

A Work Project, presented as part of the requirements for the Award of a Master's degree in
Finance from the Nova School of Business and Economics.

Economic Analysis of Rooftop Solar Panels in Aalen, Germany

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19/12/2023

Summary of rooftop solar analysis

Location: Aalen, Germany

Date of analysis: 19.12.2023

Recommendation: Install 5 solar panels (7.55 m²), for a net present value (NPV) of 5,538€, with a payback of 3.18 years.

1 Main economic results

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
Government subsidies and 75% credit	5,538.16	3.18	33.42	0.0895
Government subsidies and 100% credit	5,509.64	0.00	n/a	0.0960
No government subsidies and 100% equity	5,055.71	7.13	13.54	0.0700
No government subsidies and 75% credit	4,227.07	4.45	25.00	0.0953

(All rows are for the same number of panels)

2 Additional results

When an energy storage system with a capacity of 15,498 kWh is employed, the NPV amounts to 3,980.31€. The sensitivity analysis reveals that the NPV is positively correlated with both the electricity purchase price (in €/kWh) and the electricity selling price to the grid (in €/kWh). As these prices increase, the NPV experiences a corresponding increase. Notably, the parameters of loan amount and installation cost emerge as particularly volatile scenarios within the analysis.

3 Main inputs and assumptions

Household and Economics

Electricity Consumption	3,478.48	kWh/year	Inflation	1.9%	per year
Electricity price – buy	0.351	EUR/kWh	Bank loan interest rate	6.7%	per year
Electricity price – sell	0.082	EUR/kWh	Bank loan maturity	15.0	years
	0.071	EUR/kWh	Equity cost of capital	3.1%	per year
	0.062	EUR/kWh			

PV panels

Peak power	435.00	W/panel	System losses	14.0%	of output
Panel area	1.51	m ² /panel	Degradation with age	0.4%	Per year
Useful life	20.00	Years	Maintenance costs	1.0%	Year per panel
			Total cost of optimal installation size (without subsidies)	5,538	EUR
			Total cost of optimal installation size (after subsidies)	5,538	EUR

The subsidies influence the financing and not the price of the photovoltaic (PV) system.

4 Government subsidies

The Kreditanstalt für Wiederaufbau (KfW), a German financial institution, supports the installation of a solar power system with a favorable interest rate of 5.34% (C Rating). Additionally, a legislative measure supports the sell-to-grid price with a subsidy of up to 8.2 ct/kWh.

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1 Introduction

“It’s simply not realistic to believe that the oil and gas industry are going to take the lead in solving the climate crisis.” – Al Gore, Former US President and Climate Campaigner (Al Gore, 2023).

The world faces an urgent challenge – to halt climate change and reduce dependence on fossil fuels. In 2022, solar energy offers a significant solution and can be used by everyone (United Nations, 2022). The sun, as an inexhaustible energy source, plays a significant role in transforming the world’s energy supply.

In Germany, the final energy consumption of private households was 29.00% in 2022 (Energiebilanzen Arbeitsgemeinschaft e.V, 2023). The Aalen region is no exception. The private emissions consumption in this region was 30.28% in 2018 (Stadt Aalen, 2018). The majority of 84.08% of the energy comes still from coal, oil and gas, resources that both pollute the environment and make energy supply uncertain (UmweltBundesamt, 2023). Rising energy costs and the need to minimize environmental impact require urgent action to switch to renewable energy. This is where solar energy comes into play (Reuters, 2023).

Solar panels, mounted on private residences, are not only environmentally friendly, but also offer homeowners the opportunity to reduce their energy costs while increasing their energy independence (Koonen, 2023). However, despite this potential, the Aalen region has not yet tapped the full potential of solar technology. There are still barriers and challenges that must be overcome to encourage its wider adoption and application (Appendix A).

The importance of this issue extends beyond the environmental aspect. Solar panels on private residences not only allow homeowners to actively contribute to reducing CO₂ emissions, but also offer significant economic benefits. Reducing energy costs, feeding excess energy into the

grid, and financial incentives through government programs are just some of the benefits offered by this technology.

This paper aims to delve into a thorough examination of the motivation behind and the benefits associated with the installation of solar cells on private residences in the Aalen region and why installing 5 solar panels could be worth a NPV of 5,538.16€.

2 Research Methodology and Assumptions

The aim of this work is to determine the economic viability of a PV system in the Aalen region. Therefore, various evaluation parameters are taken into consideration. The NPV, the Internal Rate of Return (IRR) and the Levelized Cost of Electricity (LCOE) are used as the basis for the analysis (Rodríguez, 2022). These Key Performance Indicators (KPIs) are analyzed in different financing formats:

Table 1: Ways of financing

Gov. subsidies and 75% credit
Gov. subsidies and 100% credit
No. gov. subsidies and 100% equity
No. gov. subsidies and 75% credit

For additional analysis, it is assessed how the NPV and IRR change under different influences of technical and economic parameters by using a scenario analysis. An additional analytical dimension is introduced, wherein an explanation is directed towards the comportment of the basic figures in the context of alterations in two influential parameters, facilitated through the incorporation of a sensitivity analysis (Sandia National Laboratories, 2023).

Furthermore, an assessment is calculated using NPV and IRR when using a battery. This demonstrates the feasibility of generating potential savings through an increased level of self-sufficiency in the supply aspect.

The assumptions are divided into two different areas. One pertains to the data structure, while the other concerns economic parameters. The data structure indicates the situation in the region

and how this is determined. On the one hand, these are input parameters which reflect the consumption but also the energy output of the PV system. On the other hand, it describes which components and which PV system is used. Through these economic parameters, the objective is to evaluate the impact of external variables on the project. There are regional differences such as subsidies but also supra-regional variables such as inflation or interest rates that affect the project. The aim is to include as many variables as possible to achieve an accurate result (Appendix B).

2.1 Data Structure and Environmental Assumptions

The data structure is divided into the areas of solar irradiance, load and radiation. Each of these parameters integrated separately into the model and is therefore subject to its own assumptions.

2.1.1 Radiation

The calculation of solar irradiation is a central topic in the PV area (Opie, 2022). These assumptions form the basis for the planning, designing and the operation of the solar systems. The following procedure considers the environmental influences and how they affect the economic efficiency of the PV system. To calculate solar radiation, many factors must be considered. This chapter aims to explain the most important assumptions.

The radiation was measured hourly over a time horizon of 15 years (2005 to 2020). An average of 15 years is used in the following model to assume the exact average annual solar radiation that will prevail in the future. The assumptions supplement the following:

Solar irradiation: This project is a PV system in Aalen at the location, Latitude (decimal degrees): 48.831; Longitude (decimal degrees): 10.097. This PV system is aligned with an optimum angle of slope 36 degrees and a 17 degrees Azimuth. This implies that the PV system operates under ideal solar radiation conditions (Photovoltaic Geographical Information System, 2023). All results presented in the following refer to this data.

Cloud cover and atmospheric conditions: The presence of clouds and other atmospheric conditions can significantly affect the amount of incident solar radiation. It is assumed that the system is not influenced by additional shade. The database from the Photovoltaic Geographical Information System is used (Photovoltaic Geographical Information System, 2023). The data is taken for the years 2005 to 2020 and the average is assumed for this project (European Commission, 2023). This procedure is intended to adjust values that are well above average and those that are well below average to a realistic value. This results in an output of 12,792.62 kWh per year. It is assumed that exactly this level of irradiation will be available in the coming years and that the environmental influences will not change.

Pollution modeling: Air pollution and polluted solar panels can reduce the amount of incident solar radiation. In this model the assumption is that there is no additional pollution to the 14.00% (European Commission, 2023). In addition, 1.00% maintenance costs are calculated, which also include the cleaning of the solar panels and do not lead to any further irradiance (Kost, et al., 2021).

2.1.2 Load

The basis of the load profile is made up of a multi-layered database, which was obtained both people from the region and using simulation software. Samples were taken from 10 different geographical regions in the city of Aalen to ensure a representative range of consumption (Appendix C) with an average of 3.8 people per household and an average energy consumption of 3,304.56 kWh. Linear interpolation produces a value of 3,478.48 kWh for a household of 4 people.

In addition, a comprehensive simulation was carried out to generate the hourly energy consumption patterns of households. Using simulation software, different scenarios were modeled to reflect the diversity of potential energy consumption patterns. The software enabled the precise recording of hourly consumption quantities, which are now analyzed in conjunction with

the real data in order to gain well-founded insights into the hourly energy consumption of households (Pflugradt, 2022).

2.2 Economic Parameters

Economic parameters are influencing factors that arise from both the installation and the economic conditions.

2.2.1 Cost Structure of the Photovoltaic

The PV system consists of several components that need to be purchased and installed. These are, the solar panels themselves, but also the inverter and the costs incurred by installing the entire system. In the following, a bottom-up approach was chosen in which the total costs are calculated based on the solar cells.

Solar panels: It is assumed that the project will be implemented with Tiger Neo N-type; 54HL4R-B (Jinko Solar, 2022). This solar panel has the following features:

Table 2: Solar panel

Name	JKM54HL4R-B	Max. Power Voltage (Vmp)	32.99V
Type	Mono- crystalline	Module efficiency	21.77%
Dimension	1762x1134x30mm	Max. Power (Pmax)	425Wp

These are among the best-selling solar panels in the world and are also widely used in southern Germany and the Aalen region. They are mono-crystalline panels which have the highest market share in the Aalen region (Jan Figgenger; David Haberschusz; Sebastian Zumühlen; Dirk Uwe Sauer, 2021). The following chart shows the price scale for these solar panels which is based on certain purchase quantities:

Table 3: Price Solar Panels

Count of panels (incl. Delivery)	Price per panel (€)
1 – 20	515.00
21 – 35	479.00
35+	459.00

Inverter: The price of the inverter is determined by the cost of the solar panels. Since the different power of the panels leads to a different choice of the inverter, the price of the inverter cannot be determined in a general way. For the inverter a linear interpolation is assumed (Appendix D). The power loss of the inverter is already compensated with 0.40% which is assumed for the solar modules and therefore not considered separately.

Table 4: Inverter costs

Type of inverter	Power (W)	Price (€)
VEVOR WVC-600W Micro Grid	600.00	121.99
VEVOR Power Inverter 5000W	4,000.00	577.99
Sungrow SH 5.0/6.0/8.0/10RT	6,000.00	1,100.90

The cost of the inverter increases linearly per converted power in watts. The assumption was made that the cost of the inverter is based on the power of the solar panels. When assessing the capacity of the inverter relative to the solar panels, it is determined to be approximately 22.50%. This calculation involves expressing this value as a percentage of the overall expense incurred by the solar panels, thereby incorporating these costs into consideration.

Maintenance: The maintenance cost is assumed based on the solar panel price. Since this cost is also strongly dependent on the quantity of panels, this value cannot be determined in general. The maintenance expenditures encompass insurance coverage for the solar panels and the inverter, in addition to the costs associated with cleaning. In these computations, it is presupposed that the panels undergo cleaning procedures, entailing the procurement of requisite tools such as a high-pressure cleaner and smaller cleaning instruments. For this calculation a maintenance cost of 1.00% is assumed of the panel costs which aligns with a paper from Mr. Kost of Fraunhofer Institut (Kost, et al., 2021).

2.2.2 Cost Structure Battery

The SMA Home Storage model was selected for the use of an additional battery (SMA Solar Technology, 2021). To achieve comparability, different battery sizes are compared with each other. These batteries have the following characteristics:

Table 5: Battery Characteristics

Characteristics of the battery	SMA 3.2	SMA 9.8	SMA 16.4
Usable energy capacity (kWh)	3.28	9.84	16.40
Price (€)	2,339.00	5,501.00	9,851.00
Installation cost (€)	499.00	832.00	999.00
Total costs Battery (€)	2,838.00	6,333.00	10,850.00
Nominal voltage (V)	96.00	288.00	480.00
Efficiency (%)	94.50	94.50	94.50
Usable efficiency (kWh)	3.01	9.21	15.50

Table 5 shows that as the size of the battery increases, the costs for the battery also increases, as do the installation costs. It is assumed that batteries cannot guarantee 100.00% utilization. Based on this, an efficiency of 94.50% is assumed which is specified by the manufacturer (SMA Solar Technology, 2021). It is assumed that there are no further losses. This changes the usable efficiency of the respective battery.

2.2.3 Financing

The aim of this work is an average family of four people. This is subject to 1.5 full-time jobs in the household. The rating is estimated a “C” on a rating table from “A” to “I” which is equal to the rating “good” (Kreditanstalt für Wiederaufbau, Konditionsübersicht für Endkreditnehmer, 2023). The deposit of collateral with a potential up to 80.00% is included. For the determination of the interest rate, online offers from internet comparison portals as well as an offer from a local bank were obtained (Check24, 2023). These are considered in equal parts to obtain an average value of 6.70%. This is aligned with the subsidies of the KfW which makes the assessment according to the same pattern.

Government subsidies: For the promotion of PV projects a nationwide promotion program of the KfW is applicable. The program promotes a better interest rate to the end user. The conditions have different terms (5, 10, 15, 20 years) whereby only the maturity and not the interest conditions change. For this project, a term of 15 years is assumed, as this is also recommended by the KfW (Kreditanstalt für Wiederaufbau, Konditionsübersicht für Endkreditnehmer, 2023). To have an adequate comparison, the loan without subsidy program is also calculated with a term of 15 years. As described earlier in the text, a rating of "C" is assumed. This corresponds to a debit interest rate of 5.34% and an effective interest rate of 5.45% (Appendix E). According to KfW, this rating is assumed for the creditworthiness of a family with one person working full-time and one person working part-time. It is assumed that the funding of KfW Bank does not change over the term of the project. When not starting the project now the financing cannot be guaranteed as KfW offers are subject to a limited budget.

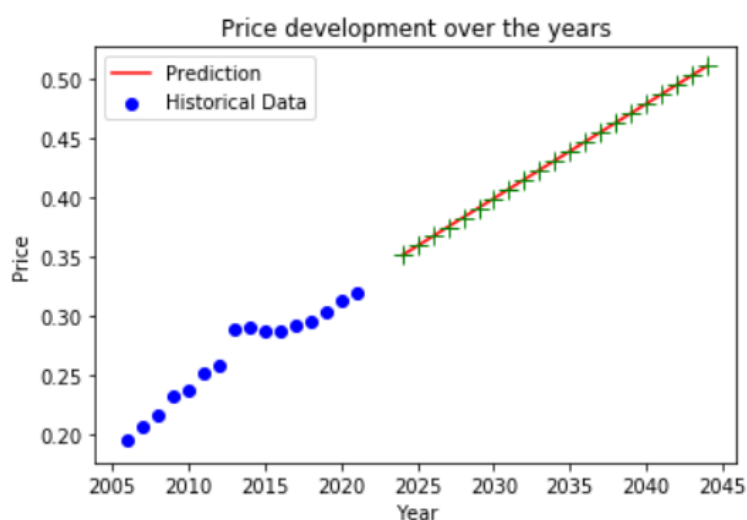
2.2.4 Macroeconomic factors

Inflation Rate: The European Central Bank's (ECB) target inflation rate is well below 2.00%. Looking at Germany's historical inflation from 2003 to 2022, the inflation rate is 1.93%. Despite very high inflation recently, a long-term inflation rate should be chosen for a project duration of 20 years. With a view of 19 years, which is near the project duration, the number of 1.93% is reliably. A distinct assumption has been formulated concerning the inflation rate applicable to energy costs, delineated subsequently.

Electricity cost: Price fluctuations have been noticeable in recent years, particularly in the domain of electricity which leads to a very volatile factor in the overall picture. To determine the costs, electricity prices from 2006 to 2021 of Germany were considered. These form an average that applies very well to the Aalen region as the electricity costs are very similar. These numbers are adjusted for the years 2022 and 2023 as they are on average 17.13% higher. This is largely due to the energy crisis in Germany. It is assumed that the energy prices will decrease in the

next few years due to geopolitical easing (Publications Office of the European Union, 2023). A linear interpolation for the years 2024 to 2044 was created. This reflects the time horizon the project takes place. This leads to the inference that the inflation rate closely aligns with that of core inflation, although it does not precisely replicate its pattern. The linear interpolation proceeds with a slope of 1.90% or 0.008 cents per year. The amount of costs per kWh is taken for each year individually.

Figure 1: Linear interpolation of energy prices



Electricity sell to grid: The sale of energy in Germany is substituted with a fixed rate which is regulated in the Renewable Energies Act (EEG) and calculated according to the size of the PV system. The feed-in tariff is guaranteed for 20 years, which corresponds to the duration of the project. After the guaranteed time frame, the feed-in tariff rate is recalculated. The EEG assumes the following values to determine the feed-in tariff:

Table 6: Compensation for selling to grid

Size of the PV plant	Compensation when selling to grid (€/kWh)
>10 kWp	0.082
10-40 kWp	0.071
<40kW	0.062

It is noteworthy that compensation is consistently disbursed up to the upper limit, and the lower feed-in tariff is only invoked if the upper limit is surpassed.

In the absence of income substitution stemming from energy sales, the tariff parameters under examination are confined to those contractual arrangements existing between end consumers and the energy supplier. In the analytical assessment of the sales value, the temporal scope spans from the years 2012 to 2020, with subsequent adjustments applied for the years 2021 and 2022. Notably, during the latter period, the average tariff is observed to be 11.57 ct/kWh, constituting a substantial escalation of 23.81% beyond the established mean from 2012 to 2020, which stood at 3.62 ct/kWh. It is to note that the utilized parameter for the model is the 3.62 ct/kWh figure, reflecting the feed-in tariff without substitutions for sell to grid. This parameter is presumed to grow congruent with the trajectory of energy inflation.

Equity cost of capital: The foundational premise for computing the cost of equity in the present photovoltaic project involves the utilization of Germany's 10-year swap rate, standing at 3.05% on 15.11.2023. The decision to adopt this interest rate as a fixed assumption is grounded in Germany's stable creditworthiness, underscored by its triple-A rating. Additionally, it is predicated on the presumption that swap rates offer a dependable indicator of anticipated future interest rates. In light of the distinctive attributes of the photovoltaic project, the 3.05% swap rate is employed as a consistent benchmark for ascertaining the cost of capital of this project. This determination facilitates a precise computation of the requisite return on equity and significantly contributes to the comprehensive evaluation and profitability analysis of the photovoltaic project.

3 Economic Analysis

The foundational analysis of a PV system constitutes the cornerstone of any comprehensive economic evaluation. In this section, the focus centers on critical financial metrics, including the NPV, IRR, and LCOE. These parameters are pivotal in comprehending the profitability of investing in renewable energy sources.

LCOE: The LCOE indicates the average price per unit of electricity generated (in megawatt hours) that a system would have over its entire service life in order to cover all costs and achieve a certain return. The formula for the LCOE is:

$$LCOE = \frac{\textit{Present Value of Total Cost Over the Lifetime}}{\textit{Present Value of All Electricity Generated Over the Lifetime}}$$

- The present Value of Total Cost Over the Lifetime describes the total costs for the construction and installation of the PV system. This includes the costs for solar panels, inverters, mounting systems, electrical installation, planning and other related expenses.
- The present Value of All Electricity Generated Over the Lifetime is the cumulative amount of energy generated by the PV system over its entire lifetime, measured in megawatt hours.

Subsequently, a detailed sensitivity analysis is conducted, exploring the relationship between the electricity purchase price and the selling price. Emphasis is placed on the development of NPV to quantify the impact of price fluctuations on overall profitability.

The scenario analysis broadens the perspective by individually varying various parameters. A profound examination of the effects on NPV and IRR enables the identification of risks and opportunities influencing the performance of the PV system.

Another dimension of the analysis concerns the integration of a battery storage system and its effects on NPV and IRR. This investigation addresses not only the technological aspects but also deepened into the financial implications, highlighting the significance of energy storage solutions for the economic viability of renewable energy projects.

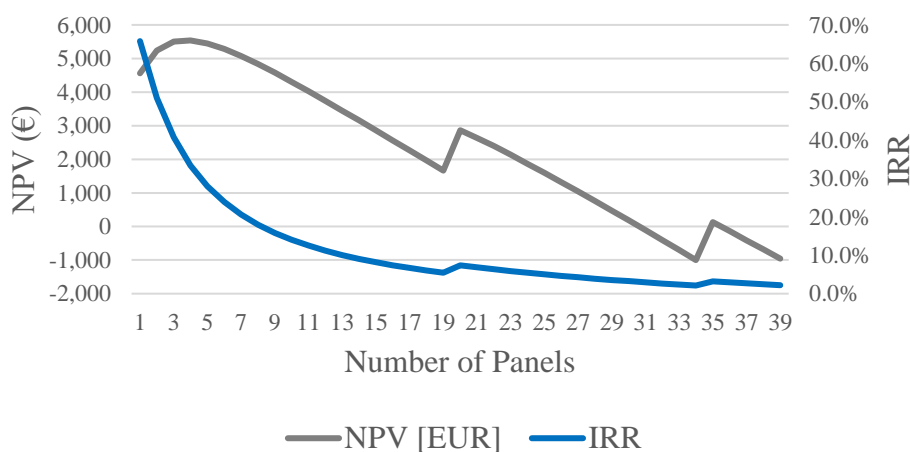
Finally, diverse financing methods are considered. The comparison of NPV and IRR under different financing structures allows for the determination of the optimal capital structure for the PV project, thereby maximizing long-term economic success. This comprehensive analysis

not only provides insights into the financial performance of a PV system but also contributes to strategic decision-making for optimizing economic viability.

3.1 Basic Analysis

To ascertain the optimal number of panels, it is imperative to establish the input database and identify the maximum NPV for panels ranging from 1 to 40, based on the previous analysis and assumptions.

Figure 2: NPV and IRR with government subsidies and 75% credit



The elevations in both NPV and Internal IRR observed for configurations involving 21 and 35 panels can be attributed to the availability of discounts from the PV supplier. These discounts contribute to a reduction in total costs, thereby augmenting the NPV.

The NPV demonstrates a temporary rise followed by a decline across its entire spectrum, except within the domains associated with discount. Simultaneously, the IRR manifests an asymptotic trend converging toward zero. It is noticeable that the NPV behaves asymmetrically to the IRR. By maximizing the NPV, five panels are the optimal with a value of 5,538.16€. It is recommended to install 5 solar panels. It is essential to underscore that the NPV is subject to the influence of several factors, and the maximization thereof is depend on a complex interaction

of several factors. An examination of alternative modes of financing unveils a comparable scenario.

Figure 3: NPV with government subsidies and 100% credit

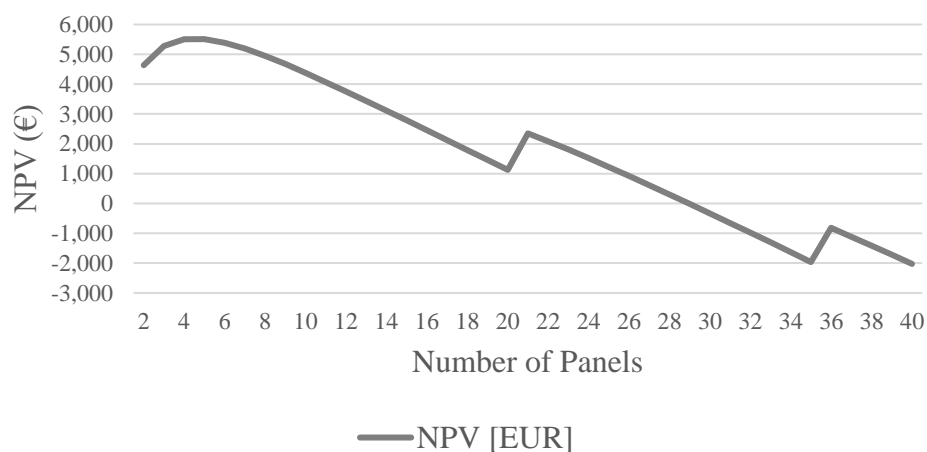


Figure 4: IRR and NPV with no government subsidies and 100% equity

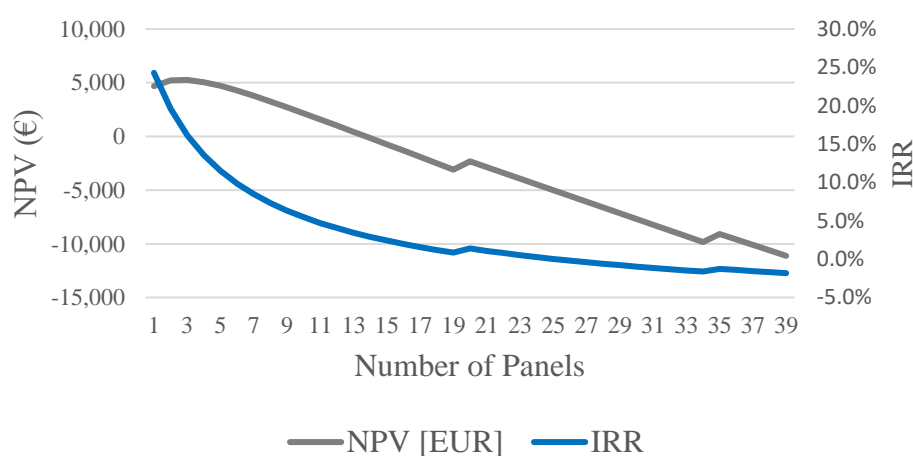


Table 7 describes the performance of alternative financing modalities and governmental subsidies concerning key financial metrics such as NPV, IRR, LCOE, and the Payback Period (PP).

Table 7: KPIs for different types of financing

Financing	NPV (€)	IRR (%)	LCOE (€/kWh)	PP (Years)
Government subsidies and 75% credit	5538.16	33.42	0.0895	3.18
Government subsidies and 100% credit	5509.64	n/a	0.0960	n/a
No government subsidies and 100% equity	5055.71	13.54	0.0700	7.13
No government subsidies and 75% credit	4227.07	25.00	0.0953	4.45

In instances of complete debt financing, where 100.00% of the investment amount is covered by a loan, the interpretation of the IRR is not possible since the cashflow is positive in the first year. This is attributable to the possibility of a negative NPV stemming from the higher interest costs of the loan in comparison to the anticipated returns on the investment. In the case of an initial investment of zero and exclusively positive cash flows in subsequent periods, a PP of zero results. In this scenario, the Payback method proves unsuitable as it lacks a temporal dimension for amortization and fails to draw conclusions regarding the profitability or actual value of the investment. The financing scenarios with government support display only slight variations in NPV, as the equity cost of capital at 3.05% closely aligns with the subsidized financing rate of 5.34%. The noteworthy difference arises predominantly with the remaining 25.00% due to stemming the contrast between 100.00% financing and 75.00% financing.

In comparison to the unsubsidized financing alternatives, the differential is considerably more pronounced. This variation can be attributed to differences in both financing structures and the revenues generated through the sale of electricity. The difference in interest rate difference is largely due to the ECB's interest rate policy in correlation with Germany's very good rating. Interest rates have risen by 4.50% from 0.00% to 4.50% in the last 17 months (Statista Research Department, 2023). The adjustments of interest rates by the ECB are reflected belatedly in the subsidies provided by KfW, resulting in significant disparities in financing.

The IRR reveal a notable trend, with the Base Case exhibiting by far the highest IRR, followed by the financing scenario with 75.00%. This observation underscores the positive impact of leverage on the IRR, indicating that the combination of factors results in the Base Case yielding the most favorable outcome.

3.2 Sensitivity Analysis

In the sensitivity analysis, the influence of various parameters on the NPV and IRR of the overall project is calculated. The starting point is the base case, which forms the basis of this work.

Parameters within this model are used to determine discount and premium rates. The results show the influence on the profitability of the overall project. The following describes the deviation of the NPV and IRR in absolute terms and the percentage deviation. All data is held constant, maintaining ceteris paribus conditions.

Table 8: Scenario Analysis electricity cost

Electricity cost (2024 forecast) EUR/kWh	Base case	Pessimistic case	Optimistic case
	0.35	0.37	0.33
NPV (€)	5,538.16	5,982.00	5,094.00
IRR (%)	33.42	36.21	31.12
Difference NPV (%)	-	8.02	(-8.02)
Difference IRR (%)	-	7.49	(-7.45)

In a scenario with a 5.00% deviation in electricity costs, the NPV behaves proportionally, while the IRR varies only slightly. This suggests a symmetrical relationship of the parameter. Increasing electricity costs positively impact the NPV because it is more attractive to substitute electricity at higher costs, thereby increasing savings.

Table 9: Scenario Analysis sell to grid

Electricity price for selling to grid (with subsidies) EUR/kWh	Base case	Pessimistic case	Optimistic case
	0.082	0.092	0.072
NPV (€)	5,538.16	5,754.00	5,322.00
IRR (%)	33.42	34.81	32.14
Difference NPV (%)	-	3.90	(-3.90)
Difference IRR (%)	-	4.07	(-4.04)

In the context of selling to the grid, there exists a symmetrical relationship in NPV and an approximately linear relationship in IRR. With a higher feed-in tariff, both the NPV and IRR of the PV system increase, as higher revenues can be generated.

Table 10: Scenario Analysis Inflation

Inflation cost of energy % per year	Base case	Pessimistic case	Optimistic case
	1.90	2.90	0.90
NPV (€)	5,538.16	6,381.76	4,786.16
IRR (%)	33.42	34.91	31.93
Difference NPV (%)	-	15.24	(-13.58)
Difference IRR (%)	-	4.55	(-4.67)

In the context of inflation, both the NPV and IRR exhibit asymmetry. This is attributed to the significant impact of inflation on discounting, resulting in an asymmetrical pattern of behavior. The weighting of cash flows further into the future is reduced in the calculation of NPV, leading to this asymmetric pattern. An increase in the inflation rate on the electricity price can result in a higher electricity price, as the subsidiary to the purchase price becomes greater.

Table 11: Scenario Analysis interest rate

Bank loan interest rate with gov. Subsidiaries	Base case	Pessimistic case	Optimistic case
% per year	5.34	6.31	4.33
NPV (€)	5,538.16	5,303.00	5,765.00
IRR (%)	33.42	31.60	35.20
Difference NPV (%)	-	(-4.23)	4.10
Difference IRR (%)	-	(-5.38)	5.27

In the analysis of financing costs, it can be observed that the NPV and IRR exhibit not precisely but approximately symmetrical behavior. This can be explained by the fact that debt capital costs of debt are discounted, and hence, later cash flows are less weighted. However, this difference is minimal as the NPV and IRR do not undergo substantial changes.

Table 12: Scenario Analysis maturity

Bank loan maturity	Base case	Pessimistic case	Optimistic case
Years	15.00	20.00	10.00
NPV (€)	5,538.16	5,390.00	5,692.00
IRR (%)	33.42	37.66	27.00
Difference NPV (%)	-	(-2.68)	2.78
Difference IRR (%)	-	12.67	(-19.22)

By extending the maturity period, the magnitude of cash flows in the near future increases, with these experiencing heightened weighting. This results in a minor adjustment to the NPV, while significantly influencing the IRR. The increase in the maturity period leads to a rise in cash flows in the foreseeable future, with these receiving heightened weighting. This gives rise to a slight modification in the NPV, while the IRR is notably affected.

Table 13: Scenario Analysis equity cost

Equity (household) cost of capital	Base case	Pessimistic case	Optimistic case
% per year	3.05	4.05	2.05
NPV (€)	5,538.16	4,869.43	6,315.09
IRR (%)	33.42	33.42	33.42
Difference NPV (%)	-	(-12.08)	14.04
Difference IRR (%)	-	0.00	0.00

In the case of the equity cost of capital, it is notable that the IRR remains unchanged. This is because the IRR pertains to the cost of debt capital, whereas in this context, it concerns equity costs. Consequently, a decrease in equity cost leads to an increase in NPV.

Table 14: Scenario Analysis loan amount

Loan amount	Base case	Pessimistic case	Optimistic case
Fraction of Total installation cost	0.75	1.00	0.50
NPV (€)	5,538.16	5,369.50	5,707.24
IRR (%)	33.42	n/a	22.10
Difference NPV (%)	-	(-3.06)	3.06
Difference IRR (%)	-	-	(-33.98)

When altering the financing amount, the IRR cannot be computed for a project entirely funded through debt. However, it is noteworthy that reducing the debt-equity ratio significantly decreases the IRR, while concurrently increasing the NPV. This phenomenon can be clarified by the concept of leverage.

Table 15: Scenario Analysis installation cost

Total installation cost	Base case	Pessimistic case	Optimistic case
€	3926.88	4319.56	3534.19
NPV (€)	5,538.16	5,026.87	6,050.21
IRR (%)	33.42	28.21	40.47
Difference NPV (%)	-	(-9.25)	9.25
Difference IRR (%)	-	(-16.48)	20.45

In the total installation costs, a symmetrical relationship is evident in the NPV, which is not predominant in the IRR. The reduction in costs leads to an increase in both the NPV and the IRR.

3.3 Battery Usage

The use of a battery has many different advantages. There are effects such as independence from the electricity supplier and reserves in the event of possible blackouts. In addition, a battery can also bring economic advantages. The purchase price for energy is higher than the selling price, energy can be used more cheaply. This occurs to a large extent which can lead to an increase in the NPV. In a survey in southern Germany, which is in the area of the planned project, respondents cited protection against rising electricity costs and their own contribution to the energy transition as the most important points (Jan Figgenger; David Haberschusz; Sebastian Zumühlen; Dirk Uwe Sauer, 2021). The outlook for 2023 in the area of new installations of integrated storage solutions was so great that there will be significant delays in delivery. There is a recognizable trend of developing around the topic of battery solutions. (Enkhardt, 2022). On the other hand, there are the costs of the battery. The following battery is assumed for the analysis of this initial situation:

Table 16: Battery characteristics

Characteristics of the battery	SMA 3.2	SMA 9.8	SMA 13.1	SMA 16.4
Usable energy capacity (kWh)	3.28	9.84	13.12	16.40
Nominal voltage (V)	96.00	288.00	384.00	480.00
Efficiency (%)	94.50	94.50	94.50	94.50
Usable efficiency (kWh)	3.01	9.25	12.34	15.45

Efficiency is considered when analyzing the use of the battery. This is calculated using the following formula:

$$Usable\ efficiency = Energy\ capacity \times Efficiency$$

All energy losses are factored through this determination. It is assumed that no further losses occur, and that the battery has this efficiency on average over the entire period.

Taking these parameters into account, an analysis was carried out for the base case. This is represented by financing 75% debt and 25% equity including government subsidies. The following results in terms of NPV and IRR are achieved by using the battery:

Table 17: Battery KPIs

Battery scenario	NPV (€)	IRR (%)	Self-consumption (%)
Base case without battery	5,538.16	33.42	41.61
SMA Home Storage 3.2	2,995.13	7.36	65.20
SMA Home Storage 9.8	3,980.31	7.36	71.69
SMA Home Storage 16.4	(-1,514.82)	1.61	85.77

By analyzing the use of a battery apparently the additional installation cannot achieve a higher NPV or IRR. These results are in line with leading research (Jan Figgenger; David Haberschusz; Sebastian Zumühlen; Dirk Uwe Sauer, 2021). Nevertheless, this study shows that working with an integrated storage solution has a maximum satisfaction rate of 71.69%. When comparing the batteries, the optimal size would be the SMA Home Storage 9.8 with a storage volume of 9.23 kWh. This results on the one hand from the ratio between the number of kWh of the battery and the costs and also from the subsidiarity of the purchased electricity. The use of a battery increases the proportion of self-used energy. This value increases successively with the installation of the battery as well as with the increase in size of the battery. When using the largest battery examined, the share of own use is 85.77%, while the base case has an own use of 41.61%. At the same time, there is less participation in revenues from the sale of surplus electricity. The two variables of revenue from the sale of electricity and the purchase price for electricity are therefore the two most important variables for this analysis.

3.4 Scenario Analysis

In the following the impact of various KPIs in different financing scenarios is explained. This chapter provides a detailed examination of how highly sensitive KPIs react to changes in two parameters at the same time. The analysis delves into the relationship between the electricity purchase price and the electricity selling price to the grid. For non-government supported

projects, a comparison is conducted between the electricity purchase price and the useful lifetime, as discrepancies in non-government supported projects lack substantive significance. Furthermore, the examination includes an assessment of the project's dynamics with the incorporation of a battery in the base case.

Without battery and with government subsidies: It can generally be seen that a higher electricity price has a positive effect on the NPV, as do rising sales prices, which was also shown in section 3.2. The NPV fluctuates in the case of 75% financing from 1,959€ to an NPV of 9,089€. In the case of 100% financing, the range is 1,931€ and 9,060€.

Table 18: Sensitivity with government subsidies and 75% credit

		Electricity buy price in €/kWh					
		€	0.31696	0.35658	0.3962	0.43582	0.47544
Electricity price for selling to grid in €/kWh	0	1,959	2,876	3,765	4,654	5,542	
	0.041	2,874	3,763	4,652	5,540	6,429	
	0.082	3,761	4,649	5,538	6,427	7,316	
	0.123	4,647	5,536	6,425	7,313	8,202	
	0.164	5,534	6,423	7,311	8,200	9,089	

Table 19: Sensitivity with government subsidies and 100% credit

		Electricity buy price in €/kWh					
		€	0.31696	0.35658	0.3962	0.43582	0.47544
Electricity price for selling to grid in €/kWh	0	1,931	2,848	3,736	4,625	5,514	
	0.041	2,846	3,734	4,623	5,512	6,400	
	0.082	3,732	4,621	4,621	6,398	7,287	
	0.123	4,619	5,508	6,396	7,285	8,174	
	0.164	5,505	6,394	7,283	8,172	9,060	

Without battery and without government subsidies: Without state support and with 100% equity financing, the NPV fluctuates between (-1,730)€ and 10,060€. With a 75% credit ratio, the NPV fluctuates between (-422)€ and (-8,395)€ (Appendix F and G).

With battery and without government subsidies: When using a battery, the same metrics are considered as before. Here, the SMA Home Storage 9.8 performs best by far and does not have a negative NPV. It already had the highest NPV in Chapter 3.3.

Table 20: Sensitivity with battery and SMA Home Storage 9.8

		Electricity buy price in €/kWh				
Electricity price for selling to grid in €/kWh	€	0.31696	0.35658	0.3962	0.43582	0.47544
	0	367	1,947	3,478	5,009	6,541
	0.041	667	2,198	3,729	5,261	6,792
	0.082	918	2,449	3,980	5,512	7,043
	0.123	1,169	2,700	4,231	5,763	7,294
	0.164	1,420	2,951	4,482	6,014	7,545

The other analyses show significantly greater fluctuations (Appendix H and Appendix I).

3.5 Comparison with other results in Germany

The underlying chapter focuses on a comparative analysis of the viability of PV systems in the benchmark case of 75% debt financing with subsidies across the cities of Aalen, Frankfurt, and Munich. To establish a consistent basis for the financial model, certain input parameters are assumed to be uniform due to their applicability across Germany. Table 21 summarizes the equal assumptions.

Table 21: Assumptions Germany 1

Parameter	Frankfurt	Munich	Aalen
Long Term Inflation Rate		1.9%	
Equity Cost		3.1%	
System Losses and Degradation with Age		14.0%	
Electricity Selling Price with Subsidies		0.082 (€/kWh)	
Electricity Selling Price without Subsidies		0.036 (€/kWh)	
Debt Ratio		75.0%	

The differences in input parameters arise from valuation differences, coupled with the variability of local conditions. The regions not only diverge in terms of their geographic features such as solar irradiance but also in terms of local subsidies, electricity buy costs and electricity consumption. The different results are further affected by deviating model assumptions such as the PV panels installed, the lifetime of the system, maintenance cost, and bank loan maturity. The table below shows the differences in each region affecting the profitability of the PV system.

Table 22: Assumptions Germany 2

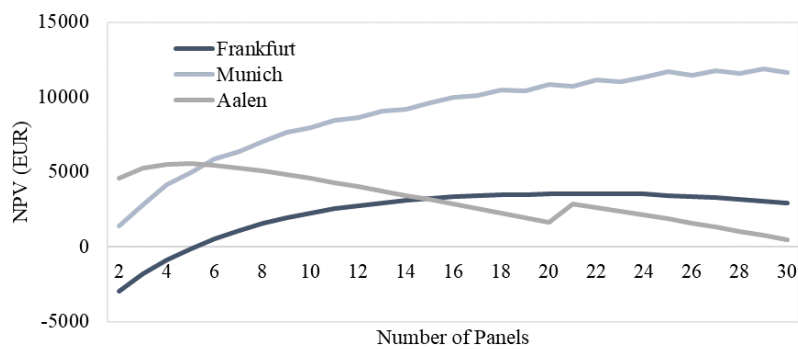
Parameter	Frankfurt	Munich	Aalen
PV System Lifetime (years)	25	25	20
Maintenance Cost	2%	26€/kWp	1%
Bank Loan Maturity (years)	10	5	15
Electricity Cost (EUR/kWh)	0.38	0.34	0.35
Bank loan Interest Rate with Gov. Subsidies	3.35%	5.14%	5.34%
Consumption (kWh)	4,500	4,500	3,478
Peak Power of 1 Panel (W)	425	435	435
Price per Wp with Subsidy (EUR)	1.89	1.26	1.81
Annual Generation (kWh) per Installed kWp	1,072.95	1,135.9	1,337
Total Price for 15 Panels with Subsidies (EUR)	12,050.25	8,206	11,781
Generation for 15 Panels (kWh)	6,840	7,412	8,722

The resulting differences in the financial metrics for a size of 15 panels are shown in Table 23.

Table 23: Results

KPI's	Frankfurt	Munich	Aalen
NPV (€)	3,234	9,646	3,155
IRR (%)	6.48%	14.10%	9.07%
Payback period (years)	15.7	9.18	15.5
LCOE (€/kWh)	0.1176	0.0752	0.0895

The results indicate a strong influence of local subsidies. While initial investment subsidies lead to a significantly higher NPV in the case of Munich, Aalen shows the least favorable conditions, as only governmental subsidies in the form of guaranteed feed-in tariffs apply. Frankfurt's interest rate subsidy shows some improvement of the NPV but not as effective as the initial investment subsidy. Other model-based assumptions such as differences in the expected lifetime of the PV system, maintenance cost and bank loan maturity contribute further to these differences. Figure 5 depicts how the NPV behaves for panel quantities ranging from 2 to 30. The graph illustrates that the installation of larger numbers of panels becomes favorable for Munich and Frankfurt while Aalen reaches its peak already at a system size of five panels.

Figure 5: NPV Comparison

4 Limitations

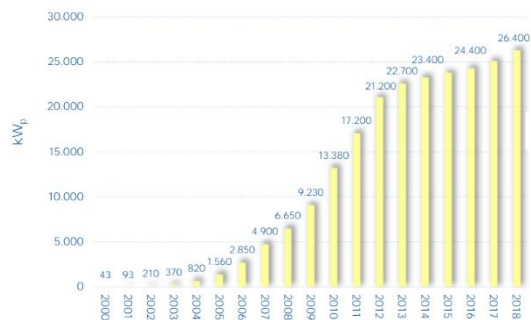
The limitation of these analyses lies in the simplification of the real complexity of the system under investigation. By focusing on the comparability of base cases, there is a risk that nuanced interactions between variables and subtle dynamics in the system are neglected. In addition, unobserved external influences or emergent phenomena may not be considered, which could lead to a possible underestimation of the complexity of the context under consideration. Furthermore, the limitation to basic scenarios can lead to specific extreme cases or unusual developments being disregarded, which may limit the generalizability of the results. To overcome this limitation, it is necessary to understand the analysis as a starting point and to consider additional details and nuances as part of the further analysis to obtain a more comprehensive picture of the system. Unpredictable external influences, such as political changes or unexpected technological breakthroughs, could have a significant impact on the results. These factors are difficult to predict and may affect the transferability of the results.

5 Conclusion

It can be asserted that it is advisable to install a solar system for private use in Aalen. The optimal quantity in this context is five panels, resulting in a NPV of 5,538.16€, inclusive of government incentives. Despite the adoption of conservative parameters and consideration of numerous scenarios, the favorable aspects outweigh the challenges from both environmental and economic perspectives.

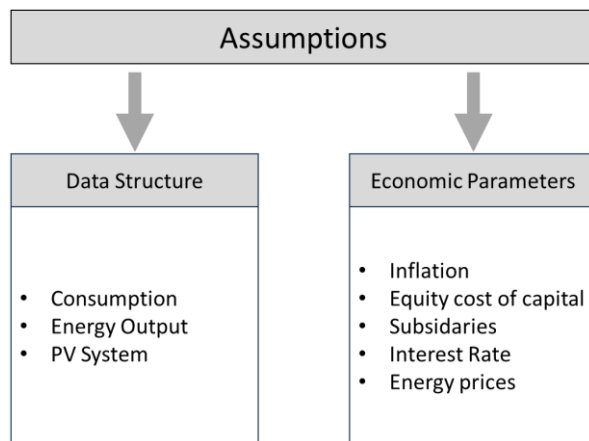
6 Appendix

Appendix A: Development of installed PV power in the city of Aalen



Source: (Stadtwerke Aalen, 2018)

Appendix B: Structure of Assumptions

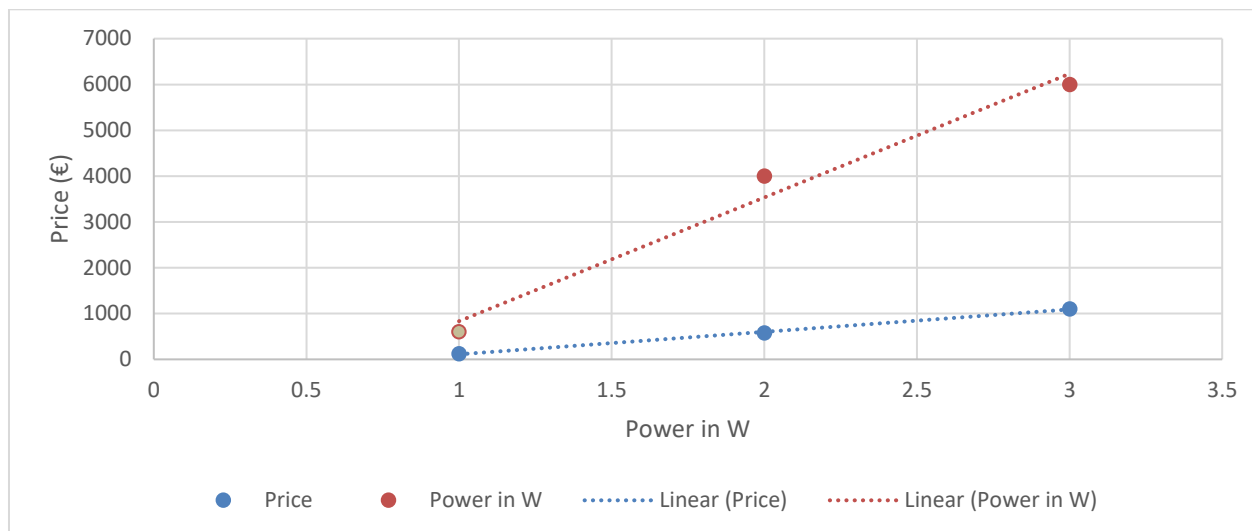


Source: Own illustration

Appendix C: Sample household consumptions in Aalen

City	Street	People in household	Consumption Q1 (kWh)	Consumption Q2 (kWh)	Consumption Q3 (kWh)	Consumption Q4 (kWh)
Aalen	Im Heimatwinkel	3	5827.54	2646.23	1814.02	3630.22
Aalen	Elsterweg	2	605.89	1830.56	1367.61	2825.07
Aalen	Auf der Heide	6	6461.24	4575.52	3240.38	4635.20
Aalen	Obere Wöhrstr.	4	5326.33	1332.34	4544.32	5363.27
Aalen	Fuchsweg	4	5959.44	3162.93	188.71	5932.50
Aalen	Ludwigstr.	4	1941.00	3882.40	511.82	5567.48
Aalen	Bischof-Str.	4	5782.53	4094.75	5952.94	1732.38
Aalen	Nachtigallweg	4	4195.42	1734.48	1286.36	5727.08
Aalen	Bahnhofstr.	4	2468.40	2043.59	2946.87	3435.61
Aalen	Kastanienweg	3	2656.22	1288.62	1216.40	2448.56

Appendix D: Relationship between inverter power and cost



Appendix E: Conditions and Ratings Kreditanstalt für Wiederaufbau

Rating	A	B	C	D	E	F	G	H	I
Debit interest rate (%)	4.64	5.04	5.34	5.84	6.44	7.14	7.64	8,74	11.04
Effective interest rate(%)	4.72	5.14	5.45	5.97	6.60	7.34	7.87	9.04	11.51

Source: (Kreditanstalt für Wiederaufbau, Konditionsübersicht für Endkreditnehmer, 2023)

Appendix F: Sensitivity with no government subsidies and 100% equity

		Electricity buy price in €/kWh					
Electricity price for selling to grid in €/kWh		€	0.31696	0.35658	0.3962	0.43582	0.47544
	0		(-1,730)	(-1,488)	(-1,247)	(-1,006)	(-764)
	0.041		325	794	1,264	1,733	2,202
	0.082		2,247	2,932	3,617	4,302	4,987
	0.123		4,048	4,936	5,825	6,714	7,603
	0.164		5,735	6,816	7,898	8,979	10,060

Appendix G: Sensitivity with no government subsidies and 75% credit

		Electricity buy price in €/kWh				
Electricity price for selling to grid in €/kWh	€	0.31696	0.35658	0.3962	0.43582	0.47544
	0	(-1,730)	(-1,488)	(-1,247)	(-1,006)	(-764)
	0.041	325	794	1,264	1,733	2,202
	0.082	2,247	2,932	3,617	4,302	4,987
	0.123	4,048	4,936	5,825	6,714	7,603
	0.164	5,735	6,816	7,898	8,979	10,060

Appendix H: Sensitivity with battery and SMA Home Storage 3.2

		Electricity buy price in €/kWh				
Electricity price for selling to grid in €/kWh	€	0.31696	0.35658	0.3962	0.43582	0.47544
	0	(-611)	826	2,219	3,612	5,004
	0.041	(-179)	1,214	2,607	4,000	5,393
	0.082	210	1,602	2,995	4,388	5,781
	0.123	598	1,990	3,383	4,776	6,169
	0.164	986	2,379	3,771	5,164	6,557

Appendix I: Sensitivity with battery and SMA Home Storage 16.4

		Electricity buy price in €/kWh				
Electricity price for selling to grid in €/kWh	€	0.31696	0.35658	0.3962	0.43582	0.47544
	0	(-4,699)	(-3,337)	(-2,016)	(-695)	625
	0.041	(-4,406)	(-3,086)	(-1,765)	(-444)	876
	0.082	(-4,155)	(-2,834)	(-1,514)	(-193)	1,128
	0.123	(-3,904)	(-2,583)	(-1,263)	58	1,379
	0.164	(-3,653)	(-2,332)	(-1,012)	309	1,630

Appendix J: Legal disclaimer

I hereby declare under oath that the submitted Master's Thesis has been written solely by me without any third-party assistance, information other than provided sources or aids have not been used and those used have been fully documented. Sources for literal, paraphrased and cited quotes have been accurately credited.

This work used infrastructure and resources funded by Fundação para a Ciência e a Tecnologia (UID/ECO/00124/2013, UID/ECO/00124/2019 and Social Sciences DataLab, Project 22209), POR Lisboa (LISBOA-01-0145-FEDER-007722 and Social Sciences DataLab, Project 22209) and POR Norte (Social Sciences DataLab, Project 22209).

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