Micro-economic assessment of residential PV and battery systems: the underrated role of financial and fiscal aspects

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https://doi.org/10.1016/j.apenergy.2020.115667

Abstract

The German Federal Government, in order to achieve its renewable energy targets, has promoted the deployment of solar PV. Small residential PV installations coupled with battery energy storage systems are gaining momentum, as the appeal of self-consumption has grown. We conducted an economic analysis to assess the profitability and optimal configuration of these technologies from the perspective of heterogeneous households that are subject to the current German regulatory framework. In this regard, we consider heterogeneous potential for the self-consumption of electricity (e.g. household size, energy efficiency), as well as heterogeneous financial (i.e. metrics, parameters, sources of financing) and fiscal (i.e. tax treatment, tax rate) aspects. We find that the use of alternative financial metrics (i.e. payback period, real internal rate of return and net present value) as criteria for evaluating profitability has a significant impact on the rankings of system configurations. Furthermore, fiscal aspects are crucial to assessing profitability and marginally relevant for optimal system configuration, while financial aspects are of great importance for both. Our results on optimal battery coupling (as opposed to stand-alone PV) show that rates of adoption range between 0% and 94% of the analyzed load profiles, following the variation of such finance-related dimensions (e.g. discount rates, inflation, debt versus equity financing). We conclude that such findings on the impact of such factors are highly relevant in terms of designing cost-efficient and effective policies that aim to foster energy transitions, both in Germany and elsewhere, especially at a time of very low interest rates.

1 Introduction and background

The Renewable Energy Sources Act (hereinafter *EEG*, *Erneubare-Energien-Gesetz*) has been one of the main pillars of the German energy transition (*Energiewende*) and its overarching climate goals, namely the progressive reduction of national greenhouse gas (hereinafter GHG) emissions. The *EEG* has established financial support and the preferential feed-in of electricity from renewable energy sources (hereinafter RES), as the electricity sector (especially coal power generation) is responsible for roughly one third of GHG emissions in Germany [1, 2], whereas nuclear energy is currently being phased out. Since the first *EEG* in 2000, a series of *EEG* revisions have periodically established a subsidy to be paid for the year of installation and the subsequent 20 years for each kWh of electricity fed into the power grid. Such subsidies vary according to the technology, size and date of the installation. Within the *EEG*, solar photovoltaic systems (hereinafter PV), and in particular small rooftop installations, have been granted the most rewarding subsidy scheme (i.e., feed-in tariffs, hereinafter FiTs). As a result, at the end of 2018, around 1.6 million PV systems were installed in Germany (approx. 60% with a capacity below 10 kW_p), which added up to a total capacity of 45.9 GW [3]. Moreover, solar energy accounted for approximately (hereinafter approx.) 7.1% (45.8 TWh) of gross electricity generation in 2018 [4].

However, the deployment of solar photovoltaic installations has not followed a stable pattern. In fact, a boom took place between 2009 and 2012[1] [5], presumably as a result of their high profitability, given the combination of falling technology costs and generous FiTs [6]. After 2012, additional PV capacity decreased sharply following a considerable reduction of FiTs, and fell short of its annual deployment goal of approx. 2.5 GW outlined in the *EEG-2014* and *EEG-2017*. Furthermore, the same amendments set an upper limit of 52 GW for PV installed capacity, after which the current promotion schemes will cease to apply to new installations. On the other hand, in order to achieve the afore-mentioned climate and energy goals, the capacity of PV is projected to be between 120 GW and 290 GW by 2050 [3]. At the time of writing (in the first half of 2020), it remains unclear what kind of policies will be adopted in order to achieve such future scenarios.

Aside from direct promotion through FiTs, the rate of grid electricity plays a major role in the economics of residential PV in Germany. Around 2012, both FiTs and the levelized cost of electricity generated by small PV installations dropped below the retail price of electricity[2]. P*roducers* were thus incentivized to become *prosumers*, shifting from a "full producer" paradigm (i.e., generating electricity to sell it in full) to a "residual producer" one (i.e., generating electricity primarily for self-consumption purposes) [7]. Furthermore, since the *EEG-2014*, self-consumed electricity has been exempted from the *EEG* surcharge[3] if it is generated by installations with a maximum peak power of 10 kW. This stimulated the diffusion of smaller PV systems under this threshold from mid-2014 onwards [8]. This paradigm shift

[1] Between 2000 and 2008, PV capacity increased from 0.1 GW to 6.1 GW. In the subsequent 4 years (2009-2012), it then rose by 28 GW. As a comparison, during the same 4 years only approx. 8 GW of wind energy capacity was added.
[2] So-called grid- or socket-parity was achieved.
[3] Installations above this threshold pay a share (40%) of the EEG surcharge, which amounted to 6,401 ct/kWh in 2019.

brought battery energy storage (hereinafter BES) systems to the attention of homeowners. The additional investment in BES enables an increase in the self-consumption rate of self-generated electricity by uncoupling the timing of electricity consumption from its production. Since 2013, new installations of residential PV systems have been increasingly coupled with BES systems, in part thanks to government-sponsored financial support[4] [8].

After years of sluggish growth in PV capacity, the 2.5 GW target was finally surpassed in 2018. Not only is residential PV deployment gaining fresh momentum, but also its coupling with BES is becoming the prevalent option[5] [9, 10]. In this respect, it is important to understand the profitability of such technologies in relation to self-consumption paradigms. In particular, the extent to which household characteristics affect the profitability and optimal sizing of PV and BES systems, and how this investment decision is significantly influenced by financial and fiscal aspects, remain unanswered. Moreover, given the rapidly sinking FiTs[6], it is expected that household heterogeneity (i.e., potential for self-consumption) will become an increasingly decisive factor for the economic viability of a PV system and its sizing, while the potential for co-adopting BES systems might rise.

To answer these research questions, we conducted a nuanced economic assessment of residential PV and BES systems that accounts for household heterogeneity and the surrounding financial environment. In particular, we studied the impact of household characteristics that shape the electricity load profile, determining self-consumption potential (i.e., size, employment status, energy intensity, vacation), as well as the impact of finance-related factors that are connected to the socio-economic status of a household (i.e., income tax rate, source of financing), to the general macroeconomic environment (i.e., inflation), or to both of them (i.e., discount rate). Moreover, we considered alternative tax treatments, eligible for German households, and show how relevant this aspect is in terms of profitability. As the financial performance of cash flows can be assessed through alternative indicators (i.e., net present value, real internal rate of return, payback period), we considered all these metrics and discussed their implications as evaluation criteria for optimal investment decisions (i.e., optimal system sizing). In order to perform our analysis, we first identified 4 household types, generated 240 simulated load profiles for each household type (960 in total) and subsequently conducted technical simulations of PV and BES operation. Finally, we calculated the resulting annual cash flows and adjusted them according to alternative tax regimes and financial factors. This allowed us to address not only the substantive research

[4] In 2013, the German government started to subsidize small PV-coupled battery systems covering up to 30% (reduced to 10% in 2018) of the investment costs through its state-owned development bank (KfW). Those signing up for this program also had to agree to partake in the scientific evaluation of decentralized BES and limit its peak feed-in: while in the first years of the program the majority signed up for this grant and monitoring program, it is estimated that only 20% of small BES adopted in 2017 were participating in the program [8]. At the end of 2018, the KfW subsidy program ended, with costs of BES having sunk, thus making it an investment of increasing interest, regardless of government subsidization.

[5] It is estimated that more than half of new small-scale PV installations are today coupled with BES and approx. 125,000 residential battery systems were deployed in Germany by the end of 2018 [10].

[6] Between August 2014 and August 2018, FiTs for PV installations below 10 kW_p only fell slightly from 12.75 ct/kWh to 12.20 ct/kWh, following the slow growth in additional capacity. FiTs subsequently plummeted to 11.47 ct/kWh (January 2019), and then to 9.87 ct/kWh (January 2020), as a result of the recent rapid growth.

questions raised above, but also to discuss methodological research questions, namely the sensitivity of such economic assessments with respect to financial output metrics.

The case of Germany is of particular interest, given the current and projected deployment of PV, the strong incentives to self-consume electricity, the increasing relevance of solar *prosumers*, and the ongoing debate about reforming energy and climate policies. Nevertheless, the majority of this study's findings and conclusions can be transferred to the context of other countries.

The paper proceeds as follows: In Section 2, we summarize the literature on the economic assessment of residential PV and BES systems. Section 3 provides a detailed description of the data and methods used in the study. In Section 4, we present the main results of the technical and economic analyses. In Section 5, we discuss our findings and provide an outlook for further research. In Section 6, we present our conclusions.

2 Literature review

Many studies have analyzed the economic viability of residential PV and BES systems, focusing on several technical, economic and regulatory aspects. O'Shaughnessy et al. [11] provide a recent literature review on the economics of technologies that can defer the use of residential PV self-generated electricity. These not only include battery storage, but also load control technologies (e.g., heat pumps, smart home appliances). Whereas the former technology can directly store PV electricity and shift self-consumption (or exports to the grid[7]), the latter[8] aims to reshape the electricity load profile (e.g., through thermal storage) and match it with PV output. Across the studies analyzed in [11], assumed technology costs, rate structures and load profile heterogeneity are the main drivers behind diverging assessments. With respect to BES, the main findings of the review [11] are the following:

- Low grid export rates make the coupling of BES an increasingly attractive option in comparison to stand-alone PV. This is valid until a point where residential photovoltaic becomes uneconomical in absolute terms.
- Batteries are not yet cost-effective and further costs reductions are required (well below 500 $/kWh). Such an improvement in costs is unlikely to be reached in the near future.
- Despite their poor economic performance, demand for residential BES systems is growing around the world. Other co-benefits[9] from BES should therefore also be taken into account in order to better understand this phenomenon.

[7] Within the current regulatory framework (flat feed-in tariffs), this would not be profitable; however in a framework with dynamic feed-in prices, BES could be used for energy arbitrage purposes.
[8] In this study, we focus on electricity storage. However, load re-shaping would affect the findings of any residential photovoltaic assessment that strictly uses exogenous load profiles. In fact, PV self-consumption may increase up to 15% thanks exclusively to demand side management [12].
[9] E.g., back-up power or aspiration to achieve self-sufficiency independent of monetary considerations (see [13]).

- In some limited cases, BES can boost the profitability of stand-alone PV systems, i.e., when demand charges are included in the rate structure or in the case of TOU (time-of-use) rates where PV generation does not occur during peak periods.

The latter point does not (yet) apply to Germany. However, many studies on the topic focus on this country, where high retail electricity prices and falling grid export rates boost the appeal of self-consumption. A study from 2014 [14]found that under high BES prices (3000 €/kWh) and a FiT of 15 ct[10]/kWh, battery-coupled photovoltaic systems were uneconomical in absolute terms (not only compared to stand-alone PV), whereas in the long term, under expected BES prices of 600 €/kWh and a FiT of 2ct/kWh, they would be the optimal solution. Another study from the same year assumed that FiTs would be phased out, with lead–acid[11] batteries found to be economically viable as early as 2013 [15]. Similarly, more recent studies assume low FiTs (e.g., average wholesale price) [16-18], an hourly wholesale price [19] or no compensation for exports to the grid [20]. As of today, while BES costs have decreased significantly, FiTs have not sunk accordingly. It is, therefore, still relevant to analyze the profitability of PV, assuming a guaranteed feed-in compensation of approx. 10 ct/kWh, especially in light of the fast diffusion of residential battery storage among German households.

Aside from compensation for exports to the grid, many other regulatory aspects (e.g., retail electricity rate structure) may change in the near future. Their impact on the economics of PV and BES thus requires further research (e.g., see [18]), which cannot be addressed within this one study. Furthermore, a number of studies consider the variation of technical characteristics of system configuration and/or battery technology (e.g.,[19, 21-23]), battery dispatch optimization (e.g.,[16, 17, 19, 24-26]), alternative locations (e.g.,[22, 27]), load profile changes over time [28] or the co-adoption of load-reshaping technologies, in particular heat pumps and electric vehicles (e.g., [16, 29, 30]). With this in mind, we focus primarily on the other determinants that affect the variation of results in the literature [11]: household heterogeneity and system costs.

Studies such as [16, 23, 25] account for household heterogeneity by calculating the profitability and optimal configuration of PV–BES systems across several load profiles, possibly under different scenarios and assumptions. Beck et al. [17] use several load profiles to analyze the impact of time resolution on investment optimization results. To this end, they find that low temporal resolution can greatly overestimate the accuracy of self-consumption levels (especially for stand-alone PV), while a 5-min resolution is generally found to yield good results, and a 15-min resolution can still be sufficient for profiles with few peak loads. Bertsch et al. [20] distinguish between load profiles according to 2 different household types and locations, meaning that heterogeneity is not only due to random variation, but also to certain household characteristics. A different approach is implemented by Klingler et al. [31], who empirically created household groups through a cluster analysis of 400 real load profiles. In this paper,

[10] Euro-cent

[11] In this paper, BES systems are understood to be lithium-based batteries, if not otherwise specified. This is the prevailing technology, amounting to approx. 90% of the estimated residential BES systems [10].

we analyze profitability across 4 household types, with further variations (i.e., vacation and energy efficiency) within each type. In this regard, the use of energy efficiency devices and vacation activities might represent different behavioral or lifestyle approaches.

With regard to system costs, the majority of studies assume size-independent costs per kW or kWh (especially for BES), although this misrepresents the actual market conditions and results in an underestimation of the optimal system size. Notably Dietrich et al. [32] and Bergner et al. [33] analyze PV offerings published online, as well a market survey on BES, in order to estimate size-dependent system costs. Similarly to their studies, we account for size-dependent system costs, but with major differences in estimated costs, since we select actual offerings from a large retailer.

Furthermore, the majority of studies overlook the effect of taxation on the initial investment as well as on future cash flows. Taxation is partially considered in [34], whereas in [32] a comprehensive taxation regime is considered. In this study, we assess the economics of 6 major tax treatment alternatives that German PV adopters can decide between. Finally, we focus on the financial environment where this investment decision takes place, which has been largely ignored in the literature to date. We analyze the impact of financial aspects such as inflation, discount rates, types of financing, and the use of different financial metrics, given that these features are crucial to evaluating any potential investment. Most importantly, we vary these financial and fiscal aspects simultaneously and across heterogeneous load profiles in order to create and analyze a broad spectrum of cases and to allow us to fully understand their impact. In doing so, we aim to fill a gap in the literature, which not only concerns financial and fiscal aspects per se, but also household-specific characteristics (e.g., loan interest rates, income tax rates, employment status, household size) that both encompass and go beyond load profile heterogeneity.

3 Methods, data and assumptions

In this study, we conducted a three-stage techno-economic analysis. Firstly, we generated a set of synthetic load profiles. Secondly, we used these load profiles as input for technical modeling of the operation of PV and BES systems in order to obtain an annual level of total self-consumption and feed-in. Finally, we calculated and evaluated the resulting cash flows to assess profitability and financially optimal system configuration. Figure 1 provides an overview of the methodological approaches implemented. In this Section, we will describe in detail the methods, data and assumptions used in this study.

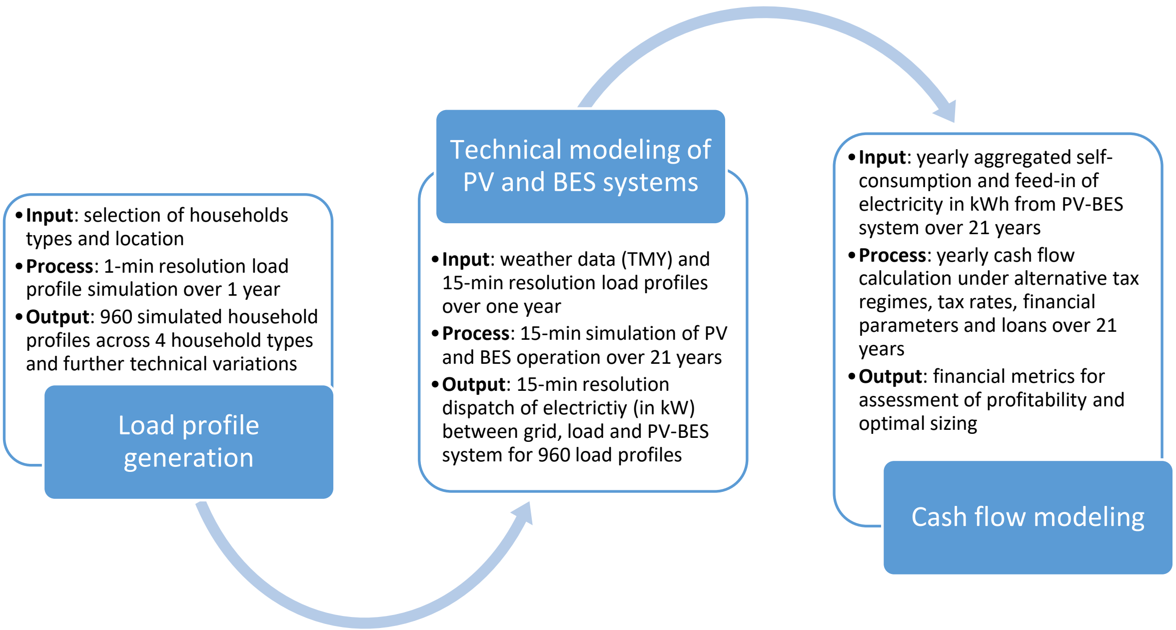

Figure 1 - Overview of methods

3.1 Technical analysis

3.1.1 Weather data

The weather data used to calculate the yearly PV generation profile comprise typical meteorological year (TMY) data collected over the period 2007–2016. This consists of a freely downloadable file from the European Commission website [35]. It contains hourly data of several weather variables for a given location, including:

- Global horizontal irradiance
- Direct normal irradiance
- Diffuse horizontal irradiance
- Dry bulb temperature (2m temperature)
- Wind speed

The dataset is produced by selecting the data for the most typical months observed over the 10-year period [36]. As a location, we chose the city of Essen, which is situated at the heart of one of the most densely populated regions of Germany.

3.1.2 Load profile data

In order to consider household heterogeneity with regard to electricity consumption, we make use of simulated load profiles. In contrast to standard load profiles or averaged load profiles, these show a more realistic behavior and do not tend to overestimate PV self-consumption [34]. Alternatively, real load profiles from smart meter data are also used in the literature (e.g., [16, 17, 23, 31]), yet their availability is very limited. We generated a dataset of simulated load profiles that accounts for different electricity consumption patterns between different household types, as well as within household types, by using the *LoadProfileGenerator* (LPG, version 7.2) [37]. This tool, which has already been used in several studies (e.g., [20, 22, 28, 34]), simulates the behavior of household members and the consequent usage of electrical devices over one year on a 1-minute resolution. Within the LPG, we selected four predefined household types all located in the city of Essen, namely: a 4-person household with 2 adults in full-time employment and 2 children (hereinafter HH1a); a 4-person household with 1 adult in full-time employment, 1 adult at home and 2 children (hereinafter HH1b); a 2-person household with 2 retired adults (hereinafter HH2a); and a 2-person household with 2 adults in full-time employment (hereinafter HH2b)[12]. With this selection, we aimed to obtain a fair characterization[13] of potential technology adopters, namely owner-occupiers of (semi-)detached houses. Moreover, in comparison to the default households, we standardized the vacation period for all households and picked 2 variants: either a 20-day vacation in July or a 16-day vacation in December. Likewise, we chose 2 variants with respect to the energy efficiency of electric devices: one with exclusively energy-saving devices, and one with random devices. Finally, we also accounted for random heterogeneity as we ran 30 different random seeds for energy-saving households and 90 different random seeds for households with random devices.

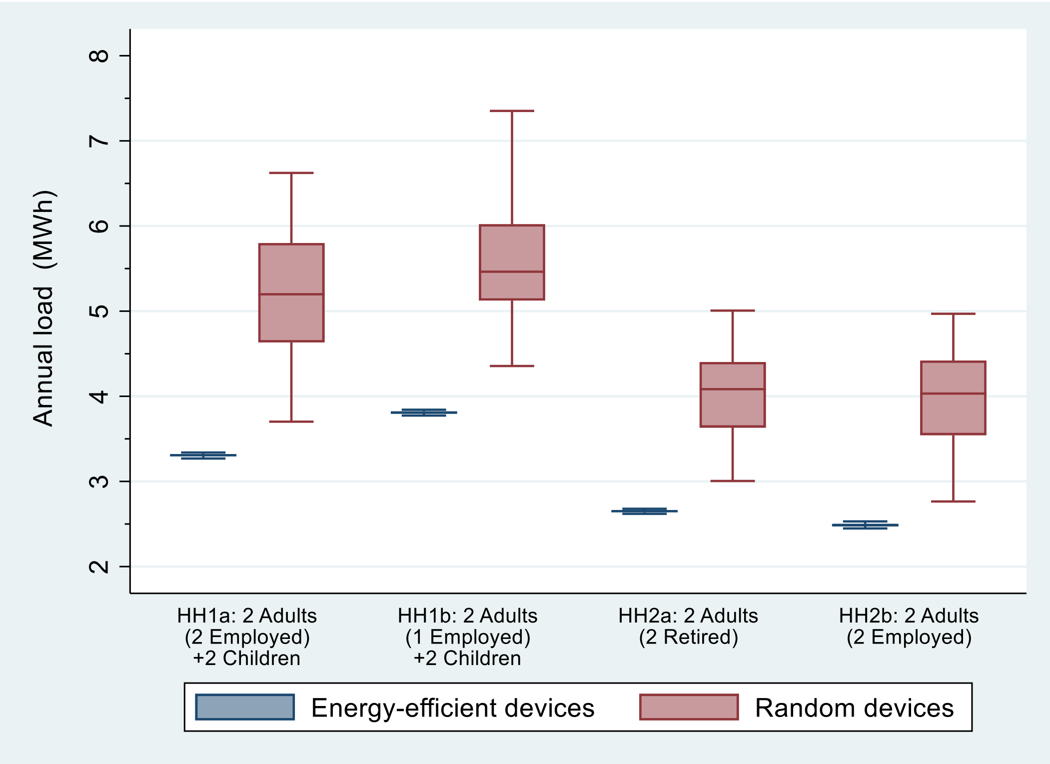

Figure 2 - Distribution of the total annual consumption of electricity by household type and electrical energy efficiency

This simulation was repeated for both vacation variants and 4 household types, resulting in 240 load profiles for each household type (960 load profiles in total). Figure 2 shows the distribution of total yearly electricity consumption for each household type and the energy intensity of devices. It can be seen that variability among households with energy-efficient profiles is very low, whereas profiles with

[12] Within the *LoadProfileGenerator*, these correspond to the following predefined households: "*CHR27 both at work with 2 children*" (in this paper as HH1a), "*CHR44 Family with 2 children, 1 at work, 1 at home*" (in this paper as HH1b), "*CHR54 Retired Couple, no work*" (in this paper as HH2a), "*CHR33 Couple under 30 years with work*" (in this paper as HH2b).

[13] Although the majority of households in Germany are one-person households, owner-occupiers are mostly couples with and without children, who live predominantly in residential buildings with 1 or 2 dwellings, according to the most recent available data [38, 39].

random electrical devices show a large variability that motivates the use of more random seeds. The first set of households share the same electrical devices: since only the most efficient devices within each category of devices (e.g., refrigerators) are permitted for the simulations, the only drivers of variability are vacation and the random behavior of household members, which seems to barely affect the total annual consumption of electricity. Conversely, households with random electrical devices diverge greatly with respect to total energy consumption. This is a result of the underlying variability of the efficiency of devices within each category.

3.1.3 Modeling of photovoltaic and battery systems

The modelling of PV generation, battery operation and electricity dispatch is performed through publicly available software, namely the System Advisor Model (SAM, version 2018.11.11), a techno-economic tool developed at the National Renewable Energy Laboratory (NREL) [40]. This tool, which is used for example in [41], allows a great level of detail for designing renewable energy installations. We run our calculations by using the detailed photovoltaic model for a residential installation. This consists of a module and inverter model, which respectively calculate solar-energy-to-DC electricity and DC-to-AC electricity conversion, and account for losses associated with each component. Moreover, SAM allows us to exogenously specify further losses on irradiation, DC and AC output. All in all, SAM uses the data on irradiation, temperature and wind speed (see section 3.1.1), as well as location data, to calculate the performance of the user-specified combination of a PV array and inverter for each time step of the analysis over one year (for further details, see [42]). In the case of stand-alone PV, the net AC output is used to meet the load, whereas the surplus electricity is fed into the grid. Since meteorological data are on an hourly resolution, we converted them to 15-min resolution through interpolation. In contrast, we aggregated 1-min load profiles to 15-min data points in order to perform our simulation on this level of resolution. The technical simulation was repeated for 21 years: SAM accounts for the degradation of module performance over time, while the input data on weather and load are kept at a constant over the entire period of analysis.

With regard to technical input parameters, within SAM, we were able to select modules coinciding with turnkey offerings of PV systems (see Section 3.2.2). Meanwhile, we manually entered the characteristics of 4 different inverters for each of the PV sizes considered, taking into account the limitation of PV output to 70[14]% of the installed peak power in the case of stand-alone PV systems. After setting exogenous losses of irradiance (i.e., soiling), DC (i.e., module mismatch, diodes and connection, DC wiring) and AC output (i.e., AC wiring), stand-alone PV systems achieve a performance ratio of approx. 85% and final electricity generation of approx. 950 kWh/kW (as shown in Table 11 in the Appendix). Such values are in line with [3]. We also consider the coupling of BES: given that our analysis centers on simultaneous co-adoption with PV, we assumed the battery to be DC-connected (see Figure 3) in order to minimize energy losses (i.e., AC/DC conversions) and system costs.

[14]This is part of the regulation established in the *EEG* laws.

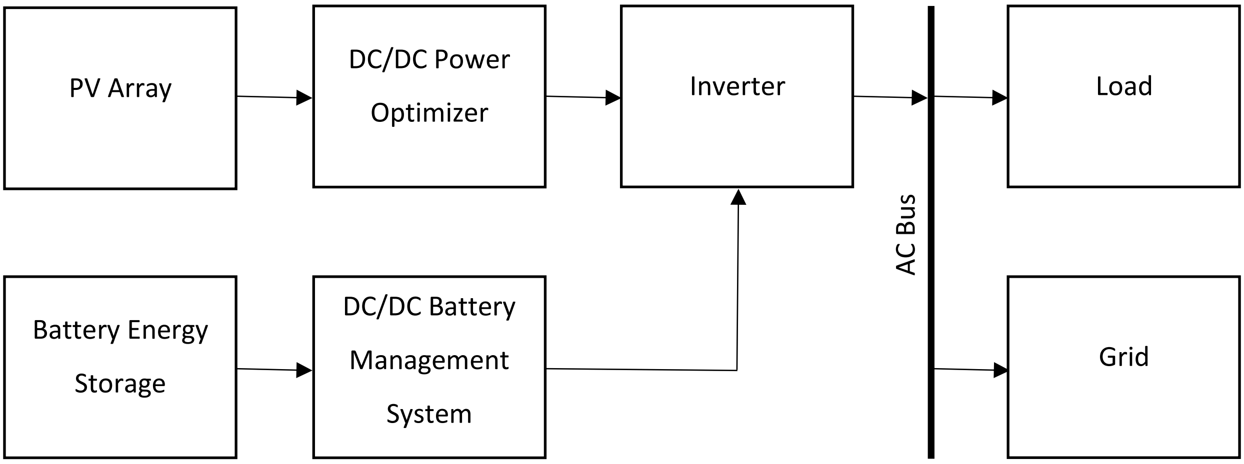

Figure 3 – PV system coupled with BES system

The SAM battery model is quite complex and accounts for many factors influencing battery performance: voltage variation with charge state, which affects battery efficiency; capacity fade due to cycles and aging; and temperature effects on capacity (see [43, 44] for a detailed description of the model). Table 1 provides an overview of the battery characteristics selected within SAM. By selecting a battery chemistry, a set of default battery properties are input into the battery model.

	System	Parameters		Notes
Input in SAM	PV	Location and climate	Essen, Germany	
		Module material	Mono-c-Si	
		Module efficiency	18.66%	
		Tilt	30°	
		Orientation	South	
		Yearly degradation	0,5 %	
		Irradiation losses	5%	Losses not endogenously modeled
		DC losses	3.5%	
		AC losses	1%	
		Inverter efficiency	97%(S) / 97.8(M-L) / 98%(XL)	Inverter and its efficiency depends on PV size
		Inverter AC/DC ratio (only PV)	From 0.75 to 0.88 (0.70 stand-alone PV)	See Inv_AC/DC in Table 11
	BES	Configuration	DC-connected	
		Chemistry	Lithium-Ion (NMC)	
		Cycle degradation at 80% DoD	80% capacity after 4000 cycles	See BES output in Table 11
		Cycle degradation at 30% DoD	80% capacity after 8000 cycles	
		Max DoD	90%	
		Cell voltage	3.7 V	
		DC/DC conversion efficiency	98%	

Table 1 - Overview of main technical assumptions specified within the SAM framework

We subsequently set a manual dispatch strategy, which follows one simple rule: PV electricity first meets the load, then charges the battery until the battery reaches the highest state of charge (hereinafter, SoC) – which is set at 95% – before finally being fed into the grid. Discharge occurs whenever the load cannot be met by the PV, and as long as the SoC is above the minimum threshold, which is set at 5%.

The battery properties and operation determine average battery round-trip efficiencies at between approx. 87% and 93% (see Table 11). Although we do not model smart BES operation, we assume that it would not reduce our potential for self-sufficiency while being able to shave the peaks in the PV feed-in. Therefore, in contrast to stand-alone PV, no limitation is applied to inverter output capacity. Given the uncertainties regarding the end of battery lifetimes, and in order to avoid further assumptions on future BES replacement[15], we assume that batteries continue to be operated for the entire time period of analysis, and follow the same degradation pattern. Table 1 provides an overview of the assumed technical parameters. Under the current regulatory framework with flat electricity prices per kWh and FiTs, only 2 technical results are of interest for our cash flow analysis: the total amount for each year y of self-consumed electricity (ele_sc_y) and electricity exported to the grid (ele_exp_y). We automated our calculations over 960 load profiles by running SAM through Python (version 3.7.3). At the same time, the technical results were directly entered into our cash flow model.

3.2 Economic analysis

Table 2 summarizes the nomenclature of the variables and parameters used for our economic analysis.

Indices		**Parameters**	
y:	yearly time index	inf:	inflation rate
reg:	index of tax regime type	r:	real discount rate
am:	index of amortization type	d:	nominal discount rate
Technical variables		τ:	income tax rate
ele_sc_y:	electricity self-consumption in *y* (kWh)	vat:	value-added tax (VAT) rate
ele_exp_y:	electricity exports to grid in *y* (kWh)	i:	interest rate on loan
ann_load:	total annual load (kWh)	n:	loan term and period (years)
Price variables		**Tax-related variables**	
PV_cost:	gross PV system cost (€)	$vat\_adj_{reg,y}$:	rate to adjust values according to *reg* in *y*
BES_cost:	gross BES system cost (€)		
op_cost_y:	gross operating costs in *y* (€)	p_sc_y:	fictitious price of self-consumed electricity for VAT calculation (€/kWh)
p_ele_y:	gross price of grid electricity in *y* (€/kWh)	$val\_sc_{reg,y}$:	value of self-consumed electricity for income tax calculation under *reg* in *y* (€)
fmc_y:	gross fixed monthly charge for grid electricity in *y* (€)	$dep_{reg,am,y}$:	value to write down for income tax calculation under *reg* and *am* in *y* (€)
FiT:	feed-in tariff for exports to grid (€/kWh)		

Table 2 - Nomenclature for economic analysis

3.2.1 Financial metrics, parameters and sources of financing

We aim to assess the financial performance of investment in PV and BES systems from the perspective of a German household. It is, therefore, important to consider the quantitative criteria for evaluating such project as well as the financial environment in which the evaluation takes place and the heterogeneous actors carrying out the assessment.

[15] Replacement is usually assumed to take place when the battery reaches 80% of its initial capacity. Given that battery degradation depends on its usage (i.e., energy throughput), larger storage would be replaced several years after smaller storage (see Table 11 in the Appendix).

A common metric for evaluating an investment is the simple payback period (SPB), namely the time needed to repay the initial investment. This might be a suitable metric for its intuitiveness, especially in a context where the decision is being made by private citizens. However, this metric has two major flaws: it does not account for the time value of money (i.e., opportunity cost), nor for what happens after the payback. The net present value (NPV), namely the sum of discounted future cash flows minus the initial investment cash outflow, solves both SPB issues. Many studies in the literature use this metric, yet, as noted in [20], it requires the assumption of a discount rate, namely opportunity cost, which may vary for each household as well as different financial conditions and expectations. The real internal rate of return (IRR), namely the discount rate that would result in a NPV of 0, has the advantage of not requiring any assumptions on discount rates, meaning that the resulting IRR can be compared with any interest rate from alternative investment opportunities. However, IRR is not appropriate for choosing between investments of different magnitudes, as in the case of PV and BES optimal sizing. In fact, IRR does not provide information on *how much money will be made* but rather a *percentage of profitability* that is attached to a given combination of PV and BES systems. We therefore weigh up the pros and cons of all three metrics and discuss the implications of potential diverging outcomes.

With respect to NPV, a rate must be assumed to discount future cash flows, whereas inflation affects all 3 metrics. Several studies assume discount rates of 4–5% (e.g., [16, 18, 23]) and test the sensitivity of results to such assumptions, but fail to explicitly consider inflation (with the exception of [32]). As a reference case, we assume a real discount rate (r) of 2% and an inflation rate (inf) of 2%. However, a nominal discount rate of 4.04% might seem too conservative at times of very low (even negative[16]) interest rates. Of course, the perceived investment risk, opportunity cost and/or financing costs for PV and BES systems, which are required to determine a concrete discount rate, might be highly variable across households and affected by many characteristics (e.g., income, expectations, inclinations). Therefore, such aspects cannot be fully addressed within this study. However, we believe it to be realistic that many households might implicitly assume a real discount rate of lower than 2%. We therefore test the sensitivity of our results to the variation of r by setting it to 0% and 1%. Moreover, during the last few years, actual inflation has remained below the European Central Bank (ECB) target of 2%. Accordingly, we consider the alternative scenario where inf = 1%. These variations of parameters imply nominal discount rates (d) ranging from 1% to 4.04%.

We also assess how the profitability of this investment is affected by its means of financing, as we consider full equity financing (reference case) as well as a loan that covers 100% of the initial adoption costs[17].

For the sake of simplicity, we assume that such a loan is paid back over a period n of 10 years, with a fixed annuity depending solely on the loan interest rate, i, and the initial investment. Given that government-sponsored loans for investment in residential renewable energy technologies are available,

[16] The European Central Bank has been setting (nominal) negative interest rates for several years [45].
[17] These can be either net or gross depending on the initial tax regime (see Section 3.2.4).

we assume 2 variants of low interest rates, i.e., 1% and 3%, respectively, for low-risk and medium-risk borrowers.

3.2.2 Investment and operating costs

In order to derive realistic cost estimates for PV systems with the option of coupling with BES, we analyzed the estimated turnkey offerings available on the websites of PV installers. We found one large retailer providing estimated turnkey prices for each PV system size, in combination with different battery sizes[18], with indications for the modules, inverters and battery models, and brands. Each marginal increase in PV system size (i.e., additional module) does not correspond with an equal increase in the final price, even when accounting for fixed installation costs. More interestingly, marginal costs do not always decrease in line with system size. In fact, some underlying step-wise costs can be deduced (e.g., inverters). For this reason, we chose to limit our analysis to 4 PV sizes that have the lowest investment costs per kW_p compared to a system with plus or minus one module. Table 3 shows the PV systems analyzed in this study as well as the assumed net[19] adoption costs. The assumed system costs might seem low when compared to the literature. Indeed, PV installations might actually be significantly more expensive due to house-specific technical reasons, which is why we consider our assumptions to be an optimistic scenario.

	PV systems (€ per kW_p)				BES systems (€ per kWh)			
	4.72 kW_p [S]	6.49 kW_p [M]	7.96 kW_p [L]	9.73 kW_p [XL]	3.3 kWh [S]	6.5 kWh [M]	9.8 kWh [L]	13.1 kWh [XL]
Initial investment	1233.1	1153.2	1057.3	983	990.6	694.5	571.3	519.8
Operating costs (year 1)	26.2	21.4	19	17	-	-	-	-

Table 3 – System-specific net investment and operating costs of PV and BES systems.

Many studies (e.g., [18, 23, 27, 34]) assume operation and maintenance costs as a percentage of PV investment costs (usually 1% to 1.5%). We follow the approach of [20] and assume initial fixed gross costs (op_cost_1) amounting to €100 for all system sizes (e.g., hire of PV meter and insurance), plus €10 per kW_p (e.g., cleaning, repairs). This results in total operating costs between 1.7% and 2.1% of initial PV costs in the first year (y). Operating costs increase yearly because of inflation (inf), as shown in Equation 1):

$$op\_cost_y = op\_cost_1 \times (1 + inf)^{y-1}$$

1)

[18] We selected four battery energy storage systems whose capacities are reported in Table 3. In addition, the power ratings of the S-, M-, L- and XL BES are 3.0 kW, 4.4 kW, 5.0 kW and 5.0 kW, respectively.

[19] A value-added tax of 19% must be added to obtain gross costs. In Table 3, we report net investment and operating costs of technologies to allow for an international comparison.

3.2.3 Electricity import and export to/from the grid

We assume that installation takes place on January 1, 2020, when the FiT was 9.87 ct/kWh. Such a FiT is paid for the year of installation and the following 20 years, meaning that our analysis covers 21 years. In terms of electricity withdrawn from the grid, we adopted the price components of the cheapest tariff offered (i.e., not the default tariff) by the local default supplier[20]. In gross terms, this amounted to 27.86 ct/kWh) (p_ele_1) plus €8.33 of the fixed monthly charge (fmc_1). In our analysis, we assume a stable electricity price in real terms (real escalation rate is 0%), although it increases with inflation, as shown in Equations 2) and 3). In the analyzed literature, electricity rates are usually assumed to increase by 2–2.5%, at least in nominal terms. Indeed, inflation is a factor that has often been overlooked. Hedging against increasing electricity prices has been one of the main motivations for adopting battery systems [8]. However, despite this widely shared assumption, prices have remained stable in the last few years [46][21].

$$p\_ele_y = p\_ele_1 \times (1 + inf)^{y-1}$$

2)

$$fmc_y = fmc_1 \times (1 + inf)^{y-1}$$

3)

3.2.4 Taxation

In order to account for the tax treatment of earnings[22] deriving from the adoption of PV and BES, we follow the procedure outlined in [48]. Self-consumption is subject to value-added tax (VAT), meaning households have to pay a 19% VAT rate (*vat*) on a fictitious purchase price for self-consumed electricity (p_sc_y). This price is based on the actual retail electricity rate and is calculated as follows:

$$p\_sc_y = \frac{p\_ele_y}{1 + vat} + \frac{fmc_y}{1 + vat} \times \frac{12}{ann\_load}$$

4)

On the other hand, under this regime, households receive a reimbursement of the VAT paid on the initial gross investment cost. This only applies to both PV and BES if they are adopted simultaneously[23]. Moreover, the VAT on gross operating costs is reimbursed as well. This standard tax regime is known as the *Regelbesteuerung* (hereinafter *Rb*) and involves a relatively high level of paperwork and communications with the taxation authority.

Alternatively, given that the annual revenues from a small PV system are not expected to exceed €17,500, households can opt for a simplified tax regime for small business, namely the *Kleinunternehmerregelung* (hereinafter *Kur*). Under this regime, PV system owners are not required to

[20] Around 70% of retail electricity consumers purchase electricity from their local default suppliers (*Grundversorger*) [46].

[21] Retail electricity prices might even decline in the upcoming years if a CO2-based reform of surcharges and taxes would be implemented [47]. However, in this paper, we limit our analysis to the current regulatory framework.

[22] Revenues from feed-in, as well as savings on electricity bills.

[23] Our assumption on co-adoption (and not BES subsequent installation) is crucial for a major cost reduction, since BES can be considered as part of the PV business asset from the perspective of value-added taxation.

pay the VAT on self-consumption, but they also do not receive a VAT refund on the initial gross investment cost or on the yearly operating costs.

After 5 years under the *Rb* regime, it is possible to switch to the *Kur* regime for the following fiscal years. This allows users to take advantage of both regimes: in the first year the VAT on the investment cost is refunded, while starting from the seventh year no VAT on self-consumption must be paid. For an overview of the impact of taxation on this economic assessment, we calculate the cash flows of these 3 alternative tax regimes: *Rb*, *Kur,* and this last mixed regime, hereinafter *Rb→Kur.* To adjust values affected by tax regimes, we use $vat\_adj_{reg,y}$, where *reg* is the tax regime. If *reg* = *Rb→Kur*, an adjustment from gross to net values occurs depending on *y*. For each given year, vat_adj_{reg} must have one of the two following values:

$$vat\_adj_{Rb} = 1 + vat \quad \text{or} \quad vat\_adj_{Kur} = 1$$

5)

Aside from value-added tax, earnings deriving from PV electricity are subject to income tax, with a tax rate τ[24]. The taxable income for a given year is the difference between feed-in income and the self-consumption value minus operating costs and depreciation of the PV system[25]. In Equation 6), the value of self-consumption for a given year *y* is calculated on the basis of production costs (i.e., it is not dependent on the grid electricity price).

$$val\_sc_{reg,y} = \frac{ele\_sc_y}{ele\_sc_y + ele\_exp_y} \times \left(dep_{reg,Linear,y} + \frac{op\_cost_y}{vat\_adj_{reg,y}} \right)$$

6)

In Equation 6), depreciation (*dep*) must occur linearly (see index *Linear*) over 20 years[26], meaning that 5% of the initial PV investment costs plus the yearly $op\_cost_{reg,y}$ represent the production costs. These can be either gross or net values depending on the tax regime. Finally, Equation 7) demonstrates how the taxable income ($tax\_inc_{reg,am,y}$) is calculated.

$$tax\_inc_{reg,am,y} = ele\_exp_y \times FiT + val\_sc_{reg,y} - dep_{reg,am,y} - \frac{op\_cost_y}{vat\_adj_{reg,y}}$$

7)

In Equation 6), *dep* may differ from Equation 7), since different types of amortization schedules (*am*) can be chosen to write down the initial cost of a PV investment. By means of the special amortization (known as the *Sonderabschreibung*, hereinafter *Special*), up to 20% of the initial PV investment costs can be additionally deducted during the first 5 years. Consequently, we analyze 2 possible amortization

---

[24] We assume that this additional income is taxed either at 23.97% or at 42%. These correspond, respectively, to the initial marginal tax rate for a single-person income within the third bracket of the German income tax (i.e., taxable income equal to €14,533) and to the marginal tax rate of an income within the fourth income tax bracket (i.e., taxable income between €57,051 and €270,500)

[25] Only expenditures for PV systems can be deducted through amortization. In fact, BES systems are only deductible if more than 10% of stored electricity is exported to the grid.

[26] In the 21st year, no depreciation occurs, since PV has already been written off. Moreover, only the initial tax regime (i.e., net or gross investment cost) matters in terms of determining a constant amount to be written down yearly.

types: *Linear* (5% yearly) and *Special* (25% in year 1; 5% in years 2 to 5, and approx. 3.67% for the remaining 15 years).

To summarize, as depicted in Table 4, we include 3 alternative tax regimes and 2 amortization types into our cash flow analysis, thus obtaining 6 alternative results for each financial metric.

Tax regime (*reg*)	Initial investment	Operating costs	Self-consumed electricity	Amortization (*am*)
Rb	VAT refund	VAT refund	VAT charge	*Linear or Special*
Kur	No VAT refund	No VAT refund	No VAT charge	
Rb→Kur	VAT refund	VAT refund for the first 6 years	VAT charge for the first 6 years	

Table 4 – Overview of the alternative combination of tax regimes (reg) and amortization (am)

3.2.5 Summary of cases

Table 5 summarizes all the variations with respect to financial and fiscal aspects. In total, when calculating the NPV of a given system for a given load profile, we can obtain 216 different values: one for each combination of the alternative regimes and rates considered in our cash flow analysis. In order to reduce complexity, we define a reference case on the basis of which we vary such dimensions. For this base case, we assumed *inf* = 2%, *r* = 2%, τ =42% and a project fully financed with equity. With regard to fiscal treatment, we show in Section 4.2.1 that the *Rb→Kur* tax regime paired with *Special* amortization achieves the highest profitability across all simulations. The number of cases is thus reduced by focusing on the results relative to this taxation treatment, since, in contrast to the other dimensions, it can be chosen by the investor.

	Dimensions of cash-flow analysis						
	Financial parameters		Fiscal dimensions			Financing sources	
Financial metrics	*inf* (%)	*r* (%)	*reg*	*am*	τ (%)	Equity	Debt: *i* (%) on loan
SPB	1/2*	-	*Rb* or *Kur* or *Rb→Kur*+	*Linear* or *Special*+	23.97/42*	no loan*	-
IRR							
NPV		0/1/2*					1/3

Table 5 – Summary of the financial and fiscal dimensions

*Notes: *indicates value for reference case, + indicates alternative for optimal fiscal treatment.*

However, adopting the *Kur* regime from year 1 has the advantage of involving less paperwork. It is therefore plausible that some households might actually prefer this regime in spite of its lesser financial performance. However, the scope of our analysis is limited to the monetary motives for adopting residential PV, which is why we consider the best case according to this focal point.

3.2.6 Cash flow modeling

To calculate the NPV and IRR of an investment, we need to define the discounted value of cash flows. Firstly, before accounting for taxation, we show the discounted cash flows resulting from self-consumption (i.e., savings), grid exports and operating costs in Equations 8), 9), and 10), respectively:

$$DCf\_sc = \sum_{y=1}^{21} ele\_sc_y \times p\_ele_y \times (1+d)^{-y}$$

8)

$$DCf\_exp = \sum_{y=1}^{21} ele\_exp_y \times FiT \times (1+d)^{-y}$$

9)

$$DCf\_op = \sum_{y=1}^{21} op\_cost_y \times (1+d)^{-y}$$

10)

Secondly, we calculate the discounted stream of cash flows due to value-added taxation. By default, all prices in our analysis include VAT. Under the *Kur* regime, no additional cash flow takes place because of this tax, as shown in Equation 12). On the contrary, in Equation 11), under *Rb*, VAT on investment and operating costs is refunded, whereas it is levied on self-consumption. In Equation 13), under *Rb→Kur*, cash flows deriving from value-added tax only occur during the first 6 years.

$$DCf\_vat_{Rb} = \frac{(PV\_cost + BES\_cost) \times vat}{vat\_adj_{Rb}} + \sum_{y=1}^{21} \left(\frac{op\_cost_y \times vat}{vat\_adj_{Rb}}\right) \times (1+d)^{-y} - \sum_{y=1}^{21} ele\_sc_y \times p_{sc,y} \times vat \times (1+d)^{-y}$$

11)

$$DCf\_vat_{Kur} = 0$$

12)

$$DCf\_vat_{\mathrm{Rb}\rightarrow\mathrm{Kur}} = \frac{(PV\_cost + BES\_cost) \times vat}{vat\_adj_{Rb}} + \sum_{y=1}^{6} \left(\frac{op\_cost_y \times vat}{vat\_adj_{Rb}}\right) \times (1+d)^{-y} - \sum_{y=1}^{6} ele\_sc_y \times p_{sc,y} \times vat \times (1+d)^{-y}$$

13)

Thirdly, we consider the cash flows deriving from income taxation, which depend both on the type of amortization and on the tax regime. These cash flows are shifted by one year, since tax returns are filed in the year following the actual generation of income, as shown in Equation 14):

$$DCf\_inctax_{reg,am} = \sum_{y=2}^{21} \tau \times tax\_inc_{\,reg,am,(y-1)} \times (1+d)^{-y}$$

14)

Finally, we show our financial output metrics. The NPV is equal to the sum of all discounted cash flows minus the initial investment cost, as shown in Equation 15). The (real) IRR is derived by setting *NPV* = 0 and adjusting this value for inflation.

$$NPV = DCf\_sc + DCf\_exp + DCf\_op + DCf\_vat_{reg} - DCf\_inctax_{reg,am} - PV\_cost - BES\_cost$$

15)

To calculate the SPB, $CumCf\_all_{reg,am,y}$ is taken as the cumulative sum of all cash flows that have not been discounted (i.e., $d = 0$) minus the initial investment up to a given year. We find the year k for which the maximum non-positive value is reached, where $k+1$ is the first year with a positive cumulative sum of cash flows. We then calculate the *SPB* as shown in Equation 16).

$$SPB = k + \frac{-CumCf\_all_{reg,am,k}}{CumCf\_all_{reg,am,k+1}}$$

16)

In Equation 17), we model the additional cash flows that would take place in the case of initial investment financed through debt. Such cash flows include the positive flow of the amount borrowed, the annuity repayment over 10 periods (n), as well as the interest expenses that can be deducted from the taxable income. Through the sum of Equations 15) and 17), we obtain the NPV of the total discounted cash flows that include borrowing and loan repayment.

$$DCf\_loan_{reg} = \frac{PV\_cost + BES\_cost}{vat\_adj_{reg}} - \sum_{y=1}^{n} \frac{(PV\_cost + BES\_cost)}{vat\_adj_{reg}} \times \frac{i \times (1+i)^n}{(1+i)^n - 1} \times (1+d)^{-y}$$
$$+ \sum_{y=1}^{n} \tau \times i \times \frac{(PV\_cost + BES\_cost)}{vat\_adj_{reg}} \times \frac{(1+i)^n - (1+i)^{y-1}}{(1+i)^n - 1} \times (1+d)^{-(y+1)}$$

17)

4 Results

4.1 Technical results

Table 11 in the Appendix shows selected input and output values of the technical simulation with SAM, reporting median values across all 240 simulations per household type (HH) and size of PV and BES systems (i.e., both energy intensity and vacation variants are included). The amount of usable electricity provided by the complete system in the first year is around 950 kWh per kW_p of PV installation. This varies across simulations due to inverter sizing (e.g., 70% limitation for stand-alone PV), inverter efficiencies (larger inverters are more efficient) and battery operation (e.g., more energy stored implies more losses). From the household perspective, the most insightful technical result is probably the degree of self-sufficiency, namely the share of annual power consumption directly supplied by the PV–BES system. Figure 4 depicts the median self-sufficiency rate by household type for each of the considered system configurations. The results are relative to the first year of operation, as both PV and storage performances diminish over time. An XL stand-alone PV system is expected to provide self-sufficiency rates of around 44% in the case of households where not all adults are in full-time employment (HH1b and HH2a), whereas households with 2 adults in full-time employment (HH1a and HH2b) would cover roughly 34–35% of their electricity demand.

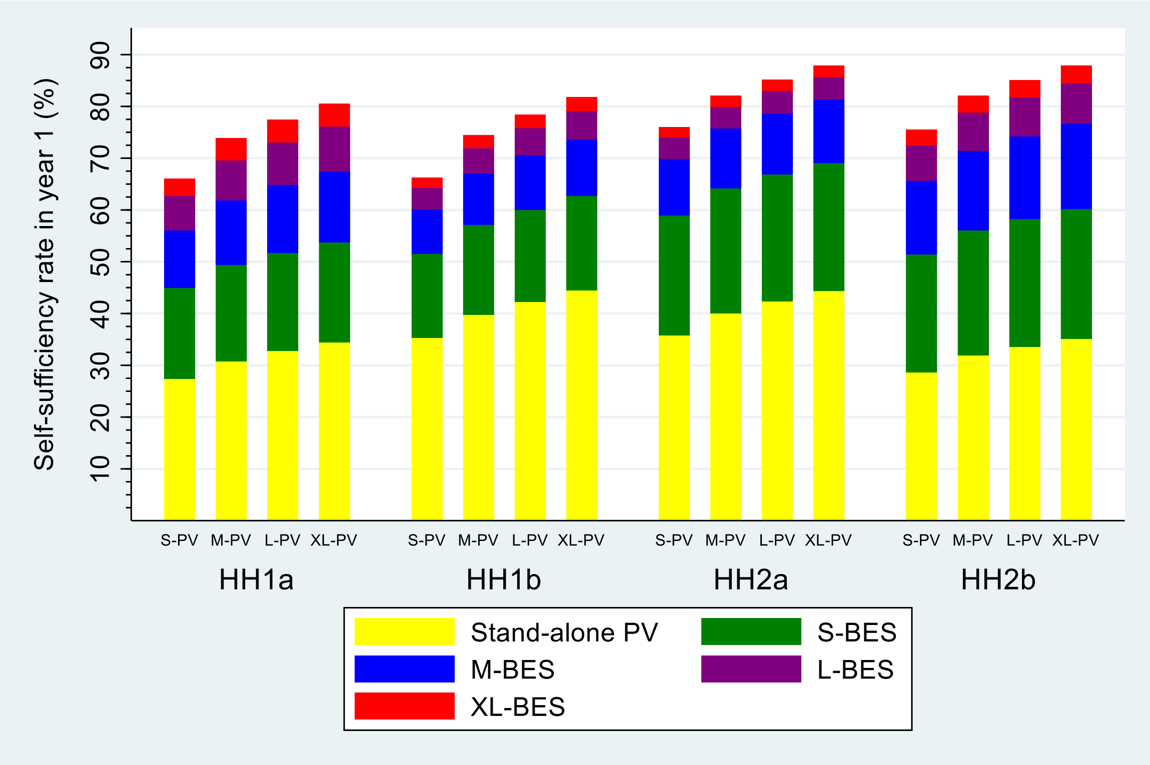

Figure 4 – Cumulative self-sufficiency rate from additional BES by household type and PV system (median values by household type)

By adding BES systems, self-sufficiency increases with major differences across household types and system sizes. For example, the coupling of an S battery with an S-PV system (4.72 kW_p) is expected to boost self-sufficiency by approx. 16–17 percentage points (hereinafter pp) for HH1a and HH1b, compared to 23 pp for HH2a and HH2b, whereas an XL battery combined with an XL-PV can push self-sufficiency from 35% to 88% (HH2b). However, the largest gains are seen with the S and M batteries. Indeed, switching from a 6.5 kWh to a 13.1 kWh battery enhances self-sufficiency, in the best case (namely for HH1a with XL-PV), by approx. 13 pp. On the other hand, after the first year of operation, large batteries improve their relative self-sufficiency potential when compared to smaller ones, as larger batteries have the advantage of a slower capacity fade due to less intensive use (i.e., fewer cycles elapse over the same time period). In the following subsections, we will assess in which cases boosting the potential for self-sufficiency coincides with an increase in expected profitability.

4.2 Economic results

4.2.1 *Impact of fiscal treatment*

Figure 5 illustrates the comparison of IRR resulting from different taxation treatments within the same simulation. In particular, we show the difference between the IRR of the *Rb→Kur/Special*[27] cash flows and each of the other taxation alternatives (including no taxation). Across 76,800[28] simulations, selecting this taxation treatment results in an additional positive return in comparison to all other alternatives. The positive return in comparison to "no taxation" is due to the fact that default investment costs (i.e., *PV_cost* and *BES_cost*) include value-added tax. The closest alternative is represented by the same regime *Rb→Kur* paired with a linear amortization: opting for the special amortization results in a median additional IRR of approx. 0.25 pp. Consequently, in the following subsections, our results refer to the evaluation of the after-tax cash flows under the *Rb→Kur* regime and a special amortization, since these constitute the most profitable fiscal treatment across all considered simulations.

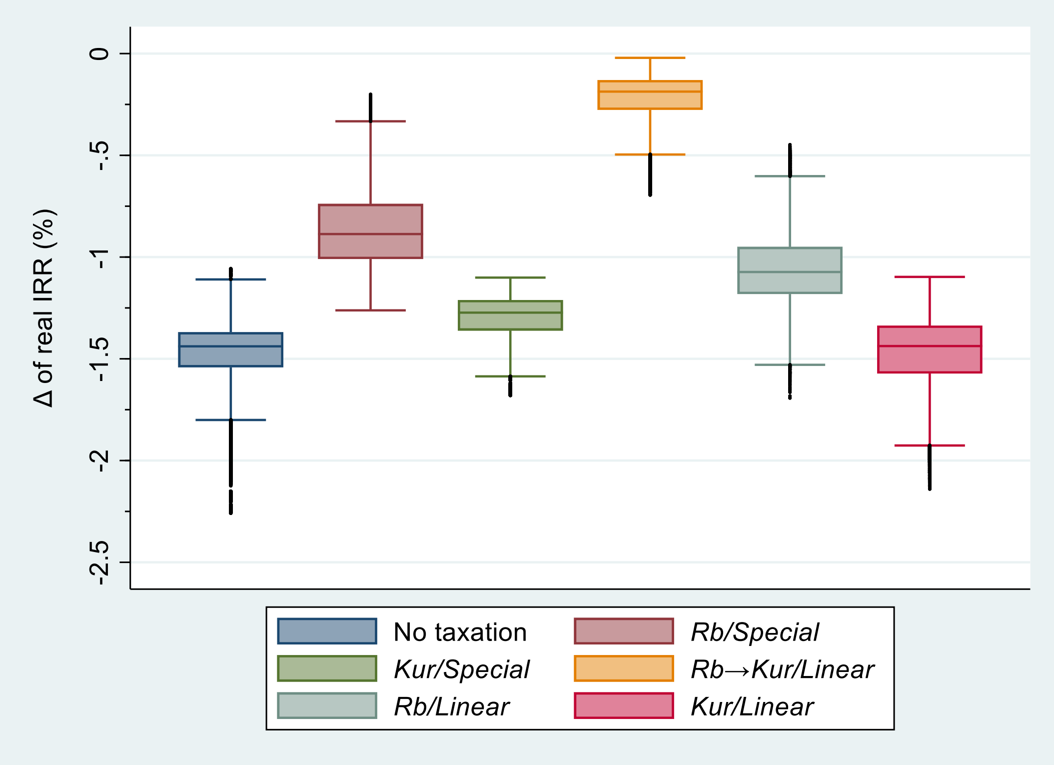

Figure 5 – Distribution of IRR differences (Δ) within simulationw.r.t. the Rb→Kur regime paired with Special amortization

4.2.2 *Impact of financial metrics*

In this subsection, we present the economic results of the reference case simulations (i.e., *inf* = 2%, *r* = 2%, τ =42% and equity financing) under the most profitable tax treatment (*Rb→Kur/Special*).

We find that the FiT is sufficient to make the XL-PV system the most profitable system for all household load profiles (i.e., independent of self-consumption potential), and according to all the considered financial metrics. However, expected profitability varies across households: Figure 6 reports financial

[27] Namely the cash flows in Equation 15) where *reg* = *Rb→Kur* and *am* = *Special.*

[28] Namely 20 systems, multiplied by 960 load profiles, multiplied by 4 cases (i.e., 2 inflation rates, 2 income tax rates).

output metrics of the optimal system configuration for each of the 960 load profiles. The simple payback period ranges from less than 7 years to more than 11.5 years, the real internal rate of return spans from less than 4% to almost 10%, and the NPV ranges from €1,700 to almost €8,500. Moreover, the plots show a strong correlation between annual load and financial output metrics, as higher consumption implies higher potential for electricity savings (in contrast to less profitable feed-in). At the same level of annual load, a clear distinction in profitability is noticeable between households with both adults in full-time employment (HH1and HH2b) and households with at least one stay-at-home adult (HH1b and HH2a), as the latter benefit from higher levels of self-consumption due to load profiles that are a better match for PV generation. Aside from household type, little variability in profitability can be attributed to load profile shape resulting from random household behavior and vacation period. To this end, the reader can easily spot clusters of observations in the same color (i.e., same household type), sharing low levels of annual load and profitability. These correspond to load profiles with efficient electrical devices whose low variability in annual load (see Figure 2) translates to low variability in financial output metrics. Figure 6 also provides information about optimal system configurations: while the adoption of stand-alone XL-PV maximizes the IRR and minimizes the SPB for all considered load profiles, the NPV is maximized for a minority (approx. 9.9%) of household load profiles by an XL-PV system paired with a battery. This corresponds to approx. one quarter of HH1a, one eighth of HH2b, and 3 HH1b load profiles. The choice of financial metrics is therefore crucial in terms of comparing profitability across different system configurations.

As discussed in Section 3.2.1, optimal sizing according to IRR differs from NPV sizing, since the IRR is attached to a given PV and BES configuration, which is not transferable to larger investments (i.e., system sizes). While investing a small amount (i.e., stand-alone PV) could generate cash inflows *more efficientl*y (i.e., higher IRR), investing a larger amount (i.e., BES-coupled PV) could generate larger net cash flows in spite of its lower return (i.e., higher NPV). Although PV systems just below 10 kW_p are always the most profitable investment under the current framework, households might still not install the largest photovoltaic system (e.g., due to available rooftop space), which is why we report the median profitability for each PV–BES combination as well as the rankings of system configurations in Table 12. We find that stand-alone PV is the most profitable choice across all simulations that include S-, M- and L-PV systems, according to all three metrics. Aside from optimal systems, we observe that NPV evaluation criterion tends to favor large batteries over smaller ones, whereas the opposite is true for the IRR and – in particular – SPB criteria.

In conclusion, studies which find that the coupling of batteries improves the economics of PV systems tend to assume very low or non-existent FiTs. However, this is not currently the case for Germany. Nevertheless, in our analysis, a minority of simulated households that have a mismatch between load and PV generation (i.e., households with 2 adults in full-time employment) and/or a very high level of annual load might already find BES systems to be optimal. This result hinges upon the metrics

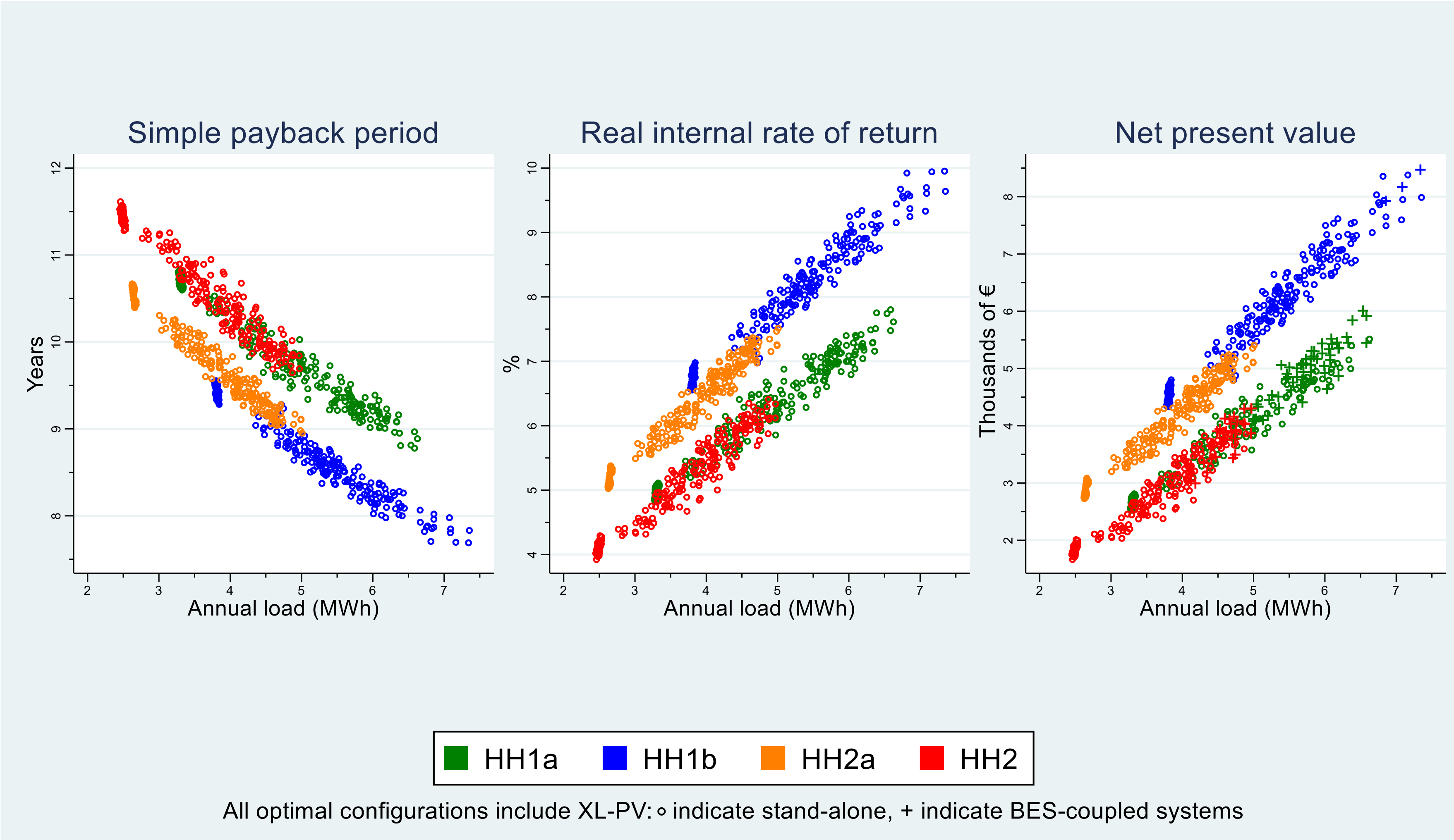

Figure 6 – Financial output metrics of optimal system configurations (reference case) by household type and annual load.

considered when optimizing system size. Indeed, if a household considers the adoption of PV and BES systems as a financial decision, seeing it, for example, as an investment opportunity with the expectation of a relatively high yield in the long term compared to alternative investments (or to financing costs), the NPV and its assumed discount rate are rather crucial in terms of deciding which combination of PV and BES should be adopted in the ideal scenario. Meanwhile, the IRR is independent of alternative investment opportunities, financing costs and subjective perceived risks. For this reason, it serves us better to perform a straightforward evaluation of the different streams of cash flows deriving from the same initial investment cost across different simulated household load profiles. Finally, the SPB only provides a financial result that is easy to grasp, but which is not very informative for a comparison across different households or system configurations. For this reason, in the following subsections, we will concentrate exclusively on results concerning IRR and NPV.

4.2.3 Impact of financial parameters and tax rates

In the reference case examined in the previous section, we assumed a real discount rate of 2%, inflation of 2%, and an income tax rate of 42%. Here, we report the results following the variations of r, *inf* and τ summarized in Section 3.2.5.

Unsurprisingly, the NPVs of PV and BES adoption increase significantly when assuming real discount rates of 0% or 1%[29]. More interestingly, the ranking of the most profitable system combinations is also affected when considering the NPV criterion. Once again, the best system combinations always include an XL-PV for all 960 simulated load profiles and cases. However, optimal storage sizing is greatly affected: Figure 7 reports the share of household load profiles that maximize NPV by adopting a BES-coupled system. In our reference case (last column in lower right block), a battery increases the NPV of a stand-alone XL-PV only for 9.9% of the 960 load profiles. With respect to variations of inflation rates, we observe that a lower inflation rate (i.e., 1% instead of 2%) has a positive effect on both IRR and NPV metrics, since by definition this increases the real value of future positive cash flows. However, lower inflation proportionally affects growth in retail electricity rates, reducing the potential for savings due to self-consumption, while boosting the financial appeal of the nominally fixed feed-in income. A lower inflation might thus partially hinder the diffusion of battery-coupled PV systems in spite of lower nominal discount rates. For example, with *inf* = 1%, τ = 42%, r = 2%, a battery is optimal only in 3.9% of the simulated households (last column in lower left block in Figure 7), as opposed to 9.9% in the reference case (where *inf* = 2%). The last dimension to be varied within this cash flow analysis is the household-specific tax rate on income deriving from PV electricity. Interestingly, with τ = 23.97%, profitability can both rise or fall compared to the reference-τ,

[29] In this subsection, we mostly focus on the impact on the optimal system configuration and refer to Figure 7. For details on the impact on profitability, refer to Table 13 in the Appendix.

depending on the system under consideration. In particular, a lower tax rate only has a positive effect on IRR and NPV when XL-PV systems are adopted. More importantly, tax rates can also affect the decision concerning battery adoption, for example starting from the reference case and then shifting to the lower τ-variant cuts the adoption rate of batteries from 9.9% to 5.4% (last column in upper right block in Figure 7).

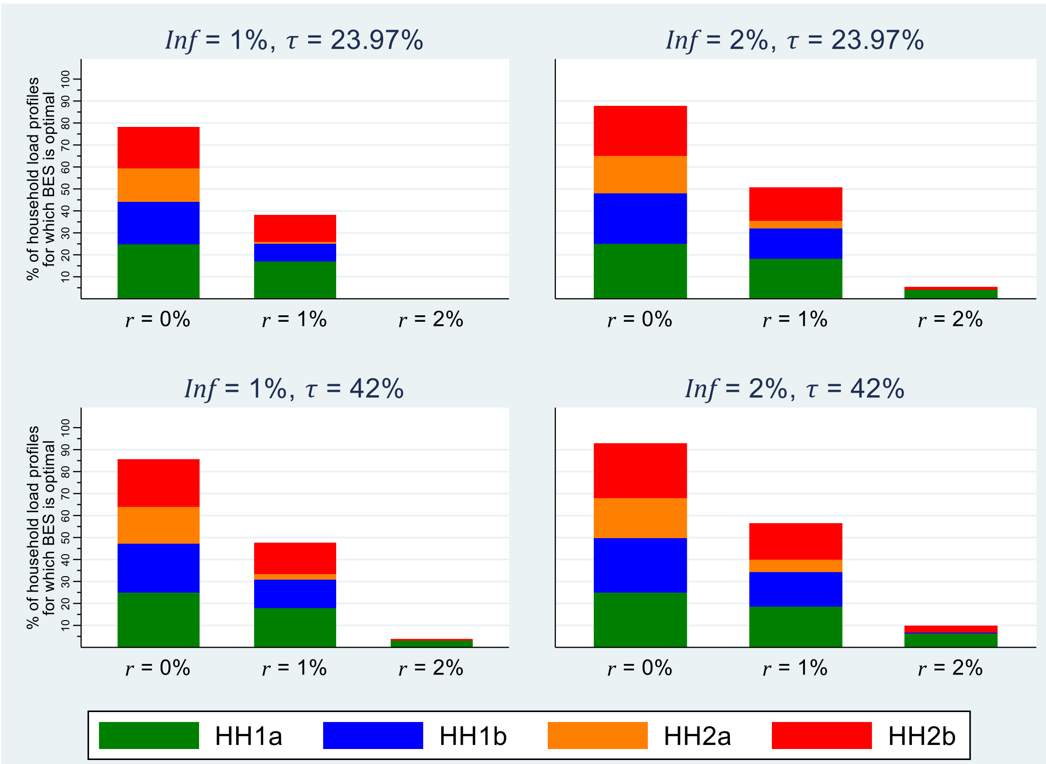

Figure 7 – Share of the 960 load profiles for which BES adoption is optimal (according to the NPV criterion), by household type, inflation, real discount and tax rates.

In conclusion, we have shown how choosing the optimal system configuration is greatly influenced by assumptions concerning financial parameters and tax rates, which can be both household- and environment-specific. In contrast to other considered metrics which always favor stand-alone PV, the adoption of BES systems based on NPV maximization can range from 0.2% (with r = 2%, inf = 1%, τ = 23.97%) to 92.9% (with r = 0%, inf = 2%, τ = 42%) of the simulated household load profiles. Across all the considered cases, optimal storage adoption is firstly achieved by HH1a, followed by HH2b, HH1b and, finally, HH2a households. In Section 4.2.5, we quantify the average impact of these dimensions on profitability and optimal storage sizing.

4.2.4 Impact of financing sources

So far, we have analyzed the cash flows of a project financed exclusively through equity capital. In this section, we investigate the impact on the NPV of an investment entirely financed through borrowed capital, assuming an interest rate of either 1% or 3%. First of all, we notice that a loan with such low nominal interest rates might render the adoption of PV and BES systems more appealing from a financial perspective. By definition, if the nominal discount rate *d* is higher than the nominal interest rate on the loan *i*, the NPV of any project will be higher if financed through debt instead of equity. With $i = d$, the investor only obtains the same NPV through equity or debt financing if interest is not deductible from taxable income (or if τ = 0%). However, interest rates on loans for PV and BES systems are tax-deductible, meaning that even with $i > d$, debt financing can reach a higher NPV than through equity financing. The condition under which debt performs better than equity financing is summarized in Equation 18) (this can be derived from Equation 17) in Section 0).

$$DCf\_loan_{reg} > 0 \rightarrow \frac{q^n - 1}{q - 1} - \frac{q^n \times \delta(1 - \delta^n)}{1 - \delta} + \tau\delta^2 \left(\frac{q^n (1 - \delta^n)}{1 - \delta} - \frac{1 - q^n \delta^n}{1 - q\delta}\right) > 0$$

18)

where: $q = 1 + i;\ \delta = \frac{1}{1+d}$

Following this, we report limit values for *i*, above which equity financing reaches a higher NPV than debt financing across the aforementioned financial and tax parameters (Table 6). If households have access to a loan where *i* = 1%, debt financing improves the financial performance of the investment in all the cases considered in this study. Conversely, if *i* = 3%, equity financing results in a larger NPV in 4 out of 12 considered cases (i.e., values < 3% in Table 6), for example if *inf* = 1% and *r* = 0%.

τ	***inf*** =1%			***inf*** =2%		
	r = 0%	***r*** = 1%	***r*** = 2%	***r*** = 0%	***r*** = 1%	***r*** = 2%
23.97%	1.31%*	2.62%*	3.93%	2.61%*	3.93%	5.24%
42%	1.71%*	3.41%	5.09%	3.40%	5.09%	6.77%

Table 6 – Maximum values of interest rates on loan (i) to obtain a superior NPV performance through debt financing
*Notes: *indicates values below 3%.*

An increase in profitability, in terms of NPV, can be very significant, especially for a low interest rate paired with 2% inflation and a real discount rate of 2% (see Table 14 in the Appendix). Furthermore, as shown in Table 7, rankings of systems are also affected. In fact, it would be optimal for an additional up to 85.2% of simulated load profiles to adopt a BES system in comparison to the case with equity financing (if *r* = 2%, *inf* = 2%, τ = 23.97% *i* = 1%). On the contrary, with *r* = 0% and *i* = 3%, stand-alone systems are favored over battery-coupled ones, i.e., up to an additional 47% of simulated households would adopt a stand-alone PV system in the case of debt financing.

In summary, households that bear (or perceive) a high cost of the time value of money and have access to low interest rates benefit greatly from financing the adoption of PV and BES systems through borrowing. Such low interest rates might even be considered a sort of subsidy to promote the diffusion of these technologies. Moreover, such loan opportunities are not neutral for system configuration, as they may foster a more noticeable diffusion of battery systems, especially with larger storage. This impact will be more thoroughly investigated in the next subsection.

i	*τ*	***inf* =1%**			***inf* =2%**		
		***r* = 0%**	***r* = 1%**	***r* = 2%**	***r* = 0%**	***r* = 1%**	***r* = 2%**
1%	**23.97 %**	4.3%	17.5%	64.0%	5.9%	31.9%	85.2%
	42 %	7.3%	24.3%	70.4%	0.8%	37.0%	83.4%
3%	**23.97 %**	-47.0%	5.2%	7.4%	-24.5%	21.8%	36.9%
	42 %	-33.1%	7.5%	25.5%	-15.0%	24.4%	50.6%

Table 7 – Impact of loan on the share of load profiles for which BES coupling is optimal (difference between equity and debt financing)

4.2.5 Drivers of profitability and storage sizing

After reporting the outcomes of the cash flow analysis under alternative assumptions, we assess the average impact of the all preset variations of household and financial characteristics on the profitability of PV and BES systems, as well as their optimal sizing. For the first purpose, we run 5 OLS regressions[30] to explain the determinants of financial performance (IRR) for the largest PV combined with alternative battery systems, and to quantify the isolated effect of the examined dimensions. The models in Table 8 explain between 82.8% (Model 5) and 86.9% (Model 2) of the dependent variable (IRR). Unsurprisingly, the constant[31]of the stand-alone PV is approx. 1.8 pp to 2.8 pp higher than BES-coupled systems. Taking HH1a as a base value, a stand-alone PV has, on average, an IRR that is higher by 1.73 pp for HH1b, with this additional return declining with increasing storage capacity (0.80 pp with an XL-BES). On the contrary, households with 2 retired persons (HH2a) show a negligible difference from HH1a in the case of no or small batteries, whereas IRR increasingly diverges if a larger storage capacity is deployed (-0.73 pp with an XL-BES). Meanwhile, HH2b has a negative difference across all BES sizes, yet it reaches the IRR closest to HH1a with an M-BES (i.e., 0.73 pp). More importantly, we find that load profiles with energy-efficient devices have a significantly lower profitability by more than 1 pp, meaning that this effect is often larger than household-type variation. This effect intensifies for large BES systems up to 1.67 pp, implying that the lack of energy-saving devices particularly favors the adoption of large storage. Conversely, the impact of a higher inflation rate is negative, but diminishes with storage size from approx. -0.7 pp to -0.4 pp, as future savings from grid electricity rise. Finally, vacation and tax rate have a minor, yet significant, impact on absolute profitability.After gauging the impact of each of the drivers on system-specific profitability, we investigate how the factors considered in this study influence optimal storage[32] sizing, i.e., the probability that the highest NPV is reached by combining an XL-PV coupled with a given storage size (including no storage). In Table 9, we summarize the effect of different discount rates on optimal system sizing across all cases considered in 0 and 4.2.4. For instance, with a discount rate of 2%, stand-alone PV is the best system

[30] We estimated the econometric models of this section using Stata 16.
[31] In our OLS, the constant corresponds to the predicted IRR of a system for a type 1a household with energy-efficient devices, vacation in July, a marginal tax rate of 23.97% and with an expected inflation rate of 1% (i.e., base levels of factor variables).
[32] Since PV maximization (under 10 kW_p) is optimal across all simulations, no factor affects its sizing (under the current level of FiT). Only 4 system combinations are optimal, given that optimal configurations always include an XL-PV and either an M-, L-, or XL-BES.

for 65.8% of our simulations, whereas with $r = 0\%$, it is only optimal for 15.8% of the simulations. We can therefore conclude that the real discount rate, ceteris paribus, greatly affects optimal storage sizing, as it can influence the potential share of adoption of a given system by up to 50 pp.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
XL-PV with:	**No BES**	**S-BES**	**M-BES**	**L-BES**	**XL-BES**
	IRR (%)	**IRR (%)**	**IRR (%)**	**IRR (%)**	**IRR (%)**
HH1a	*reference*	*reference*	*reference*	*reference*	*reference*
HH1b	1.729*** (0.022)	1.418*** (0.017)	1.183*** (0.017)	0.975*** (0.019)	0.801*** (0.021)
HH2a	0.064** (0.022)	0.060*** (0.017)	-0.164*** (0.017)	-0.482*** (0.019)	-0.731*** (0.021)
HHTb	-0.985*** (0.022)	-0.782*** (0.017)	-0.729*** (0.017)	-0.838*** (0.019)	-0.955*** (0.021)
Random devices	1.364*** (0.018)	1.117*** (0.014)	1.256*** (0.014)	1.513*** (0.016)	1.673*** (0.017)
Vacation in Dec.	0.178*** (0.015)	0.183*** (0.012)	0.201*** (0.012)	0.193*** (0.014)	0.178*** (0.015)
42% tax rate	-0.133*** (0.015)	-0.115*** (0.012)	-0.083*** (0.012)	-0.072*** (0.014)	-0.073*** (0.015)
2% inflation	-0.704*** (0.015)	-0.552*** (0.012)	-0.471*** (0.012)	-0.425*** (0.014)	-0.399*** (0.015)
Constant	5.853*** (0.024)	4.042*** (0.019)	3.968*** (0.019)	3.640*** (0.022)	3.082*** (0.024)
No. of observations	3840	3840	3840	3840	3840
R^2	0.864	0.869	0.858	0.842	0.828

Table 8 – OLS regression on the determinants of system-specific IRR
*Notes: Standard errors in parentheses; *p < 0.05, **p < 0.01, ***p < 0.001; two-tailed tests.*

	***r* = 0%**	***r* = 1%**	***r* = 2%**
stand-alone XL-PV	15.77%	38.32%	65.76%
XL-PV with M-BES	13.43%	5.26%	2.18%
XL-PV with L-BES	57.19%	46.89%	26.98%
XL-PV with XL-BES	13.61%	9.52%	5.08%
No. of observations	11520	11520	11520

Table 9 – Percentage frequency of optimal system according to the NPV criterion by discount rate

In order to assess the scale of the impact of all remaining financial and technical dimensions, we ran 3 ordered logistic regressions across all the optimal[33] simulations, one for each discount rate, where storage

[33] Namely, simulations where the considered system is found to maximize NPV for the considered load profile, under a set of assumed financial dimensions.

sizes are the levels of the ordered dependent variable. Following Williams [49], we thus calculate the average marginal effects of each independent variable on the prediction that a given system combination is the optimal one and report these results in Table 10. In comparison to HH1a, stand-alone PV systems have a higher probability of optimal adoption for all other household types and discount rates ranging from 11.3% (HH1b, r = 0%) to 55% (HH2a, r = 1%). Vacation has a relatively small impact on optimal system configuration, diminishing, most notably, the probability of stand-alone adoption, on average, by -7.8% if r = 2%, and mostly favoring L batteries (4.8%). On the contrary, depending on the discount rate, stand-alone PV is between approx. 41% and 64% less likely to be adopted in the case of a household where devices are not energy saving. The magnitude of the impact is amplified for r below 2%: e.g., with r = 0%, a major shift from stand-alone (-49.7%) and M-BES (-13.4%), to L- (+45.1%) and XL-BES (+18%) is predicted.

With regard to financial and fiscal aspects, moving from a 23.97% to a 42% tax rate has an average marginal effect of -8.8 % on stand-alone PV optimality (with r = 2%), whereas it increases the adoption of L- and XL-BES coupled systems by 5.5 pp and 3.3 pp, respectively. Inflation has a stronger effect: a rise from 1% to 2% decreases stand-alone adoption by -17.1% with r = 2%. Although both tax and inflation rates have a milder impact for lower real discount rates, marginal effects on optimality are stronger for XL-BES than L-BES (e.g., +6.8% vs.+1.4%, respectively, in the case of inflation with r =0%). Finally, the type of financing has major effects on storage sizing. In the case of i = 1% and r = 2%, the probability of stand-alone optimality falls by -53.3% compared to equity financing, which benefits L- (+39.7 %) and XL-BES (+11.8%). For lower r, the impact is milder, yet the adoption of XL-batteries is mostly promoted (+3.1% with r = 0%). However, if the loan is issued with an interest rate of 3 %, r = 0% implies a slight negative effect on the optimality of L- and XL-BES (-1.3% and -4.3%). However, for r > 0% and i = 3%, L and XL batteries again benefit from borrowing. In particular, the predicted adoption of L-BES systems increases by 27.4% if r = 2%.

All in all, we have quantified and ranked the impacts (i.e., average marginal effects) of drivers that determine optimal system sizing. Among the variables that affect cash flow analysis indirectly through self-consumption, we found that not only household type but also energy efficiency is highly relevant for optimal system sizing and that such considerable effects remain valid for low real discount rates. Among the finance-related variables, financing source is the most decisive dimension for system configuration, followed by inflation and tax rates. However, the relevance of such factors is weakened in the case of low r values. In fact, these average marginal impacts are conditional on the assumed real discount rate, which, in its own right, noticeably influences optimal system sizing.

	r = 0%	*r* = 1%	*r* = 2%
HH1a	reference	reference	reference
HH1b			
stand-alone XL-PV	0.113	0.202	0.232
XL-PV with M-BES	0.052	0.028	0.003
XL-PV with L-BES	0.235	0.045	-0.105
XL-PV with XL-BES	-0.399	-0.274	-0.129
HH2a			
stand-alone XL-PV	0.319	0.550	0.423
XL-PV with M-BES	0.220	0.044	-0.004
XL-PV with L-BES	-0.085	-0.289	-0.273
XL-PV with XL-BES	-0.453	-0.305	-0.147
HH2b			
stand-alone XL-PV	0.140	0.187	0.191
XL-PV with M-BES	0.044	0.024	0.002
XL-PV with L-BES	0.235	0.058	-0.074
XL-PV with XL-BES	-0.419	-0.269	-0.119
Vacation in July	reference	reference	reference
Vacation in December			
stand-alone XL-PV	-0.019	-0.055	-0.078
XL-PV with M-BES	-0.009	-0.004	0.001
XL-PV with L-BES	0.005	0.028	0.048
XL-PV with XL-BES	0.023	0.030	0.029
Energy efficient devices	reference	reference	reference
Random devices			
stand-alone XL-PV	-0.497	-0.641	-0.412
XL-PV with M-BES	-0.134	0.022	0.022
XL-PV with L-BES	0.451	0.493	0.322
XL-PV with XL-BES	0.180	0.126	0.067
23.97% tax rate	reference	reference	reference
42% tax rate			
stand-alone XL-PV	-0.031	-0.067	-0.088
XL-PV with M-BES	-0.014	-0.005	0.001
XL-PV with L-BES	0.008	0.035	0.055
XL-PV with XL-BES	0.038	0.037	0.033
1% inflation	reference	reference	reference
2% inflation			
stand-alone XL-PV	-0.056	-0.136	-0.171
XL-PV with M-BES	-0.026	-0.010	0.002
XL-PV with L-BES	0.014	0.072	0.108
XL-PV with XL-BES	0.068	0.074	0.061
No Loan	reference	reference	reference
Loan (i=1%)			
stand-alone XL-PV	-0.023	-0.195	-0.533
XL-PV with M-BES	-0.012	-0.015	0.018
XL-PV with L-BES	0.003	0.093	0.397
XL-PV with XL-BES	0.031	0.117	0.118
Loan (i=3%)			
stand-alone XL-PV	0.040	-0.053	-0.327
XL-PV with M-BES	0.016	-0.003	0.020
XL-PV with L-BES	-0.013	0.035	0.274
XL-PV with XL-BES	-0.043	0.021	0.032
No. of observations	11520	11520	11520

Table 10 – Average marginal effects of battery sizing determinants. Based on ordered logistic regression

Notes: all average marginal effects are significantly different from 0 (p-value of z statistics < 0.001, two-tailed tests).

5 Discussion and outlook

Our starting point for this analysis is that the adoption of residential PV and BES systems is not, above all, a trivial investment decision, since it involves long-term planning and considerable funds. Against this background, we aimed to improve the transparency of such an economic assessment by simultaneously analyzing the impact of several financial (e.g., inflation rate, real discount rate, loan financing) and fiscal aspects (i.e., tax treatment, income tax rate) on the economic evaluation of these energy technologies and their respective sizing. In the context of the different properties of financial metrics (i.e., simple payback period (SPB), real internal rate of return (IRR), net present value (NPV)) that can be used to assess the financial performance of an investment, we calculated all these metrics to attain a comprehensive evaluation. Our findings on the financial and fiscal aspects, which have often been overlooked in the literature, apply to Germany and to its current regulatory framework, yet the insights on their impact are universally valid. As a matter of fact, the insights into the use of alternative financial metrics remain valid independent of the specified context. The variation of financial parameters can be replicated in the context of other locations and regulatory frameworks, and, in particular, the results on the impact of financing sources on profitability are generally transferable. While the cash flow modeling can be adapted to consider alternative regulatory frameworks, the technical modeling can be directly applied to any geographical region.

First of all, we demonstrated that residential investors can choose between several fiscal treatments, which result in significant differences in the expected returns on investment. Moreover, fiscal regulation incentivizes the simultaneous adoption of BES and PV, while it discourages the retrofitting of batteries at a later stage. The tax regime *Rb→Kur* coupled with special amortization is optimal for all the considered cases, which is why we focus on evaluating the corresponding cash flows.

We thus show how the current level of FiTs and legislation on self-consumption incentivize – through substantial financial gains – the installation of residential PV systems and capacity maximization under the threshold of 10 kW_p. We find this to be valid across all simulated households and cases, and according to any financial metrics, namely SPB, IRR or NPV. However, we also find that the use of different financial metrics considerably affects the decision on storage sizing: the NPV criterion tends to favor the coupling of larger storage in comparison to IRR and SPB. Although the NPV criterion increases the overall profitability of batteries, in our reference case, BES co-adoption emerges as the best system choice for only approx. 10% of simulated household load profiles.

In general, we conclude that NPV is more suitable for comparing investment opportunities with different initial costs, since the high return of relatively small investments (e.g., stand-alone XL-PV) cannot be obtained by larger investments (e.g., XL-PV coupled with L-BES). In other words, if a household faces the choice of investing €10,000 with an expected return (i.e., IRR) of 6%, or €18,000 with a return of 5%, only NPV metrics can provide a quantitative decision rule between these alternative investments. On the contrary, in our view, IRR is more suitable for comparing the same investment opportunities (i.e., same system combinations) across different load profiles, since such metrics provide an objective financial performance of different cash flows originating from the same initial investment cost and irrespective of household-specific financial aspects, i.e., discount rate, type and cost of financing.

Consequently, we ran a set of OLS regressions to assess the isolated impact of different household characteristics on the profitability of a subset of system combinations, finding, among other things, that energy-efficient devices decrease profitability by more than 1 pp and that this impact increases with battery size. Therefore, a trade-off might arise between efficiency measures to reduce electricity consumption and the adoption of PV and BES.

In order to address the uncertainty and heterogeneity regarding discount rates, inflation rates and income tax rates, we considered several alternative values. We identified an impact on the absolute values of system-specific profitability as well as on the ranking of the most profitable system configurations. As a result of these finance-related variations, in the case of equity financing, optimal battery adoption ranges from approx. 0% to 93%[34] of the simulated households. Similarly, we analyzed the impact of financing source, finding that debt financing increases the profitability of the investment in most of the considered cases[35] and that it also considerably affects optimal storage sizing. Indeed, by running an ordered logit estimation, we found that the impact of the type of financing is among the most crucial factors for system configuration. We believe that the type of financing might be included among the pre-determined household-specific characteristics, not only if the household has no availability of equity capital, but also if the household can choose between debt or equity. In other words, if a household has enough equity for the adoption of PV and BES systems, as well the opportunity to obtain a loan with $i = 1\%$, it might still opt to use equity instead of debt because of the lack of alternative investment opportunities (i.e., the household is a lender).

All in all, with this analysis we have demonstrated the relevance of accounting for household heterogeneity not only with respect to technical aspects (i.e., load profiles), but also in terms of financial and fiscal aspects. We found that both sets of drivers are very decisive for optimal system configuration, and, more importantly, for the decision to invest in battery storage. In particular, to the best of our knowledge, this is the first study to find BES systems to be economically optimal for a significant portion of households, under the system costs, electricity rates and FiTs currently present in the case of Germany. Such results are valid in the absence of non-monetary motivations (e.g., aspiration to reach self-sufficiency) or expectations of escalating electricity prices (in real terms). Moreover, with respect to the international literature, such results stand out, since PV-coupled batteries are found to be the economic optimal solution despite the lack of complex tariff structures (e.g., demand charges, flexible prices). However, the results are based upon a favorable

[34] If we consider loan financing, the rate of optimal battery adoption achieves approx. 94% of load profiles.
[35] Depending on the combination of interest, tax and nominal discount rates.

assumption with respect to the lifetime of the batteries (as we discuss in detail below) as well as optimistic assumptions regarding investment costs (as discussed in Section 3.2.2).

Our findings have a set of important implications. Firstly, the growing diffusion of BES-coupled PV systems in Germany might be the result of a calculated, and financially driven, investment decision, the underlying causes of which might be traced back to a combination of lack of opportunities for low-risk financial returns (e.g., negative interest on government bonds), availability of savings or attractive loans, affordable BES system costs, favorable tax treatment[36], relatively high FiTs and expensive retail electricity. Of course, other factors, such as environmental concerns, fear of above-inflation escalating electricity prices and the ambition to become "independent" of large utilities companies, might also play a major role in triggering this *prosumers* trend. Such questions cannot be addressed within this techno-economical study. In fact, this would require further investigation by means of other methodological approaches (e.g., surveys) in order to test the influence of such non-monetary motives on this adoption decision.

Secondly, the decision to adopt technologies to generate and store electricity at household level seems to be driven by micro-level economic considerations. However, such a positive economic assessment is crucially reliant on a set of politically determined conditions. The goal of political decision-making ought to be the public interest, yet it is not clear what the macro-level impact of the current regulatory framework might be. It could be called into question whether establishing a 10 kW_p threshold in self-consumption legislation, or technology- and size-dependent FiTs, etc., has brought about cost-efficient outcomes (i.e., deployment of RES) needed to reach climate and energy goals. In future, a further decrease in (or abolition of) FiTs would enhance the scope for increasing self-consumption rates, i.e., the adoption of BES. However, electricity bill savings, which derive from self-consumption, might also be considered an indirect subsidy, at least for parts of the bill (e.g., network charges). *Prosumers* avoid paying energy charges significantly affected by regulated price components[37] [46]. Indeed, German households pay one of the highest electricity rates across the world [50]. For instance, the *EEG* surcharge paid by retail consumers in 2019 amounted to 6.405 ct/kWh + VAT, i.e., around 27% of the electricity price assumed in this analysis (see Section 3.2.3). This renewable energy financing mechanism has been criticized, since it only burdens electricity while leaving other energy carriers unaffected. A CO_2-based reform of surcharges and levies for the entire energy sector would make grid electricity more affordable [47], thus reducing the profitability of self-consumption paradigms. Similarly, a reform concerning grid charges has also been proposed to curb unfair distributional effects on standard electricity consumers [51, 52]. All in all, several potential changes within the regulatory framework might greatly influence the decision regarding the adoption and operation of PV and BES systems. It is

[36]In the case of the subsequent addition of a BES to a pre-existing PV system, VAT is not reimbursed, i.e., BES investment costs rise by 19%. This might have the effect of accelerating battery adoption in order to take advantage of high FiTs.

[37]Infrastructure costs, surcharges and taxes levied on each kWh withdrawn from the grid amount to roughly three-quarters of the retail electricity price [46].

worth noting that such reforms would have retroactive effects, since they would affect the profitability of previously installed PV and BES systems. Although we do not intend to criticize self-consumption paradigms altogether, we believe that the set of direct and indirect (dis)incentives that drive the adoption, sizing and operation of energy-related technologies[38] should be carefully analyzed and its implications discussed. These sort of policy considerations are beyond the scope of this study, but they could be investigated by extending the analysis carried out here.

Finally, we consider how our results are valid only within the scope our study and the assumptions made in this context. We recognize that technical simulations might be improved with respect to time resolution, since a 15-min resolution may result in an overestimation of the potential self-consumption (especially for stand-alone PV). Moreover, weather data are based on hourly average observations, meaning that the highly volatile dynamic of PV generation cannot be captured by our analysis. However, our analysis works under the assumption that load profiles are exogenous, i.e., households have no capacity at all to adapt their consumption to PV generation. This is a standard assumption in this kind of study, albeit one that we do not believe to be realistic. The use of profiles that consider both load-shifting behavior, as well as the use of smart devices for load control, would improve the estimated potential of direct self-consumption from PV. Moreover, household load profiles, and even the climate (i.e., PV electricity generation), could change considerably during such a long period of analysis. Another technical limitation concerns assumptions about battery lifetime, since there are many uncertainties regarding their actual degradation, especially after a drop below 80% of their initial capacity (see Table 11). A second investment to replace battery cells might be necessary during the considered period, particularly in the case of small batteries, which are more intensively used. However, we presume this would restore the full capacity of the BES at a much lower cost per kWh. Similarly, a PV system could be operated after 21 years and continue to generate positive cash flows.

Nevertheless, such limitations concerning our technical simulation do not affect the findings concerning the magnitude of the impacts of financial and fiscal aspects discussed here. Moreover, limitations probably concern any economic assessment that can be realistically conducted by any actual homeowner: it is plausible to expect that any potential adopter subjectively accounts for uncertainties[39] in the discount rate or in a minimum IRR threshold, below which no investment is carried out. In this paper, we have partially addressed this aspect by considering the impact of alternative discount rates. However, in order to fully appreciate the role of these subjective aspects, further research and different methodological approaches would be required.

[38] Not only PV and BES, but also technologies needed for sector coupling (e.g., heat pump, heat storage, electric vehicles, etc.).
[39] Not only uncertainties on technical aspects, but also on future prices and regulations.

6 Conclusions

We carried out an economic analysis to assess the profitability of residential photovoltaic and battery systems from the perspective of German private households. For this purpose, we simulated heterogeneous load profiles with respect to several household characteristics (i.e., size, employment status, energy efficiency and vacation) and ran technical simulations to obtain yearly self-consumption, as well as exports of PV electricity to the grid, across several system configurations (i.e., sizes of PV and BES). Following these results, and after selecting a set of assumptions with regard to prices and costs, we were able to calculate yearly cash flows. However, given our focus on the monetary motives to adopt such technologies, we adjusted such cash flows to account for several tax treatment alternatives. In order to assess the financial performance of each system configuration, we calculated 3 different financial metrics and show how these diverge with regard to system ranking, thus concluding that NPV is best suited for optimal system sizing. Finally, we consider uncertainty and household heterogeneity regarding financial and fiscal dimensions. We therefore varied our assumptions with regard to inflation, discount rate, marginal tax rate, and source of financing.

All in all, we find that while taxation treatment is crucial to correctly estimating profitability and only marginally relevant for system sizing, financial aspects are greatly important for both matters. In particular, taxation regime can be optimally used to reduce initial investment costs by obtaining a VAT refund. Moreover, optimal amortization improves profitability by reducing the tax burden on overall income during the first few years, whereas a higher tax rate can marginally favor larger storage adoption. However, low real discount rates and debt financing with low interest rates, aside from increasing profitability, massively boost the potential for storage. We conclude that this latter finding is very relevant from a policy perspective, especially at times of very low interest rates, as has been the case in the last few years. Policy-makers, who aim to promote the adoption of RES, should consider such financial and fiscal aspects, since these are not only relevant for estimating the profitability achievable by potential investors, but also for predicting what type and size of installations will be deployed. In this regard, accurate predictions with regard to potential for RES adoption and operation would support the drafting of policies, which can help to shape an effective and cost-efficient energy transition and, therefore, a successful transformation path towards carbon neutrality.

7 Acknowledgements

This study was conducted within the framework of the Virtual Institute "Smart Energy" (VISE). The VISE is funded by the European Regional Development Fund (EFRE) and by the federal state of North Rhine-Westphalia (EFRE-0600037).

8 Appendix

Input					PV & BES output (year 1)					BES output							
										Operation (year 1)		Residual capacity		Energy throughput		80 % of residual capacity	
HH type	PV size kWp	BES size kWh	Annual load kWh	Inv_AC/DC ratio	Energy kWh	kWh/kWp kWh	Perfomance ratio	Self-cons. share	Self-suff. share	Peak kW	Efficiency %	10 years %	20 years %	10 years kWh	20 years kWh	Time years	Throughput kWh
1a	4.72	0	4827.6	0.699	4450.4	942.9	0.844	0.291	0.274	-	-	-	-	-	-	-	-
		3.3		0.890	4420.9	936.6	0.838	0.490	0.449	2.85	86.56	76.53	51.71	7713.1	13628.8	8.52	6762.3
		6.5		0.890	4404.7	933.2	0.835	0.612	0.560	4.20	89.15	80.43	59.21	12706.2	23408.4	10.25	12948.7
		9.8		0.890	4407.2	933.7	0.835	0.682	0.627	4.20	90.71	84.00	66.55	15996.3	30116.2	12.35	19622.3
		13.1		0.890	4411.3	934.6	0.836	0.719	0.661	4.20	91.48	86.85	72.51	17933.9	34527.1	14.79	26416.0
	6.49	0		0.693	6167.1	950.3	0.850	0.239	0.307	-	-	-	-	-	-	-	-
		3.3		0.770	6143.9	946.7	0.847	0.388	0.494	2.87	87.53	76.61	52.02	8207.0	14410.1	8.54	7101.9
		6.5		0.770	6125.0	943.8	0.844	0.485	0.619	4.25	90.07	79.29	57.49	13813.4	25062.1	9.63	13578.7
		9.8		0.770	6126.0	943.9	0.845	0.546	0.696	4.82	91.60	82.29	62.94	17881.7	33320.6	11.25	19980.2
		13.1		0.770	6131.0	944.7	0.845	0.577	0.738	4.81	92.43	85.33	68.81	20360.2	38995.0	13.33	26897.0
	7.96	0		0.691	7566.7	950.0	0.850	0.208	0.328	-	-	-	-	-	-	-	-
		3.3		0.754	7549.4	947.8	0.848	0.331	0.517	2.87	87.66	76.68	52.36	8368.1	14693.7	8.57	7290.1
		6.5		0.754	7528.8	945.2	0.846	0.415	0.649	4.25	90.18	79.26	57.25	14409.2	26043.4	9.61	14062.8
		9.8		0.754	7528.7	945.2	0.846	0.467	0.731	4.82	91.65	81.83	61.75	18642.2	34703.6	10.92	20220.6
		13.1		0.754	7534.1	945.9	0.846	0.492	0.774	4.81	92.50	84.84	67.60	21094.5	40607.6	12.90	27012.3
	9.73	0		0.699	9281.0	953.4	0.853	0.178	0.345	-	-	-	-	-	-	-	-
		3.3		0.822	9307.0	956.1	0.855	0.279	0.537	2.88	87.94	76.97	52.90	8484.0	14940.9	8.67	7482.3
		6.5		0.822	9284.6	953.7	0.853	0.351	0.675	4.25	90.45	79.37	57.54	14881.2	26831.2	9.67	14571.8
		9.8		0.822	9285.0	953.8	0.853	0.395	0.761	4.83	91.89	81.56	61.62	19295.3	35976.3	10.76	20496.6
		13.1		0.822	9290.6	954.4	0.854	0.415	0.805	4.82	92.75	84.37	66.58	21734.8	41949.7	12.58	27220.2
1b	4.72	0	5253.9	0.699	4450.4	942.9	0.844	0.411	0.353	-	-	-	-	-	-	-	-
		3.3		0.890	4427.9	938.1	0.839	0.608	0.516	2.84	87.33	74.68	46.05	7809.3	13837.2	7.96	6371.9
		6.5		0.890	4419.7	936.4	0.838	0.709	0.601	4.20	89.88	81.35	60.81	12117.6	22692.4	10.62	12971.4
		9.8		0.890	4422.1	936.9	0.838	0.758	0.643	4.20	91.05	85.62	69.80	14532.2	27794.9	13.60	19667.6
		13.1		0.890	4425.0	937.5	0.839	0.780	0.663	4.20	91.66	88.58	76.16	15715.8	30520.8	17.04	26353.7
	6.49	0		0.693	6167.1	950.3	0.850	0.335	0.397	-	-	-	-	-	-	-	-
		3.3		0.770	6151.4	947.8	0.848	0.484	0.571	2.87	88.23	73.27	43.41	8305.1	14495.4	7.52	6474.1
		6.5		0.770	6140.7	946.2	0.847	0.569	0.670	4.24	90.88	79.53	56.80	13433.2	24584.9	9.70	13210.6
		9.8		0.770	6142.8	946.5	0.847	0.611	0.719	4.81	92.08	83.89	65.67	16504.6	31453.4	12.26	20074.1
		13.1		0.770	6146.6	947.1	0.847	0.633	0.745	4.78	92.69	87.16	72.86	17990.7	35124.6	15.19	26967.7
	7.96	0		0.691	7566.7	950.0	0.850	0.291	0.422	-	-	-	-	-	-	-	-
		3.3		0.754	7557.0	948.8	0.849	0.415	0.600	2.87	88.40	73.11	44.02	8520.8	14782.3	7.49	6572.2
		6.5		0.754	7545.7	947.4	0.848	0.488	0.705	4.24	90.98	78.64	54.97	14008.9	25456.6	9.37	13262.5
		9.8		0.754	7547.4	947.6	0.848	0.526	0.758	4.82	92.16	83.19	64.09	17273.2	32775.4	11.71	20156.9
		13.1		0.754	7550.6	948.0	0.848	0.544	0.784	4.79	92.78	86.60	71.48	18868.0	36779.7	14.48	27110.6
	9.73	0		0.699	9281.0	953.4	0.853	0.250	0.445	-	-	-	-	-	-	-	-
		3.3		0.822	9315.5	956.9	0.856	0.352	0.627	2.87	88.74	73.59	45.32	8673.1	15076.4	7.60	6804.5
		6.5		0.822	9302.7	955.6	0.855	0.413	0.736	4.25	91.24	78.08	53.53	14444.0	26220.4	9.19	13337.4
		9.8		0.822	9303.7	955.7	0.855	0.444	0.790	4.82	92.40	82.74	62.93	17795.3	33843.2	11.44	20265.2
		13.1		0.822	9306.6	956.0	0.855	0.460	0.818	4.80	93.03	86.25	70.55	19459.0	37975.1	14.16	27264.7

Table 11a – Overview of technical input and output values (median values by household type)

Input					PV & BES output (year 1)					BES output							
										Operation (year 1)		Residual capacity		Energy throughput		80 % of residual capacity	
HH	PV size	BES size	Annual load	Inv_AC/DC	Energy	kWh/kWp	Perfomance	Self-cons.	Self-suff.	Peak	Efficiency	10 years	20 years	10 years	20 years	Time	Throughput
type	kWp	kWh	kWh	ratio	kWh	kWh	ratio	share	share	kW	%	%	%	kWh	kWh	years	kWh
2a	4.72	0	3782.6	0.699	4450.4	942.9	0.844	0.297	0.358	-	-	-	-	-	-	-	-
		3.3		0.890	4433.7	939.3	0.840	0.502	0.589	2.83	87.77	74.44	45.47	7964.6	14099.0	7.82	6424.2
		6.5		0.890	4432.3	939.1	0.840	0.597	0.699	4.17	90.65	81.31	60.20	12361.4	23155.0	10.61	13149.6
		9.8		0.890	4437.1	940.1	0.841	0.631	0.740	4.00	91.72	86.18	70.53	14290.7	27838.8	14.13	19990.4
		13.1		0.890	4439.6	940.6	0.842	0.647	0.760	4.00	92.15	89.26	77.44	15130.5	29766.1	17.86	26671.4
	6.49	0		0.693	6167.1	950.3	0.850	0.242	0.401	-	-	-	-	-	-	-	-
		3.3		0.770	6158.6	949.0	0.849	0.393	0.642	2.85	88.74	73.48	44.10	8316.1	14494.3	7.59	6527.7
		6.5		0.770	6155.8	948.5	0.849	0.463	0.757	4.21	91.63	80.47	58.22	13073.7	24437.9	10.23	13371.4
		9.8		0.770	6161.2	949.3	0.849	0.490	0.799	4.51	92.67	85.57	69.06	15115.8	29370.9	13.51	20325.2
		13.1		0.770	6163.0	949.6	0.850	0.502	0.821	4.53	93.09	88.80	76.30	16034.2	31554.5	17.17	27171.4
	7.96	0		0.691	7566.7	950.0	0.850	0.208	0.424	-	-	-	-	-	-	-	-
		3.3		0.754	7565.5	949.9	0.850	0.334	0.669	2.85	88.92	73.41	44.85	8453.3	14687.1	7.56	6622.2
		6.5		0.754	7562.3	949.5	0.850	0.393	0.786	4.21	91.71	80.02	57.17	13376.8	24893.4	10.01	13415.6
		9.8		0.754	7567.2	950.1	0.850	0.413	0.830	4.58	92.72	85.30	68.37	15423.4	30026.5	13.27	20396.8
		13.1		0.754	7568.5	950.2	0.850	0.424	0.852	4.64	93.15	88.62	75.85	16332.7	32197.5	16.85	27290.9
	9.73	0		0.699	9281.0	953.4	0.853	0.178	0.443	-	-	-	-	-	-	-	-
		3.3		0.822	9324.8	957.9	0.857	0.281	0.691	2.86	89.27	73.88	46.09	8579.1	14918.1	7.68	6810.2
		6.5		0.822	9320.5	957.4	0.857	0.329	0.813	4.22	91.98	79.76	56.64	13612.9	25342.2	9.85	13480.9
		9.8		0.822	9325.4	957.9	0.857	0.347	0.857	4.57	92.97	85.20	68.07	15631.2	30454.9	13.18	20493.0
		13.1		0.822	9326.8	958.1	0.857	0.356	0.879	4.61	93.40	88.54	75.70	16502.7	32568.5	16.79	27429.8
2b	4.72	0	3676.2	0.699	4450.4	942.9	0.844	0.230	0.287	-	-	-	-	-	-	-	-
		3.3		0.890	4428.0	938.1	0.839	0.431	0.515	2.85	87.20	77.14	53.09	7864.6	13857.9	8.71	7011.4
		6.5		0.890	4418.6	936.2	0.838	0.550	0.656	4.18	90.00	80.46	59.63	12846.3	23538.4	10.26	13187.4
		9.8		0.890	4421.4	936.8	0.838	0.609	0.725	4.20	91.23	84.49	67.16	15766.8	30159.8	12.66	19870.6
		13.1		0.890	4425.5	937.6	0.839	0.636	0.755	4.20	91.90	87.63	73.90	17247.1	33614.3	15.64	26710.2
	6.49	0		0.693	6167.1	950.3	0.850	0.187	0.319	-	-	-	-	-	-	-	-
		3.3		0.770	6151.4	947.8	0.848	0.336	0.560	2.87	88.07	77.04	53.22	8262.1	14502.3	8.69	7304.0
		6.5		0.770	6140.6	946.2	0.847	0.433	0.714	4.22	90.97	79.95	58.59	13894.1	25369.0	9.96	13786.6
		9.8		0.770	6143.7	946.7	0.847	0.475	0.788	4.79	92.15	83.54	64.88	17022.0	32472.4	11.98	20211.9
		13.1		0.770	6147.8	947.3	0.848	0.496	0.821	4.78	92.87	86.86	72.07	18550.3	36159.4	14.75	27202.9
	7.96	0		0.691	7566.7	950.0	0.850	0.161	0.336	-	-	-	-	-	-	-	-
		3.3		0.754	7557.4	948.8	0.849	0.285	0.583	2.87	88.20	77.11	53.39	8375.6	14771.9	8.71	7481.7
		6.5		0.754	7545.5	947.3	0.848	0.366	0.742	4.22	91.06	79.98	58.59	14362.7	26285.7	9.98	14217.3
		9.8		0.754	7549.2	947.8	0.848	0.401	0.818	4.79	92.24	83.11	64.29	17483.3	33435.7	11.69	20356.1
		13.1		0.754	7553.3	948.3	0.848	0.418	0.851	4.78	92.94	86.53	71.20	19104.1	37259.6	14.38	27308.0
	9.73	0		0.699	9281.0	953.4	0.853	0.138	0.351	-	-	-	-	-	-	-	-
		3.3		0.822	9315.3	956.9	0.856	0.239	0.602	2.87	88.44	77.30	53.74	8465.3	14972.1	8.79	7638.0
		6.5		0.822	9302.9	955.6	0.855	0.306	0.768	4.23	91.32	80.12	58.87	14729.3	26946.6	10.07	14642.6
		9.8		0.822	9306.7	956.0	0.855	0.336	0.845	4.80	92.51	82.94	63.99	17939.5	34276.6	11.63	20715.0
		13.1		0.822	9311.2	956.5	0.856	0.350	0.879	4.79	93.19	86.30	70.62	19498.8	38166.7	14.18	27433.2

Table 11b – Overview of technical input and output values (median values by household type)

	Input				Monetary output (year 1)		Financial output metrics			System ranking		
HH	PV size	BES size	PV+BES cost	Op. Costs (year 1)	Savings	FiT income	SPB	IRR	NPV	SPB	IRR	NPV
type	kWp	kWh	€	€	€	€	years	%	€	rank	rank	rank
1a	4.72	0	6926	147.2	361.1	311.3	10.7	5.25	1863.3	4	4	13
		3.3	10816		603.4	222.5	13.3	2.62	539.2	18	19	19
		6.5	12298		751.4	168.6	13.3	2.75	752.6	17	17	17
		9.8	13588		836.6	137.8	13.5	2.66	744.7	19	18	18
		13.1	15029		883.2	122.7	14.2	2.12	146.0	20	20	20
	6.49	0	8906	164.9	411.0	463.1	10.4	5.47	2548.1	3	3	9
		3.3	12796		663.4	370.7	12.5	3.35	1390.7	14	15	16
		6.5	14278		827.8	311.3	12.4	3.50	1765.3	13	13	14
		9.8	15568		933.0	274.4	12.5	3.46	1894.1	15	14	12
		13.1	17009		985.4	256.1	13.1	3.06	1515.1	16	16	15
	7.96	0	10021	179.7	437.6	591.8	10.0	5.93	3258.3	2	2	5
		3.3	13911		696.1	498.3	11.9	3.94	2185.0	10	11	11
		6.5	15393		869.9	434.7	11.8	4.09	2659.6	8	9	8
		9.8	16683		978.1	395.5	11.9	4.05	2878.6	11	10	7
		13.1	18124		1034.2	377.4	12.4	3.66	2534.3	12	12	10
	9.73	0	11388	197.4	461.0	752.7	9.8	6.26	4001.2	1	1	1
		3.3	15278		722.5	663.1	11.3	4.42	3012.3	6	7	6
		6.5	16760		908.0	594.8	11.3	4.58	3590.7	5	5	3
		9.8	18050		1022.3	554.8	11.4	4.56	3881.9	7	6	2
		13.1	19491		1075.0	536.5	11.8	4.17	3578.3	9	8	4
1b	4.72	0	6926	147.2	510.1	258.6	9.1	7.54	3425.7	4	3	13
		3.3	10816		749.5	171.4	11.7	4.30	2112.7	16	16	18
		6.5	12298		873.2	127.1	12.0	4.09	2207.8	17	17	17
		9.8	13588		934.4	105.6	12.5	3.65	1929.4	19	19	19
		13.1	15029		961.7	96.0	13.4	2.87	1106.0	20	20	20
	6.49	0	8906	164.9	575.6	404.8	9.1	7.51	4327.9	3	4	9
		3.3	12796		829.8	313.1	11.1	4.91	3165.3	11	12	15
		6.5	14278		972.7	261.1	11.2	4.79	3441.5	13	13	12
		9.8	15568		1046.4	235.6	11.6	4.49	3372.4	14	14	14
		13.1	17009		1083.6	222.9	12.3	3.84	2706.6	18	18	16
	7.96	0	10021	179.7	613.8	529.4	8.8	7.87	5179.2	2	2	4
		3.3	13911		874.0	435.7	10.6	5.45	4097.4	7	8	10
		6.5	15393		1024.9	381.4	10.7	5.35	4469.7	9	9	8
		9.8	16683		1104.8	353.3	11.0	5.08	4495.9	10	10	7
		13.1	18124		1144.8	339.5	11.6	4.47	3901.5	15	15	11
	9.73	0	11388	197.4	647.5	686.6	8.6	8.07	6063.8	1	1	1
		3.3	15278		913.3	595.7	10.2	5.89	5077.8	5	5	5
		6.5	16760		1070.7	538.8	10.3	5.80	5512.5	6	6	3
		9.8	18050		1151.1	510.1	10.6	5.55	5600.7	8	7	2
		13.1	19491		1193.2	495.8	11.2	4.96	5027.6	12	11	6

Table 12a – Economic input, output values (median values by household type) and ranking of the financial performance of systems in the reference case

Legend: optimal systems within each household type are highlighted in green-scale according to their observed frequency (≥5, ≥25, ≥50, ≥75 and ≥ 95% of simulations correspond, respectively, to 5 levels of darkness); optimal system conditional on PV size in blue-scale.

Input					Monetary output (year 1)		Financial output metrics			System ranking		
HH type	PV size kWp	BES size kWh	PV+BES cost €	Op. Costs (year 1) €	Savings €	FiT income €	SPB years	IRR %	NPV €	SPB rank	IRR rank	NPV rank
2a	4.72	0	6926	147.2	368.5	308.7	10.6	5.37	1939.7	4	4	11
		3.3	10816		620.3	217.6	13.1	2.83	718.6	15	17	17
		6.5	12298		737.5	176.5	13.2	2.87	883.8	16	16	16
		9.8	13588		780.7	161.6	13.9	2.41	457.3	18	18	19
		13.1	15029		801.2	154.5	14.9	1.61	-473.1	20	20	20
	6.49	0	8906	164.9	415.1	461.6	10.4	5.53	2598.5	3	3	6
		3.3	12796		674.7	369.0	12.4	3.44	1486.5	10	12	13
		6.5	14278		794.3	325.8	12.5	3.46	1731.5	12	11	12
		9.8	15568		841.5	310.0	13.0	3.06	1379.3	14	14	14
		13.1	17009		861.7	302.9	13.9	2.35	489.3	19	19	18
	7.96	0	10021	179.7	439.1	591.3	10.0	5.94	3271.9	2	2	3
		3.3	13911		703.6	497.2	11.8	3.98	2236.4	7	8	8
		6.5	15393		827.1	453.0	11.9	3.96	2511.0	9	9	7
		9.8	16683		871.3	438.0	12.4	3.58	2203.5	11	10	10
		13.1	18124		894.4	430.1	13.3	2.88	1314.2	17	15	15
	9.73	0	11388	197.4	460.7	752.8	9.8	6.24	3989.0	1	1	1
		3.3	15278		729.7	662.1	11.3	4.44	3033.7	5	5	5
		6.5	16760		854.0	617.3	11.5	4.41	3361.8	6	6	2
		9.8	18050		901.0	600.8	11.9	4.03	3064.1	8	7	4
		13.1	19491		925.2	592.6	12.7	3.37	2215.6	13	13	9
2b	4.72	0	6926	147.2	284.8	338.3	11.8	3.96	1076.7	4	4	11
		3.3	10816		530.7	249.0	14.4	1.74	-219.0	19	19	19
		6.5	12298		675.5	196.4	14.1	2.00	3.0	16	17	17
		9.8	13588		750.5	170.8	14.4	1.94	-70.0	18	18	18
		13.1	15029		784.0	159.0	15.2	1.37	-770.4	20	20	20
	6.49	0	8906	164.9	320.8	495.0	11.5	4.26	1588.2	3	3	9
		3.3	12796		576.3	402.7	13.5	2.43	432.0	15	15	15
		6.5	14278		739.5	343.4	13.2	2.74	844.7	12	12	14
		9.8	15568		813.6	318.3	13.4	2.68	861.3	13	14	13
		13.1	17009		848.4	306.0	14.1	2.15	210.3	17	16	16
	7.96	0	10021	179.7	340.4	626.3	10.9	4.76	2199.1	2	2	4
		3.3	13911		598.6	533.1	12.8	3.02	1109.7	10	11	10
		6.5	15393		769.7	471.7	12.5	3.33	1654.7	8	8	8
		9.8	16683		842.9	446.6	12.8	3.23	1678.2	9	9	7
		13.1	18124		879.7	433.2	13.4	2.70	1036.2	14	13	12
	9.73	0	11388	197.4	356.8	789.6	10.6	5.14	2844.7	1	1	1
		3.3	15278		620.3	699.6	12.1	3.54	1847.8	6	7	6
		6.5	16760		793.7	636.5	11.9	3.84	2488.5	5	5	3
		9.8	18050		870.3	609.6	12.2	3.71	2535.9	7	6	2
		13.1	19491		908.2	596.6	12.8	3.19	1911.1	11	10	5

Table 12b – Economic input, output values (median values by household type) and ranking of the financial performance of systems in the reference case

Legend: optimal systems within each household type are highlighted in green-scale according to their observed frequency (≥5, ≥25, ≥50, ≥75 and ≥ 95% of simulations correspond, respectively, to 5 levels of darkness); optimal system conditional on PV size in blue-scale.

Input			Inflation = 1%								Inflation = 2%							
			Income tax rate = 23.97%				Income tax rate = 42%				Income tax rate = 23.97%				Income tax rate = 42%			
			IRR	NPV			IRR	NPV			IRR	NPV			IRR	NPV		
HH	PV size	BES size	%	r = 0%	r = 1%	r = 2%	%	r = 0%	r = 1%	r = 2%	%	r = 0%	r = 1%	r = 2%	%	r = 0%	r = 1%	r = 2%
type	kWp	kWh		€	€	€		€	€	€		€	€	€		€	€	€
1a	4.72	0	5.54	3912.0	2961.0	2139.8	5.79	3987.4	3046.8	2234.2	4.97	3392.3	2505.4	1738.7	5.25	3508.9	2626.5	1863.3
		3.3	2.85	2962.9	1781.3	760.5	2.97	3036.4	1866.1	854.6	2.48	2522.9	1394.8	419.5	2.62	2631.6	1509.6	539.2
		6.5	2.91	3479.6	2114.8	936.1	3.01	3546.6	2194.4	1025.9	2.63	3101.6	1782.0	641.6	2.75	3199.8	1888.0	752.6
		9.8	2.79	3728.9	2210.6	902.7	2.87	3784.5	2281.4	985.1	2.56	3395.5	1916.7	641.8	2.66	3479.9	2011.7	744.7
		13.1	2.23	3290.8	1680.2	291.8	2.29	3340.0	1744.5	368.7	2.04	2983.7	1408.1	49.5	2.12	3060.2	1495.5	146.0
	6.49	0	5.96	5432.3	4174.6	3088.3	6.07	5369.1	4141.3	3080.3	5.33	4677.4	3513.3	2506.6	5.47	4681.2	3537.5	2548.1
		3.3	3.73	4655.9	3152.7	1853.8	3.77	4620.0	3144.7	1868.9	3.27	3981.1	2560.9	1332.4	3.35	4004.4	2603.5	1390.7
		6.5	3.79	5365.5	3653.4	2174.9	3.84	5341.2	3656.3	2200.6	3.42	4753.1	3115.4	1700.1	3.50	4782.8	3164.4	1765.3
		9.8	3.69	5746.1	3875.4	2260.7	3.75	5732.0	3887.9	2295.4	3.39	5183.7	3380.4	1823.2	3.46	5219.3	3435.3	1894.1
		13.1	3.27	5575.6	3581.0	1857.8	3.31	5563.7	3593.9	1892.9	3.00	5048.2	3115.5	1445.6	3.06	5083.3	3168.8	1515.1
	7.96	0	6.60	6826.7	5344.7	4064.5	6.57	6584.7	5153.7	3917.0	5.92	5881.3	4516.9	3336.7	5.93	5732.2	4405.9	3258.3
		3.3	4.45	6139.0	4401.6	2900.4	4.42	5943.3	4253.1	2791.9	3.94	5271.7	3641.5	2231.4	3.94	5160.0	3565.1	2185.0
		6.5	4.49	6943.0	4990.7	3304.4	4.48	6780.1	4872.2	3223.4	4.07	6140.5	4286.6	2683.8	4.09	6054.6	4234.0	2659.6
		9.8	4.39	7441.7	5312.9	3475.4	4.39	7296.7	5210.6	3409.2	4.03	6688.8	4651.4	2891.6	4.05	6615.8	4610.9	2878.6
		13.1	3.97	7283.5	5034.8	3095.7	3.97	7151.8	4945.7	3041.6	3.64	6565.3	4403.7	2538.2	3.66	6502.5	4373.1	2534.3
	9.73	0	7.09	8390.1	6649.1	5144.8	6.94	7915.4	6252.7	4815.4	6.37	7209.4	5615.7	4236.6	6.26	6860.6	5327.9	4001.2
		3.3	5.09	7800.6	5794.1	4060.1	4.96	7382.7	5449.3	3777.8	4.52	6694.8	4825.4	3207.9	4.42	6393.1	4580.8	3012.3
		6.5	5.13	8718.0	6484.8	4555.5	5.03	8348.5	6184.1	4313.5	4.64	7677.9	5572.8	3752.6	4.58	7416.3	5365.0	3590.7
		9.8	5.02	9297.2	6877.3	4788.2	4.95	8956.2	6602.4	4571.2	4.60	8307.9	6009.1	4023.0	4.56	8068.9	5821.9	3881.9
		13.1	4.60	9194.3	6645.0	4445.6	4.53	8874.1	6388.7	4243.8	4.21	8241.9	5808.4	3707.5	4.17	8019.4	5636.3	3578.3
1b	4.72	0	7.68	5821.7	4664.2	3665.6	7.95	5887.5	4742.0	3753.4	7.24	5363.9	4262.0	3310.7	7.54	5467.0	4371.7	3425.7
		3.3	4.44	4888.1	3499.1	2300.3	4.57	4949.0	3573.2	2385.3	4.15	4509.2	3165.4	2004.9	4.30	4601.7	3266.3	2112.7
		6.5	4.18	5285.8	3716.6	2363.2	4.29	5337.0	3782.6	2441.3	3.97	4962.6	3431.0	2109.4	4.09	5042.0	3520.9	2207.8
		9.8	3.73	5196.7	3514.5	2064.3	3.82	5241.6	3575.1	2138.0	3.55	4909.7	3259.7	1837.1	3.65	4980.7	3342.4	1929.4
		13.1	2.95	4470.7	2730.8	1231.7	3.01	4511.9	2788.5	1302.8	2.79	4200.7	2490.6	1016.9	2.87	4267.2	2569.5	1106.0
	6.49	0	7.83	7589.9	6098.4	4811.3	7.99	7538.6	6076.3	4814.0	7.32	6902.8	5495.6	4280.1	7.51	6912.8	5526.1	4327.9
		3.3	5.17	6810.6	5074.2	3575.0	5.25	6783.4	5074.5	3598.4	4.80	6201.9	4539.2	3102.7	4.91	6228.4	4585.3	3165.3
		6.5	5.00	7408.1	5472.0	3801.3	5.08	7391.1	5481.9	3833.8	4.70	6858.6	4988.0	3373.2	4.79	6890.5	5039.7	3441.5
		9.8	4.66	7570.2	5491.2	3698.4	4.73	7559.0	5506.6	3736.1	4.40	7062.8	5043.4	3301.5	4.49	7097.2	5097.7	3372.4
		13.1	4.00	7035.3	4876.3	3015.5	4.06	7026.0	4893.6	3055.0	3.77	6550.5	4447.9	2635.2	3.84	6585.1	4502.6	2706.6
	7.96	0	8.34	9140.6	7408.6	5913.8	8.39	8928.4	7244.9	5791.3	7.78	8265.4	6641.2	5238.1	7.87	8138.9	6551.3	5179.2
		3.3	5.83	8441.5	6457.5	4744.2	5.85	8273.7	6334.4	4659.1	5.41	7642.1	5755.8	4125.6	5.45	7551.3	5698.8	4097.4
		6.5	5.66	9140.2	6946.5	5053.9	5.69	8999.1	6848.2	4991.1	5.30	8401.4	6296.8	4480.5	5.35	8331.2	6259.2	4469.7
		9.8	5.35	9413.4	7064.0	5037.0	5.38	9289.0	6980.1	4987.7	5.03	8719.0	6452.8	4496.6	5.08	8660.8	6425.5	4495.9
		13.1	4.72	8962.0	6522.2	4418.9	4.74	8845.3	6445.7	4376.3	4.43	8293.2	5932.8	3897.1	4.47	8240.2	5910.9	3901.5
	9.73	0	8.71	10863.5	8855.2	7121.5	8.65	10435.2	8500.9	6830.5	8.10	9755.8	7884.6	6267.4	8.07	9444.6	7631.3	6063.8
		3.3	6.42	10273.8	8003.1	6042.1	6.34	9901.3	7699.7	5797.5	5.93	9238.3	7095.0	5242.3	5.89	8973.4	6884.3	5077.8
		6.5	6.24	11031.1	8547.1	6403.9	6.19	10700.3	8281.3	6193.6	5.82	10055.8	7690.5	5648.3	5.80	9825.2	7511.1	5512.5
		9.8	5.93	11374.3	8725.6	6439.8	5.89	11069.7	8483.5	6250.6	5.56	10445.7	7909.2	5719.5	5.55	10236.1	7748.8	5600.7
		13.1	5.32	10948.3	8204.9	5839.2	5.28	10656.1	7974.1	5660.6	4.97	10045.7	7411.2	5138.1	4.96	9845.6	7259.5	5027.6

Table 13a – Median NPV values and optimal systems by household type, under alternative financial and fiscal parameters

Legend: Optimal systems in green-scale and optimal systems conditional on PV, respectively, in green- and blue-scale according to their observed frequency. (≥5, ≥25, ≥50, ≥75 and ≥ 95% of simulations correspond, respectively, to 5 levels of darkness).

Input			Inflation = 1%								Inflation = 2%							
			Income tax rate = 23.97%				Income tax rate = 42%				Income tax rate = 23.97%				Income tax rate = 42%			
			IRR	NPV			IRR	NPV			IRR	NPV			IRR	NPV		
HH type	PV size kWp	BES size kWh	%	r = 0% €	r = 1% €	r = 2% €	%	r = 0% €	r = 1% €	r = 2% €	%	r = 0% €	r = 1% €	r = 2% €	%	r = 0% €	r = 1% €	r = 2% €
2a	4.72	0	5.65	4006.7	3044.8	2214.2	5.90	4081.5	3130.1	2308.2	5.08	3490.4	2592.1	1815.7	5.37	3606.2	2712.5	1939.7
		3.3	3.04	3178.9	1977.1	938.6	3.17	3249.8	2059.5	1030.6	2.68	2743.5	1594.6	601.2	2.83	2849.5	1706.9	718.6
		6.5	3.03	3670.9	2274.2	1069.0	3.12	3731.4	2348.0	1153.7	2.75	3296.0	1943.8	776.4	2.87	3387.9	2044.2	883.8
		9.8	2.54	3417.8	1919.8	628.5	2.62	3471.0	1987.3	707.8	2.31	3070.9	1613.2	356.3	2.41	3154.0	1706.2	457.3
		13.1	1.75	2551.5	1014.6	-310.0	1.81	2603.1	1080.9	-231.7	1.54	2217.8	719.4	-572.4	1.61	2298.5	810.3	-473.1
	6.49	0	6.01	5495.8	4229.9	3136.6	6.12	5433.0	4197.0	3128.9	5.39	4743.6	3570.9	2556.9	5.53	4747.5	3595.3	2598.5
		3.3	3.81	4781.4	3263.6	1951.5	3.86	4742.0	3251.9	1963.6	3.36	4107.3	2672.5	1430.7	3.44	4127.2	2711.6	1486.5
		6.5	3.75	5354.9	3633.6	2147.8	3.80	5324.1	3630.5	2168.1	3.39	4740.9	3094.0	1671.5	3.46	4764.6	3137.5	1731.5
		9.8	3.32	5176.3	3347.1	1769.4	3.37	5149.9	3348.2	1793.6	3.00	4595.0	2835.5	1317.1	3.06	4620.6	2880.9	1379.3
		13.1	2.60	4367.7	2489.2	869.8	2.63	4341.6	2490.7	894.5	2.30	3799.7	1989.0	427.3	2.35	3824.6	2034.1	489.3
	7.96	0	6.60	6845.1	5359.9	4077.0	6.58	6603.4	5169.2	3929.8	5.93	5900.8	4533.1	3350.1	5.94	5751.9	4422.4	3271.9
		3.3	4.49	6196.1	4456.8	2953.4	4.46	5999.8	4307.7	2843.6	3.98	5328.2	3696.2	2284.0	3.98	5215.9	3619.2	2236.4
		6.5	4.38	6805.6	4854.5	3170.0	4.36	6630.2	4724.4	3078.4	3.95	5997.1	4144.9	2544.5	3.96	5899.8	4081.9	2511.0
		9.8	3.96	6679.3	4613.4	2831.3	3.94	6515.3	4493.6	2749.1	3.57	5904.2	3932.4	2230.4	3.58	5815.1	3877.0	2203.5
		13.1	3.24	5865.6	3752.7	1930.6	3.22	5705.2	3636.2	1851.3	2.88	5103.1	3082.5	1339.0	2.88	5016.4	3029.3	1314.2
	9.73	0	7.08	8376.4	6636.2	5132.7	6.92	7901.6	6239.7	4803.2	6.35	7195.6	5602.8	4224.5	6.24	6846.7	5314.9	3989.0
		3.3	5.11	7823.6	5819.3	4084.4	4.98	7405.4	5472.7	3800.3	4.54	6716.2	4849.4	3231.1	4.44	6414.2	4603.0	3033.7
		6.5	4.98	8478.5	6259.6	4343.3	4.87	8095.2	5946.1	4089.6	4.49	7430.5	5340.7	3534.3	4.41	7156.6	5121.5	3361.8
		9.8	4.55	8363.0	6027.4	4011.9	4.45	7995.4	5728.0	3770.8	4.10	7347.4	5136.1	3226.5	4.03	7085.6	4928.0	3064.1
		13.1	3.87	7595.3	5207.7	3148.0	3.77	7235.0	4915.0	2913.0	3.44	6593.7	4328.6	2373.0	3.37	6337.8	4125.8	2215.6
2b	4.72	0	4.36	2952.8	2104.4	1371.3	4.59	3032.8	2194.0	1468.9	3.69	2402.5	1622.5	947.4	3.96	2525.8	1749.1	1076.7
		3.3	2.03	2041.4	958.7	22.0	2.14	2119.1	1046.3	118.2	1.60	1570.1	545.1	-342.5	1.74	1685.1	664.5	-219.0
		6.5	2.20	2577.2	1303.6	205.8	2.30	2646.5	1385.0	297.5	1.89	2167.1	943.0	-112.8	2.00	2269.8	1052.7	3.0
		9.8	2.10	2742.3	1328.6	108.0	2.17	2804.4	1403.9	193.4	1.84	2377.6	1007.0	-177.6	1.94	2470.3	1107.7	-70.0
		13.1	1.51	2181.7	686.5	-602.5	1.57	2236.6	755.5	-521.7	1.29	1837.5	382.3	-872.5	1.37	1922.0	476.5	-770.4
	6.49	0	4.87	4271.0	3137.9	2158.7	4.94	4201.4	3098.6	2145.0	4.15	3480.0	2445.6	1550.2	4.26	3480.3	2466.3	1588.2
		3.3	2.89	3501.5	2119.9	926.5	2.92	3457.6	2104.5	935.0	2.37	2790.0	1496.3	377.6	2.43	2808.5	1534.3	432.0
		6.5	3.08	4256.1	2663.2	1284.7	3.12	4226.7	2659.2	1304.0	2.67	3609.8	2095.4	783.8	2.74	3637.1	2140.0	844.7
		9.8	2.96	4526.2	2775.5	1264.2	3.00	4501.1	2777.1	1288.7	2.62	3925.2	2247.4	797.8	2.68	3953.3	2294.5	861.3
		13.1	2.42	4022.9	2183.5	597.4	2.44	3997.0	2185.0	621.9	2.11	3445.5	1675.2	147.9	2.15	3471.1	1720.8	210.3
	7.96	0	5.56	5552.4	4207.2	3044.6	5.48	5294.0	4001.3	2883.3	4.79	4568.7	3346.5	2288.3	4.76	4407.2	3224.0	2199.1
		3.3	3.62	4849.2	3248.3	1865.2	3.55	4634.3	3082.7	1742.4	3.05	3942.3	2454.0	1166.9	3.02	3815.5	2364.4	1109.7
		6.5	3.80	5733.5	3912.3	2337.9	3.77	5555.0	3779.4	2242.9	3.34	4893.9	3176.2	1690.1	3.33	4796.1	3112.6	1654.7
		9.8	3.63	6019.7	4035.1	2321.9	3.60	5852.5	3912.4	2237.1	3.23	5224.5	3337.0	1706.4	3.23	5133.9	3280.1	1678.2
		13.1	3.08	5517.4	3446.2	1659.5	3.05	5356.3	3329.0	1579.6	2.70	4745.5	2768.0	1061.1	2.70	4659.0	2714.8	1036.2
	9.73	0	6.12	7004.2	5412.4	4036.3	5.90	6503.7	4992.5	3685.5	5.31	5782.7	4343.9	3097.9	5.14	5412.9	4036.9	2844.7
		3.3	4.30	6401.2	4545.1	2941.7	4.13	5957.3	4178.0	2639.7	3.67	5254.7	3541.4	2059.6	3.54	4931.5	3278.8	1847.8
		6.5	4.46	7395.2	5307.4	3500.3	4.33	7002.3	4983.9	3236.6	3.93	6316.3	4362.1	2668.4	3.84	6035.8	4135.5	2488.5
		9.8	4.26	7700.3	5443.4	3498.0	4.15	7325.6	5138.9	3255.3	3.79	6665.6	4535.9	2698.6	3.71	6398.7	4324.1	2535.9
		13.1	3.71	7213.7	4872.2	2851.7	3.60	6851.5	4577.7	2614.9	3.27	6202.5	3984.8	2069.6	3.19	5945.4	3780.9	1911.1
share of load profiles for which BES-coupling is optimal			**0.0%**	**78.2%**	**38.1%**	**0.2%**	**0.0%**	**85.5%**	**47.6%**	**3.9%**	**0.0%**	**87.8%**	**50.7%**	**5.4%**	**0.0%**	**92.9%**	**56.4%**	**9.9%**

Table 13b – Median NPV values and optimal systems by household type, under alternative financial and fiscal parameters

Legend: Optimal systems in green-scale and optimal systems conditional on PV, respectively, in green- and blue-scale according to their observed frequency. (≥5, ≥25, ≥50, ≥75 and ≥ 95% of simulations correspond, respectively, to 5 levels of darkness).

Input			Inflation = 1%												Inflation = 2%											
			Income tax rate = 23.97%						Income tax rate = 42%						Income tax rate = 23.97%						Income tax rate = 42%					
			i = 1%			i = 3%			i = 1%			i = 3%			i = 1%			i = 3%			i = 1%			i = 3%		
			NPV						NPV						NPV						NPV					
HH	PV size	BES size	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%
type	kWp	kWh	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€
1a	4.72	0	3986	3499	3335	2873	2791	2353	4117	3746	3474	3122	2936	2603	3763	3301	3156	2719	2649	2233	3933	3582	3328	2995	2821	2506
		3.3	3079	2317	2365	1644	1777	1093	3239	2659	2533	1984	1950	1431	3102	2381	2411	1728	1841	1192	3294	2745	2605	2086	2036	1543
		6.5	3611	2745	2778	1959	2092	1314	3777	3118	2952	2329	2271	1681	3760	2940	2938	2160	2257	1520	3953	3329	3134	2543	2454	1894
		9.8	3874	2918	2944	2038	2180	1321	4039	3311	3119	2430	2361	1709	4123	3217	3194	2335	2427	1612	4312	3622	3388	2735	2625	2006
		13.1	3452	2393	2491	1489	1704	754	3622	2816	2671	1909	1891	1169	3789	2786	2820	1870	2024	1123	3980	3218	3018	2296	2225	1541
	6.49	0	5528	4901	4655	4061	3925	3362	5536	5058	4690	4239	3982	3555	5154	4560	4350	3787	3677	3143	5226	4775	4440	4012	3780	3375
		3.3	4793	3892	3843	2990	3056	2248	4860	4174	3933	3284	3165	2551	4666	3813	3763	2955	3014	2246	4788	4139	3899	3285	3161	2579
		6.5	5518	4513	4424	3472	3517	2614	5609	4843	4536	3812	3647	2961	5518	4565	4457	3555	3576	2720	5657	4932	4610	3925	3741	3091
		9.8	5913	4817	4716	3678	3724	2740	6024	5189	4847	4058	3872	3125	6017	4979	4843	3859	3869	2935	6172	5382	5012	4265	4048	3340
		13.1	5758	4560	4499	3365	3456	2381	5883	4970	4642	3780	3616	2799	5959	4825	4714	3639	3680	2660	6125	5262	4891	4075	3868	3094
	7.96	0	6934	6228	5885	5217	5006	4373	6773	6235	5771	5263	4932	4451	6418	5750	5459	4825	4653	4052	6346	5837	5421	4940	4645	4189
		3.3	6288	5308	5152	4225	4208	3328	6204	5458	5110	4405	4201	3533	6017	5089	4949	4070	4059	3225	6012	5306	4974	4306	4110	3477
		6.5	7108	6024	5821	4795	4751	3778	7069	6243	5821	5040	4782	4043	6965	5938	5733	4760	4706	3783	6997	6216	5793	5054	4789	4089
		9.8	7620	6446	6213	5101	5043	3989	7609	6715	6239	5393	5099	4298	7582	6470	6219	5165	5084	4083	7637	6791	6300	5500	5187	4428
		13.1	7477	6201	6013	4805	4799	3653	7492	6520	6063	5144	4877	4007	7536	6327	6107	4961	4919	3832	7612	6693	6209	5339	5042	4217
	9.73	0	8512	7710	7264	6504	6215	5495	8129	7518	6954	6377	5969	5422	7819	7060	6686	5966	5733	5050	7558	6980	6481	5935	5577	5059
		3.3	7964	6888	6619	5600	5496	4530	7669	6850	6391	5616	5325	4592	7513	6494	6261	5295	5215	4299	7328	6553	6128	5395	5126	4431
		6.5	8897	7717	7389	6272	6131	5071	8663	7764	7217	6367	6011	5206	8575	7458	7148	6089	5955	4949	8442	7592	7062	6258	5909	5147
		9.8	9490	8220	7851	6648	6485	5344	9295	8327	7715	6800	6399	5533	9275	8071	7705	6564	6395	5312	9174	8258	7650	6783	6379	5558
		13.1	9403	8031	7697	6397	6277	5045	9239	8194	7590	6602	6218	5282	9286	7986	7640	6408	6268	5099	9213	8224	7610	6675	6275	5388
1b	4.72	0	5896	5408	5038	4576	4317	3879	6017	5646	5169	4818	4455	4122	5735	5273	4913	4475	4221	3805	5891	5540	5073	4741	4384	4069
		3.3	5004	4242	4083	3362	3317	2633	5152	4572	4240	3691	3481	2961	5088	4367	4182	3498	3426	2777	5264	4715	4362	3842	3609	3117
		6.5	5417	4552	4380	3560	3519	2742	5568	4908	4540	3917	3687	3096	5621	4801	4587	3809	3725	2987	5795	5171	4766	4176	3909	3350
		9.8	5342	4385	4248	3342	3341	2482	5496	4768	4412	3724	3514	2862	5637	4731	4537	3678	3622	2807	5812	5123	4719	4066	3809	3191
		13.1	4631	3573	3542	2540	2644	1694	4794	3988	3715	2953	2825	2103	5006	4003	3903	2953	2992	2090	5187	4425	4092	3370	3185	2501
	6.49	0	7685	7058	6579	5985	5648	5085	7706	7228	6625	6174	5716	5288	7380	6786	6333	5770	5450	4916	7458	7006	6428	6000	5560	5155
		3.3	6948	6047	5765	4912	4777	3969	7023	6337	5863	5214	4894	4280	6887	6034	5742	4933	4784	4016	7012	6363	5881	5267	4936	4353
		6.5	7561	6556	6242	5291	5143	4241	7659	6893	6362	5638	5280	4594	7623	6671	6330	5427	5249	4393	7765	7040	6486	5800	5417	4767
		9.8	7737	6641	6331	5293	5161	4177	7851	7016	6466	5677	5313	4565	7896	6858	6506	5522	5347	4413	8050	7260	6674	5927	5526	4818
		13.1	7217	6020	5794	4660	4614	3539	7345	6433	5942	5079	4778	3961	7461	6327	6046	4971	4870	3850	7626	6763	6225	5409	5060	4286
	7.96	0	9248	8542	7949	7281	6856	6222	9116	8579	7862	7354	6806	6325	8802	8134	7583	6950	6555	5954	8752	8244	7566	7085	6566	6110
		3.3	8590	7611	7208	6281	6052	5172	8534	7788	7192	6486	6068	5400	8387	7459	7063	6184	5953	5119	8403	7697	7108	6440	6022	5389
		6.5	9305	8221	7777	6751	6501	5528	9288	8462	7797	7016	6550	5811	9226	8199	7743	6770	6503	5580	9273	8493	7818	7079	6599	5899
		9.8	9592	8417	7964	6852	6605	5550	9602	8707	8008	7162	6677	5876	9612	8500	8021	6966	6689	5688	9682	8836	8115	7314	6804	6045
		13.1	9156	7880	7500	6292	6122	4977	9185	8213	7563	6644	6212	5342	9264	8055	7636	6490	6278	5191	9350	8430	7746	6876	6409	5584
	9.73	0	10985	10184	9470	8711	8192	7472	10649	10038	9203	8625	7984	7437	10366	9606	8955	8235	7764	7081	10142	9564	8785	8238	7639	7121
		3.3	10437	9362	8828	7809	7478	6512	10188	9368	8641	7867	7345	6611	10056	9037	8531	7565	7250	6333	9909	9134	8432	7698	7192	6496
		6.5	11210	10030	9452	8334	7979	6920	11014	10116	9314	8464	7891	7086	10953	9835	9266	8206	7850	6845	10851	10001	9209	8404	7831	7069
		9.8	11567	10297	9700	8496	8136	6995	11408	10440	9596	8681	8079	7212	11412	10208	9606	8465	8091	7008	11341	10425	9577	8710	8098	7277
		13.1	11157	9785	9257	7957	7671	6439	11021	9976	9175	8187	7635	6699	11090	9789	9243	8011	7699	6530	11039	10050	9233	8298	7724	6837

Table 14a – Median NPV values and optimal systems of debt-financed adoptions by household type, under alternative discount, inflation, tax and interest rates

Legend: optimal systems within each household type are highlighted in green-scale according to their observed frequency (≥5, ≥25, ≥50, ≥75 and ≥ 95% of simulations correspond, respectively, to 5 levels of darkness); optimal system conditional on PV size in blue-scale.

Input			Inflation = 1%												Inflation = 2%											
			Income tax rate = 23.97%						Income tax rate = 42%						Income tax rate = 23.97%						Income tax rate = 42%					
			i = 1%			i = 3%			i = 1%			i = 3%			i = 1%			i = 3%			i = 1%			i = 3%		
			NPV						NPV						NPV						NPV					
HH	PV size	BES size	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%	r = 0%	r = 1%	r = 2%
type	kWp	kWh	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€	€
2a	4.72	0	4081	3593	3419	2957	2865	2427	4211	3840	3557	3206	3010	2677	3861	3399	3243	2805	2726	2310	4030	3679	3414	3081	2898	2583
		3.3	3295	2533	2561	1840	1955	1271	3453	2873	2726	2178	2126	1607	3323	2601	2611	1927	2022	1373	3512	2963	2802	2283	2215	1723
		6.5	3802	2937	2938	2118	2225	1447	3962	3302	3106	2482	2399	1809	3955	3134	3100	2322	2392	1655	4141	3517	3290	2699	2585	2026
		9.8	3563	2607	2653	1747	1905	1047	3726	2997	2825	2136	2084	1432	3799	2892	2890	2031	2142	1327	3986	3297	3082	2430	2337	1719
		13.1	2712	1654	1826	824	1102	152	2885	2079	2007	1245	1290	569	3023	2020	2132	1182	1402	501	3219	2456	2332	1611	1606	922
	6.49	0	5591	4964	4711	4117	3974	3411	5600	5122	4746	4294	4031	3603	5220	4626	4408	3845	3727	3193	5293	4841	4497	4070	3831	3425
		3.3	4918	4017	3954	3101	3154	2345	4982	4296	4040	3392	3260	2645	4793	3939	3875	3066	3112	2344	4911	4261	4008	3393	3257	2675
		6.5	5508	4502	4404	3452	3490	2587	5592	4826	4510	3786	3614	2929	5505	4553	4436	3533	3547	2691	5639	4914	4584	3898	3707	3057
		9.8	5343	4247	4187	3149	3232	2248	5442	4607	4308	3518	3370	2623	5429	4390	4298	3314	3363	2429	5574	4784	4458	3710	3533	2825
		13.1	4550	3352	3407	2273	2468	1393	4660	3748	3539	2677	2617	1801	4711	3576	3587	2512	2662	1642	4866	4003	3757	2940	2842	2069
	7.96	0	6952	6247	5901	5233	5019	4385	6791	6254	5787	5279	4945	4464	6437	5769	5475	4841	4667	4066	6365	5857	5437	4956	4658	4202
		3.3	6345	5366	5207	4280	4261	3381	6261	5515	5165	4460	4252	3585	6073	5145	5003	4124	4112	3277	6067	5362	5028	4360	4161	3528
		6.5	6970	5887	5685	4659	4617	3644	6919	6093	5673	4892	4637	3898	6821	5795	5591	4618	4567	3644	6842	6061	5641	4902	4641	3940
		9.8	6858	5683	5514	4402	4399	3345	6828	5933	5522	4676	4439	3638	6798	5685	5500	4446	4422	3422	6836	5990	5567	4766	4512	3753
		13.1	6059	4783	4731	3523	3634	2488	6045	5073	4753	3834	3687	2817	6074	4865	4786	3640	3720	2633	6126	5206	4865	3995	3822	2997
	9.73	0	8498	7696	7251	6492	6203	5483	8115	7504	6941	6364	5957	5410	7805	7046	6673	5953	5721	5038	7544	6966	6468	5922	5565	5046
		3.3	7987	6911	6644	5625	5520	4554	7692	6873	6414	5640	5348	4614	7534	6515	6285	5319	5238	4322	7350	6574	6150	5417	5147	4452
		6.5	8658	7478	7164	6047	5918	4859	8409	7511	6979	6129	5787	4982	8328	7210	6916	5856	5736	4731	8183	7332	6819	6014	5681	4918
		9.8	8556	7285	7001	5798	5708	4567	8334	7366	6840	5925	5599	4732	8314	7110	6832	5692	5598	4515	8191	7275	6756	5889	5561	4740
		13.1	7804	6432	6259	4960	4980	3748	7600	6555	6116	5128	4887	3951	7637	6337	6160	4928	4934	3765	7531	6542	6100	5164	4912	4025
2b	4.72	0	3027	2539	2478	2016	2022	1584	3163	2791	2621	2270	2170	1838	2773	2311	2273	1836	1857	1442	2950	2598	2451	2118	2035	1720
		3.3	2157	1396	1542	821	1038	355	2322	1742	1713	1164	1214	694	2149	1428	1562	878	1079	430	2347	1799	1760	1241	1277	785
		6.5	2709	1843	1967	1147	1362	584	2877	2218	2143	1519	1543	953	2826	2005	2099	1321	1503	765	3023	2399	2298	1708	1704	1145
		9.8	2888	1931	2062	1156	1385	526	3059	2330	2241	1552	1570	917	3105	2199	2284	1425	1608	793	3302	2613	2484	1832	1810	1192
		13.1	2342	1284	1497	496	810	-140	2518	1712	1682	920	1000	279	2642	1640	1795	845	1102	201	2842	2080	1999	1277	1309	625
	6.49	0	4366	3739	3619	3025	2996	2433	4368	3891	3647	3196	3047	2619	3957	3363	3283	2720	2720	2186	4026	3574	3368	2941	2820	2415
		3.3	3638	2737	2810	1957	2129	1320	3697	3011	2893	2244	2231	1617	3475	2622	2699	1890	2059	1291	3592	2943	2830	2216	2202	1620
		6.5	4409	3404	3434	2482	2627	1724	4494	3729	3539	2815	2750	2065	4374	3422	3437	2535	2660	1803	4511	3787	3586	2901	2820	2170
		9.8	4693	3597	3616	2578	2727	1743	4793	3958	3736	2947	2865	2118	4759	3721	3710	2726	2843	1909	4906	4117	3871	3124	3015	2307
		13.1	4205	3007	3101	1968	2196	1121	4316	3404	3233	2371	2345	1528	4356	3222	3274	2199	2383	1362	4512	3649	3443	2627	2563	1790
	7.96	0	5660	4954	4748	4080	3986	3353	5482	4944	4619	4111	3898	3417	5105	4437	4288	3655	3605	3004	5021	4512	4239	3758	3586	3130
		3.3	4998	4019	3999	3072	3173	2293	4895	4149	3940	3235	3151	2483	4687	3759	3761	2882	2995	2160	4667	3961	3773	3105	3034	2401
		6.5	5898	4814	4743	3717	3785	2812	5844	5018	4728	3947	3802	3063	5718	4692	4623	3650	3713	2789	5738	4957	4672	3933	3784	3084
		9.8	6198	5024	4935	3823	3890	2835	6165	5271	4941	4095	3927	3126	6118	5005	4905	3850	3898	2898	6155	5309	4970	4169	3986	3227
		13.1	5711	4435	4424	3216	3363	2217	5696	4724	4446	3527	3415	2545	5716	4507	4471	3326	3442	2355	5768	4849	4550	3680	3544	2719
	9.73	0	7126	6324	6027	5268	5107	4387	6717	6106	5694	5117	4839	4292	6393	5633	5414	4694	4594	3911	6110	5532	5190	4644	4420	3902
		3.3	6565	5489	5370	4351	4377	3412	6244	5424	5119	4345	4187	3454	6073	5054	4977	4012	4067	3151	5867	5092	4826	4093	3962	3266
		6.5	7575	6395	6212	5095	5075	4016	7317	6418	6017	5167	4934	4129	7214	6096	5937	4878	4870	3865	7062	6212	5833	5028	4807	4045
		9.8	7893	6623	6417	5214	5194	4053	7664	6696	6251	5336	5083	4217	7632	6428	6232	5091	5070	3987	7504	6588	6152	5286	5033	4212
		13.1	7422	6050	5924	4625	4683	3451	7217	6172	5779	4791	4589	3653	7246	5946	5817	4585	4631	3461	7139	6150	5755	4819	4608	3721
share of load profiles for which BES-coupling is optimal			82.5%	55.6%	64.2%	31.3%	43.3%	7.6%	92.8%	71.9%	74.3%	52.4%	55.1%	29.4%	93.8%	82.6%	90.6%	63.3%	72.5%	42.3%	93.8%	93.3%	93.3%	77.9%	80.7%	60.5%

Table 14b – Median NPV values and optimal systems of debt-financed adoptions by household type, under alternative discount, inflation, tax and interest rates

Legend: optimal systems within each household type are highlighted in green-scale according to their observed frequency (≥5, ≥25, ≥50, ≥75 and ≥ 95% of simulations correspond, respectively, to 5 levels of darkness); optimal system conditional on PV size in blue-scale.

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