrespective of the income tax rate. To a large extent, tax deductibles comprise depreciations. Therefore, if, in the case of larger battery capacities, the higher investment is not accompanied by correspondingly higher revenues through self-consumption, opting for the standard IT treatment is appropriate, because there is a tax refund for the prosumer. In other words, for technology combinations with comparably high investment costs, opting for standard IT treatment enables a reduction in $LCOE_{total}$ which increases the productivity of invested capital.

The results for lowest $LCOE_{total}$ (either III-1 or III-2) are very close to the respective $LCOE_{basic,net}$, the difference ranging from 2.5 to 4.7%. Opting for the standard tax treatment for VAT and IT, case I-1, is the worst option for all technology combinations for all households, resulting in a higher $LCOE_{total}$ of between 11.9% to 21.0% compared to the optimal case III-1 or III-2.

The taxation aspects deserve further consideration and for this we focus on case I-1 (standard VAT and IT treatment). Although case I-1 is not the best in terms of $LCOE_{total}$, we use this standard tax treatment case to demonstrate IT impacts. With approximately 2.0 to 2.4 €c/kWh, the difference between $LCOE_{basic,net}$ and $LCOE_{total}$ is considerable. The main single impact is the IT impact and the second is the TD impact. With up to 2 €c/kWh, the VAT impact is also considerable (Fig. 3). The tax deductibility impact ($LCOE_{TD}$) and the impact of income taxation of revenues ($LCOE_{IT}$) are each significant with the effect of tax deductibility lower than

[3] For PV, we focus on the extra-large (XL) capacity for households (PV-XL: 9.73 kWp); see also Table S3 in Additional file 1.

[4] For BES, we use four different optional sizes: small (BES-S: 3.30 kWh), medium (BES-M: 6.50 kWh), large: (BES-L: 9.80 kWh), and extra-large (BES-XL: 13.10 kWh); see also Table S3 in Additional file 1.

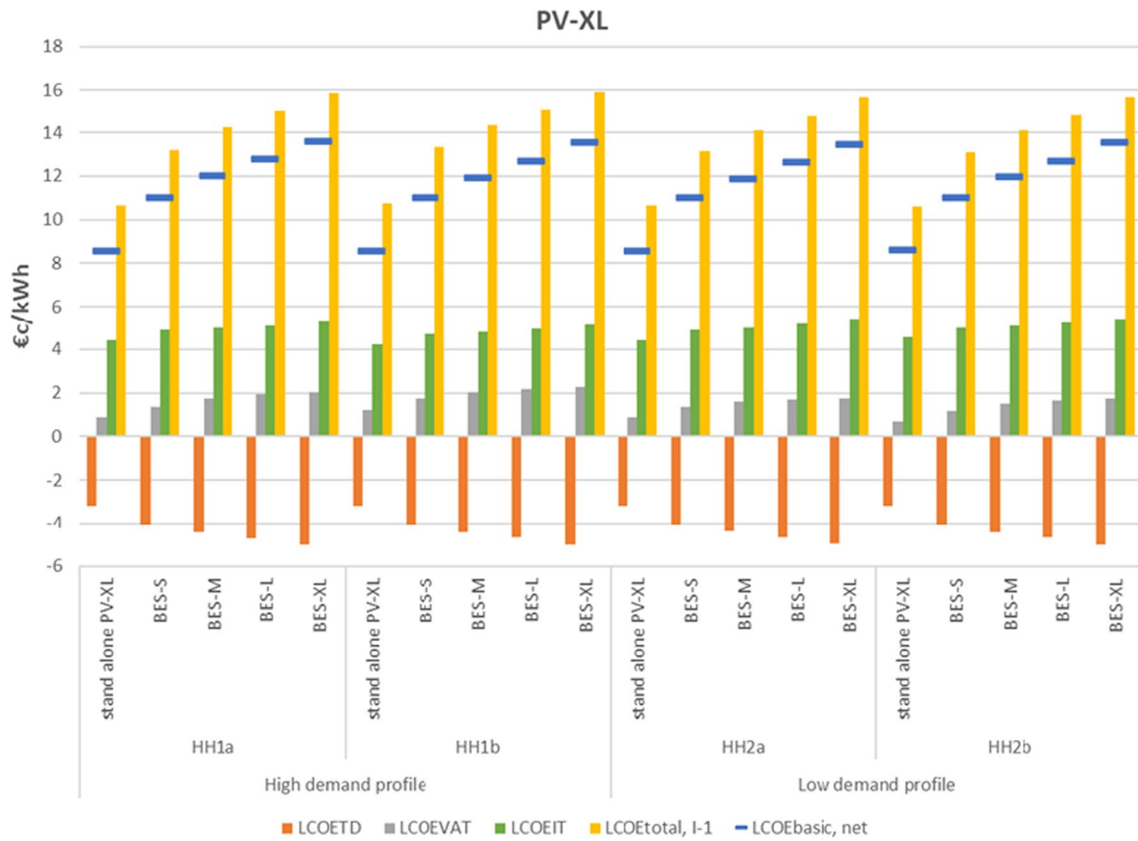

Fig. 3 Decomposition of LCOEtotal with total lower level for PV-XL and BES: Case I-1 (standard VAT and IT treatment)

IT; however, with higher BES capacities, these opposing impacts largely neutralize each other. These patterns are equal for each household.

A closer look at TD, VAT and IT effects for household types with different energy demand reveals deeper insights (Fig. 4). With increasing battery capacity, the $LCOE_{VAT}$ effect increases and outweighs the profit taxation impact (TD and IT). This pattern holds for all household types, with the level of impact higher for HH1a and HH1b, the households with higher electricity demand and self-consumption. Correspondingly, the net profit taxation impact, $LCOE_{TD}$ and $LCOE_{IT}$, reduces with battery capacity. The $LCOE_{TD}$, depending on CAPEX and OPEX, increases with BES capacity equally for all household types, the $LCOE_{IT}$ effect also increases with battery size and the level of self-consumption; however, these are opposing trends, with TD reducing and IT increasing net profit taxation.

For the revenue part, the different VAT taxation options do not merit consideration, as, by definition, the LCOE calculation integrates all taxation impacts. The LROE comprises three components: revenues from feed-in to the grid (FI), direct self-consumption SC_{dir}, and, additionally, self-consumption through battery storage SC_{bat}. Self-consumption depends on the electricity demand characteristics, i.e., on the level of demand and the socio-economic profile of the household types.

We demonstrate the results in Fig. 5. HH1b has the highest demand and the load profile shape that most closely matches PV generation, and, therefore, has the opportunity for the highest revenues from direct self-consumption M_{dir}. HH1a, with its lower energy demand, has considerably lower direct self-consumption, but comparably higher self-consumption through batteries, which increases with battery capacity. In addition, for smaller BES capacities, HH1a has higher feed-in than HH1b. In contrast, HH1b, revealing high electricity demand, has the lowest revenues from feed-in, the highest revenue from direct self-consumption, and lower revenues from self-consumption through battery storage than HH1a. It can be clearly seen that the monetary value of self-consumption through batteries is higher for HH1a than for HH1b. HH2a and HH2b, with rather low energy demand, earn lower revenue than HH1b from direct self-consumption and HH2b, with the lowest electricity demand, generates comparably large feed-in revenues. In total, for all households, the sum of revenues is highest for the

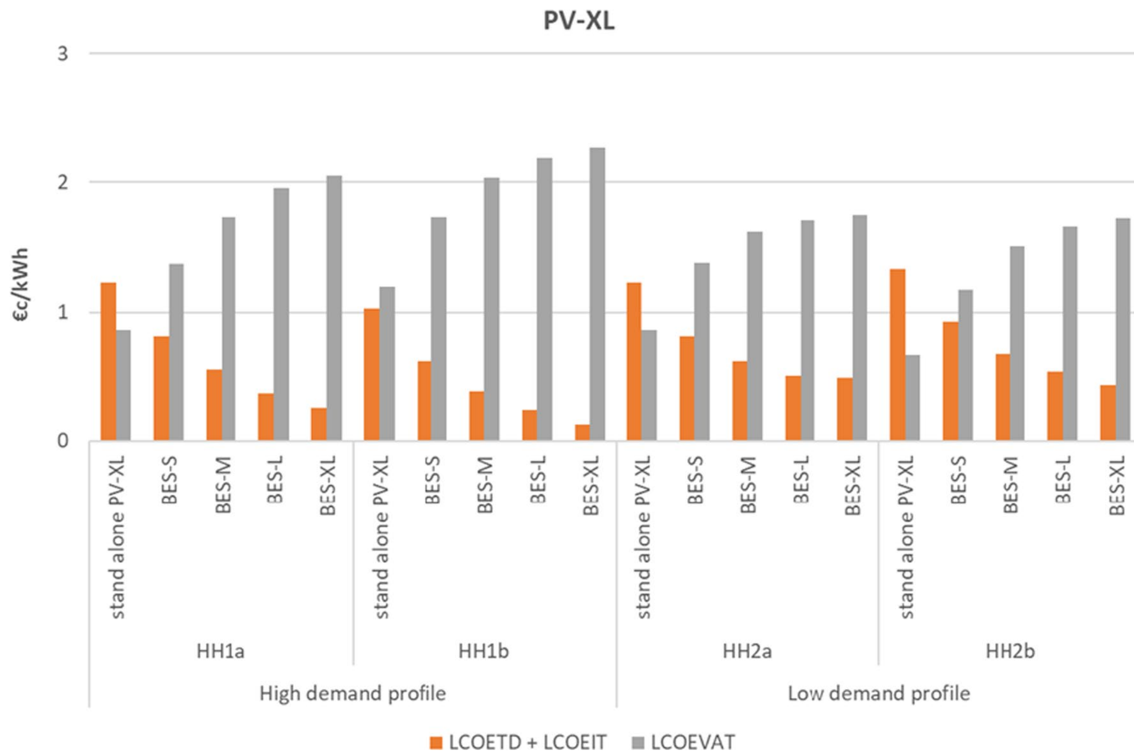

Fig. 4 Impacts of taxation on LCOEtotal with total lower level for PV-XL and BES with standard VAT/IT treatment

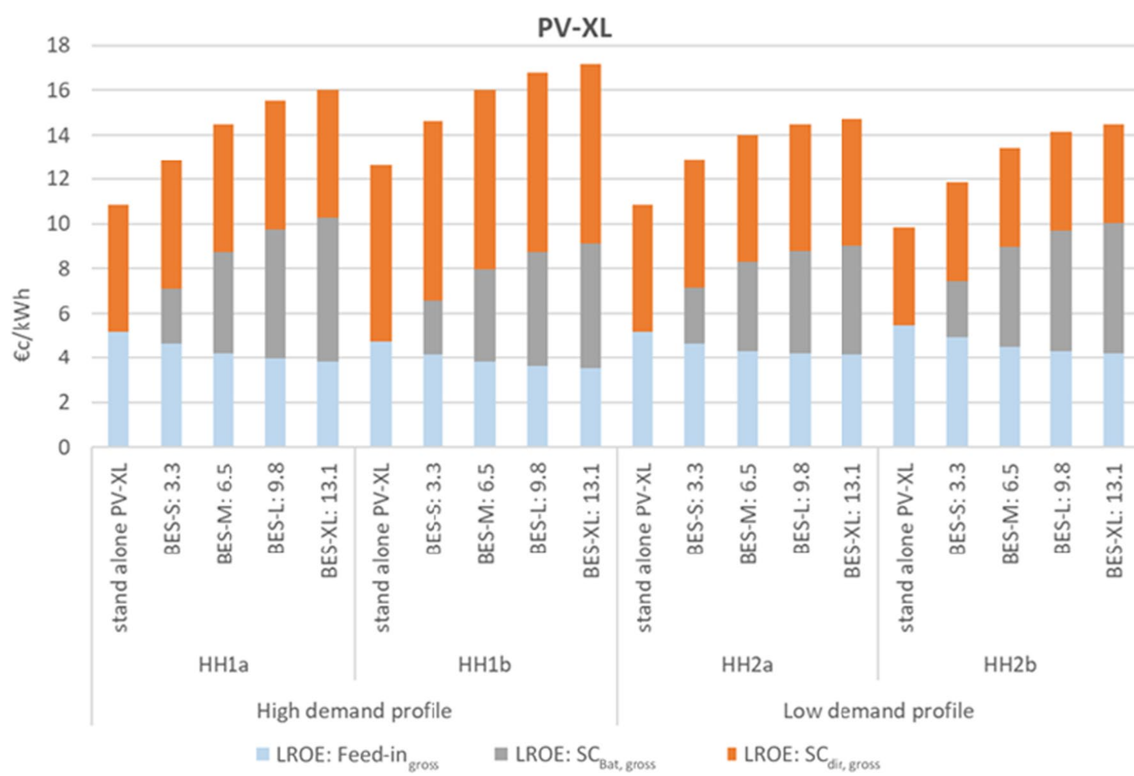

Fig. 5 LROEs and decomposition for the PV-XL and BES combinations for all household types

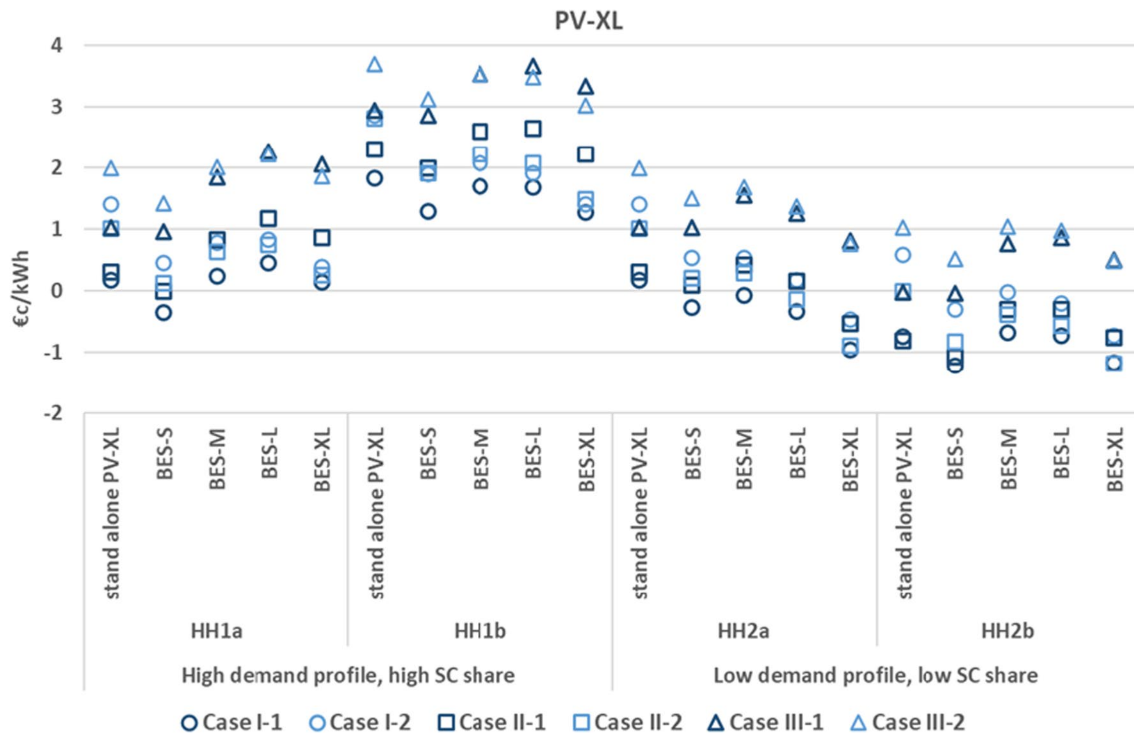

Fig. 6 LPOEs for PV-XL and BES for all households with different tax treatment options

largest battery capacity, with the highest revenues for HH1b, the household with the largest electricity demand.

Apparently, levelized profits result from revenues and costs and Fig. 6 shows the results for the six different cases combining options for VAT taxation and IT declaration. It can be clearly seen, that opting for VAT regime change (III: Rb → Kur) is the best solution for each household and all technology combinations. Considering IT treatment options, the picture is different. Households with high electricity demand and high shares of self-consumption (HH1a, HH1b) tend to choose large batteries (BES-L) and standard IT treatment, whereas households with low demand and low shares of self-consumption apply for exemption from IT with stand-alone PV (HH2a) or medium-sized battery BES-M (HH2b). Choosing other tax options and technology combinations result in monetary losses. While [25] find that configurations with batteries are never financially attractive, Fig. 6 shows that, under the LPOE indicator, they can be profitable compared to stand-alone options for households with high demand and high shares of self-consumption, although this better performance is tenuous.

In general, the $LCOE_{total}$ for case III-2 is higher than for III-1, if the real present value of tax deductibles is higher than the real present value of revenues. From Eqs. 9 and 11 in section 5 of Additional file 1, it can be seen that $LCOE_{total,III-2} > LCOE_{total,III-1} \leftrightarrow \sum_1^{20} \frac{TD_{real,t}}{(1+i))^t} > \sum_1^{20} \frac{R_{real,t})}{(1+i))^t}$ and vice versa. This is the case, if higher BES capacity and implicitly higher investment cost is accompanied by an under-proportional development of revenues through increased self-consumption. In this case, households would be incentivized to opt for the regime III-1, which results in lower $LCOE_{total}$.

Sensitivities for PV-XL and BES for household HH1b

With respect to LPOE sensitivity, we tested irradiation, process parameters, cost parameters, energy market and policy parameters, taxation policy parameters and time preference parameters for household HH1b adopting the VAT/IT treatment option III-2. HH1b represents the socioeconomic fraction with high electricity demand and high levels of self-consumption. Ranging from approximately −3 to 3.5, the resulting elasticities show a wide range, revealing over-proportionalities and under-proportionalities (Fig. 7).

From the process perspective, higher generation (M_{AC}), through either better irradiation or better efficiency (PV panels, inverter), has a significant impact on LPOE, implying a reduction of LCOE and increase of LROE at the same time. The impact on BES is approximately 50% higher than on stand-alone PV, due to the higher effect

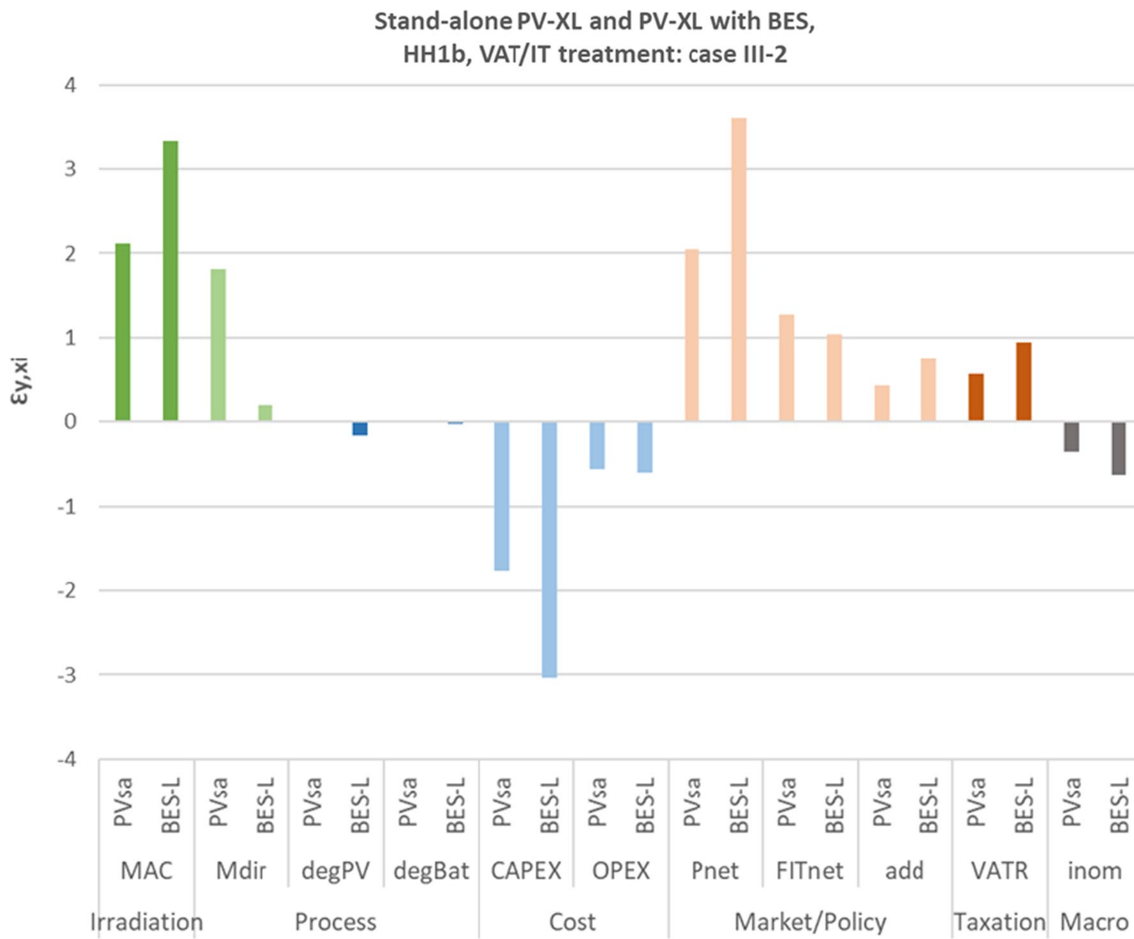

Fig. 7 LPOE elasticities for PV-XL and BES-L for HH1b with preferential VAT/IT treatment

on LROE through increased self-consumption. The impact of higher direct self-consumption is significant for stand-alone PV, but negligible for BES, as higher direct self-consumption is associated with the use of electricity from batteries. Sensitivity in the degradation of PV generation and battery storage is very low and negligible, though an interesting technical topic.

With respect to cost parameters, LPOE is highly sensitive to CAPEX. Due to the comparably higher CAPEX for BES systems, the sensitivity of BES to CAPEX is as much as 70% higher than for stand-alone PV. Therefore, CAPEX increases, e.g., due to better technical performance, is economically justified only in cases of ambitious technical progress. LPOE sensitivity towards OPEX is also significant, although much lower compared to CAPEX, as seen from the analysis of many capital-intensive technologies, i.e., in the field of renewable energy technologies.

Concerning market and policy parameters, sensitivity in electricity retail prices is slightly higher than for CAPEX, but in the opposite direction. In the absence of non-monetary preferences, higher retail prices are the driving force for the use of batteries. Again, the elasticity for BES is much higher (approximately 80%). LPOE is sensitive to FIT in both cases, although stand-alone PV shows higher sensitivity. As price increases for the purchase of electricity affects the economics of batteries, sensitivity to the above general inflation increase of electricity price (add) is significant for the economic feasibility. Sensitivity to the VAT rate is also significant, whereas sensitivity to the income tax rate (ITR) does not exist by definition for case III-2. For add (electricity price inflation rate above general inflation rate) and VATR, sensitivities are under-proportional, with sensitivity higher for BES. The results underpin the recommendation for strict analysis of residential PV-BES systems according to the prevailing regulation and taxation options.

Finally, sensitivity to the nominal discount rate[5] is significant. The higher the nominal discount rate is, the

[5] "A discount rate is the interest rate used to discount a stream of future cash flows to their present value. Depending upon the application, typical rates used as the discount rate are a firm's cost of capital or the current market rate" [26].

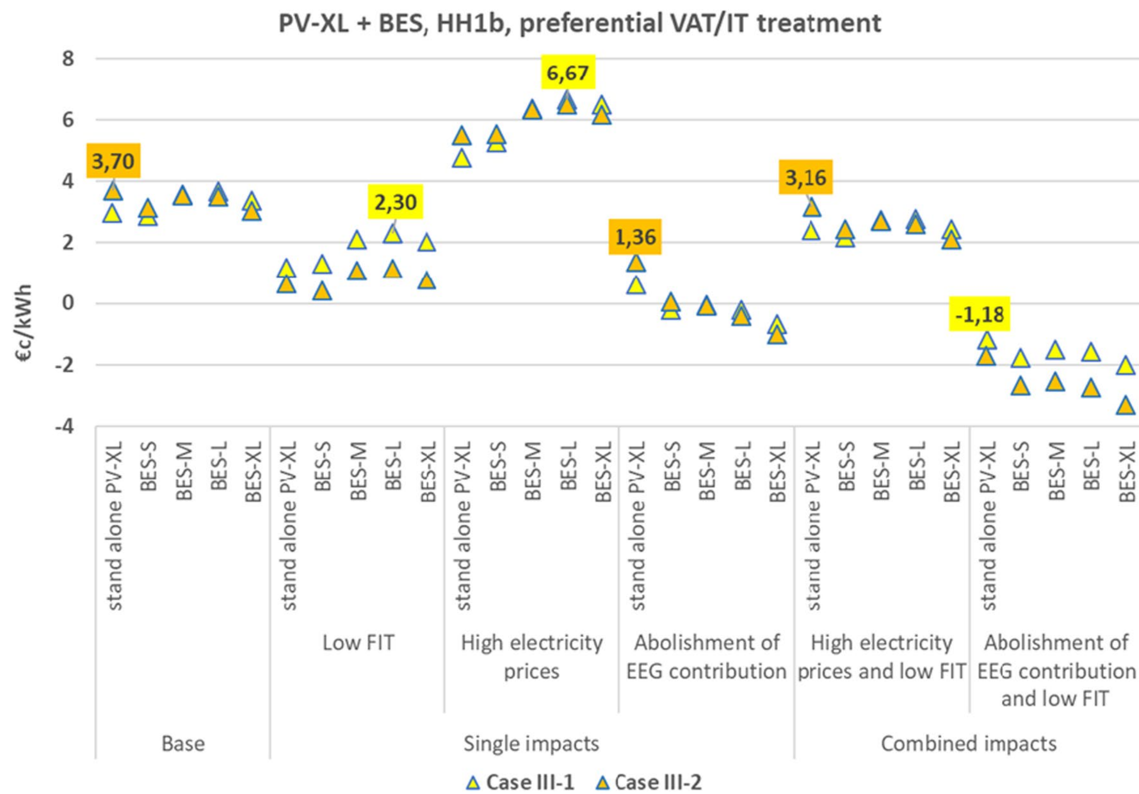

Fig. 8 Impact of parameter variations on LPOE for PV-XL and BES for HH1b (preferential VAT/IT treatment)

lower the present value worth of future income streams from PV-BES systems, with the impact more pronounced for BES. It has to be kept in mind that, with a constant inflation rate,[6] a change in the nominal discount rate implies a change in the underlying real discount rate and vice versa.[7]

In its relevance for PV-BES adoption (both PV-BES combination and size), we focus on three parameters: feed-in tariff, electricity purchase price and EEG (Renewable Energy Act) contribution (which is a component of the electricity purchase price). Currently, the German EEG has a mechanism which automatically reduces the feed-in tariff the later the PV system comes into operation. Therefore, we assume an alternative feed-in tariff 0.05 €/kWh (plus VAT) which is lower than in the reference case. Reflecting alternative assumptions about the electricity purchase price, we calculate the results for a 5 €c/kWh (plus VAT) higher initial electricity purchase price. In addition, we present the results assuming an abolition of the EEG contribution, which, in 2021, equals a reduction in the initial electricity purchase price of 6.5 €c/kWh plus VAT.

C.p., the general impacts are quite clear and Fig. 8 shows the impacts for household HH1b. With higher BES capacity, there is an incentive to apply for the standard IT treatment. This means that the present value of real revenues from feed-in and self-consumption is lower than the present value of tax deductibles. In other words, the loss from income tax on revenues is lower than the loss from non-claimed tax reduction through non-declaration of deductibles. In the three cases (i) low FIT, (ii) high electricity prices and (iii) abolition of the EEG contribution combined with low FIT, a shift from the IT exemption option to the standard IT treatment is advantageous.

Incentives for BES integration increase with the shift to lower feed-in revenues or to higher revenues from self-consumption due to higher electricity purchase prices. However, abolition of the EEG contribution reduces incentives to integrate BES due to lower revenues from self-consumption. In the case of combining parameter

[6] "In a market economy, prices for goods and services can always change. Some prices rise; some prices fall. Inflation occurs when there is a broad increase in the prices of goods and services, not just of individual items" [27].

[7] In financial mathematics and economics, the Fisher equation expresses the relationship between nominal interest rates, inflation rates, and real interest rates. In more formal terms, the relation is.
$i = \left(\frac{1+i^{nom}}{1+infl}\right) - 1$, with i^{nom}: nominal interest rate, i: real interest rate, and infl: inflation rate [28].

variations, the relative strength of the impact of a single parameter is crucial. The first two variations (low FIT, high electricity purchase prices) incentivize the shift from stand-alone PV to the integration of BES-L (combined with a shift to standard IT treatment); however, the loss in LPOE from the reduced feed-in tariff and corresponding shift to BES is ca. 40% and the gain from higher electricity purchase prices and corresponding shift to BES is ca. 80%. Abolition of the EEG contribution clearly does not incentivize BES integration due to lower revenues from self-consumption and results in LPOE lower than in the case of reduced feed-in tariff; however, LPOE loss is drastic. Combining higher electricity purchase prices and low FIT does not incentivize the integration of BES options. Abolition of the EEG contribution combined with low FIT drastically reduces LPOE and leaves all PV-BES options including PV-stand-alone uneconomic.

Discussion

Our analysis highlights the importance of different metrics to evaluate investments in energy technology configurations, such as household PV-BES systems. One indicator alone does not provide a holistic picture of the attractiveness of a technology option for investors. The LPOE (€/kWh) provides an indication of the efficiency of money invested per kWh, going far beyond the LCOE indicator which only represents the costs associated per kWh. It resembles the Internal Rate of Return (IRR) [29], i. e. the discount rate which would lead the project to have a NPV of 0, measuring the efficiency of total money invested in a project. However, indicators like the IRR and LPOE focus on specific returns (per kWh) and not absolute value creation [30]. As the net present value approach (NPV) [31], discounting cash flows over a project's lifetime, acts as a measure of the absolute value of a project [32], it perfectly complements LPOE and IRR for a holistic view on investment projects, and also for prosumage. For example, a larger PV-BES system with lower LPOE (€/kWh) could yield a higher NPV than a smaller system with higher LPOE, if the level of usable electricity is large enough for large PV-BES systems compared to small ones. This highlights that, for investors in energy projects, whether large ones or small prosumer-based PV-BES systems, financial indicators each have a different emphasis and give slightly different signals, which must be considered when evaluating the economic attractiveness of technology configurations.

Emergent energy technologies, namely, PV and battery systems, have led to electricity users no longer being passive consumers but being active in deciding upon investments in their own small generation systems. *Prosumagers*, users who produce, consume and probably store electricity via a battery [33] account for a non-trivial part of capacity in the market; as of 2020, installed household battery power in Germany represented the equivalent of a large national pumped storage plant [34], highlighting the potential system relevance of the large-scale deployment of PV-BES systems in Germany. Wider advantages of the prosumage model include greater acceptance of the *Energiewende*, as a greater role for prosumers reduces the need for large-scale centralised infrastructure. On the negative side, renewables dissemination via prosumage may be less efficient than via large-scale, centralised technologies, as smaller systems are characterised by higher specific costs. Given the interest of prosumage models for the German electricity system and the consequences of household decisions on PV-BES combinations and capacities, it is important to have a deeper understanding of the economic attractiveness of PV-BES systems for different types of households, acknowledging financial and taxation impacts. The LPOE allows not only a better understanding of the economic attractiveness of such systems for households, but also the factors that determine this attractiveness, especially those driven by policies.

LPOE reveals certain factors that are important to consider when assessing the economic attractiveness of PV-BES, keeping in mind, that the components of LPOE, namely, $LCOE_{total}$ and LROE, are affected differently. The $LCOE_{total}$ corresponds to technology costs and VAT/IT aspects (see Table S4 in section 5 of Additional file 1), whereas LROE, by definition (Eq. 12 in section 5 of Additional file 1), does not. Both components are affected by household specific electricity demand level, load profile and self-consumption options, and by levels of usable electricity. LROE is additionally affected by market and policy led parameters, such as feed-in tariff (FIT) or value added tax rate (VATR). All these affect the relationship between LPOE and $LCOE_{total}$ and, thus, which VAT and IT tax treatment option, which technology configuration (standalone PV or PV-BES) and which size will be preferred.

The LPOE indicator helps to identify factors relevant for a holistic economic evaluation of PV and PV-BES configurations for households. In relation to fiscal components, Fig. 4 shows that VAT considerations become influential compared to net profit taxation effects (from tax deductions and income tax exemptions) as self-consumption becomes more dominant. This is in line with revenue from self-consumed electricity increasingly outweighing earnings from selling electricity to the grid in exchange for a feed-in tariff.

Taking into account the fiscal options to treat value added tax (VAT) and income tax (IT), it can be shown that the most advantageous fiscal set up for VAT is case III (change of VAT regime after 5 years). VAT exemptions on self-consumed electricity, as enabled by this Rb → Kur tax structure, can, therefore, generate incentives for self-consumption and prosumage models. This indicates that it is better to forgo the VAT exemption on revenue in the first 5 years to benefit from reduced expenditure on investment costs (CAPEX) and OPEX costs. This option is generally offered for small business entrepreneurs, e. g. for grid-connected household PV systems, and, therefore, may not be regarded as a special subsidy for residential PV-BES. Concerning IT, the preferred option depends on further considerations. It turns out, that c.p. scenarios for (i) low FIT and (ii) high electricity prices incentivize the switch from the IT option 2 (opt-out IT) to option 1 (standard IT treatment) coming along with a switch from stand-alone PV-XL to PV-XL with BES-L. For PV-BES systems with high investment costs, tax deduction through depreciation is profitable up to a certain level of battery capacity, even though it results in income tax payments on self-consumption. This also holds for a scenario (III) combining abolishment of EEG contribution (implicitly reducing the electricity price) and low FIT. However, that scenario leaves all PV-BES combinations economically unattractive. Opting out of IT is a special fiscal regulation in Germany offered for household PV systems and introduced in 2022, fulfilling some technical requirements, e.g., capacity lower than 10 kWp. Foregoing tax deductibility of depreciation of investment costs and operational expenses is compensated by avoiding income tax on self-consumption and feed-in of electricity. As a tax relief, this option may rather be characterized as a special form of subsidy for residential PV-BES systems, as it is not offered to other small business activities, as, e. g., a consultancy practice giving advice for residential PV-BES investments.

Stand-alone PV systems yield the highest LPOE (Fig. 6) for all households except HH1a which is the household with the second highest annual electricity consumption (see Fig. 1). This does not indicate inconsistency in the link between LCOE and LPOE. Although the relation between $LCOE_{total}$, LROE and LPOE is complex, it is clear, that $LCOE_{base}$ considers only the energy quantity, so it is practically the same for all households. $LCOE_{total}$ (including taxation impacts) is affected by the household type because of different self-consumption options and feed-in quantities that affect both VAT and IT, and higher revenues mean higher taxes. By definition, LROE is not affected by taxation, so $LCOE_{total}$ and LROE can move in different directions. Recognizing this, a combination with BES, promoting self-consumption, is not the most profitable on a per kWh basis for the household with the highest annual load, namely, HH1b. It is reasonable that the different load profile for HH1b (with 1 adult employed rather than 2) means that additional self-consumption has a slightly lower monetary value for HH1b than HH1a, despite the higher overall annual load, because, compared to HH1a, HH1b can have a higher self-consumption with stand-alone PV. Battery increases self-consumption by a lesser magnitude in comparison with HH1a. In Fig. 2, for all households, as we would expect the LCOE is the lowest for stand-alone PV, with this configuration also yielding the highest LPOE except in the case of HH1a. For HH1a, consideration of the revenue side shifts the most attractive option to BES-L. For households other than HH1a, these findings are, however, indicative of the weaker profitability of PV-BES compared to stand-alone PV.

Our analysis provides a comprehensive breakdown of the different components of LPOE of PV-BES systems and, as such, offers guidance to policy makers about the different factors that can promote or hinder the attractiveness of these systems for households. Inflation deserves special attention when interpreting the results of LPOE, as, for PV-BES, money illusion might be an important point. In general, inflation increases the cost of operation of PV-BES and the revenues from electricity self-consumption along the lifetime of the installation, both in nominal terms. Deflating with the inflation rate gives the real costs and real revenues from self-consumption.

Conclusions

LCOE is a standardised indicator to evaluate the cost competitiveness of energy technologies, but does not provide a full investment appraisal, in that it ignores the revenue side. In this paper, we have extended LCOE to include the revenue side, first introducing LROE (levelized revenue) and then LPOE (levelized profit) to capture the full picture of the attractiveness of PV-BES configurations for households in Germany. We integrate fiscal considerations, i.e., options for value added tax (VAT) and income tax (IT) treatment, in addition to the EEG contribution, feed-in tariffs (FIT) and electricity prices, to calculate the LPOE of different PV-BES configurations for four types of households with varying load profiles and, moreover, identify the optimal fiscal setup for households seeking to install PV-BES systems. To get a full picture and avoid money illusion for household PV-BES systems, we also integrate inflation, differentiated by general and electricity price specific inflation rates.

From a policy perspective, the findings for large household PV installations (9.73 kWp) indicate that profitability considerations, as measured by LPOE (€/kWh), do not necessarily incentivize battery storage of electricity for self-consumption. Base case considerations show that the level and profile of electricity demand as well as the level of direct self-consumption without battery storage is important. This, in turn, depends on the socio-economic profile of the respective households. In addition, the impact of selecting the optimal fiscal setup for value added tax (VAT) and income tax (IT) treatment from the options offered is relevant. The fiscal option to start with standard VAT treatment and to switch to the small business VAT treatment after some years proves best for all households and BES capacities. For the IT treatment, the picture is different. As a new IT treatment option introduced in 2022, the tax authority offers exemption from income tax payments due to the installation and operation of household PV up to 10 kWhp. For the base case, we can demonstrate for a household type with high electricity demand profile and high level of direct self-consumption, that this IT option is preferred. Parameter variations show that, for lower than base case feed-in tariffs (FIT) or higher than base case electricity price considerations, choosing the standard IT treatment option involving income tax payments can be profitable. The reason is that the present value of real revenues from feed-in and self-consumption of electricity is lower than the present value of tax deductibles from depreciation and operating costs. Essentially, this involves prosumers identifying tax-technology combinations, where the loss from income tax on revenues is lower than the loss from non-claimed tax reductions through non-declaration of deductibles. Choosing the standard IT option is aligned with integrating large battery capacity, to reach maximum LPOE levels in the respective cases. The difference is substantial—the maximum LPOE level in the case of higher than base case electricity prices is 3 times higher than in the case of lower than base case FIT. A case with abolition of EEG contribution and comparably low FIT leaves all PV-BES combinations including stand-alone PV economically unattractive, irrespective of the chosen IT treatment.

For future analysis, ideas to incentivize investment in household PV-BES deserve attention—for instance, investment grants, higher FITs for prosumage, or a special FIT for stand-alone PV installations without self-consumption based on feeding-in all electricity produced to the grid. It is also important to further study the impacts on PV-BES combinations and capacity levels for the components as well as the impact of currently rising PV investment costs. In times of high inflation rates, the role of general inflation and electricity price inflation also needs consideration. When the share of revenues based on nominally fixed FIT is high, especially in the case of full feed-in operation, 'money illusion' may turn out to be a trap.

Supplementary Information

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Additional file 1. Cost, financial and technical parameters, description of basic and extended LCOE, LROE and LPOE calculations and sensitivity assessment.

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Author contributions
GA provided the data and modelling input. WK developed the formulae and ran the calculations and wrote the methodology and findings sections of the manuscript. CSB wrote the introduction, literature review and discussion part of the manuscript and edited the manuscript. All authors read and approved the final manuscript.

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Declarations

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