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 A RESIDENTIAL GRID-CONNECTED PHOTOVOLTAIC SYSTEM IN ZURICH

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Executive Summary of Rooftop Solar Analysis

Location: Zurich, Switzerland **Date of analysis**: Feb/2022

Recommendation*: Install 23 solar panels (42.65 m^2), for a net present value of CHF 4,383.18 (EUR 4,339.35) and a payback of 25 years. If there is more roof area available, it is optimal to install even more panels.*

Main economic results

Financing	NPV in CHF (EUR)	Payback in years	IRR in %/year	LCOE in CHF/kWh (EUR/kWh)
Gov. subsidies and 75% debt	4,383 (4,339)	25	1.77%	0.0965 (0.0956)
Gov. subsidies and 100% equity	11,002 (10,892)	19	3.93%	0.0768 (0.0760)
No gov. subsidies and 100% equity	1,708 (1,691)	27	0.86%	0.1045 (0.1035)

(All rows refer to 23 panels)

Additional results

Adding a battery at today's market prices does not add value to the project. Only when prices decrease in the future, a battery adds value to the project.

The NPV of installing solar panels is highly sensitive to the total annual consumption and the electricity price (buy). The higher both parameters the higher the NPV. For high combinations of both parameters, a battery is adding value – even at today's market prices.

The NPV can vary within a very large range dependent on the future developments of significant input parameters, such as electricity prices, consumption, or maintenance costs.

Main inputs and assumptions

Household and Economics

Electricity Consumption	5,000	kWh/year	Inflation	1.5%	per year
Electricity price – buy peak hours	0.2666 (0.2639)	CHF/kWh (EUR/kWh)	Bank loan interest rate	5.3%	per year
Electricity price – buy off-peak hours	0.1568 (0.1552)	CHF/kWh (EUR/kWh)	Bank loan maturity	5	years
Electricity price – sell	0.0791 (0.0783)	CHF/kWh (EUR/kWh)	Equity cost of capital	0.46%	per year

PV panels

Peak power	390	W/panel	System losses	13.5%	of output
Panel area	1.85	m^2/panel	Degradation with age	0.5%	per year
Useful life	30	years	Maintenance costs	1%	of gross investment
Total cost of optimal installation size (before subsidies and tax deduction)				25,901 (25,641)	CHF (EUR)
Total cost of optimal installation size (after subsidies and tax deduction)[1]				16,607 (16,441)	CHF (EUR)

Government subsidies

There are subsidies for installations of at least 2kWp in size consisting of a base amount of 350 CHF and a performance amount of 380 CHF/kWp (capped at 30% of total installation cost). Equity investment is tax-deductible.

[1] Note: The tax deduction only applies to the part financed by equity. This number assumes 100% equity financing.

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1. Introduction

Despite international efforts to reduce greenhouse gas emissions, global net anthropogenic[2] emissions have continued to rise across all major groups of greenhouse gases according to the latest report published by the Intergovernmental Panel on Climate Change (IPCC) in February 2022. Even though global warming has "only" reached a level of 1.1°C above pre-industrial levels, record floods as well as extreme heats and droughts are already noticeable consequences of human-made climate change (IPCC, 2022; Levin et al., 2022). Future impacts are projected to become even more drastic with increasing numbers of wildfires, more frequent heavy rain as well as warming, acidifying and oxygen-losing oceans (Bentley, 2021). With a share of 34%, global energy systems account for the largest part of global greenhouse gas emissions. Therefore, the transition towards renewable energy will play a crucial role in fighting climate change (IPCC, 2022).

Apart from the environmental need to decarbonize energy systems, the current geopolitical situation teaches the world how risky a dependence on foreign energy imports can be. With large parts of Europe being dependent on Russian gas and oil exports, economic and political interests are heavily conflicting. A shift away from foreign gas and oil reserves towards a more independent and renewable energy system seems to be the logical next step.

One technology, which combines the decarbonization of energy systems with an increasing independence from foreign natural resources, is photovoltaic (PV). It describes the direct transformation of light energy into electric energy and thus enables everyone to profit from the free and unlimited resource of sunlight. By the end of 2020, a total of 760.4 GW in PV was installed globally with China being the biggest market followed by the EU and the USA. This capacity covers 3.7% of the world's electricity demand and helps to avoid 877 Mt in annual

[2] Originating from human activity.

CO_2 emissions (IEA, 2021). The global PV capacity is projected to increase drastically in the years to come.

This trend can also be observed by looking at recent developments in the PV capacity in Switzerland. While in 2010, PV systems provided 100 GWh/a in electricity in Switzerland, in 2020 this number was about 2,500 GWh/a, which corresponds to an increase by a factor of 25 or a compound annual growth rate of 38% (Swiss Federal Office of Energy, 2020). In 2020, solar energy covered 5% of electricity demand in Switzerland (IEA, 2021). With decreasing costs for solar panels and feed-in tariffs for PV-produced electricity, PV panels become more interesting for individual households. On top of a good conscience, users of PV panels profit from saving electricity costs by producing their own energy and from generating extra revenue by selling excess energy to the grid. Moreover, installing PV panels in Switzerland as a household was and still is – as in many other countries – incentivized through subsidies.

The central topic of the field lab "Rooftop PV", of which this report is a part, is to investigate the financial viability for a household to install rooftop PV panels in a specific location. This paper will focus on the city of Zurich in Switzerland. Located in central Europe and by its climate conditions not necessarily predestined for PV panels (1,817 hours of sunshine per year vs. 2,801 hours in Lisbon (Statista, 2022a; Weather & Climate, 2022)), Zurich seemed to be an interesting location to analyze.

2. Methodology

2.1 Basic Analysis

To evaluate the economics of rooftop solar panels in the city of Zurich, a quantitative analysis was performed. This analysis considered PV installation costs, PV technical data, solar radiation, electricity prices, household consumption and electricity load profile, subsidies as well as financing opportunities. The used data as well as the assumptions are more specifically described in chapter 3. Based on this data, the key performance indicators (explained in chapter 2.3) were calculated using two financing structures: (1) 75% debt and 25% equity, (2) 100% equity.

2.2 Additional Analyses

The basic analysis has been extended by some additional analyses. Firstly, the additional benefit of a battery was investigated by including installation, replacement and maintenance costs and correcting energy in- and outflows under battery usage. The benefit of a battery was again analyzed under both financing structures. This resulted in four different cases:

		Financing structure	
		75% debt	*100% equity*
Battery	*No*	(I) 75% debt and no battery	(II) 100% equity and no battery
	Yes	(III) 75% debt with battery	(IV) 100% equity with battery

Figure 1 - Overview of investigated cases (shaded area: basic analysis)

For all these four cases, a sensitivity and scenario analysis has been performed. The sensitivity analysis helps to understand how sensitive the key performance indicators are to changes in input parameters. The scenario analysis simulates developments of certain input parameters over time and had the purpose to map a best- and worst-case scenario to illustrate a range of possible outcomes.

2.3 Key Performance Indicators (KPIs)

Four different KPIs were computed to evaluate the economics of rooftop solar panels:

Net Present Value (NPV)	The NPV was computed by discounting equity cash flows by the cost of equity.
Internal Rate of Return (IRR)	The IRR is the rate of return that sets the NPV equal to zero. It was also calculated for equity cash flows.
Simple Payback Period	The simple payback period indicates after how many years the investment amortizes itself using undiscounted equity cash flows.
Levelized Cost of Electricity (LCOE)	The LCOE is the selling price of solar energy per kWh, which sets the NPV equal to zero, assuming that all energy is sold to the grid. This price will be calculated for t=0 and is assumed – as any other prices – to increase at inflation rate. The lower the LCOE, the more valuable is the project.

Table 1 - Overview of KPIs

3. Data and Assumptions

3.1 Household data

The analysis was performed for a four-person family living in a single house and consisting of two working parents and two children of school-age. Consumption data from three different households in and around Zurich was collected and is summarized in Appendix 1. This data was in line with further research on the medium annual consumption for a single house consisting of four people in Zurich (EKZ, 2022). Finally, a total annual consumption of 5,000 kWh was assumed. To model the hourly consumption, an electricity load profile was downloaded from the website “loadprofilegenerator.de”. This load profile was constructed using a bottom-up approach and tailored to a family of two working parents and two school-age children (Pflugrath, 2016). The annual consumption was scaled to 5,000 kWh accordingly. The electricity prices for consumers in Zurich are 0.2666 CHF/kWh during high tariff time (Mon – Sat 6am – 10pm) and 0.1568 CHF/ kWh during low tariff time (remaining time period) (EKZ, 2021). The price to sell excess solar energy to the grid is set by local electricity works and therefore varies by location within Switzerland. In Zurich it is set at 0.0791 CHF/kWh (VESE, 2022). The local electricity works are obliged to take the excess energy and compensate the producing household. Hence, the household will benefit from a feed-in compensation over the whole lifetime of PV panels. According to the Swiss Federal Ministry for Energy the selling price is oriented at the market price for electricity at the Swiss stock exchange (Energieheld, 2022b). Therefore, it is reasonable to assume that this price will increase at inflation rate. To estimate the available roof area for solar panels, several assumptions were made. The starting point was an average room size of 27.2 m^2 in Switzerland (Federal Statistical Office, 2021). The additional assumptions and calculations are summarized in the following table:

Item	Value	Explanation
(1) Avg. room size	27.2 m^2	Source: Federal statistical office
(2) Number of rooms	5	Living, Sleeping, Child 1, Child 2, Work
(3) Total area	136 m^2	(1)*(2)
(4) Number of stories	2	Assumption
(5) Floor area	68 m^2	(3)/(4)
(6) Floor width	10m	Assuming rectangular shape
(7) Floor length	6.8m	(5)/(6)
(8) Roof slope	37°	Optimal angle according to PVGIS
(9) Eaves	0.5m/ side	Assumption
(10) Usable roof area	50%	Using one side of a gable roof facing south
(11) Roof width	11m	(6) + 2*(9)
(12) Roof length	4.76m	((7)*(10))/Cos((8))+(9)
(13) % area available for panels	85%	Accounting for windows, edges etc.
(14) Available roof area	44.48 m^2	(11)*(12)*(13)

Table 2 - Deduction of available roof area

Consequently, an available roof area of 44.48 m^2 is assumed.

3.2 Economic Variables

An annual inflation rate of 1.5% is assumed in Switzerland, which is the number from December 2021 (Statista, 2022b). Since the future cash flows are avoided certain costs, they are essentially risk-free. Therefore, the equity cost of capital is estimated using the 10-year swap rate of the Swiss Franc, which was 0.46% in January 2022 (ZKB, 2022). To incorporate the effect of debt financing, several consumer loan providers have been compared (see Appendix 2) The best offer asked for an annual interest rate of 5.3% for a duration of 5 years. Lastly, the marginal tax rate in Zurich was estimated at 25%, which is in line with an average income in Zurich for two working parents (Stadt Zürich, 2018, 2022).

3.3 Solar Irradiance

The solar irradiance data for the city of Zurich was downloaded from the Photovoltaic Geographical Information System (PVGIS), a tool by the European Commission. This tool allows to download hourly radiation data for several years and locations (PVGIS, 2022). The hourly data points measure the solar radiation at a specific point in time and already account for system losses and degradation with age of solar panels. In the analysis, it is implicitly assumed that these data points are representative for the whole hour surrounding the data point. To obtain representative data for future years, an average of the solar radiation data of the five years 2012-2016 has been computed. This average was assumed to be the solar radiation for all future years in the analysis.

3.4 Solar Panels

Several solar panel providers in Zurich have been compared to identify the most cost-efficient offer (see Appendix 3). All quotes already include a recommended inverter as well as the whole installation process. The best offer was the panel "Megasol M390-HC120-wBf GGU30b" (real and linearly interpolated quotes can be found in Appendix 4). This bifacial[3] solar panel has a peak power of 390W, covers an area of 1.85 m^2 and comes with a linear performance warranty of 30 years (Megasol, 2022). Annual maintenance costs for solar panels were estimated at 1% of the gross investment, which is considered a common benchmark for solar panels in Switzerland (Energieheld, 2022a). These maintenance expenses are assumed to already include regular inverter and electricity meter replacements.

3.5 Subsidies

Subsidies in Switzerland only apply for installations of at least 2 kWp. They consist of a constant base amount of 350 CHF and a performance amount of 380 CHF/ kWp, which increases with installation size. The upper limit for said subsidies is capped at 30% of gross investment (Schweizerische Eidgenossenschaft, 2022). Moreover, any equity investment in solar panels is tax-deductible.

[3] Bifacial panels have solar cells on both sides (faces) of the panel. This allows for additional absorption of any light that is reflected from behind.

3.6 Battery data

Amongst different batteries that have been screened (see Appendix 5) the “Tesla Powerwall 2” was the most cost-efficient one. It comes with a usable capacity of 13.5 kWh and a warranty of 10 years (Tesla, 2022). Additional technical data is given in Appendix 6. Over the lifetime of the solar panels, the battery would have to be replaced twice, i.e. in year 10 and year 20. The replacement cost for the battery was computed using projected real battery cost decreases of 42% in 10 years and 50% in 20 years (Cole et al., 2021).

4. Analysis

4.1 Basic Analysis

In the basic analysis equity cash in- and outflows have been projected over the assumed lifespan of 30 years with the goal to determine the optimal number of solar panels. The equity cash flow in year 0 is the after-tax net equity investment for the solar panels, which is calculated as follows:

$$net\ equity\ investment = (gross\ investment - subsidies) * (1 - debt\ ratio) * (1 - t)$$

with:

(1) $Gross\ investment =$ Quoted/ synthetic price from solar panel provider (Appendix 4)

(2) $Subsidies = 350\ CHF + 380\frac{CHF}{kWp} * number\ of\ panels * 0.39kWp$ given that $number\ of\ panels * 0.39kWp \geq 2kWp$

(3) $debt\ ratio =$ Percentage of investment financed by debt. This number is alternated between 0% and 75%

(4) $t =$ marginal tax rate of 25%

To project the equity cash flows in the years 1-30 the solar radiation data and the consumption load profile were matched on an hourly basis over the whole time period. For each hour, the cash flows consisted of two different components:

(a) Energy savings: This is the cost that is effectively saved by consuming PV-generated electricity instead of buying from the grid. It is calculated as the product of the PV-consumed energy in kWh and the electricity price in CHF/kWh during that hour.

(b) Revenues: This is the revenue that is generated by selling excess energy to the grid. If the PV-generated energy exceeds the amount of energy needed by the household in that hour, this excess energy will be sold to the grid. This revenue is calculated as the product of the excess energy produced in kWh and the price for selling to the grid in CHF/kWh.

Once these cash flows were computed on an hourly basis, the analysis was continued on an annual level:

The annual equity cash flows in years 1-30 were then computed in the following way:

$$CF_t = savings_t + revenue_t - maintenance\ costs_t - loan\ repayment_t$$

with:

(1) $savings_t$ = Sum of all hourly savings within that year.

(2) $revenue_t$ = Sum of all hourly revenues within that year.

(3) $maintenance\ costs_t$ = Maintenance costs for that year as a fraction of gross investment.

(4) $loan\ repayment_t$ = Annual interest and principal payments of consumer loan (if any).

Items (1), (2) and (3) have been adjusted from nominal to real values by accounting for inflation on an annual level.

Once the after-tax net equity investment and the cash flows from years 1-30 were calculated, the KPIs could be computed for different amounts of solar panels under two different financing structures.

The NPV was computed as:

$$NPV = -net\ equity\ investment + \sum_{t=1}^{30} \frac{CF_t}{(1+r)^t}$$

with $r = cost\ of\ equity = 0.46\%$.

The IRR was computed by solving for the discount rate r, which sets the NPV equal to zero.

The simple payback was given by the first year, in which the cumulative undiscounted equity cash flow turns positive.

Lastly, the LCOE is defined as:

$$LCOE = \frac{PV\ of\ total\ lifetime\ cost}{PV\ of\ total\ lifetime\ output} = \frac{net\ equity\ investment + \frac{maintenance\ costs_t + loan\ repayment_t}{(1+r)^t}}{\frac{E_t}{(1+r)^t}}$$

with E_t being the total system output in kWh per year.

However, as this formula returns an LCOE, which is constant over the whole life of the project, the calculation was adapted to account for inflation and retrieve the effective LCOE in year 0[4].

4.2 Additional Analyses

4.2.1 Battery

Adding a battery affects the cash flows and thus the value of the project via two ways:

(a) Additional investment and maintenance costs: The battery has to be installed in year 0 and replaced in years 10 and 20, which results in additional equity investments (and debt repayments). Moreover, maintenance costs of 1% of gross investment at t=0 are assumed, in line with the maintenance costs of solar panels.

(b) Increased electricity savings: A battery allows for storage of solar energy, which is not used at a specific point in time. This energy can then be used at a later point in time when production is not sufficient to cover the needed electricity. This effectively means that a household can increase its level of self-consumption from solar panels. This has a favorable effect on future cash flows, as the price to buy from the grid is higher than the price to sell to the grid. Therefore, adding a battery will increase electricity savings and decrease revenue from selling to the grid. However, as the increase in electricity savings outweighs the decrease in revenue, overall cash flows will increase.

The electricity in- and outflows with a battery have been modeled accounting for technical battery data, such as usable capacity, maximum charging power and battery losses (Umwelt-Campus Birkenfeld, 2021).

[4] This was done via the Goal Seek function in Microsoft Excel.

The central question of the battery analysis is whether the benefits of an increased self-consumption exceed the costs of installing, replacing, and maintaining a battery. To answer this question NPV, IRR, Payback and LCOE have been computed for a PV system including a battery. Comparing these metrics to the results without a battery will show whether installing a battery adds value to the overall project.

4.2.2 Sensitivity Analysis

To understand how sensitive the NPV is to changes of input parameters, a sensitivity analysis for two of the most crucial input parameters has been performed: the total annual household consumption in kWh and the electricity price to buy at peak hours in CHF/kWh. This analysis helps to understand how strong the NPV varies with changes in these input parameters. Therefore, the total annual consumption was varied in a range between 2,000 and 20,000 kWh and the peak electricity price (buy) was varied in a range between 0.15 and 0.35 CHF/kWh.

4.2.3 Scenario Analysis

As developments of certain input parameters are uncertain, the scenario analysis had the purpose to map a best- and worst-case scenario around the scenario of the basic analysis (base case). Therefore, assumptions about four different parameters were made:

Item	**Bad case**	**Base case**	**Best case**
Change in electricity price buy (before inflation)	-2% p.a.	0% p.a.	+2% p.a.
Change in electricity price sell (before inflation)	-2% p.a.	0% p.a.	+2% p.a.
Change in level of household energy consumption	-2% p.a.	0% p.a.	+2% p.a.
Annual maintenance costs as percentage of gross investment	1.5%	1%	0.5%

Table 3 - Scenario Analysis assumptions

These particular parameters were chosen, as they all heavily affect the NPV of solar panels. Above-inflation increasing electricity prices (buy and sell) will have a significantly positive effect on the NPV, as cost savings and revenue will increase. The opposite will be the case for below-inflation increasing electricity prices. An annual increase in the level of household energy consumption favors the value of solar panels, as it increases the self-consumption from solar panels. Conversely, a decreasing consumption would lower the NPV. Lastly, maintenance costs make up significant cash flows in years 1-30. Therefore, it seemed reasonable to include high- and low-maintenance cost scenarios in this analysis.

5. Results and Recommendations

5.1 Basic Analysis

To determine the optimal number of panels, the NPV for installing different numbers of panels between 1 and 50 was computed. The output summary table containing NPV, IRR, Payback and LCOE for all amounts of panels can be found in Appendix 7. For both financing cases (i.e. 75% debt as well as 100% equity) installing as many panels as possible given a roof area of 44.48 m^2 is the optimal decision. Hence, installing 23 panels maximizes the NPV under the assumptions of the basic analysis. Annual electricity flows for 23 panels are summarized below:

Total consumption	5,000 kWh
Total generation of PV panels	9,636 kWh
Self-consumption from PV	1,623 kWh
Bought from grid	3,377 kWh
Sold to grid	8,013 kWh

Table 4 - Electricity flows basic analysis for 23 panels

As can be seen from the table, a total of 9,636 kWh is generated by the solar panels throughout the year. However, only 1,623 kWh are self-consumed by the household, while the rest is sold to the grid. This means that an average household can cover approximately 32.5% of its total annual consumption via solar panels.

The annual and cumulative cash flows for both financing cases and 23 PV panels are illustrated below:

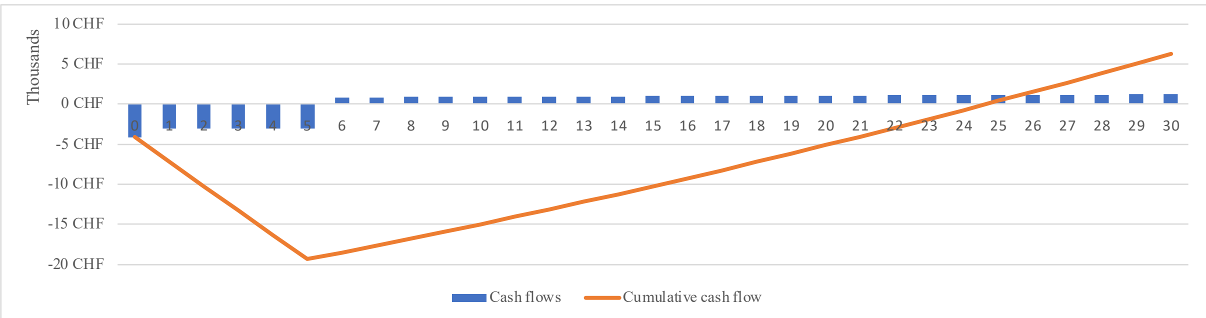

Figure 2 - Cash flows Basic analysis 23 panels (75% debt)

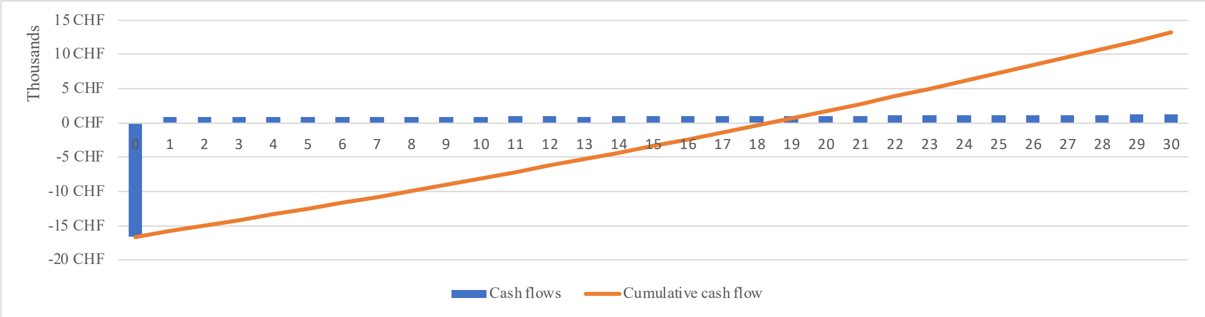

Figure 3 - Cash flows Basic analysis 23 panels (100% equity)

In the 75% debt case, the cumulative cash flow is decreasing in the first 5 years due to negative cash flows associated with the debt repayment. In the 100% equity case, the cash flows turn positive in year 1, since no debt has to be repaid. Comparing the cumulative cash flows of the two financing structures, one can recognize that the break-even occurs significantly earlier in the all-equity case.

The KPIs for both financing structures and 23 panels are compared below:

	NPV	**IRR**	**Payback**	**LCOE**
75% debt financing	CHF 4,383.18 (EUR 4,339.35)	1.77%	25 years	CHF 0.0965 (EUR 0.0956)
100% equity financing	CHF 11,002.20 (EUR 10,892.17)	3.93%	19 years	CHF 0.0768 (EUR 0.0760)

Table 5 - Results of basic analysis for 23 panels

As the cost of debt (5.3%) exceeds the cost of equity (0.46%), financing 75% of the initial investment by debt leads to a lower NPV than the all-equity alternative.

Beyond 23 panels, it is still optimal to install additional solar panels. As can be seen in Appendix 7 the NPVs for installing 30, 40 and 50 panels under the 75% debt assumption are CHF 9,209.05, CHF 14,294.97, and CHF 19,217.24 respectively (same tendency applies to 100% equity financing). This steadily increasing NPV can be explained by a combination of high fixed costs and resulting scale effects for the installation of solar panels and a relatively high electricity price to sell to the grid (0.0791 CHF/kWh). The high upfront investment required for small numbers of panels could be due to the high price and salary level in

Switzerland and especially Zurich. This high upfront investment makes small numbers of panels NPV negative. Contributing to this effect is the fact, that only installations with a minimum of 2kWp are subject to subsidies. The incentive to install any fewer than 2kWp/0.39kWp = 5.12 = 6 panels seems to be intentionally reduced by the government. For larger amounts of solar panels, scale effects kick in, which result in lower marginal and average costs per panel. The consequence is that the cost of installing an additional panel is offset by its financial benefits in the form of savings and revenue. This situation is sustained for such high amounts of panels that the additional energy generated will only be sold to the grid. This can be understood by looking at the LCOE for 40 and 50 panels, which are CHF 0.0747 and CHF 0.0695 respectively. As these numbers are below the actual compensation for selling to the grid (CHF 0.0749), any marginal investment in a solar panel will make the NPV increase, even if all electricity generated by this panel is sold to the grid.

Hence, based on the basic analysis, the recommendation would be: Install as many solar panels as possible, which is assumed to be 23 for an average single house. The minimum amount of panels to make the NPV positive is 17 (75% debt) and 10 (100% equity) respectively (see Appendix 7). Everything below that number of panels is not worth installing.

5.2 Additional Analyses

5.2.1 Battery

As in the basic analysis, the NPV for different numbers of panels including a battery was computed. The results are displayed in Appendix 8. For low amounts of panels, the benefit of a battery storage system is rather limited, as the energy production rarely exceeds consumption, and the full battery capacity is never fully used. These limited benefits combined with a high initial investment and two follow-on investments in years 10 and 20 lead to very low NPVs for low amounts of panels. The larger the number of panels, the more valuable becomes the battery. The annual electricity flows with a battery and 23 solar panels are summarized below:

Total consumption	5,000 kWh
Total production	9,636 kWh
Direct self-consumption	1,623 kWh
Self-consumption from battery	2,880 kWh
Bought from grid	497 kWh
Sold to grid	5,097 kWh
Battery losses	36 kWh

Table 6 - Electricity flows with battery for 23 panels

Total consumption and production remain unchanged compared to the case without a battery, however the self-consumption increases significantly. As can be seen from the table above, the battery increases the self-consumption by a total amount of 2,880 kWh, increasing the total consumption coverage from 32.5% to 90.1%. As explained previously, this increased self-consumption will be beneficial due to the discrepancy between buying and selling electricity prices.

Analyzing the cash flows for installing 23 solar panels and a battery yields the following results:

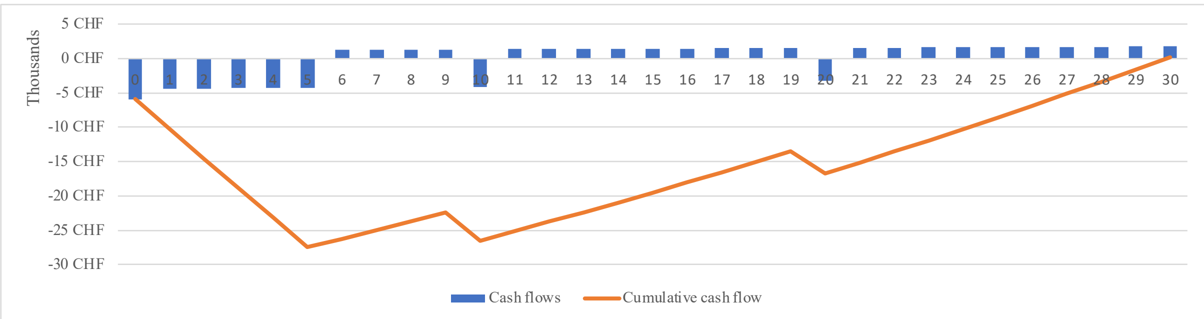

Figure 4 - Cash flows 23 panels with battery (75% debt)

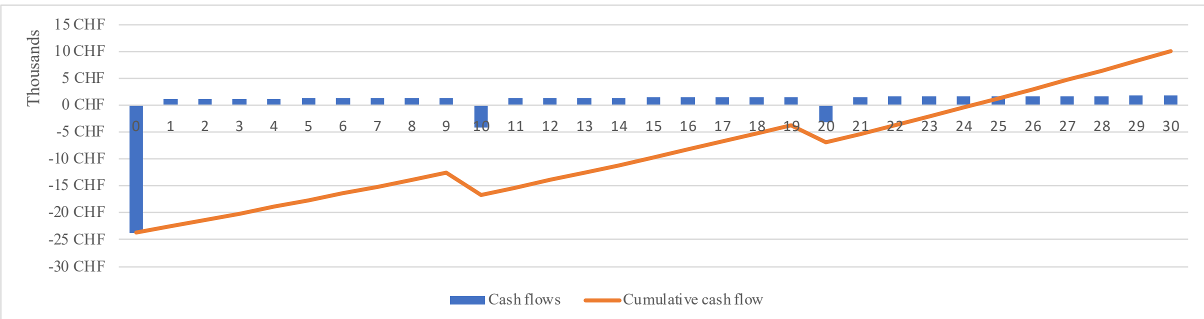

Figure 5 - Cash flows 23 panels with battery (100% equity)

Compared to the scenario without a battery the main differences are more extreme cash flows, i.e. higher initial negative cash flows and two additional negative cash flows in year 10 and 20 as well as higher positive cash flows due to increased self-consumption. The all-equity financing structure – like in the basic analysis – breaks even earlier than the 75% debt case.

The KPIs for 23 panels and a battery storage system under both financing structures are compared below:

	NPV	**IRR**	**Payback**	**LCOE**
75% debt financing	CHF -1,990.64 (EUR -1,970.74)	0.03%	30 years	CHF 0.1648 (EUR 0.1632)
100% equity financing	CHF 7,468.18 (EUR 7,393.50)	2.19%	25 years	CHF 0.1366 (EUR 0.1353)

Table 7 - Results with battery for 23 panels

In the case of 75% debt financing the NPV is still negative and only turns positive for larger numbers of panels (see Appendix 8). However, the initial investment will be paid back over the lifetime of the project. In the 100% equity scenario, the NPV is significantly positive.

However, for both financing structures, the NPV of a solar system without a battery is higher than the NPV with a battery (compare Table 5 and Table 8). Therefore, at this point in time, it is not worth adding a battery to the PV system. Nonetheless, as battery prices are projected to decrease significantly in the coming decades, it could be worth adding a battery at a later point in time. As mentioned in chapter 3.6 battery prices are expected to decrease by 42% and 50% in 10 and 20 years respectively (Cole et al., 2021). Therefore, it could be interesting to modify the model in a way, which only adds a battery in year 10 or in year 20. Running these simulations yields the following results:

	NPV	IRR	Payback	LCOE
75% debt financing	CHF 4,040.28 (EUR 3,999.88)	1.50%	27 years	CHF 0.1321 (EUR 0.1308)
100% equity financing	CHF 10,659.30 (EUR 10,552.71)	3.39%	23 years	CHF 0.1124 (EUR 0.1113)

Table 8 - Results for 23 panels when adding a battery in year 10

	NPV	IRR	Payback	LCOE
75% debt financing	CHF 4,891.55 (EUR 4,842.63)	1.81%	27 years	CHF 0.1131 (EUR 0.1120)
100% equity financing	CHF 11,510.57 (EUR 11,395.46)	3.86%	19 years	CHF 0.0934 (EUR 0.0925)

Table 9 - Results for 23 panels when adding a battery in year 20

The NPVs for both financing structures when adding a battery in year 10 are below the NPV without a battery (compare Table 5 and Table 9), however, installing a battery in year 20 leads to a higher NPV (compare Table 5 and Table 10). Hence, the final recommendation is to wait until battery prices decrease before adding it to the PV system. A battery price level, which will have a positive effect on the overall value of the project may be reached in about 20 years.

5.2.2 Sensitivity Analysis

The results of the sensitivity analysis for 23 panels of the four cases from Figure 1 in chapter 2.2 can be found in Appendix 9. The two key takeaways from these results are: First, the higher the total annual household consumption, the higher the NPV of solar panels. This is because higher overall consumption allows for higher self-consumption from the panels, which results in increased electricity savings. Second, the higher the price to buy electricity at peak hours, the higher the NPV at peak hours. Similar to a higher household consumption, this results in higher energy savings, with the only difference that the change in energy savings is price-driven and not volume-driven. Another major takeaway is that 100% equity financing is strictly better than 75% debt financing, which can be seen by comparing the NPVs. This is due to the aforementioned fact that the cost of equity (0.46%) is lower than the cost of debt (5.3%). Lastly, one can see that adding a battery adds value for combinations of high peak prices and high household consumptions, as the NPV with a battery outperforms the NPV without a battery.

The results of this sensitivity analysis can be summarized as follows: Firstly, the higher the household consumption and/ or the higher the electricity price, the more valuable are solar panels. Secondly, if possible, it is always better to finance the project by equity than by debt. Thirdly, adding a battery – even at today's market prices – adds value for significantly high annual household consumptions and/ or electricity prices.

5.2.3 Scenario Analysis

The results for the scenario analysis can be found in Appendix 10. It becomes clear that the NPV highly varies with how favorable or unfavorable certain variables will develop. If total consumption as well as buying and selling electricity prices were to decrease 2% per year, while solar panels were to be of high maintenance causing 1.5% of gross investment in maintenance per year, NPVs would be significantly negative in all four cases of Figure 1 in chapter 2.2. The opposite holds true for favorable developments (i.e. consumption and prices increase by 2% and maintenance costs are only 0.5% of gross investment). Here, all four cases result in NPVs of more than CHF 26,000. This result is again largely due to price- and volume-driven differences in annual electricity savings (see results sensitivity analysis). Moreover, an increasing selling price increases annual revenue from selling to the grid, while lower maintenance costs reduce cash-outflows. Another interesting finding is that in the best case the battery adds value while in the bad case it is value-destroying. This is due to an increased benefit of a battery with increasing levels of consumption, as this allows for a greater portion of self-consumption.

To conclude: The NPV of installing 23 solar panels strongly varies with developments of different input parameters creating a wide range of possible NPVs. While for favorable developments, installing a battery is value-adding, this is not the case for unfavorable developments.

6. Conclusion and Outlook

Finally, the performed analysis of this paper indicates that solar panels do not only have a positive impact on the environment and reduce the dependence on energy imports, but they are also a financially viable investment. Even though installations are expensive and solar radiation is not exceptionally high in Zurich, solar panels can produce positive NPVs.

More precisely, under the given assumption of the basic analysis, it is optimal to install 23 solar panels with an NPV of CHF 4,383.18 (75% debt) or CHF 11,002.20 (100% equity) respectively. However, if the roof area allows for more solar panels, it is optimal to even increase the number of panels. This is due to a relatively high selling price of excess electricity, which results in higher marginal benefits than marginal costs for large amounts of solar panels. Furthermore, adding a battery in year 0 does not add value to the project under the assumptions of the basic analysis. Only once battery prices decrease in the years to come, an investment at a later stage in time will be optimal. More specifically, given the assumed battery cost developments, it will be optimal to add a battery to the PV system in approximately 20 years. From the performed sensitivity analysis, it became obvious that pure equity financing leads to strictly higher project NPVs than the 75% debt financing structure, as the cost of equity is lower than the cost of debt. Moreover, it revealed that the NPV is highly sensitive to changes in electricity prices and the total annual household consumption. The higher the two parameters, the better. For combinations of high consumption and high electricity prices, a battery – even at today's market prices – adds value to the overall PV system. The scenario analysis displayed a range of potential NPVs based on (un)favorable developments of input variables. This range is very wide and thus illustrates the implied uncertainty and dependence on price developments embedded in installing solar panels.

Another main finding of all analyses is that high self-consumption is the key to increase the NPV, since the buying price for electricity is higher than the selling price. Despite varying the total annual consumption, which was done in the sensitivity and scenario analysis in this paper, it could be interesting to model changes in the load profile, which would ultimately result in changes in the self-consumption. In particular, active load management and adding components such as an electric boiler, an electric heating and/ or an EV charging station could provide additional insights into the value of solar panels and batteries.

Overall, the results of this paper indicate that installing solar panels in the city of Zurich is a financially viable investment, which is likely to result in increasing demand in the coming years. A higher density of solar panels would help to reduce dependence on natural resource-exporting nations and more importantly result in a more sustainable electricity production, which is desperately needed for overcoming one of the biggest challenges that our species is facing: climate change.

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Appendices

Appendix 1: Sample of household consumption data in City of Zurich

	Household 1	**Household 2**	**Household 3**
Household description	Single house: 2 working parents, 1 child (17 years old)	Single house: 1 working parent, 1 stay-at-home parent, 2 children (12 and 15 years old)	Semi-detached house: 1 single working parent, 2 children (7 and 11 years old)
Electric boiler?	No	No	No
Electric heating?	No	No	No
Total annual consumption	4,752 kWh	5,911 kWh	4,321 kWh

Appendix 2: Loan providers and Interest rates

		Interest rate p.a.	
Lender	Lower Limit	Upper Limit	Assumed rate
bob credit	4.90%	9.90%	7.40%
Lend Kredit	4.92%	9.79%	7.36%
Migros Bank Privatkredit	4.70%	5.90%	5.30%
good finance Privatkredit	6.40%	6.40%	6.40%
Bank-now CREDIT.now Privatkredit	6.90%	9.90%	8.40%
Cashgate Privatkredit	7.90%	7.90%	7.90%
Cembra Barkredit	7.95%	9.95%	8.95%
eny Finance eny Credit	4.50%	9.90%	7.20%

Appendix 3: Quotes of solar panel providers

Provider	Montage system	Solar Modul	Efficiency	Length (mm)	Width (mm)	Space (sqm)	Size per module in Wp	Quantity	Total Investment	Installation Size in kWp	Required Roof Size (sqm)	Cost per panel	Cost per kWp
				1690	996			10	CHF 17,841.00	3.45	16.83	CHF 1,784.10	CHF 5,171.30
		Megasol M345-HC120-bBf GGU30b	20.51%			1.68	345	20	CHF 24,040.00	6.90	33.66	CHF 1,202.00	CHF 3,484.06
								30	CHF 28,808.00	10.35	50.50	CHF 960.27	CHF 2,783.38
				1773	1046			10	CHF 18,430.00	3.85	18.55	CHF 1,843.00	CHF 4,787.01
		Megasol M385-HC120-bBf GGU30b	20.80%			1.85	385	20	CHF 25,195.00	7.70	37.09	CHF 1,259.75	CHF 3,272.08
	Lockup roof (on-roof)							30	CHF 29,544.00	11.55	55.64	CHF 984.80	CHF 2,557.92
				1773	1046			5	CHF 15,777.00	1.95	9.27	CHF 3,155.40	CHF 8,090.77
								10	CHF 18,430.00	3.90	18.55	CHF 1,843.00	CHF 4,725.64
		Megasol M390-HC120-wBf GGU30b	21.05%			1.85	390	20	CHF 24,340.00	7.80	37.09	CHF 1,217.00	CHF 3,120.51
								30	CHF 29,544.00	11.70	55.64	CHF 984.80	CHF 2,525.13
								40	CHF 35,756.00	15.60	74.18	CHF 893.90	CHF 2,292.05
				1669	999			10	CHF 18,939.00	3.25	16.67	CHF 1,893.90	CHF 5,827.38
Stählin		Megasol M325-60-b GG3	19.55%			1.67	325	20	CHF 26,375.00	6.50	33.35	CHF 1,318.75	CHF 4,057.69
								30	CHF 33,109.00	9.75	50.02	CHF 1,103.63	CHF 3,395.79
				1669	999			10	CHF 18,939.00	3.30	16.67	CHF 1,893.90	CHF 5,739.09
	Layup roof (on-roof)	Megasol M330-60-w GG3	19.85%			1.67	330	20	CHF 26,375.00	6.60	33.35	CHF 1,318.75	CHF 3,996.21
								30	CHF 33,109.00	9.90	50.02	CHF 1,103.63	CHF 3,344.34
				1669	999			10	CHF 18,939.00	3.25	16.67	CHF 1,893.90	CHF 5,827.38
		Megasol M425-60-t BF GG3	19.55%			1.67	325	20	CHF 26,375.00	6.50	33.35	CHF 1,318.75	CHF 4,057.69
								30	CHF 33,109.00	9.75	50.02	CHF 1,103.63	CHF 3,395.79
				1100	1695			10	CHF 22,737.00	2.70	18.65	CHF 2,273.70	CHF 8,421.11
		Megasol M270-60 Terracotta GG Level Dose L	16.60%			1.86	270	20	CHF 30,238.00	5.40	37.29	CHF 1,511.90	CHF 5,599.63
	Level Indachystem (in-roof)							30	CHF 40,532.00	8.10	55.94	CHF 1,351.07	CHF 5,003.95
				1100	1695			10	CHF 20,183.00	3.35	18.65	CHF 2,018.30	CHF 6,024.78
		Megasol M335-60-b GG Level Dose L	19.85%			1.86	335	20	CHF 27,274.00	6.70	37.29	CHF 1,363.70	CHF 4,070.75
								30	CHF 33,452.00	10.05	55.94	CHF 1,115.07	CHF 3,328.56
	In-roof	3S MegaSlate II 6DL 195 Wp	18.20%	1300	875	1.14	195	85	CHF 58,424.50	16.58	96.69	CHF 687.35	CHF 3,524.86
Helion	On-roof	Jinko Tiger JKM370 HC	20.28%	1756	1039	1.82	370	68	CHF 59,869.84	25.16	124.06	CHF 880.44	CHF 2,379.56
	On-roof	Jinko Tiger JKM 350 HC Black	20.10%	1692	1029	1.74	350	34	CHF 39,273.24	11.90	59.20	CHF 1,155.10	CHF 3,300.27

Appendix 4: Real and synthetic quotes for chosen solar panel

#panels	Quoted Price	Linearly interpolated price	Req. Roof area
1		CHF 3,155.40	1.85
2		CHF 6,310.80	3.71
3		CHF 9,466.20	5.56
4		CHF 12,621.60	7.42
5	CHF 15,777.00	CHF 15,777.00	9.27
6		CHF 16,307.60	11.13
7		CHF 16,838.20	12.98
8		CHF 17,368.80	14.84
9		CHF 17,899.40	16.69
10	CHF 18,430.00	CHF 18,430.00	18.55
11		CHF 19,021.00	20.40
12		CHF 19,612.00	22.25
13		CHF 20,203.00	24.11
14		CHF 20,794.00	25.96
15		CHF 21,385.00	27.82
16		CHF 21,976.00	29.67
17		CHF 22,567.00	31.53
18		CHF 23,158.00	33.38
19		CHF 23,749.00	35.24
20	CHF 24,340.00	CHF 24,340.00	37.09
21		CHF 24,860.40	38.95
22		CHF 25,380.80	40.80
23		CHF 25,901.20	42.65
24		CHF 26,421.60	44.51
25		CHF 26,942.00	46.36
30	CHF 29,544.00	CHF 29,544.00	55.64
40	CHF 35,756.00	CHF 35,756.00	74.18
50		CHF 41,968.00	92.73

Appendix 5: Battery comparison

Model	Connection to PV installation	Capacity (kWh)	Price in CHF	Price per kWh
Varta Element 6	AC	6	9,200	1,533
Varta Element 9	AC	9	12,200	1,356
Varta Element 12	AC	12	15,400	1,283
Fronius Energy Package	DC	6	11,000	1,833
E3DC S10 Hauskraftwerk E AI 4Z	DC	9.2	14,500	1,576
Tesla Powerwall 2	AC	13.5	9,500	704
innov energy salidomo 9	AC	9	15,880	1,764
GREENROCK Home	AC/DC	9	14,000	1,556

Appendix 6: Technical Data "Tesla Powerwall 2"

Item	Value	Unit
Material cost	9,500	CHF
Total energy	14	kWh
Usable energy	13.5	kWh
Warranty	10	years
Initial state of charge	5	kWh
Real power, max continuous (charge and discharge)	5	kW
Round trip efficiency	90%	%
Losses	0.05%	%
Max discharge depth	1.35	kWh
Battery cost reduction in 10 years	42.00%	% of current battery cost
Battery cost reduction in 20 years	50.00%	% of current battery cost
Replacement cost year 10	5,510	CHF
Replacement cost year 20	4,750	CHF

Appendix 7: Results of Basic analysis

Results (no battery and 75% debt financing)

Number of Panels	NPV (CHF)	NPV (EUR)	IRR	Payback (years)	LCOE (CHF/kWh)	LCOE (EUR/kWh)
1	-CHF 1,162.05	-1,150.43 €	-2.43%	0	CHF 0.3034	0.3004 €
2	-CHF 3,251.13	-3,218.62 €	-3.87%	0	CHF 0.3034	0.3004 €
3	-CHF 5,725.41	-5,668.16 €	-4.90%	0	CHF 0.3034	0.3004 €
4	-CHF 8,339.62	-8,256.22 €	-5.62%	0	CHF 0.3034	0.3004 €
5	-CHF 11,036.17	-10,925.81 €	-6.17%	0	CHF 0.3034	0.3004 €
6	-CHF 8,818.28	-8,730.10 €	-4.66%	0	CHF 0.2465	0.2440 €
7	-CHF 7,794.32	-7,716.37 €	-3.76%	0	CHF 0.2170	0.2149 €
8	-CHF 6,817.06	-6,748.89 €	-3.01%	0	CHF 0.1949	0.1930 €
9	-CHF 5,873.06	-5,814.33 €	-2.37%	0	CHF 0.1778	0.1760 €
10	-CHF 4,960.61	-4,911.01 €	-1.82%	0	CHF 0.1640	0.1624 €
11	-CHF 4,160.10	-4,118.50 €	-1.37%	0	CHF 0.1533	0.1518 €
12	-CHF 3,383.82	-3,349.99 €	-0.96%	0	CHF 0.1444	0.1429 €
13	-CHF 2,626.68	-2,600.41 €	-0.60%	0	CHF 0.1368	0.1355 €
14	-CHF 1,887.44	-1,868.56 €	-0.27%	0	CHF 0.1304	0.1290 €
15	-CHF 1,169.99	-1,158.29 €	0.02%	30	CHF 0.1247	0.1235 €
16	-CHF 472.80	-468.08 €	0.29%	30	CHF 0.1198	0.1186 €
17	CHF 212.36	210.24 €	0.53%	29	CHF 0.1155	0.1143 €
18	CHF 886.48	877.61 €	0.76%	28	CHF 0.1116	0.1105 €
19	CHF 1,550.08	1,534.58 €	0.97%	27	CHF 0.1082	0.1071 €
20	CHF 2,202.98	2,180.95 €	1.17%	27	CHF 0.1051	0.1040 €
21	CHF 2,939.36	2,909.96 €	1.38%	26	CHF 0.1020	0.1009 €
22	CHF 3,665.37	3,628.72 €	1.58%	26	CHF 0.0991	0.0981 €
23	CHF 4,383.18	4,339.35 €	1.77%	25	CHF 0.0965	0.0956 €
24	CHF 5,093.19	5,042.26 €	1.95%	25	CHF 0.0941	0.0932 €
25	CHF 5,795.51	5,737.56 €	2.12%	24	CHF 0.0920	0.0910 €
30	CHF 9,209.05	9,116.96 €	2.84%	23	CHF 0.0832	0.0824 €
40	CHF 14,294.97	14,152.02 €	3.50%	21	CHF 0.0747	0.0739 €
50	CHF 19,217.24	19,025.07 €	3.94%	20	CHF 0.0695	0.0688 €

Results (no battery and 100% equity financing)

Number of Panels	NPV (CHF)	NPV (EUR)	IRR	Payback (years)	LCOE (CHF/kWh)	LCOE (EUR/kWh)
1	-CHF 218.82	-216.63 €	-0.13%	0	CHF 0.2387	0.2363 €
2	-CHF 1,364.66	-1,351.01 €	-1.53%	0	CHF 0.2387	0.2363 €
3	-CHF 2,895.71	-2,866.75 €	-2.53%	0	CHF 0.2387	0.2363 €
4	-CHF 4,566.68	-4,521.02 €	-3.23%	0	CHF 0.2387	0.2363 €
5	-CHF 6,320.00	-6,256.80 €	-3.76%	0	CHF 0.2387	0.2363 €
6	-CHF 4,313.93	-4,270.79 €	-2.30%	0	CHF 0.1950	0.1930 €
7	-CHF 3,175.66	-3,143.90 €	-1.42%	0	CHF 0.1718	0.1701 €
8	-CHF 2,084.09	-2,063.25 €	-0.70%	0	CHF 0.1544	0.1528 €
9	-CHF 1,025.78	-1,015.52 €	-0.08%	0	CHF 0.1408	0.1394 €
10	CHF 0.97	0.97 €	0.46%	29	CHF 0.1300	0.1287 €
11	CHF 933.85	924.51 €	0.90%	27	CHF 0.1216	0.1203 €
12	CHF 1,842.49	1,824.07 €	1.29%	26	CHF 0.1145	0.1134 €
13	CHF 2,732.00	2,704.68 €	1.64%	25	CHF 0.1086	0.1075 €
14	CHF 3,603.61	3,567.58 €	1.96%	24	CHF 0.1035	0.1024 €
15	CHF 4,453.42	4,408.88 €	2.24%	23	CHF 0.0990	0.0980 €
16	CHF 5,282.97	5,230.14 €	2.50%	22	CHF 0.0952	0.0942 €
17	CHF 6,100.50	6,039.50 €	2.74%	22	CHF 0.0917	0.0908 €
18	CHF 6,906.98	6,837.91 €	2.96%	21	CHF 0.0887	0.0878 €
19	CHF 7,702.95	7,625.93 €	3.16%	21	CHF 0.0860	0.0851 €
20	CHF 8,488.21	8,403.33 €	3.35%	20	CHF 0.0835	0.0827 €
21	CHF 9,335.85	9,242.49 €	3.55%	20	CHF 0.0811	0.0803 €
22	CHF 10,173.13	10,071.40 €	3.75%	19	CHF 0.0788	0.0781 €
23	CHF 11,002.20	10,892.17 €	3.93%	19	CHF 0.0768	0.0760 €
24	CHF 11,823.47	11,705.23 €	4.10%	18	CHF 0.0749	0.0742 €
25	CHF 12,637.05	12,510.68 €	4.26%	18	CHF 0.0732	0.0725 €
30	CHF 16,606.89	16,440.82 €	4.95%	17	CHF 0.0663	0.0656 €
40	CHF 23,106.73	22,875.67 €	5.57%	16	CHF 0.0596	0.0590 €
50	CHF 29,442.93	29,148.50 €	5.99%	15	CHF 0.0555	0.0550 €

Appendix 8: Results of Battery Analysis

Results (Battery and 75% debt financing)

Number of Panels	NPV (CHF)	NPV (EUR)	IRR	Payback (years)	LCOE (CHF/kWh)	LCOE (EUR/kWh)
1	-CHF 23,704.86	-23,467.81 €	N/A	0	CHF 1.8748	1.8561 €
2	-CHF 24,484.32	-24,239.48 €	N/A	0	CHF 1.0891	1.0782 €
3	-CHF 25,314.15	-25,061.01 €	N/A	0	CHF 0.8272	0.8189 €
4	-CHF 26,159.54	-25,897.94 €	-13.03%	0	CHF 0.6962	0.6893 €
5	-CHF 27,048.22	-26,777.74 €	-10.83%	0	CHF 0.6177	0.6115 €
6	-CHF 23,038.74	-22,808.35 €	-8.33%	0	CHF 0.5084	0.5033 €
7	-CHF 20,483.14	-20,278.30 €	-6.70%	0	CHF 0.4415	0.4371 €
8	-CHF 18,212.01	-18,029.89 €	-5.50%	0	CHF 0.3914	0.3875 €
9	-CHF 16,301.29	-16,138.28 €	-4.61%	0	CHF 0.3524	0.3488 €
10	-CHF 14,628.40	-14,482.12 €	-3.89%	0	CHF 0.3212	0.3180 €
11	-CHF 13,233.28	-13,100.94 €	-3.33%	0	CHF 0.2962	0.2932 €
12	-CHF 12,000.62	-11,880.61 €	-2.86%	0	CHF 0.2753	0.2726 €
13	-CHF 10,882.12	-10,773.30 €	-2.46%	0	CHF 0.2577	0.2551 €
14	-CHF 9,818.96	-9,720.77 €	-2.10%	0	CHF 0.2426	0.2402 €
15	-CHF 8,801.15	-8,713.14 €	-1.78%	0	CHF 0.2295	0.2272 €
16	-CHF 7,843.33	-7,764.90 €	-1.48%	0	CHF 0.2180	0.2159 €
17	-CHF 6,950.26	-6,880.76 €	-1.22%	0	CHF 0.2079	0.2059 €
18	-CHF 6,093.44	-6,032.50 €	-0.98%	0	CHF 0.1989	0.1970 €
19	-CHF 5,276.34	-5,223.58 €	-0.76%	0	CHF 0.1909	0.1890 €
20	-CHF 4,495.74	-4,450.78 €	-0.56%	0	CHF 0.1837	0.1818 €
21	-CHF 3,628.85	-3,592.56 €	-0.35%	0	CHF 0.1768	0.1750 €
22	-CHF 2,793.43	-2,765.49 €	-0.15%	0	CHF 0.1706	0.1688 €
23	-CHF 1,990.64	-1,970.74 €	0.03%	30	CHF 0.1648	0.1632 €
24	-CHF 1,205.17	-1,193.12 €	0.21%	30	CHF 0.1596	0.1580 €
25	-CHF 441.10	-436.69 €	0.37%	30	CHF 0.1548	0.1533 €
30	CHF 3,158.64	3,127.05 €	1.07%	28	CHF 0.1356	0.1342 €
40	CHF 8,332.09	8,248.77 €	1.84%	26	CHF 0.1139	0.1128 €
50	CHF 13,145.21	13,013.76 €	2.38%	25	CHF 0.1010	0.1000 €

Results (Battery and 100% equity financing)

Number of Panels	NPV (CHF)	NPV (EUR)	IRR	Payback (years)	LCOE (CHF/kWh)	LCOE (EUR/ kWh)
1	-CHF 19,921.82	-19,722.60 €	N/A	0	CHF 1.6154	1.5993 €
2	-CHF 19,758.05	-19,560.47 €	N/A	0	CHF 0.9271	0.9178 €
3	-CHF 19,644.64	-19,448.20 €	N/A	0	CHF 0.6976	0.6906 €
4	-CHF 19,546.80	-19,351.33 €	-11.69%	0	CHF 0.5829	0.5771 €
5	-CHF 19,492.25	-19,297.32 €	-9.18%	0	CHF 0.5141	0.5089 €
6	-CHF 15,694.59	-15,537.64 €	-6.48%	0	CHF 0.4244	0.4202 €
7	-CHF 13,024.67	-12,894.43 €	-4.75%	0	CHF 0.3685	0.3648 €
8	-CHF 10,639.23	-10,532.84 €	-3.48%	0	CHF 0.3265	0.3232 €
9	-CHF 8,614.21	-8,528.07 €	-2.55%	0	CHF 0.2938	0.2909 €
10	-CHF 6,827.01	-6,758.74 €	-1.81%	0	CHF 0.2677	0.2650 €
11	-CHF 5,299.52	-5,246.53 €	-1.23%	0	CHF 0.2467	0.2442 €
12	-CHF 3,934.49	-3,895.15 €	-0.75%	0	CHF 0.2292	0.2270 €
13	-CHF 2,683.63	-2,656.80 €	-0.34%	0	CHF 0.2145	0.2123 €
14	-CHF 1,488.10	-1,473.22 €	0.03%	30	CHF 0.2018	0.1998 €
15	-CHF 337.94	-334.56 €	0.37%	29	CHF 0.1908	0.1889 €
16	CHF 752.25	744.72 €	0.66%	29	CHF 0.1812	0.1794 €
17	CHF 1,777.69	1,759.91 €	0.93%	28	CHF 0.1727	0.1710 €
18	CHF 2,766.87	2,739.20 €	1.17%	27	CHF 0.1652	0.1635 €
19	CHF 3,716.33	3,679.17 €	1.39%	27	CHF 0.1585	0.1569 €
20	CHF 4,629.30	4,583.01 €	1.60%	26	CHF 0.1524	0.1509 €
21	CHF 5,607.45	5,551.38 €	1.81%	26	CHF 0.1466	0.1452 €
22	CHF 6,554.13	6,488.59 €	2.01%	25	CHF 0.1414	0.1400 €
23	CHF 7,468.18	7,393.50 €	2.19%	25	CHF 0.1366	0.1353 €
24	CHF 8,364.91	8,281.26 €	2.36%	24	CHF 0.1323	0.1310 €
25	CHF 9,240.24	9,147.84 €	2.52%	24	CHF 0.1283	0.1270 €
30	CHF 13,396.29	13,262.32 €	3.21%	22	CHF 0.1122	0.1110 €
40	CHF 19,983.66	19,783.83 €	3.97%	19	CHF 0.0940	0.0930 €
50	CHF 26,210.71	25,948.60 €	4.49%	18	CHF 0.0831	0.0822 €

Appendix 9: Results of Sensitivity Analysis

No battery and 75% debt

		Peak electricity price buy				
		CHF 0.150	CHF 0.200	CHF 0.267	CHF 0.300	CHF 0.350
Household consumption (kWh)	2,000	-CHF 3,503	-CHF 2,349	-CHF 812	-CHF 41	CHF 1,113
	3,500	-CHF 2,316	-CHF 457	CHF 2,018	CHF 3,260	CHF 5,118
	5,000	-CHF 1,324	CHF 1,124	CHF 4,383	CHF 6,018	CHF 8,465
	10,000	CHF 1,014	CHF 4,845	CHF 9,947	CHF 12,506	CHF 16,336
	20,000	CHF 3,970	CHF 9,548	CHF 16,979	CHF 20,705	CHF 26,283

No battery and 100% equity

		Peak electricity price buy				
		CHF 0.150	CHF 0.200	CHF 0.267	CHF 0.300	CHF 0.350
Household consumption (kWh)	2,000	CHF 3,116	CHF 4,270	CHF 5,808	CHF 6,578	CHF 7,732
	3,500	CHF 4,303	CHF 6,162	CHF 8,637	CHF 9,879	CHF 11,737
	5,000	CHF 5,296	CHF 7,743	CHF 11,002	CHF 12,637	CHF 15,084
	10,000	CHF 7,633	CHF 11,464	CHF 16,566	CHF 19,125	CHF 22,955
	20,000	CHF 10,589	CHF 16,167	CHF 23,598	CHF 27,324	CHF 32,902

Battery and 75% debt

		Peak electricity price buy				
		CHF 0.150	CHF 0.200	CHF 0.267	CHF 0.300	CHF 0.350
Household consumption (kWh)	2,000	-CHF 23,407	-CHF 20,584	-CHF 16,824	-CHF 14,939	-CHF 12,116
	3,500	-CHF 19,765	-CHF 14,936	-CHF 8,503	-CHF 5,277	-CHF 447
	5,000	-CHF 16,976	-CHF 10,550	-CHF 1,991	CHF 2,302	CHF 8,728
	10,000	-CHF 12,623	-CHF 3,529	CHF 8,585	CHF 14,660	CHF 23,754
	20,000	-CHF 9,734	CHF 1,181	CHF 15,720	CHF 23,011	CHF 33,927

Battery and 100% equity

		Peak electricity price buy				
		CHF 0.150	CHF 0.200	CHF 0.267	CHF 0.300	CHF 0.350
Household consumption (kWh)	2,000	-CHF 13,948	-CHF 11,125	-CHF 7,365	-CHF 5,480	-CHF 2,657
	3,500	-CHF 10,306	-CHF 5,477	CHF 956	CHF 4,182	CHF 9,012
	5,000	-CHF 7,517	-CHF 1,091	CHF 7,468	CHF 11,761	CHF 18,187
	10,000	-CHF 3,164	CHF 5,930	CHF 18,044	CHF 24,118	CHF 33,213
	20,000	-CHF 275	CHF 10,640	CHF 25,179	CHF 32,470	CHF 43,385

Appendix 10: Results of Scenario Analysis

Parameter	Bad case	Base case	Best case
Assumptions			
Annual change in electricity price buy (before inflation)	-2%	0%	2%
Change in electricity price sell (before inflation)	-2%	0%	2%
Annual change in self consumption	-2%	0%	2%
Maintenance costs as percentage of gross investment	1.50%	1%	0.50%
KPIs (no battery and 75% debt)			
NPV (CHF)	-CHF 10,887.86	CHF 4,383.18	CHF 26,134.75
NPV (EUR)	-10,778.98 €	4,339.35 €	25,873.41 €
IRR	-5%	1.77%	6%
Payback	N/A	25	18
LCOE (CHF/ kWh)	CHF 0.1102	CHF 0.0965	CHF 0.0829
LCOE (EUR/kWh)	0.1091 €	0.0956 €	0.0821 €
KPIs (no battery and 100% equity)			
NPV (CHF)	-CHF 4,268.84	CHF 11,002.20	CHF 32,753.77
NPV (EUR)	-4,226.15 €	10,892.17 €	32,426.23 €
IRR	-1.77%	3.93%	7.73%
Payback	N/A	19	14
LCOE (CHF/ kWh)	CHF 0.0904	CHF 0.0768	CHF 0.0632
LCOE (EUR/kWh)	0.0895 €	0.0760 €	0.0625 €
KPIs (battery and 75% debt)			
NPV (CHF)	-CHF 25,530.44	-CHF 1,990.64	CHF 31,592.85
NPV (EUR)	-25,275.14 €	-1,970.74 €	31,276.92 €
IRR	-10.26%	0.03%	5.16%
Payback	0	30	19
LCOE (CHF/ kWh)	CHF 0.1835	CHF 0.1648	CHF 0.1462
LCOE (EUR/kWh)	0.1817 €	0.1632 €	0.1447 €
KPIs (battery and 100% equity)			
NPV (CHF)	-CHF 16,071.62	CHF 7,468.18	CHF 41,051.67
NPV (EUR)	-15,910.90 €	7,393.50 €	40,641.15 €
IRR	-7.51%	2.19%	6.82%
Payback	0	25	16
LCOE (CHF/ kWh)	CHF 0.1553	CHF 0.1366	CHF 0.1180
LCOE (EUR/kWh)	0.1537 €	0.1353 €	0.1168 €