Master-Thesis:

The Value of Decentralized Solar PV for Consumers, Suppliers and Society

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Abstract

New dynamics are taking place in the European power sector. The strong cost decrease of distributed generation and battery technologies drive the decentralization of the European energy system but also, and more importantly, transform the way value is created. Evidently, players in the retail market today need to operate closer to the residential and commercial end-consumer.

Against this background and in order to shed some new light on the current debate around prosumers, this report analyses different policy scenarios. It models – for three European markets – several combinations of solar and battery storage solutions. For each combination and market various options are considered on how self-consumed and injected excess solar electricity is remunerated. This approach allows to better estimate the concrete economic benefits for end-consumers and, from there, to explore how energy suppliers – incumbents or new entrants – will be able to capture business opportunities by creating new value propositions for their customers. These new offers will in turn make distributed generation smarter and more system relevant. In this decentralized world, solar will become a new factor of performance and differentiation amongst electricity suppliers. Some may decide to continue operating in a business as usual mode. Others will seize this opportunity, create new business models, and run ahead of the pack.

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DISCLAIMER

 (Note that commas instead of periods are used to indicate decimal points.)

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ABBREVIATIONS

B2B	Business-to-Business
B2C	Business-to-Consumer
CAPEX	Capital Expenditure
DPBP	Dynamic Payback Period
el.	electricity
FCR	Frequency Containment Reserve
FFR	Fast Frequency Response
FRCI	Fast Reactive Current Injection
FRR	Frequency Restoration Reserve
HTW	Hochschule für Technik und Wirtschaft
IRR	Internal Rate of Return
kWh	Kilowatt-hour
kWp	Kilowatt-peak
LCOE	Levelized Cost Of Electricity
NPV	Net Present Value
OPEX	Operational Expenditure
PV	Photovoltaic
RM	Ramping Margin
RR	Replacement Reserve

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS:

- **The analysis conducted for this report shows that solar – alone or in combination with battery storage - can bring economic benefits to a growing share of European consumers**. However, with potentially changing policy designs and more prosumers, there is need to develop new business models to ensure that self-generation and consumption are made smarter and benefit the whole system.
- **At a time when maintaining or gaining consumer satisfaction is more than ever challenging,** offering new "decentralized energy solutions" to prosumers becomes a factor of performance and differentiation amongst electricity suppliers. Only innovative players will be able to maintain the needed trust and thereby grow their business in a "connected-everything" environment.
- **New strategies will bring system benefits.** New business models will not only make distributed generation more accessible but they will also unlock flexibility potential at consumer level by offering services to grid operators.

This overall transition requires a dynamic and adequate regulatory environment. The following regulatory adjustments – at both European and national levels – are needed to develop a prosumer-friendly policy:

- **Adapt market rules to accelerate the development of enablers and make self-generation and consumption smarter**. Future policy design reforms should further facilitate market integration of residential and commercial solar PV(-battery) systems. As shown by the economic analysis, an abrupt implementation of the "constraint scenario," where, for example, high taxes and grid charges are applied to self-consumed electricity, has a disincentivizing effect on the progressive smartening (e.g. via battery storage linked to declining technology costs) of decentralized generation. Prosumers are therefore preferably not subject to any (or only slight) charges on the electricity they self-generate and consume.
- **Implement policy designs that enable the "energy transition".** A "prosumer-friendly" approach should be reflected in the way future policies are designed. Particular attention should be given to the quantified and real impact of prosumers on the grid.
- **Reflect upon a combination of the "market integration" and "constraint" scenario**, as a suitable variant in a transition towards a complete integration of prosumers. Frameworks at national level can strive a balance between maintaining a minimum level of remuneration for the electricity injected into the grid and exposing the self-consumed electricity in a staggered approach to grid charges in a way that reflects the technology cost digression of solar and battery storage.

1. Introduction: Decentralized solar PV systems creating benefits for prosumers, suppliers and society

The European energy sector is going through a major transformation process. One of the main trends of recent years is a shift from consumers to prosumers as a new active "operational" entity, for example via residential solar PV generation. This trend is currently reinforced by declining costs of battery storage – driving a combination of solar PV and battery systems that allow for increased self-consumption. This shift leads to a continuous physical decentralization of the energy system and results in a progressive change in the value-creation of the energy economy: from commodities (electricity) to services (IEA-RETD, 2014). These transition processes are reflected in the most recent strategies of leading energy suppliers such as E.ON: "Empowering customers. Shaping markets" (E.ON, 2015) and Engie (previously called GDF Suez) in Europe: "[…] adapting to the profound changes in the energy sector and focusing more than ever on its customers (GDF Suez, 2015). With regard to these facts, it is very likely that the relationship with the final customer – turning into a prosumer with new needs – will be an important factor of differentiated performance among suppliers and new entrants. In this context solar PV, possibly combined with battery storage, can be expected to have a key role to play as it provides value to the prosumer (e.g. economic benefits, green image etc.) (Ebers & Wüstenhagen, 2015). As such, PV systems could become an important asset for energy suppliers by i) creating new revenue streams, ii) reaching out to new customers and iii) maintaining trust with existing ones. In addition to the creation of customer and supplier value, IEA-RETD (2014) identified system and social benefits such as flexibility, ancillary services and job creation that can be provided by decentralized solar PV. The concrete value creation for all stakeholders however, depends on market conditions that are and will continue to be based on (future) policy designs derived from European policies. Consequently, future political decisions on topics such as remuneration of excess electricity and or additional charges for self-consumed electricity are likely to considerably impact the described value potentials related to solar PV. With regard to the mentioned value streams for i) consumers, ii) electricity suppliers and iii) the society/energy system, SolarPower Europe identified that literature to date generally focuses only on one specific value cluster rather than providing a holistic perspective that allows balanced conclusions. This leads to drastic and questionable statements such as "The Utility Death Spiral Scenario Is Realistic" or "The centralized electric utilities are doing everything in their power to impede the growth of decentralized energy generation […]" (Edison International, PG&E Corporation, Pinnacle West Capital Corporation, Southern Company, 2015).

Accordingly, it is important to provide a scientifically based assessment that focuses on a combination of the above mentioned value streams in order to objectively analyse whether described developments may ultimately lead to imbalances or rather to win-win-win situations for individuals, electricity suppliers and society / the energy system as a whole.

Therefore, this research addresses the following questions:

- How high are economic benefits of decentralized solar PV(-battery) system combinations with respect to various policy scenarios on self-consumption and remuneration of excess electricity in European markets and can such benefits be expected to trigger investments by consumers?
- How and how much value can electricity suppliers create around decentralized solar PV?
- What social/system benefits can decentralized solar PV(-battery) systems provide?

2. Objectives, work streams and methods of this study

The overall aim of this research is to identify the created "value" of transitioning towards more decentralized energy systems based on solar PV(-battery) systems in several European member states with regard to three stakeholder value-clusters; i) customer value, ii) electricity supplier value and iii) social/system value. For each of the respective clusters the term "value" is defined differently, consequently the methods used in this report are adjusted accordingly. This is indicated in Figure 1 which provides a condensed overview of the objectives and related work streams of this study.

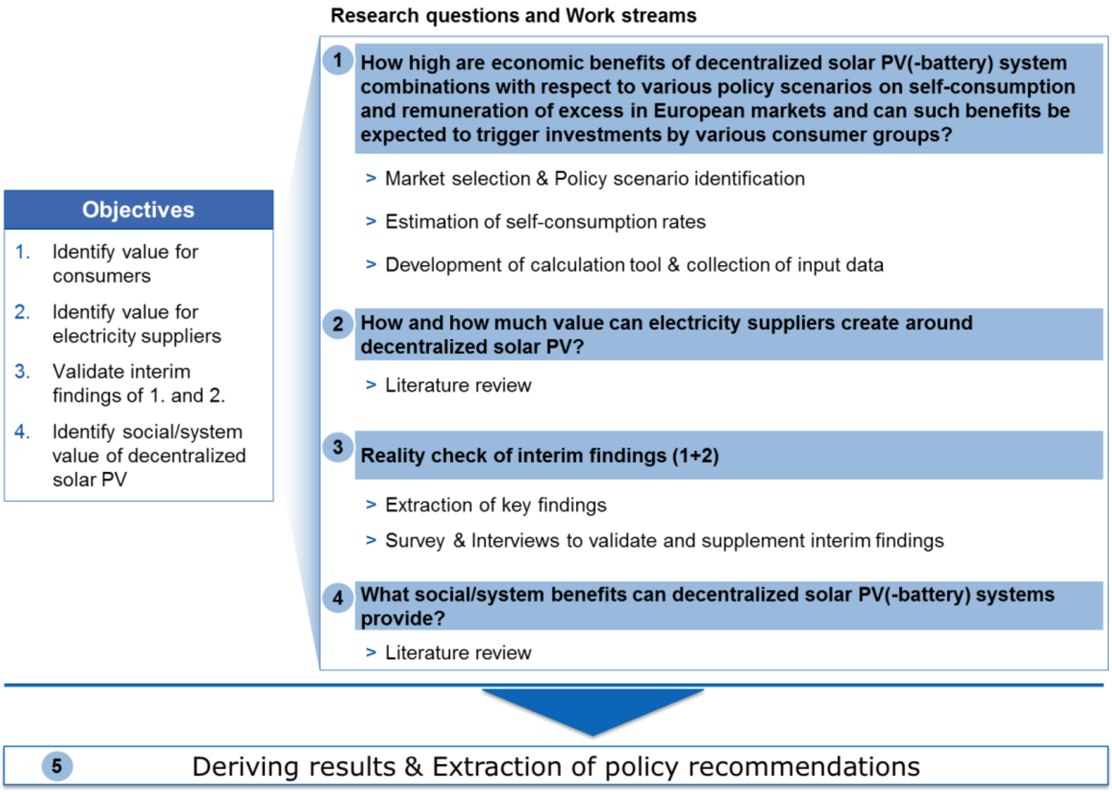


Figure 1 : Objectives and work streams of the study[1]

The following sub-sections start by specifying the term "value" for each of the clusters and define the boundaries as well as scope of the respective objectives. They are structured according to the different work-streams and provide detailed information on definitions, policy scenarios, selected markets, methods, limitations in addition to data and literature utilized. The aforementioned specifications build the basis for the final outcomes described in Section 3 followed by a discussion of the results in Section 4. Finally, Section 5 provides conclusions and policy recommendations.

[1] As a result of time constraints within this research, it was not possible to test the hypotheses in Step 4 via a survey and or interview since these had to be done simultaneously with the Fourth Work Stream.

2.1 Specifications on Cluster I: "Value identification for consumers"

Several sources identified that economic benefits are one of the major reasons for consumers to install solar PV systems (Ebers & Wüstenhagen, 2015 and chilternsolar.co.uk, 2015). Consequently, this part of the study focuses exclusively on analysing how different levels of i) self-consumption (including various PV system -battery combinations)[2], ii) remuneration of excess electricity and iii) an additional charge for self-consumption will impact the economic benefits of **two consumer segments**

- **i)** **residential agents** – defined as individual households with an assumed solar PV size of 4 kWp and
- **ii)** **commercial agents** considered as industry/public buildings with an assumed solar PV size of 100 kWp.

With respect to these segments, it is important to acknowledge that individuals within both groups are likely to have diverse "preferences and selection criteria" when making their final investment decision[3]. As such, the three "most common approaches to project selection" are assessed. These are the i) Net Present Value (NPV), ii) Internal Rate of Return (IRR) and iii) Dynamic Payback Period (DPBP) (investopedia.com, 2015). These indicators are defined as follows:

The NPV is the difference of the present value of cash inflows and cash outflows resulting from an investment and the amount of this investment. The "present value" is calculated by applying a discount rate on future cash flows (taking into account the fact that "consumers have a time preference that can be expressed by a discount rate (…), they are indifferent about receiving an amount of x now or" a higher amount of y in n years from now). If the result is positive the project can be considered to be profitable, meaning that a project will generate a net benefit (the generated cash inflows of a project exceed the cash outflows of investment and operating costs). On the other hand, if the result is negative, the project leads to a net loss (the cash outflows of

[2] "The self-consumption rate is the amount of electricity actually consumed onsite as a percentage of the total electricity produced. The degree of energy self-sufficiency measures how much of the total electricity needed by the consumer can be obtained from their own renewable energy system." (European Commission, 2015)

[3] Some residential consumers for example may only be interested in the timeframe after which their investment will be amortized in order to be sure that they will recover their initial investment costs. (Note that many residential consumers are also non-experts and can easily understand the concept of payback times.) Whereas a commercial entity or a consumer seeking for investment opportunities with limited risks, e.g. in order to maximise return on existing capital when compared to current rates for saving accounts etc. may be much more interested in the final return (NPV) and or the return in relation to the initial investment costs (IRR).

investment and operating costs exceed the generated cash inflows). Due to the fact that NPV calculations derive an absolute figure that does not necessarily provide a good "indication of the project's profitability in relation to the initial investment" complementary calculations that derive the IRR and DPBP are conducted in order to assess this profitability (Blok, 2007, businessdictionary.com, 2015 and investopedia.com, 2015). **The IRR is defined** as the "discount rate […] where the net present value of the project is zero", while **the DPBP provides** an indication on how many years it will take to recover the costs of a project (taking into account the present value of cash in and out flows by considering a discount rate) (Blok, 2007).

In light of the above, the main target of the assessment within the "costumer value cluster" is to provide a first estimation on aforesaid investment decision criteria for several European markets. This is different to existing literature today, which mostly focuses on calculations of

- **i)** "best or worst cases" based on specific input parameters related to a single site or
- **ii)** the Levelized Cost of Electricity (LCOE) by taking into account cost declines of solar PV(-battery) technologies and comparing the respective LCOE outcomes with the expected electricity price escalations of a market in order to indicate when "grid parity"[4] will be reached.

These types of assessments (specific best and or worst cases) however are either not representative for a market (i) or focus on developments mainly interesting for expert groups within the energy economy (ii). Consequently, they do not directly provide an insight for consumers and/or policy makers on how the typical economic benefit indicators (NPV, IRR and DPBP) – being considered when taking final investment decisions – are impacted when policy designs alter the remuneration of excess electricity and/or the exposure of self-consumed electricity to additional charges.

[4] Grid parity in this case refers to electricity generated from solar PV with a LCOE below or equal to the price paid when purchasing electricity from the grid

2.1.1 Selection of markets and overview of assessed policy scenarios

This study therefore assesses three different policy design scenarios and their effect on the economics of residential PV systems combined with battery storage in three European markets, namely the UK, Germany and Portugal. Additionally, with respect to the limitations discussed in Section 2.1.2, it was possible to assess the economics of one commercial PV(-battery) system combination for the German market. Aforementioned markets were selected based on two indicators: i) variety in irradiation and ii) recently updated support schemes (information available to SolarPower Europe as of June 2015). An overview of the policy scenarios and PV-battery system combinations with their estimated self-consumption rates that are equally applied for all assessed countries is provided in Figure 2 in the following section.

2.1.2 Method for and limitations of applied self-consumption rates and battery sizes

Considering the illustrated parameters of self-consumption rates and battery sizes for residential agents (Figure 2) it must be noted that these were derived based on an external tool from the Hochschule für Technik und Wirtschaft (HTW) Berlin. They are therefore subject to several limitations as aforementioned tool derives its outcomes based on average household load and PV generation profiles in Germany (that already include assumptions on irradiation, degradation etc.). As the generation of the assumed PV-system size in this report is separately calculated (see Section 2.1.3), the applied inputs on self-consumption and battery sizes must be seen as a first approximation and may deviate slightly for the German market. Since load profiles of residential consumers within the remaining markets may diverge, above-mentioned facts are likely to cause additional deviations for the assessments on Portugal and the UK. Furthermore, the HTW tool assumes that (due to the degradation of the battery capacity over time) 90% of the initial capacity can be utilized over the battery lifetime. This assumption however might be rather optimistic when considering the assessment period (25 years) of this research, meaning that the actual (net) battery size to guarantee the applied self-consumption rates for the entire assessment period may be slightly higher.[5]

[5] Note that the International Battery & Energy storage Alliance (IBESA) assumes a battery lifetime of 20 years (Hoehner, 2015), while battery producers such as Saft reports lifetimes of 20 years and more (Saft, 2011) similarly as Hoppecke premium batteries (SEA, 2016). Beegy, a company offering PV and battery combinations also assumes a 20 years' lifetime for its battery combined with a PV system (beegy.com, 2016)

With regard to commercial agents, it must be mentioned that load profiles can be significantly different and depend on the specific type of sector (the load profile of a chemical production plant is likely to be very different to the one of a supermarket for example). As a consequence, it was not possible to use the publicly available HTW Berlin Tool to estimate self-consumption rates and battery sizes. Due to these facts, a contact to one of the researchers responsible for the tool provided by the HTW as well as to a commercial agent was established. The latter provided a load profile, while the HTW was willing to support this research and provided simulations that derived self-consumption rates corresponding to the provided load profile (considering no storage as well as various battery sizes)[6]. Due to the fact that load profiles of commercial agents are subject to high confidentiality it was only possible to provide an estimation of defined economic indicators with regard to the German market.

Assessed countries			
Residential systems considered for each country	**One 4 kWp (residential) PV system with** • **No Battery ≈ 27% self-consumption** • **Small Battery (2,3 kWh net capacity) ≈ 46% self-consumption** • **Large Battery (8,3 kWh net capacity) ≈ 66% self-consumption**		
Commercial system considered for Germany	**One 100 kWp (commercial) PV system with** • **No Battery ≈ 69% self-consumption** • **Small Battery (33,5 kWh net capacity) ≈ 78% self-consumption** • **Large Battery (100 kWh net capacity) ≈ 87% self-consumption**		
Scenarios for each country	**Reference Sc.**	**Market Integration Sc.**	**Constraint Sc.**
Remuneration of excess electricity	According to (renewable) policy design June 2015	According to wholesale prices 2014	According to (renewable) policy design June 2015
Electricity cost saving potential	100%	100%	Depending on Battery size: • No Battery → 70 % • Small battery → 80% • Large battery → 90%

Figure 2 : Overview of assessed policy scenarios, PV-Battery systems and self-consumption rates

Note that the constraint scenario anticipates two developments within the energy economy. The first one relates to the fact that decreasing electricity demand (and therewith costs) due to self-consumption will ultimately lead to a lower compensation of grid services as these are currently remunerated via the electricity price. As consumers (even with high self-sufficiency rates) however are very likely to continue to depend on grid services (due to the variability of PV production) they are therefore not allowed to save the full electricity price since it partly reflects aforesaid remuneration needs. Secondly, this scenario takes into account that increasing solar

[6] Note that that initial match of electricity demand (load profile) and PV generation (for the commercial agent assessed in this report) is very high and is therefore already related to a very high self-consumption. Utilizing (increasing) battery capacities therefore have only a very limited effect when aiming to achieve very high self-consumption rates which is caused by the fact that – according to the load profile – the electricity stored during the day is not used during the night.

PV penetration creates peak injections that may in turn lead to grid issues. The peak injections however can be reduced by using battery storage. In respect to both developments, this scenario reduces the electricity cost saving potential for all system types, while anticipating that systems combined with a battery are allowed to save more since their impact on the grid can be expected to be lower.

2.1.3 Method for the estimation of economic benefits

As illustrated in Figure 3 the assessment of the economic benefits considered in this report is based on an economic model (Excel-tool) that was developed in the course of this research.

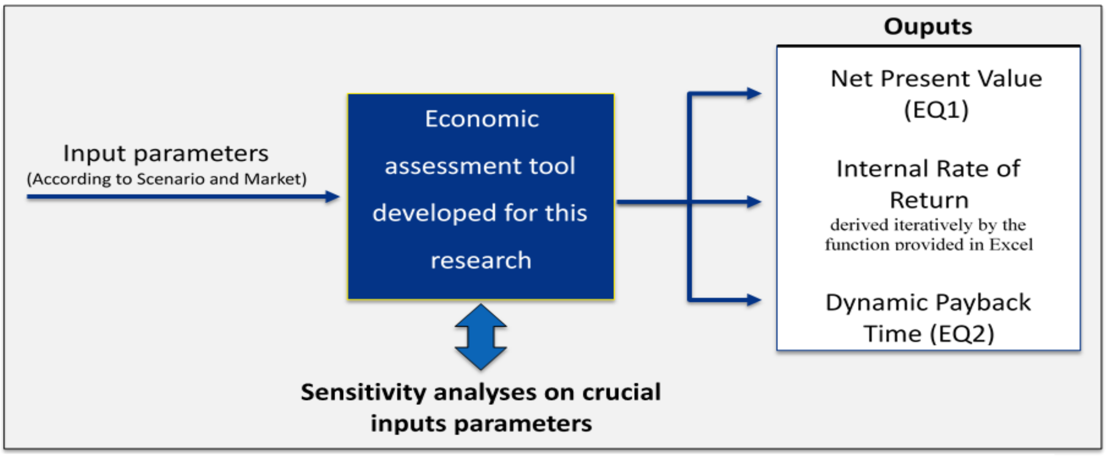


Figure 3 : Structure of the economic assessement

The following provides an overview of the applied formulas and assumptions used for the economic evaluation.

The NPV is calculated as shown in Equation 1:

Equation 1: Net Present Value

$$\boldsymbol{NPV\ of\ decentral\ PV\ system} = -Investment + \sum_{i=1}^{n} \frac{Benefits - Costs}{(1+r)^i}$$

- To limit complexity and ensure comparability between cases and or markets, investment costs are considered to be fully taken upfront and financing options such as access to investment grants or cheap borrowed capital are excluded.
- The cost parameter covers typical operational costs for solar PV and, where appropriate, battery systems according to estimated system sizes and corresponding investment costs.
- Benefits are based on scenarios (see Figure 2) considering the following input variables:
    - Self-consumption rates
    - Remuneration of excess electricity

The *cost* parameter (referring to operational costs of the PV and battery system) is determined by using Equation 2 and is equally applied for all countries. It is based on the notion that annual cost can be defined as a percentage of investment cost.

Equation 2

$$Costs_{in\ year\ i} = PV\ System\ investment\ costs\ (€) * Operational\ costs\ PV\ system\ (\%)$$
$$+ Batterysystem\ investment\ costs\ (€)$$
$$*\ Operational\ costs\ Battery\ system\ (\%)$$

For determining the *benefit* parameter (defined as i) electricity costs saved and ii) the remuneration of excess electricity) however it is necessary to take into account the individual policy designs of the selected markets. Consequently, the approaches of calculating this parameter vary as shown in Equation 3 to 5.

Equation 3: Determination of benefits for the German market

$$Benefits_{in\ year\ i} = Electricity\ costs\ saved_{year\ i} + Earnings\ of\ Excess\ Electricity\ _{year\ i}$$

$$Electricity\ costs\ saved_{year\ i}{}^{7}$$
$$= \Big(Annual\ el.demand\ (kWh) - installed\ capacity\ (kWp)$$
$$* Yield\ \left(\frac{kWh}{kWp}\right) * (1 - degradation\ rate)^{year\ i} * self\ consumption\ (\%)$$
$$* electricity\ price_{year\ i}\left(\frac{€}{kWh}\right)\Big) * electricity\ cost\ saving\ potential\ (\%)$$

$$Earnings\ Excess\ Electricity_{year\ i}$$
$$= (Installed\ capacity\ (kWp) * Yield\ \left(\frac{kWh}{kWp}\right)$$
$$* (1 - degradation\ rate)^{year\ i} - electricity\ self\ consumed\ (kWh))$$
$$* Remuneration\ of\ Excess\ Electricity\ (\frac{€}{kWh})$$

For Portugal, the formula used for the German market is adapted such that a grid charge, corresponding to the framework valid in July 2015, reduces the electricity costs saved:

[7] Note that for the commercial sector in Germany a reduction of the electricity costs saved has to be taken into account. It is derived based on the policy design valid in June 2015 that defines that 35% of the so called EEG-Umlage (0,624 €/kWh) has to be paid on self-consumed electricity. The Electricity costs saved as derived in EQ 3 are therefore reduced by $Electricity\ self\ consumed_{in\ year\ i}(kWh) * 0{,}0624\ \left(\frac{€}{kWh}\right) * 0{,}35$. For value specifications see Figure 4.

Equation 4 : Determination of benefits in Portugal

$$Benefits_{in\ year\ i} = Electricity\ costs\ saved_{year\ i} - Grid\ Charge_{year\ i} + Earnings\ of\ Excess\ Electricity_{in\ year\ i}$$

$$Grid\ charge^{8}{}_{year\ 1\ to\ 10} = Residential\ electricity\ price\ in\ 2015\ \left(\frac{€}{kWh}\right) * 0{,}21 * 0{,}3 * installed\ capacity\ (kWp) * Yield\ \left(\frac{kWh}{kWp}\right) * (1 - degradation\ rate)^{year\ i} * self\ consumption\ (\%)$$

$$Grid\ charge_{year\ 10\ to\ 25} = Residential\ electricity\ price\ in\ 2015\ \left(\frac{€}{kWh}\right) * 0{,}21 * 0{,}5 * installed\ capacity\ (kWp) * Yield\ \left(\frac{kWh}{kWp}\right) * (1 - degradation\ rate)^{year\ i} * self\ consumption\ (\%)$$

With regard to the policy design of the UK as of June 2015 the formula of the German market is adapted in a way that not only the excess electricity is remunerated but also the generated electricity of the PV system ("Generation tariff"). This is modelled such that the benefits are increased:

Equation 5 : Determination of benefits for the UK[9]

$$Benefits_{in\ year\ i} = Electricity\ costs\ saved_{year\ i} + Earnings\ of\ Generation\ tariff_{in\ year\ i} + Earnings\ of\ Excess\ Electricity_{in\ year\ i}$$

$$Earnings\ of\ Generation\ tariff_{in\ year\ i} = Generation\ tariff\ \left(\frac{€}{kWH}\right) * Installed\ capacity\ (kWp) * Yield\ \left(\frac{kWh}{kWp}\right) * (1 - degradation\ rate)^{year\ i}$$

With respect to the above parameters, Figure 4 provides an overview of the rounded values utilized for the economic calculations within each of the selected markets. Additionally, parameters equally applied for all countries are shown. For additional comments as well as the specific sources for each of these parameters please see Table 21 in Appendix 1.

[8] Note that the grid costs in 2014 had a share of 21% in the residential electricity price and that 30 or 50 % of these must be paid, depending on the installed capacity of renewables in Portugal (SolarPower Europe, 2015). It is therefore assumed that within the first 10 years of this assessment 30% are applicable whereas for the remaining 15 years 50% are applied (see Figure 4 for value specifications).

[9] Note that the market integration scenario assumes that the generation tariff is not valid.

Germany	residential	Commercial
Yield (kWh/kWp)	936	
Retail el. Prices (ct/kWh)	29,8	13,51
Annual el. price escalation (%)	5	5
Remuneration of excess el. Reference & add. Tax Sc. / Market Ingt. Sc. (ct/kWh)	12, 4 / 4	8,6 / 4
Payment of EEG Umlage (ct/kWh self consumed)	-	2,184

Portugal	residential
Yield (kWh/kWp)	1494
Retail el. Prices (ct/kWh)	22
Annual el. price escalation (%)	5,8
Remuneration of excess el. for all Scenarios (ct/kWh)	3,93
Grid charge (€/a) for 10 & 15 years respectively	
No Battery	25 & 40
2,3 kWh net battery	41 & 68
8,3 kWh net battery	49 & 81

United Kingdom	residential
Yield (kWh/kWp)	920
Retail el. Prices (ct/kWh)	19,6
Annual el. price escalation (%)	5,2
Remuneration of excess el.: Reference & add. Tax Sc. / Market Ingt. Sc. (ct/kWh)	6,79 / 5,15
Generation Tariff: Reference & Add. Tax. Sc. (ct/kWh)	18

Equally applied for all countries	Resi-dential	Comm-ercial	Units
Investment for PV systems	1540	1240	€/kW
Investment for Battery systems	1075	589 (33,5 kWh) 473 (100 kWh)	€/kWh net
Discount rate	4	6,5	%
Timeframe for calculations	25		Years
Degration of PV systems	0,2		%
Operational costs PV systems**	1,5		%
Operational costs Battery systems**	1,5		%
Annual el. demand residential	3500	133768	kWh
PV(-battery) system sizes and self-sufficency rates	Specifications provided in Figure 2		

Figure 4[10]: Overview of rounded input parameters used

[10] Note that the table that illustrates values "equally applied for all countries" refers only to the German market when specifying values for the commercial sector as was explained in Section 2.1.2. Values of investment costs exclude VAT as country specific incentives might reduce such payments depending on the specific situation of the consumer (e.g. type of housing, type of PV-battery system combination etc.) and tax law. As detailed analyses on the tax laws in the respective countries exceed the scope of this research (would require a very high level of knowledge on tax-systems and are additionally limited due to language barriers in particular in the case of Portugal) a change of investment costs in respect to the VAT level can be anticipated in the sensitivity analyses: The general VAT level for Germany, UK and Portugal is 19, 20 and 23 percent respectively, the sensitivity analyses assuming a 20% increase of investment costs approximately reflect the full tax payment. For additional comments as well as the specific sources for each input parameter please see Table 25 in Appendix I. Note that the battery costs include battery cells, inverter, charge controller, cabling and installation cost and may seem high in relation to costs reported e.g. by Tesla (around $ 3 000 for 7 kWh), which usually exclude various of the aforementioned cost parameters (Tesla, 2016).

Equation 6 shows the approach to determine the dynamic payback period, and Table 1 provides an example of the approach:

Equation 6: Steps for calculating the dynamic payback period

Step 1:

If the *discounted* Cumulative Cash Flow$_{\text{in year } i}$ < 0, then count as 1 year for amortization

Step 2:

If the *discounted* Cumulative Cash Flow$_{\text{in year } i}$ > 0, then divide the absolute value of the *discounted* Cumulative Cash Flow$_{\text{in year } i-1}$ by the *Discounted* Cash Flow $_{\text{in year } i}$

Table 1: Example of Step 1 and 2 for dynamic payback period calculations

Period / Year	Discounted Cash Flow	Discounted Cumulative Cash Flow	Step 1	Step 2
1 (investment)	- 154 946	- 154 946	Count as **1** year	x
2	91 015	- 63 930	Count as **1** year	x
3	46 268	- 17 663	Count as **1** year	x
4	43 137	25 475	x	$\frac{17\,663}{43\,137} = 0{,}4\ years$
Dynamic Payback Period = 3,4 years				

Since the described analyses are based on uncertain and potentially changing input parameters (Figure 2 and 4), sensitivity analyses for all scenarios were conducted. Their structure is as follows:

- For the reference scenario, a one variable sensitivity analysis assesses the impact upon the NPV and DPBP when the
  - **i)** initially applied discount rate of 4% (for all PV-battery system combinations) is changed,
- while the impact of a change upon the IRR and DPBP is illustrated for the following input variables
  - **ii)** PV system costs
  - **iii)** battery system costs
  - **iv)** electricity price increase
  - **v)** remuneration of excess electricity (only for the market integration scenario)
  - **vi)** electricity cost saving potential (only for the constraint scenario)
- Secondly, a two variable sensitivity analysis (based on the reference scenario) investigates how a change in the remuneration of i) excess electricity as well as ii) the electricity cost saving potential would impact the IRR and DPBP of the various PV system combinations for residential consumers[11]. This acknowledges for the fact that future policies may use a compromise of the two additional scenarios such that the remuneration of excess electricity is reduced while at the same time a charge for self-consumption is set. It should be noted that in the assessment for the UK market the generation tariff is varied instead of the remuneration of excess electricity as the latter is already close to wholesale prices and therefore less likely to be reduced drastically. Where the outcomes of the reference scenario already indicate strong negative results, this analysis is not conducted since it would only focus on how the support would need to be increased such that these systems become more economical. This is however very unlikely and would be contradictory to the current policy trends that focus on reducing support as declining technology costs will result in more economic benefits as is analysed in the one-variable sensitivity analyses.
- Focus upon the DPBP and IRR was laid as early results of the conducted survey within this study indicated that these are the most interesting parameters to assess. (Note that in case DPBPs that exceed the timeframe of this assessment are not illustrated in the respective diagrams.)

[11] As the economic outcomes for commercial consumers are linked to their specific consumption profiles the two variable sensitivity analyses are not conducted since corresponding policy recommendations would only be valid for this particular case. See Section 2.1.4 (limitations of the economic benefit assessment). The same is obviously valid for the one variable sensitivity analyses, however, the purpose of these analyses is to provide an insight on how uncertainty related to the input parameters used would change the specific business case rather than to provide general recommendations on future policy designs.

Table 2 provides an overview of the applied ranges with regard to the assessed input parameters:

Table 2 : Specifications for sensitivity analyses

Input parameter	Variation	Argument
PV system costs	70 to 130% of the initial value	A variation applied in the "PV Investor Guide – New business models for photovoltaics in international markets" uses a range of 20% (Grundner, Jesús Baez Morandi, & Wörlen, 2014). On top of this an additional safety margin of 10% is processed.
Discount rate	0 to 12%	As implicit consumer discount rates may be very high for low income groups and lower for high income groups this wide spectrum is used. The higher range of 12% leads to negative and or very limited economic benefits for all PV-battery combinations and is therefore the last value illustrated in the analysis.
Remuner-ation of excess electricity (€/kWh)	0,0 to 0,08 (commercial, Germany) 0,0 to 0,12 (residential, Germany) 0,0. to 0,12 (Portugal) 0,0 to 0,1 (UK)	The lower range is chosen to cover for potential retrospective measures and or the possibility that in a market integration scenario the remuneration of excess electricity is very limited. The higher range is chosen such that it equals the current support scheme in the respective country with an exception in case of Portugal as its reference scenario already equals the market integration scenario (excess electricity is remunerated according to wholesale prices, see Appendix I). Consequently, a wide range is applied. Similarly, for the case in the UK, the range is slightly extended as the remuneration within the market integration scenario is already close to the reference scenario given the fact that the UK also remunerates the generation of the PV system.
Battery investment costs	30 to 150% of the initial values for the medium and large battery	The lower range is chosen in order to investigate annually expected cost declines of 20 to 30% (Deutsche Bank, 2015) within the next 3-4 years. The higher range is chosen in order to acknowledge for various ranges that can be found in many sources that report on battery costs such as (IRENA, 2015) and (pv magazine, 2015). (Note that initial costs used in this report include battery cells, inverter, charge controller, cabling and installation cost.)
Electricity price increase	0 to 8%	A wide range is chosen as this parameter is attached to great uncertainty. In addition to this range the impacts of an annual potential decrease of electricity prices of around 2% (rounded value) are outlined. Thereby it is taken into account that increasing renewable capacities currently lead to low wholesale prices (sometimes even negative) and that such price developments may be forwarded to consumers in the future, potentially leading to a decrease of (retail) electricity prices.

2.1.4 Limitations of the economic benefit assessment

With reference to the economic evaluation the following limitations must be taken into account:

- Technology costs – Capital Expenditure (CAPEX) as well as Operational Expenditure (OPEX) – (for PV systems, Batteries etc.) refer to values found in literature and may not be equally applicable for the specific markets assessed in this research (different climate zones, labour costs etc.). Moreover, potential subsidies upon the initial investment costs of PV systems and or batteries are excluded in this research.
- Self-consumption rates and battery sizes are subject to the limitations described in Section 2.1.2 and provide a first approximation.
- Due to the described circumstances relating to the commercial consumer assessed in this report, it is not possible to derive general conclusions for the commercial segment since the economic evaluation of this report most likely does not represent "the average" commercial consumer (see Section 2.1.2).
- The electricity price escalations for each of the assessed markets are assumed to be constant (annually increasing/decreasing) and do not consider variations over time.
- The assumed discount rate for the residential sector of 4% may not represent the implicit consumer discount rates for PV(-battery) system combinations as similarly discussed by Blok, 2007.
- Since battery systems may provide the option for new tariffs (e.g. comprehensive time of use navigation and demand response opportunities) the initial benefits of increased self-consumption could be topped based on additional revenue streams (next to the remuneration of excess electricity and the electricity cost saving potential). As such, customers that allow their suppliers to utilize their (battery) capacities for extra grid services may be remunerated accordingly. Although an assessment of such revenue streams is related to many additional parameters such as grid age and or constraints as well as market regulations etc. Fitzgerald & Morris, 2015 provide an estimation on these benefits for the U.S market, where time of use navigation and demand response could provide additional benefits of about 15 and 10 USD per month respectively. It should be noted that the European electricity market is fundamentally different to the U.S market and that these estimations are therefore not considered in this report. Nevertheless, the above facts indicate that the benefits of increased self-consumption may very well be increased by additional revenue streams that would ultimately lead to higher total economic benefits of solar PV systems that are combined with batteries.

2.2 Specifications on Cluster II: "Value identification for electricity suppliers"

This part of the study reflects upon the potential value (qualitatively and quantitatively) that electricity suppliers could gain by offering customer-side solar PV solutions as part of their portfolio. As a result of strong value creation from close-to-customer PV business models leading towards a further decentralization of the energy system, several barriers for their implementation may exist (for instance, when considering that business models today are rather based on a centralized energy system approach). However, they also provide the opportunity to improve electricity-supplier-customer-relationships and create additional value, for example by retaining existing and or winning new customers, increase cross-selling potentials or utilising decentralised generation capacities to realise system benefits etc.

2.2.1 Method outline for Cluster II

In order to qualitatively identify how changed customer relationships could create value for electricity suppliers, a literature review is conducted. As a first step, customer expectations related to decentralised PV business models are identified. Additionally, officially available data upon the willingness and or expected amount of customers that are to install PV systems is used to identify whether the creation of customer-side-PV business models increases in importance. Secondly, based on an extraction of the most important barriers for creating monetary value out of such business models, further literature with focus upon business model innovation is used to identify potential ways to overcome afore identified barriers. Finally, based on literature referring to monetary quantifications such as increasing acquisitions or the value of reduced churn rates (i.e. "The percentage of subscribers to a service that discontinue their subscription to that service in a given time period." (investopedia, 2016)), estimations in respect to economic benefits are derived by considering the market shares of companies and customers interested in PV related business models. Table 3 provides an overview of part of the literature used.

Table 3 : Literature assessed for value identification of Cluster II

Topic	Literature / Sources of Data
Barriers for decentralized PV business model implementation	• German utilities and distributed PV: How to overcome barriers to business model innovation (Richter, 2013)
• **Business model invention** • **Assessment of customer interest in decentralized solar PV business models**	• Bridges to new solar business models: Opportunities to increase and capture the value of distributed solar photovoltaics (Bell, Creyts, Lacy, & Sherwood, 2014) • Accenture: The New Energy Consumer: Unleashing Business Value in a Digital World (Accenture, 2015) • The Handbook of Research on Energy Entrepreneurship (W Stenhagen & Wuebker, 2011)
Changes of customer-relationships due to decentralized PV business models	• Opower – The value of the engaged energy consumer (Opower, 2014) • Opower – Five universal truth about Energy consumers (Opower, 2013) • RolandBerger – Solar PV could be similar to the shale gas disruption for the utilities industry (Confais, Fages, & van den Berg, 2015)

2.3 Method for conducted survey on Cluster I and II

Based on the results of afore described literature review (Cluster II) as well as the background information provided for Cluster I (value for the consumer), interim conclusions throughout the sections are extracted and tested / supplemented via a survey conducted in the course of this study. The survey targets the following topics and corresponding interim findings:

- Developments in the energy economy, anticipated consumer interest and electricity supplier opportunities around solar PV.
- Factors influencing consumer investment decisions around solar PV.
- Barriers for implementing PV business models.
- Views on how to overcome solar PV business model barriers.

The survey was distributed via email (three weeks in a row with a final deadline after 4 weeks) to 381 stakeholders within the energy economy. The sample was structured as follows:

Table 4 : Survey -sample – Amount of stakeholders and sectors targeted[12]

Type of stakeholder / Sector	Amount of people sent to
PV-sector related company: System Developer / PV Module Producer and/or BOS (Cables and connectors, Inverters, Power Control Tools, Storage, Trackers)	123
Power Sales (Utilities)	63
Association (energy related)	60
Research Institutions	54
Energy Policy Sector	33
Consulting sector	18
Aggregator	15
Consumer organizations	10
Financial Sector	2
NGOs	2
Weather services	1
Total	**381**

2.4 Method for interviews on Cluster I and II

Based on the outcomes of the analyses concerning Cluster I and II as well as the above described survey process (which excluded Cluster III for the reason described in Section 2, footnote 1), a summary of the method and interim results of this study was produced as a basis for conducting interviews in order to validate and supplement corresponding outcomes. Potential interview candidates were contacted via email. In total, three interviews were conducted[13], that touched upon all clusters and topics assessed in this research by including a

- consumer association
- large integrated energy company
- new entrant (offering solar PV-battery combinations as a business model)

The interviews lasted between 40 and 70, minutes and were conducted via telephone (GoToMeeting). The summary and questions for the respective interview candidates that were distributed for preparation purposes prior to the interview are provided in Appendix IV. Note that not all topics and questions were answered as corresponding partners either were not willing to share or simply did not have access to information to some of the questions. The style of the interviews was therefore "semi-structured", generally defined as follows:

[12] Note that the stakeholder clusters are based on the internal customer relationship management program of SolarPower Europe.
[13] Due to confidentially issues the names of companies and interview partners cannot provided.

"A semi-structured interview is a qualitative method of inquiry that combines a pre-determined set of open questions (questions that prompt discussion) with the opportunity for the interviewer to explore particular themes or responses further.

A semi-structured interview does not limit respondents to a set of pre-determined answers (unlike a structured questionnaire).

Semi-structured interviews are used to understand how interventions work and how they could be improved. It also allows respondents to discuss and raise issues that you may not have considered." (evaluationtoolbox, 2016).

2.5 Cluster III: "Social and system aspects around solar PV" – Specifications and Method

This part of the study is based on a literature review upon several value streams for the society and the energy system. It provides a short summary on literature findings related to ancillary services that can be provided by solar PV, the potential of battery storage to limit peak injections and thereby reduce grid extension as well as macro-economic effects such as employment and financial impact on governments. Table 5 provides an overview of the most important literature used.

Table 5 : Literature assessed for value identification of Cluster III

Topic	Literature / Sources of Data
Reduction of CO_2 emissions	Best practices on Renewable Energy Self-consumption (EY Belgium, 2015)
• **Provision of system services** • **Limitation of grid expansion and system integration costs (based on a combination of PV and battery storage)**	• The susccessful stress test of Europe's power grid - more ahead (Vorrink, et al., 2015) • Grid support services by wind and solar PV: a review of system needs, technology options, conomic benefits and suitable market mechanisms (Van Hulle, et al., 2014) • Kurzgutachten zur Abschätzung und Einordnung energiewirtschaftlicher, ökonomischer und anderer Effekte bei Förderung von objektgebundenen elektrochemischen Speichern (Hollinger, et al., 2013) • Wissenschaftliches Mess- und Evaluierungsprogramm Solarstromspeicher. Aachen: isea (Institut für Stromrichtertechnik und Elektrische Antriebe) and RWTH Aachen (Kairies, et al., 2015)
Macroeconomic effects of solar PV(-battery) system deployment including employment	Solar Photovoltaics Jobs & Value Added in Europe (EY Belgium, 2015)

3. Results

The following sections illustrate the results corresponding to the structure of Section 2. First, the outcomes and corresponding conclusions with regard to the economic assessment (including the results of one variable sensitivity analyses upon crucial input parameters) for the two agent groups are shown in Section 3.1 and 3.2 respectively. In Section 3.3 two variable sensitivity analyses illustrate the results of a potential combination of the market integration and constraint scenario. (Note that complementary sensitivity analyses are presented in Appendix II). This is followed by the results and interim conclusions of the literature review with regard to the value of solar PV for electricity suppliers in Section 3.4. The outcomes of the conducted survey that assesses and concludes whether the main hypotheses and findings for Cluster I and II are also shared among various energy industry related stakeholders are provided in Section 3.5. Section 3.6 then presents the results and conclusions based on expert-interviews. Finally, Section 3.7 illustrates the results of the literature review upon potential social and energy system benefits related to solar PV.

3.1 Cluster I: Economic assessment and interim conclusions for residential consumers

The following sub-sections present the outcomes for each of the assessed countries. The different results relating to the introduced scenarios (reference, market integration and constraint) are described, illustrated and compared. The structure for each of the assessed countries is as follows:

1. **An overview of the numeric overall outcomes** is shown in a table.
2. A **“heat-map” that provides an easy to grasp comparison** of all scenarios and PV-battery combinations is illustrated.

   The worst economic results are shown in the upper left (red) area indicating unfavourable economic results, that is, high dynamic payback times, low net present values and low internal rates of return. Correspondingly, the best achievable economic results are presented in the lower right (green area).

After this initial overview, **in-depth analyses provide insights on**

- **The developments of electricity costs:** an investment in a PV system – potentially combined with a battery – would result in economic benefits in case that the i) realisable electricity cost savings based on self-consumption and ii) remuneration of excess electricity over the assessment period exceed the initial investment costs of a corresponding PV(-battery) system.
- **The *present value* of these benefit streams over the assessment period:** , comparison of the accumulated electricity costs of a consumer without a PV(-battery) system to the electricity costs of consumers with a 4 kWp PV and potential battery system combinations (medium = 2,3 kWh net battery, large = 8,3 kWh net battery).
- **A direct evaluation of investment and total operational costs in relation to the present value of benefit streams.**
- **Cash flows that indicate the dynamic payback period:** the year when the discounted cumulative cash-flow breaks even with 0 €. It should be noted that the investment in the respective PV-battery system is assumed to be made in 2015 and that it starts to operate in 2016 for a timeframe of 25 years, i.e. until 2041.
- **IRR comparisons** that summarise the profitability of the various PV battery system options in relation to their initial investment.
- **Average annual and monthly benefits.**
- **The sensitivity of the economic assessments upon crucial input parameters** (Note that a comprehensive overview of all inputs is shown in Appendix I and that additional results of **one variable sensitivity analyses** are described in Appendix II).
- **Interim conclusions referring to the second part of the first research question.**

3.1.1 Germany

Overview of numeric overall outcomes and "heat-map" of all scenarios and PV-battery combinations

Table 6 : Overview of the economic evaluation for the German residential market

Self-consumption [%] / Battery size [kWh net]		Reference Sc.			Market Int. Sc.			Constraint Sc.		
		NPV [€]	IRR [%]	DPBP [years]	NPV [€]	IRR [%]	DPBP [years]	NPV [€]	IRR [%]	DPBP [years]
High ≈ 66%	**8,3**	4 132	5,87	20,97	2 461	5,12	22,89	2 095	4,98	23,19
Medium ≈ 46%	**2,3**	7 409	9,41	14,2	4 755	7,52	17,56	4 570	7,56	17,11
Standard ≈ 27%	**0**	5 990	10,36	12,56	2 403	6,64	14,8	3 491	8,03	15,73

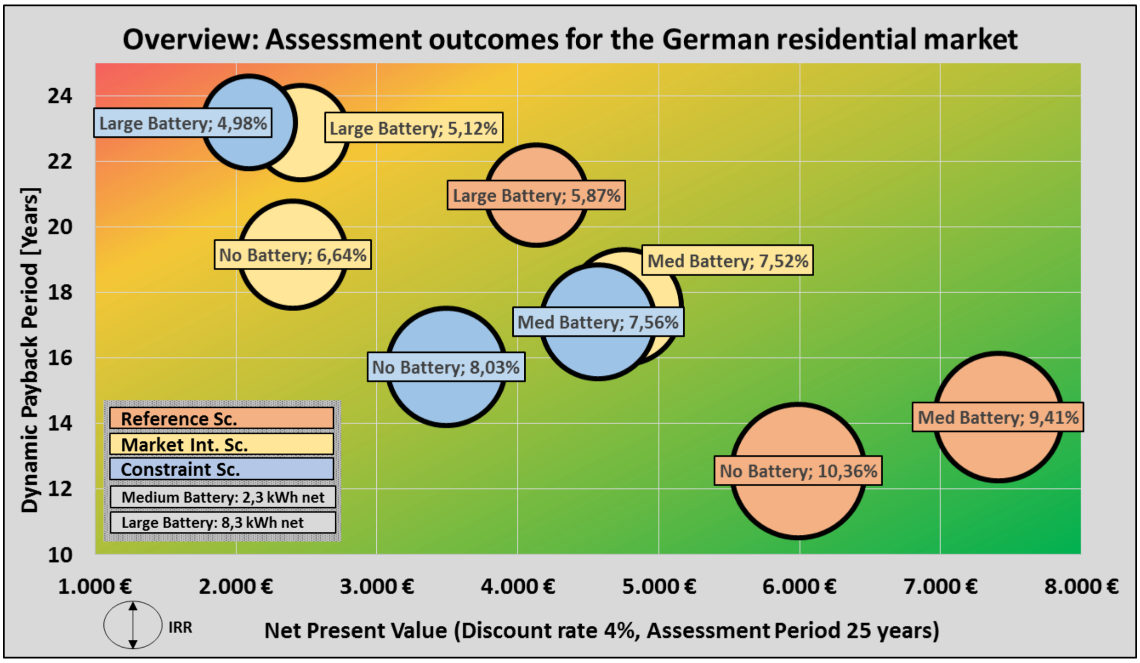


Figure 5 : Illustration and comparison of economic indicators for the German residential market

The following summarises the highlights that can be extracted based on the overall outcomes in Table 6 and Figure 5:

- Generally, with respect to all scenarios and investigated systems, the reference scenario realises the best economic results.
- Within the reference scenario, the most favourable results are achieved by a PV system without a battery, closely followed by a PV system with a medium sized (2,3 kWh net) battery. A combination with a large battery (8,3 kWh net) system results in a DPBP that exceeds 20 years and an IRR of below 6% with a corresponding NPV of approximately 4 000 €. It is therefore the least interesting case from a pure economic perspective.
- Four cases relating to the market integration and additional tax scenario are placed in the yellow/greenish area, indicating adequate economic results in respect to the overall outcomes. The DPBPs are between 15 and 18 years, with corresponding NPVs roughly between 3 500 and 4 700 € and a variation of IRRs from 7,5 to 8%.
    - In the market integration scenario, a PV system combined with a medium sized battery achieves the best possible economic results. It has slightly higher benefits (approximately 1% higher IRR) when compared to the case of a PV system without a battery.
    - Considering the constraint scenario, the analysis reveals that a PV system without a battery achieves better economic results (higher IRR and roughly one year lower DPBP) than a PV system combined with a medium sized battery.
- With regard to the assessed cases of PV systems combined with large batteries and all scenarios – the analyses demonstrate that such combinations result in the least favourable economic results. Although all cases remain positive, the final economic benefits are rather limited and may not lead to an investment only based on economic interests.
- Finally, when comparing PV systems with a large or medium battery it can be seen that the differences of their economic evaluations are rather small within the market integration and constraint scenario (within the latter scenario the results are slightly worse for a system combined with a large battery but slightly better for the one with a medium sized battery).

Considering the overall comparison of all scenarios, the following provides detailed background information, insights and analyses:

Developments of electricity costs

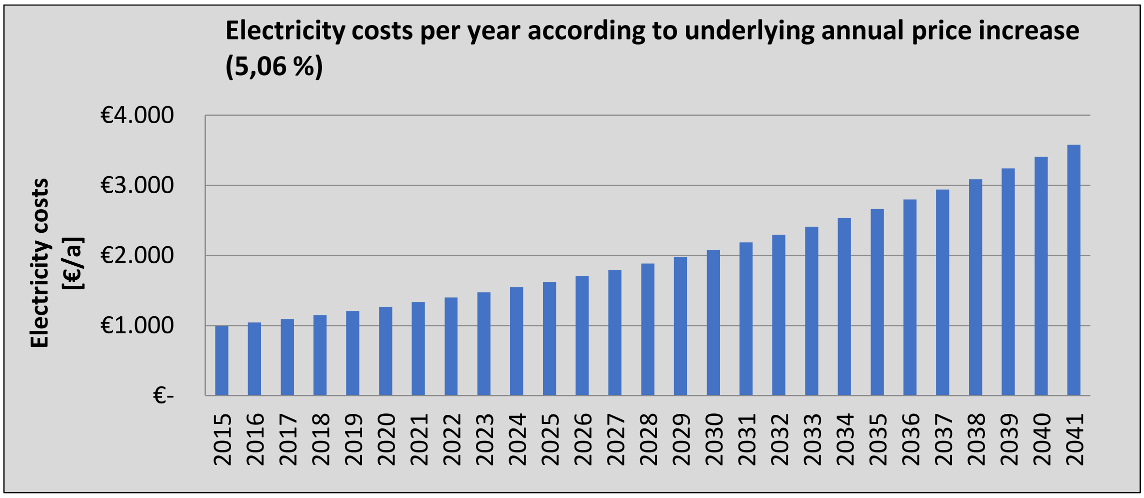


Figure 6 : Assumed electricity cost development for residential consumers in Germany

It can be seen that the total annual electricity costs of an average household would increase from about 1000 € to about 3500 € over the assessment period (assuming an average consumption of 3500 kWh/a and an initial price of 0,29 €/kWh in 2015). This is important to keep in mind for the following analyses:

The *present value* of benefit streams over the assessment period

Figure 7 illustrates the *present value* (light green area) of the benefit streams, i.e. electricity costs saved and remuneration of excess electricity. It becomes obvious that large battery systems achieve the highest accumulated benefits over the assessment period for all scenarios, whereas PV systems without batteries realize lower total benefits. This is caused by the fact that the electricity cost saving potential (on average for all scenarios) has a share of 81%, while the remuneration of excess electricity contributes to 19% to the total benefit values.

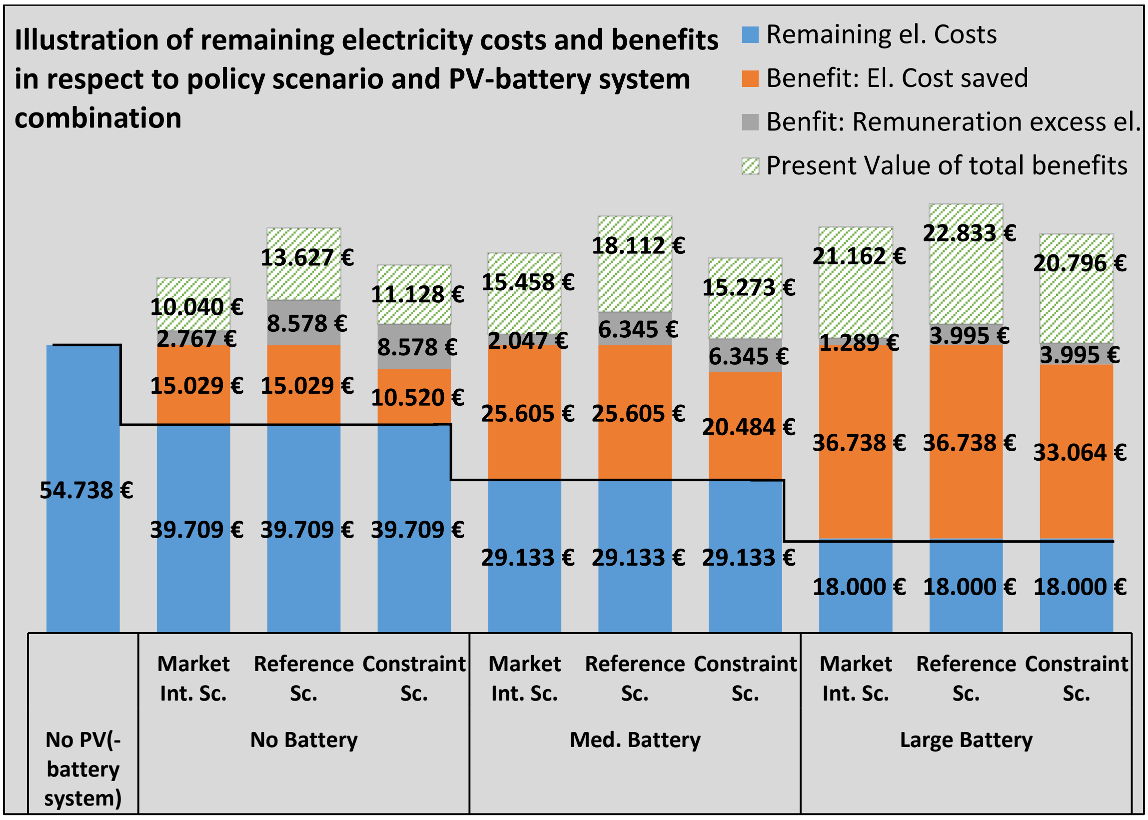


Figure 7: Electricity cost comparison according to PV-battery system and illustration of discounted cumulative benefits for residential consumers in Germany

The above findings (Figure 7) show that the ability to save upon electricity costs is of utmost importance in order to realise sufficient benefits that ultimately lead to an economic case for the various PV-battery system combinations. With respect to PV systems combined with a battery it becomes obvious that the reduction of the electricity cost saving potential (10 and 20% for the large and medium battery respectively) within the constraint scenario reduces the potential benefit stream drastically (by around 3 700 and 5 100 € correspondingly) when compared to the reference scenario. A lower remuneration level for excess electricity (as in the market integration scenario) on the other hand has a much lower impact on the total benefits of these system types (grey bars). This is different for PV systems without a battery since the reduced remuneration of excess electricity decreases the benefits by around 5 800 € whereas the additional charge of 30% on self-consumed electricity (i.e. only 70% of the electricity costs can be saved) reduces the benefit stream of the electricity cost saving potential by only around 4 500 €.

Direct evaluation of investment and total operational costs in relation to the present value of benefit streams

The investment (dark grey and orange number) and total operational (light grey and red number) costs in relation to the present value of benefit streams are shown in Figure 8. It illustrates that the highest monetary net benefits are achieved in the reference scenario, followed by the market integration option, while the constraint scenario results in the least favourable monetary net benefits. The only exception is a PV system without a battery. Such systems achieve higher net benefits in the constraint scenario when compared to the market integration scenario. This can be attributed to their "business model" being more reliant on the remuneration of the excess electricity than on the actual electricity cost saving potential as has been shown in Figure 7. Note that the highest monetary net benefit (7 409 €) is achieved in the reference scenario based on a PV system combined with medium sized battery, followed by a system without a battery (5 990 €). The lowest net benefit is 2 095 € and relates to a system with a large battery in the constraint scenario.

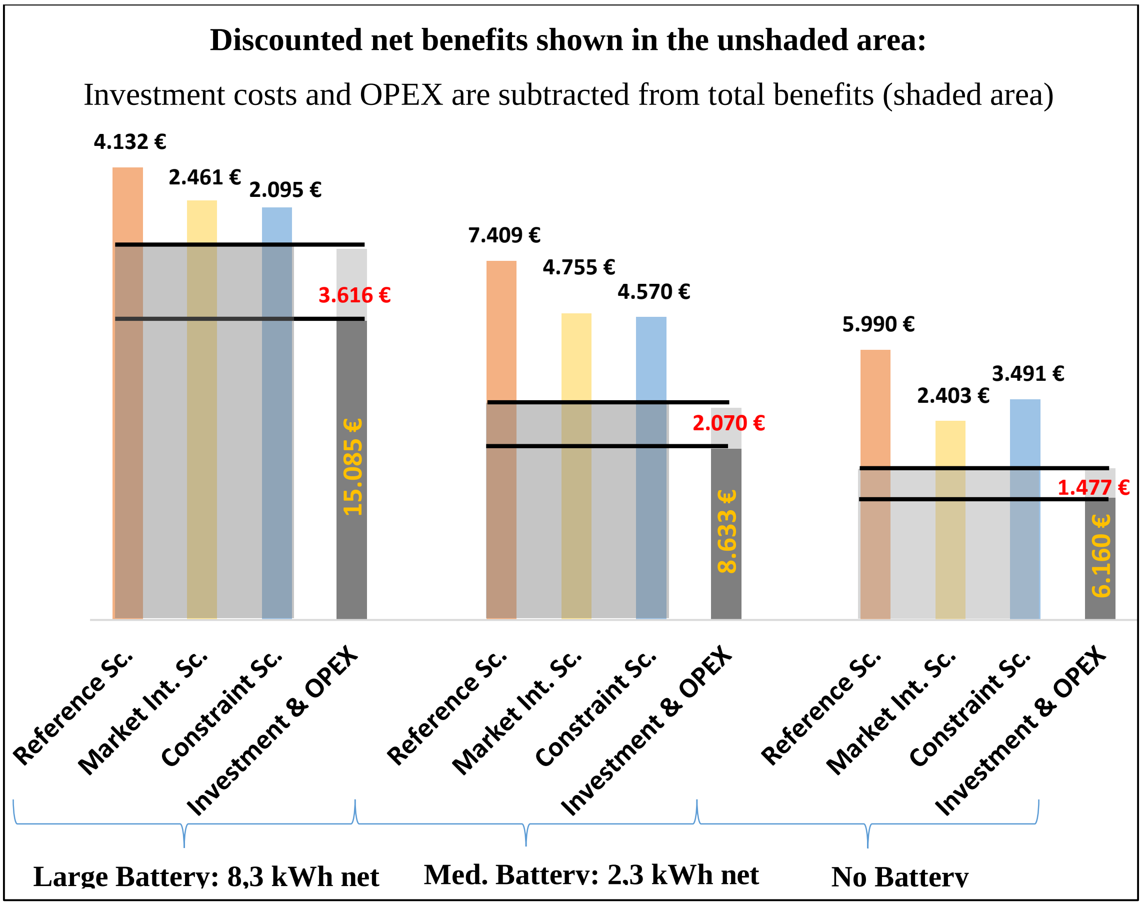


Figure 8 : Discounted net benefits in respect to investment costs and OPEX for residential consumers in Germany[14]

[14] Assumes battery investment costs of 1075,26 €/kWh and PV system costs of 1540 €/kWp (with 1,5 % annual OPEX in respect to investment costs for each of the system components)

Cash flows indicating the dynamic payback period

The cash flow diagrams (Figure 9 to 11) illustrate the discounted and net cumulative as well as annual benefit developments over time. Based on the cash flow diagrams, it can be derived that a PV-only system is the first variant that reaches its break-even point in the reference and constraint scenario, whereas the PV system combined with a medium battery amortizes slightly faster in the market integration scenario. The simple PV system however has the highest NPV (ergo lowest loss before amortisation) until a certain point in time (depending on the policy scenario) when its cumulative benefits are exceeded by the PV system combined with a medium sized battery. With regard to the reference scenario, this is the case in year 20 (Figure 9). The same is valid for the market integration (Figure 10) and constraint scenario (Figure 11) in year 16 and 23 respectively. That the PV only system has a higher NPV until these points in time can be explained by its significantly lower investment costs compared to systems combined with a battery (the variant with a large version does not exceed the cumulative benefits of the single PV system and the PV system with medium sized battery in any scenario). This means that consumers that are risk averse (or potentially depend on financing options and must therefore pay loans) may prefer to recover a larger share of their investment within a short period of time. In this case they would be more likely to invest in PV-only systems although the total amortisation time may be longer (see market integration scenario).

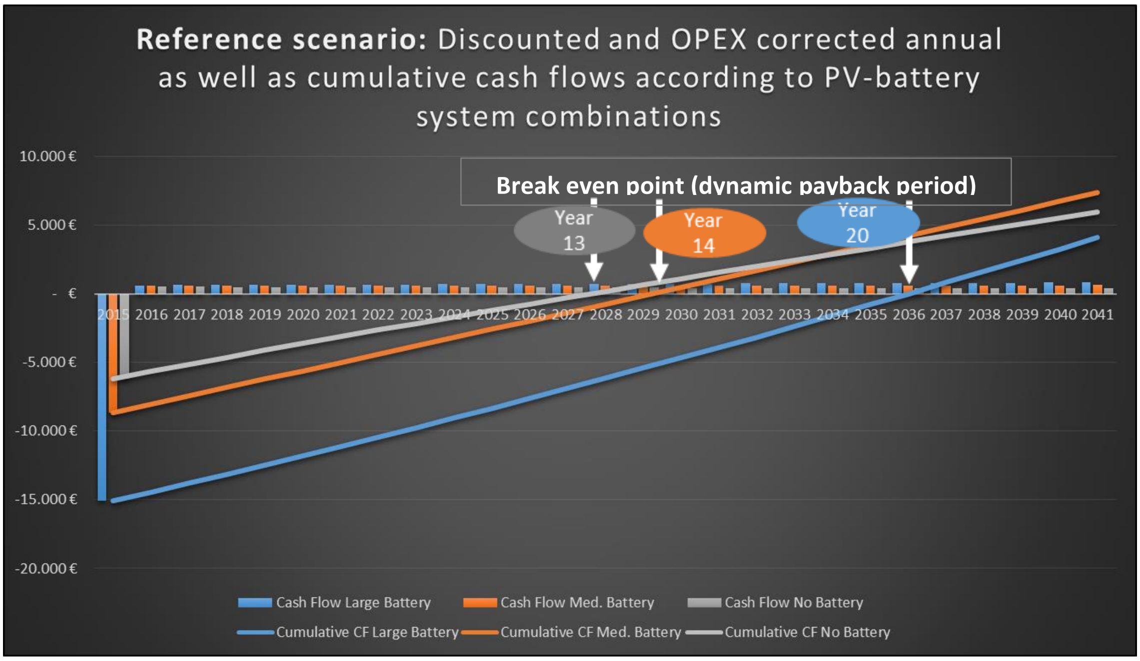


Figure 9 : Cash Flow developments according to the reference sc. in the German residential market

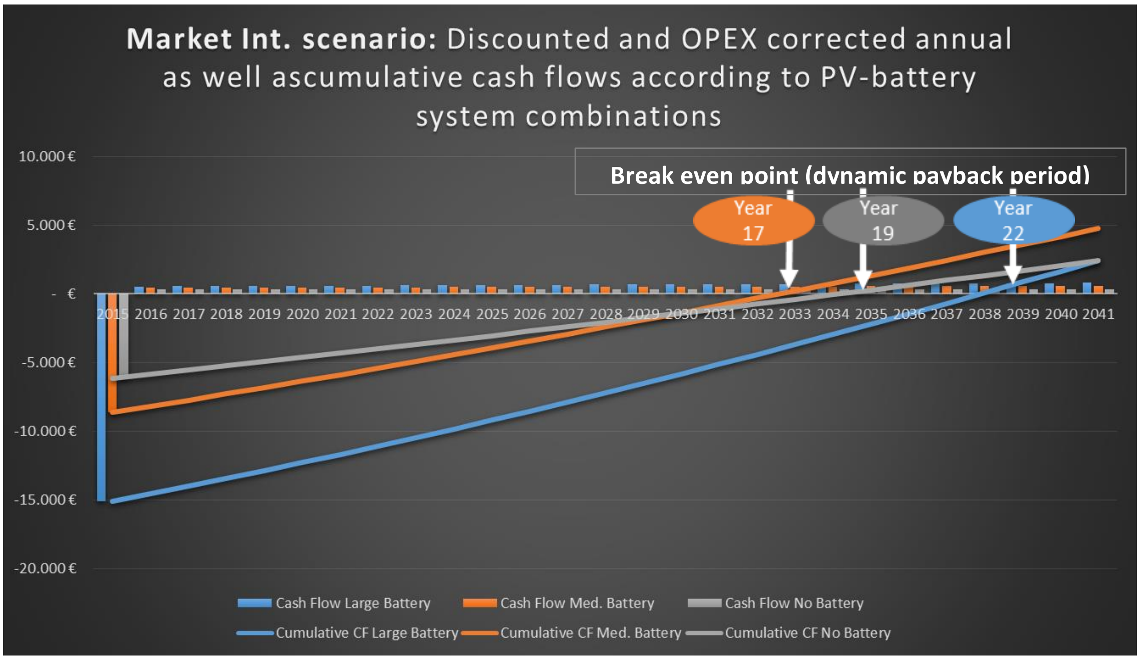


Figure 10 : Cash Flow developments according to the market int. sc. in the German residential market

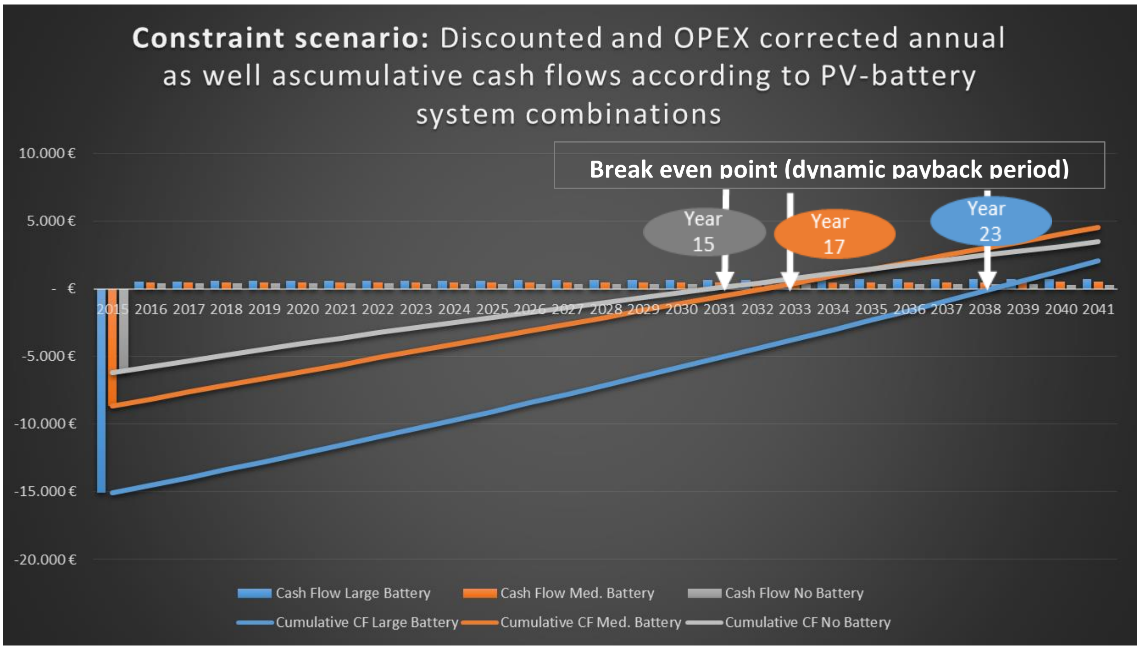


Figure 11 : Cash Flow developments according to the constraint sc. in the German residential market

Although the total and therewith average achievable benefits increase with the size of the battery especially due to higher electricity cost saving potentials as illustrated in Figure 7 and 8, these additional benefits are not large enough to recover the higher investment costs within the amortization timeframes of PV-only systems. The only scenario in which a medium sized battery recovers its investment costs in a timeframe equal to the simple PV system is the market integration design option because the remuneration of excess electricity in this case is significantly lower which results in a slight competitive disadvantage for the system without battery storage.

IRR comparisons

Figure 12 compares the IRR of the various PV(-battery) system combinations within the assessed policy design scenarios.

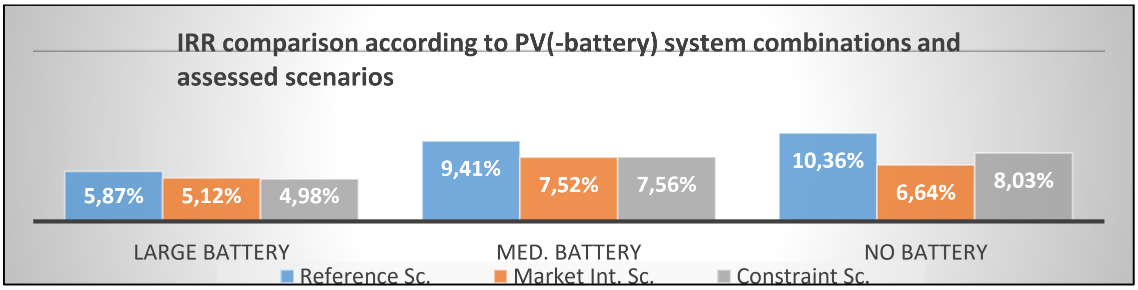


Figure 12 : Overview of IRR in relation to PV(-battery) system and assessed policy designs for German residential consumers

The rule of thumb to cut off projects that exceed a lifetime of 15 years if their IRR is not slightly above “the inverse of the pay-back period” (Blok, 2007) is realised when comparing Figure 12 and Table 7.

- PV systems combined with large batteries do not meet this criterion in any scenario.
- PV systems combined with a medium battery match this criterion in case of the reference and market integration scenario.
- PV only systems exceed the required IRR only within the reference scenario.

Table 7 : Cut off values for assessed systems and scenarios in Germany [15]

	Reference Sc.		Market Int. Sc.		Constraint Sc.	
	Cut off value	Difference to IRR	Cut off value	Difference to IRR	Cut off value	Difference to IRR
PV syst. with large battery	6,25%	-0,38%	5,88%	-0,76%	5,88%	-0,9%
PV syst. with medium battery	8,33%	1,08%	7,14%	0,38%	7,69%	-0,13%
Simple PV syst.	10%	0,36%	6,67%	-0,03%	8,33%	-0,3%

However, as the residential sector commonly does not have specific decision criteria that define critical amortisation times and or IRRs (Blok, 2007), implicit consumer discount rates for PV(-battery) systems may be sufficiently met even in case of slightly worse results – especially when considering additional non-economic benefits such as increased self-sufficiency. In addition to the above analysis Box 1 provides an insight in the discounted and OPEX corrected average annual and monthly benefits that can be realized in the respective policy scenarios.

[15] Note that the rule of thumb refers to the simple payback period, i.e. the point in time when the (undiscounted) cumulative cash-flows become positive.

Box 1: Benefit comparison of PV-battery system combinations over total lifetime (25 years) in respect to assessed policy scenarios

Reference Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remuneration of excess el.) [€]	Annual	**739**	**617**	**467**
	Month	**62**	**51**	**39**
Dynamic Payback Period [Years]		**21**	**14**	**13**

- A large battery system achieves an average annual electricity cost reduction plus an additional revenue stream from excess electricity of 739 €. This reduces the consumers' electricity bill by about 62 € every month over the next 25 years. However, the high investment costs (and higher operational expenses) of this type of system require rather long DPBPs of about 21 years.
- A PV system without a battery has a DPBP of only 13 years. Nonetheless, due to lower self-consumption (lower savings on electricity costs), the average monthly benefits are reduced to about 39 €.
- Combining a PV system with a medium sized battery reduces the electricity bill in total by about 51 € a month and increases the DPBP by only one year when compared to the system without a battery.

Market Integration Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remuneration of excess el.) [€]	Annual	**675**	**515**	**329**
	Month	**56**	**43**	**27**
Dynamic Payback Period [Years]		**23**	**18**	**19**

- As in the reference scenario, a PV system combined with a large battery results in the highest possible benefits and reduces the consumers bill by about 56 € per month (only about 5 € less than in the reference scenario).
- Due to the fact that the remuneration of excess electricity is lower (0,04 €/kWh instead of 0,124 €/kWh) compared to the reference scenario, the consumer faces only slightly higher DPBPs for PV systems combined with large and medium batteries (2 and 4 years respectively). A PV system without a battery however faces way higher amortization times of 6 years. This is caused by the fact that a large part of the produced electricity has to be fed into the grid, leading to 12 € reduction of monthly benefits compared to the reference scenario.

Constraint Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remuneration of excess el.) [€]	Annual	**661**	**508**	**371**
	Month	**55**	**42**	**26**
Dynamic Payback Period [Years]		**23**	**17**	**16**

- Due to the fact that this scenario accounts for additional charges on self-consumption, the potential savings on electricity costs are reduced by 10 and 20 % for large and medium PV-battery combinations respectively. This leads to a reduction of monthly benefits by about 7 € (large battery) and 9 € (medium battery) and increases the amortization time by 2 and 3 years respectively when compared to the reference scenario.
- As the remuneration of excess electricity is kept at the same level as in the reference scenario, a simple PV system achieves the most favorable result with regard to the DPBP. However, it becomes obvious that a 30% reduction of the electricity cost saving potential for the simple PV system as assumed in this scenario has also strong effects on the monthly savings (reduced by about 13 €).

Box 1: Assessment of DPBP and annual as well as monthly average benefit potential for residential consumers in Germany

Sensitivity of outcomes upon crucial input parameters assessed (additional analyses are provided in Appendix II.I)

Assessment of a change in the discount rate:

As can be seen in Figure 13 reducing the discount rate by 30% from 4% to 2,8% would result in a NPV increase of about 3 500, 2 800 and 2 000 € for the PV system combined with a large, medium and no battery respectively. The DPBPs for the PV only and medium battery combination in this case would be reduced by about 1 year whereas the DPBP for a system combined with a large battery would be reduced by 2 years. Furthermore, the analysis upon variations of the discount rate reveals cut off values (indicated by red boxes) of 5,6% (PV system with a large battery), 9,2% (PV system with a medium sized battery) and 10% (simple PV system) that lead to “close to zero” NPV results. Finally, it must be mentioned that the NPV of a PV system combined with a large battery would be almost as high as the one for a system combined with a medium sized battery in case that the discount rate applied would be 0.

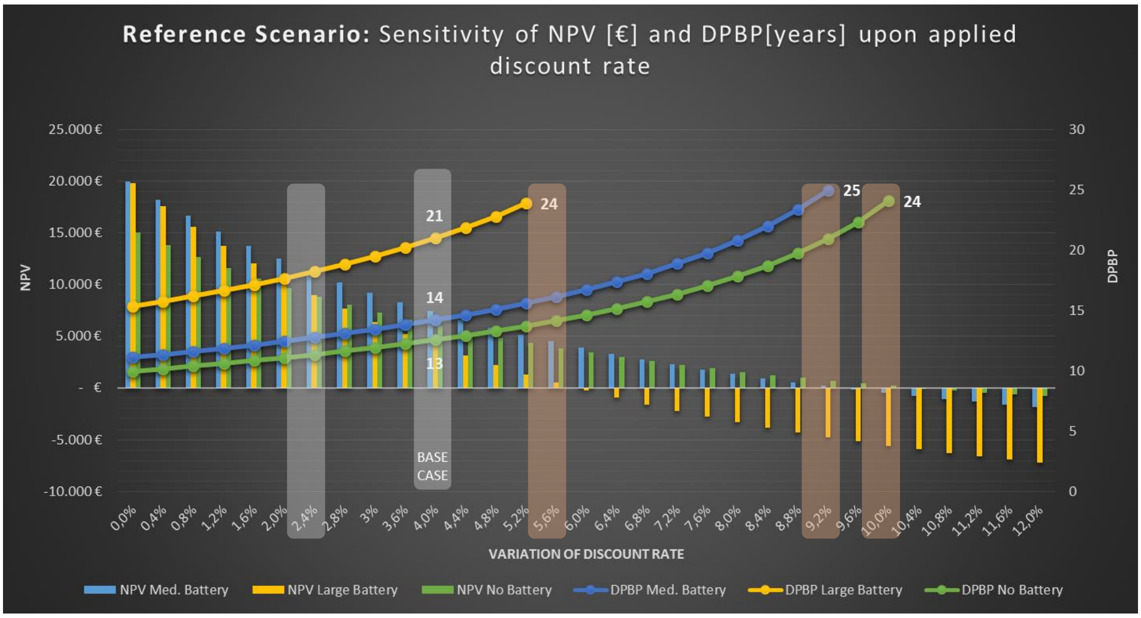


Figure 13 : Reference Sc. Germany - One variable sensitivity analysis of potential discount rates

Assessment of a change in total investment costs:

In order to illustrate the potential impact in case that the full VAT of 19% would need to be paid, Figure 14 shows how a variation of the total investment costs would change the assessed indicators. It becomes obvious that a 20% increase would still result in adequate economic results for the simple and medium battery PV-system combination, whereas the version with the large battery would be at the edge of being economical (25 years DPBP and an IRR of around 4%).

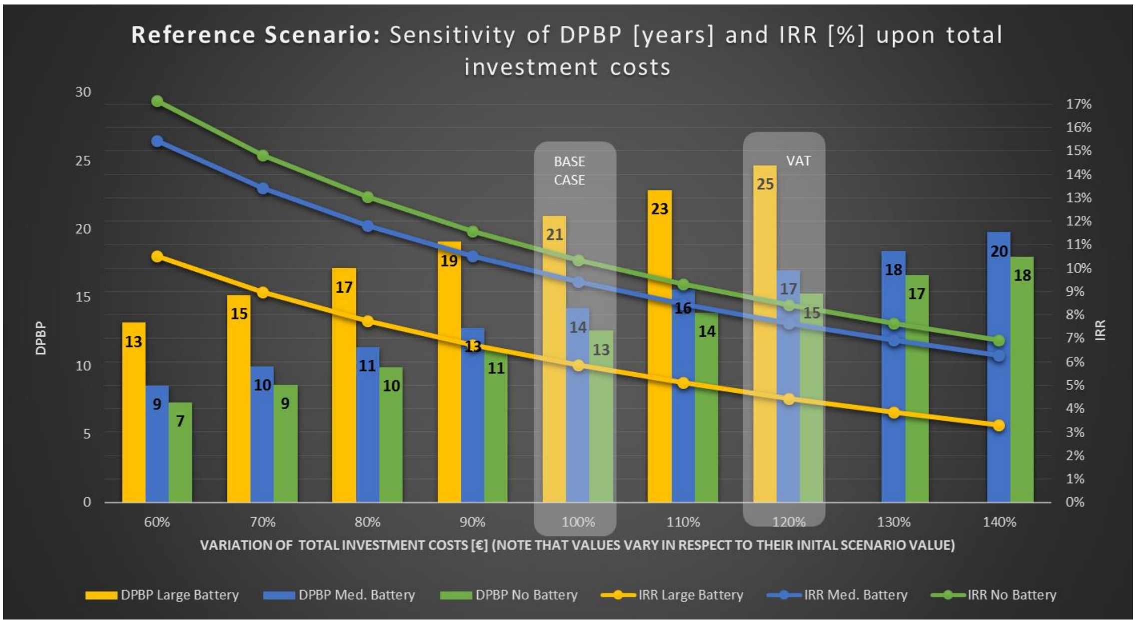


Figure 14 : Reference Sc. Germany - One variable sensitivity analysis on variations of the assumed total investment costs

Assessment of a change in the assumed electricity price increase (Figure 15)

Considering variations in the assumed electricity price increase, the analysis reveals that a system combined with a large battery relies on an annual price increase of about 1% over the entire assessment period in order to remain at least an IRR of 2% (covering common inflation rates). A PV system combined with a medium sized battery on the other hand would continue to be profitable even if the electricity price would not increase at all (IRR of 5% with a corresponding DPBP of 21 years). Systems without a battery however would result in an IRR of about 7% and remain with a DPBP as low as 16 years in case that electricity prices would not increase over the assessment period (25 years).

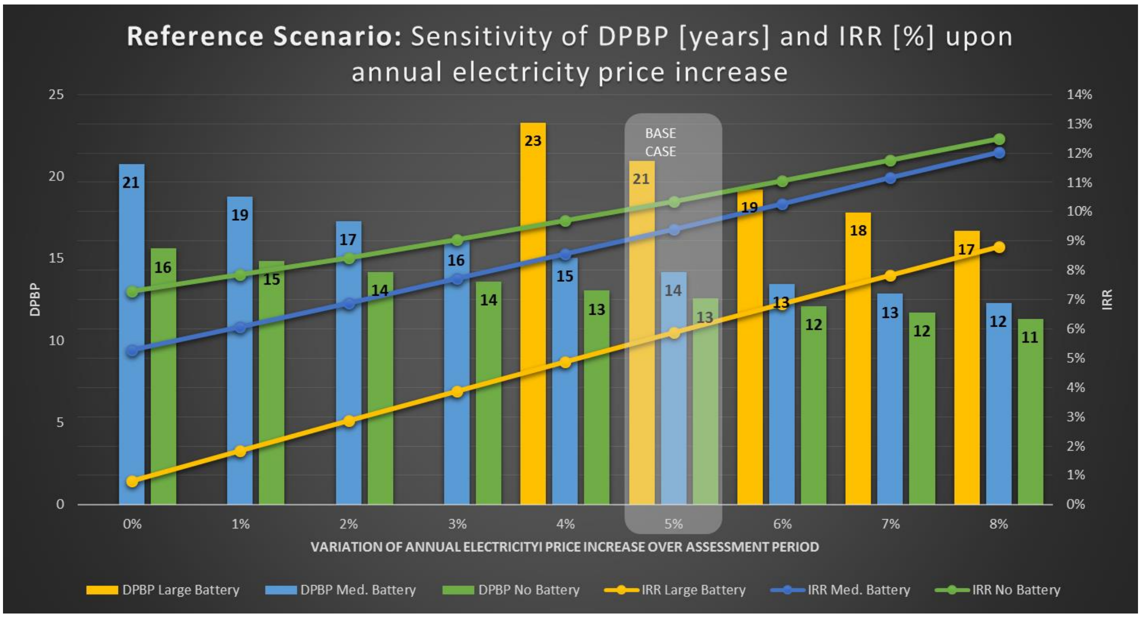


Figure 15 : Reference Sc. Germany - One variable sensitivity analysis on variations of the assumed el. price increase

Assuming an annual electricity price decrease of 1,5% over the assessment period would result in losses for PV systems combined with large batteries, while the ones with medium batteries would be at the edge of being economical. Simple PV systems on the other hand would remain to be financially beneficial as can be seen in Table 8.

Table 8: Impact of annually decreasing electricity prices on residential systems in Germany:

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 6 340	> 0	< assessment period
Medium battery	111	4	< assessment period
No battery	1 707	7	17

Assessment of a change in battery investment costs

With reference to the variation of the assumed battery investment costs, a reduction of 30% (see 70% value in the Figure 16) would lead to a break-even of the PV system combined with a medium sized battery and the simple PV system. (Note that this may also explain the reason why residential consumers in Germany currently invest in a combination of PV and storage as the subsidy by the KfW reduces the investment costs by about 30% (Deign, 2015)). Within the next two years (assuming an annual investment cost reduction of 30% for batteries (Deutsche Bank, 2015)) a PV system combined with a medium sized battery would achieve an IRR of 10% while a combination with a large battery would realise an IRR of 8 % in respect to the reference scenario and assumptions taken in this report. This indicates that more adequate economic benefits will be achievable within short to medium time frames for both considered options. Nevertheless, a cost-reduction of around 70% would be necessary so that the large battery PV system combination would achieve better economic results than the simple PV system. Additionally, it can be seen that both battery system combinations would remain beneficial even when their investment costs were 50% higher. However, the DPBP of the large battery system would already exceed the timeframe of this assessment (25 years) in case the investment costs were 30% higher. The increase of the DPBP in relation to higher investment costs for the medium sized battery system combination on the other hand is less steep and would increase only by 2 years when compared to the base case.

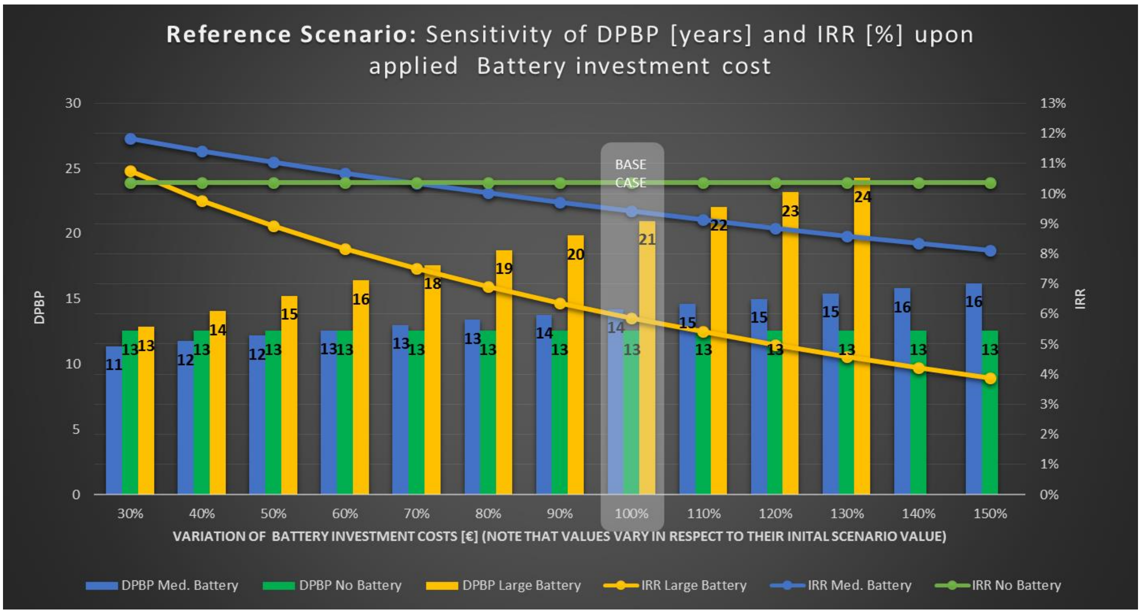


Figure 16 : Reference Sc. Germany- One variable sensitivity analysis of Battery investment costs

Assessment of a change in the electricity cost saving potential

Figure 17 shows a variation of the electricity cost saving potential within the constraint scenario. The ranges above 100% are shown to provide an indication of the respective value within the reference scenario (where for all systems 100% electricity cost saving potential was assumed). It can be seen that any further reduction within the constraint scenario (below 90%) for a large battery would result in a DPBP that exceeds 25 years (corresponding IRRs would be below 4%). For a PV system combined with a medium sized battery a reduction to 70% (i.e. only about 50% of electricity costs could be saved) would increase the DPBP to above 25 years, whereas for a simple PV system the electricity cost saving potential could be reduced to only 45% (corresponds to 50% value in the diagram) while remaining an IRR of about 5% with a corresponding DPBP of 23 years.

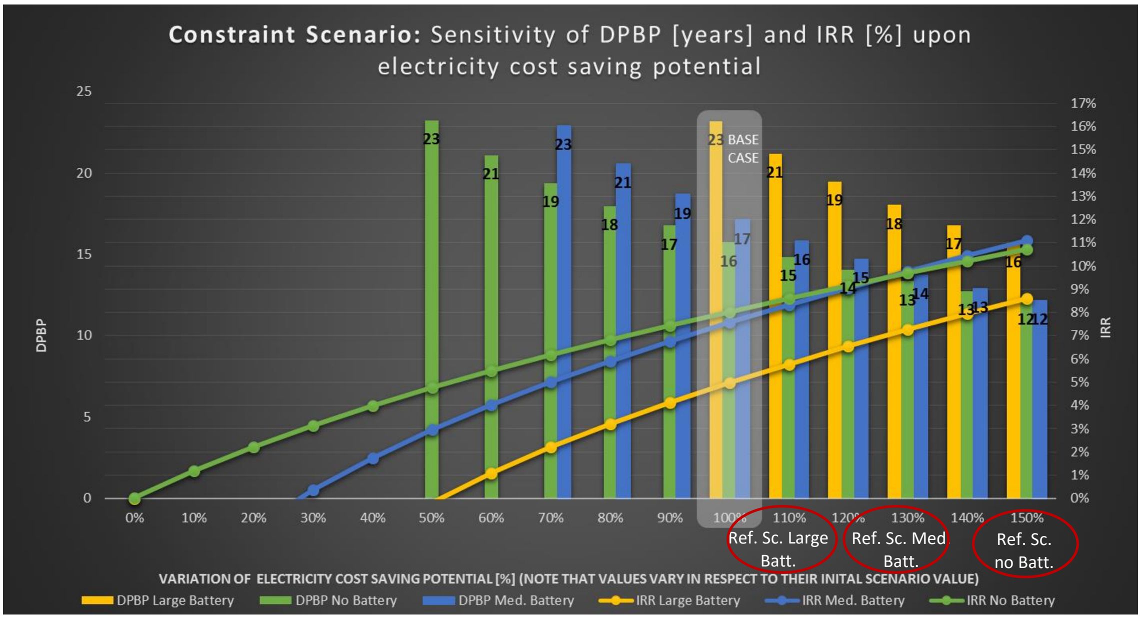


Figure 17 : Constraint Sc. Germany - One variable sensitivity analysis on the assumed el. cost saving potential

<u>Interim conclusions based on analysed outcomes and sensitivity analyses</u>

- Overall, with respect to all policy scenarios, PV(-battery) system combinations as well as economic indicators assessed, it can be concluded that an investment in PV systems remains economical (and exceeds – or is at least close to do so – estimated cut-off values based on common rules). This is especially valid for the PV only variant and systems combined with a medium sized battery.
- Moreover, it becomes clear that any further step towards the "market integration scenario" (i.e. reducing the remuneration of excess electricity) would incentivise investments into combining PV systems with medium sized batteries.
- Considering the implemented charges in the initial constraint scenario (i.e. without any further changes), the economic outcomes are similar to the one in the market integration scenario. Thereby concluding that additional charges should indeed be set the way they are described in the scenario, e.g. lower charges for large batteries and higher charges for systems without or medium sized batteries.
- Overall, the above indicates that investments by all types of consumer groups are very likely, especially with declining technology costs.
- The outcomes of the sensitivity analyses confirm the above by showing that if input parameters within the assessed scenarios would be changed such that they would have a negative impact on the economic results (e.g. higher discount rates, higher total investment costs as well as lower electricity price increases as shown in Figure 13, 14 and 15 respectively) the final outcomes would remain positive, i.e. no net losses. (Note that for PV only systems, and those combined with a medium sized battery, economic benefits would prevail even if electricity prices would decrease in the reference scenario).
- Since the applied discount rate has a significant impact on the NPV and DPBP, it can be concluded that low income groups that can be expected to have rather high discount rates and tend to prefer low risk investments would choose to invest in PV only systems (lowest losses in case of technical failures etc. due to lowest investment costs), whereas agents with high incomes and most likely lower discount rates would tend to invest in PV systems with (larger) battery systems.
- Furthermore, it can be derived that with declining technology costs for batteries (assuming these decline faster than for PV-only systems), a combination with medium sized batteries is very likely to result in the highest economic benefits in respect to all scenarios in short to medium timeframes (Figure 16).
- An additional charge on self-consumed electricity would reduce the business value for systems combined with batteries, pushing the economic interest clearly away from

combinations with large batteries. (Note that this statement refers to the sensitivity analysis in Figure 17).

3.1.2 Portugal

Overview of numeric overall outcomes and “heat-map” of all scenarios and PV-battery combinations

The reference scenario equals the market integration scenario in the case of Portugal. This is caused by the fact that the remuneration of excess electricity is already below the wholesale price under the current policy design as explained in Appendix 1. The following text refers therefore from now on only to the reference and constraint scenario.

Table 9 : Overview of the economic evaluation for the Portuguese residential market

Self-consumption [%] / Battery size [kWh net]		Reference / Market Int. Sc.			Constraint Sc.		
		NPV [€]	IRR [%]	DPBP [years]	NPV [€]	IRR [%]	DPBP [years]
High ≈ 66%	**8,3**	5 758	6,4	20,54	3 463	5,5	22,21
Medium ≈ 46%	**2,3**	8 784	9,83	14,24	5 283	7,77	17,38
Standard ≈ 27%	**0**	5 316	9,24	14,8	2 234	6,45	19,64

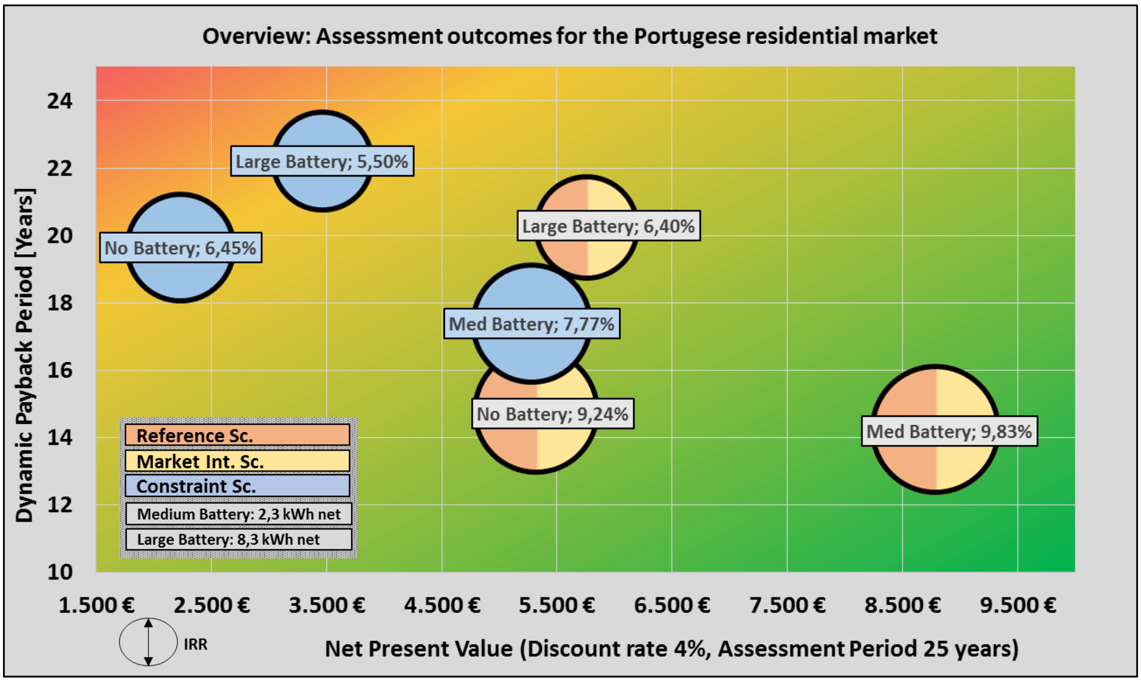


Figure 18 : Illustration and comparison of economic indicators for the Portuguese residential market

The following summarises the highlights that can be extracted based on the overall outcomes in Table 9 and Figure 8:

- From the two assessed scenarios and investigated systems it can be seen that the PV system combined with a medium sized battery achieves the best economic results, followed by PV-only systems. Combinations with a large battery however result in the least favourable economic benefits. Nevertheless, the analysis reveals that the latter combinations remain at least slightly beneficial (IRRs of 5,5 and 6,4 % and corresponding DPBP of around 14 and 20 years with regard to the constraint and reference scenario respectively).
- Within the reference scenario, the difference between the PV system with a medium sized battery and the simple PV system is rather small in terms of IRRs (both around 9%), however, the NPV for the former system is much higher (about 3 480 €). Based on these results both systems are illustrated in the greenish area. This is different in the constraint scenario, where the IRR of the system with a medium sized battery compared to the one without a battery is about 1,3 % higher, while the difference in the NPV is smaller (around 3 000 €). The PV only system is therefore illustrated in the yellow/reddish area whereas the system with a medium battery is placed in the greenish/yellow area.
- Finally, it can be seen that the PV system with a medium sized battery achieves similar economic benefits within the constraint scenario as systems with a large or no battery within the reference scenario.

Considering the overall comparison of all scenarios, the following provides detailed background information, insights and analyses:

Developments of electricity costs

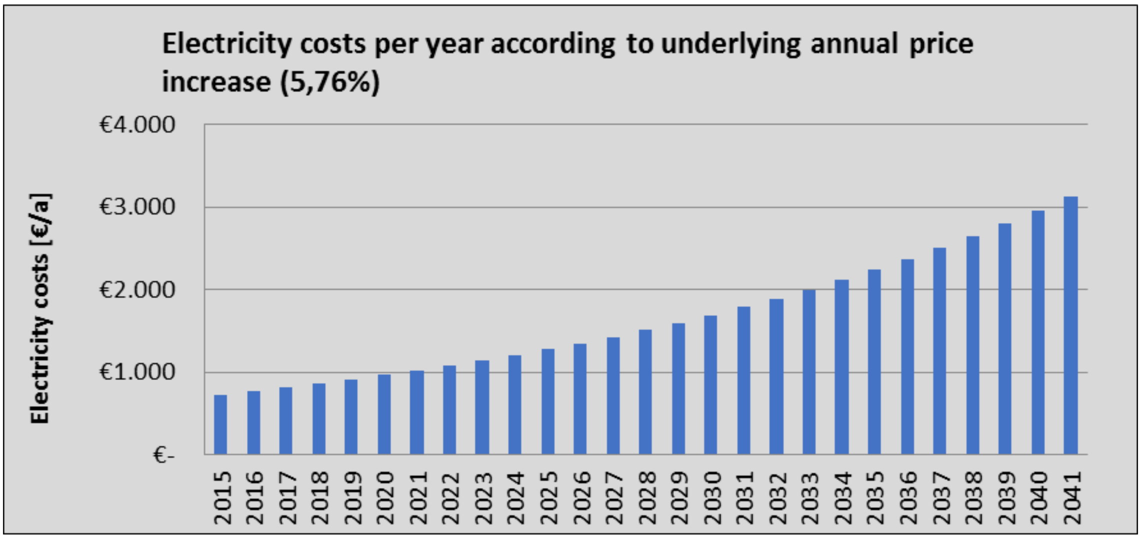


Figure 19 : Assumed electricity cost development for residential consumers in Portugal

It can be seen that the total annual electricity costs of an average household would increase from about 730 € to about 3100 € over the assessment period (assuming an average consumption of 3500 kWh/a and an initial price of 0,22 €/kWh in 2015). This is important to keep in mind for the following analyses:

<u>The *present value* of benefit streams over the assessment period</u>

Figure 20 illustrates the *present value* (light green area) of the benefit streams, i.e. electricity costs saved and remuneration of excess electricity. The large battery systems achieve the highest accumulated benefits over the assessment period for all scenarios, whereas PV systems without batteries realize lower total benefits. This is caused by the fact that the electricity cost saving potential (on average for all scenarios) has a share of 88%, while the remuneration of excess electricity contributes to 12% to the total benefit values.

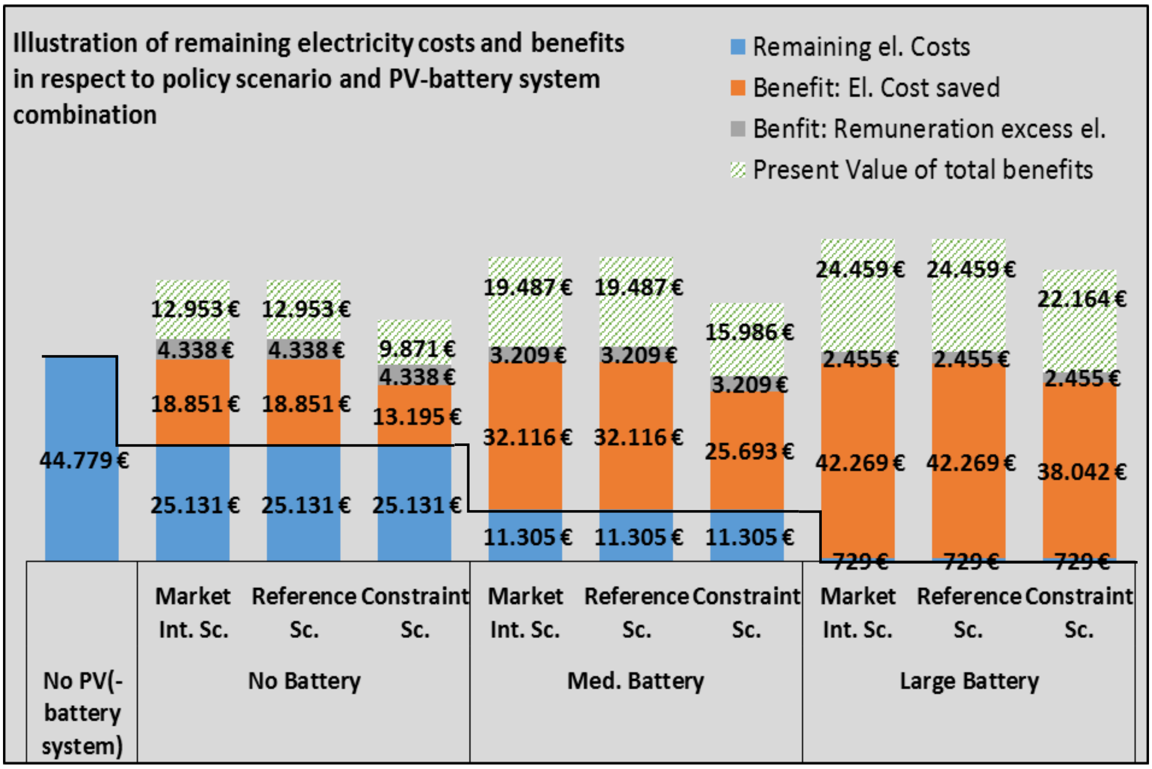


Figure 20 : Electricity cost comparison according to PV-battery system and illustration of discounted cumulative benefits for residential consumers in Portugal

The above findings (Figure 20) show that the ability to save upon electricity costs is of utmost importance – particularly since the remuneration of excess electricity contributes very little to the overall benefits. With regard to the assessed PV systems combinations and the constraint scenario it becomes obvious that the reduction of the electricity cost saving potential (10, 20 and 30 % for the PV system with a large, medium and no battery respectively) reduces the potential benefit stream drastically (by around 6 400, 4 200 and 5600 € correspondingly) when compared to the reference scenario.

Direct evaluation of investment and total operational costs in relation to the present value of benefit streams

The investment (dark grey and orange number) and total operational (light grey and red number) costs in relation to the present value of benefit streams are shown in Figure 21 (remember that the reference scenario is the same as the market integration scenario in the assessment for Portugal). The highest monetary net benefit (8 784 €) is achieved in the reference scenario based on a PV system combined with a medium sized battery, followed by a system with a large battery (5 758 €). The lowest net benefit is 2 234 € and relates to a system with no battery in the constraint scenario.

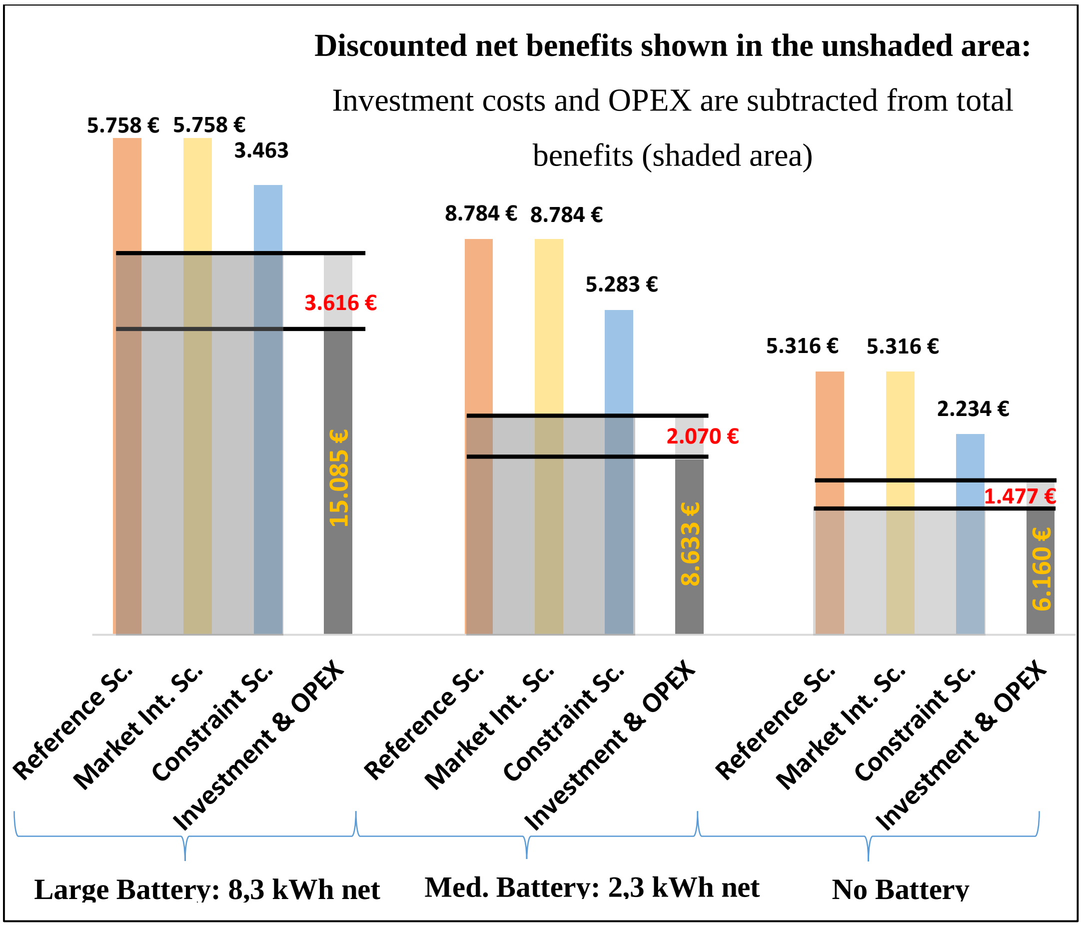


Figure 21 : Discounted net benefits in respect to investment costs and OPEX for residential consumers in Portugal[16]

[16] Assumes battery investment costs of 1075,26 €/kWh and PV system costs of 1540 €/kWp (with 1,5 % annual OPEX in respect to investment costs for each of the system components)

Cash flows indicating the dynamic payback period

The cash flow diagrams (Figure 22 and 23) illustrate the discounted and net cumulative as well as annual benefit developments over time. Based on the cash flow diagrams it can be derived that a PV system combined with a 2,3 kWh net battery is the first variant that reaches its break-even point in the reference and constraint scenario (Figure 22 and 23 respectively), whereas the PV systems combined with a large or no battery amortise slower. The simple PV system however has the highest NPV (ergo lowest loss before amortization) until a certain point in time (depending on the policy scenario) when its cumulative benefits are exceeded by the PV system combined with a medium sized battery. With regard to the reference scenario, this is the case in year 14 (Figure 22.). The same is valid for the constraint scenario (Figure 23) in year 16. That the PV only system has a higher NPV (lower loss) until these points in time can be explained by its significantly lower investment costs compared to systems combined with a battery. This means that consumers that are risk averse (or potentially depend on financing options and must therefore pay loans) may prefer to recover a larger share of their investment within a short period of time. In this case they would be more likely to invest in PV-only systems although the total amortization time may be longer. Note that the cumulative cash-flow curve of a PV system combined with a large battery intersects with the one of a simple PV system approximately in year 25 in both scenarios. This shows that despite the fact that large battery systems may have higher total benefits, it takes almost the entire assessment period for these systems to achieve better economic results than a PV system without a battery. Considering this fact, consumers may again prefer the simple PV system when considering the uncertainty of input parameters used in this study.

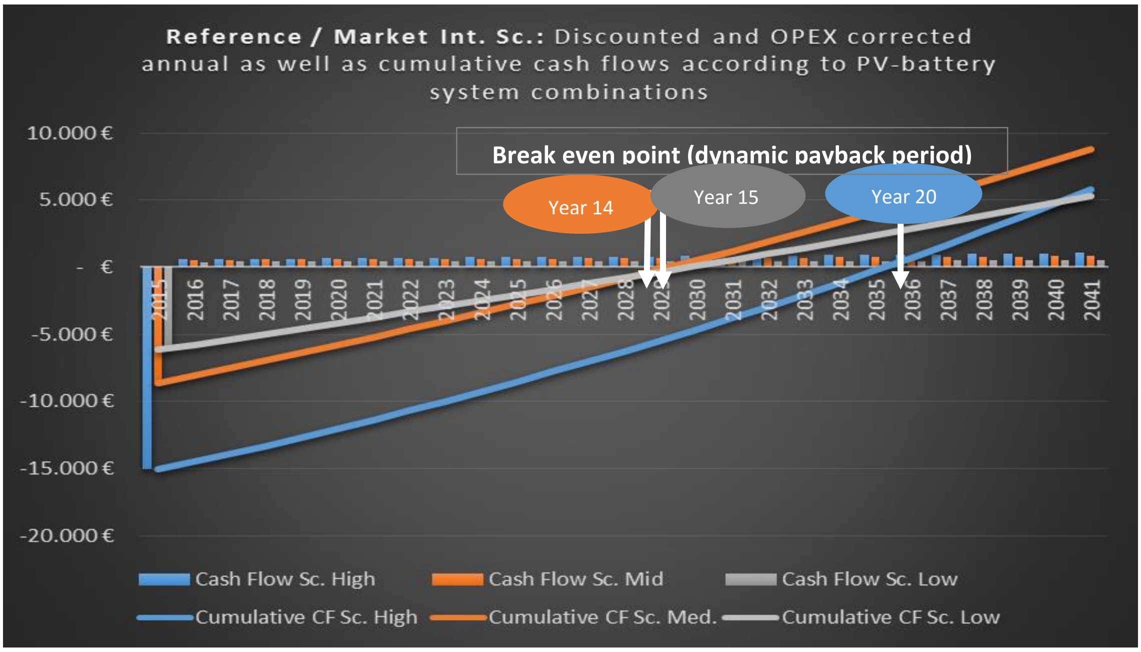


Figure 22 : Cash Flow developments according to the reference scenario in the Portuguese residential market

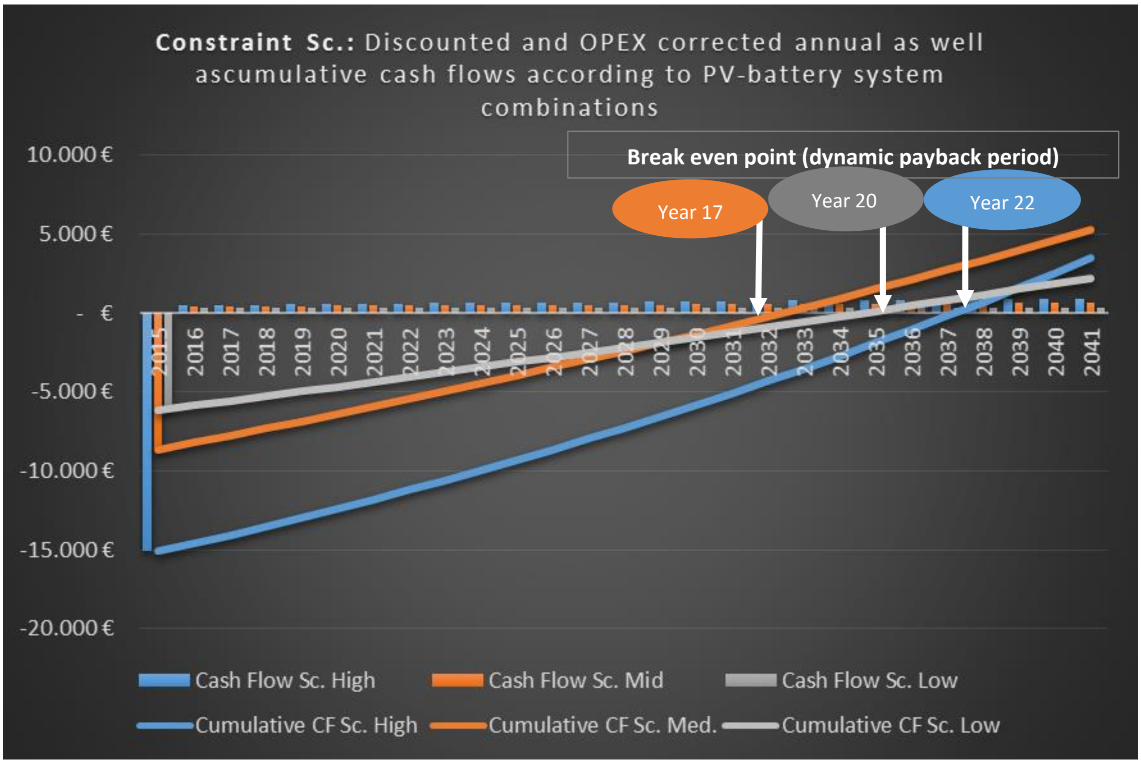


Figure 23 : Cash Flow developments according to the constraint scenario the Portuguese residential market

IRR comparisons

Figure 24 compares the IRR of the various PV(-battery) system combinations within the assessed policy design scenarios.

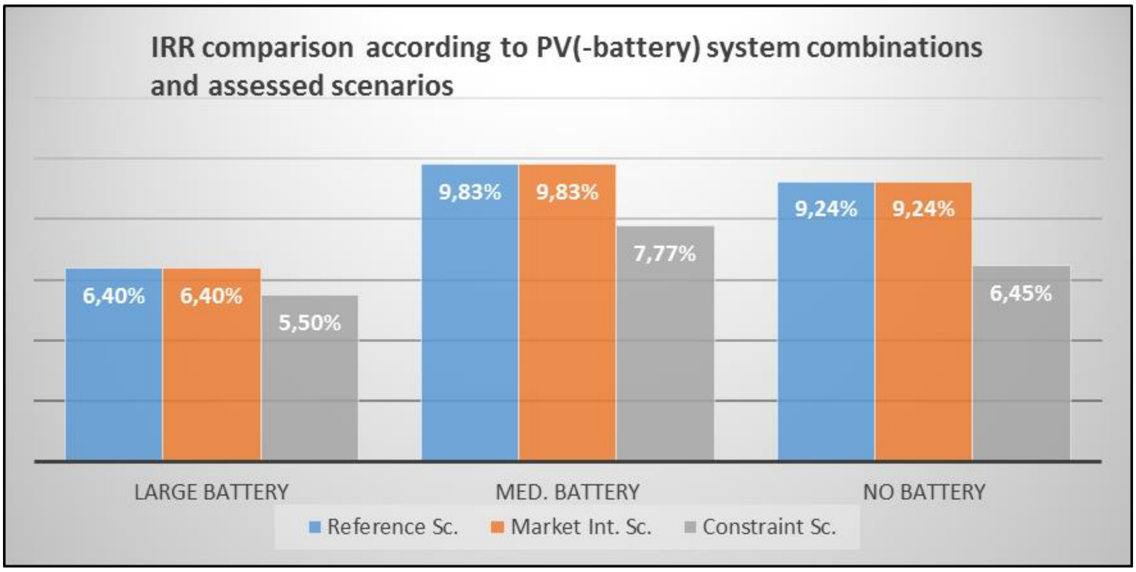


Figure 24 : Overview of IRR in relation to PV(-battery) system and assessed policy designs for Portuguese residential consumers

The rule of thumb to cut off projects that exceed a lifetime of 15 years if their IRR is not slightly above "the inverse of the pay-back period" (Blok, 2007) is realised when comparing Figure 24 and Table 10:

- PV systems combined with large batteries meet this criterion only in the reference/market integration scenario.
- PV systems combined with a medium battery match this criterion also in the constraint scenario.
- PV only systems exceed the required IRR only within the reference/market integration scenario.

Table 10 : Cut off values for assessed systems and scenarios in Portugal[17]

	Reference / Market Int. Sc.		Constraint Sc.	
	Cut off value	**Difference to IRR**	**Cut off value**	**Difference to IRR**
PV syst. with large battery	6,25%	0,15%	5,88%	-0,39%
PV syst. with medium battery	8,33%	1,49%	7,14%	0,63%
Simple PV syst.	8,33%	0,9%	6,67%	-0,21%

However, as the residential sector commonly does not have specific decision criteria that define critical amortisation times and or IRRs (Blok, 2007), implicit consumer discount rates for PV(-battery) systems may be sufficiently met even in case of slightly worse results – especially when considering additional non-economic benefits such as increased self-sufficiency.

In addition to the above analysis Box 2 provides an insight in the discounted and OPEX corrected average annual and monthly benefits that can be realized in the respective policy scenarios.

[17] Note that the rule of thumb refers to the simple payback period, i.e. the point in time when the (undiscounted) cumulative cash-flows become positive.

Box 2: Benefit comparison of PV-battery system combinations over total lifetime (25 years) in respect to assessed policy scenarios

Reference / Market Int. Sc.	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remun-eration of excess el.) [€]	Annual	**802**	**670**	**441**
	Month	**67**	**56**	**37**
Dynamic Payback Period [Years]		**20**	**14**	**15**

- A large battery system achieves an average annual electricity cost reduction plus an additional revenue stream from excess electricity of 802 €. This reduces the consumers' electricity bill by about 67 € every month over the next 25 years. However, the high investment costs (and higher operational expenses) of this type of system require rather long DPBPs of about 20 years.
- A PV system without a battery has a DPBP of only 15 years. Nonetheless, due to lower self-consumption (lower savings on electricity costs), the average monthly benefits are reduced to about 37 €.
- Combining a PV system with a medium sized battery reduces the electricity bill by about 56 € per month while the DPBP is 14 years, i.e. one year below the system without a battery.

Constraint scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remun-eration of excess el.) [€]	Annual	**713**	**535**	**323**
	Month	**59**	**45**	**27**
Dynamic Payback Period [Years]		**22**	**17**	**20**

- Due to the fact that this scenario accounts for additional charges on self-consumption, the potential savings on electricity costs are reduced by 10 and 20 % for large and medium PV-battery combinations respectively. This leads to a reduction of monthly benefits by about 8 € (large battery) and 11 € (medium battery) and increases the amortization time by 2 and 3 years respectively when compared to the reference scenario.
- Despite the fact that the remuneration of excess electricity is kept at the same level as in the reference scenario, the additional reduction of 30% on the electricity cost saving potential reduces the monthly benefits by around 10 € for the simple PV system. Its DPBP is therefore increased by 5 years and it remains less interesting than a PV system with a medium battery. In fact, the DPBP in this scenario is only 2 years lower than for the PV system with a large battery.

Box 2: Assessment of DPBP and annual as well as monthly average benefit potential for residential consumers in Portugal

Sensitivity of outcomes upon crucial input parameters assessed (additional analyses are provided in Appendix II.II)

Assessment of a change in the discount rate

As can be seen in Figure 25 reducing the discount rate by 30% from 4% to 2,8% would result in a NPV increase of about 4 000, 3 200 and 2 000 € for the PV system combined with a large, medium and no battery respectively. The DPBPs for the PV only and medium battery combination in this case would be reduced by about 1 year whereas the DPBP for a system combined with a large battery would be reduced by 2 years. Furthermore, the analysis upon variations of the discount rate reveals cut off values (indicated by red boxes) of 6,4% (PV system with a large battery), 9,6% (PV system with a medium sized battery) and 9,2% (simple PV system) that lead to “close to zero” NPV results. Note that the NPV of a PV system combined with a large battery would exceed the NPVs of the two other assessed systems in case that discount rate of 0% would be applied.

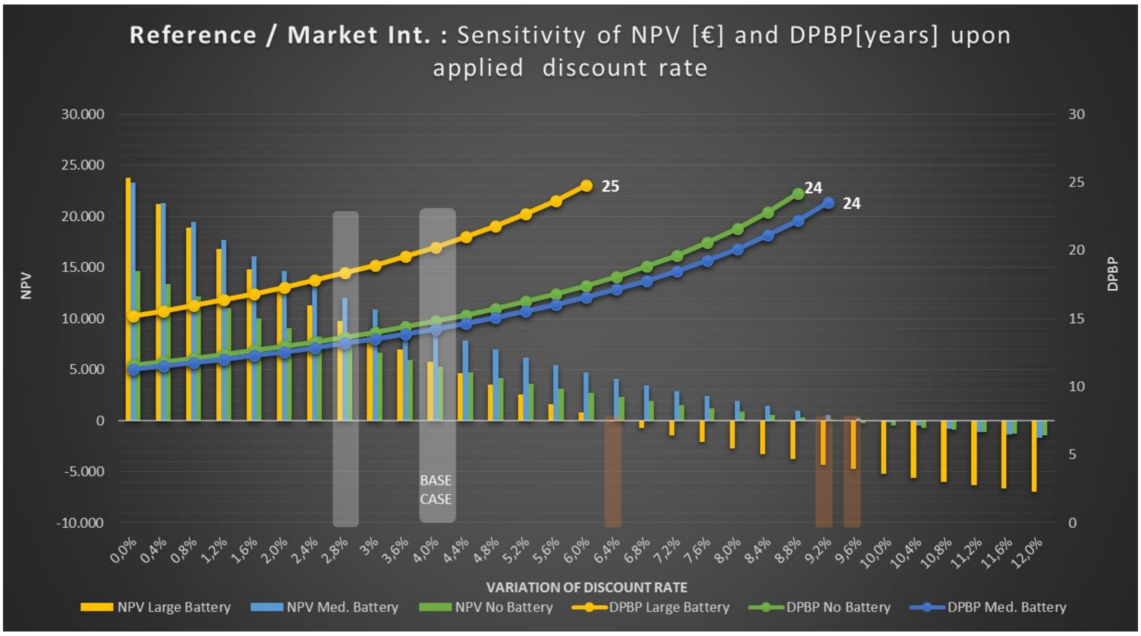


Figure 25 : Reference Sc. Portugal - One variable sensitivity analysis of potential discount rates

Assessment of a change in PV investment costs

A reduction of the PV investment costs by 30% (to 4 312 €) would increase the NPV by around 1 850 € for all systems (Figure 26). As a consequence, the IRR curve of the PV only system crosses the one combined with a medium sized battery slightly, indicating that the former system would achieve a slightly higher IRR than the system with a medium battery. Additionally, the DPBPs would be reduced by 2, 3 and 4 years for the PV system combined with a large, medium and no battery respectively. With higher PV investment costs on the other hand, the curves of the two systems expand, indicating that systems with a medium sized battery would have better results. Assuming that consumers would add battery storage to recently installed PV systems on which they paid a 20% VAT charge, while e.g. due to subsidy reasons this charge would not be applicable for the battery system, the PV only system would have a two years higher DPBP.

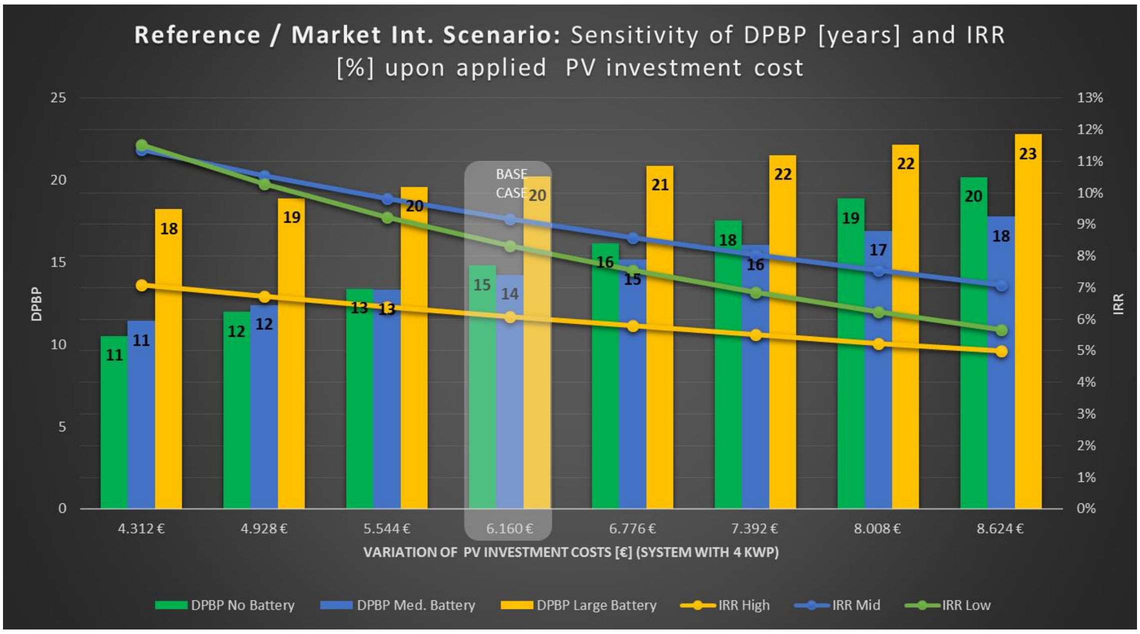


Figure 26 : Reference Sc. Portugal - One variable sensitivity analysis of PV investment costs

Assessment of a change in battery investment costs (Figure 27)

With regard to the variation of the assumed battery investment costs, it becomes obvious that a reduction of 50% would lead to a break-even of the PV system combined with a large battery and the simple PV system. Within the next two years (assuming an annual investment cost reduction of 30% for batteries (Deutsche Bank, 2015)) a PV system combined with a medium sized battery would achieve an IRR of 12% (DPBP of 12 years) while a combination with a large battery would realize an IRR of 10 % (DPBP of 14 years) in respect to the reference scenario and assumptions taken in this report. This indicates that a combination of a PV system with batteries is very likely to be more beneficial than PV only systems with IRRs of around 9% in rather short time-frames. Additionally, it can be seen that both battery system combinations would remain beneficial even when their investment costs were 50% higher. However, the DPBP of the large battery system would be close to 25 years in this case. The increase of the DPBP in relation to higher investment costs for the medium sized battery system combination on the other hand is less steep and amounts to only two years when compared to the base case.

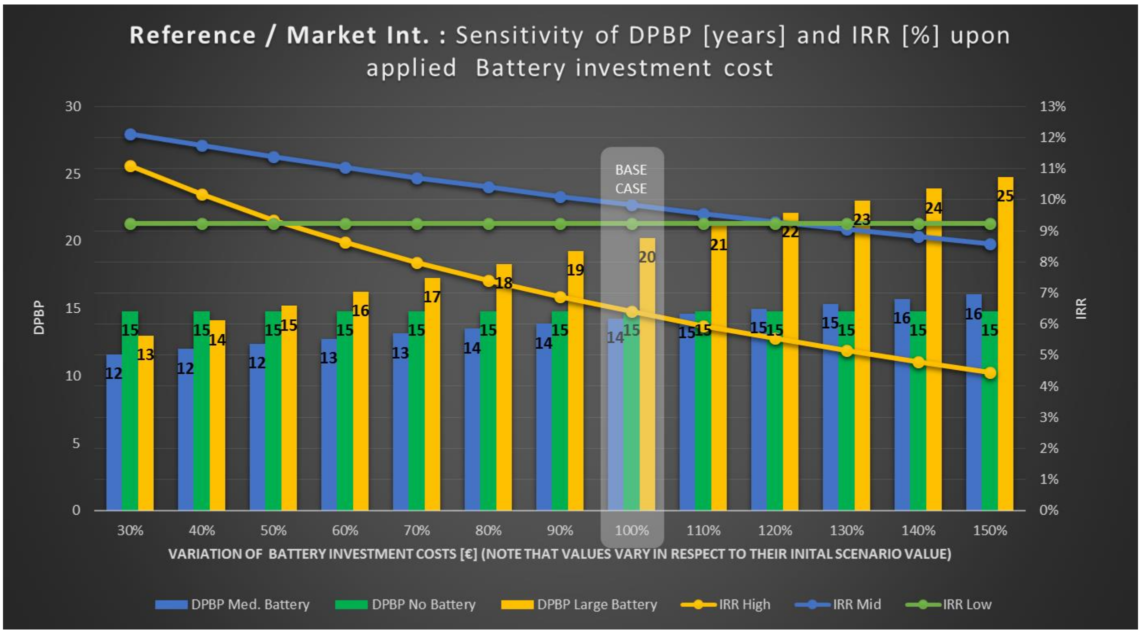


Figure 27 : Reference Sc. Portugal- One variable sensitivity analysis of Battery investment costs

Assessment of a change in the assumed electricity price increase

Considering the assumed electricity price increase, Figure 28 reveals that a system combined with a large battery relies on an annual price increase of about 4,6% over the entire assessment period in order to remain a DPBP of below 25 years. A PV system combined with a medium sized or no battery on the other hand would remain an IRR of around 4% (slightly higher for the system without a battery) even if the electricity price would not increase at all, however, the corresponding amortization times would be above 25 years. Considering an el. price increase of only one percent would result in DPBPs of about 22 and 21 years (system with a medium and no battery respectively).

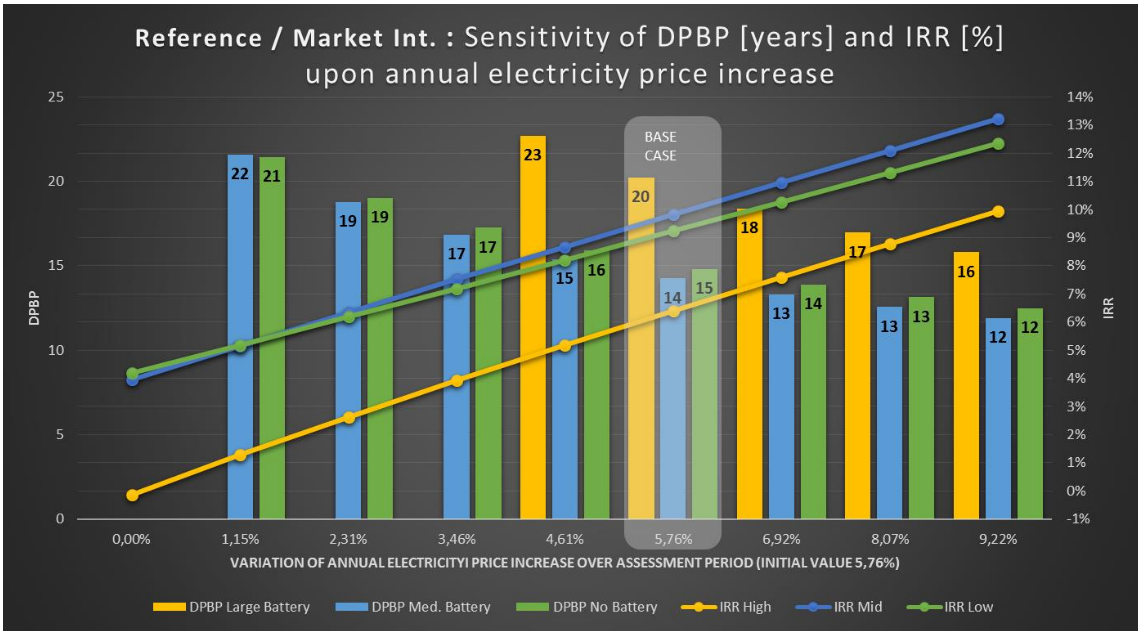


Figure 28 : Reference Sc. Portugal - One variable sensitivity analysis on variations of the assumed el. price increase

In case electricity prices annually decrease by 1,7% over the assessment period, all system variants would have negative NPVs based on the initially applied discount rate of 4%. PV only and systems combined with a medium sized battery however would reach a break-even in case that the discount rate would be lowered to about 3 and 2 % respectively. This can be derived based on Table 11.

Table 11: Impact of annually decreasing electricity prices on residential systems in Portugal:

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 7843	> 0	< assessment period
Medium battery	- 1531	2	< assessment period
No battery	- 738	3	< assessment period

Interim conclusions based on analysed outcomes and sensitivity analyses

- Overall, with respect to all policy scenarios, PV(-battery) system combinations as well as economic indicators assessed, it can be concluded that an investment in PV systems remains economical (and exceeds – or is at least close to so – estimated cut-off values based on common rules). However, simple PV systems remain the least risky investment due to lower investment costs while achieving similar results as systems combined with medium batteries. Consequently, low income groups may prefer this type of system, however, when neglecting aforementioned circumstances, investors would prefer PV systems combined with a medium sized battery as they achieve the highest benefits when compared to systems without and or a large battery.
- However, it is clear that the differences of the final outcomes with regard to the PV only and system combined with a medium sized battery are rather small (IRR and DPBPs are very close) and that, for example based on slightly higher battery investment costs the PV only system would achieve better economic results.
- Nevertheless, the case of Portugal, with a policy design that has already taken a further step towards market integration of solar PV (excess electricity is remunerated below wholesale prices), demonstrates what has been concluded for Germany: PV systems combined with medium batteries are the preferable investment option when remunerating the excess electricity based on wholesale prices (note that Portugal has significant higher irradiation and therefore results overall in better economic outcomes compared to Germany).
- The outcomes of the sensitivity analyses confirm that PV(-battery) system combinations are economical by showing that even in case that input parameters within the assessed scenarios would be changed such that they would have a negative impact on the economic results (e.g. higher discount rates, higher investment costs, lower and or no electricity price increases Figure 25 to 27) the final outcomes would remain positive, i.e. no net losses. With regard to the electricity price increase however it must be mentioned that in case of annual decreases business cases may become negative based on the initially assumed discount rates.
- Finally, with declining technology costs for PV systems but more importantly for batteries, a combination with medium sized batteries is likely to remain the best investment option in respect to all scenarios in short to medium timeframes.
- Overall, the results indicate that investments in solar PV can be expected to prevail, especially when considering additional non-economic benefits, and when bearing in mind declining investment costs and or that high income groups are likely to apply lower discount rates.

3.1.3 United Kingdom

Overview of numeric overall outcomes and "heat-map" of all scenarios and PV-battery combinations

Table 12 : Overview of the economic evaluation for the UK residential market

Self-consumption [%] / Battery size [kWh net]		Reference Sc.			Market Int. Sc.			Constraint Sc.		
		NPV [€]	IRR [%]	DPBP [years]	NPV [€]	IRR [%]	DPBP [years]	NPV [€]	IRR [%]	DPBP [years]
High ≈ 66%	**8,3**	6 406	7,08	17,6	- 4 315	1,73	26	5 068	6,5	18,8
Medium ≈ 46%	**2,3**	11 131	12,6	9,91	222	4,19	25,43	9 266	11,46	10,84
Standard ≈ 27%	**0**	11 088	16,07	7,42	- 1	4	26	9 446	14,74	8,06

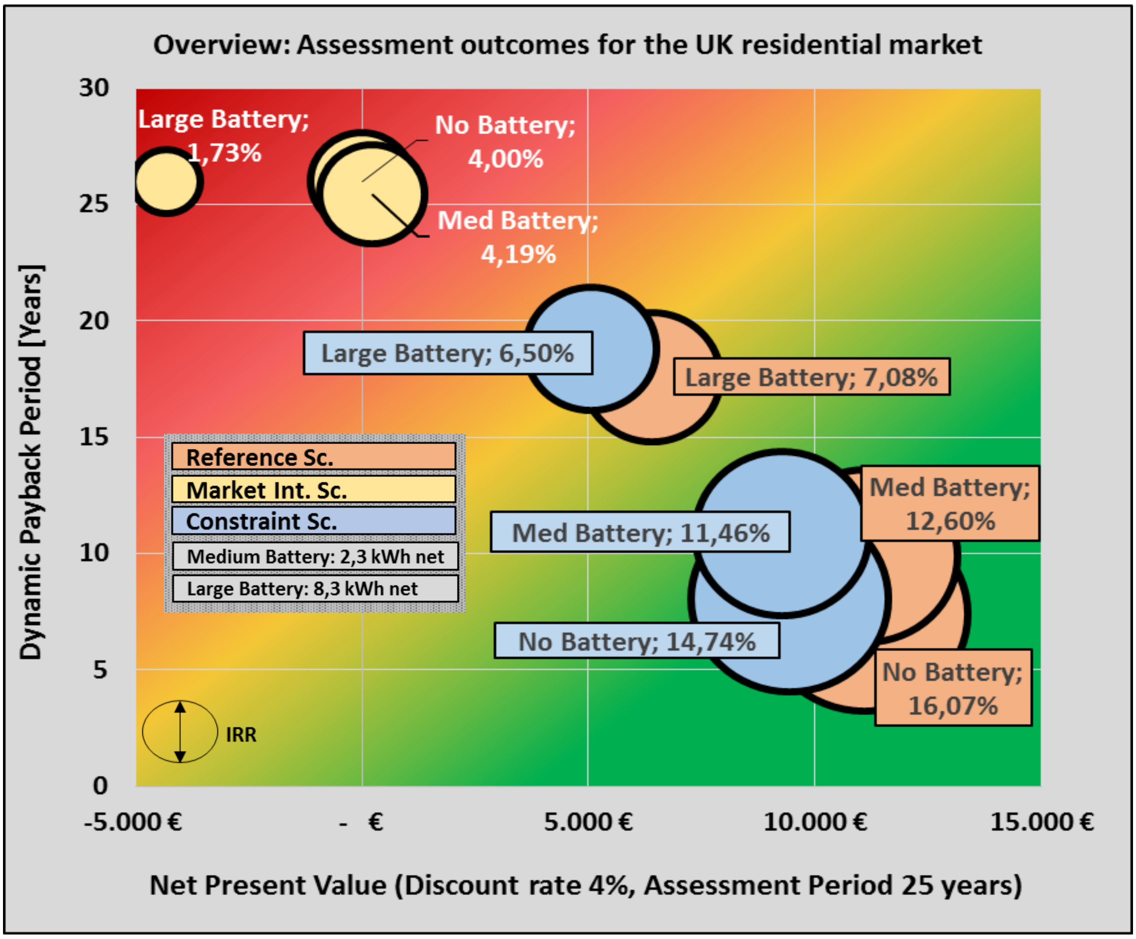


Figure 29 : Illustration and comparison of economic indicators for the German residential market

The following summarises the highlights that can be extracted based on the overall outcomes in Table 12 and Figure 29:

- For all scenarios and investigated systems, the reference scenario realises the best economic results, closely followed by the constraint scenario. The worst outcomes are related to the market integration scenario.
- Within the reference scenario, the most favourable results are achieved by a PV system without a battery, followed by a PV system with a medium sized (2,3 kWh net) battery (green area in Figure 29). A combination with a large battery (8,3 kWh net) system results in a DPBP that slightly exceeds 16 years, an IRR of above 7% and a corresponding NPV of approximately 6 000 € (yellow area). Although aforementioned results may seem sufficient enough to invest in such a system combination, the two other assessed system variants clearly perform better (IRRs of about 16 and 12 % for a PV only and a PV system combined with a medium battery respectively). Consequently, the version with a large battery remains the least interesting case from a pure economic perspective – which is valid for all assessed scenarios.
- Two of the four cases that are placed in the greenish area relate to the constraint scenario and PV systems with no and or a medium sized battery. Their economic benefits are slightly below the ones achieved by the same system types in the reference scenario (IIRs are roughly 1% lower). Similarly, the second case within the yellow area is related to the constraint scenario and a large battery system, which would again achieve slightly lower results when compared to the reference scenario (e.g. one year higher DPBP and about 1 400 € lower NPV).
- Considering the outcomes of the market integration scenario, all system types assessed are placed in the red area. While PV systems with a large and or no battery result in small losses and DPBPs of above 25 years, the only system that provides at least a small benefit (222 €) is the PV system combined with a medium sized battery.

Considering the overall comparison of all scenarios, the following provides detailed background information, insights and analyses:

Developments of electricity costs

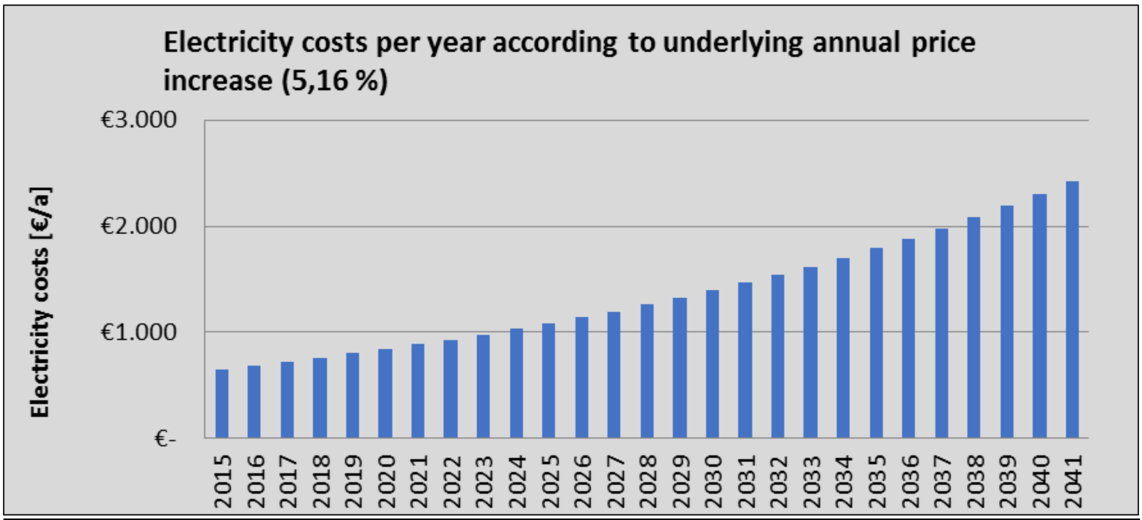


Figure 30 : Assumed electricity cost development for residential consumers in the UK

It can be seen that the total annual electricity costs of an average household would increase from about 650 € to about 2 400 € over the assessment period (assuming an average consumption of 3500 kWh/a and an initial price of 0,1966 €/kWh in 2015). This is important to keep in mind for the following analyses[18]:

[18] Note that in the course of the study el. price forecasts up to 2030 produced by an official entity in the UK were found. Nevertheless, the described method used for assuming price increases in this study was maintained since the respective forecasts regarding their average price increase are assessed and highlighted in the sensitivity analyses. The mentioned forecasts refer to the following three scenarios and a corresponding annual average increase of the el. price:

- High: ≈ 2 %
- Central: ≈ 1,5 %
- Low: ≈ 1%

Source: gov.uk, 2012

<u>The *present value* of benefit streams over the assessment period</u>

Figure 31 illustrates the *present value* (light green area) of the benefit streams, i.e. electricity costs saved, generation tariff and remuneration of excess electricity. It becomes obvious that large battery systems achieve the highest accumulated benefits over the assessment period for all scenarios, whereas PV systems without batteries realise the lowest total benefits when directly comparing the assessed scenarios. This is since the electricity cost saving potential (on average for all scenarios) has a share of 56 %, while the generation tariff and remuneration of excess electricity contribute 37 % and 7% to the total benefit values respectively.

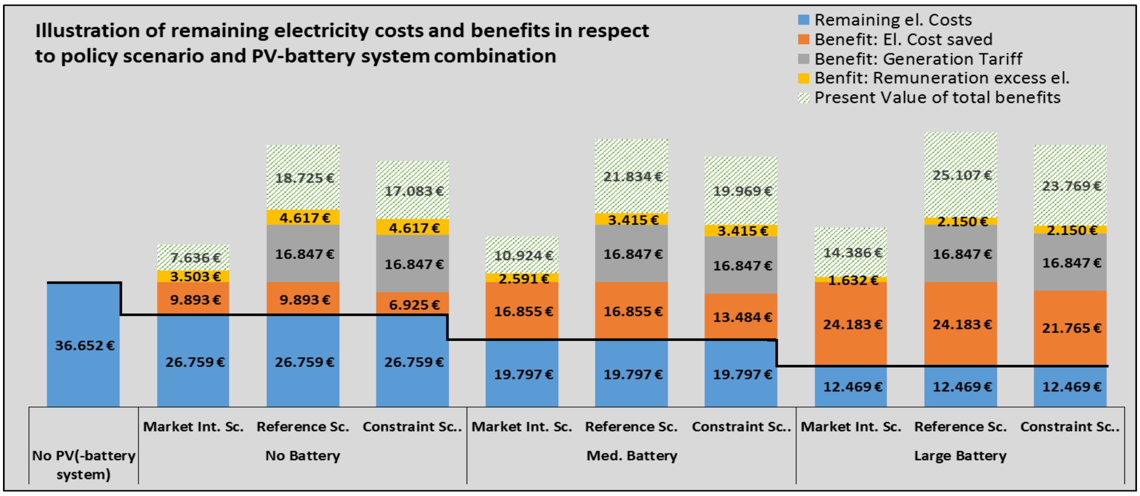


Figure 31 : Electricity cost comparison according to PV-battery system and illustration of discounted cumulative benefits for residential consumers in the UK

Taking a closer look at Figure 31 reveals that the ability to save upon electricity costs is only a major contributor to the benefits within the market integration scenario (for all system types) and – with regard to the other scenarios – in case that PV systems are combined with large batteries.

This is different in the reference and constraint scenarios with regard to PV systems without a battery. In this case the major contributor to the total benefits is clearly the generation tariff.

With regard to PV systems combined with a medium battery, the electricity cost saving potential and generation tariff contribute almost equally to the total benefits (difference of about 8 €) in the reference scenario, whereas in the constraint scenario, the generation tariff has a higher share (around 3 300 €) when compared to the electricity cost saving potential.

Overall, it becomes obvious that the reduction of the el. cost saving potential (10, 20 and 30% for PV systems combined with a large, medium and no battery respectively) within the constraint scenario reduces the respective benefit stream only by around 2 400, 3 400 and 3 000 € correspondingly) when compared to the reference scenario. The complete reduction of the generation tariff (as in the market integration scenario) and a lower remuneration level for excess electricity on the other hand have a much higher impact on the total benefits (a reduction of more than 15 000 € for all assessed system types).

Direct evaluation of investment and total operational costs in relation to the present value of benefit streams

The investment (dark grey and orange number) and total operational (light grey and red number) costs in relation to the present value of benefit streams are shown in Figure 32. It illustrates that the highest monetary net benefit (11 131 €) is achieved in the reference scenario based on a PV system combined with medium sized battery, followed by a system without a battery (11 088€). The lowest net benefit is 222 € and relates to a system with a medium battery in the market integration scenario, based on which the remaining system variants with a large and or no battery result in net losses (4 315 and 1 € respectively).

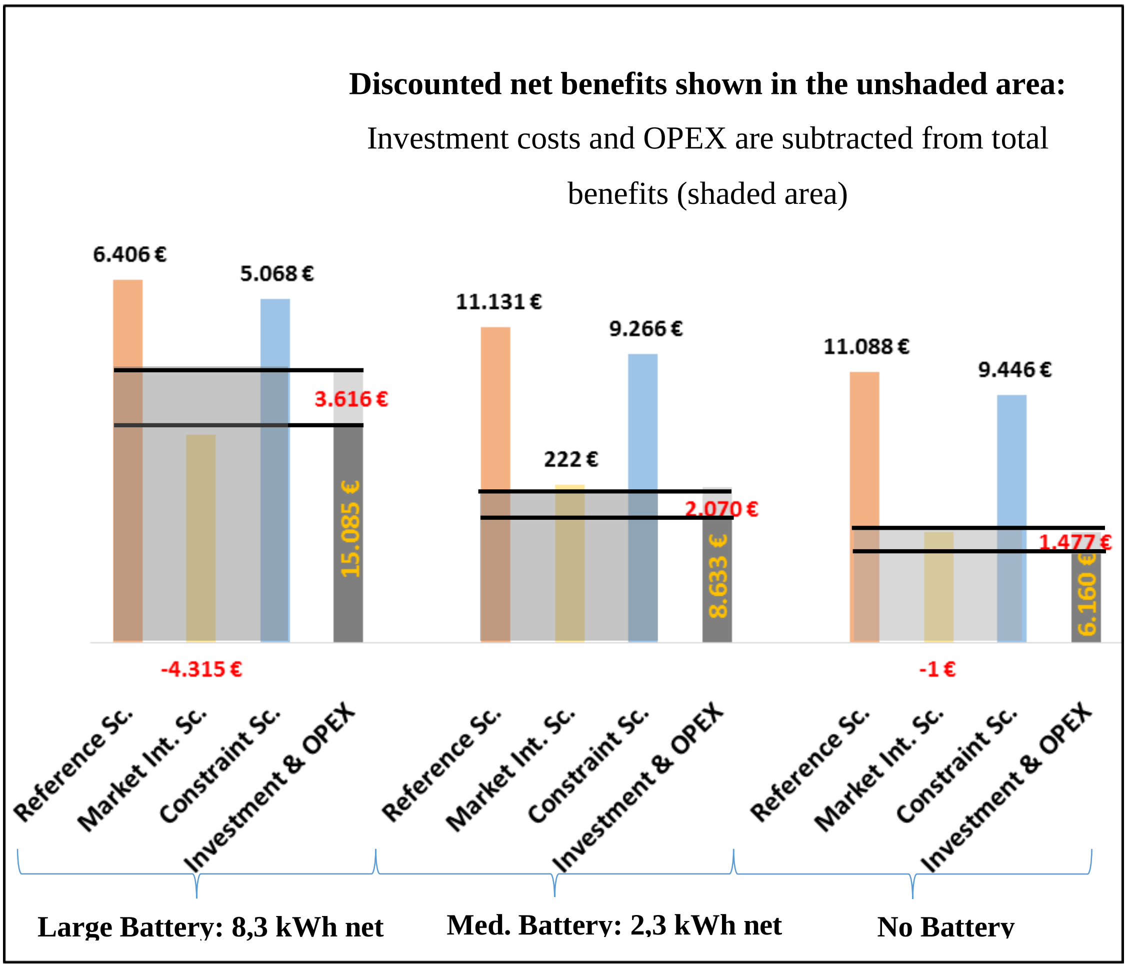


Figure 32 : Discounted net benefits in respect to investment costs and OPEX for residential consumers in the UK[19]

[19] Assumes battery investment costs of 1075,26 €/kWh and PV system costs of 1540 €/kWp (with 1,5 % annual OPEX in respect to investment costs for each of the system components)

Cash flows indicating the dynamic payback period

The cash flow diagrams (Figure 33 to 35) illustrate the discounted and net cumulative as well as annual benefit developments over time. Based on the cash flow diagrams, it can be deduced that a PV-only system is the first variant that reaches its break-even point in the reference and constraint scenario (Figure 33 and 35 respectively), whereas the PV system combined with a medium battery amortises slightly faster in the market integration scenario (Figure 34). With regard to the latter scenario, the simple PV system however has the highest NPV (ergo lowest loss before amortization) until year 25 when its cumulative benefits are exceeded by the PV system combined with a medium sized battery.

Likewise, within the reference scenario, the PV only system remains to have the highest net benefits after the break-even point until the illustrated cumulative curve of the PV system combined with a medium battery intersects shortly before the end of the assessment period (note that this is similarly valid for the constraint scenario in which the curves emerge but do not intersect, meaning that the PV only system remains to have higher cumulative benefits as was shown in Figure 32).

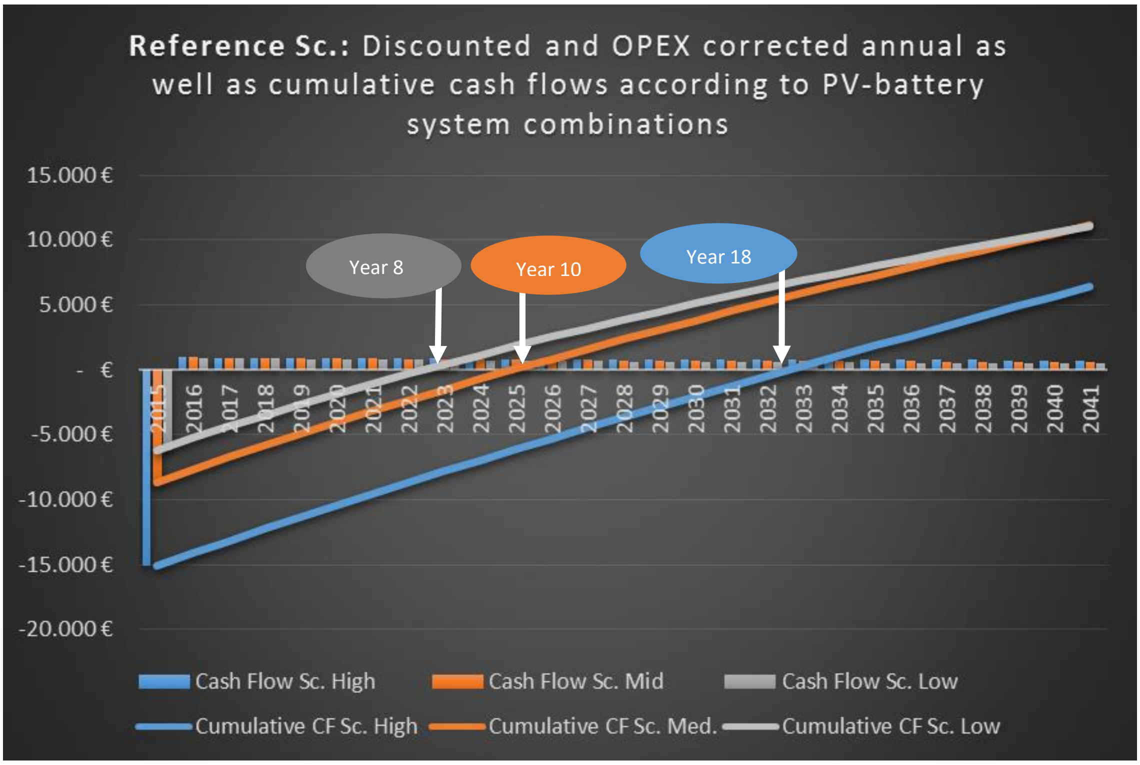


Figure 33 : Cash Flow developments according to the reference sc. in the UK residential market

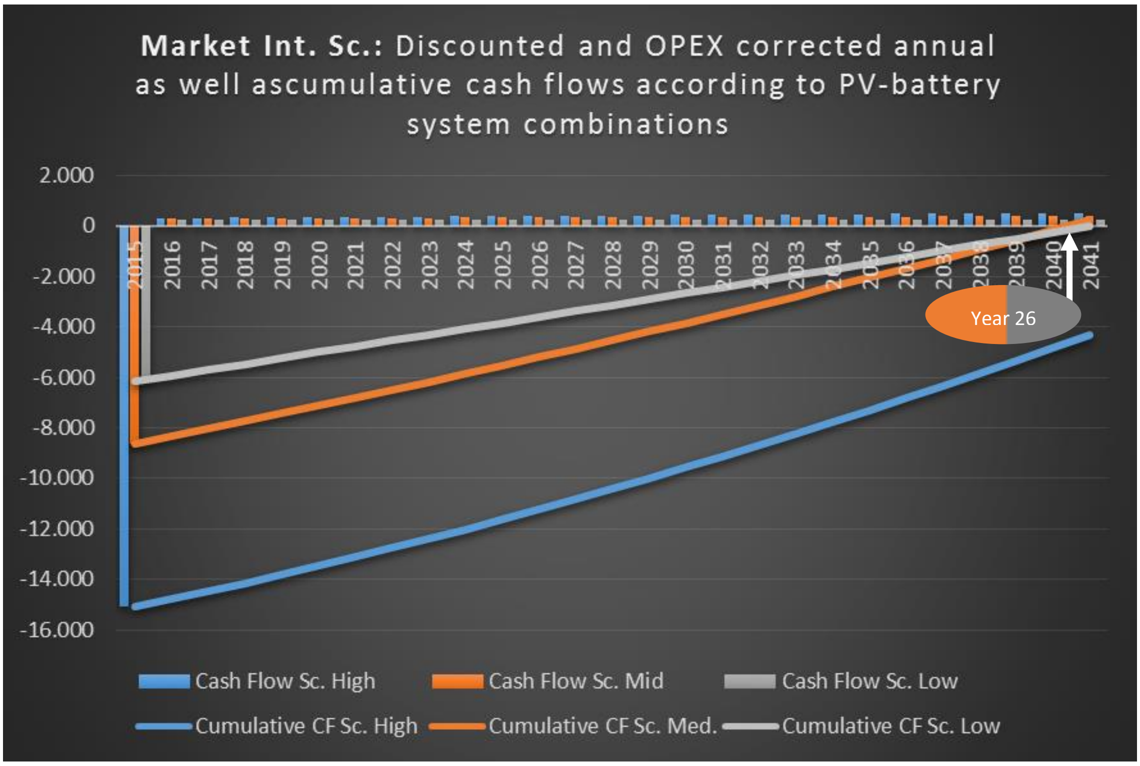


Figure 34 : Cash Flow developments according to the market int. sc. in the UK residential market

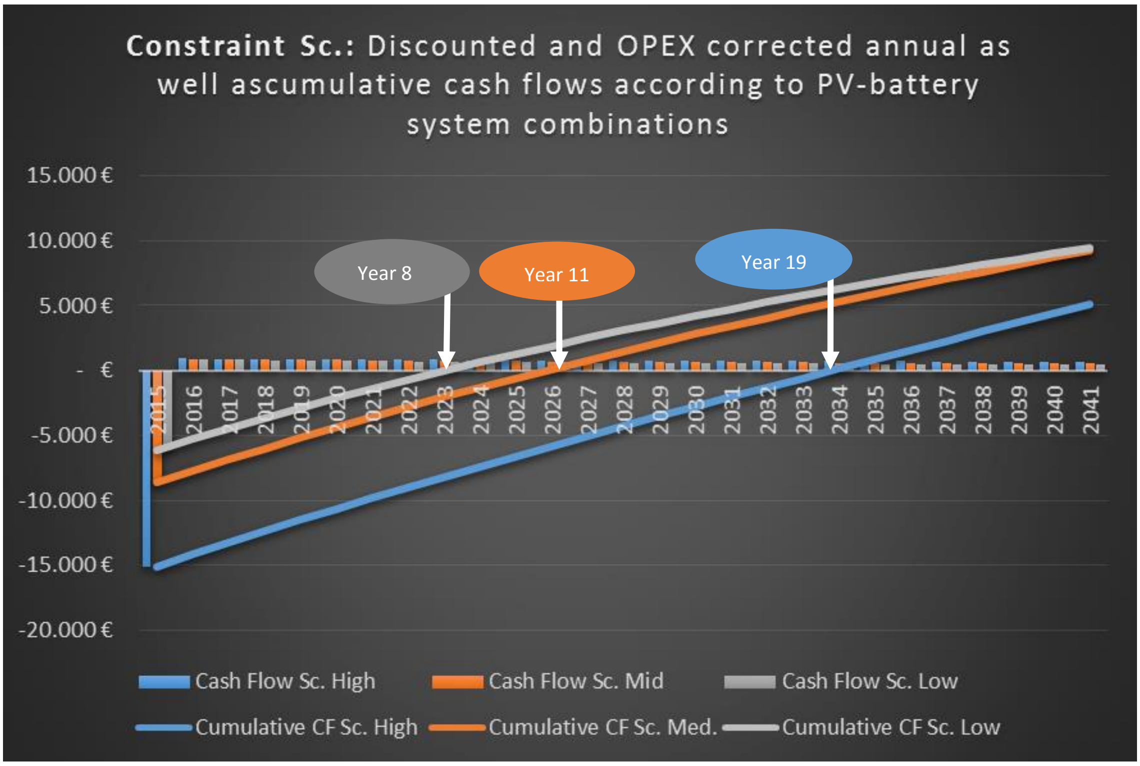


Figure 35 : Cash Flow developments according to the constraint sc. in the UK residential market

IRR comparisons

Figure 36 compares the IRR of the various PV(-battery) system combinations within the assessed policy design scenarios.

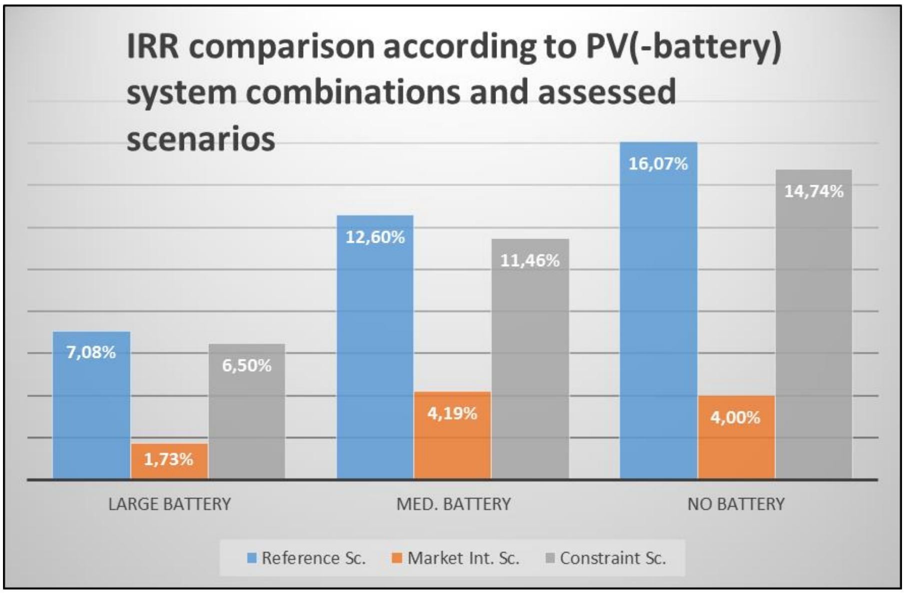


Figure 36 : Overview of IRR in relation to PV(-battery) system and assessed policy designs for UK residential consumers

The rule of thumb to cut off projects that exceed a lifetime of 15 years if their IRR is not slightly above "the inverse of the pay-back period" (Blok, 2007) is realised when comparing Figure 36 and Table 13

- PV systems combined with large batteries do not meet this criterion in any scenario.
- PV systems combined with a medium and or no battery match this criterion within the reference and constraint scenario.

Table 13 : Cut off values for assessed systems and scenarios in the UK [20]

	Reference Sc.		Market Int. Sc.		Constraint Sc.	
	Cut off value	Difference to IRR	Cut off value	Difference to IRR	Cut off value	Difference to IRR
PV syst. with large battery	7,7%	-0,61%	4,35%	-2,62%	7,14%	-0,64
PV syst. with medium battery	11,11%	1,49%	5,56%	-1,37%	11,11%	0,34
Simple PV syst. (no battery)	14,3%	1,79%	5,56%	-1,56%	14,29%	0,46

[20] Note that the rule of thumb refers to the simple payback period, i.e. the point in time when the (undiscounted) cumulative cash-flows become positive.

Nevertheless, as the residential sector commonly does not have specific decision criteria that define critical amortisation times and or IRRs (Blok, 2007), implicit consumer discount rates for PV(-battery) systems may be sufficiently met even in case of slightly worse results – especially when considering additional non-economic benefits such as increased self-sufficiency.

In addition to the above analysis Box 3 provides an insight in the discounted and OPEX corrected average annual and monthly benefits that can be realised in the respective policy scenarios.

Box 3: Benefit comparison of PV-battery system combinations over total lifetime (25 years) in respect to assessed policy scenarios

Reference Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs +generation tariff + remuneration of excess el.) [€]	Annual	**827**	**760**	**663**
	Month	**69**	**63**	**55**
Dynamic Payback Period [Years]		**18**	**10**	**7**

- A large battery system achieves an average annual electricity cost reduction plus additional revenue streams from excess electricity and generation tariff of 827 €. This reduces the consumers' electricity bill by about 69 € every month over the next 25 years. However, the high investment costs (and higher operational expenses) of this type of system require rather long DPBPs of about 18 years.
- A PV system without a battery has a DPBP of only 7 years. Despite that this system has lower savings on electricity costs, the benefits are substantial due to the high remuneration of excess electricity and the generation tariff. The average monthly benefits are therefore only reduced to about 55 €.
- PV systems with a medium battery reduce the el. bill by about 63 € a month and increase the DPBP by three years when compared to a PV only system.

Market Integration Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs +generation tariff + remuneration of excess el.) [€]	Annual	**414**	**341**	**237**
	Month	**35**	**28**	**20**
Dynamic Payback Period [Years]		**NA**	**25**	**NA**

- As in the reference scenario, a PV system combined with a large battery results in the highest possible benefits and reduces the consumers bill by about 35 € per month. The savings of the reference scenario are almost reduced by a factor of 2.
- Due to the fact that the remuneration of excess electricity is lower (0,52 €/kWh instead of 0,068 €/kWh) and that the generation tariff is not applicable compared to the reference scenario, the PV systems combined with large or no batteries do not amortize within the assessment period. A PV system with a medium battery however faces way higher amortization times of 15 years while its monthly benefits are reduced by a factor of two when compared to the reference scenario.

Constraint Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs +generation tariff + remuneration of excess el.) [€]	Annual	**775**	**688**	**600**
	Month	**65**	**57**	**50**
Dynamic Payback Period [Years]		**19**	**11**	**8**

- Due to the fact that this scenario accounts for a grid charge, the potential savings on electricity costs are reduced by 10 and 20 % for large and medium PV-battery combinations respectively. This leads to a reduction of monthly benefits by about 4 € (large battery) and 6 € (medium battery) and increases the amortization time by about 1 years for both cases when compared to the reference scenario.
- As the remuneration of excess electricity as well as the generation tariff are kept at the same level as in the reference scenario, a simple PV system achieves the most favorable result with regard to the DPBP. The assumed 30% reduction of the electricity cost saving potential for this system under this scenario has similar effects on the monthly savings (reduced by about 5 €) as for the other assessed system combinations.

Box 3: Assessment of DPBP and annual as well as monthly average benefit potential for residential consumers in the UK

Sensitivity of outcomes upon crucial input parameters assessed (additional analyses are provided in Appendix II.III)

Assessment of a change in the discount rate

As can be seen in Figure 37 reducing the discount rate by 30% from 4% to 2,8% would result in a NPV increase of about 3 600, 3 100 and 2 700 € for the PV system combined with a large, medium and no battery respectively. The DPBPs for the PV only and medium battery combination in this case would be reduced by about 1 year whereas the DPBP for a system combined with a large battery would be reduced by 2 years. Furthermore, the analysis upon variations of the discount rate reveals a cut off value (indicated by the red box) of about 6,8% for the PV system with a large battery to remain at least slightly profitable. For PV systems with a medium or no battery, the NPV would be around 400 and 2 000 € respectively in case the discount rate would be as high as 12 %. Note that the PV system combined with a large battery would achieve very similar NPV results as the PV only system in case a discount rate of 0% would be applied.

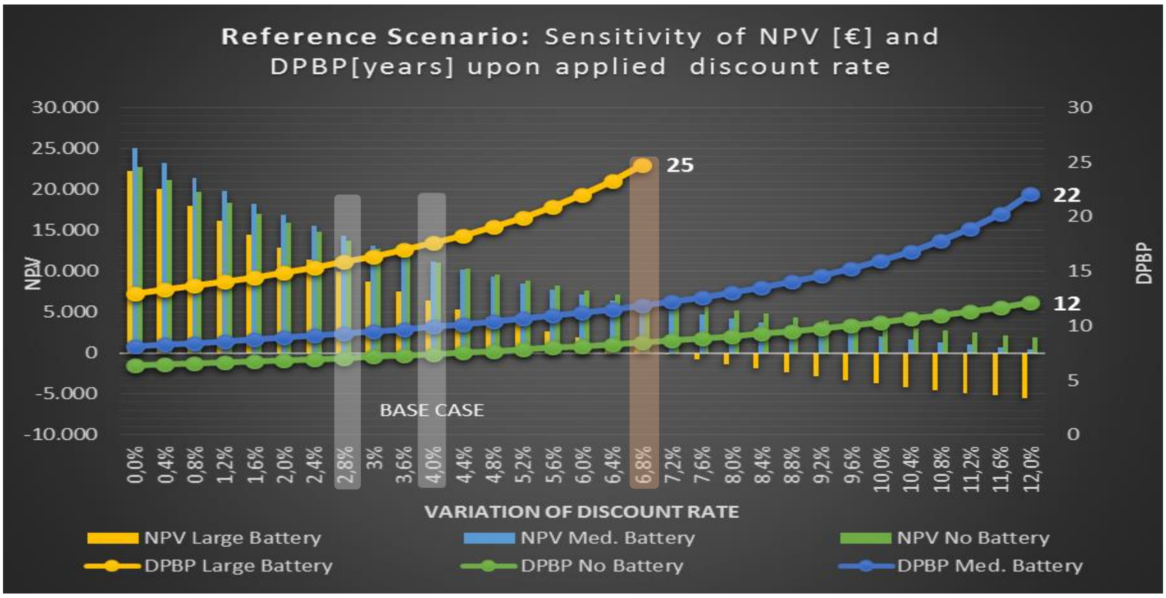


Figure 37 : Reference Sc. UK - One variable sensitivity analysis of potential discount rates

Assessment of a change in total investment costs

In order to illustrate the potential impact in case that the full VAT of around 20% would need to be paid, Figure 38 shows how a variation of the total investment costs would change the assessed indicators. It becomes obvious that a 20% increase would still result in adequate economic results for the simple and medium battery PV-system combination, whereas the version with the large battery would be related to a rather high DPBP (around 22 years) and an IRR of around 5%).

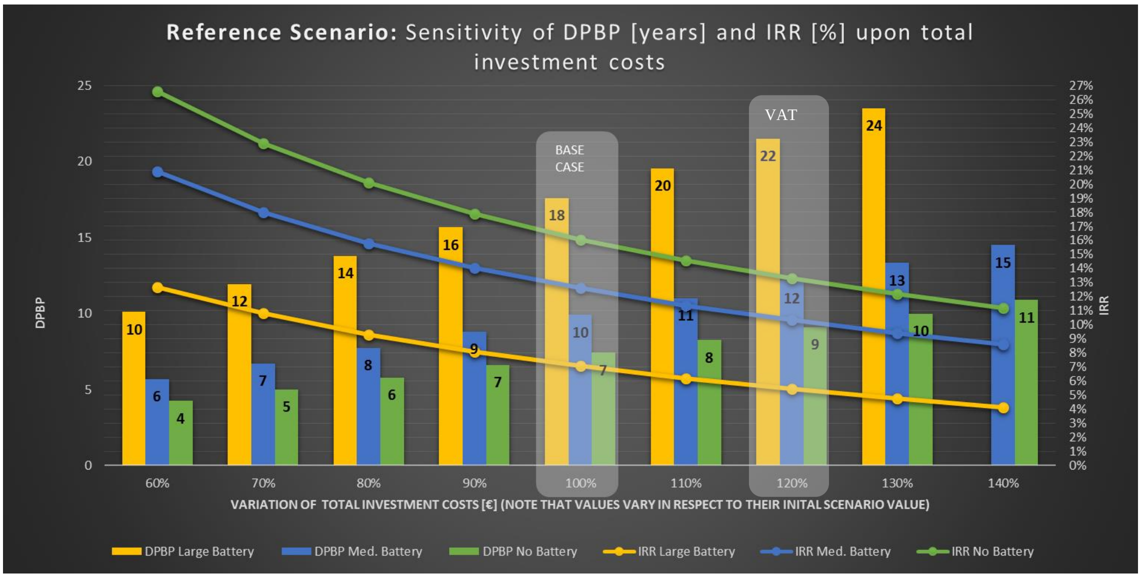


Figure 38 : Reference Sc. UK - One variable sensitivity analysis on variations of the assumed total investment costs

Assessment of a change in the assumed electricity price increase (Figure 39)

With regard to the assumed electricity price increase the analysis below reveals that all assessed system types under the reference scenario would remain profitable even if the price would not increase at all. Considering the official average price forecasts until 2030 (which are assumed to be valid also for the remaining assessment period of this study), it can be derived that these would increase the DPBP of PV systems combined with a medium and or no battery by only around one year compared to the base case. With regard to systems with a large battery, the DPBP would be increased by around 3, 4 and 5 years according to the high, central and low scenario respectively. This indicates that the economic benefits under this scenario are hardly impacted by a change in the electricity price. The most sensitive variation being the PV system combined with a large battery.

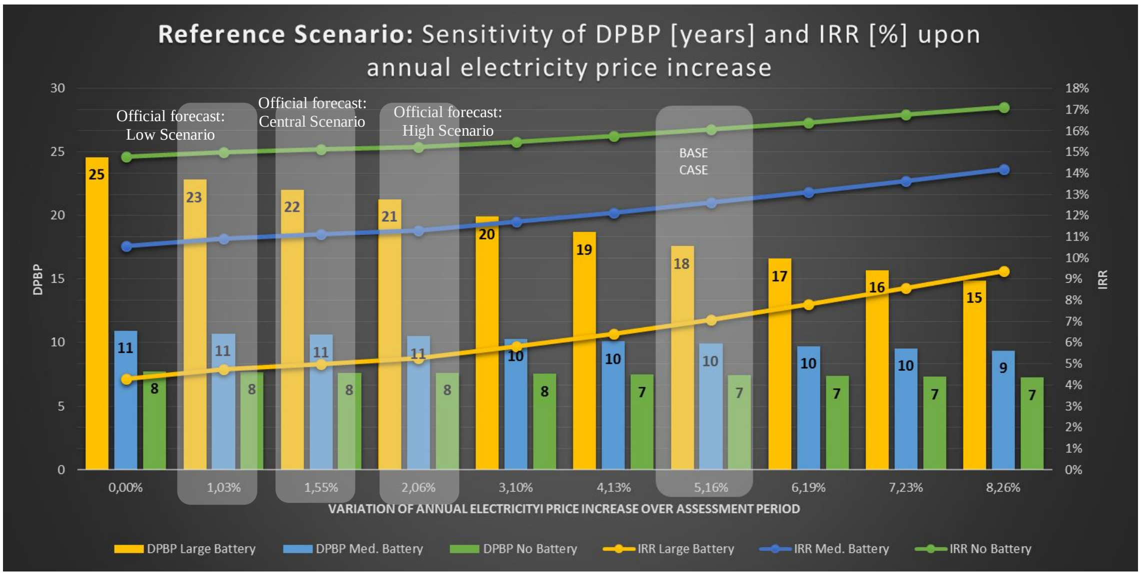


Figure 39 : Reference Sc. UK - One variable sensitivity analysis on variations of the assumed el. price increase

Although the official forecasts do not consider a potential decline in electricity prices, the additional assessment of an annually decreasing electricity price by 1,6% over the assessment period of this report (Table 14) reveals that the economic results of PV only systems and those combined with a medium sized battery would remain positive, while the overall outcomes of combinations with large batteries would be at the edge of being economical (slight losses).

Table 14 : Impact of annually decreasing electricity prices on residential systems in the UK:

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 451	4	< assessment period
Medium battery	6 267	10	11
No battery	8 233	14	8

Assessment of a change in battery investment costs

With regard to the variation of the assumed battery investment costs it becomes obvious that a reduction of 70% (see 30% value in Figure 40) would almost lead to a break-even of the PV system combined with a medium sized battery and the simple PV system. Based on the assumption that battery investment cost decrease annually by around 30% (Deutsche Bank, 2015)) and in case that the current support scheme would not be adapted it would take 2 to 3 years for the PV system combined with a medium battery to become an interesting investment alternative. The PV system combined with a large battery is the least interesting case even if costs were reduced by more than 70%. Additionally, it can be seen that all battery system combinations would remain beneficial even when their investment costs were 50% higher. However, the DPBP of the large battery system would be around 23 years, which is almost double as high as the DPBP for the medium battery system.

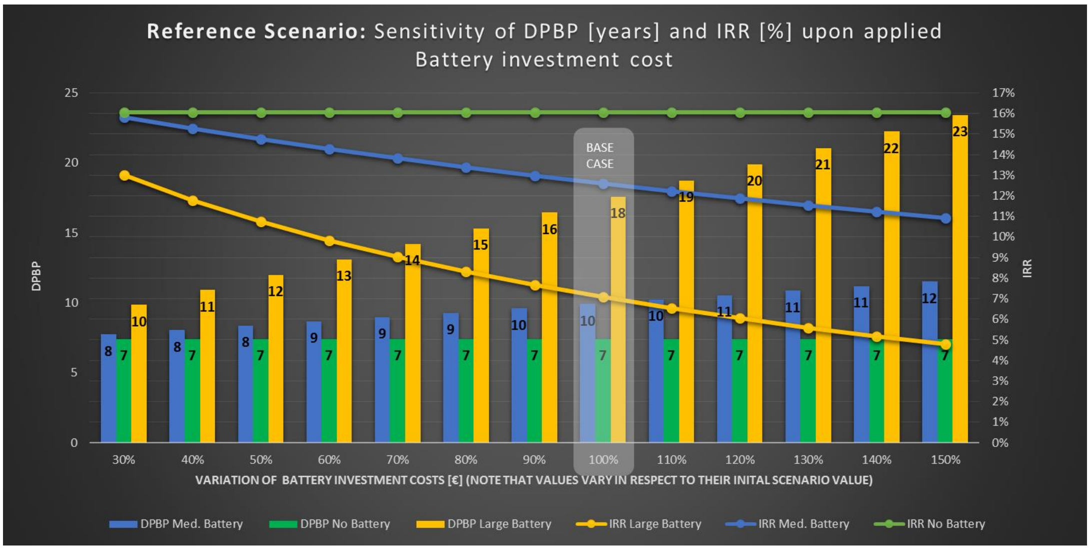


Figure 40 : Reference Sc. UK- One variable sensitivity analysis of Battery investment costs

Assessment of a change in the remuneration of excess electricity (Figure 41)

Although the overall benefits would decline, it can be seen that the initially small difference of the PV system combined with a medium battery compared to the PV only system would continue to grow in favour of the system with a battery in case the remuneration of excess electricity would be reduced. Similarly, in case that the remuneration would be completely phased out, the IRR curves of the PV only system and the one combined with a large battery intersect, indicating that the latter system would be the better investment alternative. Nevertheless, within the market integration scenario all systems are already at the edge of being economically beneficial and any further reduction of the remuneration of excess electricity would result in DPBPs higher than the assessment period, i.e. IRRs below or around 4%. Supposing that the remuneration of excess electricity increased (since this scenario assumes that the generation tariff is completely phased out), it can be seen that even a remuneration of 10 ct/kWh would not lead to a significant improvement for PV systems combined with a battery. (The DPBP of the variant with a medium battery would only be reduced by around 3 years, whereas the version with a large battery would be still above 25 years). This is different for the PV only system, which is most sensitive to an increase in the remuneration of excess electricity (as only around 30% of the produced electricity is self-consumed by using this system). Consequently, its IRR would be increased to around 7% while the DPBP would be reduced from more than 25 to around 19 years.

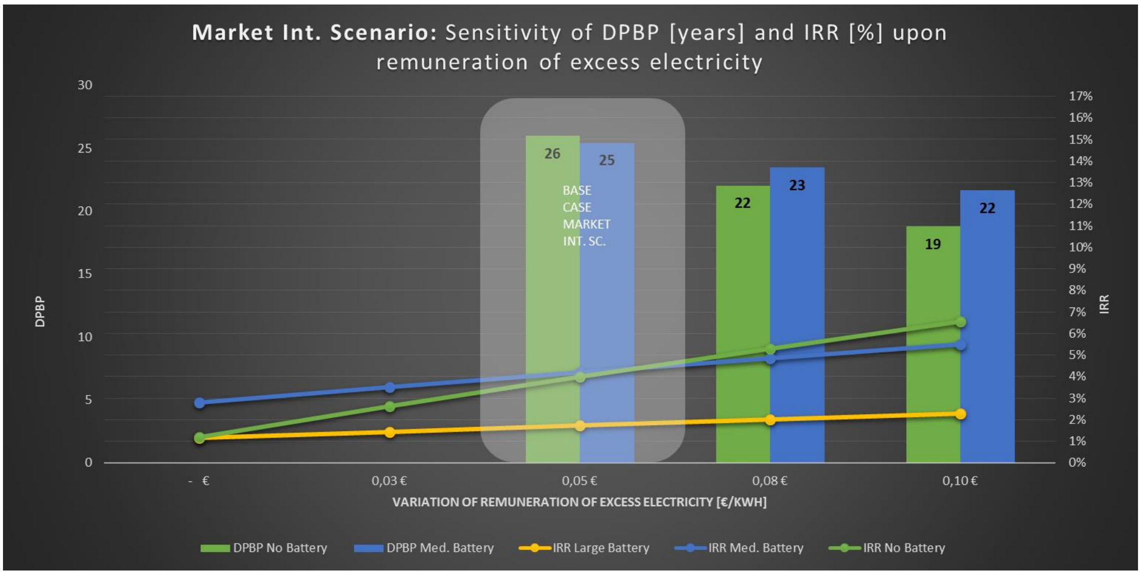


Figure 41 : Market Int. Sc. UK - One variable sensitivity analysis on potential variations of the remuneration of excess el.

Interim conclusions based on analysed outcomes and sensitivity analyses

- Overall, in respect to the reference and constraint scenario, it can be concluded that the assessed PV(-battery) system combinations achieve positive economic results that exceed – or are at least close to do so – estimated cut-off values based on common rules. In terms of IRR and DPBPs this is especially valid for the PV only variant, which achieves better economic results than systems combined with a medium sized or large battery. Consequently, this is very likely to trigger investments among all consumer groups in respect to aforementioned scenarios.
- Furthermore, with regard to the market integration scenario that assumes that the generation tariff is completely phased out it can be concluded that investments would become unattractive for all system types assessed (resulting in losses or close to zero NPVs and corresponding IRRs, i.e. below or around 4%).
- Nevertheless, assuming lower discount rates shows that the DPBPs of the medium sized battery and PV only system emerge strongly, indicating that high income groups that tend to have lower interest rates may find an investment in a combination with a medium battery more interesting, especially when considering declining technology costs.
- The outcomes of the sensitivity analyses for the reference and constraint scenario confirm this by showing that even in case that input parameters within the assessed scenarios would be changed such that they would have a negative impact on the economic results (e.g. higher discount rates, higher investment costs, lower electricity price increases etc.) the final outcomes would remain positive, i.e. no net losses. Similarly, when assuming an annual electricity price decrease the assessed system types would either be close to break-even and or continue to deliver beneficial outcomes. However, it becomes also clear that even strong changes that would favour battery installations, e.g. significant lower investment costs, would not be able to exceed the IRRs that are achievable with the PV only system.
- Although the PV system combined with a medium sized battery would achieve slightly better economic outcomes based on the initially assumed input parameters in the market integration scenario, the sensitivity analyses reveal that the PV only system could quickly break-even or achieve better results, e.g. in case that the remuneration of excess electricity would be slightly increased in this scenario. Overall, the generation tariff should not be phased out completely in case that the market integration scenario is implemented (due to low overall benefits). However, when considering a progressive reduction of the generation tariff in the other two scenarios (additional sensitivity analyses in Figure 100 and 108) reveals that such a development would incentivise

investments in combining PV with batteries (as the economic outcomes of PV-only systems and those combined with a battery would converge), especially when assuming an additional potential decline in the remuneration of excess electricity (keeping in mind the slightly favourable outcomes for batteries in the market integration scenario).

3.2 Cluster I: Economic assessment and interim conclusions for commercial consumers

3.2.1 Germany

<u>Overview of numeric overall outcomes and "heat-map" of all scenarios and PV-battery combinations</u>

Table 15 : Overview of the economic evaluation for the German commercial market

Self-consumption [%] / Battery size [kWh net]		**Reference Sc.**			**Market Int. Sc.**			**Constraint Sc.**		
		NPV [€]	IRR [%]	DPBP [years]	NPV [€]	IRR [%]	DPBP [years]	NPV [€]	IRR [%]	DPBP [years]
High ≈ 87%	**100**	8 553	6,89	24,66	1 591	6,57	25,75	- 11 495	5,95	NA
Medium ≈ 78%	**33,5**	31 851	8,21	20,77	20 521	7,61	22,49	- 4 371	6,25	NA
Standard ≈ 69%	**0**	43 089	9,16	18,42	27 008	8,17	20,91	- 4 924	6,16	NA

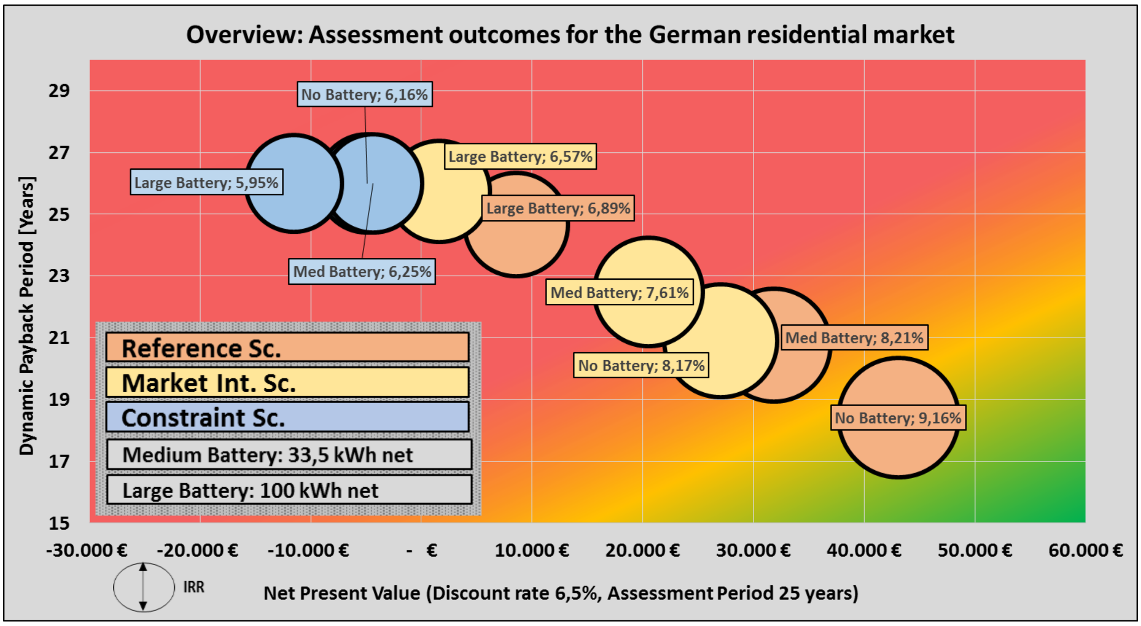


Figure 42 : Illustration and comparison of economic indicators for the German commercial market

The following summarises the highlights that can be extracted based on the overall outcomes in Table 15 and Figure 12:

- Generally, with respect to all scenarios and investigated systems – it becomes obvious that the reference scenario realises the best economic results.
- However, with regard to the above illustration it becomes clear that only the PV system without a battery within the reference scenario may achieve sufficient benefits for a commercial entity to invest (greenish area, IRR of above 9% with a corresponding NPV of around 43 000 € and a DPBP of 18 years). The remaining systems within the same and all other assessed scenarios exceed DPBPs of 20 years (or do not amortise within the assessment period) and are therefore illustrated in the yellow/red area.
- Furthermore, it can be derived that PV only systems are ranked first, followed by the medium sized battery combination and the variant with a large battery within the reference and market integration scenario. The only case in which a combination with a medium sized battery achieves slightly better results than a PV-only system is the constraint scenario. It should however be noted that all assessed system types result in a net loss within the latter scenario (IRRs of below 6,5 %) and would therefore most likely not be considered as an investment opportunity.
- Finally, when comparing reference and market integration scenario, it is shown that the PV only system achieves similar results as the system combined with a medium sized battery in the reference scenario (IRR difference of 0,4%).

Considering the overall comparison of all scenarios, the following provides detailed background information, insights and analyses:

Developments of electricity costs

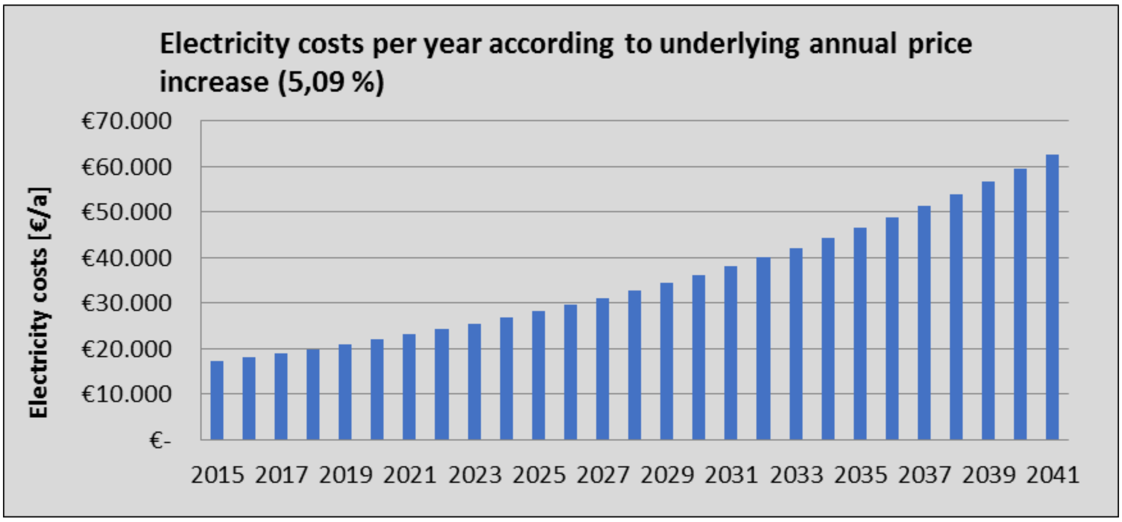


Figure 43 : Assumed electricity cost development for commercial consumers in Germany

It can be seen that the total annual electricity costs of the commercial entity assumed in this study would increase from about 17 000 € to about 63 000 € over the assessment period (assuming an electricity consumption of 133 768 kWh/a and an initial price of 0,1351 €/kWh in 2015).

Please note the mentioned limitation that commercial entities usually have individually designed contracts. It may therefore be possible that an additional demand charge would be applicable and or that the actual electricity price of this entity may already include such a charge. Furthermore, it may be possible that the assumed electricity price is lower. This is important to keep in mind for the following analyses:

<u>The *present value* of benefit streams over the assessment period</u>

Figure 44 illustrates the *present value* (light green area) of the benefit streams, i.e. electricity costs saved and remuneration of excess electricity. It becomes obvious that large battery systems achieve the highest accumulated benefits over the assessment period for all scenarios, whereas PV systems without batteries realise lower total benefits. This is caused by the fact that the electricity cost saving potential (on average for all scenarios) has a share of 92 %, while the remuneration of excess electricity contributes to 8 % to the total benefit values.

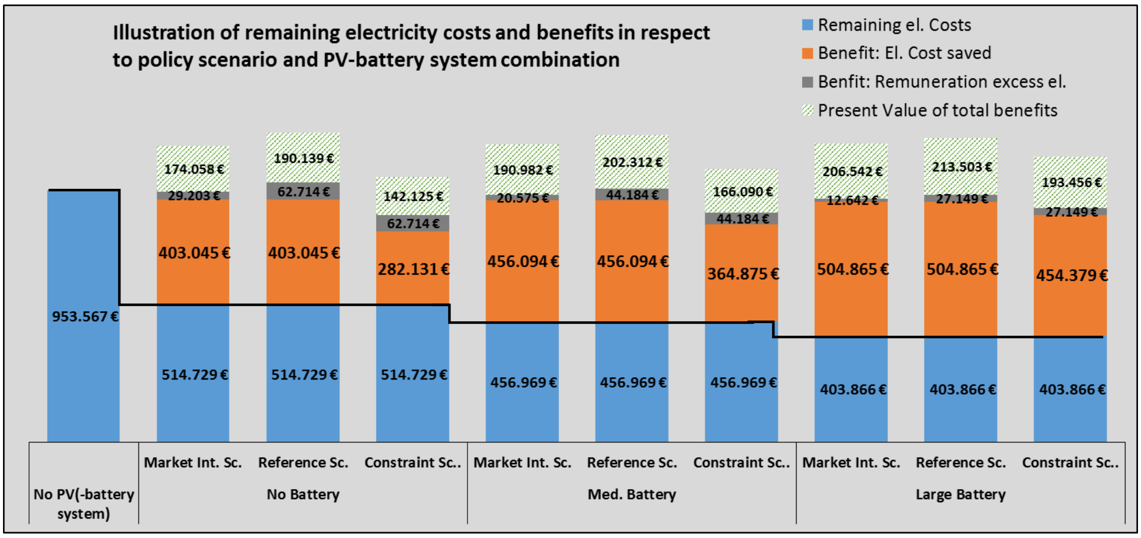


Figure 44 : Electricity cost comparison according to PV-battery system and illustration of discounted cumulative benefits for residential consumers in Germany

The above findings (Figure 44) show that the ability to save upon electricity costs is of utmost importance for the commercial consumer since the self-consumption rate is already in the order of 70% even without combining the PV system with an additional battery storage. With regard to PV systems assessed in this report, the reduction of the el. cost saving potential (10, 20 and 30% for the PV system combined with a large, medium and no battery respectively) within the constraint scenario reduces the potential benefit stream drastically (by 50 486, 91 219 and 120 914 € correspondingly) when compared to the reference scenario. A lower remuneration level for excess electricity (as in the market integration scenario) on the other hand has a very limited impact on the total benefits of these system types (10 to 15 thousand Euro).

Direct evaluation of investment and total operational costs in relation to the present value of benefit streams

The investment (dark grey and orange number) and total operational (light grey and red number) costs in relation to the present value of benefit streams are shown in Figure 45 It illustrates that the highest monetary net benefit (43 089 €) is achieved in the reference scenario based on a simple PV system, followed by the system combined with a battery (31 851€). The lowest net benefit is 1 591 € and relates to a system with a large battery in the market integration scneario Systems within the constraint scenario result in losses of around 11 500, 4 400 and 4 900 € (large, medium and no battery respectively).

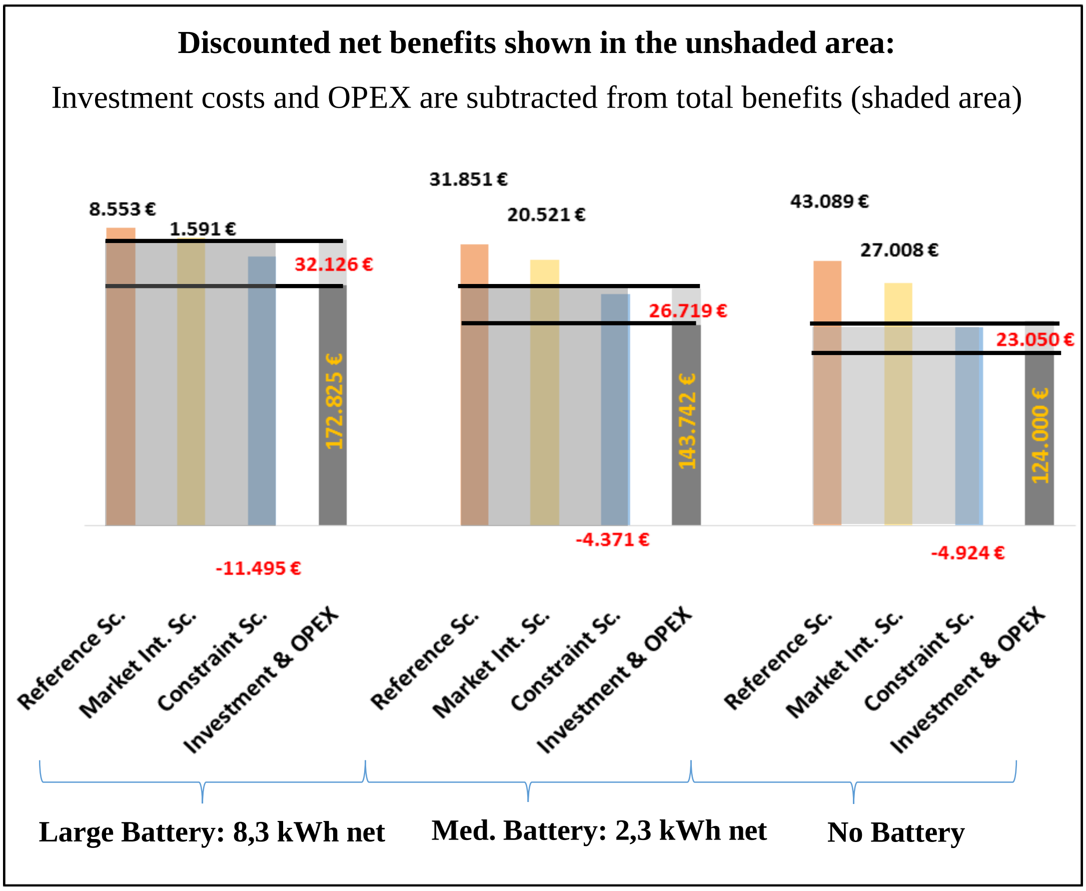


Figure 45 : Discounted net benefits in respect to investment costs and OPEX for commercial consumers in Germany

Cash flows indicating the dynamic payback period

The cash flow diagrams (Figure 46 to 48) illustrate the discounted and net cumulative as well as annual benefit developments over time. Based on the cash flow diagrams it can be derived that a PV-only system is the first variant that reaches its break-even point in the reference and market integration scenario (Figure 46 and 47), whereas the PV system combined with a medium battery would amortise slightly faster in the constraint scenario assuming that the assessment period would be extended (Figure 48). Furthermore, it can be seen that the curves of PV only systems and the ones with batteries only emerge very slightly over time in all cases (even with constantly increasing electricity costs and rather high el. cost saving potential at the end of the assessment period). The scenario in which this happens the fastest is the constraint scenario (Figure 48) as the reduction on the el. cost saving potential is the highest for the PV only system (here the curves intersect at the end of the assessment period).

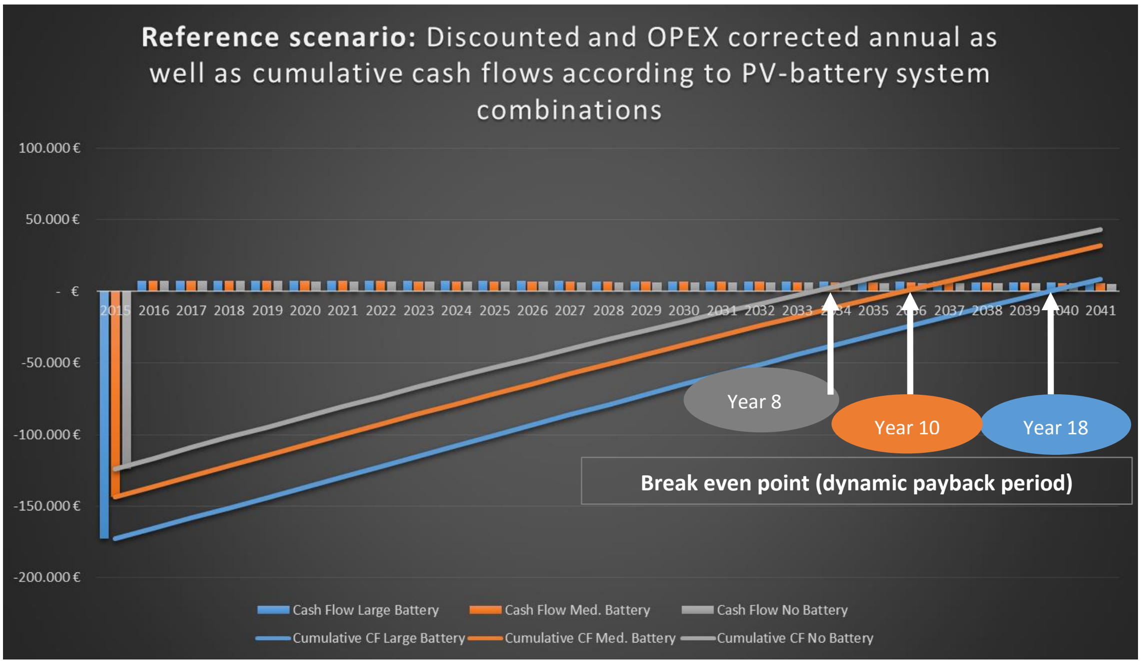


Figure 46 : Cash Flow developments according to the reference sc. in the German commercial market

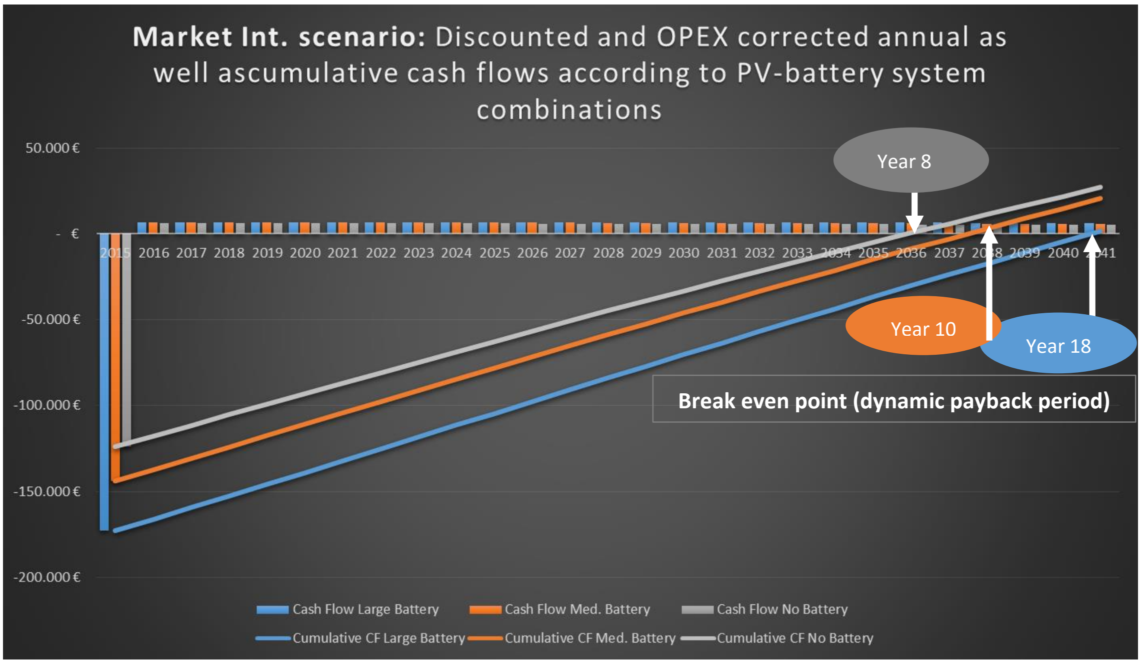


Figure 47 : Cash Flow developments according to the market int. sc. in the German commercial market

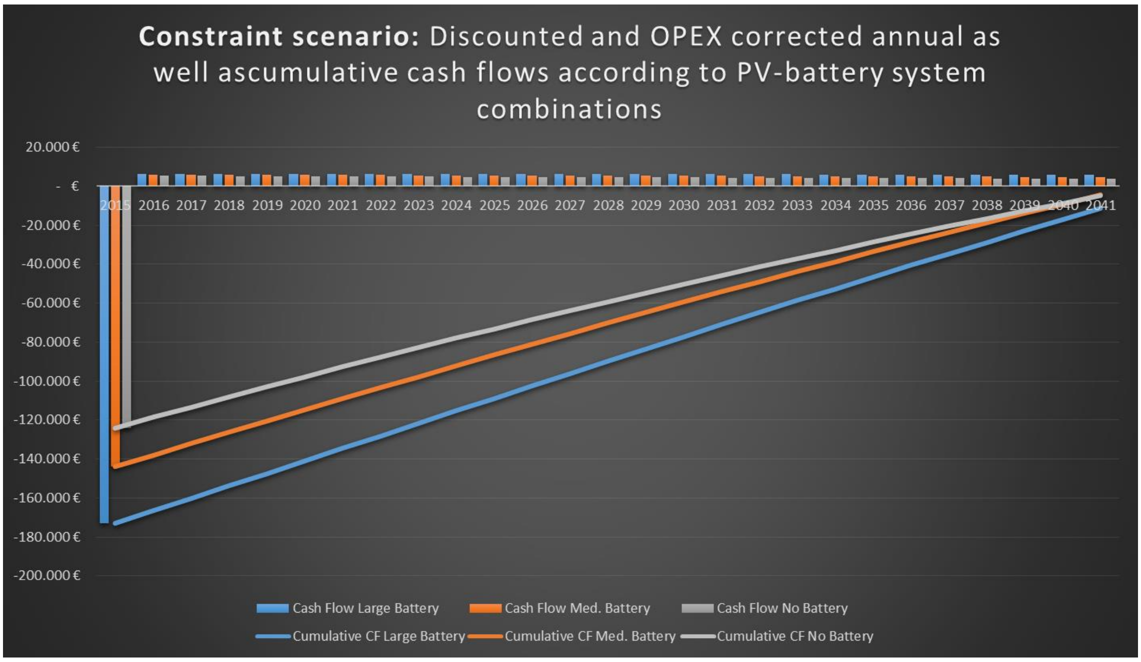


Figure 48 : Cash Flow developments according to the constraint sc. in the German commercial market

IRR comparisons

Figure 49 compares the IRR of the various PV(-battery) system combinations within the assessed policy design scenarios.

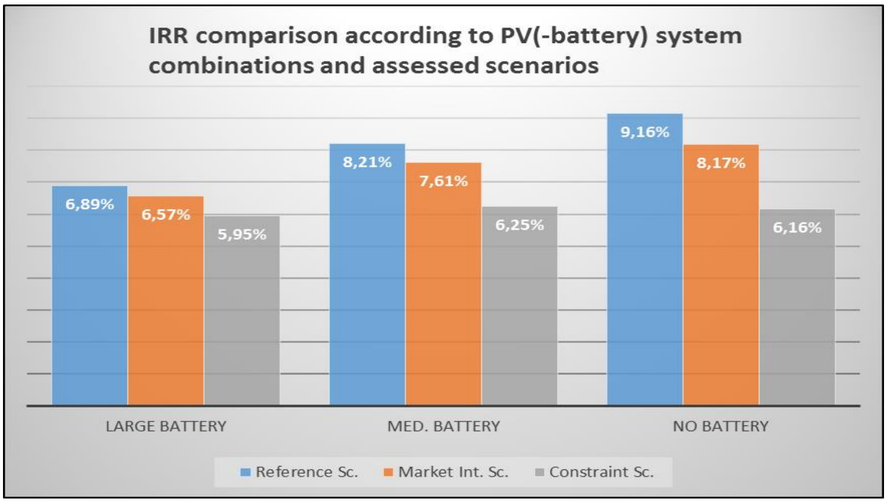


Figure 49 : Overview of IRR in relation to PV(-battery) system and assessed policy designs for German commercial consumers

The rule of thumb to cut off projects that exceed a lifetime of 15 years if their IRR is not slightly above "the inverse of the pay-back period" (Blok, 2007) is realised when comparing Figure 49 and Table 16

- PV systems combined with large batteries meet this criterion only in the reference scenario.
- PV systems combined with a medium battery match this criterion in the reference and market integration scenarios.
- PV only systems are align with this rule in the reference and market integration scenario.

Table 16 : Cut off values for assessed commercial systems and scenarios in Germany [21]

	Reference Sc.		Market Int. Sc.		Constraint Sc.	
	Cut off value	Difference to IRR	Cut off value	Difference to IRR	Cut off value	Differenc e to IRR
PV syst. with large battery	6,67%	0,226%	6,67%	-0,09%	6,25%	-0,3%
PV syst. with medium battery	7,69%	0,518%	7,14%	0,46%	6,25%	0%
Simple PV syst.	8,33%	0,823%	7,69%	0,48%	6,67%	-0,5%

[21] Note that the rule of thumb refers to the simple payback period, i.e. the point in time when the (undiscounted) cumulative cash-flows become positive and that calculations refer to unrounded numbers

It should however be noted that this refers to one specific and not general examples of commercial agents. Furthermore, slightly higher benefits may be achieved based on a reduction of a demand charge, in particular when considering PV systems combined with batteries. This may lead to better results depending on the individual tariff scheme. Moreover, some commercial entities may see additional reasons such as “green image” as an important factor to consider when investing in solar PV.

In addition to the above analysis Box 4 provides an insight in the discounted and OPEX corrected average annual and monthly benefits that can be realised in the respective policy scenarios.

Box 4: Benefit comparison of PV-battery system combinations over total lifetime (25 years) in respect to assessed policy scenarios

Reference Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remuneration of excess el.) [€]	Annual	**6 976**	**6 754**	**6 427**
	Month	**581**	**563**	**536**
Dynamic Payback Period [Years]		**25**	**21**	**18**

- A large battery system achieves an average annual electricity cost reduction plus an additional revenue stream from excess electricity of 6 976 €. This reduces the consumers' electricity bill by about 581 € every month over the next 25 years. However, the high investment costs (and higher operational expenses) of this type of system require rather long DPBPs of about 25 years.
- A PV system without a battery has a DPBP of 18 years. Due to a high initial match of generation and consumption the savings on electricity costs are only reduced to about 536 € when compared to the system with a large battery.
- Combining a PV system with a medium sized battery reduces the electricity bill in total by about 568 € a month and increases the DPBP by three years when compared to the system without a battery.

Market Integration Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remuneration of excess el.) [€]	Annual	**6 708**	**6 318**	**5 808**
	Month	**559**	**527**	**484**
Dynamic Payback Period [Years]		**NA**	**23**	**21**

- As in the reference scenario, a PV system combined with a large battery results in the highest possible benefits and reduces the consumers bill by about 559 € per month (only about 22 € less than in the reference scenario).
- This reduction is caused by the fact that the remuneration of excess electricity is lower (0,04 €/kWh instead of 0,0859 €/kWh) compared to the reference scenario. As a consequence, the PV system combined with a large battery does not amortize within the assessment period (although the increase in DPBPs is generally rather small – for the system with a medium and or no battery 2 and 4 years respectively). With regard to the latter systems the monthly savings are correspondingly reduced by 36 and 52 € as less electricity is self-consumed when compared to the large battery.

Constraint Scenario	Average	PV system & Large battery	PV system & Med. battery	PV system
Total discounted and OPEX corrected benefits (Savings on el. costs + remuneration of excess el.) [€]	Annual	**6 205**	**5 360**	**4 580**
	Month	**517**	**447**	**382**
Dynamic Payback Period [Years]		**NA**	**NA**	**NA**

- Due to the fact that this scenario accounts for a grid charge, the potential savings on electricity costs are reduced by 10, 20 and 30% for large and medium battery and PV only systems respectively. This leads to a drastic reduction of monthly benefits for all systems: by about 64 € (large battery), 116 € (medium battery) and 154 € (PV only). As a consequence, none of the systems reaches its break-even point within the assessment period.

Box 4: Assessment of DPBP and annual as well as monthly average benefit potential for commercial consumers in Germany

Sensitivity of outcomes upon crucial input parameters assessed (additional analyses are provided in Appendix II.IV)

Assessment of a change in PV investment costs (Figure 50)

A reduction of the PV investment costs by 30% (to 86 800 € would increase the NPV by around 37 200 € for all systems, which corresponds to an average IRR increase of about 3% with a corresponding DPBP decrease of 6 years. In case the PV investment costs are 10% higher, the system combined with a large battery would exceed a DPBP of 25 years. Similarly, the system with a medium battery would result in the same DPBP if the investment costs were increased by 20%. A possible scenario for this would be that consumers would add battery storage to a recently installed PV system on which they paid a 19% VAT charge, whereas due to subsidy reasons this charge would not be applicable for the battery system. With regard to the IRR curves it can be observed that these expand with declining costs and emerge with increasing costs. However, the "economic ranking" of the systems would not change within the assessed range, meaning that PV only systems would always achieve the best economic results.

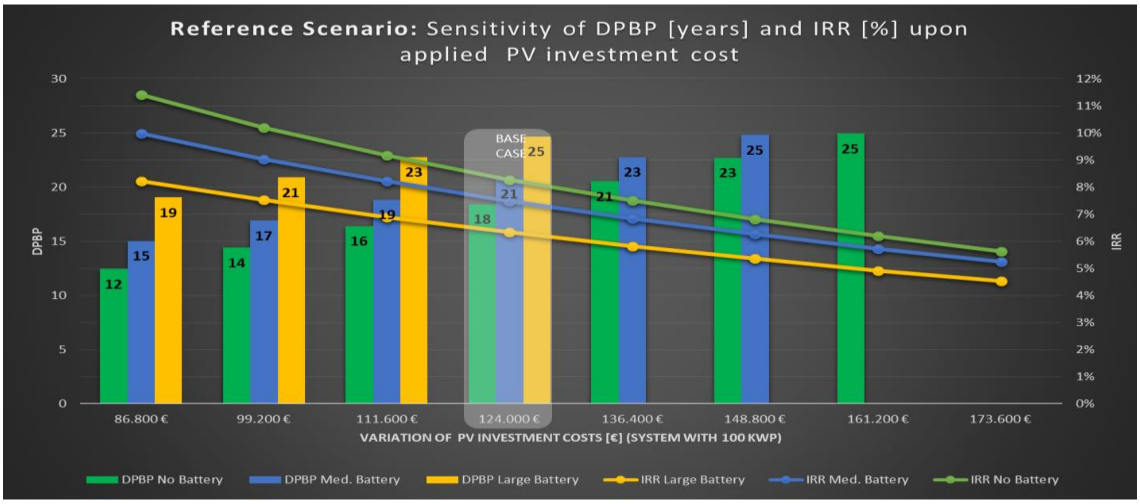


Figure 50 : Reference Sc. commercial sector Germany - One variable sensitivity analysis of PV investment costs

Assessment of a change in battery investment costs

With regard to the variation of the assumed battery investment costs, it becomes obvious that a reduction of 70% (see 30% value in Figure 51) would lead to a break-even of the PV system combined with a medium sized battery and the simple PV system. Within the next two to three years (assuming an annual investment cost reduction of 30% for batteries (Deutsche Bank, 2015)) a PV system combined with a medium sized battery would achieve an IRR of 9% while a combination with a large battery would realize an IRR of above 8,5 % in respect to the reference scenario and assumptions taken in this report. This indicates that more adequate economic benefits will be achievable within short to medium time frames for both considered options.

Additionally, it can be seen that the medium sized battery system would not result in losses even when its investment costs was 50% higher as is the case for the system with a large battery (IRRs of slightly below 8 and 6% respectively). However, the DPBP of the large battery system would already exceed the timeframe of this assessment (25 years) in case the investment costs were 20% higher. The increase of the DPBP in relation to higher investment costs for the medium sized battery system combination on the other hand is less steep and would increase by less than one year when compared to the base case.

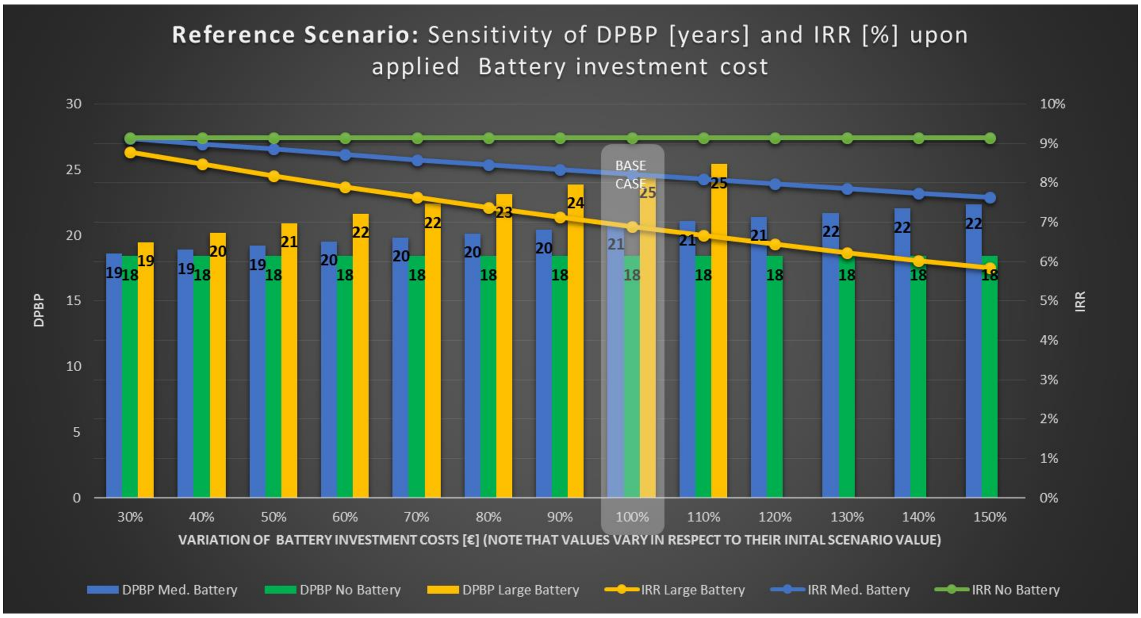


Figure 51 : Reference Sc. commercial sector Germany- One variable sensitivity analysis of Battery investment costs

Market Integration (Figure 52) and Constraint (Figure 53) Scenario – Assessment of a change in PV investment costs

The PV system combined without a battery continuous to achieve a higher IRR in the market integration scenario when compared to a system with a medium battery for the entire range of PV investment costs assessed in this report – even if the former were increased by as much as 40% (see Figure 52 where the lines representing the IRR emerge and begin to intersect, which is not the case in the reference scenario).

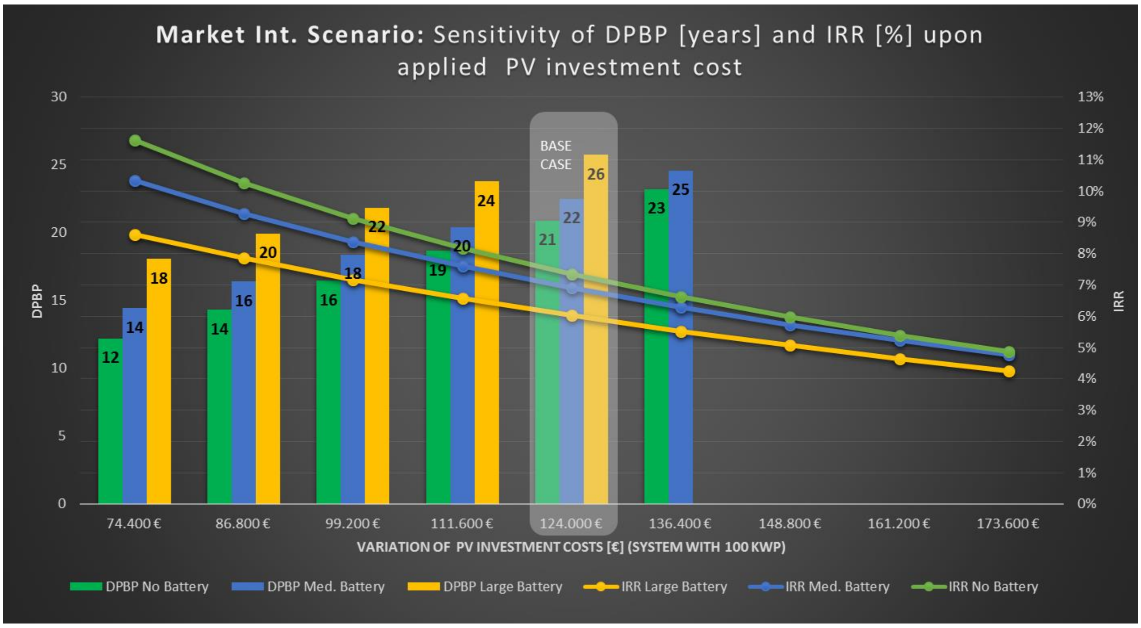


Figure 52 : Market Integration Sc. commercial sector Germany - One variable sensitivity analysis of PV investment costs

Reducing the investment costs by 10 to 20% (Figure 53) would cause the IRR lines of the PV system without a battery to intersect with the one of the medium sized battery system indicating that the former would quickly result in better outcomes with declining technology costs for solar PV. However, only 10% higher investment costs for PV systems than initially assumed in this study would result in an intersection of the IRR curve of the large battery PV system with the ones of the two alternatives. This behaviour is very different to the reference scenario in which no intersection can be observed for the entire range of investment costs assessed.

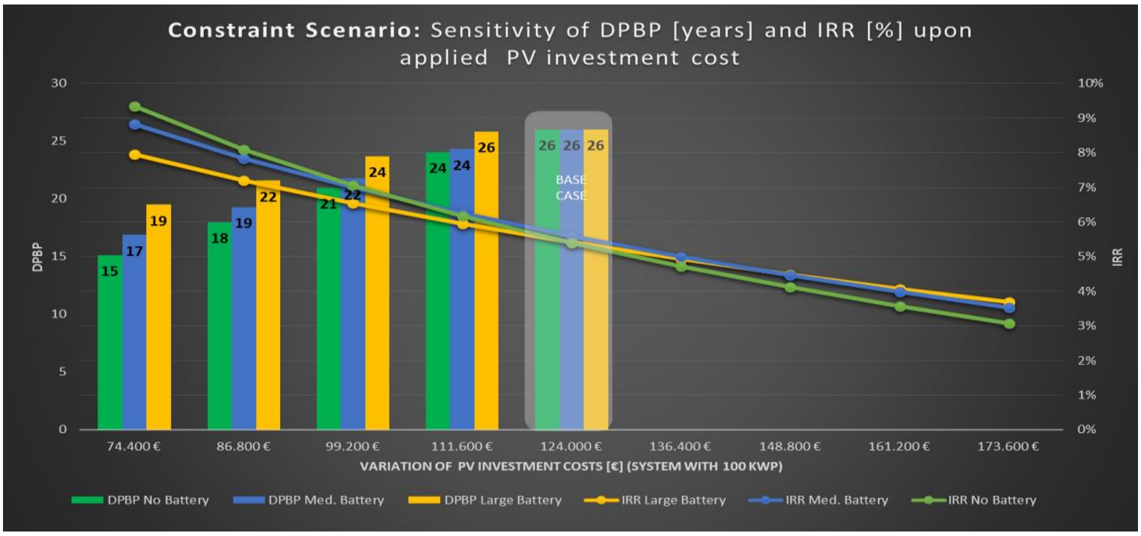


Figure 53 : Constraint Sc. commercial sector Germany - One variable sensitivity analysis of PV investment costs

Interim conclusions based on analysed outcomes and sensitivity analyses

- Overall, with respect to the reference and market integration scenario, it can be concluded that the assessed PV(-battery) system combinations achieve positive economic results that exceed – or are at least close to do so – estimated cut-off values based on common rules. Furthermore, it can be derived that PV only systems remain to achieve the best economic results even in case of the market integration scenario.
- However, the DPBPs are rather high in all cases and may not be sufficient for a commercial entity to invest in (if so, the PV only system variant would be the preferable option).
- With reference to DPBPs, the sensitivity analyses reveal that these may become significantly lower with declining PV investment costs, particularly for PV only systems. The reason aforementioned systems are also more interesting within the market integration scenario lies in the fact that the self-consumption rate for the assessed commercial agent is already significant even without additional storage. As a consequence, a combination with a battery is unlikely to result in significant better results even when the most favourable developments would manifest, e.g. considering 40 to 50% reduced battery investment costs in the market integration scenario (see Figure 114).
- In case that the constraint scenario would be implemented, an investment would clearly become uninteresting (PV investment costs would need to be reduced by at least 20% to achieve a similar result to the one of the reference scenario).

3.3 Cluster I: Two variable sensitivity analyses as a potential combination of assessed policy scenarios

The following sections elaborate upon the outcomes of the two variable sensitivity analyses that change the initially applied parameters of "remuneration of excess electricity" and "electricity cost saving potential" of the respective reference scenarios[22]. This section thereby anticipates that policy makers may implement a compromise of the market integration and constraint scenario. The assessment focuses on residential consumers and starts with the German market, followed by the Portuguese and the English. Based on the results general conclusions are drawn in Section 3.3.4.

3.3.1 Germany

- Figure 54: A PV-system combined with a large battery requires a remuneration of excess electricity of at least 6 ct/kWh when reducing the electricity cost saving potential to 90% in order to achieve a DPBP of below 25 years and a corresponding IRR of 4%.
- Figure 55 and 56: Comparing the PV-only system with the PV-medium battery system shows that the former achieves shorter DPBPs and therewith at least slightly higher IRRs in case that the remuneration of excess electricity is varied between 7 and 12 ct/kWh while the electricity cost saving potential is within a range of 40 and 60 percent. (Note that in these cases the DPBP for the system with a medium sized battery exceeds 25 years, i.e. has a maximum IRR of 4%). However, once the remuneration of excess electricity is below/around 6 ct/kWh, the PV system with a medium sized battery achieves better economic results even when the electricity cost saving potential is reduced down to 70%. Additionally, it can be seen that the system with a medium sized battery achieves DPBPs of below 25 years and therewith higher IRRs compared to the PV only system which would be linked to DPBPs of above 25 years in case that:
    - The remuneration of excess electricity is around 4 ct/kWh while the electricity cost saving potential is reduced by 30%.
    - The remuneration of excess electricity is between 1 and 3 ct/kWh while the electricity cost saving potential is reduced by 20%.
    - The remuneration of excess electricity is 0 ct/kWh while the electricity cost saving potential is reduced by 10 and 20%.

[22] Mind the note of Section 2.1.3: In the assessment for the UK market the generation tariff is varied instead of the remuneration of excess electricity as the latter is already close to wholesale prices and therefore less likely to be reduced drastically

Large Battery

Remuneration of excess electricity — Electricity cost saving potential

IRR

	- €	0,01 €	0,03 €	0,04 €	0,05 €	0,06 €	0,07 €	0,09 €	0,10 €	0,11 €	0,12 €
10%					-16%	-14%	-13%	-12%	-11%	-11%	-10%
20%	-9%	-9%	-8%	-8%	-7%	-7%	-7%	-6%	-6%	-6%	-5%
30%	-5%	-5%	-5%	-4%	-4%	-4%	-4%	-4%	-3%	-3%	-3%
40%	-3%	-3%	-2%	-2%	-2%	-2%	-2%	-2%	-1%	-1%	-1%
50%	-1%	-1%	-1%	-1%	0%	0%	0%	0%	0%	0%	1%
60%	0%	1%	1%	1%	1%	1%	1%	1%	2%	2%	2%
70%	2%	2%	2%	2%	2%	2%	2%	3%	3%	3%	3%
80%	3%	3%	3%	3%	3%	3%	4%	4%	4%	4%	4%
90%	4%	4%	4%	4%	4%	4%	5%	5%	5%	5%	5%
100%	5%	5%	5%	5%	5%	5%	5%	6%	6%	6%	6%

DPBP

	- €	0,01 €	0,03 €	0,04 €	0,05 €	0,06 €	0,07 €	0,09 €	0,10 €	0,11 €	0,12 €
10%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
30%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
40%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
50%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
70%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
80%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
90%	NA	NA	NA	NA	NA	24,81	24,48	24,15	23,82	23,50	23,19
100%	23,86	23,55	23,25	22,96	22,66	22,37	22,09	21,80	21,52	21,25	20,97

Figure 54 : Reference Sc. Germany – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV system with a large battery

Med. Battery

Remuneration of excess electricity — Electricity cost saving potential

IRR

	- €	0,01 €	0,03 €	0,04 €	0,05 €	0,06 €	0,07 €	0,09 €	0,10 €	0,11 €	0,12 €
10%		-14%	-11%	-10%	-8%	-7%	-6%	-5%	-4%	-4%	-3%
20%	-7%	-6%	-5%	-5%	-4%	-3%	-3%	-2%	-1%	-1%	0%
30%	-4%	-3%	-2%	-2%	-1%	-1%	0%	0%	1%	1%	1%
40%	-1%	-1%	0%	0%	1%	1%	1%	2%	2%	3%	3%
50%	1%	1%	1%	2%	2%	2%	3%	3%	4%	4%	4%
60%	2%	2%	3%	3%	3%	4%	4%	4%	5%	5%	5%
70%	3%	4%	4%	4%	5%	5%	5%	6%	6%	6%	7%
80%	5%	5%	5%	5%	6%	6%	6%	7%	7%	7%	8%
90%	6%	6%	6%	6%	7%	7%	7%	8%	8%	8%	9%
100%	7%	7%	7%	7%	8%	8%	8%	9%	9%	9%	9%

DPBP

	- €	0,01 €	0,03 €	0,04 €	0,05 €	0,06 €	0,07 €	0,09 €	0,10 €	0,11 €	0,12 €
10%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
30%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
40%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
50%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60%	NA	NA	NA	NA	NA	NA	NA	24,52	23,52	22,57	21,66
70%	NA	NA	NA	24,98	24,04	23,13	22,25	21,41	20,61	19,84	19,11
80%	24,50	23,63	22,79	21,98	21,20	20,44	19,72	19,02	18,36	17,72	17,11
90%	21,73	21,00	20,29	19,61	18,95	18,31	17,71	17,12	16,56	16,03	15,51
100%	19,51	18,88	18,27	17,69	17,13	16,59	16,07	15,57	15,09	14,63	14,20

Figure 55 : Reference Sc. Germany – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV system with a medium sized battery

PV Only

Remuneration of excess electricity — Electricity cost saving potential — IRR

Electricity cost saving potential	- €	0,01 €	0,03 €	0,04 €	0,05 €	0,06 €	0,07 €	0,09 €	0,10 €	0,11 €	0,12 €
10%		-14%	-10%	-7%	-5%	-4%	-2%	-1%	0%	1%	2%
20%	-9%	-7%	-5%	-4%	-3%	-1%	0%	0%	1%	2%	3%
30%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	3%	4%
40%	-3%	-2%	-1%	0%	1%	2%	2%	3%	4%	5%	5%
50%	-1%	0%	1%	1%	2%	3%	4%	4%	5%	6%	6%
60%	0%	1%	2%	3%	3%	4%	5%	5%	6%	7%	7%
70%	2%	2%	3%	4%	4%	5%	6%	6%	7%	7%	8%
80%	3%	3%	4%	5%	5%	6%	7%	7%	8%	8%	9%
90%	4%	4%	5%	6%	6%	7%	7%	8%	9%	9%	10%
100%	5%	5%	6%	7%	7%	8%	8%	9%	9%	10%	10%

DPBP

Electricity cost saving potential	- €	0,01 €	0,03 €	0,04 €	0,05 €	0,06 €	0,07 €	0,09 €	0,10 €	0,11 €	0,12 €
10%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
30%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
40%	NA	NA	NA	NA	NA	NA	NA	NA	NA	23,84	21,66
50%	NA	NA	NA	NA	NA	NA	NA	24,95	22,78	20,86	19,16
60%	NA	NA	NA	NA	NA	NA	23,83	21,90	20,17	18,63	17,25
70%	NA	NA	NA	NA	24,80	22,90	21,16	19,58	18,16	16,88	15,73
80%	NA	NA	NA	23,82	22,10	20,51	19,06	17,74	16,55	15,47	14,49
90%	NA	24,68	22,99	21,41	19,95	18,60	17,37	16,24	15,22	14,29	13,45
100%	23,82	22,26	20,80	19,44	18,18	17,03	15,96	14,99	14,11	13,30	12,56

Figure 56 : Reference Sc. Germany – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV-only system

3.3.2 Portugal

- Figure 58: A PV-system combined with a large battery requires an electricity cost saving potential of at least 90% in case that the excess electricity is remunerated within a range of 0 to 2 ct/kWh in order to achieve a DPBP of below 24 years and a corresponding IRR of 5%. Based on a remuneration level between 4 and 10 ct/kWh, the el. cost saving potential can be reduced to 80% - leading to corresponding DPBPs of below 25 and 22 years, whereas in case of a reduction down to 70% a remuneration of 10 ct/kWh would be necessary to achieve DPBPs of below 25 years.
- Figure 57 and 59: Comparing the PV-only system with the PV-medium battery system shows that the former achieves shorter DPBPs and therewith at least slightly higher IRRs in case that the remuneration of excess electricity is varied between 4 and 10 ct/kWh while the electricity cost saving potential is within a range of 40 and 60 percent. (Note that the system with a medium sized battery exceeds DPBPs of 25 years in cases where the electricity cost saving potential is 40% and the remuneration of excess el. between 6 and 8 ct/kWh. For the same system this is valid for any further reduction of the electricity cost saving potential, whereas a PV-only system would continue to achieve IRRs of 5 to 7 % (and DPBPs below 25 years) even if the electricity cost saving potential was reduced to 30 or 20% as long as the remuneration of excess electricity is between 8 and 10 ct/kWh).

- However, once the remuneration of excess electricity is below/around 4 ct/kWh, the PV system with a medium sized battery achieves better economic results even when the electricity cost saving potential is reduced down to 70%. Additionally, it can be seen that the system with a medium sized battery achieves DPBPs of below 25 years and therewith higher IRRs compared to the PV only system which would be linked to DPBPs of above 25 years in case that:
    - The remuneration of excess electricity is around 2 ct/kWh while the electricity cost saving potential is reduced by 40%.
    - The remuneration of excess electricity is between 0 ct/kWh while the electricity cost saving potential is reduced by 30%.

Med. Battery

IRR

Electricity cost saving potential	Remuneration of excess electricity: - €	0,02 €	0,04 €	0,06 €	0,08 €	0,10 €
10%	-12%	-8%	-6%	-4%	-2%	-1%
20%	-5%	-3%	-2%	-1%	1%	2%
30%	-2%	-1%	1%	2%	3%	4%
40%	1%	2%	2%	3%	4%	5%
50%	2%	3%	4%	5%	6%	6%
60%	4%	5%	5%	6%	7%	8%
70%	5%	6%	7%	7%	8%	9%
80%	6%	7%	8%	8%	9%	10%
90%	7%	8%	9%	9%	10%	11%
100%	9%	9%	10%	10%	11%	12%

DPBP

Electricity cost saving potential	Remuneration of excess electricity: - €	0,02 €	0,04 €	0,06 €	0,08 €	0,10 €
10%	NA	NA	NA	NA	NA	NA
20%	NA	NA	NA	NA	NA	NA
30%	NA	NA	NA	NA	NA	NA
40%	NA	NA	NA	NA	NA	22,76
50%	NA	NA	NA	23,59	21,44	19,50
60%	NA	24,29	22,27	20,39	18,67	17,11
70%	22,99	21,20	19,52	17,98	16,56	15,28
80%	20,30	18,79	17,38	16,08	14,90	13,82
90%	18,15	16,86	15,66	14,55	13,54	12,63
100%	16,40	15,28	14,24	13,29	12,42	11,63

Figure 57 : Reference Sc. Portugal – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV system with a medium sized battery

Large Battery

IRR

Electricity cost saving potential	Remuneration of excess electricity: - €	0,02 €	0,04 €	0,06 €	0,08 €	0,10 €
10%		-13%	-11%	-9%	-8%	-7%
20%	-7%	-6%	-5%	-5%	-4%	-3%
30%	-4%	-3%	-3%	-2%	-1%	-1%
40%	-2%	-1%	-1%	0%	0%	1%
50%	0%	1%	1%	1%	2%	2%
60%	1%	2%	2%	3%	3%	3%
70%	3%	3%	3%	4%	4%	5%
80%	4%	4%	5%	5%	5%	6%
90%	5%	5%	5%	6%	6%	6%
100%	6%	6%	6%	7%	7%	7%

DPBP

Electricity cost saving potential	Remuneration of excess electricity: - €	0,02 €	0,04 €	0,06 €	0,08 €	0,10 €
10%	NA	NA	NA	NA	NA	NA
20%	NA	NA	NA	NA	NA	NA
30%	NA	NA	NA	NA	NA	NA
40%	NA	NA	NA	NA	NA	NA
50%	NA	NA	NA	NA	NA	NA
60%	NA	NA	NA	NA	NA	NA
70%	NA	NA	NA	NA	NA	24,50
80%	NA	NA	24,58	23,69	22,83	21,99
90%	23,82	23,01	22,21	21,43	20,67	19,94
100%	21,67	20,94	20,24	19,55	18,89	18,25

Figure 58 : Reference Sc. Portugal – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV system with a large battery

PV Only

IRR — Remuneration of excess electricity

Electricity cost saving potential	- €	0,02 €	0,04 €	0,06 €	0,08 €	0,10 €
10%	-16%	-7%	-3%	0%	2%	4%
20%	-7%	-3%	0%	2%	4%	5%
30%	-3%	-1%	1%	3%	5%	7%
40%	-1%	1%	3%	5%	6%	8%
50%	1%	3%	4%	6%	7%	9%
60%	2%	4%	5%	7%	8%	10%
70%	3%	5%	6%	8%	9%	11%
80%	5%	6%	7%	9%	10%	11%
90%	6%	7%	8%	10%	11%	12%
100%	7%	8%	9%	11%	12%	13%

DPBP — Remuneration of excess electricity

Electricity cost saving potential	- €	0,02 €	0,04 €	0,06 €	0,08 €	0,10 €
10%	NA	NA	NA	NA	NA	NA
20%	NA	NA	NA	NA	NA	20,87
30%	NA	NA	NA	NA	22,52	18,02
40%	NA	NA	NA	24,01	19,44	15,99
50%	NA	NA	NA	20,81	17,22	14,46
60%	NA	NA	22,10	18,44	15,52	13,23
70%	NA	23,27	19,64	16,60	14,16	12,22
80%	24,33	20,77	17,69	15,13	13,04	11,36
90%	21,83	18,76	16,11	13,91	12,10	10,64
100%	19,78	17,10	14,80	12,88	11,30	10,00

Figure 59 : Reference Sc. Portugal – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV-only system

3.3.3 United Kingdom

- Figure 60: A PV-system combined with a large battery requires a generation tariff of least 11 ct/kWh when reducing the electricity cost saving potential to 90% in order to achieve a DPBP of below 25 years and a corresponding IRR of 4%.
- Figure 61 and 62: Comparing the PV-only system with the PV-medium battery system shows that the former always achieves shorter DPBPs and therewith higher IRRs. Additionally, in case that the generation tariff is varied between 0,2 and 13 ct/kWh while the electricity cost saving potential is varied correspondingly within a range of 90 and 10% (i.e. refers to a 0,2 €/kWh generation tariff and a 90% el. cost saving potential etc.) it remains DPBPs of below 25 years and IRRs of at least 4% while in these cases the DPBP for the system with a medium sized battery exceeds 25 years, i.e. has a IRR of close to or below 4%.

Large Battery

Variation of genereation tariff [€/kWh]

IRR — Electricity cost saving potential

	0,00 €	0,02 €	0,04 €	0,05 €	0,07 €	0,09 €	0,11 €	0,13 €	0,14 €	0,16 €	0,18 €
10%	0%	-14%	-10%	-8%	-6%	-5%	-4%	-2%	-1%	-1%	0%
20%	-11%	-8%	-7%	-5%	-4%	-3%	-2%	-1%	0%	1%	1%
30%	-7%	-6%	-4%	-3%	-2%	-2%	-1%	0%	1%	2%	2%
40%	-5%	-4%	-3%	-2%	-1%	0%	0%	1%	2%	2%	3%
50%	-3%	-2%	-2%	-1%	0%	1%	1%	2%	3%	3%	4%
60%	-2%	-1%	0%	0%	1%	2%	2%	3%	3%	4%	5%
70%	-1%	0%	1%	1%	2%	2%	3%	4%	4%	5%	5%
80%	0%	1%	1%	2%	3%	3%	4%	4%	5%	5%	6%
90%	1%	2%	2%	3%	3%	4%	4%	5%	5%	6%	6%
100%	2%	2%	3%	4%	4%	5%	5%	6%	6%	7%	7%

DPBP — Electricity cost saving potential

	0,00 €	0,02 €	0,04 €	0,05 €	0,07 €	0,09 €	0,11 €	0,13 €	0,14 €	0,16 €	0,18 €
10%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
30%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
40%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
50%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	23,98
70%	NA	NA	NA	NA	NA	NA	NA	NA	NA	23,57	21,91
80%	NA	NA	NA	NA	NA	NA	NA	24,92	23,21	21,64	20,22
90%	NA	NA	NA	NA	NA	NA	24,49	22,88	21,40	20,04	18,80
100%	NA	NA	NA	NA	NA	24,10	22,59	21,18	19,88	18,69	17,60

Figure 60 : Reference Sc. UK – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV system with a large battery

Med. Battery

Variation of genereation tariff [€/kWh]

IRR — Electricity cost saving potential

	0,00 €	0,02 €	0,04 €	0,05 €	0,07 €	0,09 €	0,11 €	0,13 €	0,14 €	0,16 €	0,18 €
10%	-9%	-6%	-3%	-2%	0%	1%	2%	4%	5%	6%	7%
20%	-5%	-3%	-2%	0%	1%	2%	3%	5%	6%	7%	7%
30%	-3%	-2%	0%	1%	2%	3%	4%	5%	6%	7%	8%
40%	-1%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%
50%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
60%	1%	2%	3%	4%	5%	6%	7%	8%	9%	9%	10%
70%	2%	3%	4%	5%	6%	7%	8%	8%	9%	10%	11%
80%	3%	4%	5%	6%	7%	7%	8%	9%	10%	11%	11%
90%	4%	5%	6%	6%	7%	8%	9%	10%	10%	11%	12%
100%	5%	5%	6%	7%	8%	9%	10%	10%	11%	12%	13%

DPBP — Electricity cost saving potential

	0,00 €	0,02 €	0,04 €	0,05 €	0,07 €	0,09 €	0,11 €	0,13 €	0,14 €	0,16 €	0,18 €
10%	NA	NA	NA	NA	NA	NA	NA	NA	23,12	19,67	17,11
20%	NA	NA	NA	NA	NA	NA	NA	23,73	20,31	17,70	15,67
30%	NA	NA	NA	NA	NA	NA	24,28	20,91	18,28	16,19	14,50
40%	NA	NA	NA	NA	NA	24,78	21,49	18,84	16,71	14,97	13,54
50%	NA	NA	NA	NA	NA	22,02	19,39	17,23	15,45	13,96	12,72
60%	NA	NA	NA	NA	22,52	19,92	17,74	15,92	14,39	13,11	12,01
70%	NA	NA	NA	22,98	20,42	18,24	16,39	14,83	13,50	12,37	11,39
80%	NA	NA	23,41	20,90	18,72	16,86	15,26	13,90	12,73	11,72	10,84
90%	NA	23,81	21,35	19,19	17,32	15,70	14,30	13,09	12,05	11,15	10,35
100%	24,17	21,78	19,64	17,77	16,13	14,70	13,47	12,39	11,45	10,63	9,91

Figure 61 : Reference Sc. UK – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV system with a medium sized battery

PV Only

Variation of genereation tariff [€/kWh] — IRR

Electricity cost saving potential	0,00 €	0,02 €	0,04 €	0,05 €	0,07 €	0,09 €	0,11 €	0,13 €	0,14 €	0,16 €	0,18 €
10%	-4%	-2%	0%	2%	4%	5%	7%	8%	9%	11%	12%
20%	-2%	0%	2%	3%	5%	6%	7%	9%	10%	11%	12%
30%	-1%	1%	2%	4%	5%	7%	8%	9%	10%	12%	13%
40%	0%	2%	3%	5%	6%	7%	9%	10%	11%	12%	13%
50%	1%	3%	4%	5%	7%	8%	9%	10%	12%	13%	14%
60%	2%	3%	5%	6%	7%	9%	10%	11%	12%	13%	14%
70%	3%	4%	5%	7%	8%	9%	10%	11%	13%	14%	15%
80%	3%	5%	6%	7%	8%	10%	11%	12%	13%	14%	15%
90%	4%	5%	7%	8%	9%	10%	11%	12%	13%	15%	16%
100%	5%	6%	7%	8%	10%	11%	12%	13%	14%	15%	16%

DPBP

Electricity cost saving potential	0,00 €	0,02 €	0,04 €	0,05 €	0,07 €	0,09 €	0,11 €	0,13 €	0,14 €	0,16 €	0,18 €
10%	NA	NA	NA	NA	NA	20,66	16,91	14,32	12,42	10,96	9,82
20%	NA	NA	NA	NA	23,27	18,79	15,72	13,50	11,82	10,51	9,47
30%	NA	NA	NA	NA	20,93	17,33	14,73	12,79	11,29	10,10	9,14
40%	NA	NA	NA	23,31	19,15	16,13	13,89	12,17	10,82	9,73	8,84
50%	NA	NA	NA	21,17	17,71	15,13	13,16	11,62	10,39	9,39	8,56
60%	NA	NA	23,35	19,47	16,52	14,27	12,52	11,13	10,00	9,07	8,30
70%	NA	NA	21,37	18,07	15,52	13,53	11,95	10,68	9,64	8,78	8,06
80%	NA	23,37	19,75	16,89	14,65	12,86	11,44	10,28	9,32	8,51	7,83
90%	NA	21,54	18,39	15,88	13,88	12,28	10,97	9,90	9,01	8,26	7,62
100%	23,40	20,00	17,24	15,00	13,21	11,75	10,56	9,56	8,73	8,03	7,42

Figure 62 : Reference Sc. UK – Two variable sensitivity analysis on remuneration of excess el. and el. cost saving potential for a PV-only system

3.3.4 Conclusions of two variable sensitivity analyses

With reference to the analyses of this section it can be concluded that:

- PV systems combined with large batteries cannot compete with PV systems combined with medium and or no batteries meaning that the latter will always achieve better results in any potential case assessed in these analyses and based on the assumptions taken in this study.
- Any change of the electricity cost saving potential parameter has a significant impact upon PV-systems combined with large batteries (see also the outcomes of previous analyses). Combining a reduction of the electricity cost saving potential with a decrease in the remuneration of excess electricity (Germany or Portugal) and or the generation tariff in case of the UK would result in very unfavourable economic outcomes for these system types. Since PV system combined with large batteries generally have the least economic benefits investments in such system is likely already rather limited. Consequently, any potential combination of the market integration and constraint scenario that would reduce financial gains further would not be desirable for triggering investments in these types of systems.
- In case of Germany and Portugal there is a change with regard to the economic "ranking" of PV-only and PV systems combined with medium batteries depending on specific combinations of the market integration and constraint scenario. This is however

not the case for the UK, where – within the assessed ranges of this report – such a change cannot be observed. Referring to the former two markets, this indicates that a potential compromise of the two policy design options (market integration and constraint scenario) should be set up such that it takes into account the business model specifics of PV-only and PV-battery system combinations. In general, a compromise of both design options would allow to set up conditions such that:

- Investment decisions from a pure financial perspective with regard to the above mentioned systems types would prevail, i.e. benefits would be similar to the ones assessed in the reference scenarios with either a slight increase or decrease depending on the specific compromise of the policy designs. Although the “final ranking” of the two systems in terms of economic benefits would remain the same, this type of policy design would allow to increase or decrease the economic outcomes within certain ranges while the initial signal regarding the investment incentive in corresponding system types would only be slightly adjusted.
- On the other hand, a compromise between the two policy designs could also be set such that the initial ranking of PV only and PV systems combined with medium sized batteries would change in. This type of design would then allow policy makers to trigger investments in certain system types, e.g. towards combining PV systems with medium sized batteries. This could be useful in case certain policy targets e.g. in respect to the implementation of PV-battery systems are to be reached while remaining certain investment incentives with regard to PV-only systems.

3.4 Cluster II: Opportunities for value creation around decentralized solar PV for electricity suppliers

The above analyses revealed that from a consumer perspective, in particular residential ones, the investment in solar PV continues to make economic sense. This is true even in case of declining remuneration of excess electricity or additional charges on self-consumption (if applied to a certain extent), whereby a continuous interest and an uptake around/of solar PV is very likely to prevail or even increase in the near future. Regarding PV only systems and declining PV investment costs, this is valid for all types of consumer groups (residential ones with low and or high incomes and corresponding discount rates as well as for commercial agents). Furthermore, it has been shown that in case of a market integration scenario and when considering additional benefits such as self-sufficiency, a combination of PV systems with batteries (anticipating declining investment costs) may very likely become the favourable investment decision. As a consequence, the following content focuses on consumer demands and the role of electricity suppliers in this context:

The trends of prosumerism and increased decentralisation of the energy system go hand in hand with additional mega trends such as digitalisation and automation. Combined, these evolutions lead to increased interconnections among people, things and machines (Siemens, 2015). With regard to such developments as well as increasing public interest in the energy economy, caused by higher awareness upon climate change and increasing electricity costs etc., solar PV provides electricity suppliers new opportunities to engage with their customers. This is backed by a globally representative survey conducted by Accenture, 2015, which identified that more than 55% of customers are interested to purchase or sign up for solar PV products within a timeframe of 5 years. Figure 63 highlights the increasing interest in products related to solar PV – if provided by electricity suppliers –over the two recent years.

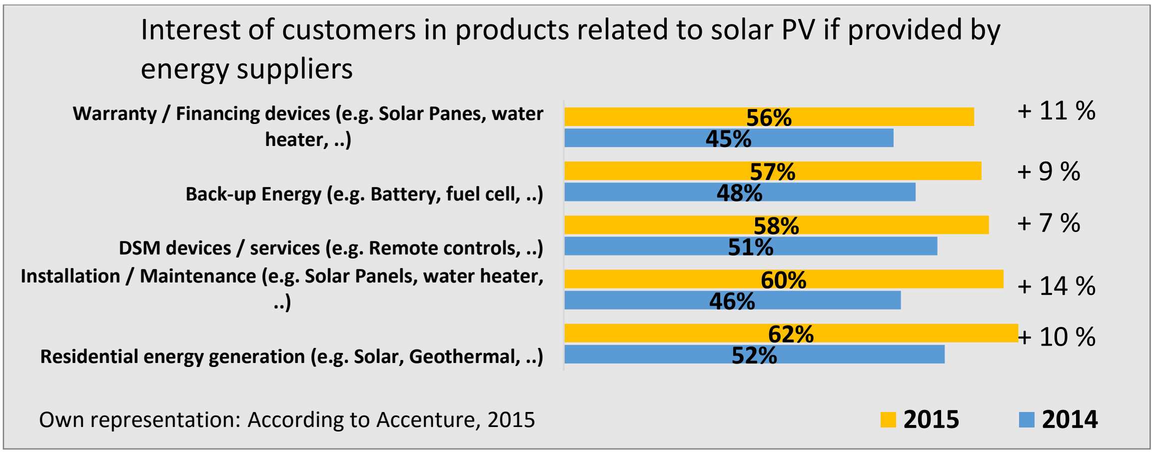


Figure 63 : Development of consumer interests in solar PV related products

The steep increase (10.2 % on average) on all of the mentioned products and services in Figure 63 suggests that the energy economy will need to change from a transaction-oriented sector with a linear value chain towards a customer-centric and service based system focussed on value clusters. Given that this change has not been accomplished so far can be attributed to the fact that the current offers of electricity suppliers seem not to meet consumer expectations and needs. A study conducted by Opower, 2013 shows a significant gap[23] between customer expectations and electricity supplier service-performance[24]. While US suppliers apparently already have ramped up their services (or are generally meeting their customer expectations better), the gap between expectations and measured performance within Europe is about 30% as shown in Figure 64.

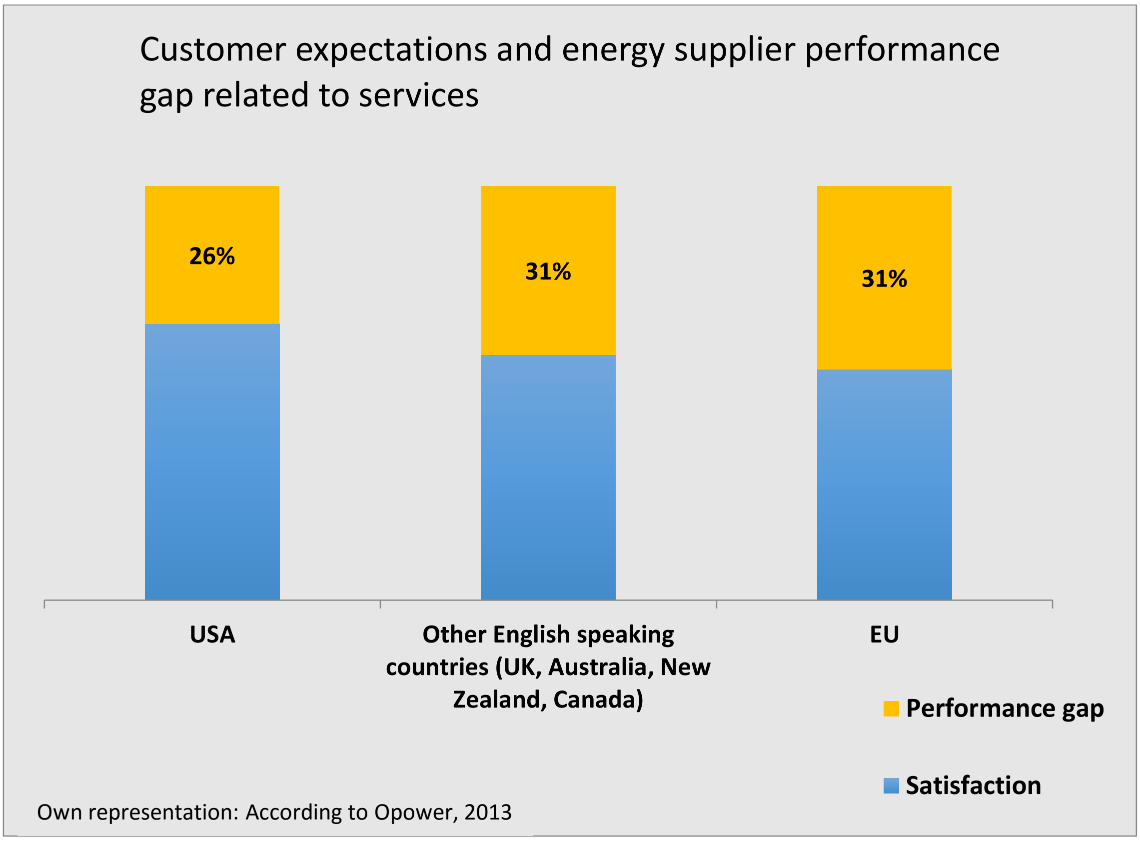


Figure 64: Electricity supplier performance-gap on customer service expectations

With reference to Figure 63 and 64, it can be concluded that a large part of consumers wants to be more "active participants" that engage and contribute to the current change of the energy sector, expecting their electricity suppliers to support and or enable them in becoming so, e.g. by providing tailored solutions, personalised information and offers around solar PV. This is

[23] Refers to questions on how important services are to customers and how they rate the performance of their utility in respect to these services
[24] E.g. costs, personalised information and outreach

validated by the fact that almost 60% of consumers (globally) – especially those between 18 and 34 years – show interest in investments that increase their self-sufficiency (Accenture, 2015).

However, despite these developments, some consumers may prefer to remain rather passive and may not be very interested in new technologies and services. Nevertheless, almost all consumers have one common interest: they would like to reduce their electricity bills. A good example for this can be seen in the article of Bradshaw, 2013 that refers to customers in the UK, where “Worries about affordable energy beat fears about job security […]”. With this in mind and in respect to further findings of Opower, 2013 upon consumers’ expectations related to energy-supplier cost performance, an even higher gap of about 50% is revealed for the UK and further European countries as shown in Figure 65.

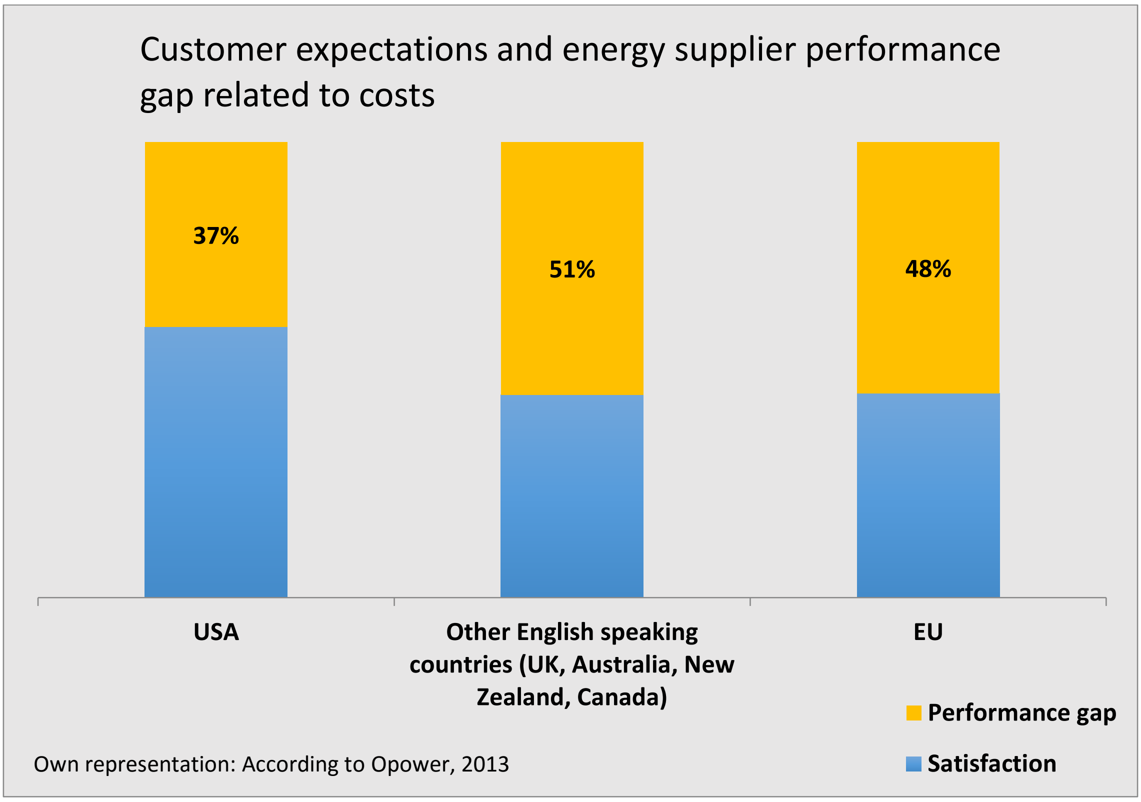


Figure 65: Electricity supplier performance-gap on customer cost expectations

Another interesting fact relating to the performance gaps in Figure 65 and considering electricity prices vary significantly across regions; is that consumers that face very high retail prices are not necessarily less satisfied with the cost-performance of their supplier when compared to consumers in countries with lower prices. As a result, many consumers may not evaluate their suppliers on the actual cost per kWh but rather on what they receive in terms of additional value, e.g. services, billing information, support etc. (Opower, 2013).

Overall, Figures 63 to 65 show that consumers are expected to expand their interest towards home energy generation units, energy management and or financing services topped with maintenance as well as new billing or additional information services either to increase self-sufficiency or to lower electricity bills.

Considering these findings while taking into account the outcomes of the economic evaluations in Section 3.1, solar PV installations could provide electricity suppliers a unique opportunity to meet a large part of the identified performance gaps. This is especially true when considering the results of Accentures', 2015 global survey among consumers presented in Figure 66. It shows that almost half of all customers would be interested to purchase products related to solar PV from their electricity suppliers.

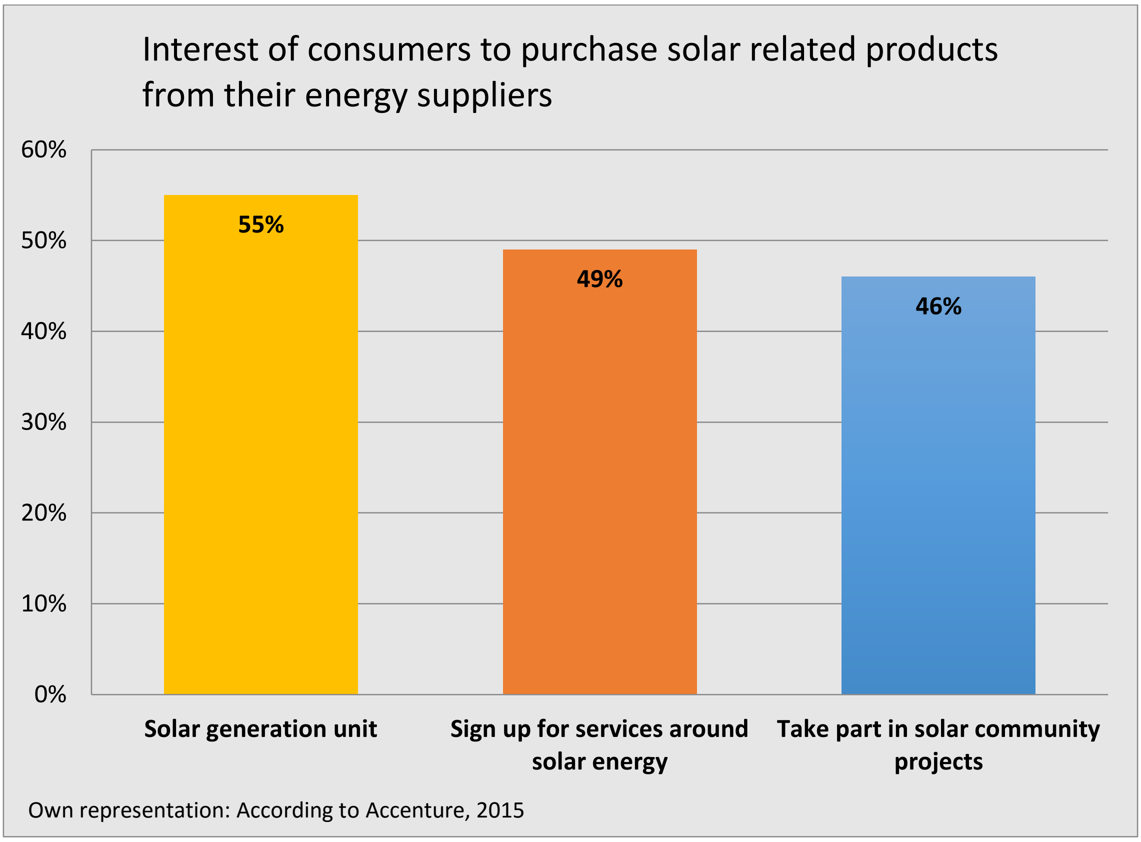


Figure 66: Customer interest to purchase solar related products from electricity suppliers

When compared with other companies that potentially could offer solar related products; electricity suppliers, together with specialised companies in solar PV, are clearly the preferred provider as can be seen in Table 17.

Table 17: Overview of consumers' preferred solar PV product providers

Specialized Solar PV company	74%
Electricity supplier	71%
Home improvement / Electronics provider	41%
Cooperative / Community organization	38%
Maintenance / Repair company	33%
Phone / Cable Provider	18%
Online retailer	16%

Source: Accenture, 2015

Given findings above, Figure 67 aims to take a holistic perspective on today's value creation within the energy economy. Considering the variety of regulatory environments across Europe and recently experienced market developments (strong volatility and or declining wholesale prices), value creation along the traditional value chain has, currently is and will continue to go through major transformation processes. Depending on geographic location and generation portfolios, industry players experience strong volatilities in creating profits within the first section of the value chain. The second part, covering grid operations, is strongly regulated and therefore allows only limited although stable revenues. Finally – as has been shown – energy suppliers currently miss out significant opportunities of value creation in the last part of the value chain that targets energy consumers and services.

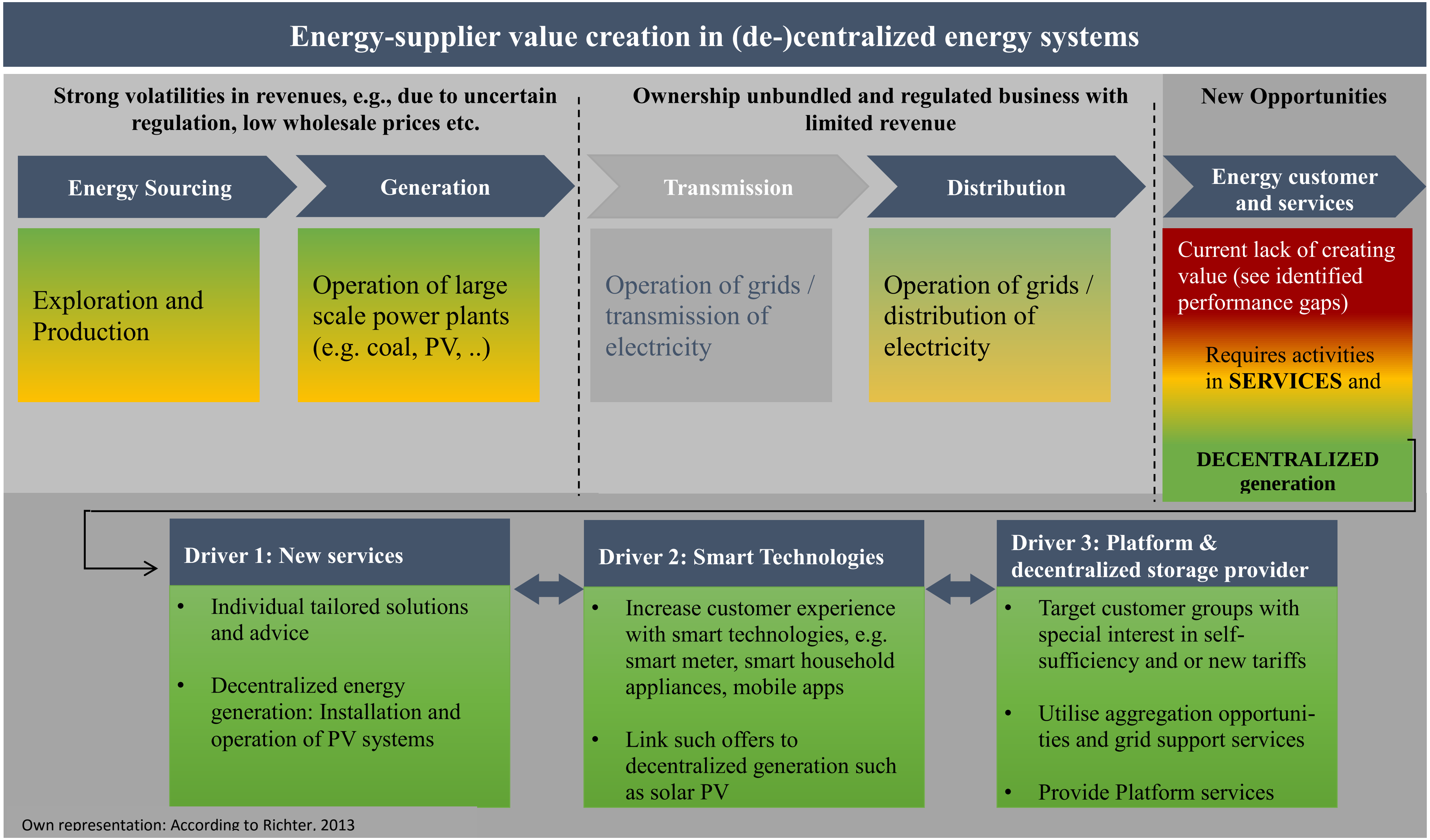


Figure 67 : Snapshot of current and future value creation in the energy economy

Although these findings seem to be very positive for electricity suppliers and their role in the changing energy system, the implementation of solar PV related business models is also facing several barriers as is discussed in the following section.

3.4.1 Barriers for implementing PV related business models

- One of the most important barriers for offering such business models is that residential as well as commercial solar PV systems are rather small and within the range of a few kW to MW. Although providing installation, financing and maintenance services for residential and commercial agents may lead to reasonable returns that exceed cut-off values, the initial investment from an energy-supplier perspective will never be close to large-scale generation units that used to be their core-business. As total revenue values will be small, this results in a potential **"Lack of profitability".**
- A second barrier might be customer-related. Although there is proof of significant demand in solar PV offers, many consumers might fear to start long-term agreements with energy companies. Additionally, the actual demand for financing services might turn out to be considerably lower than is currently assumed, especially because the majority of the interested group being 18 to 34 years might invest at times when technology costs are significantly lower. Furthermore, it can be expected that consumers that are able to finance buildings may prefer to invest in solar PV based only on equity in order to increase their returns. In respect to these facts this may result in a potential **"lack of demand"**.
- Finally, consumers that are already of the opinion that their energy-supplier cost performance is unfair might be not willing to pay for additional services outside of the actual PV installations. Therefore, potential benefits that suppliers may realise with extra services may not offset the increasing costs per costumer. This would lead to a **"lack of overall value for electricity suppliers"**.

Considering the above, identified barriers that are similarly described by Richter, 2013, electricity suppliers need to identify and evaluate possible business model options that result in increased return per customer either i) by reducing their spending on a per customer basis or ii) by developing services that create additional benefits that consumers are willing to pay for. In fact, a combination of both options, tailored to customer segments with different needs, may succeed to cover the described and existing performance gaps and create additional economic benefits for electricity suppliers. Therefore, the following section provides an overview on the potential value creation related to decentralized solar PV.

3.4.2 Enablers and energy supplier value proposition based on decentralized solar PV

In order to assess the potential development of business models that increase economic benefits Figure 68 provides an overview of the value proposition segments related to distributed solar PV.

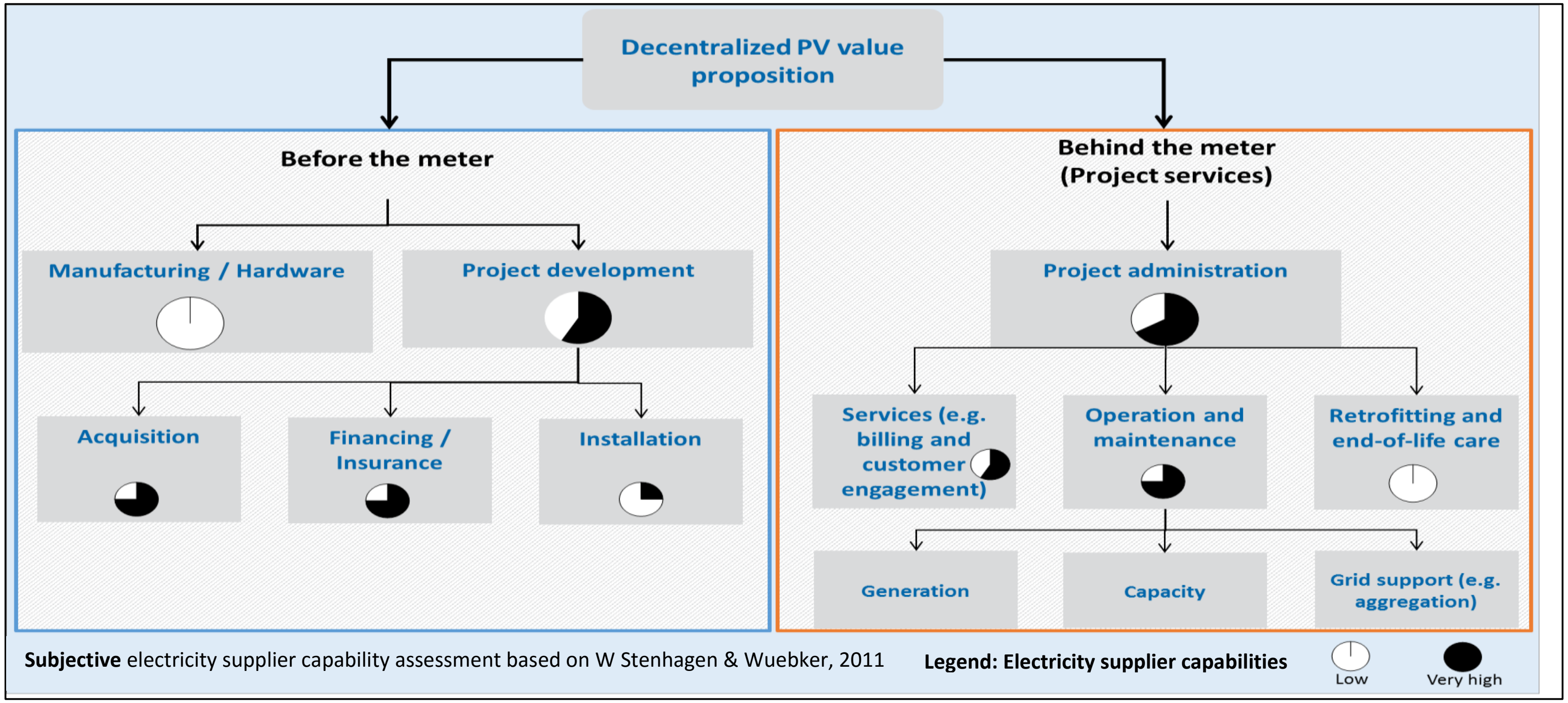


Figure 68 : Decentralized PV value proposition chain and electricity supplier capabilities[25]

[25] Note that this overview is based on a subjective assessment found in literature. Initially, the survey in Section 3.5 was defined such that this assessment should have been tested, however, unfortunately, the reply rate to this question and in particular of utilities was too low to derive a balanced/clear conclusion.

Considering potential solar PV providers shown in Table 17 have different capabilities with regard to the illustrated segments in Figure 68, future business models are likely to be based on new partnerships (also due to regulatory design, e.g. data-management) among electricity suppliers, companies specialised in solar PV as well as telecommunication and electronic providers (e.g. home automation etc.). Considering the existing capabilities of electricity providers and their potential partners, all players can contribute significantly to the evolving business models around decentralized solar PV. A very recent and good example for this can be seen in the partnership of EnerNOC and SunPower. Together the companies “Enhance Energy Intelligence of Commercial and Industrial Customers” by combining energy intelligence software and solar solutions that “enable SunPower’s customers to verify the impact of their solar energy investments and drive optimum energy savings”. (ENERNOC, 2015). This shows that partnerships present an effective way of realising higher values for both the electricity suppliers and the consumer, **increasing benefits for all parties and tackling the identified barrier “lack of profitability**. Combining the existing expertise of various players related to the segments in Figure 69 will result in cost savings as well as benefit increasing synergies.

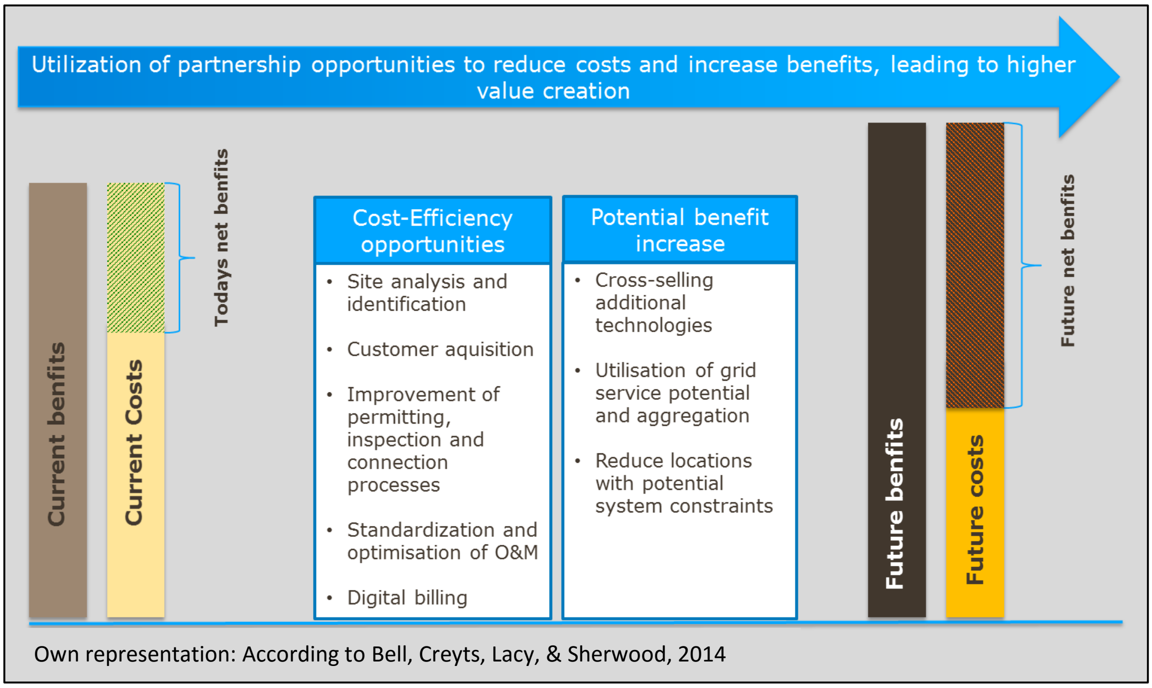


Figure 69 : Options to increase the business model value of decentralized solar PV

Overall, the role of electricity providers is related to three main pillars as shown in Figure 70:

The *first pillar* "reliable combination & added value of solar PV with digital and automation technologies" relates to offering product packages (cross-selling) that support consumers to make full use of the trends in the field of smart technologies (smart home appliances, smart metering, etc.). The role of suppliers in this field is to ensure that they enable consumers to both manage their generation and demand on an autonomous basis. Based on these options consumers will have a clear overview on their energy costs and generation, allowing them to manage their budgets better and to achieve energy targets. This **tackles not only all of the identified performance gaps but also the "lack of the profitability" barrier.**

The *second pillar* "ensuring availability and access to decentralized solar PV" relates to the fact that major electricity suppliers can utilize their existing and strong customer base to run efficient acquisition and capture the increasing customer interest in solar PV. (Note that increasing competition for consumers may hinder them to achieve this in the future in a most cost efficient way). This role could easily be extended by offering additional options such as access to community solar programs and platforms similar to peer-to-peer communities like Airbnb. That way the customer base that initially relates only to agents with the possibility of on-site solar PV generation can be extended to those without direct options and **tackles the identified barrier of "lack of demand"**. Furthermore, this approach allows electricity suppliers without strong solar PV capabilities to increase their benefits in this area by partnering with specialized solar PV companies that on the other hand have low capabilities and or high costs for acquisition of customers. Overall, this would lead to **increasing profitability** for both parties.

The *last pillar* "Utilization of capacity for grid support" targets the potential value that lies in operating decentralized PV capacity (e.g. for consumers that prefer to stay passive and or in situations of grid constraints). Electricity suppliers could identify the most suitable system locations for solar PV integration and implement or externalize solar projects in these regions. By focusing on the potential of "shifting panel orientation to better align with peak loads", easy to grasp system benefits could be realized in a first step. In a second step, this could be complemented by advanced storage and inverter technologies that may ensure grid support whenever needed. This may increase the **overall value for electricity suppliers.**

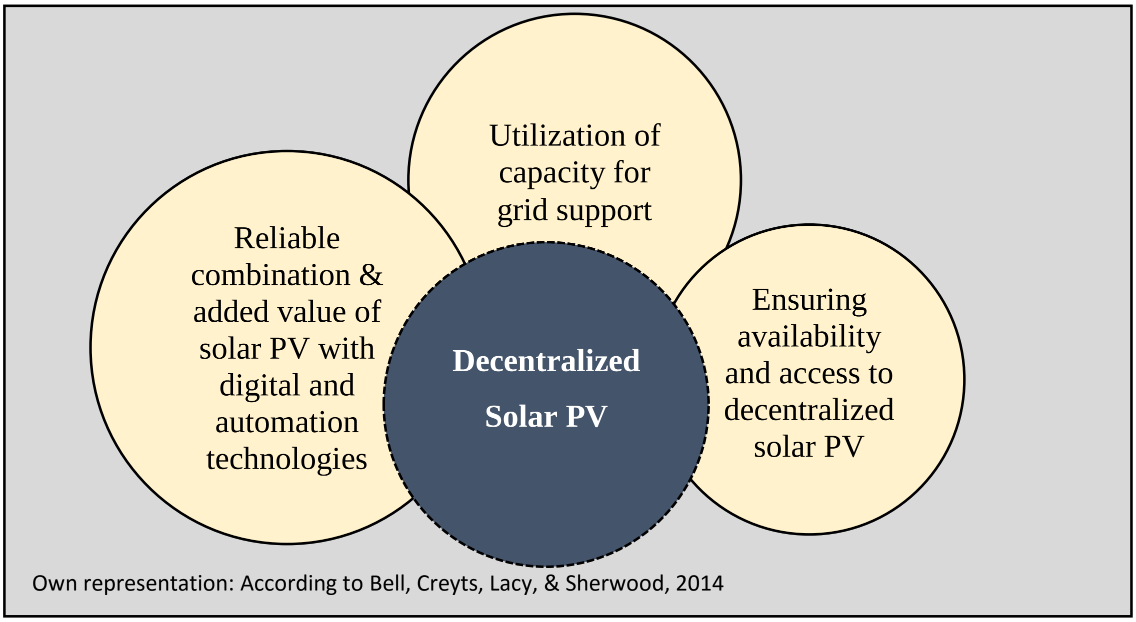


Figure 70: The role of electricity suppliers around decentralized solar PV

Although a quantitative assessment on the potential annual benefit per consumer based on the various value proposition options depends on several factors such as location, electricity price, consumer types, company structures and capabilities etc., Opower, 2013 succeeded in "Quantifying the value of strong customer relationships for European Utilities". Aforementioned paper provides estimations on achievable benefits related to increased customer engagement (Table 18). As it can be assumed that consumers signing up for solar PV products will automatically be engaged accordingly, these **estimations are used to provide a rough estimation for *part of the potential value creation around solar PV*.**

Table 18: Potential of annual electricity supplier benefits based on increased consumer engagement[26]

Solar PV related engagement effects	Impact	Estimated annual benefit per household [€]
Customer relationship	Reduced churn and increased acquisition	3 – 8
Digital engagement	Lower cost to serve	7 – 11
Marketing effectiveness	Increased cross-sell and up-sell	1 – 10
Demand Response	Improved load management	0.5 – 8
Total		**11.5 – 37**

The following provides estimation examples on the potential market volume based on the findings in Table 18:

[26] Source: (Opower, 2013)

With regard to the assessed countries in Section 3.1, the amount of households in 2014 was about 40, 28 and 4 million for Germany, the UK and Portugal respectively (statista, 2015).

- Considering the amount of German private customers of RWE and EON in 2014, which were about 6.6 and 6.2 million respectively (RWE, 2015) and (Meinke, 2014), while taking into account that "RWE lost 5 percent of its German clients and E.ON lost 12 percent over the last three years" (Steitz, 2014),
- Table 19 and 20 provide an overview of a rough estimation on the market potential, taking into account the findings of Section 3.4.

Table 19 : Estimation of total benefit volumes based on increased customer engagement in selected countries

Estimation of potential benefits outlined in Table 14 in selected countries[27]		
	Benefits/a [mln. €] lower range	**Benefits/a [mln. €] higher range**
Germany	**180**	**578**
UK	**126**	**405**
Portugal	**18**	**58**

Table 20: Example of electricity supplier benefits based on increased customer engagement for selected companies[28]

	Potential benefits on reduced churn and increased acquisition **[mln. €] lower range**	Potential benefits on reduced churn and increased acquisition **[mln. €] higher range**
RWE	**0,3**	**0,7**
E.ON	**0,6**	**1,6**
	Other benefits of Table 14 **[mln. €/a] lower range**	Other benefits of Table 14 **[mln. €/a] higher range**
RWE	**11**	**37**
E.ON	**10**	**35**
Total RWE	**11,3**	**37,7**
Total E.ON	**10,6**	**36,6**

[27] Assumes that the stated benefit values in Table 18 are applicable for 55% of the households in the assessed countries and that the stated values could be finally achieved for 71% of these 55% (percentage assumptions based on Section 3.4)

[28] Divides the amount of customers of RWE and E.ON by 2 – which was the average size of households in Germany in 2012 (TekCarta, 2015). Based on this outcome, it is assumed that the stated benefit values in Table 18 are applicable for 55% of these consumers and that the benefits could be finally achieved for 71% of these 55% (percentage assumptions based on Section 3.4).

The fact that the above estimations cover only a small part of the market around decentralized solar PV is validated by a recent statement of Franco Gola, Head of Energy Solutions PV at E.ON Germany who claims that "The market potential for the small installations segment, up to 30kW, is estimated to be worth around a billion Euros annually according to our estimates." (Enkhardt, 2015). This is backed by another statement in a newspaper article of "Die Zeit" in which "E.ON Connecting Energies" states that "traditional generation will no longer be the main revenue contributor, but that focus will be on assisting customers to produce and consume their own electricity in the most efficient manner – a market that they estimate to be worth over 100 billion euros." (Tenbrock, 2013). In addition to these estimated market potentials it should also be taken into account that almost 90% of consumers that are interested to invest in increased self-sufficiency would continue to demand the option of traditional electricity supply services (i.e. back-up in case of outages, low generation etc.) (Accenture, 2015), which would most likely result in additional benefits to the above estimations as well as qualitatively described value proposition options.

3.4.3 Interim conclusions for Cluster II

In respect to the above it can be concluded that:

- Electricity suppliers are to become "energy solution providers" with an increasing number of consumers that actively engage and "partner" with their supplier rather than a remaining a passive consumer.
- Despite the trend of increasing demand in solar PV as well as complementing products, there will be consumer segments that prefer to stay rather passive. Therefore, electricity suppliers should provide new and transparent tariff structures and offers that meet various consumer demands.
- New partnerships among various stakeholders with different core competencies are essential to succeed in increasing the potential economic benefits of business models around decentralized solar PV.
- Solar PV can be seen as a new strategic gateway of electricity suppliers not only to cover the changing needs of consumers but also to engage them more in the transformation of the energy system as well as to open up new business opportunities and revenue streams
- The findings in this section will result in a triple win situation for all stakeholders as shown in Figure 71.

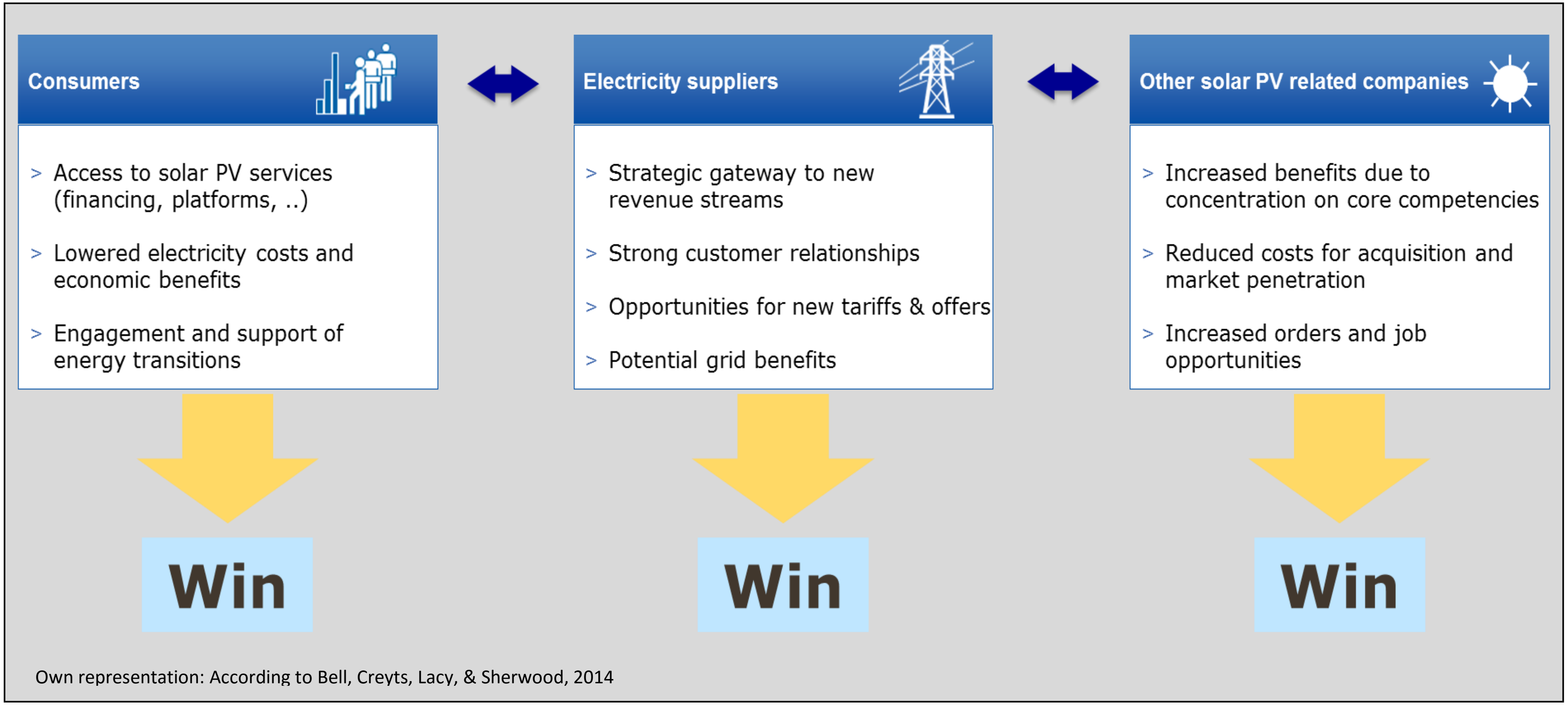


Figure 71 : Decentralized solar PV leading to win-win-win situations for all stakeholders

3.5 Cluster I and II: Survey results – Reality check of interim findings

The following illustrates and summarizes the main outcomes of the conducted survey. The results are then directly related to the findings of the previous sections (3.1 to 3.4).

Table 21 shows the number of people that received the survey within each stakeholder group and their corresponding reply rates.

Table 21 : Survey reply rate and participant overview

Type of stakeholder	Number of receivers	Number of answers	Reply rate	Function of replier(s)
PV-sector related company[29]	123	3	2%	CEO, Technical Director, Head of system technology
Power Sales (Utilities)	63	2	3%	Analyst, Solar Technology Manager
Association (energy related)	60	7	12%	CEO (2), Policy Advisor, Managing Director, Research Consultant, Head of policy, Head of PV
Research Institutions	54	6	11%	Project Manager, Research engineer, Head of PV systems and Distributed Generation Department, Senior researcher/Project manager, Research professor, Group leader
Energy Policy Sector	33	0	0%	
Consulting sector	18	3	17%	CEO, (2) Project managers
Aggregator	15	0	0%	
Consumer organizations	10	1	10%	Renewable Energy project coordinator
Financial Sector	2	1	50%	Technology Officer
NGOs	2	1	50%	Head of Brussels office
Weather Services	1	1	100%	Business Developer
Total	**381**	**25**	**7%**	6 CEOs / Directors, 6 Heads/leaders, e.g. of departments, 1 Professor, 9 (Technology/Project) Managers/consultants/developers/ researchers,1 Policy advisor and 1 Analyst

[29] System Developer / PV Module Producer and/or BOS (Cables and connectors, Inverters, Power Control Tools, Storage, Trackers)

Basic information on participants (Figure 72 and 73)

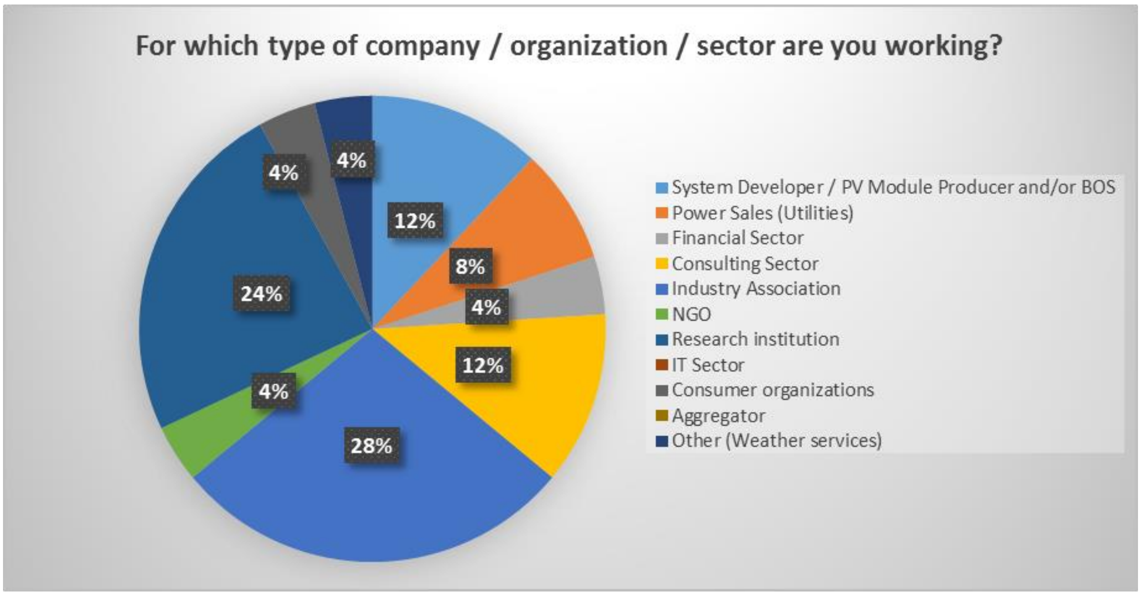


Figure 72 : Survey participant structure

- The five main sectors that contributed to the survey of this study were industry associations, research institutions, PV related companies, consultancies and utilities.

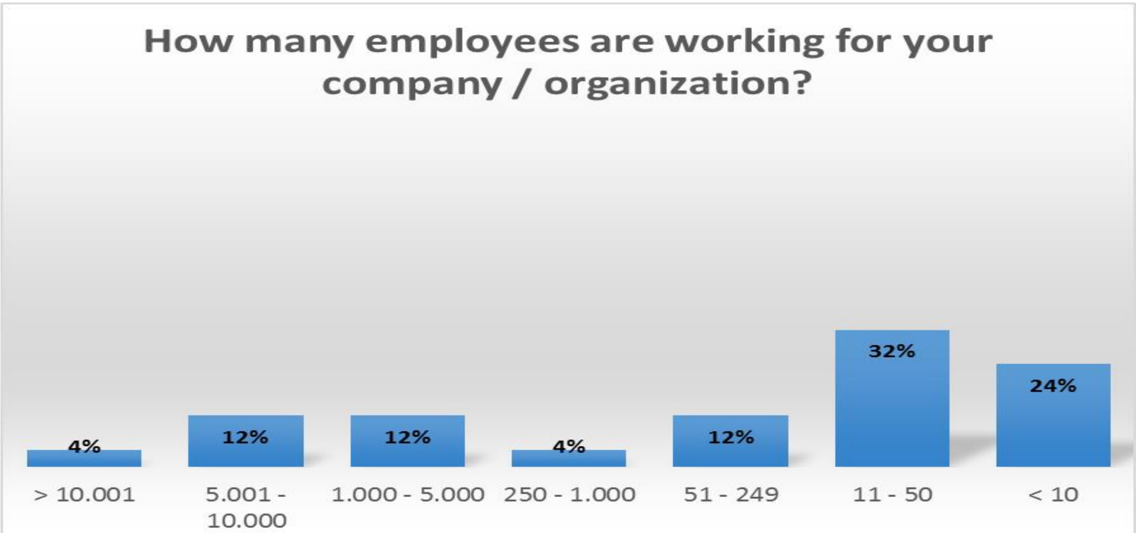


Figure 73 : Size of companies that contributed to the survey

- Overall, the answers are based on individuals that work for a great variety of companies in terms of employees, i.e. from very large to very small. However, within the range of 250 – 1000 and above 10000 only one organization took part in the survey.
- The rather high share of the lower ranges (11 – 50 and below 10) is linked to the large share of associations that took part in the survey (none of them have more than 50 employees).

Developments in the energy economy, anticipated consumer interest and electricity supplier opportunities around solar PV (Figure 74 to 77)

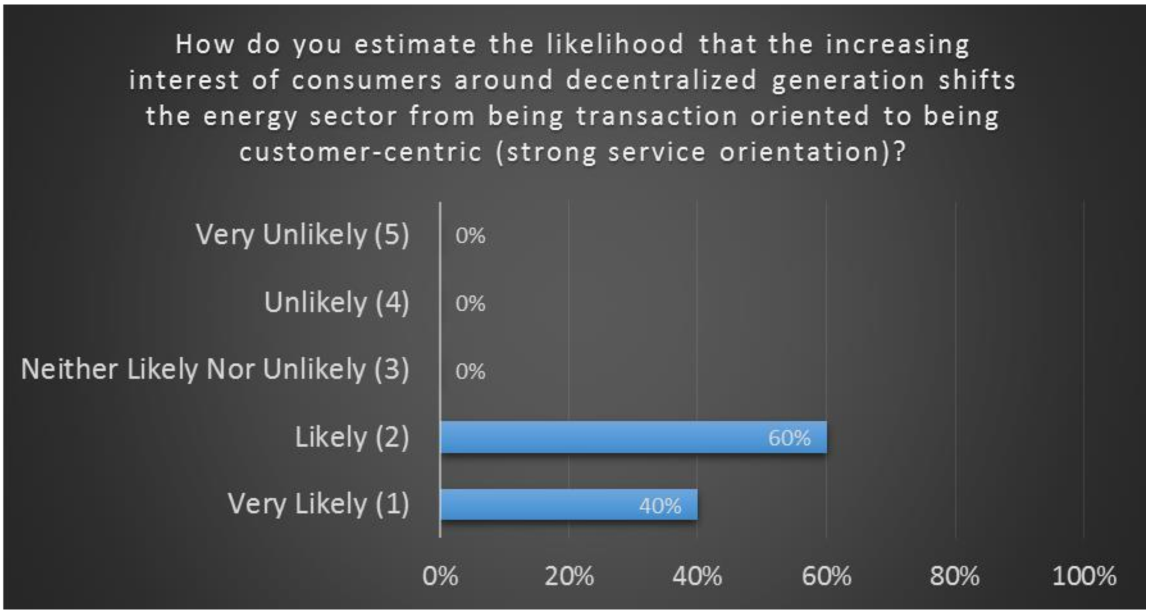


Figure 74 : Estimated likelihood that the energy economy shifts from being transaction to service oriented

- The fact that either “likely”, or, closely followed “very likely” has been chosen clearly confirms the corresponding findings of Section 3.4 e.g. Figure 67 and pillar 1 in Figure 70 which strongly relate and promote the increase of service orientation.

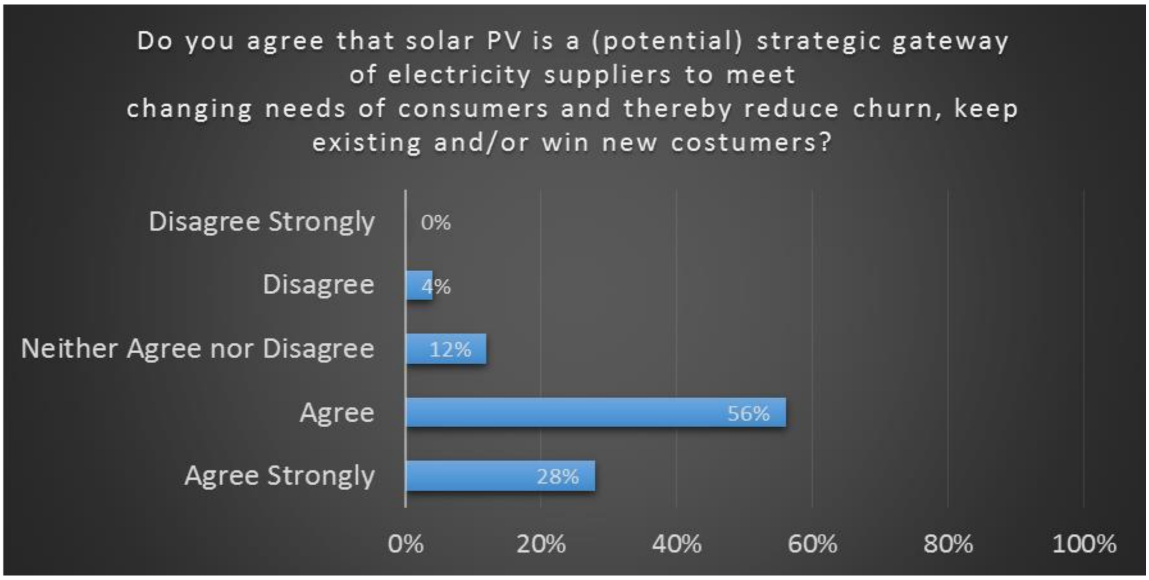


Figure 75 : Estimated likelihood that solar PV is a strategic gateway for el. suppliers to meet changing needs of consumers

- More than 80% of the participants are of the opinion that solar PV can be seen as a "strategic gateway" for electricity suppliers. This indicates strong consensus on the findings within Section 3.4 (Pillar 2 and the strong position of suppliers to connect and meet consumers demand around solar) and is also reflected in the additional comments of the survey participants:
    - "Providing solar solutions to customers will help keep a new generation of customers engaged with utilities." – CEO industry association
    - "Consumers with PV (and in the future also with storage) have less interest in buying electricity, but in buying system services via the grid and buying maintenance services for their equipment in their home."- Analyst in an utility
    - "Electricity suppliers can benefit from distributed generation by providing this as an additional service by using new business models, as for example, an integrated energy efficiency service for the customers which would also bring savings for the suppliers." – Consultant
    - "Electricity supplier could take advantage of the "trust" of the customer to start proposing PV as a new offer." – Technology officer in the financial sector
    - "Surely better for keeping existing / attracting new customers" – Consultant (Project Manager)

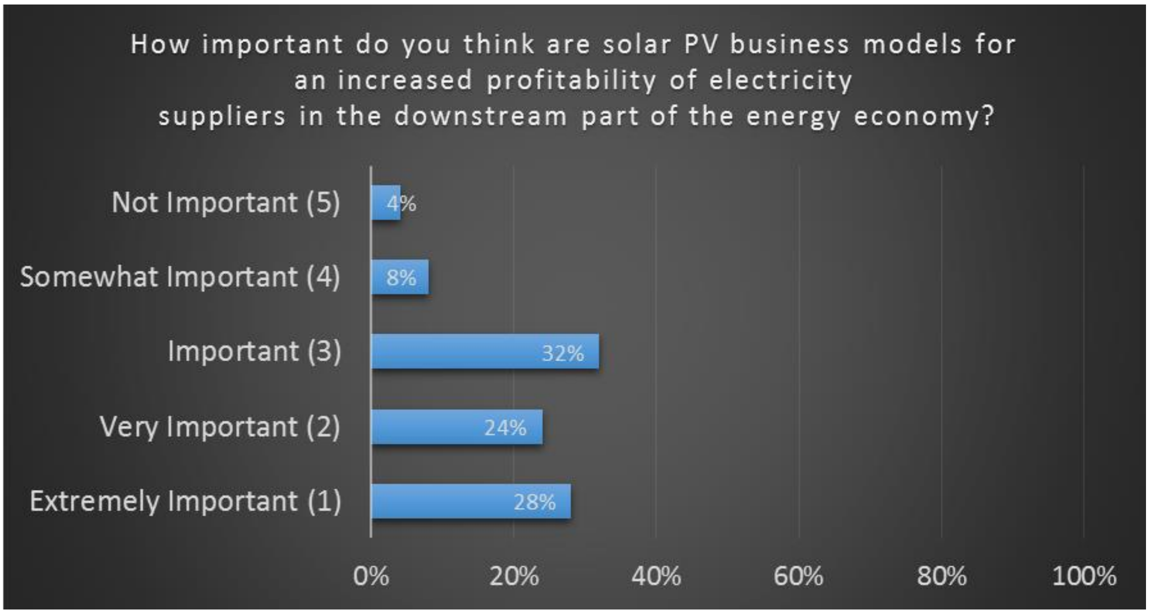


Figure 76 : Importance of business models for an increased profitability of el. suppliers

- Although more than 50% of the answers indicate that solar business models have a rather high importance to increase the profitability of suppliers within the downstream part (the majority of replies sees it only as an "important" factor), more than 10% estimate a moderate contribution of solar PV in this regard. Considering additional comments related to this question confirms that several barriers need to be overcome and that strong action is needed from utilities to succeed in the market:
  - "It's not yet so clear that they can gain money with PV. It's a very competitive market, I doubt that they are fit for it" – Managing director of an industry association
  - "Innovative business models will have to be considered, like: - Crowdfunding (see Engies' efforts to involve citizens/consumers/clients through more actively through crowdfunding) - Offering real time prices to consumers/clients who can take advantage of them to reduce their energy bills" – Consultant (Project Manager)
  - "Since a larger number of customers will use PV (plus storage), a Utility cannot ignore these larger number of customers." – Analyst in an utility
  - "Important to for customer retention, thus indirectly important for profitability" – CEO industry association

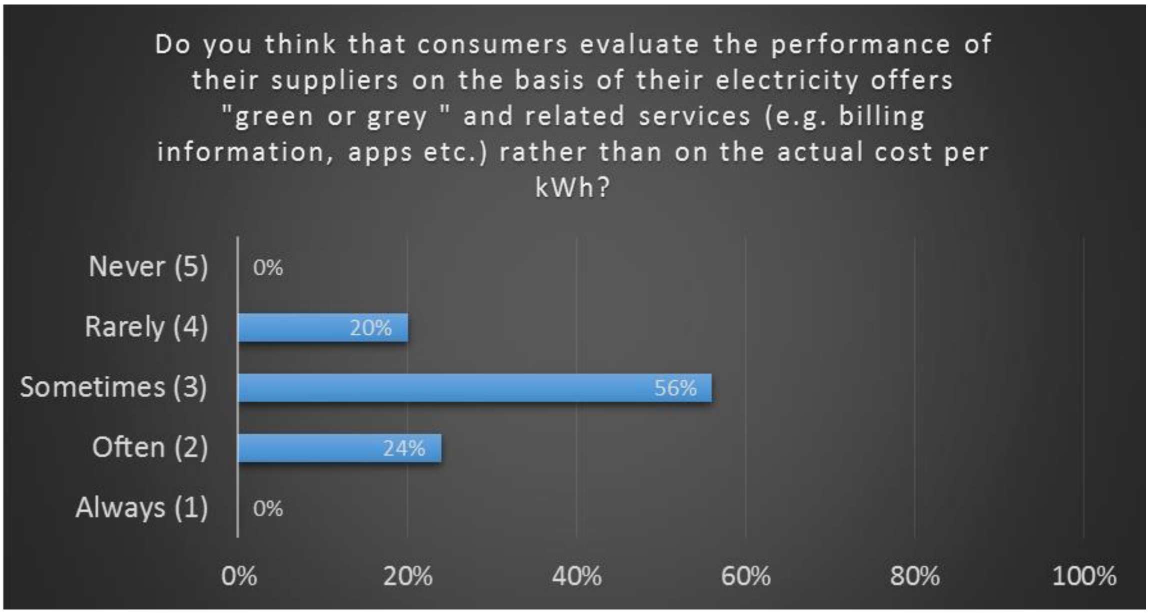


Figure 77 : Opinions on how consumers evaluate the performance of their el. suppliers

- Considering that more than 50% of the participates voted for "sometimes" and taking into account additional comments to this question, there is consensus that "price" is a very crucial parameter for consumers when deciding on an electricity supplier. However, there is a clear tendency that it is not the only criterion for consumers and that extra services are already considered as an important factor. A barrier related to information and traceability was identified. This finding stands slightly in contrast to what was stated in Section 3.4 and a finding of Opower that "many consumers may not evaluate their suppliers on the actual cost per kWh but rather on what they receive in terms of additional value, e.g. services, billing information, support etc."
  - "In the end most customers are rather Price oriented, so one has to be competitive on this. That the Services are working properly is a must, but this will in the end not be decisive. Utilities not performing on billing etc. will vanish from the market, and the rest has the Quality but has to compete on Prices."- Analyst in an utility
  - "Surveys show that the price still remains the most important factor for consumers' choice, followed by questions related to service quality and the environmental performance (share of renewable electricity in the fuel mix, suppliers' commitment to investments in additional renewable generation capacities)." – Renewable energy project coordinator, Consumer organisation

- "We are in a transition and some do choose green - others are used to the status quo and just want a kwh bill through the letter box each month, anecdotally I'd say older consumers are more like this." – CEO of an industry association
- ""Electricity lacks the traceability which is required to make "green" electricity offers attractive to most consumers." – Project manager of a research institution
- ""green electricity" is a very abstract thing, not like organic food. Only very well informed people will understand the concept." – Managing director of an industry association

Factors influencing consumer investment decisions around solar PV (Figure 78 to 80)

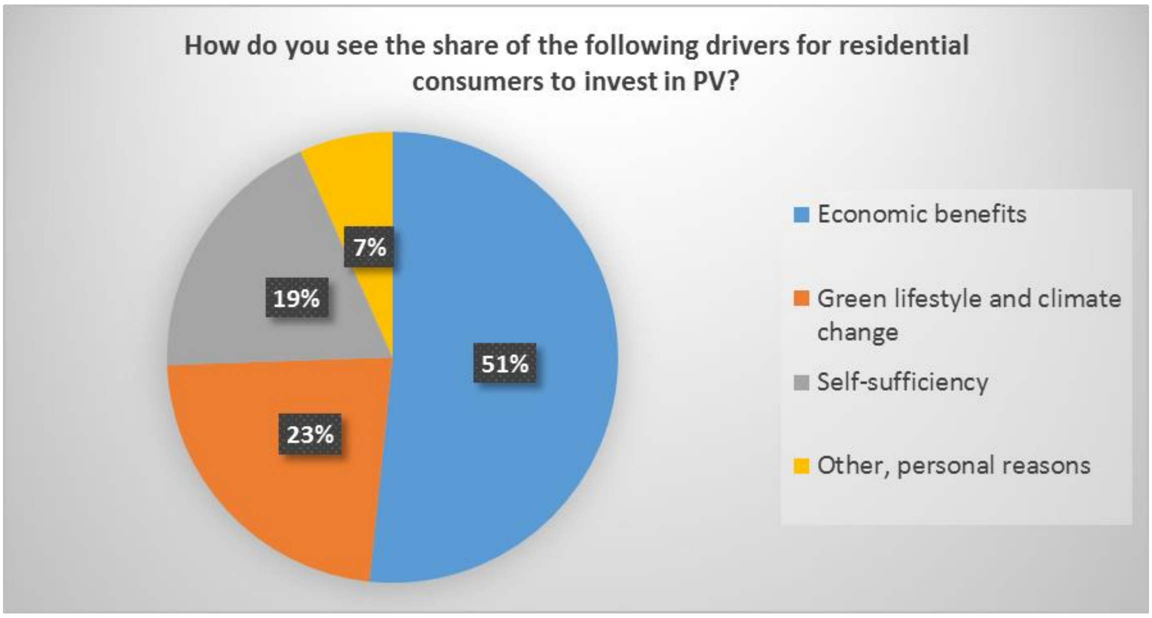


Figure 78 : Drivers for residential consumers to invest in solar PV

- Overall this outcome confirms that economic benefits can be considered to be a key element for consumers that decide to invest in solar PV. However, it shows also that green image and climate change as well as self-sufficiency are likely to contribute to around 40% of the final investment decision. For examples on "other, personal reasons" please see the listed replies in Table 22.

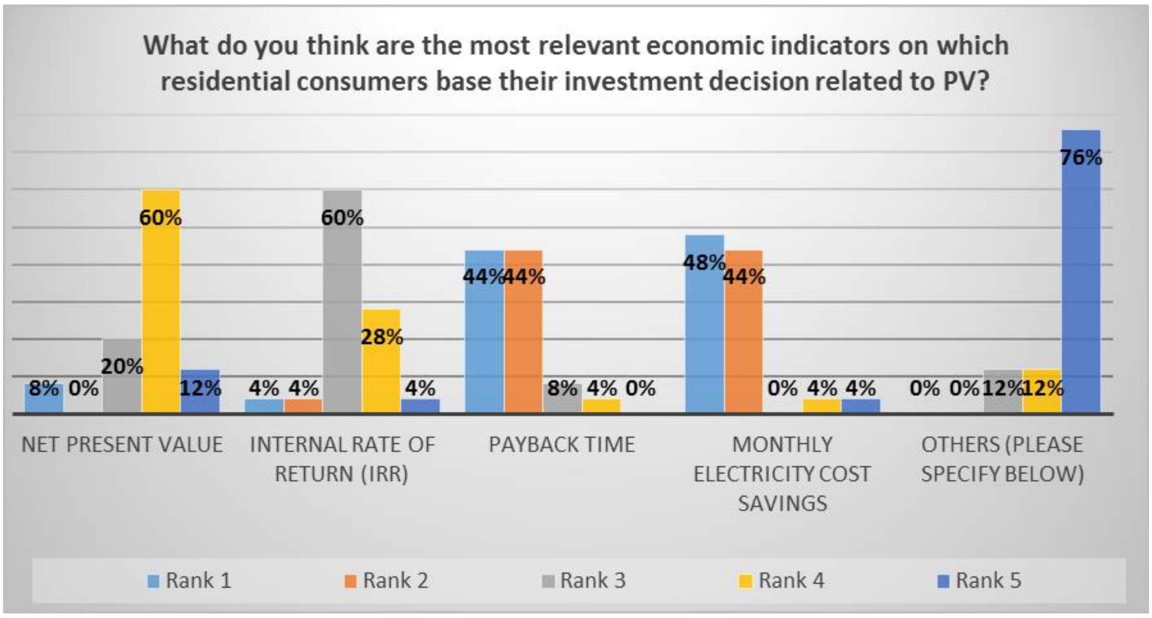


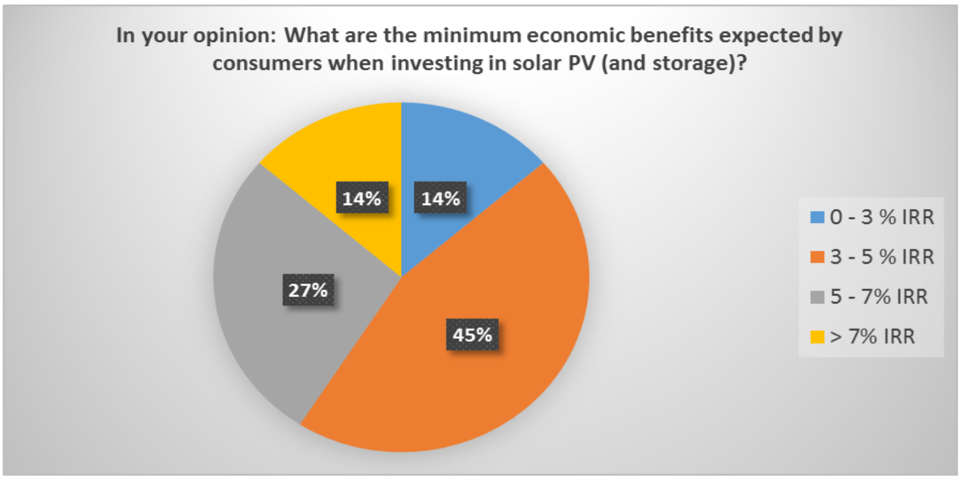
Figure 79 : Ranking of economic indicators on which consumers are expected to base their investment decisions related to PV

- With regard to the relative importance of economic benefits the above findings point out that “Monthly electricity cost savings” and “payback time” are considered to be the most important indicators for consumers, followed by IRR and NPV, while “others” are clearly ranked as the least important factors. For the latter category several examples were provided:

Table 22 : Additional economic and non-economic parameters influencing consumer investment decisions

Economic	Non-economic
“Impact on house value”	“Ease of purchase and installation”
“Level of feed in tariff if existing.”	“attraction of electronic devices, interesting interface and control via mobile phone (pioneer/ early adopter interest)”
“Risks related to operation and maintenance costs. Reliability on the technology and yield forecasts. Risks on damage in the system.”	“Insurance of their PV installation”
“Taxes, also tax exemptions, are critical for customers also.”	“Origin of materials (Europe manufacturing)”

- These findings support the calculation and assessment of the various economic indicators within this report as they cover the variety of consumers' most important indicators for decision making.
- Note that the final ranking of this survey is somewhat consistent with existent research of the University of Texas on the "Economics of Individual Decision-Making: Buy vs. Lease Differences in the Adoption of Residential Solar". The latter found that "respondents reported using payback period as one of the methods used for evaluating the financial attractiveness of their investment (66%) as opposed to NPV (7%), IRR (27%), Net monthly savings (25%), or "Other methods" used (6%) (Rai & Sigrin, 2012).
- With regard to the rather low ranking of NPV it should be noted that this parameter can be assumed to be important for rather rational decision makers "who at the very least would base the decision on a net present value (NPV) calculation, if not compare that NPV to alternative investment options" (Rai & Sigrin, 2012).
- However, (as the mentioned study refers to a survey conducted in Texas), it should also be considered that differences in culture, policy design etc. could cause a substantial difference between answers of consumers in Europe and Texas.



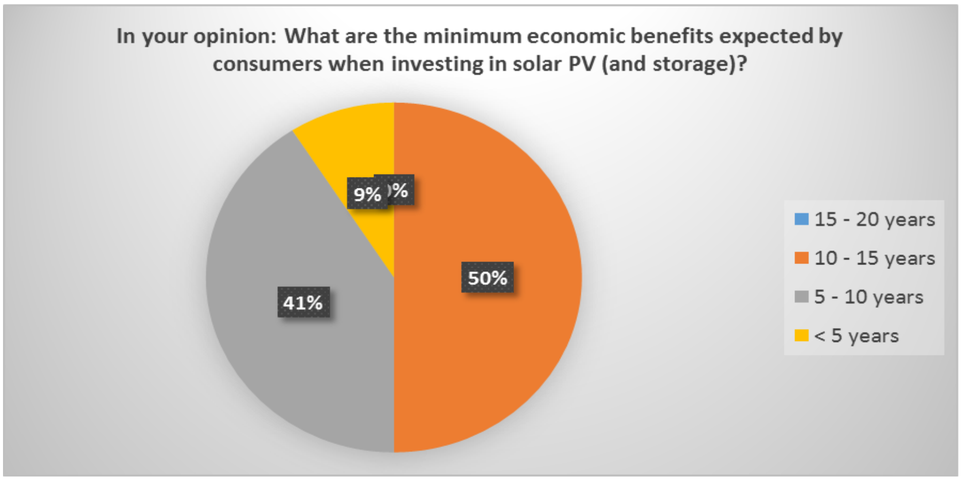


Figure 80 : Expected minimum economic benefits that consumers require for investing in solar PV

- With regard to the outcomes for expected Payback times and IRRs, it is clear that the typical range is between 5 and 15 years with IRR expectations of 3% to 7%. A few more votes were given to the lower IRR range (3-5%) and correspondingly higher payback times (10 to 15 years). The extreme of a very high payback time was never considered while IRRs above 7 and or between 0% and 3% were voted for only 3 times.
- This finding clearly supports the conclusion that – especially when taking into account that a significant share for investments decisions in solar PV(-battery) is not related to economic indicators – solar PV and its potential combination with battery storage are to remain extremely interesting for consumers (in all assessed policy scenario types). This is particularly valid when considering declining technology costs and potential additional revenue streams enabled (which were not assessed in this study but could provide additional value as was stated in Section

2.1.4) based on a stronger market integration and new business models as was pointed out in Section 3.1 and 3.2.

The above outcomes related to economic benefits and parameters (Figure 78 to 80) are similarly found by a recent report published by RWTH Aachen (Kairies, et al., 2015) that assessed the drivers for consumers in Germany for installing solar PV combined with battery storage:

- Around 80% of the consumers stated that they installed PV storage in order to be protected against rising electricity prices and to pro-actively support the energy transition.
- Additionally, 60% named interest in the technology as a substantial driver.
- Reductions in feed-in tariffs and save investments however were only considered by about 20% as a driver.
- Similarly, only around 47,8% of the consumers that installed solar PV combined with batteries stated that they were expecting a net benefit, while 42,6% were only expecting a break-even and 9,6% were even expecting a net loss.

Based on the results above, and since the report particularly targets PV systems combined with storage, it concludes that mainly so-called “Innovators” or “Early Adopters” are interested in a solar PV battery combination and that a contribution to the energy transition rather than economic benefits are the main investment driver for this consumer group.

The above supports the conclusion of Section 3.1.1: PV only systems are the best investment alternative within the German market and would therefore be chosen from a pure economic perspective when considering the reference scenario, however, an extension of investment decision parameters that include non-monetary parameters such as self-sufficiency are likely to trigger investments decisions in favour of PV systems combined with batteries.

Additionally, the above findings support the hypothesis in Section 3.4 that an increasing amount of consumers want to actively participate in energy transitions and become more sensible to topics such as climate change.

Barriers for implementing PV business models

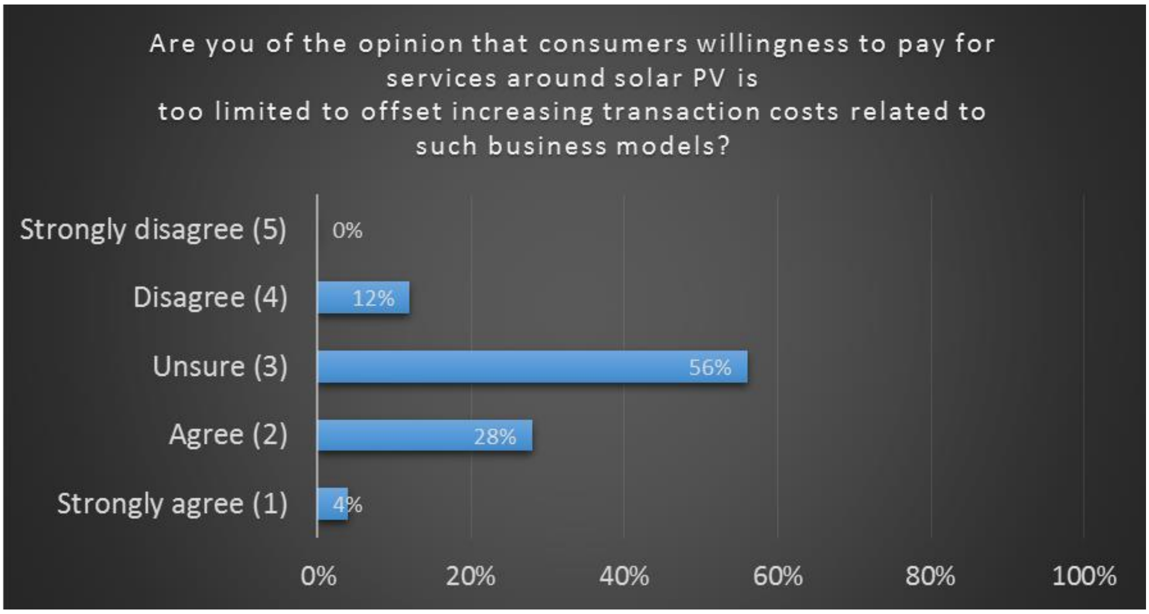


Figure 81 : Opinions the willingness of consumers to pay for services around solar PV

- Although a large part of the participants is "unsure" and or neutral with regard to the question, the remaining votes seem to indicate a tendency to agree rather than to disagree with regard to the mentioned barrier in Section 3.4.1.

Views on how to overcome solar PV business model barriers (Figure 82 to 84)

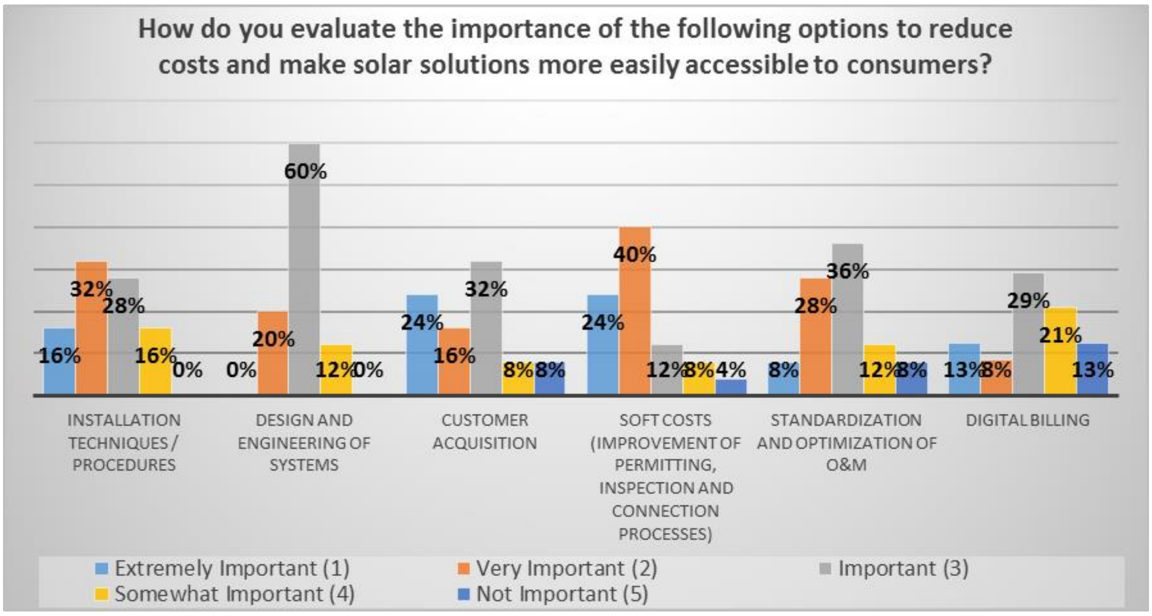


Figure 82 : Estimations on the importance of measures to reduce costs around solar PV business models

- Since there is great variety of provided options, a clear ranking is rather difficult to provide. This indicates that all mentioned possibilities seem to be of importance and it shows that the industry did not identify/agree upon one particular option:
    - Clear cases for rank 1 are customer acquisition and soft costs which were voted by 25% as most important.
    - High votes for rank 2 are again soft costs, installation techniques/procedures and standardisation and optimization of O&M.
    - The latter is however also most commonly ranked third (38%) similar is customer acquisition (33%).
    - The least important option is digital billing.

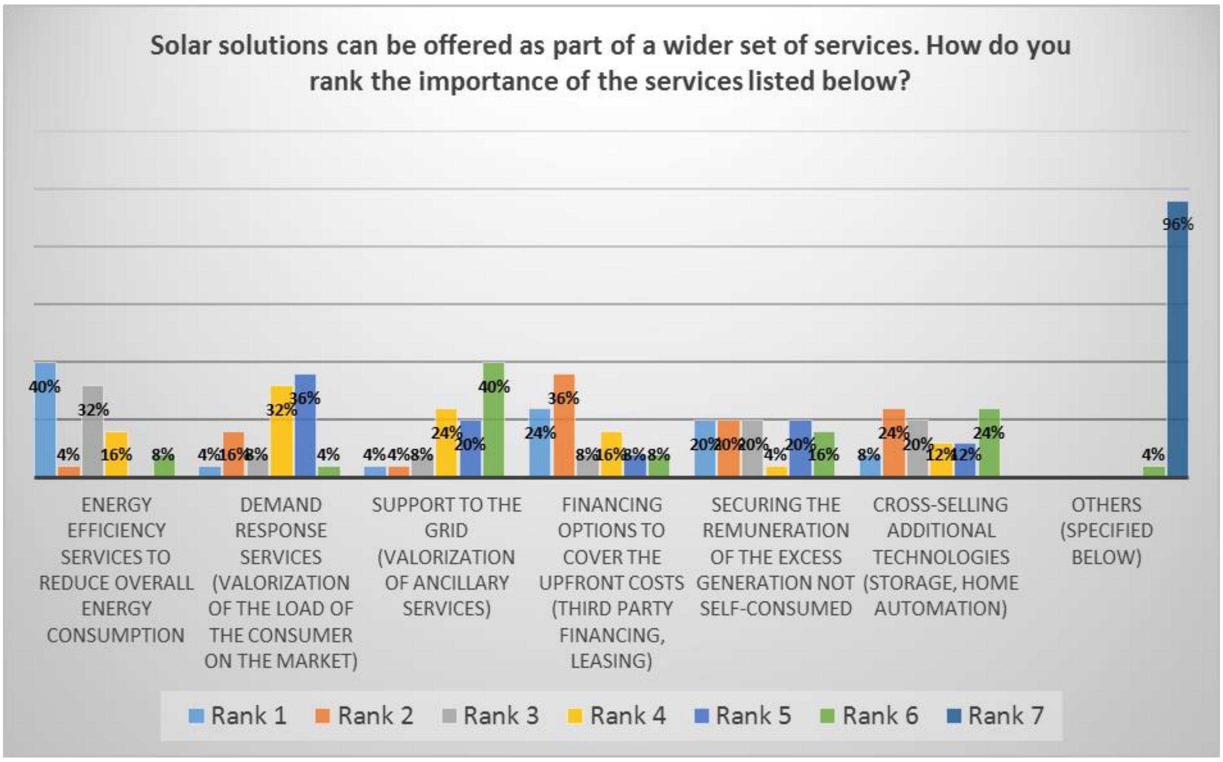


Figure 83 : Ranking on the importance of additional services around solar PV

- The three most important additional services are related to
    - Energy efficiency
    - Financing
    - Cross selling
- Less important are
    - Demand response
    - Securing of the remuneration of excess electricity
    - Support to the grid

With the additional comment of a CEO of an industry association stating that with “stronger pricing signals or contractual offers from the market and system to the consumer, demand response services and support to the grid would become much more important.”

These findings reflect upon several options considered in Section 3.4 as a potential way to overcome identified barriers related to the profitability of solar PV business models. The additional statement matches very well with the anticipated “market integration” policy scenario and supports the conclusion that further market integration, that is, convergence of wholesale and retail markets should be politically supported rather than diminishing the benefit stream of self-consumption based on additional charges.

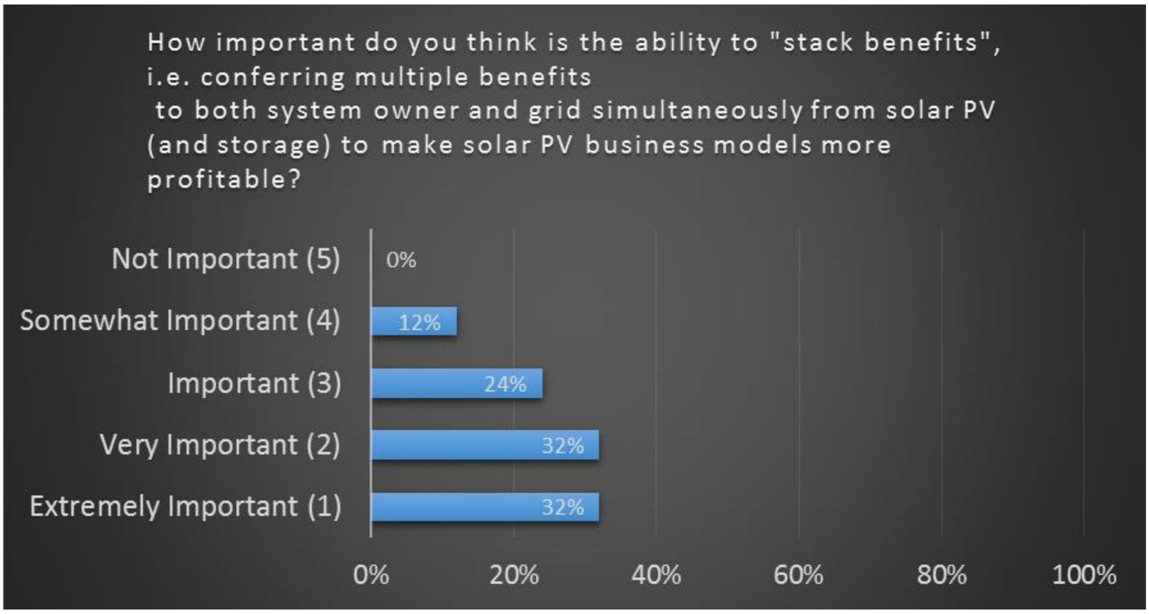


Figure 84 : Opinions on the importance to stack benefits in order to the profitability of solar PV business models

Finally, Figure 84 gives a clear indication that the survey participants agree upon the conclusion within Section 3.4 that it is important to offer solar PV(-battery) business models as part of a set of solutions that will provide the opportunity to stack benefits which will ultimately lead to an increased profitability of solar PV business models.

3.6 Cluster I and II: Interviews with industry stakeholders on interim findings

The following sub-sections (3.6.1 to 3.6.3) outline the information and opinions gained based on the exchanges with several industry stakeholders upon the interim results of the previous sections. Section 3.6.4 then provides a short summary of each interview and draws general conclusions in respect to the interim findings of this report.

3.6.1 Views of a consumer association

When considering the assessed policy scenarios and when taking a consumer perspective, the interviewee outlined that self-consumption should not be subject to any constraints, that is, consumers should be allowed to save the full electricity price. According to findings of the association, the representative explained that any fee related to self-consumption would significantly reduce consumers' interest around solar PV and should therefore be avoided in future policy designs. According to the associations position, the issue of reduced grid payments due to self-consumption could be overcome via the introduction of connection charges (€/kW), ensuring more transparency for consumers. Consumer flexibility should be encouraged, for instance, via a similar design as was assessed in the market integration scenario, however, retroactive changes regarding self-consumption schemes should be avoided by any means. The main concern of the interviewee with regard to the market integration scenario as assessed in this report is the fact that household consumers are very unlikely to have the necessary capabilities to deal with market risk exposure. A third party, preferably not the electricity supplier (due to transparency issues) but an independent "aggregator", would therefore be necessary to support and or completely take over the "consumers' integration" into electricity markets. The interview candidate however pointed out that this proposal is currently difficult to implement due to limited business opportunities for such third parties, which face one substantial barrier: aggregation of small units is linked to rather high complexity and costs, while the potential revenue streams are very limited under current market conditions, for example, due to low spreads of peak and off-peak prices. As a result, and in respect to short to medium timeframes, the association recommends prevailing policy designs with a "stable remuneration scheme for electricity fed into the grid".

When asked on how stakeholders can potentially reduce costs around PV(-battery) systems, the interviewee highlighted joint purchasing programs: by aggregating interested consumers within a certain area/country, a larger amount of systems can be ordered at once, which reduces the total associated costs with purchasing transactions and allows for scale benefits, increasing the overall profits for all involved stakeholders.

Furthermore, the associations representative mentioned leasing business models and stated that consumers should be fully informed on how leasing impacts the business case (as it often reduces the total benefits). In addition, the interviewee mentioned that companies which offer consumers the opportunity to invest in PV systems that are operated off-site consumer premises should be transparent on how the revenue streams available to the company are used (in particular if this company is an energy supplier).

With regard to drivers and barriers faced by consumers that are interested to invest in self-generation, the interviewee referred to a report that states the following: “In 2014, the CLEAR project conducted a survey amongst more than 5,000 consumers in five Member States (Belgium, Italy, the Netherlands, Portugal, Spain) on the drivers and barriers that are perceived by consumers with regard to adopting renewable self-generation technologies. The main reason for intending to buy a renewable energy solution mentioned by consumers was lowering their energy cost (63% of consumers surveyed in five Member States), followed by environmental conscience (53%). Amongst those consumers who were thinking about or who were rejecting a renewable energy technology installation, 56% mentioned the high investment cost, followed by 15% who replied that they did not know much about the technologies. […] Consumers’ willingness to contribute to combat climate change and prevent the exhaustion of fossil fuels was identified as the most important driver for investment in renewable energy technologies, followed by financial aspects like expected energy savings and the increase of the property value. However, while consumers generally share the positive aspects of renewable energy technologies, the survey revealed a high level of scepticism regarding the financial benefits of an investment. Naturally, consumers essentially want to know if it pays off.” (Gesellschaft für Konsumforschung (GfK), 2014). In addition to the above, the interviewee pointed out the finding of another survey that focused on consumers in England and Wales: “Financial returns remain the main motivation for investment in solar PV, but environmental motivations are increasingly significant.” (citizens advice, 2015).

3.6.2 Views of a new entrant

At the time of the interview, the selected stakeholder offered two types of solar PV(-battery) products for residential consumers in Germany:

- Based on PV systems without a battery, the company guarantees that consumers can save at least 50% of their electricity bill (referring to the electricity bill of the previous year without a PV system).
- Based on PV systems combined with a battery (8,3 kWh storage capacity) the enterprise covers the entire electricity bill (referring to the electricity bill of the previous year without a PV-battery system), including a flat rate up to 500 kWh/a for electricity consumption that may not be covered by the system.

In light of the above offers, the company aims to increase consumers' interest and confidence in solar PV products. The interviewee explained that consumers in Germany used to be predominantly interested in the return of their investment. However, with decreasing feed-in-tariffs (FiTs) these returns are shrinking substantially, which currently causes a slowdown of PV installations in Germany. Therefore, the two PV offerings aim to offer a completely new reason to purchase PV: Consumers are now able to be partly or completely independent of their current electricity supplier and by this, limit their exposure to power price increases, non-transparent electricity bills and low service level of existing electricity companies. Although the concept of this new business model is convincing, the company representative added, that additionally, a compelling marketing and customer focus sales approach via various channels is required. This can be explained by the fact that consumers need to invest still a considerable amount of money and have therefore a lot of questions which can only be solved by a trustful and convincing sales agent.

With regard to PV-battery system combinations, the interviewee stated that according to an extensive survey via a large market research institute, the company found that German consumers that are interested in such system variants have rather unrealistic requirements: i) "A battery should lead to complete self-sufficiency and ii) be amortised within 5 to 6 years". Although the former is unrealistic with respect to commonly installed system sizes and technology costs, the company representative outlined that the current PV and battery product targets and indirectly meets this desire as it takes over the current electricity bill completely. With reference to the PV-battery system business model, the interviewee pointed out the trend of price decreases and outlined potential future offers of "complete packages" as follows:

- **System:** 5 kWp PV linked to an 8 kWh battery
- **Investment including tax:** 10 000 €
- **Warranty:** 10 years
- Installation within one day
- No administrative work for the consumer

Further, the interview candidate described the consumer profile of those that currently invest in PV-battery system combinations as follows:

- **Gender:** Only male
- **Age:** 35 to 60 years
- **Education:** Mainly academic, many hold a PhD
- **Income:** 100 000 € per year or more
- **Other information:** Interested in technology (e.g. owner of IPADs, new cars with many additional functions, etc.), high positions in their profession, well informed via various media channels

Despite the outlined customer profile and investment requirements that currently prevail, the interviewee explained that the German market shows a trend to develop from pure economical driven investment decisions towards decisions that take additional benefits of solar PV such as “self-consumption and self-sufficiency” into account.

When asked about the assessed policy scenarios of this report, the company representative clearly stated that the market integration scenario would be the favourable alternative. In the interviewees opinion PV systems should be grid-supportive as only this allows for integration and greater penetration of PV systems. Therefore, regulatory frameworks should define a limit with regard to the electricity that is allowed to be fed into grid for all PV(-battery) systems, while ensuring that injections and battery load management are based on intelligent solutions, for example, by taking into account consumer consumption profiles and weather forecasts.

With regard to the potential of partnering with incumbents, such as having access to a broad customer base and thereby reducing costs / increase sales, the interviewee noted many opportunities in addition to implementation challenges. Despite the fact that, based on the company’s experience, brand recognition and consumer trust in their existing electricity supplier (usually being incumbents) support the sales process and consumers’ confidence in the product, the actual value of partnerships can only be leveraged if the PV company also offers the necessary sales and operational processes to the incumbent as a service. This is linked to the fact that the incumbents often lack sufficient sales channels, installers and customer data. An example is the information on electricity consumption (most commonly measured only once per year) and the fact that potential consumers (e.g. house owners) often cannot be filtered. This is further complicated by the fact that incumbents need their customers' approval in order to provide them with information regarding new products and services (e.g. via sending letters).

With regard to the potential of PV(-battery) systems to provide system services to electricity markets, the company representative confirmed that this is technically feasible but that adaptations of regulatory frameworks and market designs are necessary to unlock this potential. From a business perspective, the potential revenues are currently mainly limited for instance, due to the low remuneration of balancing services. The interviewee added that the companies' offer based on a PV system combined with an 8,3 kWh battery anticipates that aforementioned barrier will be overcome within the next 3-5 years.

3.6.3 Views of an incumbent

This interview included two participants from a multinational energy company with headquarters in France. Overall, the company is globally active in all solar PV business areas, that is residential, commercial, industrial and utility scale applications. However, within European markets and with respect to the system sizes assessed in this report, the company's main focus is the business-to-business (B2B), namely commercial / industrial segment. According to the interviewees, this is caused by the fact that the respective customer base outside France is mainly related to these sectors, while the business model for the business-to-consumer (B2C) segment is very limited in France. The latter is caused by low (retail) electricity prices in the country and retro-active changes to the support design of solar PV after 2011. As a consequence, the potential business case for consumers with regard to solar PV installations is rather limited and therefore the company reduced its activities in this sector and core market after 2011. For the above reasons, the company's main activities with regard to the B2C segment are outside Europe, such as Australia and Chile. One business model with regard to European markets particularly mentioned by the representatives was to partner with consumers that collectively invest in ground mounted PV systems. Overall, both representatives stated that the company is planning to increase their activities with regard to solar PV in European markets and the B2C segment, for example, by extending/diversifying their (existing) partnerships. The main barrier for a strong uptake in this business area (B2C) is related to the fact that some markets are simply "not ready yet", that is to say solar PV is still slightly too expensive compared to retail electricity prices, while in other markets the company has only a limited customer base and or aforementioned partnerships. However, both interviewees anticipate a strong growth in decentralized generation (in particular with continuously decreasing technology costs) and foresee an uptake in this sector. Finally, the overall strategy of the company for European markets is to take a more holistic perspective in order to develop "smart city" concepts that tackle particular issues regarding sustainability. Within these concepts, solar PV and electricity will be one of many complementing technologies (e.g. fuel cells, CHP etc.) and commodities (hydrogen, gas etc.) utilised to develop energy efficient systems that allow the company to optimize a city or a district, while meeting the energy needs of a great variety of stakeholders.

3.6.4 Interview summaries and conclusions

The interview with the consumer association revealed the following:

- The constraint scenario should not be implemented.
- The market integration scenario can be seen as a suitable option to increase consumer flexibility as long as consumers are supported to deal with market risk exposure with the prerequisite being that revenue streams for companies, for example third parties, that offer market integration support are large enough.
- Joint purchasing programs may be an additional option to reduce the overall costs of PV(-battery) systems for consumers and corresponding companies that offer such systems
- Financial benefits (in particular to break-even and to reduce electricity costs) are a significant factor for consumers' although the relative importance of this parameter across various European countries may vary.
- Next to financial benefits environmental concerns are a major driver for investments.
- The main barrier for consumers that do not invest in solar PV is high investment costs.

The perspectives of the new entrant can be summarized as follows:

- There is a shift (in the German market) from investments driven by financial benefits towards investments made due to higher self-sufficiency.
- High investment costs require professional sale approaches to gain consumers trust.
- For a broader implementation of PV-battery systems among different consumer groups' investment costs need to be reduced.
- To allow for better system integration of solar PV a policy design similar to the assessed market integration scenario should be implemented – with an additional prerequisite of this scenario being on how much electricity produced by the PV(-battery) system is allowed to be injected to the grid.

- Although partnerships between new entrants and incumbents can be supportive in increasing customer confidence in solar PV products (due to consumer trust with regard to incumbents), hurdles such as better insights in costumer structures of the respective incumbent must be overcome to fully utilise partnership potentials.
- The company anticipates that there is a potential business case related to the aggregation of residential PV(-battery) systems to provide system services (as will be assessed in Section 3.7 of this report) and that this potential can be realised within short to medium timeframes once regulatory and market design barriers are overcome.

The statements of the two employees working for an incumbent outlined that:

- The company bases its global solar PV business activities corresponding to its prevailing status for instance existing customer base as well as existing policy designs in various markets that may favour different solar PV business cases (residential, commercial, industrial and utility scale applications).
- With a view on European markets and declining technology costs, the company plans to expand its B2C activities and considers partnerships as an important way of doing so.
- Overall, the company takes rather holistic perspectives and sees solar PV as part of a technology mix that will contribute to the development of "smart city" concepts, which the company considers to be a major development within European markets.

Overall, from the content provided by the interviewees, it can be concluded that their perspectives are very much align with what has been found in previous sections:

- Investments in solar PV are (still) mainly driven based on interests related to financial benefits (Section 2.1 and 3.5).
- There is a trend away from the "financial benefit driver", or stated differently, the relative importance of environmental concerns as well as the interest in self-sufficiency is increasingly driving investment decisions towards solar PV (Section 3.4 and 3.5).
- A main barrier (being related to the financial driver) for investments are rather high investment costs – this is particularly relevant for PV systems combined with batteries (Section 3.1 and 3.2 show this based on the outcomes of the economic benefit assessment).
- For declining technology costs as well as other options to reduce upfront investment costs (e.g. joint purchasing programs) and the mentioned shift in investment decision criteria, there is agreement that solar PV will become more important for electricity suppliers and energy industry stakeholders in general (as stated in the interim conclusions of the assessments in Section 3.1 and 3.4.2 as well as in the survey).

- The value of partnerships among various stakeholder groups is clearly confirmed, noting that some barriers such as sales commitments of incumbents need to be overcome in order to leverage this potential (as was similarly found in Section 3.4).
- With regard to the assessed policy scenarios and short to medium timeframes the market integration scenario is the preferred option of the assessed alternatives. This is based on the fact that this scenario is considered to allow for better system integration of solar PV and to foster new business models in particular with regard to solar PV battery system combinations. A corresponding literature review upon potential system benefits related to solar PV(-battery) systems is conducted in the following section.

3.7 Cluster III: Overview of social and system benefits of solar PV

As Sections 3.1 to 3.5 outlined, solar PV has a high potential of providing significant value for consumers as well as electricity suppliers, an uptake of its installed capacity across various European markets, for example, in the ones assessed in this report, is very likely (and forecasted by many organisations and institutions such as Bloomberg: “Bloomberg New Energy Finance estimates that in Europe small-scale solar systems will increase their share of the electricity capacity mix to 22% by 2040, from 6% in 2014 (BNEF 2015).” (European Commission, 2015). An increasing deployment of this technology, especially in combination with storage, has been proven to be able to provide significant value for society and the energy system as a whole. The following provides an overview and summarises several findings of papers and studies related to “the value of solar PV(-battery) systems for society”:

- **Reduction of CO_2 emissions:**
  - “An Italian food processing company located in the province of Rome, with an annual consumption of about 850.000 kWh and a demand profile shifted strongly in the daytime, has installed a roof-top PV system with a capacity of 320 KWp, producing about 420.000 kWh per year. Thanks to the self-consumption mechanism, this SME is able to use 89% of the solar PV electricity produced onsite (self-consumption rate), resulting in an annual electricity bill saving of about 35% and in an annual reduction of CO2 emissions by over 200 tons.” (European Commission, 2015).
  - Similarly, any utilisation of PV electricity will reduce CO_2 emissions in respect to the current electricity mix within the assessed and most other European countries.

- **Limitation of grid expansion and system integration costs (based on a combination of PV and storage):**
    - A recent study by the university of Aachen particularly focussed on residential PV systems combined with batteries in Germany found that the installed solar PV capacity combined with battery storage under the current support scheme of the KfW reduces the PV peak generation of 30,5 MWp to a maximum of 18,3 MWp that is ultimately fed to the grid. It concludes that the existing grid capacity to integrate solar could be increased by a factor of 1,67 if all new PV installations would be combined with batteries (Kairies, et al., 2015).
    - Similarly, the EU "PV Parity project" found that "self-consumption extended by storage and demand response can reduce the additional system costs of the EU integration of solar PV at high penetration levels by around 20%." (European Commission, 2015)

- **Macroeconomic effects of solar PV(-battery) system deployment:**
    - Despite reduced remuneration of excess electricity and or additional charges for self-consumption, solar PV can be expected to remain profitable for the consumer, especially when considering declining technology costs. This illustrates that "state aid" and or the "burden on society" from a financial perspective is very likely to decline and to be reduced in the future, which is already the case in some countries such as Portugal (see description and economic evaluation of the corresponding reference/market integration scenario in Section 2 and 3.1.2).
    - Furthermore, particularly with regard to PV-battery system combinations, it must be pointed out that less electricity is fed into the grid. This in turn leads to a lower remuneration of excess electricity (as has been shown in Section 3.1), meaning that the "social burden" on financing solar PV is reduced within the market integration scenario of Germany and the UK (and likely for many other European markets). However, this reduction has to be netted with the loss in payments of grid fees and other levies/taxes that consumers with increased self-consumption do not pay as they reduce their electricity bill. That way a balanced conclusion can be drawn with regard to the social financial impact (note that other social benefits such as reduced grid extension, among others are neglected in this perspective). This approach has been taken by Aachen University that has found that aforementioned streams are balanced, that is,

equal out to approximately 0 when looking at currently installed PV-battery system combinations in Germany (Kairies, et al., 2015).

- **Provision of system services:**
  - Simple PV systems (i.e. without batteries) can, based on modern inverter technology, provide system services such as voltage support (reactive power) and negative balancing power, i.e. ramp down. PV systems combined with batteries on the other hand are capable of providing positive balancing power as well (i.e. ramp up) and additionally, they are capable of supporting black starts[30] and to limit the peak generation injection during mid-day (thereby reducing grid impact).
  - The Fraunhofer-institute concludes that solar PV(-battery) systems are technically capable of providing a wide range of services, see Table 23:

Table 23 : PV system services according to the Fraunhofer-institute[31]

	PV	PV and Battery
Reactive Power	√	√
Negative balancing	√	√
Positive balancing	X	√
Self-regulated consumption	X	√

  - Similarly, the “REserviceS” project conducted in-depth analyses on technical and economic feasibility with regard to system services provided by wind and solar.
  - Table 24 summarises the outcomes of the project in a qualitative manner. It shows that solar PV, in an aggregated and large scale format, can already provide a large number of system services from a pure technical/economic perspective but that procedural prerequisites need to be adapted such that all services can be properly utilised (Vorrink, et al., 2015).

[30] In case of total power outages “certain power stations must be able to start up without being able to draw power from the grid. This is called the “black start service” (Elia, 2015)
[31] Own representation, according to (Hollinger, et al., 2013)

Table 24 : Overview of potential system services provided by solar PV[32]

		Solar PV System Size					
		Small scale		Large scale		Aggregation	
		Tech.	Procedures	Tech.	Procedures	Tech.	Procedures
Frequency	FCR	red circle	red triangle	yellow circle	yellow triangle	green circle	yellow triangle
	FRR	red circle	red triangle	yellow circle	red triangle	green circle	yellow triangle
	RR	red circle	red triangle	yellow circle	red triangle	green circle	yellow triangle
	FFR	red circle	yellow triangle	green circle	yellow triangle	yellow circle	red triangle
	RM	red circle	red triangle	green circle	red triangle	green circle	red triangle
Voltage	SSVC	green circle	green triangle	green circle	green triangle	green circle	red triangle
	FRCI	yellow circle	red triangle	green circle	yellow triangle	green circle	red triangle

Technical Aspects		Procedures: Grid Code Requirements, prequalification procedures and Network Code Requirements, amongst others	
green circle	Implemented	green triangle	Well defined requirements / specifications in most procedures at European level
yellow circle	Partially implemented / implementable / low cost investment to enable required capacities	yellow triangle	Poorly defined requirements / specifications or not addressed in most procedures
red circle	Not implemented / implementable / high cost to implement	red triangle	Not defined / not possible due to requirements in all or most procedures
light orange box	Existing Grid Support Services	light green box	New Grid Support Services

[32] Own representation, according to (Van Hulle, et al., 2014). Detailed explanations on each of the respective services are provided in Appendix III.

- **Employment:**
  - One important indirect macro-economic effect of roof-top solar PV systems[33] (as were assessed in this study) is the creation of jobs within the EU. Aforementioned system types "support almost three times as many jobs […] than ground-mounted" systems in 2014.
  - In total, both system types were related to around 110 000 jobs, i.e. full time employees in Europe in 2014 (with more than 80 000 related to roof-top solar PV systems).
  - The total jobs for both system types are expected to increase to almost 140 000 until 2020 (with roof-top solar systems creating around 110 000 jobs by then) (EY Belgium, 2015).
  - In respect and in addition to the jobs related to the PV industry mentioned above, the second industry stream related to storage can be expected to create additional jobs.

4. Discussion

Overall, this research succeeds in delivering its initial targets:

1) Providing a first outline and overview on how various policy designs regarding the remuneration of excess electricity and charges on self-consumption would impact the business case of various PV(-battery) system combinations and thereby influence investment incentives in the assessed markets.
2) Determining on how and how much value electricity suppliers can create around decentralized solar PV.
3) Validating and supplementing the findings of 1) and 2) based on a survey and interviews with energy industry experts.
4) Identifying social/system benefits that decentralized solar PV(-battery) systems can provide.

Consequently, this study adds value to existing research by providing a holistic perspective on how current and potentially future policy designs may incentivise investments in PV-battery system combinations and how the corresponding trend of decentralization subsequently affects

[33] Note that "The solar PV market is divided in two market segments: rooftop (RT) and ground-mounted (GM). The rooftop market segment has residential, commercial and industrial applications while ground-mounted systems are mostly large scale utility installations. The division is very dependent on the individual country" (EY Belgium, 2015)

potential value creation for consumers, electricity suppliers and the society/energy system as a whole.

However, the corresponding findings remain subject to several limitations. How these were overcome and or influence the results of this research is discussed below:

- Based on the comprehensive sensitivity analyses, the limitations of the economic assessment (Section 2.1.2 and 2.1.4) are partially overcome as the influence of extensive variations of changes in the most crucial input parameters are (in)directly evaluated. A good example for this can be found in the variation of battery investment costs – the fact that declining capacities are not modelled can be taken into account by considering higher investment costs. Example: Assuming that the capacity of a large battery (8,7 kWh) is reduced by 20% (i.e. 1,74 kWh) (Samsung SDI, 2015) implies a correspondingly increase of investment costs (note that this might also be offset due to battery cost-declines over time). However, it should be noted that the provided sensitivity analyses do not provide an insight on how the uncertainty of input parameters propagates through the assessment.

  Additionally, it should be noted that this study only assessed one commercial consumer in Germany. With respect to the limitations of this assessment corresponding conclusions are therefore only applicable for this specific consumer and are only partially valid for commercial consumers with similar consumption profiles that lead to high self-consumption rates. (Note that the outcomes are strongly linked to the consumption profile and electricity tariff of commercial consumers.) Consequently, general conclusions of this assessment with regard to future policy design options and their impact on investments must be seen in relation to similar commercial consumer types as assessed in this report.

  Furthermore, when considering the assessed potential electricity price decreases as part of the sensitivity analyses it must be pointed out that although retail electricity prices developments may stagnate in some markets (e.g. as in the projected developments up to 2030 in the UK) a reduction of retail electricity prices is rather unlikely. In Germany for example electricity prices are expected to increase by up to 7,5% from 2015 to 2016 (see Appendix I) despite declining wholesale prices. With respect to this, it should be noted that the electricity cost is only one component of retail electricity bills (next to taxes, levies etc. which may be expected to rise considering the need for new infrastructure investments as a result of the energy transition). Consequently, even if lower wholesale prices would be reflected in the electricity cost component, the overall retail electricity price is rather likely to rise. The corresponding impacts of declining electricity prices on the economic indicators assessed in this report should therefore rather be seen as a theoretical option since current developments indicate opposite trends, i.e. at least slightly rising prices.

Finally, it must be pointed out that prospective additional remuneration based on potentially new tariffs enabled through battery system installations were not assessed although these are likely to improve the economics of such system types. However, as indicated in by the interviewees such tariffs are unlikely to be successfully implemented under prevailing conditions. Therefore, the outcomes of the economic assessment can be considered to provide a reasonable estimate when considering current market conditions.

- With regard to the conducted survey, note should be taken that the reply rate (7%) is below typical averages of 10 – 15% for external surveys (Fryrear, 2015). However, it must be pointed out that the survey participants hold rather high level positions, indicating a strong level of industry knowledge and understanding of the topic. Therefore, the corresponding replies can be considered to be of high quality and rather representative for the assessed industry stakeholders. Furthermore, the survey findings are complemented by expert interviews. Although specific questions on Cluster III (the outcomes in this section are based on a literature review) were not included in the former due to the reasons outlined in Section 2, footnote 1, the topic of energy system support to be provided by solar PV was touched upon in the interview with "a new entrant". (Note that the high level message of aforementioned interview regarding solar PV providing system services can be considered to be confirmed by the literature review upon this topic.).

In light of this, proposals on future research activities related to this report are as follows:

- Execution of in-depth statistical analyses (e.g. Monte Carlo) upon the results of the economic assessment in order to provide a range for the evaluated economic indicators.
- An analysis of specific and more representative cases (especially with regard to commercial consumers) in relation to the various policy scenarios, taking into account country specific consumption profiles and additional solar PV and battery system sizes within the assessed as well as other European and or global markets.
- A more detailed investigation upon the potential development of current policy design options (e.g. considering specified digression rates with regard to the remuneration of

excess electricity and or charges on self-consumption) and their impact on the economic indicators within the assessed as well as additional markets.

- An assessment on how additional services that may be provided by PV(-battery) system combinations could be remunerated and how these extra benefits would impact the economic results.
- Complementary surveys and interviews with a broader stakeholder base (including consumers) also containing the findings of the literature review with regard to Cluster III (Section 3.7).
- Research and quantification related to the potential of cost decreases and benefit increases (as illustrated in Section 3.4.2) based on partnerships among various stakeholders related solar PV and the energy economy.

5. Overall conclusions and policy recommendations

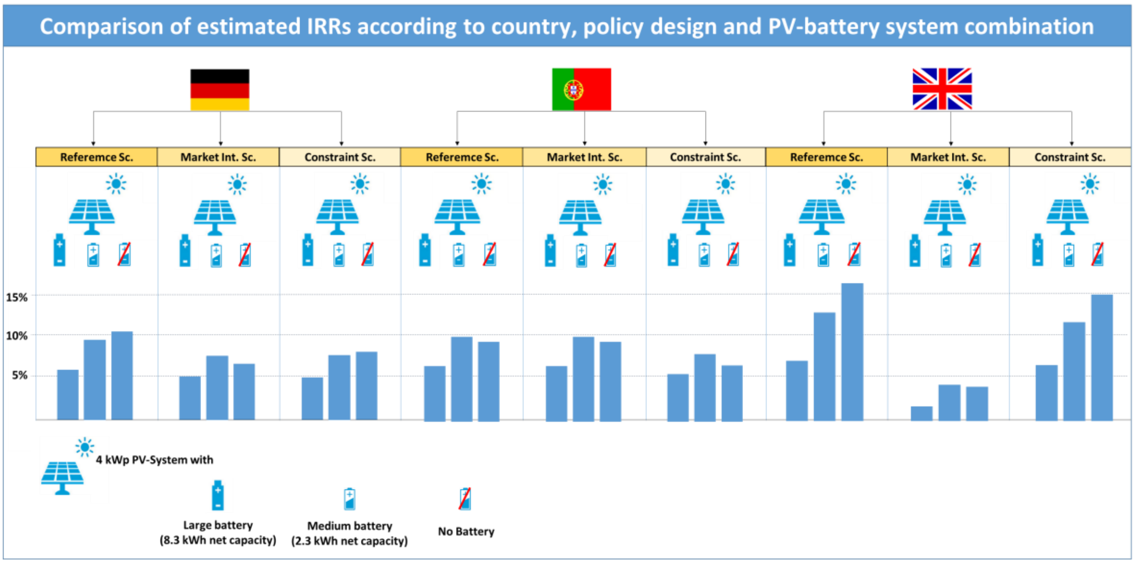


Figure 85: Final overview of economic assessment results for residential consumers

Overall, with reference to the initial research questions and methods applied, it can be stated that economic (Figure 85) as well as non-economic benefits across various countries, when considering different policy scenarios and PV(-battery) system combinations, trigger increasing consumer interest to invest in solar PV(-battery) technology and thereby to contribute to the energy transition. Electricity suppliers are in the process of adapting to this trend (by changing their strategies as well as business approaches) and have a unique position to capture value around solar PV. However, several barriers need to be overcome, for example by establishing new partnerships and making solar widely accessible for a broad base of consumers. Finally, a strong growth of the solar market provides many direct (e.g. ancillary services, CO_2 emission reductions etc.) and indirect (e.g. employment) benefits for the energy system and the society as a whole. A further market integration and declining technology costs are likely to reduce the “financial burden” on society.

With regard to the above additional and more specific conclusions can be derived:

- PV battery system combinations are already economical feasible today; however, PV only systems remain the least risky investment and achieve either better and or very similar economic results as PV systems combined with medium sized batteries, while combinations with large batteries very likely remain the least economic beneficial variants with regard to medium timeframes (five years and more).
- In case of the market integration scenario (remunerating excess electricity only at the level of wholesale prices) in Germany and the UK as well as in Portugal (where additional fees are applicable), PV systems combined medium sized batteries for residential consumers, as assumed in this report, already achieve slightly higher returns than systems without a battery.
- The impact of the assessed policy designs (market integration and constraint scenarios) upon the economic indicators assessed are clearly country and consumer (residential or commercial) specific and strongly dependent on specific (reference scenario) conditions of a member state.
- Due to economical and additional benefits such as self-consumption and green lifestyle, a large part of consumers is interested and has a strong demand in products related to decentralized solar PV, particularly when provided by their electricity suppliers. Notably around half of the German consumers that combined their PV systems with batteries do not expect economic benefits.

- Based on the above, and when taking into account various consumer interests and groups, electricity suppliers are suggested to start offering tailored solar service packages that capture consumer and energy system needs and thereby overcome identified barriers:
    - An example for rather passive and or risk averse and potentially low income groups could be to
        - Provide installation, maintenance and administrative work for PV only systems with rather low capacities (i.e. low investment costs) that initially lead to self-consumption ratios of around 30 to 35% (or even higher in case of very low capacities). The system could be completely managed by the energy supplier that buys the excess electricity for a guaranteed remuneration according to a pre-fixed tariff, while the savings on electricity costs could be subject to a certain charge administratively set (accounting for necessary grid investment support). The remaining electricity demand would be supplied by the same company.
    - An example for more active and or high income consumers could be to:
        - Install solar PV-battery systems with self-consumption rates of around 45 to 70% (i.e. higher investment costs when compared to PV only systems) combined with energy efficiency/management measures that allow consumers to actively participate in managing their electricity generation/use to a certain extent (a prerequisite could be that not more than a defined percentage of electricity produced is allowed to be injected to the grid, thereby ensuring optimisation). The excess electricity could be bought by the company in accordance to wholesale prices, while the remaining electricity demand of the consumer would be supplied by the same company.

Considering the above, future policy designs are suggested to:

- Remain subject to member state decision making in order to allow frameworks that account for specific physical conditions (e.g. grid capacities, irradiation, etc.) around solar PV in order to foster corresponding business models and the realisation of social benefits.
- Support market integration of solar PV systems (especially when combined with battery systems) by adopting / drafting network codes that allow to aggregate solar PV and to participate in wholesale markets as well as to provide system services, thereby opening opportunities for new business models. Generally, a gradual approach towards market integration is preferable and needs to be carefully assessed, (e.g. in case of the UK the generation tariff may be reduced but should not be phased out completely).
- Preferably charge self-consumption only to a very limited extent (in particular when PV systems are combined with batteries), such that it does not cut off economic and additional consumer interests – anticipating that consumers would be less interested in self-consumption if it was related to high charges. This means that the market integration design would be favourable as explained above and since aforementioned system types are also likely related to more active consumers.
- Thereby provide regulatory stability to increase investor confidence and enable electricity suppliers to create offers that tackle the rising demand around decentralized solar PV.
- Continuously push for technology cost reductions that may ultimately lead to higher economic benefits and will thereby offset additional investment opportunities for commercial as well as residential consumers, leading to a successful realisation of European energy targets.

In light of the conclusions and recommendations above, the following provides final insights and takes a holistic perspective on the overall findings of this study, providing clear guidelines for next policy steps and considerations:

- Reflect upon a combination of the market integration and constraint scenario (as was analysed by the two variable sensitivity analyses), i.e. a fourth scenario, as a suitable variant in a transition towards a complete market integration. Such a design would allow adjusting the benefit streams such that their relative importance with regard to potential PV battery system combinations can be properly addressed as proposed below (in respect to triggering investment decisions by consumers and benefits for electricity suppliers as well as the energy system and society as a whole).

  - Slightly reduce the electricity cost saving potential based on self-consumption with regard to PV only systems while at the same time guaranteeing a stable (potentially slightly reduced) remuneration of excess or generated electricity (in the case of Germany and the UK respectively as similarly implemented in Portugal).
  - Correspondingly, with regard to PV-battery combinations, remunerate excess electricity analogous to market prices (or slightly above/below), while prevailing full and or only a slightly decreased electricity cost saving potential based on self-consumption.
  - Realise above-mentioned designs corresponding to energy system needs and take into account potential reduction in grid investments that PV(-battery) systems may realise.
  - Ensure that investments remain financially interesting and can become more accessible, particularly for low income groups, while necessary support payments for grid infrastructure are guaranteed. (Note that at the same time electricity supplier business models would be able to prosper since consumers' interest would be specifically targeted and prevailed.)
- Provide incentives for the implementation of new business models around flexibility that is adjusting demand and generation to system needs and market signals, thereby electing the use of storage with regard to system needs instead of individual benefit increases. (Note that the approach of the German support for batteries takes this direction by subsidising only PV-battery combinations that do not inject more than a certain share of generation to the grid).
- Take a long term perspective (considering strong declining battery and PV technology costs) and prepare a roadmap for implementing the market integration scenario as the most suitable variant, lowering regulatory and administrative efforts and fostering new and more business models that generate additional revenue streams, particularly for battery combinations, as was mentioned in the limitation part.
- Increase consumers' awareness of the developments within the energy markets both in terms of short and long term markets.

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Appendix I – Overview of sources and detailed information on input parameters

Table 25: Specification and explanation of input parameters used

Market/ Input Parameter	Germany	Portugal	UK	Agent	Comment	Source
Timeframe for calculations (years)	25			All	Corresponding to the assumed economic lifetime of solar PV systems. Note that it is assumed that the investment is taken in 2015 and that the first benefits are achieved in 2016, i.e. the PV system starts to produce electricity from 2016 for a time frame of 25 years until and including 2041.	(IRENA, 2015)
Degradation of PV systems (%)	0,2			All		(Grundner, Jesús Baez Morandi, & Wörlen, 2014)
Operational costs of PV and Battery system – depending on system size and investment costs (%)	1,5			All	The given percentage relates to PV and battery system respectively.	(Weniger, Quaschning, & Tjaden, pv-magazine.de, 2013)
Yield (kWh/kWp installed)	936	1494	920	All		(Rekinger, et al., 2012)
Retail Electricity prices 2014 (€/kWh)	0,2978	0,2203	0,1966	Residential	Average of first and second half in 2014 corresponding to provided data in mentioned source.	(Statistisches Bundesamt (Federal Statistical Office), 2015)
Commercial Electricity prices 2014 (€/kWh)	0,1351			Commercial	Average of first and second half in 2014 corresponding to provided data in mentioned source.	(Statistisches Bundesamt (Federal Statistical Office), 2015)
Retail Electricity price	5,06	5,76	5,16	Residential	Based on the average increase from 2008 to 2014 plus an	(Statistisches Bundesamt (Federal Statistical Office),

increase (%)					additional increase of 2,5%. The former extra increase was decided to consider as the strongly evolving energy system is likely to lead to increasing electricity prices for consumers. In Germany – considered as a frontrunner in respect to the developments of the energy system – electricity suppliers will raise costs from 2015 to 2016 by up to 7,5 % (see second source).	2015) (verivox, 2015)
Commercial Electricity price increase (%)	5,09			Commercial	Based on the average increase from 2008 to 2014 plus an additional increase of 2,5%.	(Statistisches Bundesamt (Federal Statistical Office), 2015)
Remuneration of excess electricity: Reference and Tax charge scenario (€/kWh)	0,124	0,0393	0,18088 (gene-ration tariff) 0,0679 (ex-port tariff)	Residential	**Germany:** Assumes remuneration as of July 2015 **Portugal:** Value based on the average wholesale price in 2013 (see market integration scenario specifications) multiplied by 0,9 (according to support scheme in July 2015) **UK – Generation tariff:** Value considering support status in July 2015. [34]	(SolarPower Europe, BSW and Solar Trade Association, 2015)

[34] UK : Note that the support scheme in July 2015 exists of an export tariff as well as a generation tariff, meaning that a PV system owner receives two remuneration streams, one for electricity that is fed to the grid as well as one for the electricity that is generated. Values are based on an exchange rate of 1,4 (from British pounds to Euro as of 13th July 2015 (xe.com, 2015))

Remuneration of excess electricity: Reference and Tax charge scenario (€/kWh)	0,0859			Commercial	**Germany:** Assumes remuneration as of July 2015	(SolarPower Europe, 2015)
Remuneration of excess electricity: Market integration scenario (€/kWh)	0,04	0,04365	0,0515	All	Data for Germany and UK refers to 2014. Data for Portugal to 2013.	(nordpoolspot, 2015) (Willborn, Hesse, Balser, & Luh, 2014), (ERSE , 2013) and (nordpoolspot, 2015)
Tax charge Scenario - Allowed savings on electricity price	• No battery: 70% • 2,3 kWh (net) battery: 80% • 8,3 kWh (net) battery: 90%			Residential	Assumption as explained in Section 2.1.2	
Tax charge Scenario - Allowed savings on electricity price	• No battery: 70% • 33,5 kWh (net) battery: 80% • 100 kWh (net) battery: 90%			Commercial	Assumption as explained in Section 2.1.2	
Annual electricity demand (kWh)	3500			Residential	Average of household electricity use in Europe.	Data available to SolarPower Europe
Annual electricity demand (kWh)	133 768,1			Commercial	According to load profile provided by commercial contact	
Cost per usable battery capacity (€/kWh)	1075,26			Residential	Average of analyzed battery systems according to the first two mentioned sources (Source one takes the average of costs of battery systems from 2 to 10 kWh usable and converts pounds to Euro on an exchange rate of 1.42 as on 19th of August 2015). It includes costs of battery cells, inverter, charge controller, cabling and installation cost. Average price cross-checked and order of magnitude confirmed by third	(Balcombe, Rigby, & Azapagic, 2015), (Confais, Fages, & van den Berg, 2015) and (IRENA, 2015) as well as (Kairies, et al., 2015)

			and fourth source. (Note that the first source refers to lead-acid batteries in particular whereas remaining sources refer also to lithium ion battery technology, which is most commonly slightly more expensive than lead-acid batteries). Due to potential cost differences a sensitivity analysis is conducted.	
Cost per usable battery capacity (€/kWh)	589,3 (Medium Battery 472,5 (Large Battery)	Commercial	Cost for the medium (33,5 kWh net) battery derived from first source (refers to a 20 kWh net battery and converts pounds to Euro based on an exchange rate of 1.42 as on 19th of August 2015). Cost for large battery derived from second source. Takes the average cost of 100 kWh batteries analyzed – referring to Tesla Powerpack and Primus EnergyCell. Converts dollars to Euro based on an exchange rate of 0.93 as on 09th November 2015. Cost reference includes costs for: • Cells • Power Electronics • Distributor Markup • Installation labor • Installation parts • Installer Markup ,	(Balcombe, Rigby, & Azapagic, 2015), (Stepien, 2015)

			• Permitting (Due to potential cost differences a sensitivity analysis is conducted).	
PV System costs (€/kWp)	1540	Residential	Includes inverter replacement costs (assuming that the inverter costs contribute to 10% of the system). Value was cross checked by second source that refers to a "ready to use", i.e. installed PV system (excluding VAT) in Germany. As prices refer to 2014 a slightly lower price may be applicable. Due to potential cost differences sensitivity analyses are conducted.	(Huld, et al., 2014) and (Kairies, et al., 2015)
PV System costs (€/kWp)	1240	Commercial	Source refers to a "ready to use" PV system in December 2014. As prices refer to 2014 a slightly lower price may be applicable. Due to potential cost differences sensitivity analyses are conducted.	(photovoltaik-guide.de, 2015)
Discount rate (%)	4	Residential	Assumption based on findings in mentioned source. Impacts of changes therefore analyzed in a sensitivity analysis.	(Ondraczek, Komendantova, & Patt, 2014)
Discount rate (%)	6,5	Commercial	Assumption as taken in provided source.	(Rekinger, et al., 2012)
Self-consumption rate – depending on battery size	• No battery: 27% • 2,3 kWh (net) battery: 46%	Residential	• Self-consumption percentage is based on a simulation tool published by	(Hochschule für Technik und Wirtschaft Berlin, 2015) and (Weniger &

	• 8,3 kWh (net) battery: 66%		HTW. For a detailed description of the method please see the source. • Battery size based on the same tool	Quaschning, Begrenzung der Einspeiseleistung von netzgekoppelten Photovoltaiksystemen mit Batteriespeichern, 2013)
Self-consumption rate – depending on battery size	• No battery: 69,2% • 33,5 kWh (net) battery: 78,3% • 100 kWh (net) battery: 86,7%	Commercial	As explained in Section 2.1.2	

Appendix II: Additional sensitivity analyses

Appendix II.I – Additional sensitivity analyses for the German residential sector

The following highlights the results of the one variable sensitivity analysis for the reference scenario:

Figure 86: Assessment of a change in PV investment costs

A reduction of the PV investment costs by 30% (to 4 312 € would increase the NPV by around 1 850 € for all systems, which corresponds to an average IRR increase of about 2%. However, the DPBPs would be reduced by 2, 3 and 4 years for the PV system combined with a large, medium and no battery respectively. In case that the PV investment costs would be around 20% higher (7 392 €, the IRR curves of the PV only and PV system combined with a medium sized battery intersect, indicating that from this point onwards an investment in a PV system combined with a medium sized battery would make more economic sense. A possible scenario for this would be that consumers would add battery storage to a recently installed PV system on which they paid a 20% VAT charge, while due to subsidy reasons this charge would not be applicable for the battery system.

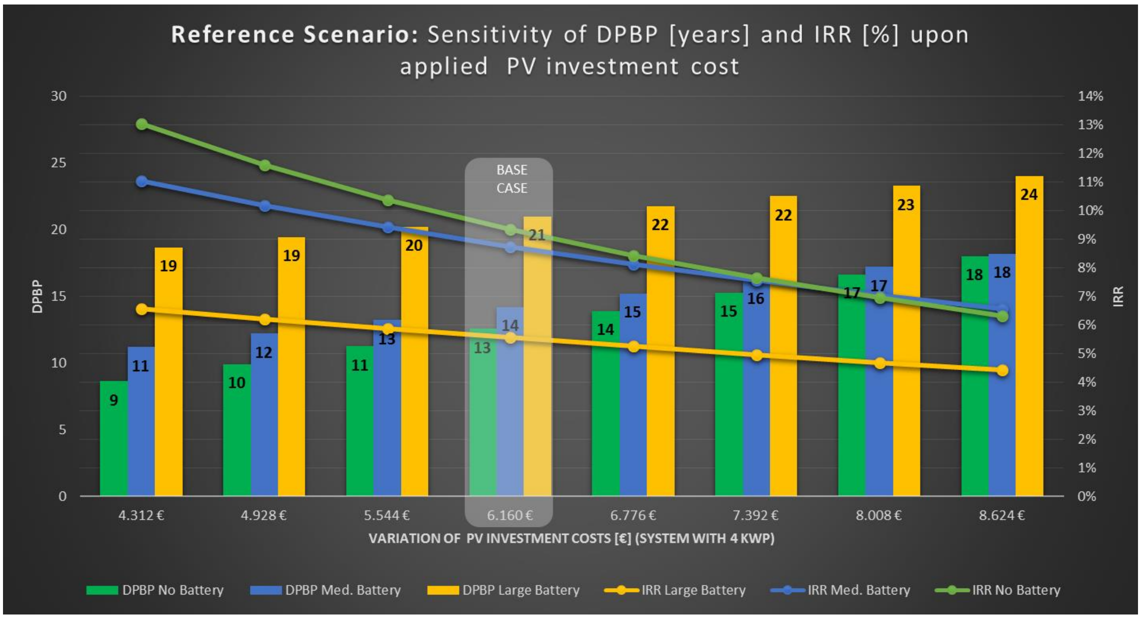


Figure 86 : Reference Sc. Germany - One variable sensitivity analysis of PV investment costs

The following highlights the results of the one variable sensitivity analysis for the market integration and constraint scenario:

Figure 87: Assessment of a change in the remuneration of excess electricity

The analysis outcomes of a variation with regard to the remuneration of excess electricity show that a PV system combined with a medium sized battery becomes more economical than a simple PV system once the remuneration would be reduced to around 8 ct/kWh (while keeping all other assumptions taken in this study constant). The only case in which a large battery would break even with a simple PV system on the other hand would be that excess electricity is not remunerated at all. With regard to the DPBPs it can be derived that large battery-PV system combinations are the least sensitive, whereas the DPBP of simple PV systems increases drastically (from 13 years in the reference scenario to 19 in the market integration scenario and to 24 years in case that excess electricity would not be remunerated at all). Overall, in respect to variations of the remuneration of excess electricity it becomes obvious that a single PV system is most sensitive to such a change due to the fact that this variant has the lowest self-consumption. Systems combined with a battery have therefore more stable results in case that the remuneration of electricity declines over time. A reduction from about 0,12 €/kWh to approximately 0,09 € /kWh, would decrease the IRR of a single PV system by about 2% whereas the same decline would lower the IRRs of a system with a medium and or large battery by less than 1% (see also Figure 54 to 56 and the two variable sensitivity analyses).

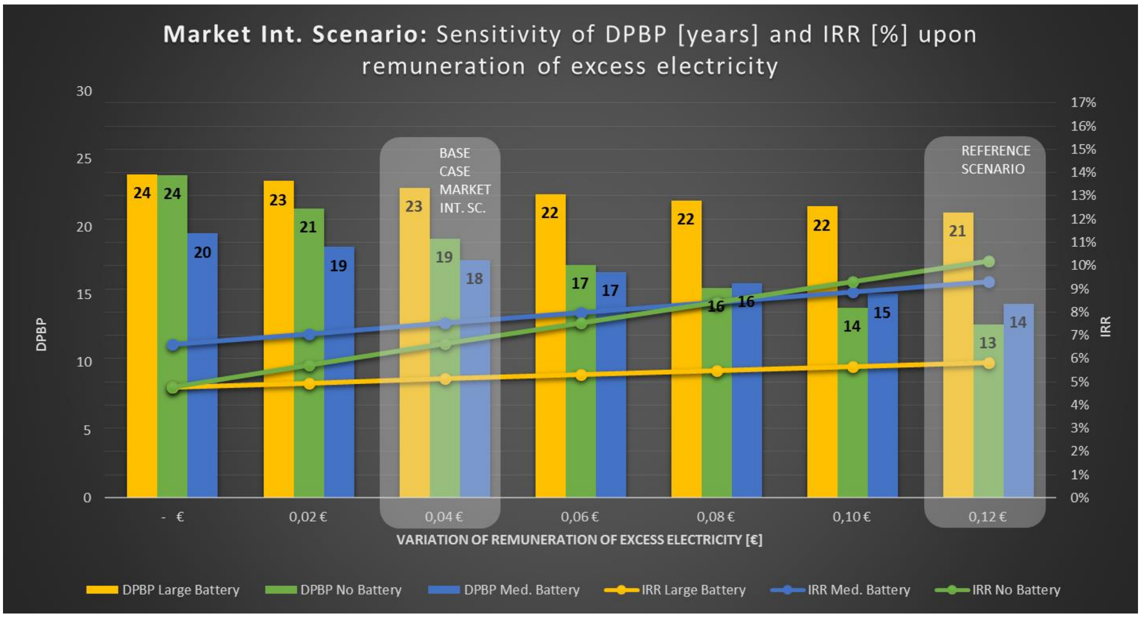


Figure 87 : Market Int. Sc. Germany - One variable sensitivity analysis on potential variations of the remuneration of excess el.

Considering these outcomes, the following can be derived by the sensitivity analyses for i) the market integration and ii) constraint scenario in relation to the reference scenario:

Figure 88 and 89: Market Integration and Constraint Scenario – Assessment of a change in PV investment costs

The PV system combined with a medium sized battery continuous to achieve an higher IRR in the market integration scenario when compared to a system without a battery for the entire range of PV investment costs assessed in this report – even if the former were reduced by as much as 30 % (see Figure 88 where the lines representing the IRR of the two aforementioned system types emerge but do not intersect). This stands in contrast to the reference scenario in which the exact opposite development can be observed, meaning that higher investment costs of a PV system, would result in a better economic performance of the system with a medium sized battery when compared to a PV only system (Figure 85). Note that for 30% higher PV system investment costs, the system combined with a large battery would achieve similar (slightly higher) IRRs than the PV-only system in the market integration scenario.

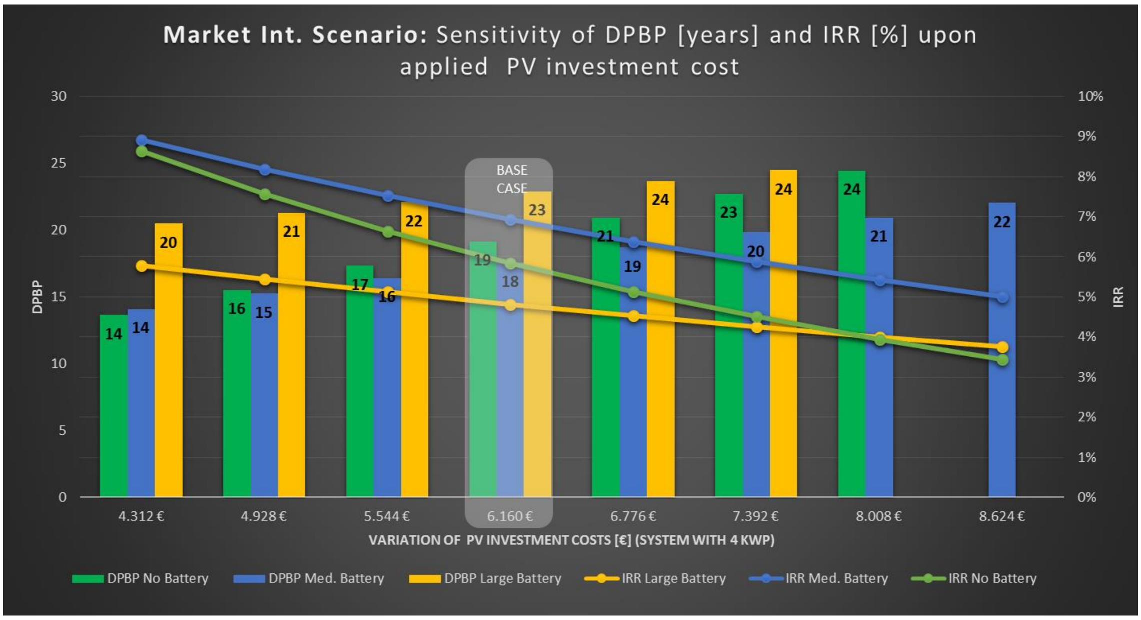


Figure 88 : Market Integration Sc. Germany - One variable sensitivity analysis of PV investment costs

A comparison of the reference and constraint scenario reveals that a variation of the initially applied PV investment costs would cause similar IRR developments for both cases (IRR curves merge with increasing costs while they spread further with declining costs), the difference is an intersection within the constraint scenario would happen faster (Figure 89 and 85).

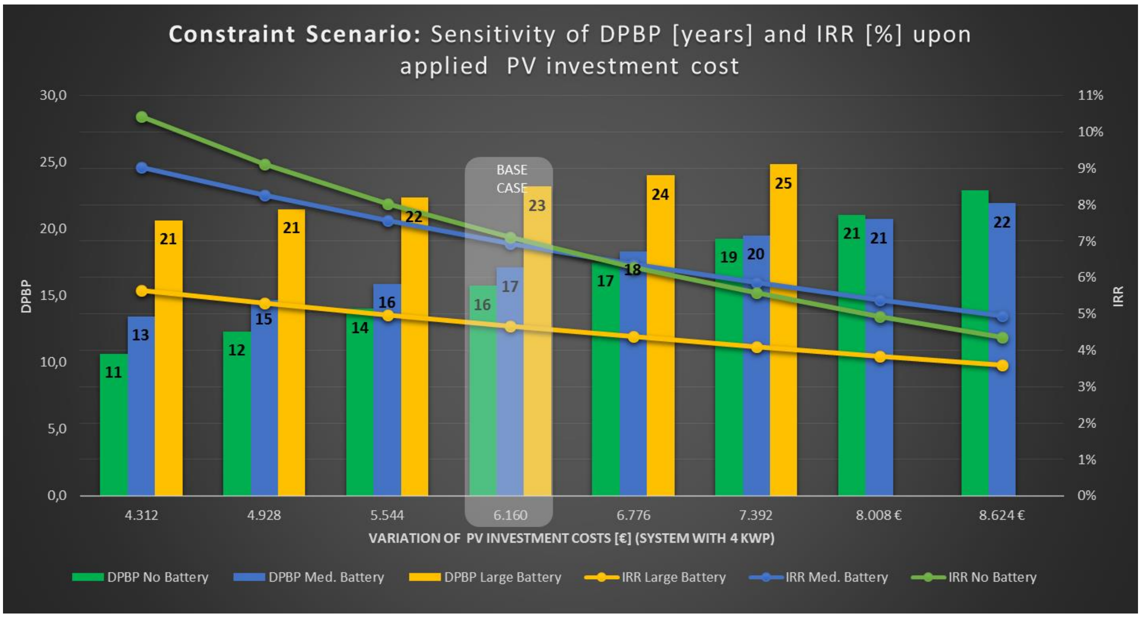


Figure 89 : Constraint Sc. Germany - One variable sensitivity analysis of PV investment costs

Figure 90 and 91: Market Integration and Constraint Scenario – Assessment of a change in battery investment costs

The analysis focussed on the market integration scenario with regard to the battery investment costs (Figure 90), reveals that the PV system combined with a medium battery (2,3 kWh net) achieves higher IRRs and lower DPBPs compared to the PV only system even if the investment costs were up to 40% higher. The system combination with a large battery would already result in similar outcomes as the PV only system if the battery investment costs were reduced by around 30%. This is significantly different to the reference scenario in which a cost reduction of about 70% would be necessary to achieve afore described outcome as was analysed in Figure 60. In case of such a high reduction in the battery investment costs, the system combined with a large battery would break even with the medium sized battery in the market integration scenario.

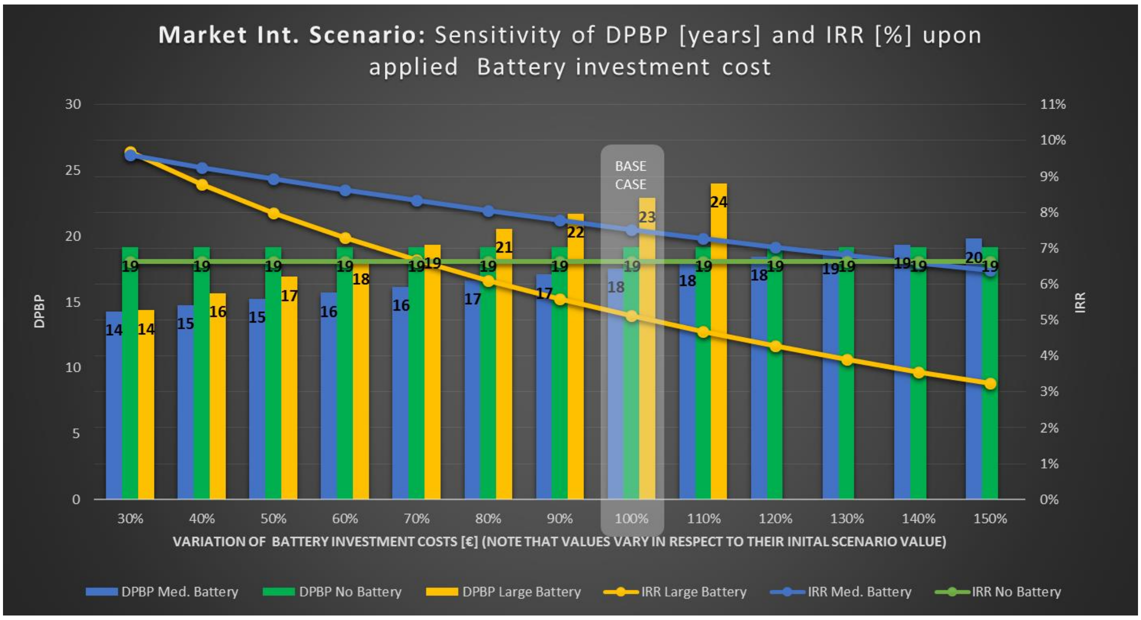


Figure 90 : Market Integration Sc. Germany - One variable sensitivity analysis on potential variations of the battery investment costs

Figure 91 shows that the above is also valid for the constraint scenario, however, a reduction of around 50% would be necessary so that the large battery system would break even with the PV-only option. With regard to the medium sized battery, it can be deduced that a cost reduction of around 20% would be necessary in the constraint scenario such that this option achieves similar results as the PV only system.

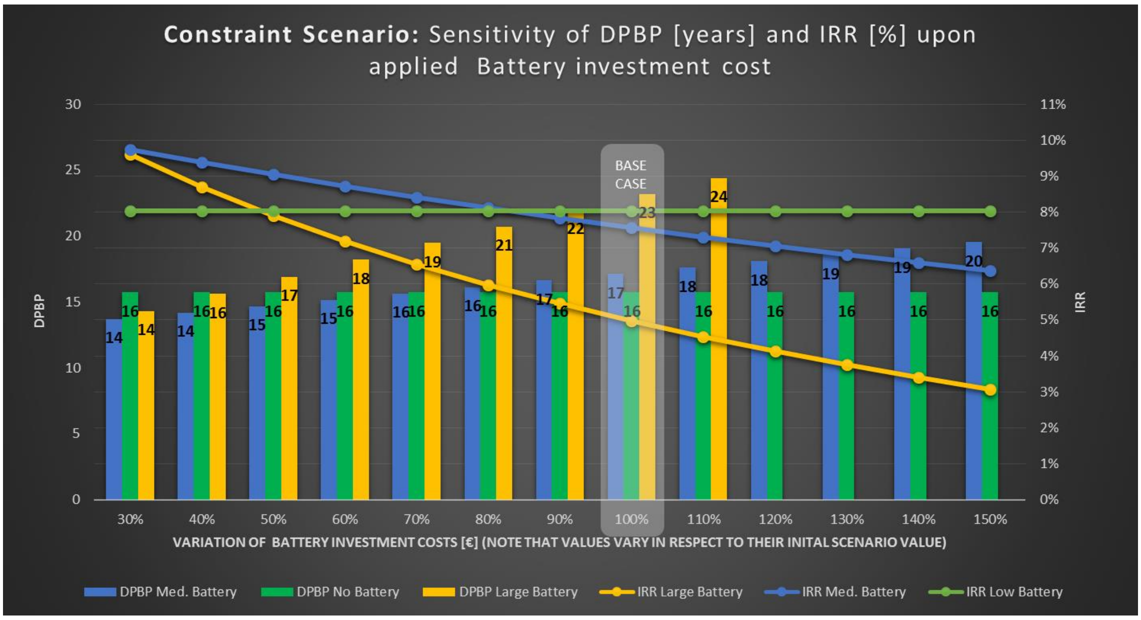


Figure 91 : Constraint Sc. Germany - One variable sensitivity analysis on potential variations of the battery investment costs

Figure 92 and 93 Market Integration and Constraint Scenario – Assessment of a change in the annual electricity price increase

Comparing the scenarios with regard to their sensitivity upon the assumed electricity price increase, it can be seen that the market integration scenario is the most sensitive in respect to this parameter. Considering Figure 92 the IRR curve and DPBP outcomes of the PV system combined with a large battery reveals that the DPBP would already exceed 25 years in case that the electricity price would increase by about 4% (the same is valid for the constraint scenario – Figure 93 – in which a PV system with a large battery would result in slightly better results in terms of IRR whereas the DPBP would be around 23 years in the reference scenario as can be seen in Figure 15)

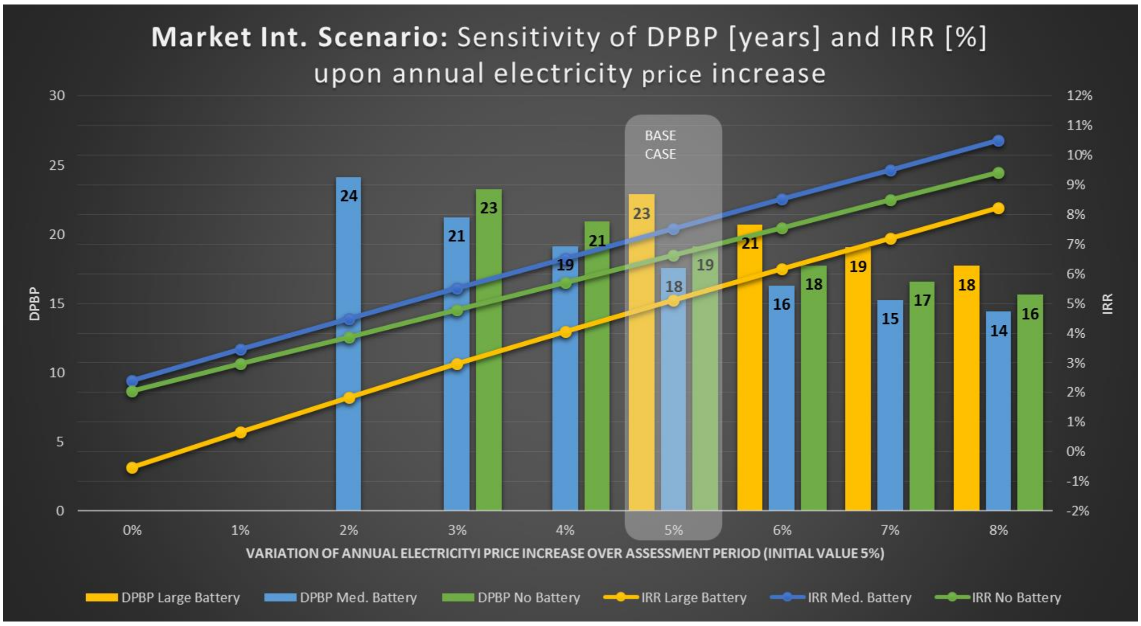


Figure 92 Market Int. Sc. Germany - One variable sensitivity analysis on the assumed el. price increase[35]

[35] Note that an annual decrease of electricity prices of 1,5% would lead to the negative results for all system types assessed in case of the market integration scenario (see table of this footnote). This is different to the reference case where only the system combined with a large battery would result in net losses.

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 8 011	> 0	< assessment period
Medium battery	- 2 543	1	< assessment period
No battery	- 1 881	1	< assessment period

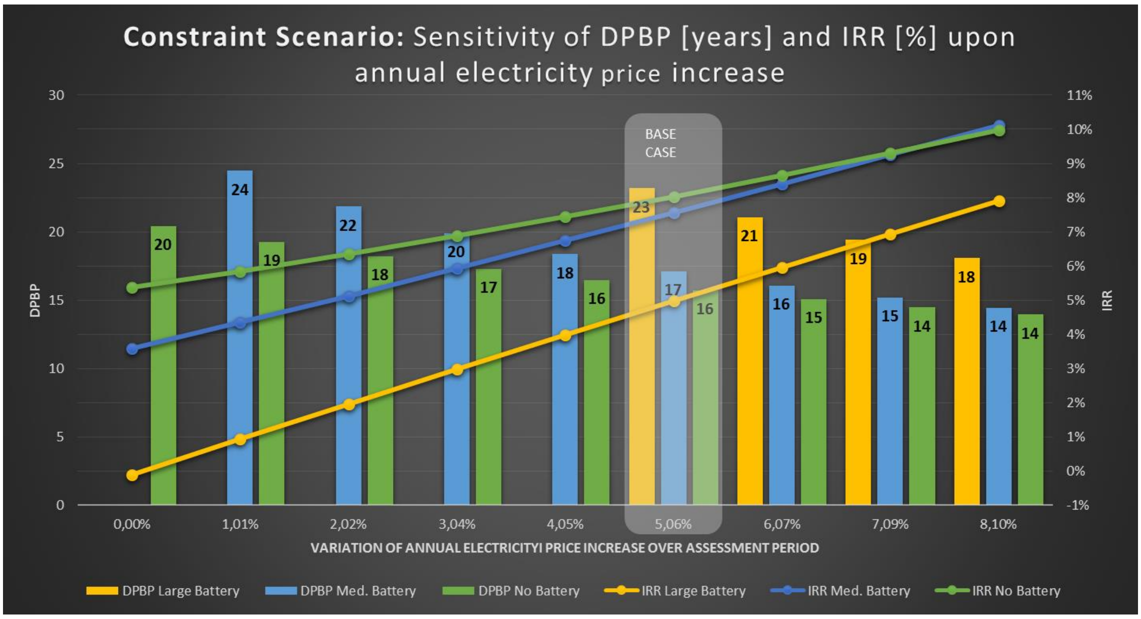


Figure 93 : Constraint Sc. Germany - One variable sensitivity analysis on variations of the assumed el. price increase[36]

The same behaviour can be observed for the PV system with a medium sized battery (it would require an electricity price increase of about 2% to remain DPBPs of below 25 years in the market integration scenario – Figure 92 – whereas within the constraint scenario an electricity price increase of around 1 % would be sufficient to amortize the system within the considered assessment period (Figure 93). However, even when there is no electricity price increase, the IRR of the PV system combined with a medium battery would remain slightly higher compared to the one of the PV only system in the market integration scenario (Figure 92).

With regard to a PV-only system and the market integration scenario, it can be seen that electricity price increase of at least 3% is required to remain an IRR of 5% and to amortise within the assessment period (Figure 92.). The same system within the constraint scenario however would remain DPBP of 20 years with an IRR of 5% (Figure 93).

[36] The assumed annual electricity prices decrease of 1,5% in the constraint scenario (table below) would only result in economic benefits (close to break-even) for the PV only system, while in the reference scenario also the system with a medium sized battery would break even.

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 7 330	> 0	< assessment period
Medium battery	- 1 269	3	< assessment period
No battery	492	5	22

Appendix II.II – Additional sensitivity analyses for the Portuguese residential sector

The following highlights the results of the one variable sensitivity analysis for the reference scenario:

Figure 94: Assessment of a change in total investment costs

In order to illustrate the potential impact for VAT of approximately 20%, Figure 94 shows how a variation of the total investment costs would change the IRR and DPBP. As such, a 20% increase would still result in adequate economic results for the simple and medium battery PV-system combination, whereas the version with the large battery would be related to a rather high DPBP of 23 years with a corresponding IRR of around 5%.

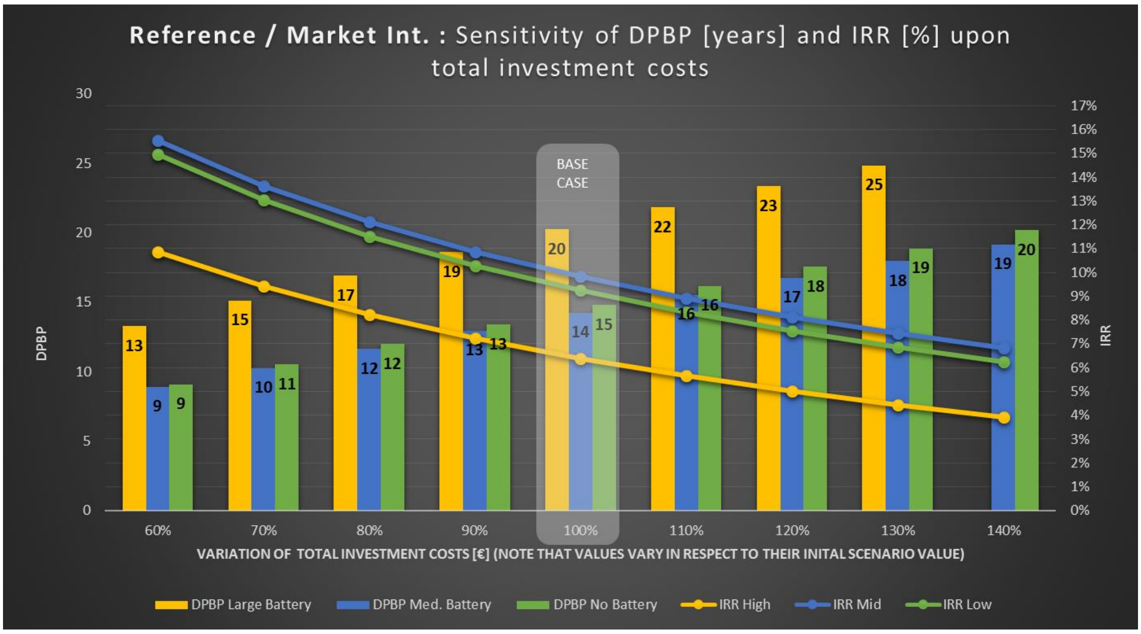


Figure 94 : Reference Sc. Portugal - One variable sensitivity analysis on variations of the assumed total investment costs

Figure 95: Assessment of a change in the remuneration of excess electricity

Based on the analysis outcomes of a variation with regard to the remuneration of excess electricity, a PV only system would be more economical than a PV system combined with a medium sized battery once the remuneration would be increased to around 6 ct/kWh (while keeping all other assumptions in this study constant). When considering no remuneration at all, it can be derived that the DPBPs of large and medium sized battery-PV system combinations would only be increased by around two years (from 20 to 22 and from 14 to 16 respectively), whereas the DPBP of simple PV systems increase drastically (from 15 to 20 years).

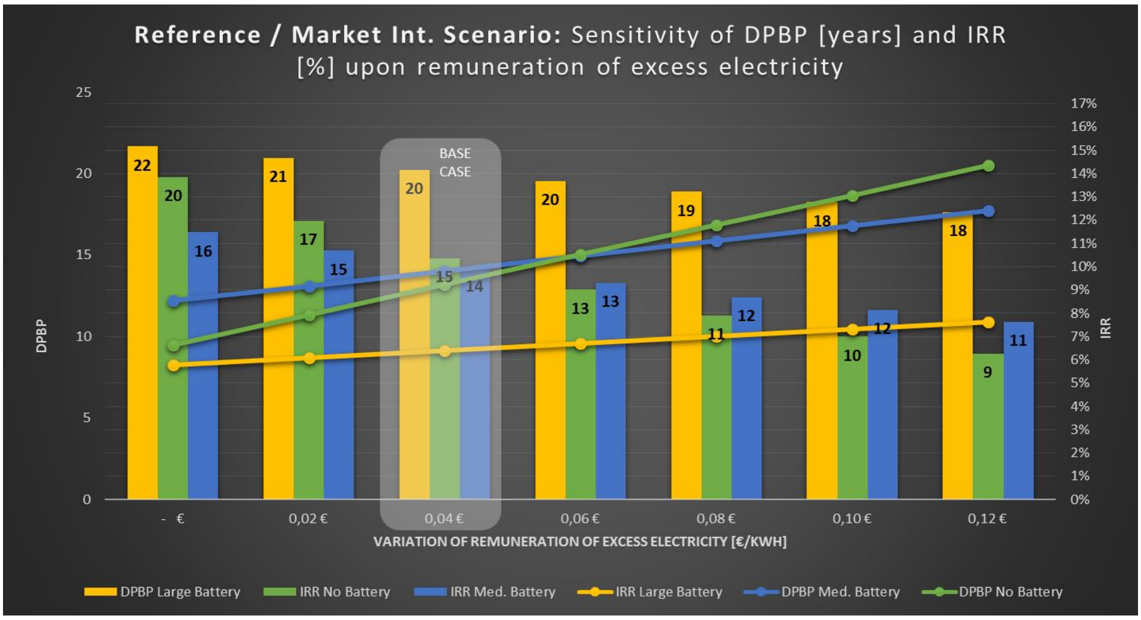


Figure 95 : Market Int. Sc. Portugal - One variable sensitivity analysis on potential variations of the remuneration of excess el.

The following highlights the results of the one variable sensitivity analysis for the constraint scenario:

Figure 96: Assessment of a change in the electricity cost saving potential

The diagram shows a variation of the electricity cost saving potential within the constraint scenario. The ranges above 100% provide an indication of the respective value within the reference scenario (where for all systems 100% electricity cost saving potential was assumed). It can be seen that any further reduction within the constraint scenario (below 80%) for a large battery would result in a DPBP that exceeds 25 years (corresponding IRRs would be below 4%). For a PV-only system a reduction to 70% (i.e. only about 50% of electricity costs could be saved) would increase the DPBP to above 25 years, whereas for a PV system combined with a medium sized battery the electricity cost saving potential could be reduced to only 56% (corresponds to 70% value in the diagram) while remaining an IRR of about 5% with a corresponding DPBP of 24 years.

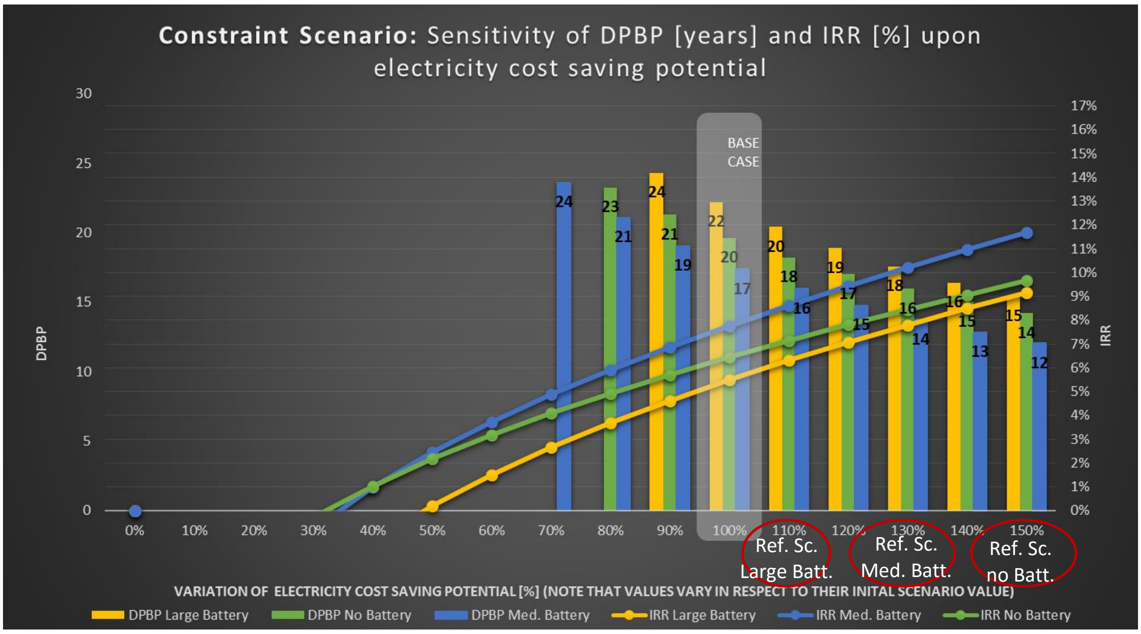


Figure 96 : Constraint Sc. Portugal - One variable sensitivity analysis on the assumed el. cost saving potential

Considering these outcomes, the following can be derived by relating the sensitivity analyses for the constraint scenario to the reference scenario:

Figure 97: Constraint Scenario – Assessment of a change in PV investment costs

The PV system without a battery achieves a higher IRR in the reference scenario when compared to a system with a medium sized battery in case that the PV investment costs assessed in this report are reduced by 30% (see Figure 26 where the lines representing the IRR intersect). As can be seen in Figure 97, this is different within the constraint scenario, where the PV system combined with a medium sized battery achieves the best economic results for the entire range of assessed PV investment costs. A scenario comparison with regard to a PV system combined with a large battery and the PV-only system reveals that the former variant starts to achieve better economic results in case that the investment costs for PV systems were only 10% higher in the constraint scenario. Consequently, the trend within the reference scenario that IRR curves of PV only and medium sized battery system combinations merge with declining costs is less strong, whereas the convergence for PV only systems and large battery system combinations is accelerated in the constraint scenario as can be seen in Figure 26 and 97.

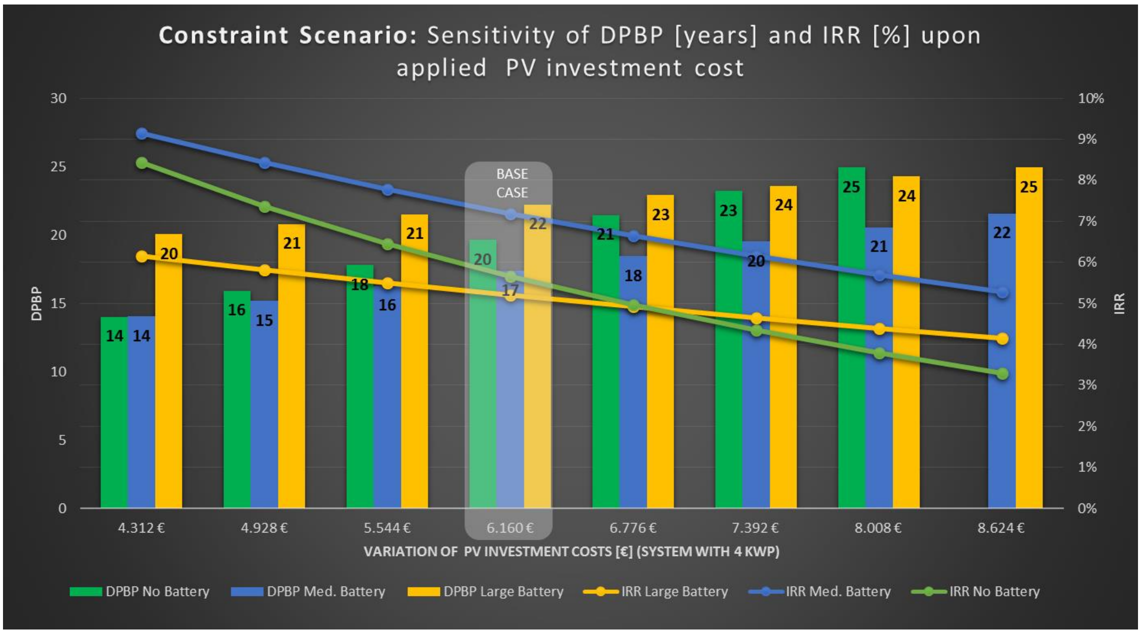


Figure 97 : Constraint Sc. Portugal - One variable sensitivity analysis of PV investment costs

Figure 98: Constraint Scenario – Assessment of a change in battery investment costs

This analysis, focussing on the constraint scenario with regard to the battery investment costs (Figure 98), reveals that the PV system combined with a medium battery (2,3 kWh net) achieves higher IRRs and lower DPBPs compared to the PV only system even if the investment costs were up to 50% higher. The system combination with a large battery would already result in similar outcomes as the PV only system if the battery investment costs were reduced by around 20%. This is significantly different to the reference scenario in which a cost reduction of about 50% would be necessary to achieve afore described outcome as was analysed above (see Figure 76). In case of a 70% reduction in battery investment costs, the system combined with a large battery would break even with the medium sized battery in the constraint scenario.

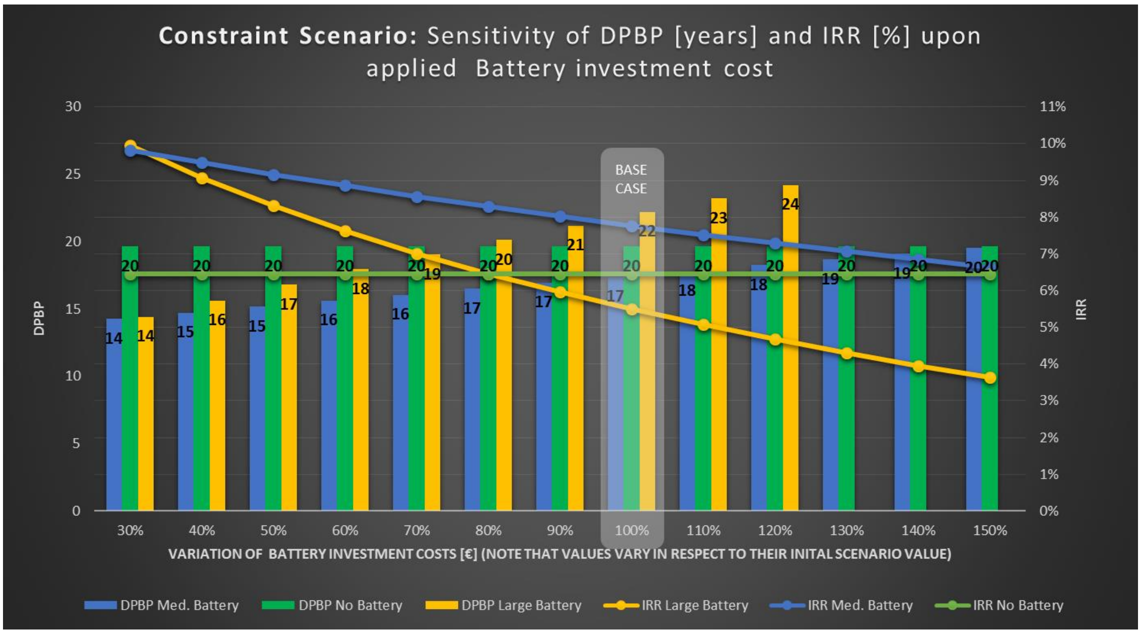


Figure 98 : Constraint Sc. Portugal - One variable sensitivity analysis on potential variations of the battery investment costs

Figure 99: Constraint Scenario – Assessment of a change in the annual el. price increase

When comparing the scenarios relative to their sensitivity upon the assumed electricity price increase, it shows that the constraint scenario is more sensitive in respect to this parameter. Considering Figure 99, the IRR curve and DPBP outcomes of the PV system combined with a large battery reveals that the DPBP would already exceed 25 years in case that the electricity price would increase by about 4.5% whereas the DPBP would be around 23 years in the reference scenario as can be seen in Figure 28).

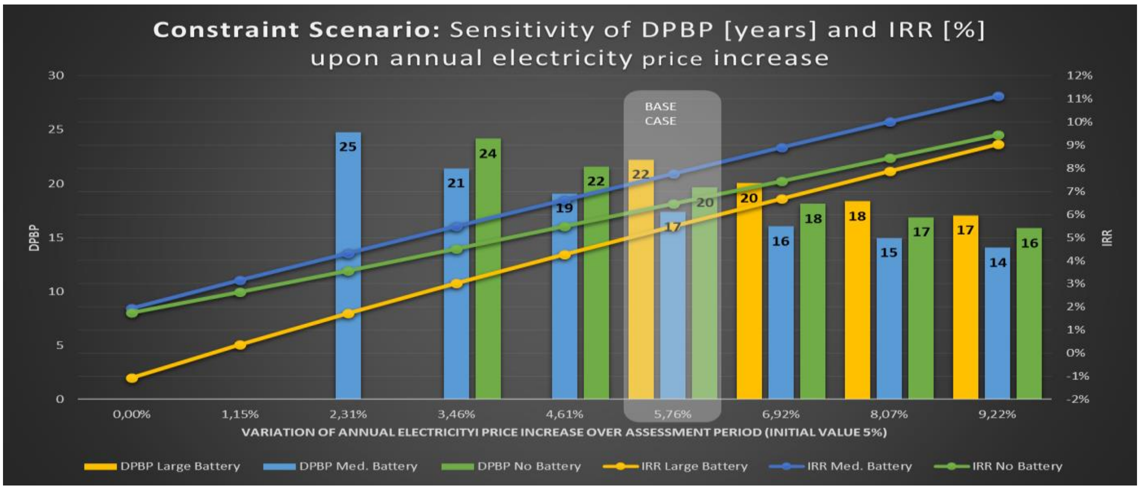


Figure 99 : Constraint Sc. Portugal - One variable sensitivity analysis on variations of the assumed el. price increase[37]

The same behaviour can be observed for the PV system with a medium sized battery (it would require an electricity price increase of about 2.3% to remain DPBPs of around 25 years in the constraint scenario. However, even in case that the electricity price increase would be around 1%, the IRR of the PV system combined with a medium battery would remain an IRR of 5% in the reference scenario.

With regard to a PV-only system and the constraint scenario, it can be seen that an electricity price increase of about 3,5 % is required to maintain an IRR of 5% and to amortise within the assessment period. The same system within the reference scenario however would remain DPBP of 17 years with an IRR of 7% (Figure 28).

[37] Note that an annual decrease of electricity prices of 1,7% in the constraint scenario would lead to higher losses for all assessed PV-system variants (Table below) when compared to the reference/market integration scenario in which for the same assumption systems without and or a medium sized battery would break even in case the discount rate would be 2 and 3% respectively instead of the initially assumed 4%.

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 8 777	> 0	< assessment period
Medium battery	- 2 969	0	< assessment period
No battery	- 2 004	0	< assessment period

Appendix II.III – Additional sensitivity analyses for the UK residential sector

The following highlights the results of the one variable sensitivity analysis for the reference scenario:

Figure 100: Assessment of a change in PV investment costs

A reduction of the PV investment costs by 30% (to 4 312 € would increase the NPV by around 1 850 € for all systems, which corresponds to a reduction of about two and three years for the systems combined with a large, medium and no battery respectively. However, the IRRs would be increased by 1, 3 and 7% for the PV system combined with a large, medium and no battery respectively. In case that the PV investment costs would be higher than assumed, the IRR curves of the PV only and PV system combined with a medium sized battery visibly converge but do not intersect – even in case of a 50 % increase. This indicates that the overall outcomes with regard to the economic indicators would most likely cause the same investment decisions as to be expected based on the initial assumptions taken in this study.

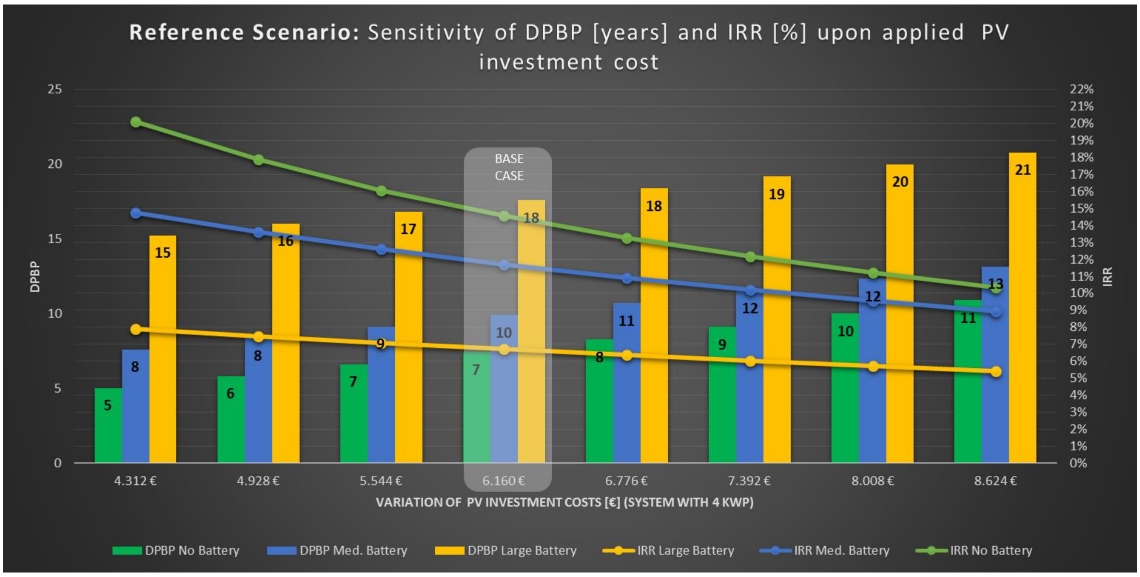


Figure 100 : Reference Sc. UK - One variable sensitivity analysis of PV investment costs

Figure 101: Assessment of a change in the assumed generation tariff

With reference to a change in the generation tariff it can be seen that a PV system combined with a large battery requires support of at least 9 ct/kWh generated in order to remain a DPBP of below 25 years. Systems without or with a medium sized battery on the other hand would remain DPBPs below 25 years and corresponding IRRs of around 5% even if the generation tariff was completely phased out. Furthermore, it can be observed that the IRR curves of PV only systems and those combined with a medium sized battery would emerge with a reduction in the generation tariff and almost intersect in case no generation tariff was in place. This indicates that PV systems combined with a medium battery as assessed in this study would most likely become the more interesting investment alternative in case that the remuneration of excess electricity was to decline along with the generation tariff. (The former statement seems to be validated by Figure 102 on the following page.)

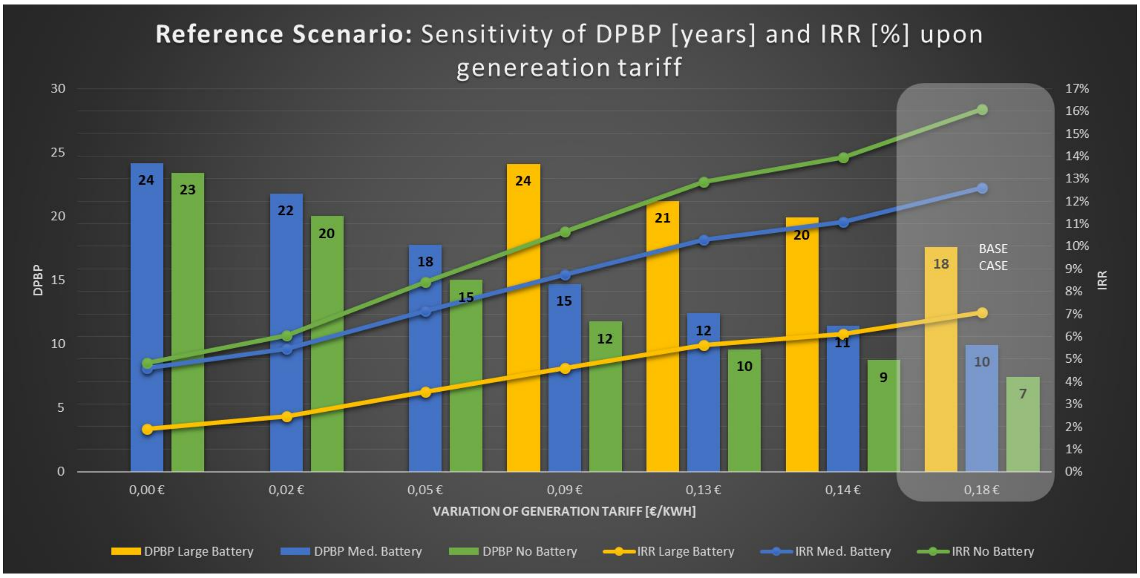


Figure 101 : Reference Sc. UK - One variable sensitivity analysis on variations of the generation tariff

The following highlights the results of the one variable sensitivity analysis for the market integration and constraint scenario:

Figure 102: Assessment of a change in the electricity cost saving potential

The diagram shows a variation of the electricity cost saving potential within the constraint scenario. The ranges above 100% are shown to provide an indication of the respective value within the reference scenario (where for all systems 100% electricity cost saving potential was assumed). It can be seen that PV only systems and those combined with a medium sized battery would remain IRRs of 11 and 6% respectively, even if the el. cost saving potential was completely phased out (while keeping the other benefit streams constant). Looking at the PV system with a large battery shows that for this variant a reduction down to 70% (in respect to the base case of this scenario) would already result in a DPBP of about 23 years, meaning that an investment would be rather unattractive. However, the IRR of this system would remain positive as long as the electricity cost saving potential would not be reduced by more than 90%.

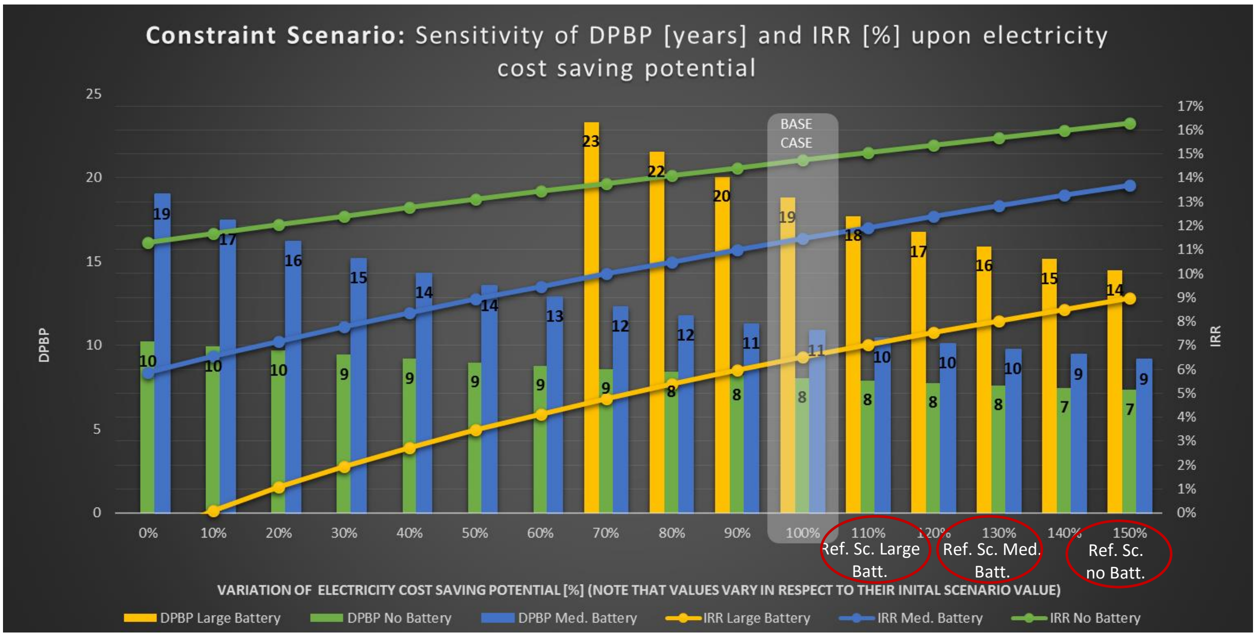


Figure 102 : Constraint Sc. UK - One variable sensitivity analysis on the assumed el. cost saving potential

Considering these outcomes, the following can be derived by the sensitivity analyses for i) the market integration and ii) constraint scenario relation to the reference scenario:

Figure 103 and 104: Market Integration and Constraint Scenario – Assessment of a change in PV investment costs

The PV system combined with a medium sized battery continuous to achieve a higher IRR in the market integration scenario when compared to a system without a battery until investment costs are reduced by 20%. From this stage onwards, the simple PV system is more profitable. This is different to the reference scenario in which the IRR curves of the various system combinations do not intersect. Correspondingly, higher investment costs of a PV system would have the opposite effects when comparing the market integration and reference Scenario. While in the latter the gap between the achievable IRRs of a system combined with a medium sized battery compared to a single system merges (Figure 104), the gap within the market integration scenario would continue to grow that is the PV system combined with a medium sized battery would be more economical.

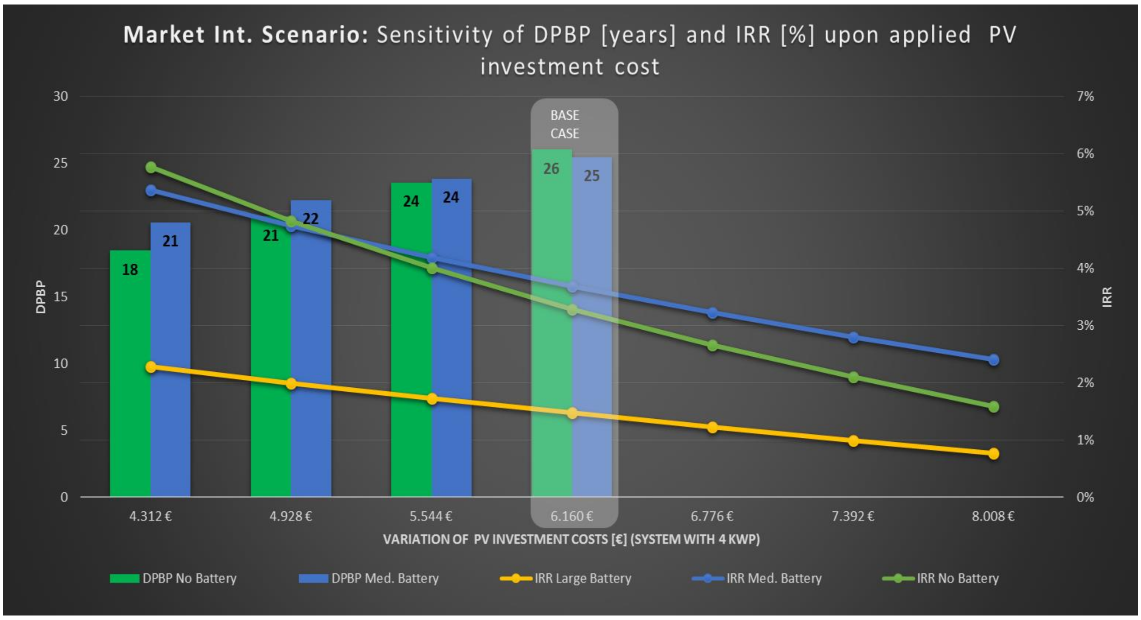


Figure 103 : Market Integration Sc. UK - One variable sensitivity analysis of PV investment costs

A comparison of the reference and constraint scenario in this regard reveals that a variation of the initially applied PV investment costs would cause similar IRR developments for both cases (IRR curves merge with increasing costs while they spread further with declining costs) as can be seen in Figure 104 and 99.

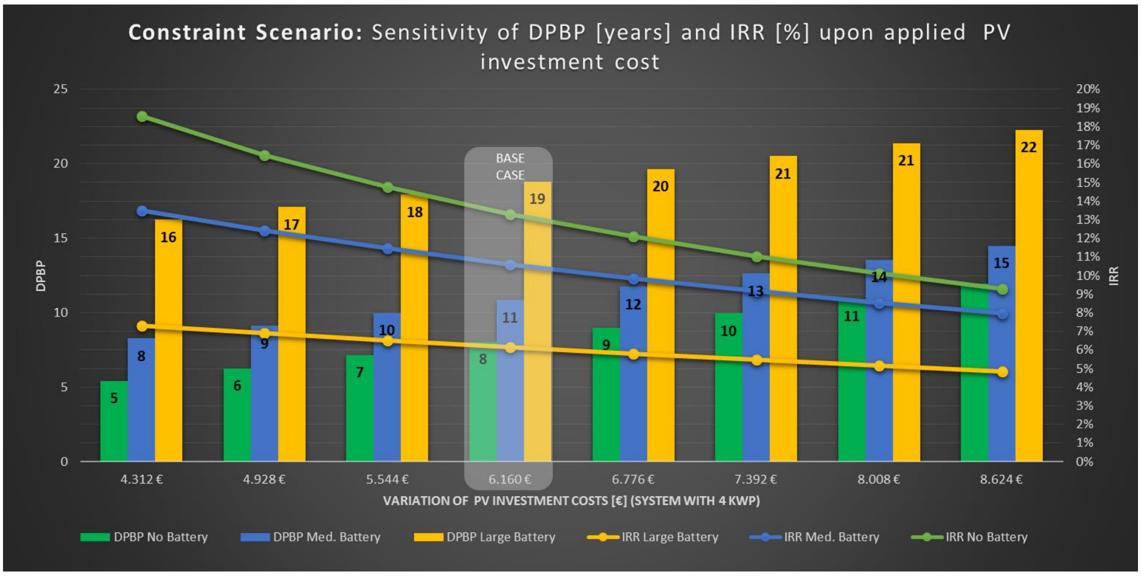


Figure 104 : Constraint Sc. UK - One variable sensitivity analysis of PV investment costs

Figure 105 and 106: Market Integration and Constraint Scenario – Assessment of a change in Battery investment costs

The analysis, focussing on the market integration scenario with regard to the battery investment costs (Figure 104), reveals that the PV system without a battery achieves higher IRRs and lower DPBPs compared to the PV system with a large battery as long as investment are not reduced by more than 50%. The system combination with a medium battery would already result in similar outcomes as the PV only system if the battery investment costs were increased by only 10%. This is significantly different to the reference scenario in which the PV only system would continue to achieve the best economic outcomes even if the battery investment costs were reduced by 70% (see Figure 40).

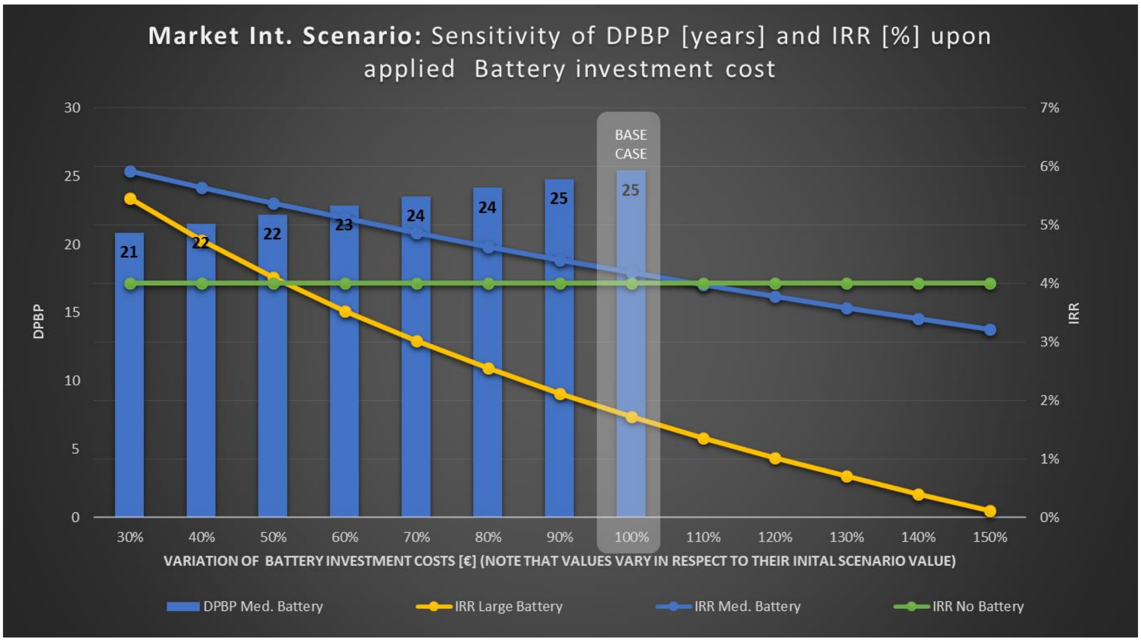


Figure 105 : Market Integration Sc. UK - One variable sensitivity analysis on potential variations of the battery investment costs

Figure 106 shows that there is hardly any difference between the constraint and reference scenario with regard to a variation of the battery investment costs (the curves have exactly the same behaviour).

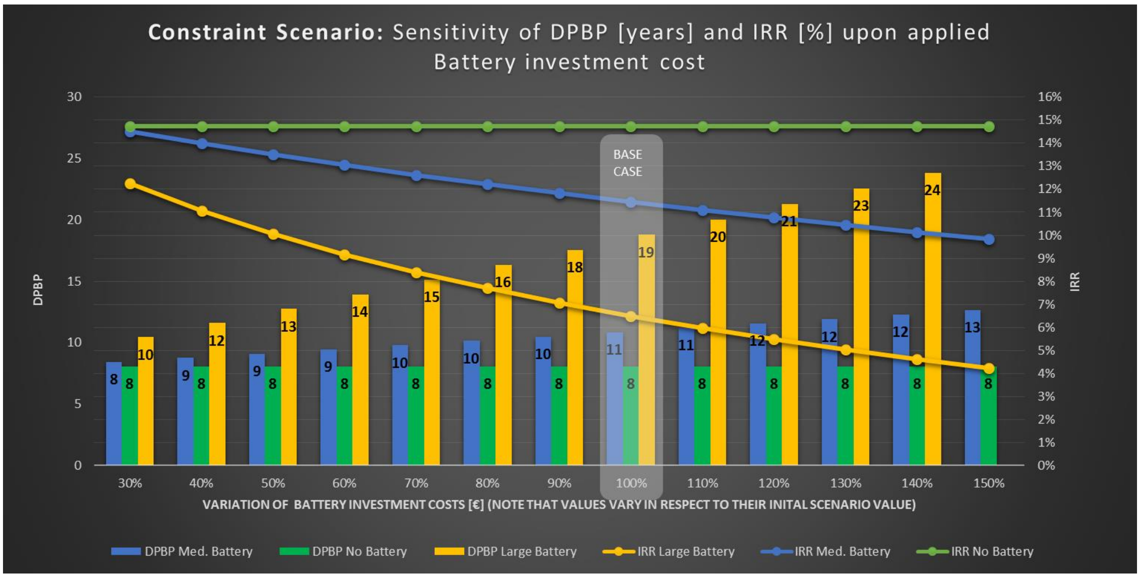


Figure 106 : Constraint Sc. UK - One variable sensitivity analysis on potential variations of the battery investment costs

<u>Figure 107 and 108: Market Integration and Constraint Scenario – Assessment of a change in the annual electricity price increase</u>

When comparing all scenarios with regard to their sensitivity upon the assumed electricity price increase, it is evident, that the market integration scenario is the most sensitive in respect to this parameter. Considering Figure 107, the IRR curve and DPBP outcomes of the PV system with a medium sized battery would not amortise within the assessment period in case that the electricity price would increase by about 4% (note that the other assessed systems already exceed the DPBP of 25 years in the base case of this scenario). Furthermore, the IRR curves of the system combined with a medium battery and the one without a battery intersect in case that the el. price would increase with around 4% annually. This indicates that the ranking – from this point onwards – of the assessed systems in respect to the economic performance would be the same as in the other two scenarios.

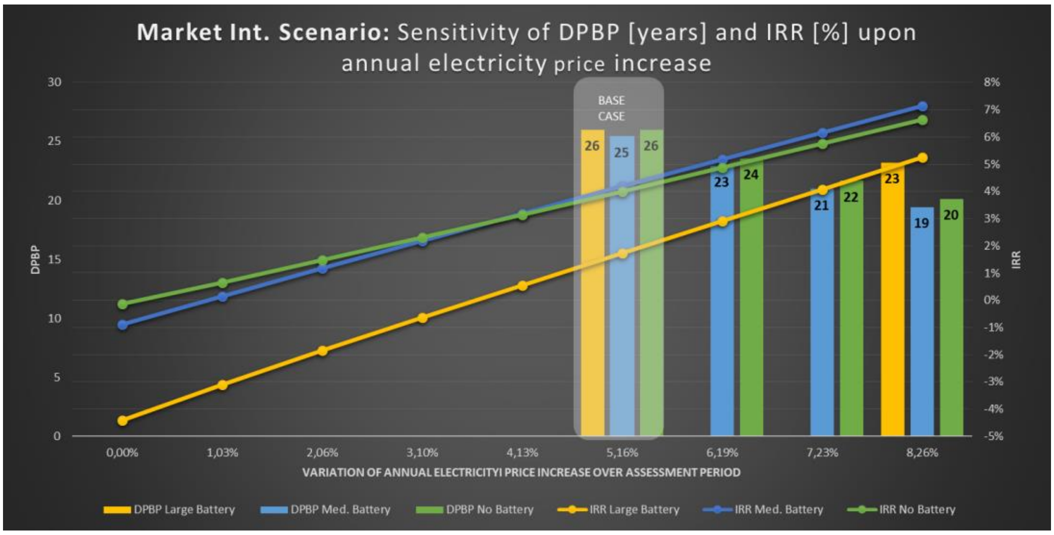


Figure 107 Market Int. Sc. UK - One variable sensitivity analysis on the assumed el. price increase[38]

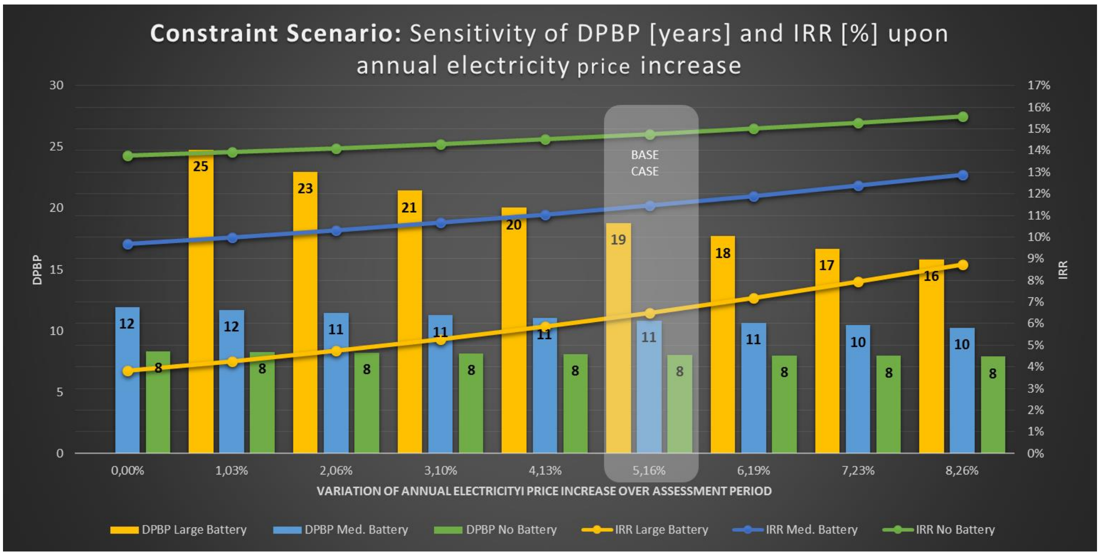


Figure 108 : Constraint Sc. UK - One variable sensitivity analysis on variations of the assumed el. price increase[39]

[38] The assumed annual decrease of electricity prices of 1,6% would result in negative economic cases in case of the market integration scenario (table below). This is different to the reference and constraint scenario in which PV systems without and or a medium sized battery would remain profitable.

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 11 172	> 0	< assessment period
Medium battery	- 4 642	> 0	< assessment period
No battery	- 2 856	> 0	< assessment period

[39] Note that an annual decrease of electricity prices of 1,6% would continue to result in beneficial results for PV only systems and those combined with a medium sized battery.

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 1 103	3	< assessment period
Medium battery	5 375	9	12
No battery	7 447	14	8

Figure 109: Assessment of a change of the generation tariff within the constraint scenario

With respect to a change in the generation tariff, it can be seen that a PV system combined with a large battery requires support of at least 13 ct/kWh generated in order to remain a DPBP of below 25 years. Systems without or with a medium sized battery on the other hand would remain DPBPs below 25 years and corresponding IRRs of around 5% even if the generation tariff was reduced to about 5 ct/kWh. Furthermore, it can be observed that the IRR curves of PV only systems and those combined with a medium sized battery would intersect with if the generation tariff was phased out completely. This is similar to the reference scenario, the main difference being that IRR curves would not intersect.

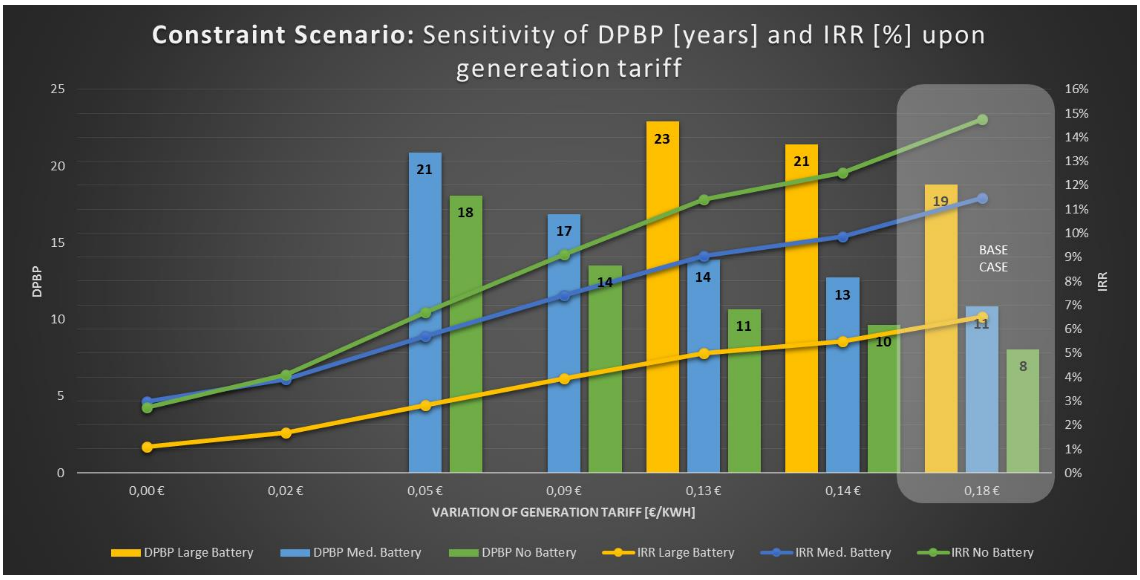


Figure 109 : Reference Sc. UK - One variable sensitivity analysis on variations of the generation tariff

Appendix II.IV – Additional sensitivity analyses for the German commercial sector

The following highlights the results of the one variable sensitivity analysis for the reference scenario:

Figure 110: Assessment of a change in the discount rate

As can be seen in Figure 110, reducing the discount rate by from 6,5% to 4,6% would result in a NPV increase of about 52 400, 49 800 and 46 600 € for the PV system combined with a large, medium and no battery respectively. The DPBPs for the PV only and medium battery combination in this case would be reduced by about 3.5 and 3 years respectively whereas the DPBP for a system combined with a large battery would be reduced by almost 5 years. Furthermore, the analysis upon variations of the discount rate reveals cut off values (indicated by red boxes) of 6,5% (PV system with a large battery – as in the base case), 7,8% (PV system with a medium sized battery) and 8,5% (simple PV system) that lead to "close to zero" NPV results. Note that in case of a discount rate of 0%, the PV system with a medium sized battery would achieve the best NPV results, followed by the PV only and large battery system combination (the difference for the latter system variants being very small).

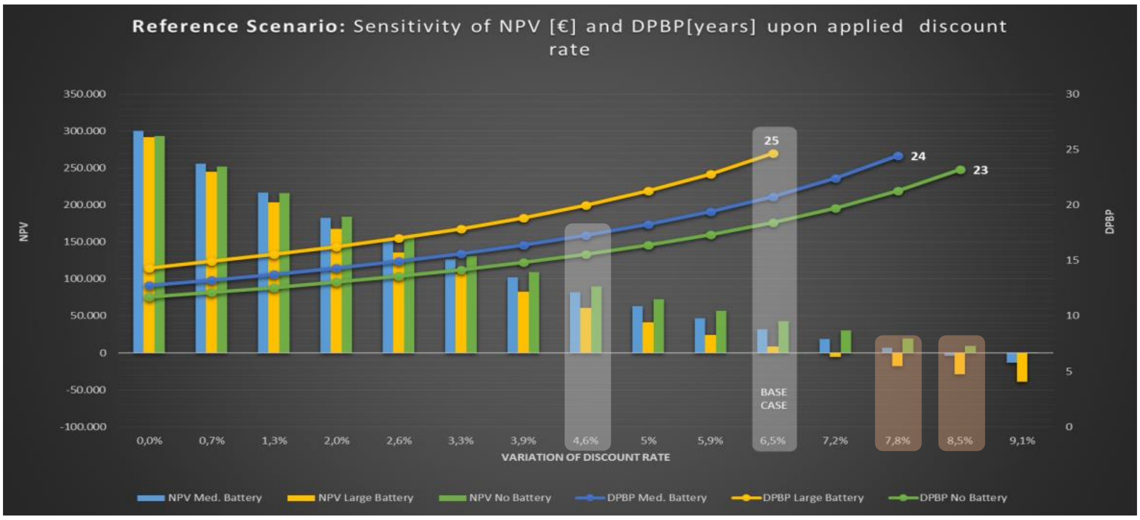


Figure 110 : Reference Sc. commercial sector Germany - One variable sensitivity analysis of potential discount rates

Figure 111: Assessment of a change in total investment costs

In order to illustrate the potential impact of 19% VAT, Figure 111 shows how a variation of the total investment costs would change the assessed indicators. Consequently, a 20% increase would still result in adequate economic results for the simple and medium battery PV-system combination (IRRs of around 7%) although the DPBP for the latter system would exceed 25 years. The version with the large battery however would result in an IRR of about 5% with a corresponding net loss of about 26 000 €.

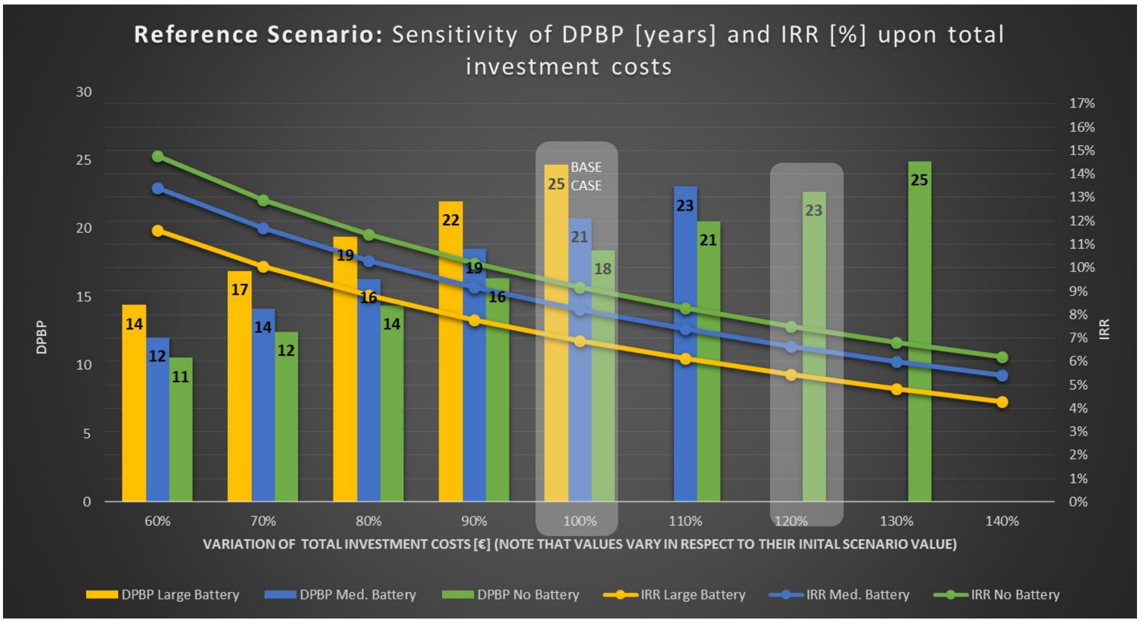


Figure 111 : Reference Sc. commercial sector Germany - One variable sensitivity analysis on variations of the assumed total investment costs

Figure 112: Assessment of a change in the assumed electricity price increase

Considering a change in the electricity price increase reveals that a system combined with a large battery relies on the assumed annual price increase over the entire assessment period in order to remain at least an IRR of around 7% (approximately matching the applied discount rate of 6,5% in the base case). A PV system combined with a medium sized battery on the other hand would continue to be profitable as long as the electricity price increases with around 4% (IRR of 7% with a corresponding DPBP of 24 years). Systems without a battery however would result in an IRR of about 7% and remain with a DPBP of 23 years in case that electricity prices would increase with around 3% over the assessment period (25 years).

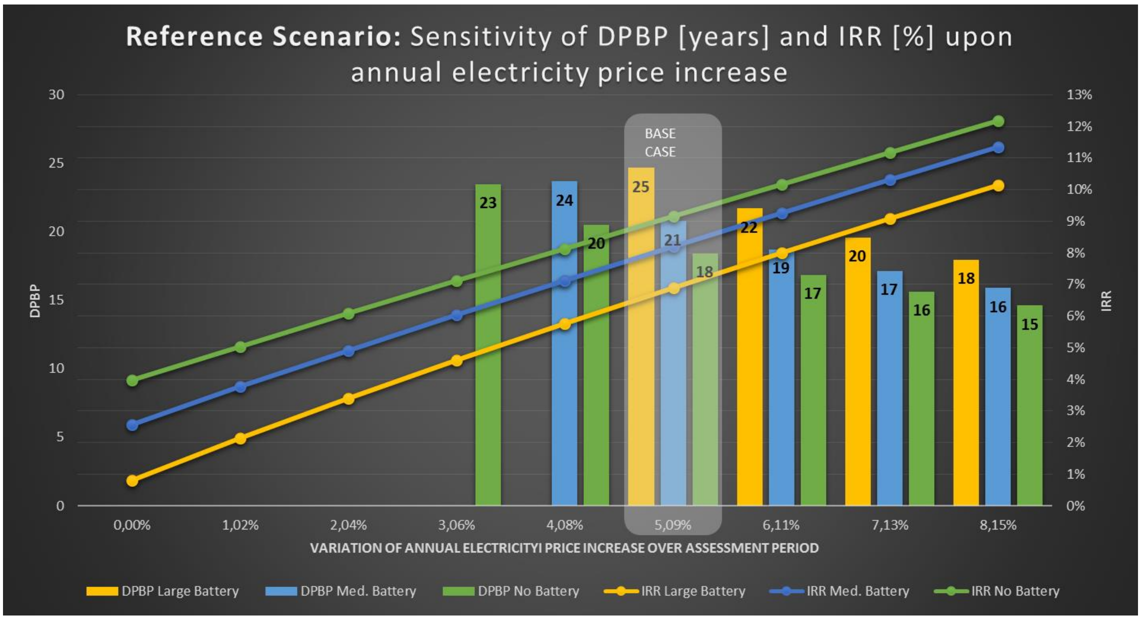


Figure 112 : Reference Sc. commercial sector Germany - One variable sensitivity analysis on variations of the assumed el. price increase[40]

[40] Note that an annual decrease of electricity prices of 1,5% would lead to losses for all assessed system types.

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 96 924	> 0	< assessment period
Medium battery	- 63 437	1	< assessment period
No battery	- 41 116	2	< assessment period

The following highlights the results of the one variable sensitivity analysis for the market integration and constraint scenario:

Figure 113 shows the analysis outcomes of a variation with regard to the remuneration of excess electricity.

From the analysis conducted, it can be seen that all assessed combinations are hardly affected over the entire range assessed. Even in cases where excess electricity would not be remunerated at all, systems with a medium and or no battery would remain IRRs of around 7%.

While the DPBPs for aforementioned system combinations are 21 and 19 years in the reference scenario respectively, they would only be increased by two and one year(s) with regard to the market integration scenario and by three and four years in case excess electricity would not be remunerated. (Note: Although the system equipped with a large battery would not amortise within the assessment period its IRR line is very straight, meaning that it would almost be completely resistant to a policy design that alters the remuneration of excess electricity.)

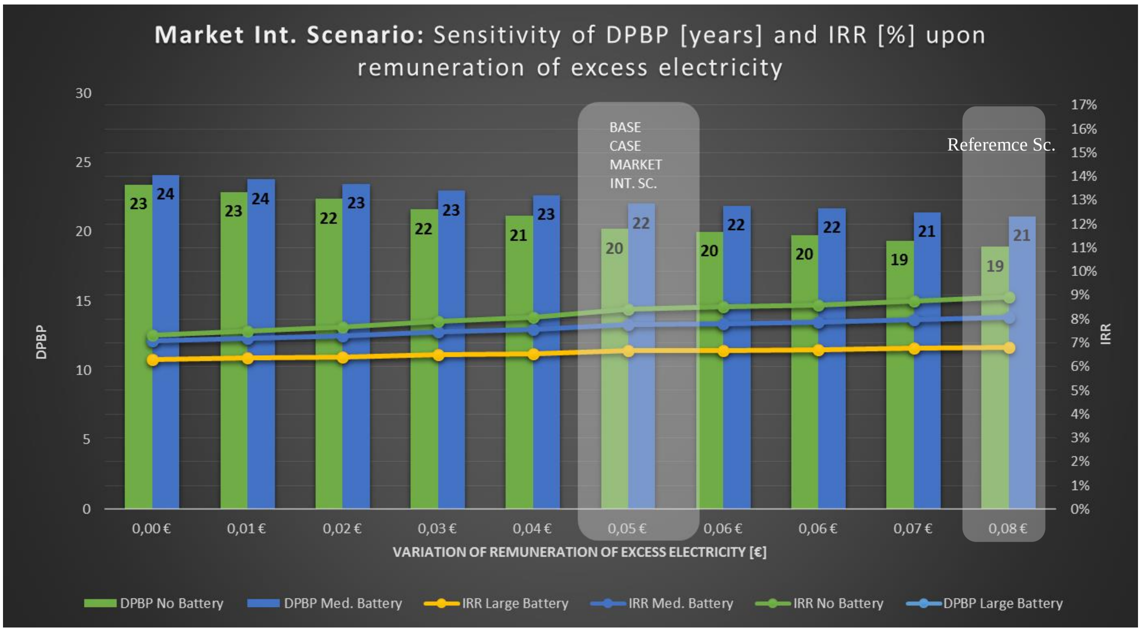


Figure 113 : Market Int. Sc. commercial sector Germany - One variable sensitivity analysis on potential variations of the remuneration of excess el.

Figure 114: Assessment of a change in the electricity cost saving potential

The diagram shows a variation of the electricity cost saving potential within the constraint scenario. The ranges above 100% are shown to provide an indication of the respective value within the reference scenario (where for all systems 100% electricity cost saving potential was assumed). Based on the illustrated curves, it becomes obvious that the commercial systems assessed in this report are extremely dependent to save upon electricity costs. Any alternation from the reference scenario towards the constraint scenario has a strong effect on the economic performance of all systems: A 10% reduction of the el. cost saving potential leads to an increase of the DPBP of about 2 years for all system types.

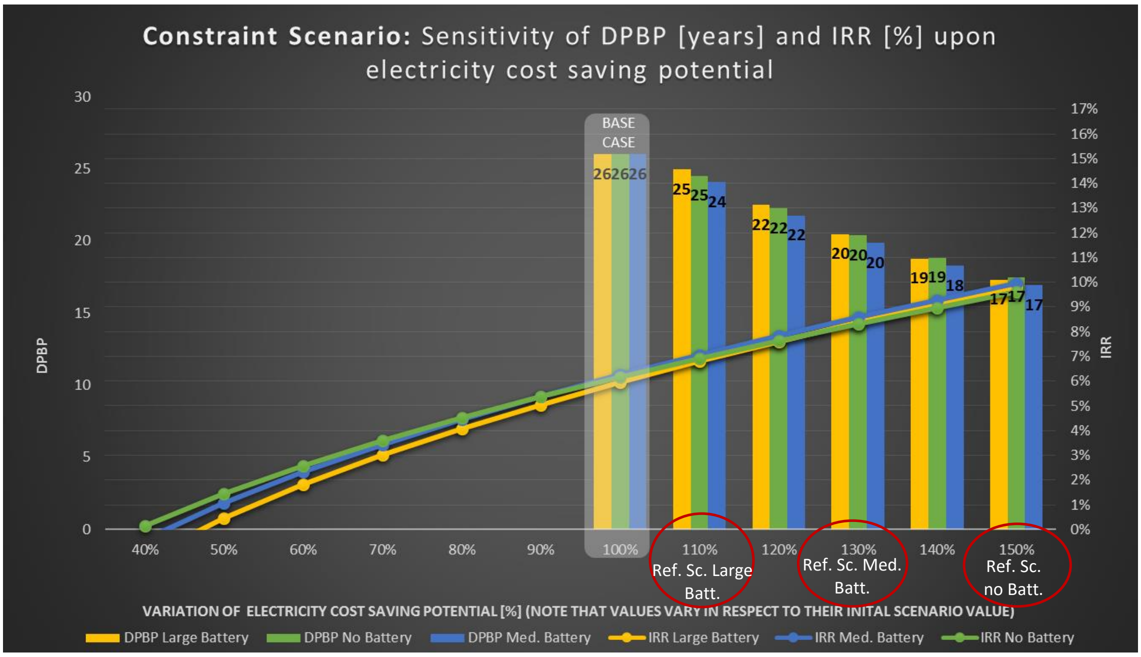


Figure 114 : Constraint Sc. commercial sector Germany - One variable sensitivity analysis on the assumed el. cost saving potential

Considering these outcomes, the following can be derived by the sensitivity analyses for i) the market integration and ii) constraint scenario relation to the reference scenario:

Figure 115 and 116: Market Integration and Constraint Scenario – Assessment of a change in battery investment costs

The analysis, focussing on the market integration scenario, reveals that the PV system combined with a medium battery (33,5 kWh net) would achieve higher IRRs and lower DPBPs compared to the PV only system if the investment costs were reduced by about 50%. The same is valid for the system combined with a large battery in case investment costs were 60% lower, while the IRR curve of the latter system starts to intersect with the one of the PV system combined with a medium sized battery once the investment costs are reduced by 70%.

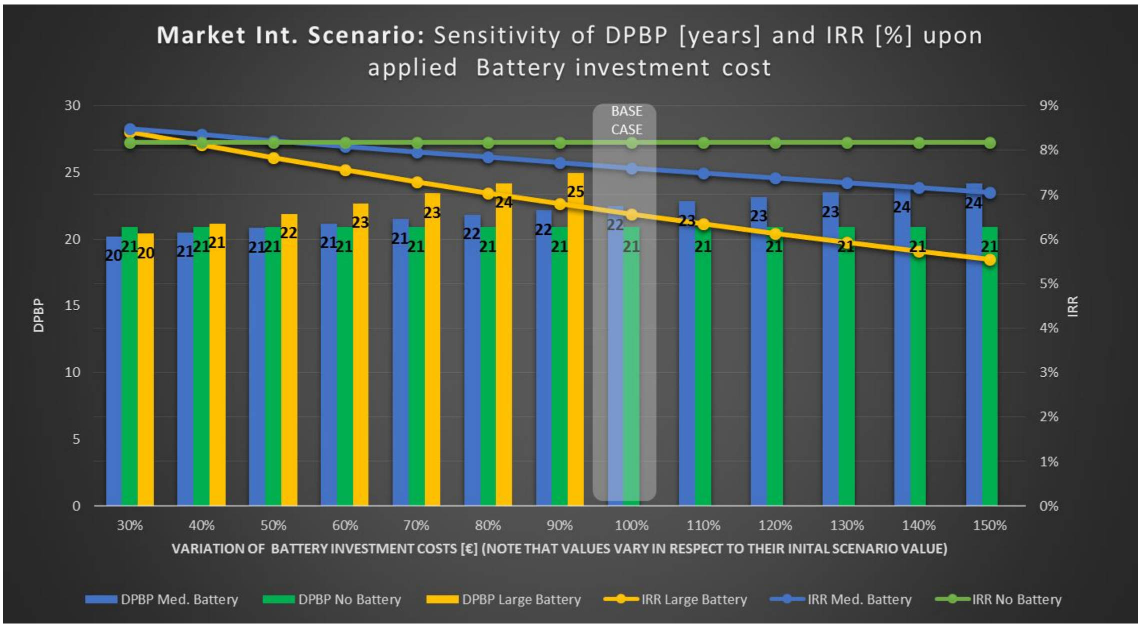


Figure 115 : Market Integration Sc. commercial sector Germany - One variable sensitivity analysis on potential variations of the battery investment costs

Figure 116 shows that the above is also valid with respect to the constraint scenario, however, a reduction of around 10% would already be sufficient so that the large battery system would break even with the PV-only option. Similarly, it would break even with the medium battery system combination if the investment costs were 30% lower. On the other hand, around 10% higher investment costs would lead to a better performance of the PV only system when compared to the variant combined with a medium battery.

Comparing the behaviours observed for the market integration and constraint scenario with the one in the reference scenario (in which the PV only system continuous to achieve better economic results in case of the described cost reductions) indicates that an implementation of the market integration/constraint scenario would most likely trigger investments in batteries within short to medium timeframes.

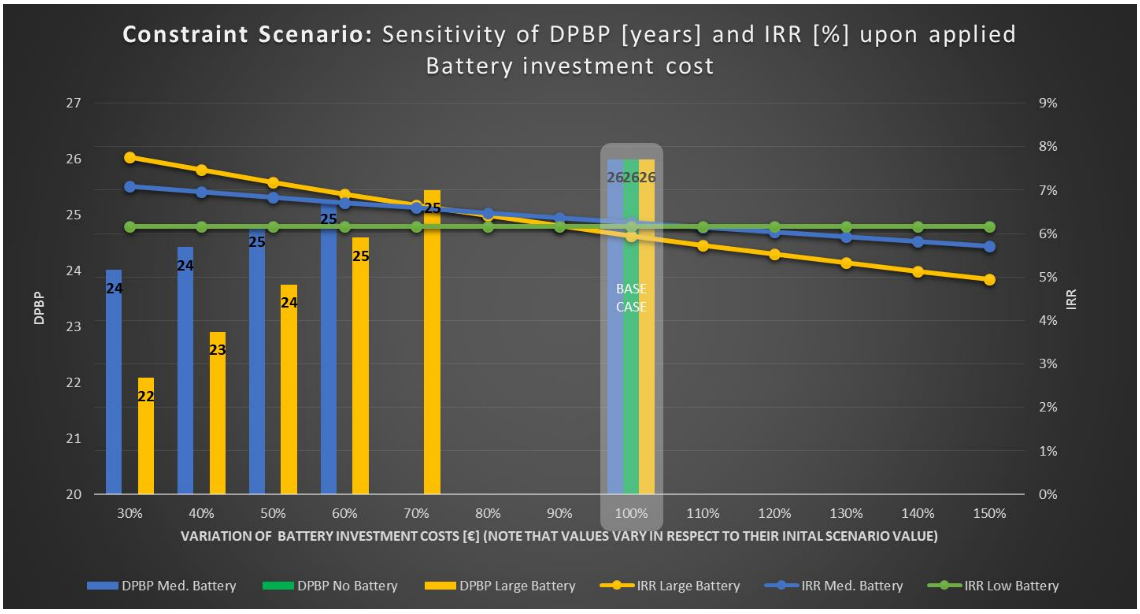


Figure 116 : Constraint Sc. commercial sector Germany - One variable sensitivity analysis on potential variations of the battery investment costs

Figure 117 and 118: Market Integration and Constraint Scenario – Assessment of a change in the annual electricity price increase

Comparing the former and reference scenario with regard the sensitivity upon the assumed electricity price increase, it is evident that the market integration scenario is more sensitive in respect to this parameter. An annual el. price increase of about 4% would already lead to DPBPs above 25 years for the PV system combined with a large and medium battery and to about 24 years for the PV only system. This is very different to the reference scenario in which systems with no and or a medium battery are related to DPBPs of 20 and 24 years respectively.

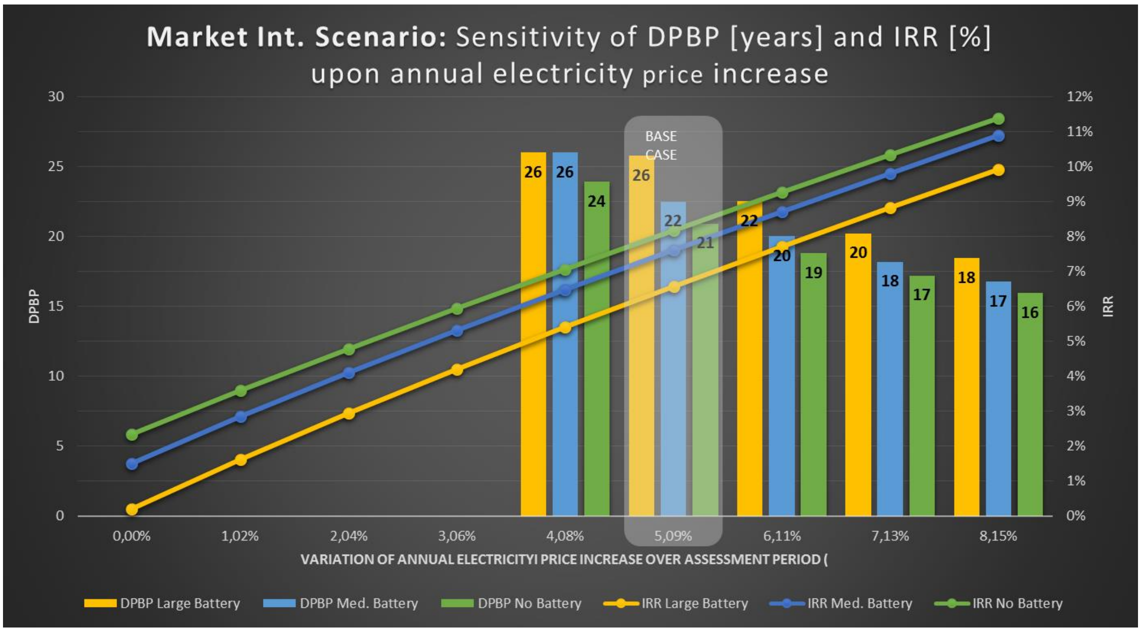


Figure 117 Market Int. Sc. Germany - One variable sensitivity analysis on the assumed el. price increase[41]

[41] Note that with an annual decrease of electricity prices of 1,5% in the market integration scenario, all systems would be related to net losses. However, when comparing the results of the scenarios with regard to the IRR, it becomes clear that for systems without and or a medium sized battery the discount rate in the reference scenario could be as high as 1 and 2% respectively in order to reach a breakeven of the investment. This is different in the market integration scenario: Systems with a medium sized battery would not achieve afore described a result even if the discount rate was 0 (this would only be the case for PV only systems).

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 103 886	> 0	< assessment period
Medium battery	- 74 766	> 0	< assessment period
No battery	- 57 197	0	< assessment period

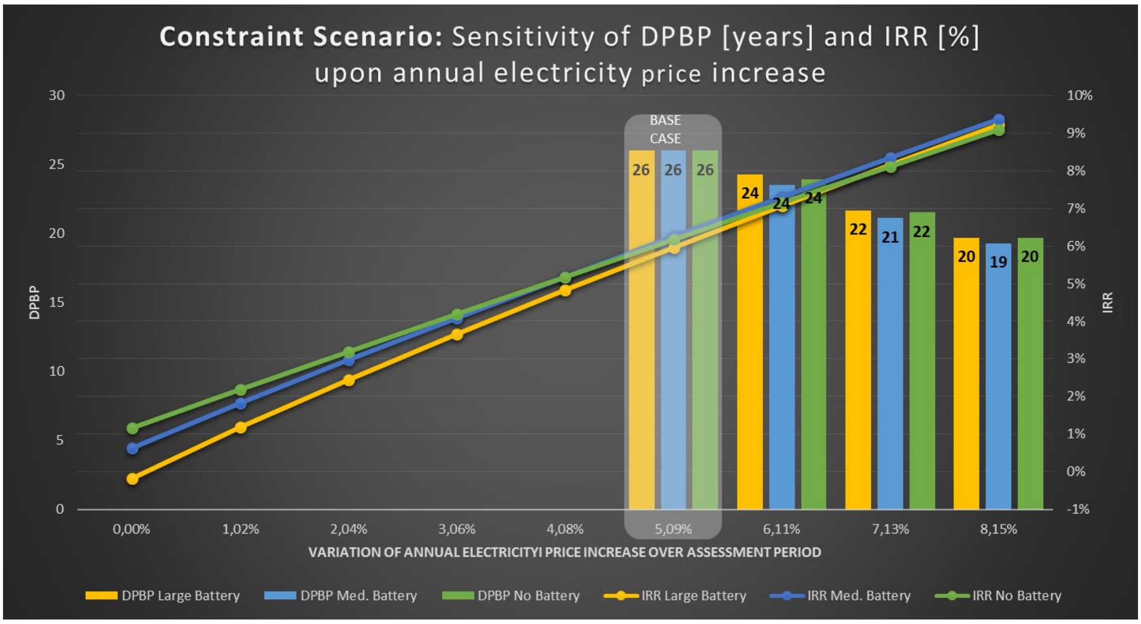


Figure 118 : Constraint Sc. commercial sector Germany - One variable sensitivity analysis on variations of the assumed el. price increase[42]

Based on the results of the sensitivity upon the electricity price increase in the constraint scenario, it can be deduced that PV only systems would start to achieve better economic results than the PV systems combined with batteries once the electricity price would increase by less than initially assumed in this study. This corresponds to the behaviour that can be observed for the entire range of assessed electricity price increases in the reference scenario. However, in case that the el. price would increase by around 6% in the constraint scenario, all IRR lines converge, while the PV system with a large battery would achieve better outcomes than the PV only system in case that electricity prices would increase by around 8%. This is different with regard to the reference scenario in which no intersection of the curves can be observed.

[42] Although total losses are higher in this scenario when compared to the market integration version, the general comment in footnote 41 prevails.

PV system with	NPV [€]	IRR [%]	DPBP [years]
Large battery	- 106 424	> 0	< assessment period
Medium battery	- 80 601	> 0	< assessment period
No battery	- 63 868	0	< assessment period

Appendix III: Potential grid services provided by solar PV

Table 26 : Explanation of grid services[43]

Frequency Support	**FCR**	**Frequency Containment Reserve**	Is also called "Primary Reserve" and is automatically activated within seconds and run for several minutes. It is used for stabilizing the frequency in case of incidents and or imbalances (e.g. due to changes in demand or generation). Target of its activation is to retain the frequency at an adequate level (close to 50 Hz). It does however not restore the system frequency to its nominal value (50 Hz in Europe). This is done by the
	FRR	**Frequency Restoration Reserve**	So called "Secondary Reserve", which can be activated (automatically and or manually) within minutes and run up to hours. It "releases" the activated FCR and restores the system frequency to its target value within a given timeframe (e.g. 15 minutes).
	RR	**Replacement Reserve**	Also known as "Tertiary Reserves". These are activated manually within minutes to hours and are used to free FRR for potential future incidents and or imbalances.
	FFR	**Fast Frequency Response**	Defined "as the additional increase in MW output from a generator or reduction in demand following a frequency event that is available within two seconds of the start of the event and is sustained for at least eight seconds." (Commission for Energy Regulation and Utility Regulator, 2013)
	RM	**Ramping Margin**	"Ramping Margin is defined as the guaranteed margin that a unit provides to the system operator at a point in time for a specific horizon and duration. There are horizons of one, three and eight hours with associated durations of two, five and eight hours respectively. The Ramping Margin is defined by *both* the minimum ramp-up and output durations. Thus the Ramping Margin represents the increased MW output that can be delivered by the service horizon time *and* sustained for the product duration

[43] Additional sources used in this table are: Germany Trade & Invest, 2015, Voet, 2015, Elia, 2015 and Energy Storage Association, 2015

			window.” (Commission for Energy Regulation and Utility Regulator, 2013)
Voltage Support	**FRCI**	**Fast Reactive Current Injection**	In order to achieve a stable (“steady stage”) voltage level within pre-defined bounds it is essential to be able to act on reactance in the grid. This is achieved by generation units that produce reactive power that offsets reactance.
	FRCI	**Fast Reactive Current Injection**	“It is defined as the capability of a generator to deliver a reactive response that shall be proportionate to the magnitude of the Voltage dip. Presently, there are no examples of system services based on this capability, but services based upon this capability may be needed much more often in the future, when there will be more need for local voltage support from distributed generators” (Holttinen, et al., 2012)

Appendix IV: Information and interview questions distributed prior to the conducted interviews

Summary on background and interim findings provided to interview candidates:

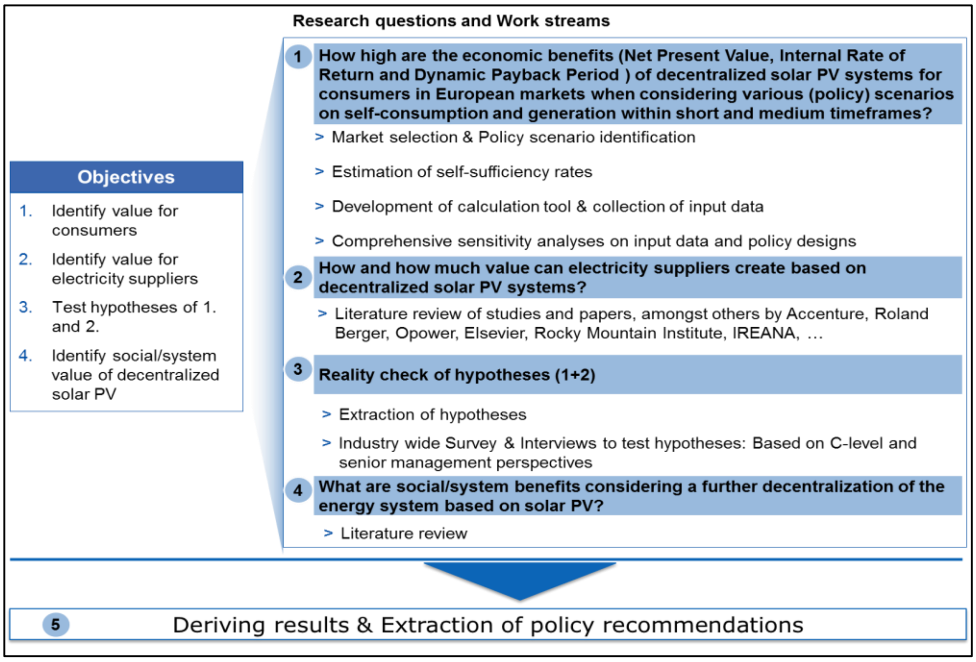
The European energy sector is going through a major transformation process. One of the main trends over the last years is a shift from consumers to prosumers as a new active "operational" entity, for example, by residential solar PV generation. This shift leads to a continuous physical decentralization of the energy system and results in a progressive change in the value-creation of the energy economy: from commodities (electricity) to services (IEA-RETD, 2014). These transition processes are reflected in the most recent strategies of leading energy suppliers such as E.ON: "Empowering customers. Shaping markets" (E.ON, 2015) and GDF Suez in Europe: "[…] adapting to the profound changes in the energy sector and focusing more than ever on its customers (GDF Suez, 2015).

With regard to these facts it is very likely that the relationship with the final customer – turning into a prosumer with new needs – will be an important factor of differentiated performance among suppliers and new entrants. In this context solar PV can be expected to have a key role to play: besides providing value to the prosumer (e.g. economic benefits, green image etc.) (Ebers & Wüstenhagen, 2015), PV systems could become an important asset for energy suppliers by i) creating new revenue streams, ii) reaching out to new customers and iii) maintaining trust with existing ones.

In addition to the creation of customer and supplier value, IEA-RETD, 2014 identified system and social benefits such as flexibility, ancillary services and job creation that can be provided by decentralized solar PV. The concrete value creation for all stakeholders however depends on market conditions that are and will continue to be based on (future) policy designs derived from European policies. Consequently, future political decisions, for instance on the remuneration of excess electricity and or additional charges for self-consumed electricity are likely to considerably impact the described value potentials related to solar PV. With regard to the mentioned value streams for i) consumers, ii) electricity suppliers and iii) the society/energy system, SolarPower Europe identified that literature to date generally focuses only on one specific value cluster rather than providing a holistic perspective that allows to derive balanced conclusions. This leads to drastic and questionable statements such as "The Utility Death Spiral Scenario Is Realistic" or "The centralized electric utilities are doing everything in their power to impede the growth of decentralized energy generation […]" (Edison International, PG&E Corporation, Pinnacle West Capital Corporation, Southern Company, 2015).

With regard to such statements, it is important to provide a scientifically based assessment that focuses on a combination of the above mentioned value streams in order to objectively analyse whether described developments may ultimately lead to imbalances or rather to win-win-win situations for individuals, electricity suppliers and society / the energy system as a whole.

The overall aim of this research is to identify the created "value" of a transition towards more decentralized energy systems based on solar PV in several European member states with regard to three stakeholder value-clusters; i) customer value, ii) electricity supplier value and iii) social/system value. This is indicated in Figure 1 which provides a condensed overview of the objectives and related work streams of this study.



The main part of the study (first research question) focuses on analysing how different levels of i) self-consumption (including various PV system -battery combinations), ii) remuneration of excess electricity and iii) an additional charge for self-consumption will impact the economic benefits of **two consumer segments, namely residential and commercial agents.**

This is different to existing literature today, which most commonly focuses on calculations of

i) "best or worst cases" based on specific input parameters related to a single site or

ii) the Levelized Cost of Electricity (LCOE) by taking into account cost declines of solar PV(-battery) technologies and comparing the respective LCOE outcomes with the expected electricity price escalations of a market in order to indicate when "grid parity" (i.e. solar PV generates electricity with a LCOE below or equal to the price paid when purchasing electricity from the grid) will be reached.

These types of assessments (specific best and or worst cases) however are either not representative for a market (i) or focus on developments mainly interesting for expert groups within the energy economy (ii). Consequently, they do not directly provide an insight for consumers and/or policy makers on how the typical economic benefit indicators (NPV, IRR and DPBP) – being considered when taking final investment decisions – are impacted when policy designs alter the remuneration of excess electricity and/or the exposure of self-consumed electricity to additional charges.

This study therefore assesses three different policy design scenarios and their effect on the economics of residential PV systems combined with battery storage in three European markets, namely the UK, Germany and Portugal. (Additionally, it was possible to assess the economics of one commercial PV(-battery) system combination for the German market). Aforementioned markets were selected based on two indicators: i) variety in irradiation and ii) recently updated support schemes (information available to SolarPower Europe as of June 2015). The latter specifications were chosen given their relative cost-reflectiveness, having in mind that retail electricity prices remain regulated in several other EU countries. An overview of the policy scenarios and PV-battery system combinations with their estimated self-consumption (based on external tools) rates that are equally applied for all assessed countries is provided in the following Figure:

	Remuneration of excess electricity	Electricity cost-saving potential
Reference Sc.	According to (renewable) policy design June 2015	100%
Market Integration Sc.	According to wholesale prices 2014	100%
Constraint Sc.	According to (renewable) policy design June 2015	Depending on Battery size
One 4 kWp (residential) PV system with		
No Battery	≈ 27% self-consumption	70%
≈ 2,3 kWh net battery	≈ 46% self-consumption	80%
≈ 8,3 kWh net battery	≈ 66% self-consumption	90%
One 100 (commercial) kWp PV system with		
No Battery	≈ 69% self-consumption	70%
≈ 33,5 kWh net battery	≈ 78% self-consumption	80%
≈ 100 kWh net battery	≈ 87% self-consumption	90%

Interim results and conclusions

Overall, in respect to the initial research questions, it can be stated that relevant economic as well as non-economic benefits across various countries, when considering different policy scenarios and PV(-battery) system combinations, trigger increasing consumer interest to invest in solar PV and thereby to contribute to the energy transition. Electricity suppliers are in the process of adapting to this trend (by changing their strategies as well as business approaches) and have a unique position to capture value around solar PV. However, several barriers need to be overcome, for example by establishing new partnerships and making solar widely accessible for a broad base of consumers.

With regard to the above additional and more specific conclusions can be derived:

- PV battery system combinations are economical feasible today; however, PV only systems remain the least risky investment and achieve either better and or very similar economic results as PV systems combined with medium sized batteries, while combinations with large batteries likely remain the least economic beneficial variants with regard to medium timeframes (five years and more).
- In case of the market integration scenario (remunerating excess electricity only at the level of wholesale prices) in Germany and the UK as well as in Portugal (where additional fees are applicable), PV systems combined medium sized batteries for residential consumers, as assumed in this report, already achieve slightly higher returns than systems without a battery.

- Due to economical and additional benefits such as self-consumption and green lifestyle, a large part of consumers is interested and has a strong demand in products related to decentralized solar PV, particularly when provided by their electricity suppliers. Notably around half of the German consumers that combined their PV systems with batteries do not expect economic benefits.
- With respect to aforementioned fact and when taking into account various consumer interests and groups, electricity suppliers are suggested to start offering tailored solar service packages that capture consumer and energy system needs and thereby overcome identified barriers

Considering the above, future policy designs should:

- Support market integration of solar PV systems (especially when combined with battery systems) by adopting / drafting network codes that allow to aggregate solar PV and to participate in wholesale markets as well as to provide system services.
- Preferably not charge self-consumption, or if so, only to a very limited extend, such that it does not cut off economic and additional consumer interests – anticipating that consumers would be less interested in self-consumption if it was related to high charges, meaning that the market integration design for these system types would be favourable.
- Provide regulatory stability to increase investor confidence and enable electricity suppliers to create offers that tackle the rising demand around decentralized solar PV.
- Reflect upon a combination of the market integration and constraint scenario (as was analysed by the two variable sensitivity analyses), i.e. a fourth scenario, as a suitable variant in a transition towards a complete market integration.

Appendix IV.I: Questions for the consumer association

Consumers

There seems to be a global trend towards an increased willingness/interest of customers to go for self-generation and consumption. According to Accenture more than 55% of customers (globally) are interested to purchase / sign up for PV. With a focus on Europe:

- How do you see the interest of consumers in self-generation and consumption?
- What do consumers expect in terms of services and self-generation/consumption from their electricity suppliers?
- Do you have knowledge on how satisfied consumers are with their electricity suppliers, especially with regard to services?

Is there information available on the consumer group, for example age, gender, educational level, income, geographical location, psychographic (such as lifestyle, personality, values) and behavioural variables (knowledge, attitude) that

  - is interested in self-generation/consumption
  - has invested in the past?
  - is expected to invest in the future (considering declining support)?

Drivers and Barriers

- What are the main barriers (such as financial situation) and drivers (for example protection against rising electricity prices and contribution to the energy transition) for future investments?
  - Regarding the driver of financial benefits, we have slightly contradictory findings:
    - i. "Economic benefits are the most important drivers for investment" (looking at declining installations along with declining incentive programs seem to support a strong co-relation)
    - ii. Versus findings for the German market concerning PV-battery system combinations, where:
      1. Only 50% of consumers' state that they expect economic benefits
      2. around 40% of consumers are fine if the investment simply breaks even

3. while 10% would even accept a loss

- Do you support the idea that more targeted campaigns on different consumer groups help to make solar offers more appealing to them?
- What other action is needed to ensure that solar PV becomes more accessible for a broad base of consumers?

Regulatory perspectives

- Consumers want simplicity, electricity companies' flexibility – what is the right balance of price signals for self-generation/consumption today and how should the relationship between energy suppliers & empowered consumers evolve in a context of converging wholesale & retail markets?

- With regard to the assessed market integration and constraint scenario (grid charges, taxes, levies, ..): What framework for self-generation and consumption is needed at EU/national level?

Business perspectives

What is your opinion on the following?

When taking into account various customer interests and groups, electricity suppliers are suggested to start offering tailored solar service packages that capture customer and energy system needs and thereby overcome potential barriers:

- An example for rather passive and or risk averse and potentially low income groups could be to:

  Provide installation, maintenance and administrative work for *PV only systems* with rather low capacities (i.e. low investment costs) that initially lead to self-consumption ratios of around 30 to 35% (or even higher in case of very low capacities). The system could be completely managed by the energy supplier that buys the excess electricity for a guaranteed remuneration according to a pre-fixed tariff, while the savings on electricity costs could be subject to a certain charge administratively set (accounting for necessary grid investment support). The remaining electricity demand would be supplied by the same company.

- An example for more active and or high income customers could be to:
  Install solar *PV-battery systems* with self-consumption rates of around 45 to 70% (i.e. higher investment costs when compared to PV only systems) combined with energy efficiency/management measures that allow customers to actively participate in managing their electricity generation/use to a certain extent. A prerequisite could be that not more than a defined percentage of electricity produced is allowed to be injected to the grid, thereby ensuring system optimization. The excess electricity could be bought by the company in accordance to wholesale prices, while the remaining electricity demand of the customer would be supplied by the same company.

What is your opinion on “Packages” that include contracts for internet, phone, solar, battery etc.?

Appendix IV.II: Questions for the new entrant

Consumers

There seems to be a global trend towards an increased willingness/interest of customers to go for self-generation and consumption. According to Accenture more than 55% of customers (globally) are interested to purchase / sign up for PV:

- How do you see the interest of consumers in self-generation and consumption in European markets?

Drivers and Barriers

What are the main barriers (e.g. financial situation, information) and drivers (e.g. protection against rising electricity prices and contribution to the energy transition) for future investments?

- Regarding the driver of financial benefits, we have slightly contradictory findings:
  4. “Economic benefits are the most important drivers for investment” (looking at declining installations along with declining incentive programs seem to support a strong co-relation)
  5. Versus findings for the German market concerning PV-battery system combinations (indicating a strong demand for self-sufficiency), where:

a. Only 50% of consumers' state that they expect economic benefits
b. around 40% of consumers are fine if the investment simply breaks even
c. while 10% would even accept a loss

You provide two alternatives, similar to the ones we assess in the study: PV systems without batteries, and PV systems combined with a battery, in a complete package including installation, apps and software.

- Can you share info, e.g. age, gender, educational level, income, geographical location, psychographic (such as lifestyle, personality, values) and behavioural variables (knowledge, attitude) about the different consumer types that are interested in simple PV systems and those combined with a battery? What are their main drivers to decide to go for one or the other variant?
- Do you support the idea that more targeted campaigns on different consumer groups help to make solar offers more appealing to them?
- What other action is needed to ensure that solar PV becomes more accessible for a broad base of consumers?

Regulatory perspectives

- Consumers want simplicity, electricity companies' and the system need flexibility – what is the right balance of price signals for self-generation/consumption today and how should the relationship between energy suppliers & empowered consumers evolve in a context of converging wholesale & retail markets?
- With regard to the assessed market integration and constraint scenario (grid charges, taxes, levies, ..): What framework for self-generation and consumption is needed at EU/national level and how do you see your business model adapting against this background?

Business perspectives

Your business model fits the description of the business model that we suggest in our study (see below). Why are you not offering more diversified packages, e.g. combinations with smaller batteries or packages that include internet and phone contracts via partnerships?

When taking into account various customer interests and groups, electricity suppliers are suggested to start offering tailored solar service packages that capture customer and energy system needs and thereby overcome potential barriers:

- An example for rather passive and or risk averse and potentially low income groups could be to:
  Provide installation, maintenance and administrative work for *PV only systems* with rather low capacities (i.e. low investment costs) that initially lead to self-consumption ratios of around 30 to 35% (or even higher in case of very low capacities). The system could be completely managed by the energy supplier that buys the excess electricity for a guaranteed remuneration according to a pre-fixed tariff, while the savings on electricity costs could be subject to a certain charge administratively set (accounting for necessary grid investment support). The remaining electricity demand would be supplied by the same company.

- An example for more active and or high income customers could be to:
  Install solar *PV-battery systems* with self-consumption rates of around 45 to 70% (i.e. higher investment costs when compared to PV only systems) combined with energy efficiency/management measures that allow customers to actively participate in managing their electricity generation/use to a certain extent. A prerequisite could be that not more than a defined percentage of electricity produced is allowed to be injected to the grid, thereby ensuring system optimization. The excess electricity could be bought by the company in accordance to wholesale prices, while the remaining electricity demand of the customer would be supplied by the same company.

  - Do you partner or have you considered to do so with incumbents or other stakeholders? E.g. in order to decrease acquisition-costs and get access to a broader customer base, thereby reducing costs and increasing benefits?

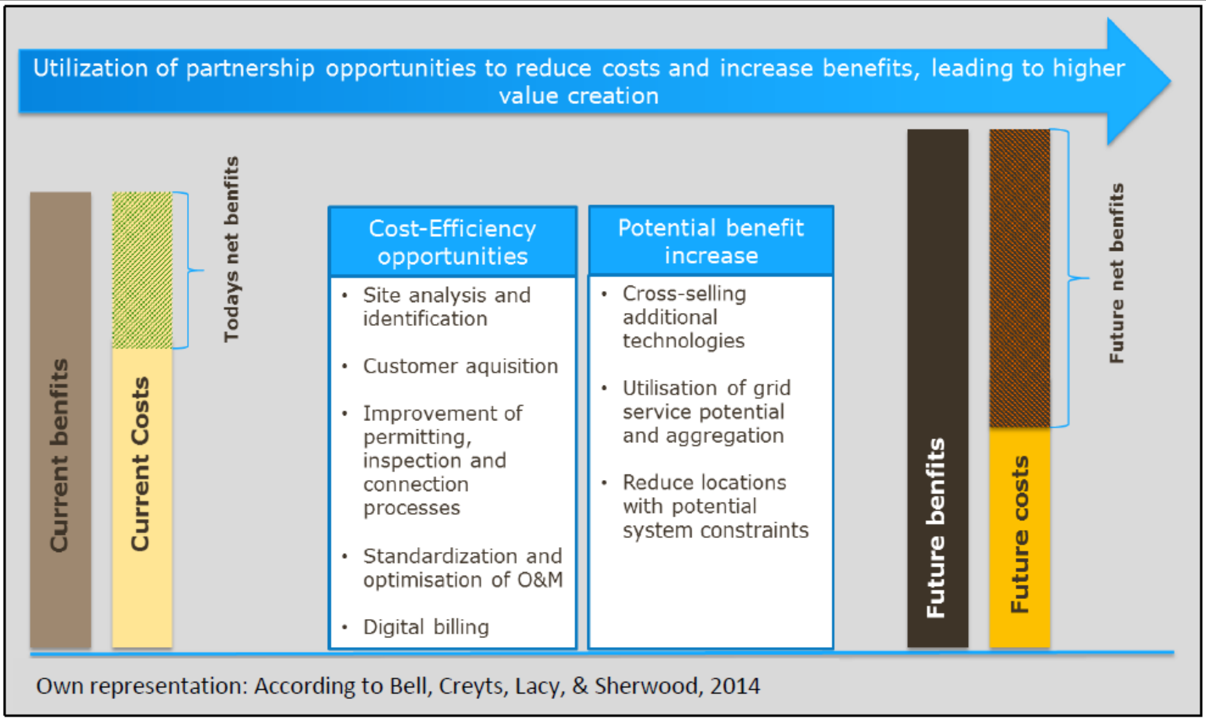


Figure 42 : Options to increase the business model value of decentralized solar PV

Appendix IV.III: Questions for the integrated energy supplier

Customers & PV:

There seems to be a global trend towards an increased willingness/interest of customers to go for self-consumption. According to Accenture more than 55% of customers (globally) are interested to purchase / sign up for PV.

- How much do you know about your customers and their interest in solar PV?
- Do you agree with the statement that solar PV is a strategic gateway to cover changing customer interests and to support the shift towards customer oriented business models? Do you believe that offering PV business models would support to retain these/gain new customers?
- Do you see different customer clusters regarding potential PV offers?
- How do you see the digital involvement of customers that have PV-systems installed?

- Do you believe aggregating customer PV(-battery) systems and or an increased customer base with such systems would allow you to increase the efficiency of internal processes?

PV Business models:

- Having Energy Efficiency as a strategic target, do you see solar PV contributing to it?
- What are your current offers around solar PV?
- What do you see as a main driver/barrier for customers to go for such offers?
- If your company provides only a very limited amount of offers and services around solar PV, why is that the case?
- How do you see the development of PV(battery) systems as a business model with the background of
  - Declining technology costs?
  - Changing policy designs?
- **How do you see the following barriers of solar PV-business models?**
  - Lack of profitability (total investment volumes are very low and therefore create only very limited benefits)
  - Lack of demand (customers scared of long-term contracts, limited interest in financing options?)
  - Lack of overall value for an electricity supplier, i.e. customers not willing to pay enough for extra services?

What is your opinion on the following?

When taking into account various customer interests and groups, electricity suppliers are suggested to start offering tailored solar service packages that capture customer and energy system needs and thereby overcome potential barriers:

- An example for rather passive and or risk averse and potentially low income groups could be to:
  Provide installation, maintenance and administrative work for *PV only systems* with rather low capacities (i.e. low investment costs) that initially lead to self-consumption ratios of around 30 to 35% (or even higher in case of very low capacities). The system could be completely managed by the energy supplier that

buys the excess electricity for a guaranteed remuneration according to a pre-fixed tariff, while the savings on electricity costs could be subject to a certain charge administratively set (accounting for necessary grid investment support). The remaining electricity demand would be supplied by the same company.

- An example for more active and or high income customers could be to:
  Install solar *PV-battery systems* with self-consumption rates of around 45 to 70% (i.e. higher investment costs when compared to PV only systems) combined with energy efficiency/management measures that allow customers to actively participate in managing their electricity generation/use to a certain extent. A prerequisite could be that not more than a defined percentage of electricity produced is allowed to be injected to the grid, thereby ensuring system optimization. The excess electricity could be bought by the company in accordance to wholesale prices, while the remaining electricity demand of the customer would be supplied by the same company.

PV and Partnerships:

- Are you planning to increase your capabilities in the solar market via partnerships? Which would be your target group? (E.g.: Specialised Solar PV company, Home improvement / Electronics provider, Cooperative / Community organization, Maintenance / Repair company, Online retailer)
- How do you see your role in new partnerships?
- What are the most promising options to reduce the costs of offering solar PV business models while at the same time increase the benefits, e.g. as illustrated in the following Figure?

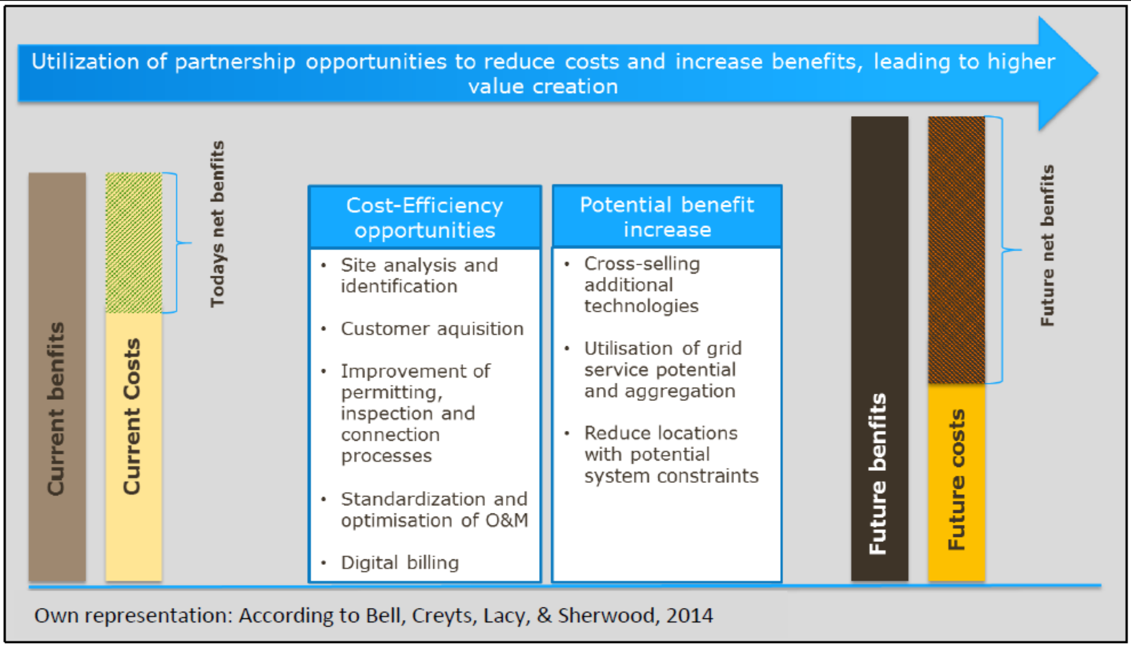


Figure 42 : Options to increase the business model value of decentralized solar PV