

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 Munich

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20/12/2023

Summary of rooftop solar analysis

Location: Munich, Germany

Date of analysis: Dec/2023

Recommendation: Install 29 solar panels (56 m²), for a net present value of 11,871.40 euros, with a payback of 9.75 years.

Main economic results

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
Gov. subsidies and 75% bank debt	11,871.4	9.75	12.49	0.0641
Gov. subsidies and 100% supplier's credit	7,671.6	8.37	26.52	0.0778
Gov. subsidies and 100% equity	12,414.9	8.76	10.60	0.0623
No gov. subsidies and 100% equity	406.7	17.7	3.24	0.0797

(All rows are for the same number of panels)

Additional results

A system of 28 panels, together with a battery of 7.7 kWh, requires an initial investment of equity investment of 4,246 euros, but provides an NPV of 16,334.3 euros, with a payback of 11.23 years.

Main inputs and assumptions

Household and Economics

Electricity Consumption	4,500	kWh/year	Inflation	1.9%	per year
Electricity price – buy	0.34	EUR/kWh	Bank loan interest rate	5.14%	per year
Electricity price – sell	0.08	EUR/kWh	Bank loan maturity	5	years
			Equity cost of capital	3.05%	per year

PV panels

Peak power	435	W/panel	System losses	13.5%	of output
Panel area	1.94	m ² /panel	Degradation with age	0.5%	per year
Useful life	25	Years	Maintenance costs	10.76	EUR/year per panel
			Total cost of optimal installation size (without subsidies)	17,700	EUR
			Total cost of optimal installation size (after subsidies)	12,390	EUR

Government subsidies

Attractive credit terms from KfW (German state-owned development bank)

Fixed feed-in tariff for 20 years by the German state, for example 0.081 EUR/kWh for a nominal output of up to 10kWh and partial utilisation of the electricity for own use

Subsidy towards the investment costs by the City of Munich: 1,500 EUR basic subsidy, further 282 EUR per kWp output of the system and additional 47 EUR per kWp output of the system if the modules installed are glass-glass modules

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1 Introduction

“You can actually power the entire United States with a 100 miles by 100 miles of solar...we have a giant fusion reactor in the sky that is the sun” With this statement, Elon Musk, a pioneer of electromobility, draws attention to the enormous potential of solar energy during a podcast end of October 2023 (Musk 2023). While Elon Musk's statement may seem exaggerated and simplistic at first glance, there is a grain of truth in it. Our planet is currently struggling with pollution from conventional energy sources, even though the sun represents an almost limitless, and free clean energy reservoir. However, the practicality of constructing a 100 miles by 100 miles solar array is not as straightforward as Musk suggests.

This scientific paper aims to recognise a realistic treatment of photovoltaic (PV) systems as a crucial part of tackling the energy crisis. It explores how every household can actively contribute to this paradigm shift in the energy sector by investing in PV systems and emphasising the role of each individual in promoting a sustainable energy future.

1.1 Research Question and Munich as an Analysed Location

This master's thesis is part of a broader research project entitled "Economic efficiency of solar roofs", which is being supervised by Prof. João Pedro Pereira. In this research project, data is collected, analysed, and then published on the website www.pvpayback.com. The aim is to create a database that makes it possible to determine and compare the conditions and economic value of installing rooftop solar systems for standard private households in different locations around the world. As part of the project, this master's thesis answers the question of the economic viability and the exact implementation of such a system in the city of Munich in Germany.

Munich is a particularly interesting location, not only because it is one of the largest cities in Germany with over 1.5 million inhabitants, but also because of its plan to become climate-

neutral by 2035, whereby solar energy is intended to play a major role. The city, which already plans to have 15 megawatt peak (MWp) of solar energy available by the end of 2023, plans to have over 60MWp of photovoltaic capacity by the end of 2028 at the latest (Stadt München 2023). In order to achieve this, Munich also wants to rely on the help of private households, which is why it offers extensive subsidies for private PV systems, a more detailed explanation of which can be found in section 2.7 Government Subsidies.

1.2 Methodology and Structure

The master's thesis is structured in two parts. In the first part, all data and assumptions are presented, and their derivation is justified, followed by the analysis in the subsequent section. The analysis pursues the approach of calculating and discounting the cash flows of the PV system over its lifecycle. In order to subsequently assess this output and make it comparable with others, the following financial ratios are used for the subsequent assessment: Net Present Value (NPV), Payback Period, Internal Rate of Return (IRR) and Levelized Cost of Energy (LCOE). While NPV, payback period and IRR are traditional financial indicators, LCOE is a financial indicator mainly used in the energy industry to calculate the life cycle costs of different power generation. It gives a minimum electricity price in €/Kilowatt hour (kWh) that must be achieved for a particular generation source to break even (Raikar und Adamson 2020). The overall aim of the project is to provide evidence that can be applied to as many different real scenarios as possible, four different financing cases are used in the analysis:

Case 1: Government subsidies and 75% bank debt	Case 2: Government subsidies and 100% equity
Case 3: Government subsidies and 100% supplier's credit	Case 4: No government subsidies and 100% equity

Table 1: Overview of analysed financing cases, Source: Own visualisation

Following the analysis, additional analyses are carried out, such as the optional installation of a battery that can temporarily store excess energy or sensitivity and scenario analyses to question critical inputs.

2 Data and Assumptions

In the following chapter, data and assumptions are presented. It should be emphasised again here that the data was selected in such a way that a recommendation can be given that is as accurate as possible and at the same time is relevant to the largest possible number of individuals.

2.1 Model and Household Assumptions

The model and household assumptions were selected for an average sample household. It was assumed that the household consists of a family of four, where both parents work during the day and the children go to school, and that they live in a free-standing house of a size suitable for a family of four. For illustration purposes, the area around Osterwaldstrasse in Munich was chosen, a suburban neighbourhood with classic detached houses in a central Munich location. Another household assumption is the maximum available surface area for a PV. For this purpose, a study was examined that was carried out in co-operation between the Technical University of Munich and the industrial company Siemens. The aim of this study was to determine the achievable photovoltaic output on roof surfaces within the geographical boundaries of Germany. The study analysed various settlement categories in Bavaria, the federal state in which Munich is located, and then determined an average area for these categories. One of these categories is the suburb in which also the residence of our model family with their house in Munich is located. Here the study calculates an average floor area of 116m². Next, a formula is used to take into account factors such as a roof pitch of 35° as well

as factors such as a reduction factor for roof structures such as a chimney or windows. Applying the final factor of 0.488 to an area of 116m² results in an average maximum possible area for a PV system of 56.61m² (Lödl, et al. 2010). Given the inherent approximations in this study arising from certain assumed variables, a modest rounding adjustment has been introduced, resulting in the utilization of the rounded value of 60m² in the present work. This decision is motivated by the intention to adopt a practical and rounded figure that takes into account the uncertainties inherent in the study, whereby a slightly larger flat area is preferable to a potential underestimate. This idea is also supported by the general framework of the project, where the size limitations of the roof are not given the greatest priority (Pereira 2023).

The construction and initial operation of the plant is scheduled for December 2023, with the start of the model falling on 1 January 2024.

2.2 Energy Consumption

The energy consumption section defines two important components: the total amount consumed by an average household per year and the hourly distribution over the whole year also called load profile.

For the total amount consumed by an average household per year, five samples were taken from households in Munich that are as close as possible to the project's model household. In addition, data was taken from Stromspiegel.de, a website supported by the Federal Ministry of Economics and Climate Protection Germany, and from Stadtwerke München, the largest local utility company in the city of Munich. Both have also published figures for sample households with four people (Weißbach 2022) (SWM 2023). As can be seen in Table 2, the values recorded are between 4,000 and 5,000kWh per year, with slight upward and downward outliers. The average of the values is 4,501kWh. For the model, a value of 4,500kWh is used. This appears to be a good approximation, especially as it lies exactly between the two assumptions of the

Federal Ministry and the public energy supplier.

Household description	Household 1	Household 2	Household 3	Household 4	Household 5	Electricity survey Germany	Information public utility company Munich
	4 Persons (House)	4 Persons (House) One parent staying at home	4 Persons (House)	4 Persons (House) Both parents working fulltime from home	4 Persons (Apartment)	4 Persons (House)	4 Persons (House)
Electric boiler	No	No	No	No	No	No	n/a
Electric heating	No	No	No	No	No	n/a	n/a
Total annual consumption	4,658 kWh	5,053 kWh	3,954 kWh	5,200 kWh	3,644 kWh	4,000 kWh	5,000 kWh
Price per kWh	0.37 €/kWh	0.31 €/kWh	0.26 €/kWh	0.30 €/kWh	0.41 €/kWh	n/a	n/a

Table 2: Overview of sample electricity consumption and costs in Munich for a standard family, Data source: Private data (Weißbach 2022) (SWM 2023)

To analyse the distribution of electricity consumption throughout the year, a load profile was generated using the synPRO tool developed by the Fraunhofer Institute. This tool incorporates precise parameters including household size, location, and types of electrical devices in use. A bottom-up method is used to provide a specific electricity consumption breakdown for the model household. This is achieved by leveraging relevant consumption data gathered on specific days of the week, coupled with corresponding weather conditions at the given location and other parameters (ISE 2023). The load profile creates the electricity consumption for the year 2023 on an hourly basis, which was then applied to our electricity consumption of 4,500kWh as a proportion; this will form the basis for the years in the future.

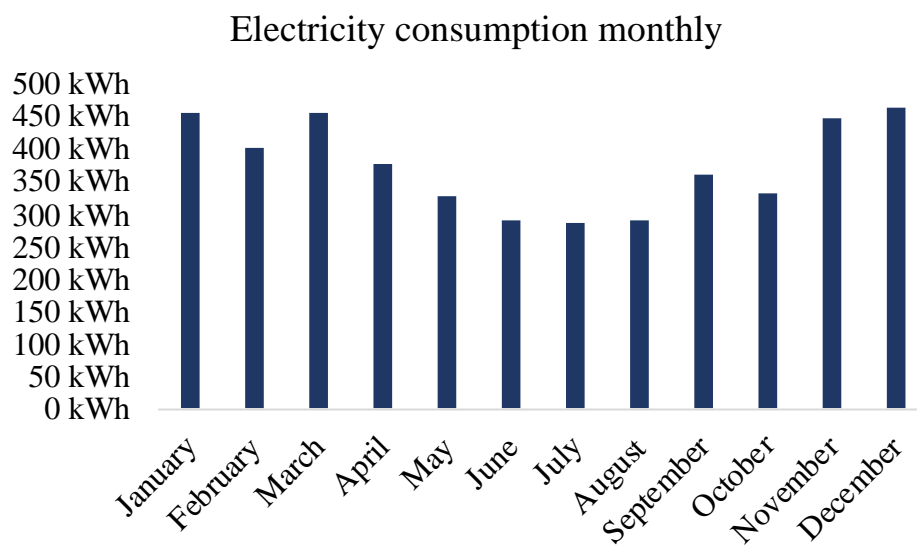


Figure 1: Overview electricity consumption monthly, Source: Own visualisation, Data source: (ISE 2023)

Figure 1 shows the monthly consumption of the load profile of our model family, particularly in the classic holiday months of June, July and August, consumption is significantly lower than in the rest of the year.

2.3 Electricity Prices

The following section analysis electricity prices, distinguishing between the price a household pays for the electricity when it buys from the supplier and the price it receives for electricity it produces and sells back.

To determine the electricity prices that a household pays, the current electricity bills of 5 different households in Munich that come close to the model household are analysed. It can be seen in Table 2 that the electricity costs vary greatly, ranging from 0.26€/kWh to 0.41€/kWh. A more in-depth analysis of electricity contracts reveals that major differences stem from factors such as the provider, contract term, whether the electricity is generated from renewable sources or not, and contracts with fixed electricity prices over a specific period of time. As the prices of the sample fluctuate greatly, the average value of the last 5 half-years of the average electricity price for private households with an energy consumption of between 2,500 and 5,000kWh in Germany from the Federal Statistical Office was also observed, which is slightly higher than the average of our samples. A more conservative approach is applied by using the German average of 0.34€/kWh (S. Bundesamt 2023).

For the electricity sold by the household, two different rates were applied. The first is the price the household receives when it sells the electricity on the open market. The other is the price supported by government subsidies. For the price on the open market, the last 10 years annual average market value for electricity from solar radiation energy in Germany was taken and used to form the average. As the values increase extremely from 2021 onwards and reach 6 times the average value of the other years in 2022, were 2021 and 2022 excluded. It is assumed that the high values in 2021 and 2022 are related to extraordinary developments that are

assumed to be temporary. Therefore, a conservative approach was chosen and 2021 and 2022 was excluded, resulting in an average sales price of 0.0361€/kWh on the free market (50Hertz Transmission GmbH 2023).

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
in €/kWh	0.04	0.04	0.03	0.03	0.03	0.03	0.05	0.04	0.03	0.09	0.21

Table 3: Average of the annual mean market value for electricity from solar radiation energy between 2011 and 2021, Source: Own visualisation, Data source: (50Hertz Transmission GmbH 2023)

In order to make investing in PV systems for private households more attractive, the German government has introduced a new fixed feed-in tariff in 2022 as part of the Erneuerbare Energie Gesetz (Renewable Energy Sources Act) (EEG). The price of the feed-in tariff is fixed for 20 years from the date on which the system is commissioned (Bundesnetzagentur 2023). To determine the price, several factors were introduced. Firstly, a distinction is made between how much electricity a system can produce and secondly, whether only the surplus electricity or all the electricity is sold.

Selling excess electricity			
Nominal power photovoltaic system	Up to 10kWp	Up to 40kWp	Up to 100kWp
Fixed feed-in tariffs	0.082 €/kWh	0.071 €/kWh	0.058 €/kWh
Selling all electricity			
Nominal power photovoltaic system	Up to 10kWp	Up to 40kWp	Up to 100kWp
Fixed feed-in tariffs	0.13 €/kWh	0.11 €/kWh	0.11 €/kWh

Table 4: Fixed feed-in tariffs for PV systems with initial operation between 01.08.2022 to 01.01.2024 under the EEG, Source: Own visualisation, Data source: (Bundesnetzagentur 2023)

It should also be noted that the tariffs are cumulative, i.e. the price of e.g. 0.082€/kWh applies to the first 10 Kilowatt peak (kWp) of the PV system and the corresponding tariffs for the following parts of the PV system. In the case of the model household, it is assumed that the household first tries to use the electricity itself before selling it, i.e. the case of selling excess electricity.

2.4 Solar Irradiance

Solar irradiation data is the foundation of every PV model and is given in W/m^2 measured in hourly sections. For the model, data was taken from the Photovoltaic Geographical Information System (PVGIS) project. This project was launched by the European Commission and provides data for solar irradiance at most places on earth. Not only can the solar radiation per m^2 be measured, but the irradiance received by a solar panel can also be simulated. In our case, the hourly data for the years 2015 to 2020 was analysed for a solar plate at the exemplary location at the Osterwaldstraße in Munich. The average of the 5 years was then taken to arrive at a precise estimate. For the solar module, the crystalline silicon technology was chosen. In addition, a fixed installation with an optimum angle of 39° and an optimum azimuth of -3° was used. In addition, 14% of the actual power has already been deducted, this is split into 13.5% for all types of system loss, which can be due to dirt on the panel or the loss through power cables on the PV system, for example. The remaining 0.5% includes the degradation with age of the solar system (European Commission 2020). In Appendix A it can be seen that Munich is almost in the region with the highest solar radiation in Germany. For our model, the annual solar radiation per m^2 is 1,136kWh, which is also close to the range displayed in Appendix A. Figure 2 shows the hourly progression of our data on a monthly basis. It can be seen that solar radiation in Munich fluctuates greatly with the seasons.

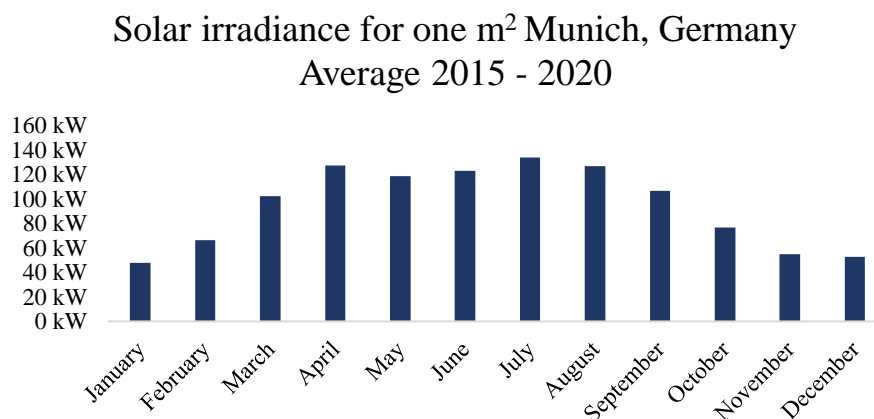


Figure 2: Overview solar irradiance in Munich, Germany Average 2015 - 2020, Source: Own visualisation, Data source: (European Commission 2020)

2.5 Solar Panels

The Solar Panels section defines three different aspects. The selection of suppliers and the basic selection of the PV system as well as the decision on its assumed service life and the annual maintenance costs. The exact selection of which provider is recommended and how many is done in section 3.2 Economic Analysis.

For the selection of solar panels in the model, it was decided to only look at offers where all services and costs are included. It is assumed that the model family does not have the technical background to buy the various parts and install them themselves and that an offer from a company that supplies a complete package is the most likely option here. For this, 252 actual offers were obtained from 4 different suppliers. In terms of PV system technology, all panels are monocrystalline solar modules. They differ mainly in terms of output and whether they are glass-glass modules. Glass-glass modules are modules that have a glass surface on the back as well as on the front and do not have an aluminium frame, as illustrated in Appendix B. Studies have shown that this technology is not only more efficient and durable than conventional solar modules with a polymer film on the back, but is also more sustainable for the environment due to the lack of an aluminium frame, even if they are slightly more expensive to purchase (Bächle and Dr Neuhaus 2021) (Sinha, et al. 2021).

The offers received therefore differ in terms of the type of panels, the number of panels and whether a battery is included; an overview of the offers received can be found in Table 5.

Supplier	Solar Modul	Size in m ²	Output per panel(s)	Price per panel (for an offer of 20 panels)	Price per per kWh (for an offer of 20 panels)	Glas-Glas-Module	Offers for the following number of panels:	Offers also obtained for with battery option
Klar Solar	Budget	2.0 m ²	430 Wp	755.28 €	1,756.47 €	No	1-30	No
	Design	2.0 m ²	435 Wp	749.50 €	1,722.99 €	No	1-30	Yes
	Langlebigkeit	2.0 m ²	440 Wp	755.49 €	1,717.02 €	Yes	1-30	Yes
SOLSTRÅLE	Base modul	2.0 m ²	410 Wp	716.61 €	1,747.83 €	No	8, 18, 28	Yes
	Essential	2.0 m ²	435 Wp	691.50 €	1,589.66 €	Yes	1-30	Yes
SVEA Solar	Design	1.9 m ²	405 Wp	691.50 €	1,707.41 €	Yes	No offers (too expensive)	No
	Pro	1.8 m ²	380 Wp	892.00 €	2,347.37 €	Yes	No offers (too expensive)	No
Zolar	Base modul	2.0 m ²	425 Wp	724.55 €	1,704.82 €	No	10, 20, 30	Yes

Table 5: Overview of offers obtained from PV system suppliers, Source: Source: (Klarsolar 2023) (Ikea 2023) (Solar 2023) (Zolar 2023)

Some parameters such as the best choice of supplier for the respective solar modules or the right inverters were decided directly in favour of the offer with the best price-performance ratio when the offers were obtained.

To evaluate the lifetimes of the solar modules and thus the time frame of the model, the lifetimes stated by the respective suppliers were analysed. However, a critical review of these figures was deemed necessary, as the data provided by the suppliers may be distorted. For this purpose, a study by the Fraunhofer Institute was used, which provides the latest findings on PV systems. According to the Institute's findings, a service life of 25-30 years is estimated (Wirth 2023). Therefore, a conservative assumption of a 25-year service life is made for the base case in the model.

To calculate the amount of operating costs, two calculation methods were considered. In the first method, the operating costs are calculated as a percentage of the investment sum. For example, the insurance company Helvetia recommends a percentage of 1-2% of the net investment sum in a detailed cost overview of photovoltaic systems (Helvetia 2023). The Fraunhofer Institute, which conducted a detailed study on the electricity generation costs of renewable energy in 2021, takes a different approach. The amount of operating costs was derived from the number of kilowatt peaks. For PV systems on rooftops with an output of less than 30kWp, the Fraunhofer Institute calculated 26€/kWp (Kost, et al. 2021). Since the amount of the investment can also be strongly influenced by the amount of the supplier's mark-up, this thesis follows the approach of the Fraunhofer Institute as this is considered more reality based.

2.6 Financing

Depending on the case, the financing in our model consists of a mix of equity and debt or just one of the two. For the equity, a discount interest rate of 3.05% as of 15.11.2023 was applied in the subsequent analysis (Chatham Financial 2023). For debt financing, the first step is to

obtain various conditions from banks for the financing of solar systems. As can be seen in Table 6 financing through the KFW Bank, which is subsidised by the state, is the most favourable with an interest rate starting at 4.72%. A rating of B was assumed for the corresponding credit rating, whereby it was considered that our example family lives in a detached house and two people work full-time, which generally speaks in favour of a secure credit rating. The duration of the loan was assumed to be 5 years.

For the supplier credit, which is to be moderated in Case 2, the offer from Klar Solar is taken as an example as they had a financing offer.

Bank	Credit line	Loan maturity	Effective annual interest rate
KFW	Up to 50,000€	5 Year(s)	4.72% to 11.51%
SWK Bank	2,500€ to 100,000€	5 Year(s)	5.29% to 8.29%
GLS Bank	10,000€ to 30,000€	10 Year(s)	5.01% to n/a
BB Bank	10,000€ to 75,000€	5 Year(s)	5.46% to n/a

Table 6: Overview of loans for the financing of PV systems Source: Source: (Bankengruppe 2023) (Swk Bank 2023) (GLS Bank 2023) (BB Bank 2023)

2.7 Government Subsidies

When examining state subsidies in Germany, it becomes evident that there exist diverse subsidy models for PV systems, impacting either the entire state or specific regions. In the context of the sample household in Munich, three distinct subsidies warrant consideration. The first pertains to the EGG, as previously discussed in Section 2.3 on Electricity Prices. As detailed earlier, this subsidy encompasses a fixed feed-in tariff for private households, along with streamlined administrative processes and a VAT reduction to 0% not only for the acquisition of solar systems but also for the electricity sold (Verbraucherzentrale 2023). The second subsidy has also been mentioned in section 2.6 Financing and includes an offer from the KFW which is intended to provide private households for the investment in a PV system with a more favourable loan offer than they might get from a normal bank (Bankengruppe 2023). The third option is provided by the City of Munich and features a set subsidy of 1,500€

for acquiring a PV system. Additionally, there's a subsidy of 282€ per kWp for the system, with an extra 47€ per kWp if the modules installed are glass-glass modules. It's important to note that the overall subsidy is capped at 30% of the total investment (Kugler 2023). Since the installation of a battery is simulated as part of scenario analyses, it should be mentioned that there are no special subsidies for batteries in connection with solar systems in Germany except for the preferential loan conditions of the KfW, which also apply to the battery.

2.8 Miscellaneous Data

Further data include inflation and tax items.

The inflation rate is calculated using the average Harmonised Index of Consumer Prices for Germany from 2003 to 2022, which results in an annual inflation rate of 1.925% (D. S. Bundesamt 2023). From a tax perspective, there are two different tax categories to be considered for the case of rooftop solar panels in Germany: VAT and income tax. Section 2.7 Government subsidies has already touched on the fact that VAT on all expenditure and income relating to solar energy systems was reduced to 0% with the EGG. The same applies to income tax, which was also reduced to 0% by a decision of the Federal Constitutional Court in 2022 as long as it is a single-family house with a rated output of less than 30kW, which in most cases is very likely to apply to the roof sizes we are looking at (Wittlinger 2023). As a result, no tax adjustment will be necessary in this model.

2.9 Data for Battery Analysis

For the battery analyses, the offers marked in Table 5 with an installed battery, which can be seen in Table 7, were newly requested. Again, it is decided to purchase the battery directly from the supplier of the solar modules, as it is assumed that this is probably the most common

case in reality since it is expected that consumers will buy the service from his hand and not have it assembled by different suppliers.

Supplier	Price	Battery storage	Max DOD
Klar Solar	5,000 €	7.7 kWh	99%
SOLSTRÅLE (Ikea)	4,800 €	5.0 kWh	100%
Zolar	5,779 €	9.6 kWh	100%
SVEA Solar	4,749 €	5.0 kWh	100%
	7,300 €	10.0 kWh	100%

Table 7: Overview of battery offers from the requested suppliers, Data source: (Klarsolar 2023) (Ikea 2023) (Solar 2023) (Zolar 2023)

A service life of 10 years was assumed for the term according to information from the providers. A new battery would then have to be purchased. As battery storage systems are currently undergoing constant further development, a study by The Royal Society of Chemistry was consulted, which predicts that battery costs will halve between 2023 and 2033 (Mauler, et al. 2021). In order to take a more conservative approach, the current price was reduced by a factor of 0.75 as the suppliers of such battery storage systems may not pass on the more favourable manufacturing costs to consumers on a 1:1 basis. Furthermore, it is assumed that the batteries will have a longer service life in 2033, which is why a new battery will no longer need to be purchased and a 15-year service life is assumed.

3 Analysis

The following analysis combines the data described in Section 2 Data and Assumptions. The generated data on solar irradiation and energy consumption is combined in Section 3.1 Electricity Distribution Analysis. This provides the basis for section 3.2 Economic Analysis in which the calculation of cash flows and other key elements of the data are generated. Further analyses are carried out in section 3.3 Additional Analyses before comparisons and differences to analyses in other German cities are drawn in the concluding section.

3.1 Electricity Distribution Analysis

The aim of the electricity distribution analysis is to determine the exact annual distribution of PV-generated electricity between own use, feed-in back into the system and purchase of missing electricity. The first step is to calculate the production of the actual panels for the 8,760 hours per year. This is done by extrapolating the solar irradiance data times the total possible output of our solar panels.

$$\left(\frac{\text{Solar irradiance data in W per hour}}{1,000} \right) * \text{Total output of the PV system in kWh}$$

$$= \text{Generation PV system in kWh}$$

If the total installed system output of the PV system is 12.62kWp, which corresponds to a possible output of 12.62kWh, the total output of the PV system over one year at the Munich site is 14,329kWh. The hourly generated kWh are divided into PV use in the household or sale to the grid depending on demand and availability in the analysis of the electricity distribution; for household consumption, the synPro load profile is used for this purpose. Figure 3 shows a possible distribution of 14,329kWh production with own use of 2,090kWh and 12,240kWh sold to the grid.

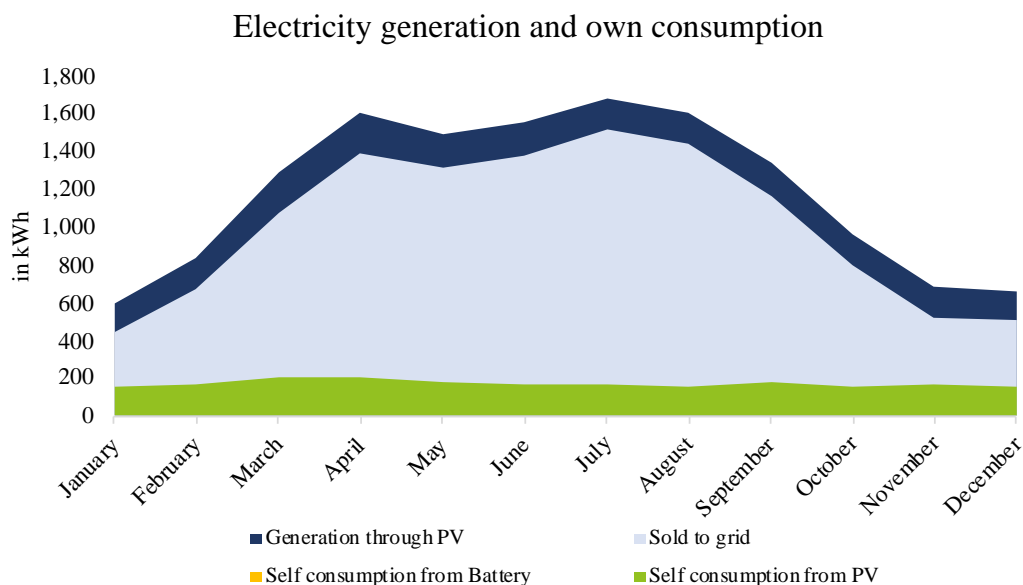


Figure 3: Example electricity generation and own consumption, Source: Own visualisation

In addition to self-consumption, 2,410kWh would still have to be purchased from the supplier. Building on the data obtained, the Economic analysis follows.

3.2 Economic Analysis

The goal of the economic analysis is to find the right combination of provider and number of panels based on the previously defined data. In doing so, it is assumed that the household decides according to the height of the NPV which provider they take and how many panels they want to invest in. Case 1: “Gov. subsidies and 75% bank debt” is the central case as it defines the exact kind and number of solar panels for the other cases as well.

To determine the highest NPV, all NPVs from relevant offers from section 2.5 Solar Panels are analysed. This is done by calculating the cash flows resulting from the annual savings generated by the PV system and by deducting expenses such as equity investments, maintenance costs, loan and interest payments. All relevant items are adjusted for inflation over the 25-year period except for the fixed compensation fee as this is fixed for 20 years, after the 20 years the market price is taken which is adjusted for inflation. The equity initial investment costs are determined by the case in question. In the case of Case 1, for example, this looks like this: Total price for 29 panels: 17,700€ Equity: 3,098€ Debt: 9,293€ Government subsidies: 5,310€. The additional payment from the City of Munich in this case, with a nominal size of the PV system of 12.6kWp, is as follows: Basic subsidy of 1,500€ plus 282€ per kWp and a further 47€ per kWp for the glass-glass modules. The subsidies are limited to 5,310€ as they would otherwise exceed 30% of the total price of the system. The cash flows generated are then discounted using the cost of equity of 3.05% defined in 2.6 Financing.

Figure 4 shows the calculated NPVs of all offers received. It can be seen that the provider "Svea Solar" with its panel series “Essential” has the best package.

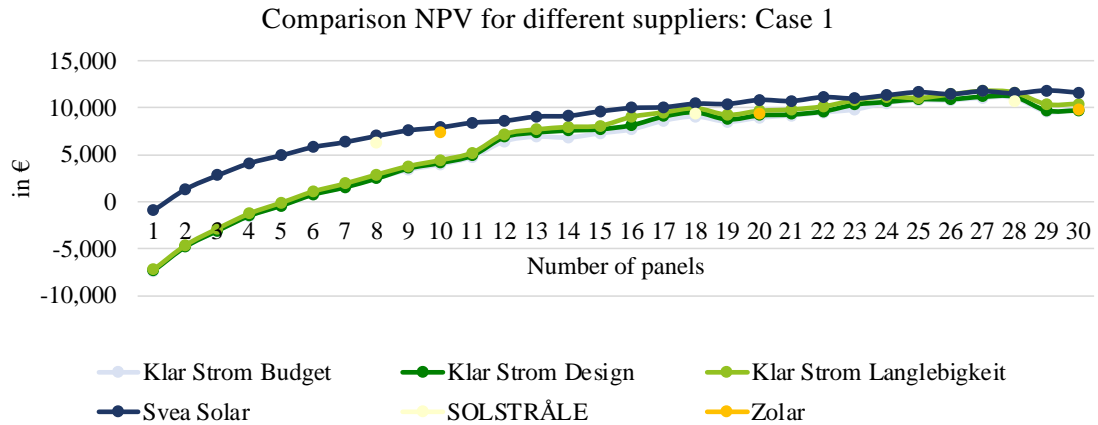


Figure 4: Comparison NPV for different suppliers: Case 1, Source: Own visualisation

This is partly due to the attractive € per kWh ratio of the panels, but also to the fact that it is a glass-glass solar panel that is extra subsidized by the city of Munich. The system achieves the maximum NPV of 11,871.4€ with a panel number of 29 units and a roof area of 56m². It is interesting to note that maximisation according to the IRR leads to a different result. As can be seen in Figure 5, a maximum IRR of 14.1% is achieved with just 15 solar panels when using solar panels from Svea Solar.

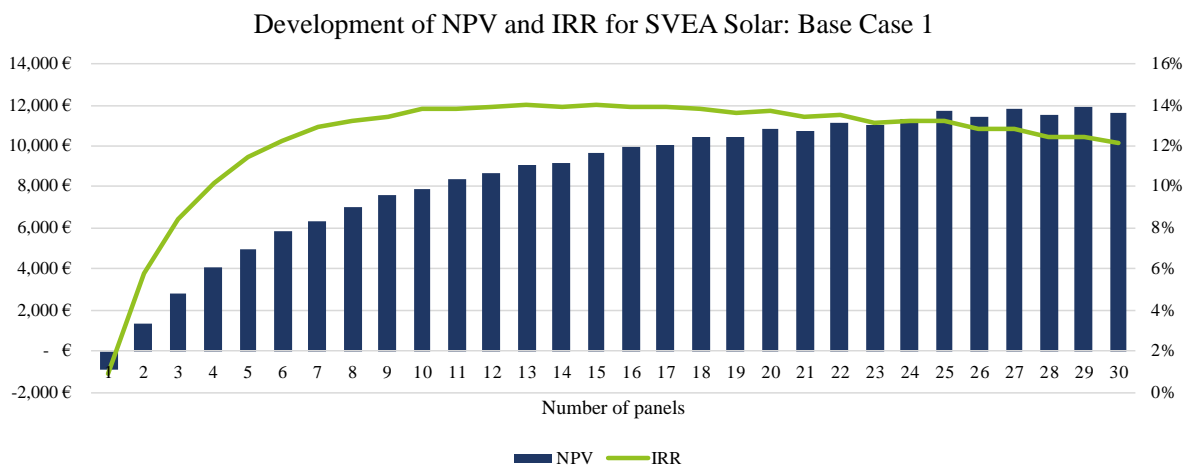


Figure 5: Development of NPV and IRR for SVEA Solar: Base Case 1, Source: Own visualisation

If the setup of “Svea Solar” and 29 panels is applied to the other financing cases, the following key figures are shown in Table 8.

Cases:	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
Gov. subsidies and 75% bank debt	11,871.40	9.75	12.49	0.0641
Gov. subsidies and 100% supplier's credit	7,671.60	8.37	26.52	0.0778
Gov. subsidies and 100% equity	12,414.90	8.76	10.6	0.0623
No gov. subsidies and 100% equity	406.70	17.7	3.24	0.0797

Table 8: Overview of the results of the basic economic analysis, Source: Own visualisation

A new perspective emerges when the NPVs for Case 4, i.e. 100% equity and without gov. subsidies, are calculated. Here it can be seen that the maximum NPV of 3,832.93€ is already reached with 9 solar panels, as can be seen in Figure 6.

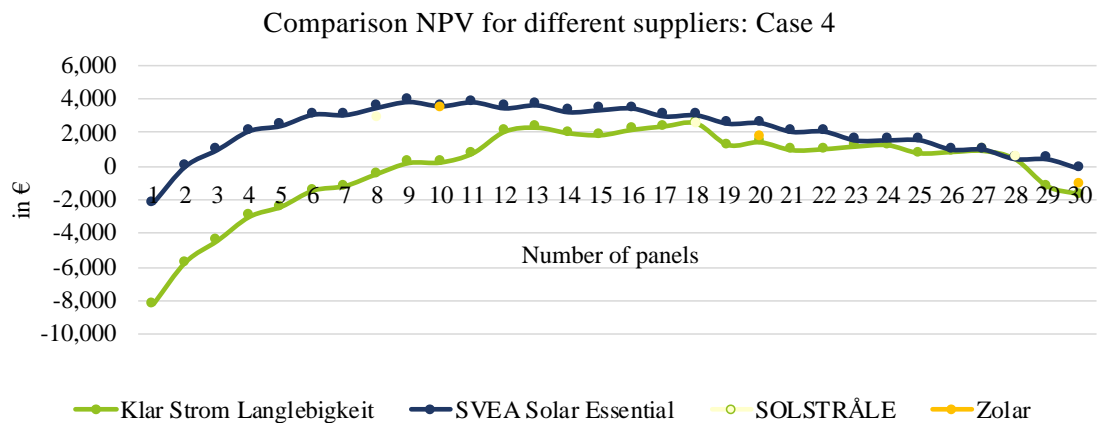


Figure 6: Comparison NPV for different suppliers: Case 4, Source: Own visualisation

3.3 Additional Analyses

In the additional analyses section, the purchase of a further battery is first examined, while various sensitivities and scenario analyses are subsequently carried out.

3.3.1 Battery Analysis

For the analyses of the profitability of a battery in addition to the PV system, the NPVs for the offers obtained were analysed again based on Case 1. Figure 7 shows that it is no longer the provider Svea Solar that has the most attractive offer, but Klar Solar with the solar panel “Langlebigkeit”, with 28 panels and a battery of 7.7kWh. As a result, the plant would have an NPV of 16,334.3€ and an IRR of 11.95%. The system achieves an LCOE of 0.0910€/kWh and

would be paid off after 11.23 years. From a purely NPV point of view, buying a battery would make sense even if the capital paid in does not have such a high rate of return and the amortisation would take longer.

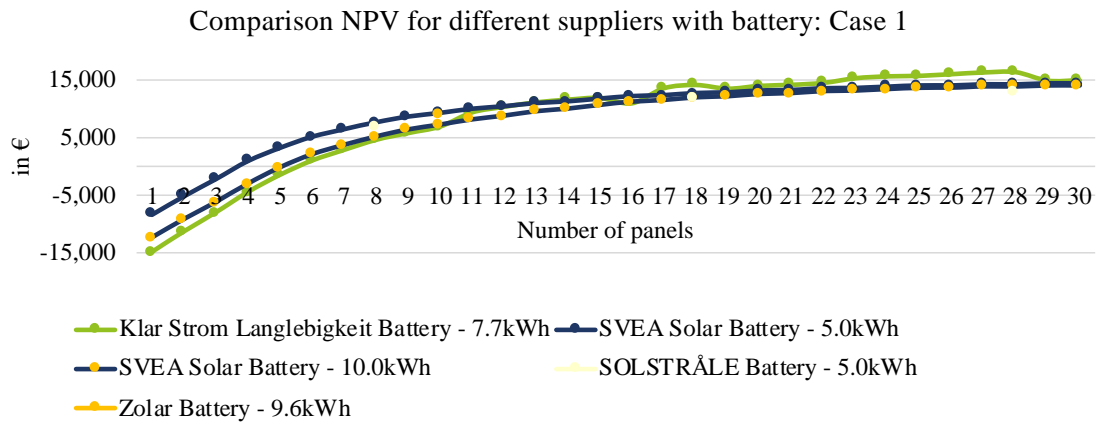


Figure 7: Comparison NPV for different suppliers with battery: Case 1, Source: Own visualisation

Figure 8 illustrates how much a battery would increase the use of self-generated electricity. Particularly in winter, more energy is initially stored in the battery than is drawn directly from the PV system. The share of purchased external electricity would fall to 340kWh, which would be only around 7.6% of the total electricity consumed. It can therefore be seen that the increased NPV is achieved through the significantly higher own use and the lower purchase of external expensive electricity despite no extra state subsidies.

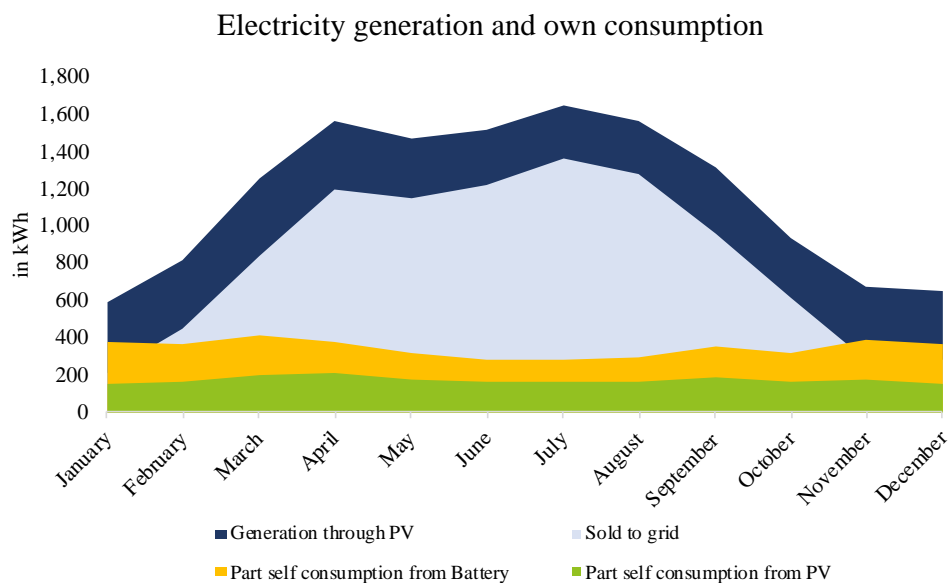


Figure 8: Profil electricity generation and own consumption Case 1 with battery, Source: Own visualisation

A dissertation prepared in 2017 specifically on the topic of the profitability of batteries as support for PV systems comes to a similar conclusion that batteries should be profitable in Germany from 2019 at the latest without external subsidies and even without the extra feed-in remuneration from the EGG (Kaschub 2017).

3.3.2 Sensitivity and Scenario Analyses

In a further step, additional sensitivity analyses and scenario analyses are carried out for base case 1 with the optimal NPV scenario of SVEA Solar with 29 panels. In Tables 9 and 10 sensitivity analyses are presented that show fluctuations in the cost of capital, i.e. equity and debt, as well as fluctuations in the purchase price of electricity costs from the grid and the level of inflation.

		Equity cost of capital				
		2.05%	2.55%	3.05%	3.55%	4.05%
Loan interest rate	3.14%	15,118.36 €	13,694.81 €	12,391.52 €	11,197.11 €	10,101.40 €
	4.14%	14,852.40 €	13,431.82 €	12,131.43 €	10,939.88 €	9,846.98 €
	5.14%	14,586.43 €	13,168.82 €	11,871.35 €	10,682.66 €	9,592.56 €
	6.14%	14,320.46 €	12,905.82 €	11,611.27 €	10,425.44 €	9,338.14 €
	7.14%	14,054.49 €	12,642.83 €	11,351.19 €	10,168.21 €	9,083.72 €

Table 9: Sensitivity analysis: Case 1, Source: Own visualisation

		Electricity cost				
		0.38 €/kWh	0.36 €/kWh	0.34 €/kWh	0.32 €/kWh	0.30 €/kWh
Inflation	2.93%	15,321.22 €	14,321.90 €	13,322.58 €	12,323.26 €	11,323.93 €
	2.43%	14,454.19 €	13,510.72 €	12,567.26 €	11,623.79 €	10,680.32 €
	1.93%	13,654.54 €	12,762.94 €	11,871.35 €	10,979.76 €	10,088.16 €
	1.43%	12,916.72 €	12,073.34 €	11,229.95 €	10,386.56 €	9,543.17 €
	0.93%	12,235.68 €	11,437.11 €	10,638.54 €	9,839.96 €	9,041.39 €

Table 10: Sensitivity analysis: Case 2, Source: Own visualisation

While the deviations in the first sensitivity analysis show a picture in line with expectations, the sensitivity analysis on rising prices is particularly interesting. In an environment like the current one, in which inflation rates can remain in the high single digits for several months, it is interesting to see how it affects an investment like ours. It shows that even if a significantly higher inflation rate is assumed and if the electricity price is higher than assumed, this is rather positive for our calculation and that our NPV will increase. Thus, with an inflation rate of

2.93% and an electricity price of 0.38€/kWh, it reaches 15,321.22€. Another interesting change to the model is the lifetime of the solar panels as already mentioned in section 2.5 Solar Panels there is no exact lifespan value for solar panels and while we have assumed a lifespan of 25 years in our planning a change here can change the result significantly. If we adjust our model, which we have also just analysed, to a scenario with a lifetime of 20 years, our NPV is only 8,636.2€ if we increase the lifetime to a scenario with a lifetime of 30 years, it increases to 14,933.7€. It can be seen that the NPV fluctuates strongly but still remains positive.

3.4 A Comparison with Other Analyses from 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 11 summarizes the equal assumptions.

Parameter	Frankfurt/ Munich/ Aalen
Long Term Inflation Rate	1.93%
Equity Cost	3.05%
System Losses and Degradation with Age	14%
Electricity Selling Price with Subsidies	0.082
Electricity Selling Price without Subsidies	0.036
Debt Ratio	75%

Table 11: Comparison assumptions Germany I, Source: Own visualisation

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.

Parameter	Frankfurt	Munich	Aalen
PV System Lifetime (years)	25	25	20
Maintanance 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	1,073	1,136	1,337
Total Price for 15 Panels with Subsidies (EUR)	12,050	8,206	11,780
Generation for 15 Panels (kWh)	6,840	7,412	8,722

Table 12: Comparison assumptions Germany 2, Source: Own visualisation

The resulting differences in the financial metrics for a size of 15 panels are shown in Table 13.

KPI's	Frankfurt	Munich	Aalen
NPV (EUR)	3,234	9,645	3,154
IRR (%)	6.48%	14.10%	9.07%
Payback period (years)	15.7	9.18	15.5
LCOE (€/kWh)	0.1176	0.0752	0.0895

Table 13: Results Germany, Source: Own visualisation

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 favourable 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.

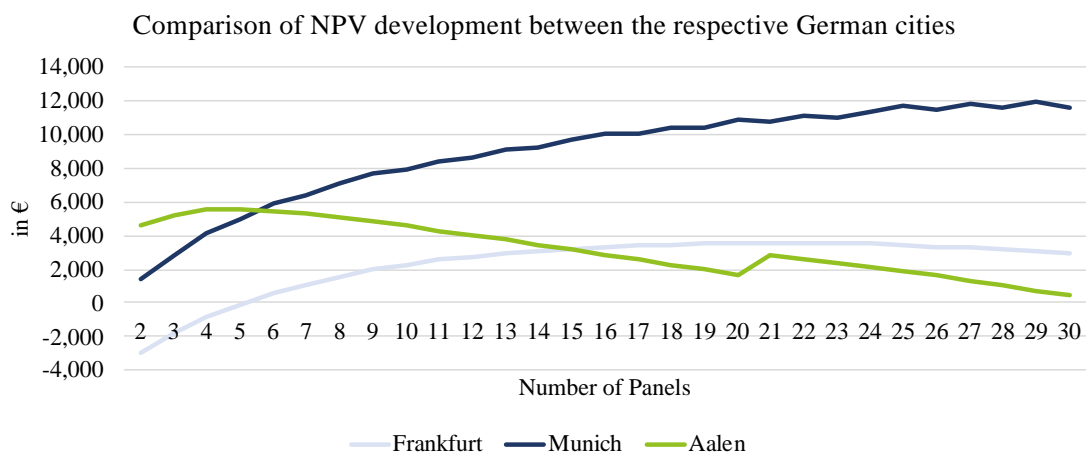


Figure 9: Comparison of NPV between the German cities, Source: Own visualisation

Figure 9 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 favourable for Munich and Frankfurt while Aalen reaches its peak already at a system size of five panels.

4 Results and Final Recommendations

Based on the results of the analyses, the initial question of whether a PV system in Munich is profitable can be answered that a PV system for a house, as described under the conditions in Munich, is financially worthwhile. This can be stated for all financing cases considered, whereby financing with Gov. subsidies and 100% equity leads to the highest NPV (Opportunity costs not taken into account). It should be emphasised that a PV system in Munich can only achieve these high capital values due to the high subsidies from the city of Munich. Especially in comparison with other German cities in section 3.4 A comparison with Other Analyses from Germany, the construction of a system is financially much more attractive in Munich than in the other cities observed thanks to the subsidies. If the purchase of a battery is also taken into account, it can be seen that it is even more financially worthwhile than the purchase without a battery, so the NPV in Case 1 with an optimal configuration is 11,871.4€ and with a battery 16,334.3€. However, when installing a PV system, it is important to consider not only the financial aspect, but also the positive ecological balance. The variant with a battery has a degree of self-sufficiency of over 90% and a high feed-in rate, which emphasises the positive environmental balance of the system. The City of Munich's intention is clear in offering these subsidies, not just to maximise profitability for citizens, but to encourage the generation of clean electricity and contribution to the grid, ensuring wider access to clean energy for all.

To summarise, the financial benefits combined with the positive environmental footprint make the installation of a PV system, especially with a battery, a compelling choice for the residents of Munich and aligns with the city's vision for a sustainable and accessible clean energy future.

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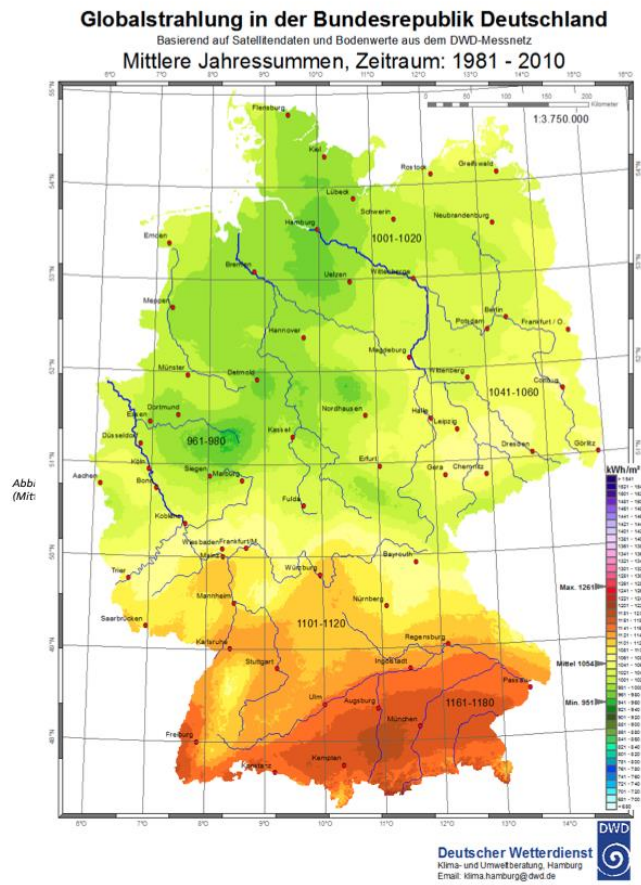
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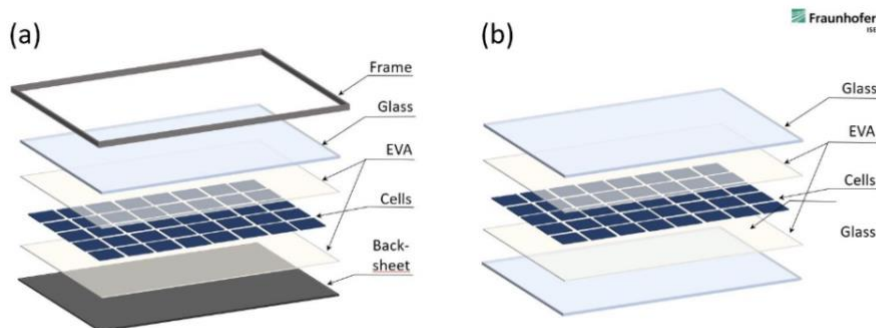
Appendices

Appendix A: Solar irradiance in Germany



Source: (Kost, et al. 2021)

Appendix B: Glass-Glass PV Modules



Glass-glass PV modules (b) do not require an aluminum frame and therefore have a lower carbon footprint than PV modules with backsheet (a). © Fraunhofer ISE

Source: (Bächle and Dr Neuhaus 2021)