

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 PHOTOVOLTAIC SYSTEMS IN STOCKHOLM,
SWEDEN

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Keywords: Sustainability; Energy Finance; Economic Analysis; Renewable Energy; PV Panels; Rooftop Solar; Alternative Investment; Stockholm; Sweden

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Abbreviations

A: Ampere

AC: Alternating current

CAGR: Constant annual growth rate

CB: Central bank

CO₂: Carbon dioxide

DC: Direct current

DCF: Discounted cash flow

EU: European Union

EUR: Euros

GDP: Gross domestic product

GWh: Gigawatt hour

IMF: International Monetary Fund

IRR: Internal rate of return

kW: Kilowatt

kWh: Kilowatt hour

LCOE: Levelized cost of electricity

NPV: Net present value

O&M: Operation and maintenance

PV: Photovoltaic

PVGIS: Photovoltaic Geographical Information System

ROT: Repairs, conversion, extension

SDG: Sustainable Development Goals

SEK: Swedish kronor

Sqm: square meter

TWh: Terawatt hour

VAT: Value-added tax

W: Watt

Wp: Watt peak capacity

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I. Executive Summary

Location: Stockholm, Sweden

Date of analysis: Dec/2023

Recommendation: install 26 solar photovoltaic (PV) panels (47.7 sqm), for a net present value (NPV) of 11,701 Euros (133,730 Swedish krona), with a payback period of 10.2 years.

Main economic results

Financing	NPV (EUR)	NPV (SEK)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)	LCOE (SEK/kWh)
Gov. subsidies, 75% bank debt	11,701	133,730	10.2	16.2%	0.0663	0.7577
Gov. subsidies, 100% supplier's credit	11,267	128,766	12.2	25.3%	0.0683	0.7809
Gov. subsidies, 100% equity	13,004	148,622	8.9	11.6%	0.0602	0.6882
No gov. subsidies, 100% equity	926	10,584	16.5	4.0%	0.0791	0.8181

(All rows are for the same number of panels)

Main inputs and assumptions

Household and Economics

Electricity Consumption	9000	kWh/year	Inflation	2023	6.9%	per year
Electricity price – buy	1.81	SEK/kWh		2024	3.6%	per year
Electricity price – sell	0.44	SEK/kWh		2025	2.7%	per year
Bank loan interest rate	6.15%	per year		2026	2.3%	per year
Bank loan maturity	12	years		2027+	2.0%	per year
Equity cost of capital	3.36%	per year	Exchange rate SEK-EUR		0.0875	SEK/EUR

PV panels

Peak power	375	W/panel	System losses	13.5%	of output	
Panel area	1.83	m ² /panel	Degradation with age	0.5%	Per year	
Useful life	25	Years	Fixed O&M cost system	480	SEK/year	
Variable O&M cost	0	SEK/year	Fixed O&M cost/panel	40	SEK/year	
Total cost of optimal installation size (without subsidies)			12,551	EUR	143,442	SEK
Total cost of optimal installation size (after subsidies)			10,116	EUR	115,614	SEK

Government subsidies

There are two main subsidies, the green deduction (grön teknik) and ROT (Repairs, Conversion, Extension) deduction. Generally, one can avail either one, but not both. Since the green deduction is often larger and therefore more recommended, it was the one assumed in this project. For solar panels, green deduction covers 19.4% of complete cost (material and installation costs). For batteries for storing self-produced electricity, green deduction covers 50% of material and labor costs. There is also an income tax reduction of 0.60 SEK/kWh for electricity fed back to the grid.

II. Introduction

This Work Project aims to determine the economic value of installing a rooftop solar photovoltaic (PV) system for a standard residential household in Stockholm, Sweden. This Work Project is integrated in a stream of similar projects developed by other students, but targeting different localities. Ultimately, this combined research seeks to raise awareness about the benefits of renewable energy sources by offering a comprehensive and accurate database of the potential savings connected with the transition from conventional to solar powered electricity generation.

Indeed, by signing the Paris Agreement in 2015, countries committed to lowering their emissions of carbon dioxide (CO₂) and other greenhouse gases, and to preparing for the effects of climate change. As such, one possibility for countries cutting their CO₂ emissions connected to energy use is by increasing their share of renewable energy. Also in 2015, the United Nations established the Sustainable Development Goals (SDG) to address global challenges and promote sustainable development. In effect, SDG 7 relates to ensuring “affordable and clean energy” for all while SDG 13 promotes urgent “climate action” to combat global warming and its impacts. Thus, renewable energy, namely solar, has the potential to play a pivotal role in achieving these goals since it represents a clean and abundant source of power.

In addition, solar PV can be considered a disruptive technology when compared to other established methods of producing electricity for various reasons. First, PV systems can be considered highly reliable as they have not any moving parts and require almost zero maintenance during its operational lifetime. Secondly, solar PV has potential for mass production and economies of scale, and allows scalability (i.e., efficiency is independent of the installation size). Other benefits of solar PV include shorter innovation cycles (as only a few weeks are required for installation), compatibility with multiple grid points rather than with just a few centralized power plants, and the possibility of connecting households behind the user side of the connection point. On top, increasingly affordable PV panels have led to a rise in the residential use, enabling energy consumers to become prosumers (simultaneously consumers and producers) (Child, et al. 2020).

With this said, quantifying the potential savings that a rooftop solar PV system can generate is extremely relevant nowadays. To do so, different types of data were collected in order to be input in an appropriate financial model. This model returned a thorough analysis, including decision-rule parameters such as the net present value (NPV), internal rate of return (IRR), payback period,

and the levelized cost of electricity (LCOE, i.e., the selling price of energy (SEK/kWh) that sets the NPV to zero, assuming all energy generated by the system is sold to the grid). It was possible to select the type of panel (with peak power of 375 W, 400 W, 415 W, 425 W or 450 W), the number of panels to install (from 1 to 10, and the maximum number of panels such that it is suitable for a residential rooftop PV project of 10 kWp), and the share of the total investment that was financed by a bank loan.

For an annual electricity consumption of 9000 kWh (average for a household of four in Sweden), the system that returned the highest NPV was composed by 26 panels of 375 W each. This corresponds to the maximum number of panels, since the NPV of the project was increasing with the number of panels. In the base-case scenario (75% of the project financed by bank debt and 25% by equity, considering government subsidies), the NPV was 133,730 SEK (equivalent to 11,701 EUR as of December 2023), the payback period was 10.2 years, the IRR was 16.2% (versus a discount rate of 3.36%), and the LCOE was 0.7577 SEK/kWh (versus a current selling price of electricity generated of 0.44 SEK/kWh). Despite the LCOE being higher than the current selling price of electricity, it is still lower than the current electricity buy price. Plus, the positive NPV and high IRR indicate that the project is financially feasible. To evaluate the project under different price settings, a scenario analysis was performed. Incorporating a battery in the system was also considered, the conclusion being that it would not add value to the project given the reliable Swedish electricity grid and the main goal of saving on energy expenditures. Lastly, it was estimated the impact of performing active energy management.

The format of this paper is as follows: *Section III* describes the Swedish electricity market and its share of renewable energy; *Section IV* clarifies the modelling assumptions; *Section V* outlines data and how inputs for this analysis were estimated; *Section VI* presents the results of the economic analysis; *Section VII* outlines the final recommendation; *Section VIII* covers some limitations of the analysis.

III. Swedish Electricity Market

i. Structure

The Swedish electricity market is from November 1st 2011 divided into four bidding areas by decision of the Swedish National Grid (Svenska Kraftnät), marked as SE1, SE2, SE3 and SE4 (see *Appendix 1*). Stockholm city is included in bidding area SE3. The explanation is that while in

Southern Sweden demand is greater than supply, Northern Sweden has an excess of electricity generation. This is because most of Sweden's wind power and hydropower is situated in the North. This has led to transmission bottlenecks, so the boundaries between the bidding areas were designed where there are congestions in the national grid. Thus, the purpose of the bidding areas is to detect where the national grid requires expansion and where an increased electricity production is required to better serve consumption. This allows to increase the efficiency of electricity supply.

Additionally, Sweden is part of the Nord Pool power market, that facilitates the trading of electricity among adhering Nordic and Baltic countries. Established in 1996, Nord Pool is the world's first power exchange and the world's first multinational power exchange. Nord Pool operates both day-ahead and intraday markets, allowing market participants to manage their electricity needs. The market is driven by supply and demand, with prices being set by a continuous auction process. As such, the Nord Pool promotes efficient, secure, and transparent electricity trading, fosters competition, encourages innovation, and facilitates the integration of renewable energy sources into the trading mix.

ii. Electricity Generation and Use

Electricity generation in Sweden mainly comes from hydropower and nuclear power (accounting for 73% of total energy production in 2021, see *Appendix 2*). This has been the case since the 1980s. Overall, electricity generation has been increasing overtime and totaled 168.6 TWh in 2021 (see *Appendix 3*). Notable recent changes in Sweden's power production include the expansion of wind power, the shutdown of two nuclear reactors (Ringhals 2 in December'19 and Ringhals 1 in December'20), and the closure of the last coal power plant in 2020.

As for electricity use, it reached its highest level in 2001, at 150 TWh. Since then, electricity use has followed a declining trend, amounting to 135.6 TWh in 2021. The sectors that use the most electricity are industrial, residential, and commercial and public services (see *Appendix 4*). Additionally, electricity consumption per capita has been decreasing since 2001 (see *Appendix 5*).

iii. Electricity Prices

In Sweden, electricity cost is divided into two parts: the cost of electricity used and the power transmission and distribution network fee (elnätsavgiften). The former is based on the Nord Pool

spot price while the latter is then divided into three parts: a fixed annual fee for having electricity connected to the house, a variable electricity transmission fee to have electricity delivered to your home (dependent on the amount of electricity used) and energy tax (energiskatt). Overall, the costs payable to the electricity supply company and to the power transmission and distribution company account individually each for 25 percent of the total costs of the electricity. The remaining 50 percent of total cost include taxes, VAT, and renewable energy certificate duties (Swedish Energy Agency 2023).

Contracts may feature 3 different electricity price settings: fixed price (guaranteed fixed price per kWh for up to 3 years), variable price (price per kWh that follows the fluctuations of the market) and hourly price (flexible price that changes from hour to hour). Regarding electricity providers, some of the most relevant in Sweden include E.ON and Vattenfall. There are also some players that stand out in terms of providing fossil-free electricity, such as Fortum (third biggest provider of carbon dioxide free electricity in Europe) and Telge Energi (only sells energy with eco-label Good Environment Choice, Bra Miljöval, by the Swedish Society for Nature Conservation, Naturskyddsföreningen).

iv. Renewable Energy in Sweden

Sweden targets 100% fossil-free electricity production in 2040 (Riksdag 2023). Indeed, wind power has increased significantly over the last 10 years and accounted for 16% of the total electricity generation in 2021 (see *Appendix 3*). As for solar PV energy generation, it has increased from 9 GWh in 2010 to 1507 GWh in 2021 (16,644% increase). Overall, 47% of the total energy supply in 2021 was from renewable sources. This comes as a result of the growing push for cleaner energy and the introduction of policy mechanisms to promote the production of electricity from renewable energy sources (e.g., Electricity Certificate System).

v. Solar Energy in Sweden

Even though Sweden has global reputation of being a leader in sustainability and energy systems, most people would consider it to have little potential for solar energy production due to its gloomy winter months with few daylight hours, plenty of snow, and extreme cold. Nonetheless, solar irradiation in Sweden is actually comparable to the United Kingdom or Northern Germany on an annual basis (see *Appendix 6*). Cold and snow might also actually aid when it comes to electricity generation. In truth, solar panel efficiency is inversely proportional to the temperature (Samal et

al. 2019). In addition, on cold, clear days, snow from the ground can reflect extra sunlight onto solar panels like a mirror, creating an “albedo effect” that allows to produce even more electricity (Andrews et al. 2012). Lastly, PV systems are installed in such a way that snow does not affect their performance. For example, solar panels’ dark, reflective glass accelerates snow melt and its slide off. Also, installations are usually tilted up at 30 to 45 degrees, which prevents snow accumulation up to some extent (Gay 2017).

Indeed, the Swedish PV market it is not yet a fully mature one. The Swedish PV development started later than in other European markets (e.g., Germany, Spain) and still is rather small. Two main reasons for this include the fact that Swedish electricity has historically been generated by low CO₂-footprint technologies (i.e., nuclear and hydropower) and comparably low electricity prices. Another explanation is poor availability of trained installers. Even though there is widespread interest, private individuals lack the knowledge, so training programs and awareness raising campaigns are needed. To tackle this, the government has promoted 2-year courses for designing PV systems within the Higher Vocational Education taught by some regional schools together with PV companies (Yrkeshögskolan 2023).

Nonetheless, total installed PV capacity in Sweden grew by 49% in 2022. This is consistent with the trend over the five previous years, where the total market grew by 45% (2021), 57% (2020), 66% (2019), 59% (2018) and 47% (2017) (see *Appendix 7*). Such strong overall growth in the last decade started with the creation of the direct capital subsidy system in 2006, and since then has been driven by decreasing system prices (mainly due to higher module efficiency and higher demand), widespread popularity among the community, increasing interest from utilities, and the tax credit for micro-producers (see *Section V.v. Government Subsidies*). Another explanation could be that the spike in interest due to high energy prices under the European energy crisis, since self-consumption of PV electricity is permitted in Sweden.

IV. Modelling Assumptions

The standard household was defined as a family of 4, with both parents going off to work during the day, and kids going to school. This is, it is assumed that there is not much activity in the house during the day. The household was also assumed to have stable electricity consumption habits throughout the duration of the project (i.e., stable annual consumption of electricity). The family lives in an isolated home whose roof has full sun exposure and enough area to mount fixed PV

panels of whatever size is optimal and at the optimal slope and azimuth. The investment was assumed to be made in 2023 (year 0) and the project was presumed to last for 25 years.

V. Data

i. Solar Irradiance and Potential Electricity Generation

Typical solar irradiance data was extracted from the Photovoltaic Geographical Information System (PVGIS 2023) at an hourly level. Data varies according to several variables: irradiance on the local, the mounting type of the PV system, the position of the panels (slope and azimuth), the PV technology used, the installed peak PV power, and the estimated system losses (i.e., all the losses in the system, that cause the power actually delivered to the electricity grid to be lower than the power produced by the PV panels).

The hourly electricity generation in a typical year was then assumed as the average between the values available for the years 2018, 2019 and 2020. Data refers to a random locale in Stockholm (59°20'09.6"N 18°00'00.0"E) since there are no significant irradiance differences across the city. It was considered that panels are mounted in a fixed position, have optimized slope and azimuth to maximize output, and use crystalline silicon technology. Indeed, this technology matches the current market offer for residential PV. As for estimated system losses, the software sets them at 14% by default and accounts for losses in cables and power inverters, dirt and snow on modules, degradation with age, and so on. Since there was no strong reason to deviate from this assumption, estimated system losses were kept at default. Indeed, it is assumed that 0.5% of the overall system losses accounts for degradation with age (Jordan, et al. 2016).

ii. Electricity Consumption

To estimate the hourly electricity consumption of a standard household, a two-stage approach was used. First, determining the total annual consumption and then understanding the hourly distribution throughout the year. For the first step, total annual consumption was assumed at 9,000 kWh following the EU-founded project Odysee-Mure statistic (2022). This is a relatively high value, as Sweden has the second highest household electricity consumption in the EU, only after Norway. This can be justified by the cold climate that leads to increased demand for heating, most often relying on electricity. Another reason is the generalized high standard of living across Sweden, that allows residents to possess various electrical appliances that contribute to overall

electricity consumption (e.g., electric stoves, dishwashers, air fryers, and other modern amenities). Indeed, Sweden was the fifth country with highest per-capita volume sales in the household appliances market worldwide (Statista 2023) (see *Appendix 8*). As such, the standard household is assumed to have electric space heating, electric water heating, and domestic electrical appliances such as washing machine, electric stove, and dishwasher. After defining the standard annual consumption, the second stage included distributing it hourly throughout the year. Since it was not possible to obtain an hourly load profile for an average Swedish household, consumption was distributed according to the hourly load profile of the bidding area SE3 as a whole (referent to the city of Stockholm and including energy usage of all sectors, instead of only the residential). This data was extracted from the Nord Pool database.

iii. PV Panels Data

To estimate the investment of the PV panels system, quotes for five different models with different characteristics were considered. Quotes were relative to the total cost (i.e., including installation work, mounting materials, etc.) and are presented in Table 1:

Table 1 - Solar PV panel total cost (in SEK) and respective panel efficiency

Peak Power Panel (W)	375	400	415	425	450
Area (sqm)	1.83	1.92	1.92	1.94	2.00
Panel Efficiency	20.5%	20.8%	21.6%	21.9%	22.5%
Total Cost (SEK/panel)	5,517	6,367	6,997	8,267	9,700

The panels vary in peak power, efficiency, dimension, and area, but they all have 25 years of useful life and are all made up of monocrystalline cells. In fact, monocrystalline solar panels are dominating in terms of cell technology and are a popular choice for residential installations due to their high efficiency, durability, long lifespan, and sleek look.

Since the Swedish PV market is still in its early years, there is still little information about the actual operation and maintenance (O&M) costs of PV systems, so these were estimated. Previous studies (Lindahl, et al. 2023) divided the yearly O&M costs into different cost categories for a single-family dwelling PV system. Starting with fixed O&M costs: land and site maintenance costs for a rooftop PV system are negligible as it claims no land and barely impacts the roof it is mounted on. Insurance costs of rooftop PV are assumed to be null as these are often protected by the standard home insurance and there is no additional real estate tax if the system is installed.

Additionally, there are no yearly fixed grid expenses nor yearly electricity balancing expenses for residential PV systems since according to the law, an electricity user may not be charged for the feed if the fuse subscription is no more than 63A and power is at maximum 43.5kW (Energimarknadsbyrån 2023). The energy needed to operate a residential PV system is also ignored. Building or installation permits for PV systems are also not necessary as of August 1st 2018 (Lindahl et al. 2023). The fixed O&M costs missing are then annual electricity maintenance and monitoring costs and annual administrative costs. It is assumed that homeowners handle the many time-consuming chores associated with running PV installations, without necessarily considering the cost of their time. Either way, the cost of an individual's own labor is approximated. Following 2022 data (as it was the most recent available), the average monthly pay in Sweden was 38,300 SEK before taxes (SCB 2023), the mean tax rate being 32.34% (Skatteverket 2023). After deductions, taxes and fees, the average monthly salary in Sweden was about 25,950 SEK. Given that 2022 contained 1960 working hours, an individual's own time was estimated at 160 SEK/hour. Nearly all software firms operating in small-scale distributed PV market sector provide free software, such as mobile applications or webpages, that allow the system owner to view summary graphs and tables and track the PV system production in real time. Because of this, it is quite simple to monitor the output of a residential PV system, as it only entails taking a quick look at those figures. It was assumed that two hours per year are needed to follow the performance (even if many spend more time tracking output just for enjoyment), so the annual electricity maintenance and monitoring costs were estimated to be 320 SEK/year. As for yearly physical monitoring expenses, a quick look at the roof is often considered sufficient to identify any mechanical issues that might occur. This process was assumed to require in total one hour each year at an approximated cost of 160 SEK/year. In terms of annual administrative expenses for residential PV systems, the majority happen in the initial months after the investment. Following that, almost everything is automated, so only residual administrative labor is required. One example is the easy tax credit handling for micro-producers of renewable electricity (Riksdag 2023). The yearly surplus of fed-in electricity must be reported by the grid-owner to the Swedish Tax Agency, and the corresponding tax decrease must then be pre-printed on the yearly tax return form that is provided to the owner of the system. The system owner then only has additional administrative work when wants to move or switch power suppliers. Since by general rule this does not occur annually, the annual administrative expenses are regarded as insignificant and are

assumed to be null. Lastly, annual module cleaning costs were also considered. Residential PV systems are typically installed with a certain inclination that allows rainfall to clear the majority of dust-pollen grains from the modules (Appels, et al. 2013). Electricity is not produced by snow-covered modules, but, if a system in Stockholm is completely coated with snow in January, the yearly electricity decrease will only be magnified by around 2%. Shoveling the snow will therefore probably take more time and cost more money than the productivity improvement may bring (Stridh 2012). Furthermore, removing the snow from the panels entails the possibility of personal harm or damaging the PV modules. So, it is advised for individuals not to remove the snow from the PV modules. Nonetheless, severe soiling (e.g., bird droppings) might reduce electricity generation (Ghazi and Ip 2014) and may be needed to be removed by hand. It was assumed that each panel required 15 minutes to clean per year, with annual module cleaning costs estimated at 40 SEK/panel. Thus, fixed O&M costs were estimated at 480 SEK/year plus 40 SEK/year/panel.

Table 2 – Fixed O&M costs categories and respective estimated cost (SEK/year)

Fixed O&M Cost Categories	Estimated Cost (SEK/year)
Annual electricity maintenance and monitoring costs	320
Annual physical monitoring costs	160
Annual land and site maintenance costs	-
Annual administrative costs	0
Annual insurance costs	-
Annual fixed grid costs	-
Annual system operating electricity	-
Annual real estate tax	-
Annual electricity trading and balancing costs	-
Other taxes	0
Total fixed O&M costs of system	480
Annual module cleaning costs (per panel)	40
Total fixed O&M costs per panel	40

Regarding variable O&M costs, these were assumed to be negligible. Indeed, the PV technology is based on solar energy, free for all. So, there are no fuel costs linked to the generation of PV energy. Plus, maintenance is not related with the amount of electricity generated, but instead with degradation, and no taxes are paid for the feed-in of electricity. As such, variable O&M costs were assumed to be negligible.

iv. Economic Data

Given the energy crisis and consequent outliers in electricity prices, year 2022 was excluded from the trend analysis performed on electricity prices. The electricity cost was assumed to be the

average price between years 2018 and 2021 for households with a consumption band of 5,000 kWh to 14,999 kWh as per Eurostat. This returns a cost of 1.81 SEK/kWh with all taxes and levies included. Electricity cost per kWh was assumed to follow the inflation trend. As for surplus PV electricity feed-in, it is currently compensated by the market price, the Nord Pool price was assumed to be the average of the SE3 day-ahead price for years between 2018 and 2021, that being 0.44 SEK/kWh. It might be possible to get additional compensation in certain cases from some electricity grid providers, but these were assumed not to be obtained. In parallel, there is an income tax reduction of 0.60 SEK/kWh for electricity fed back to the grid, for connections up to 100A and a maximum of 18,000 SEK and 30,000 kWh per year, considering that input and output from the electricity grid must be done through the same connection point, fuse, and meter. The household individuals were assumed to have had paid enough tax during the income year to be able to benefit from this tax deduction. For private entities, there is no energy tax on self-consumed electricity as long as the installed power output is less than 500 kWp, according to the Energy Taxation Act (Riksdag 2023). Additionally, if the income from the electricity sales and other possible income from the private residential property is less than 40,000 SEK per year, no income tax needs to be paid on the sale of surplus of electricity. As for VAT, there is no need to register for it if sales do not exceed 80,000 SEK before VAT (Skatteverket 2023). Despite general consensus that electricity prices will eventually decline, there is a lot of unpredictability on when and how that will happen. Therefore, electricity buy and sell prices are assumed to grow alongside inflation throughout the lifetime of the project.

Inflation data was extracted from IMF as of October 2023 outlook. According to IMF, inflation will decrease from 3.6% in 2024, 2.7% in 2025, 2.3% in 2026 to 2% in 2027, rate at which it is projected to remain constant afterwards (IMF 2023). Inflation was used to estimate growth in PV system maintenance costs, electricity cost for residential household and electricity price for selling to the grid (thus electricity savings associated with the project). In parallel, annual household income was assumed to increase at the constant annual growth rate of Swedish GDP per capita, 4% (IMF 2023). VAT in Sweden is 25% (Skatteverket 2023). The exchange rate from Swedish kronor (SEK) to Euro (EUR) was 1 SEK = 0.0875 EUR as of November 27th 2023 (Xe 2023).

The equity cost of capital of the household was assumed to be the 10-year interest rate swap set by the Swedish CB (Sveriges Riksbank) and equal to 3.36% per year as of October 13th 2023 (Cbonds 2023). Since the future cash flows are essentially avoided costs and given the AAA credit risk

rating of Sweden (Fitch Ratings 2023), this rate can be considered risk-free. While a rooftop PV project with a 25-year duration is not exactly risk-free (i.e., future cash flows are sensitive to changes in electricity buy and sell prices, macroeconomic conditions, and regulatory environment), the downside risk should be low given the 100% fossil-free electricity production by 2040 target (Riksdag 2023). Therefore, there was no compelling reason for considering a higher discount rate.

Regarding the consumer loan, three scenarios were considered, with financing the project with 0%, 75% and 100% debt. However, the base-case scenario was defined with the initial investment being financed by 75% bank debt and 25% equity. Quotes for a green loan were obtained from two Swedish banks, Swedbank and SEB. Swedbank offered a 6.15% variable annual interest rate (as of October'23), with repayment period up to 12 years for a loan amount between 30,000 SEK and 350,000 SEK (Swedbank 2023). SEB offered a 6.40% annual interest rate (as of November'23), maturing in 2 to 10 years, for a loan amount between 20,000 SEK and 350,000 SEK (SEB 2023). However, SEB's offer was only valid when buying solar cells from one of its partners (i.e., E.ON or Vattenfall). Thus, to ensure greater flexibility in our project, the interest rate assumed was 6.15% with 12-year maturity from Swedbank.

Table 3 – Bank quotes for a green loan (in SEK)

	Bank	
	Swedbank	SEB
Annual interest rate (%)	6.15%	6.40%
Repayment period (years)	up to 12 years	2 -10 years
Loan amount (SEK)	30,000 - 350,000	20,000 - 350,000

v. Government Subsidies

As for government subsidies, there are currently in place two main fundings, the green deduction (grön teknik) and ROT (Repairs, Conversion, Extension) deduction. Generally, one can avail either one, but not both. Green deduction is a unique tax reduction that is directly deducted from the invoice provided by the company installing the technology. For solar panels, it covers 19.4% of complete cost (material and installation costs). For batteries for storing self-produced electricity, it covers 50% of material and labor costs. The company then requests payment from the Swedish Tax Agency. This means that private individuals do not need to apply for the deduction themselves since the tax deduction is already on the final invoice. The tax reduction for green technology is a maximum of 50,000 SEK per person per year. As the standard household is composed by two

adults, a maximum of 100,000 SEK was assumed to be granted (Skatteverket 2023). The household was also assumed to fulfill the requirements of Swedish Tax Agency to obtain the green deduction. The ROT deduction technically covers 30% of the labor cost (Skatteverket 2023). However, the labor cost for installing solar panels is typically calculated as a fixed percentage of the total cost, making the ROT deduction amount to 9% of the total cost for solar panels. While the ROT deduction is beneficial, the green deduction is generally larger and therefore more recommended. So, if benefiting from government subsidies, the green deduction was assumed.

VI. Economic Analysis

i. Basic Analysis

This project was valued using the discounted cash flow methodology (DCF). This valuation approach estimates the net present value (NPV) of an investment based on expected future cash flows discounted at an appropriate discount rate. As such, this valuation technique considers the time value of money.

In order to determine the economic value of installing rooftop PV in Stockholm, several steps were taken. First, using the load profile and total annual consumption estimated, the hourly electricity consumption was derived in kWh (*load*). Then, the latter was compared with the hourly solar electricity generation (*gen*) for the 8,760 hours of a full year. By doing so, it was possible to determine in yearly terms the amount of self-produced electricity that was consumed by the household (*cons_{HH}*), the amount self-generated electricity that exceeded self-consumption and was thus sold to the grid (*grid_{sell}*), and the residual amount of electricity that still had to be bought from the grid in case self-production was not enough to sustain self-consumption (*grid_{buy}*) as described below in (1) and (2):

$$(1) \text{ if } load > gen, \quad cons_{HH} = gen; \quad grid_{sell} = 0; \quad grid_{buy} = load - gen$$

$$(2) \text{ if } load < gen, \quad cons_{HH} = load; \quad grid_{sell} = gen - load; \quad grid_{buy} = 0$$

From here, it was possible to compute the yearly revenue from selling excess electricity back to the grid (*revenue*) and the yearly residual cost from buying the residual load to secure consumption patterns (*cost_{buy}*). By subtracting the latter to the former, the yearly electricity expenses with the PV system were computed (*cost_{with PV}*) according to equation (3):

$$(3) \text{ cost}_{with PV} = \text{revenue} - \text{cost}_{buy}$$

Yearly electricity savings (*savings*) were then derived as the difference between the household electricity cost without the PV system ($\text{cost}_{without PV}$) and with the PV system, as explained below in (4):

$$(4) \text{ savings} = \text{cost}_{without PV} - \text{cost}_{with PV}$$

It is worth mentioning that annual electricity savings were assumed to grow yearly with inflation, in resemblance to electricity buy and sell prices. From the yearly savings, the income tax reduction ($\text{tax}_{reduction}$, growing accordingly with GDP per capita CAGR) was added, while the annual maintenance costs ($\text{cost}_{O\&M}$, also growing yearly with inflation) and the loan-repayment cash flows (*repayment*) were subtracted, resulting in the annual cash flows (*cashflow*), as stated in (5):

$$(5) \text{ cashflow} = \text{savings} + \text{tax}_{reduction} - \text{cost}_{O\&M} - \text{repayment}$$

NPV was thus derived as the sum of the project's annual cash flows discounted at the household equity cost of capital of 3.36%, minus the initial investment. The NPV was computed for all models of panels (five), and for a number of panels between 1 to 10, and then for the maximum number of panels. A maximum number of panels had to be defined given that the NPV was increasing with the number of panels (mostly due to the high government subsidies). The latter was defined as the number of panels correspondent to a PV system of 10 kWp. Indeed, a typical residential PV system generally does not exceed 10 kWp of total installed capacity (Lindahl et al. 2023). Results are presented below in Table 4:

Table 4 - Optimal installation size and NPV, base-case scenario

NPV (SEK)		Type of Panels (W)				
		375	400	415	425	450
#Panels	1	(985)	(764)	(741)	(1,498)	(1,808)
	2	8,071	8,513	8,560	7,044	6,425
	3	17,124	17,766	17,813	15,519	14,514
	4	25,774	26,379	26,263	23,078	21,407
	5	33,388	33,796	33,449	29,336	26,924
	6	40,096	40,298	39,729	34,695	31,565
	7	46,206	46,223	45,433	39,479	35,641
	8	51,896	51,738	50,731	43,859	39,311
	9	57,278	56,941	55,730	47,950	42,723
	10	62,429	61,945	60,529	51,840	45,930

	Max	133,730	126,942	118,745	94,422	77,442
#Panels Corresp. To Max		26	25	24	23	22

By analyzing Table 4, the installation setup that maximized the NPV in the base-case scenario (75% bank debt, 25% equity) was 26 panels of 375W. This translates into a PV system with an area of 47.7 sqm and total installed capacity of 9750 W. In the first year, the system would generate 10,240 kWh of electricity. Out of this, 31% (3,195 kWh) would be self-consumed while 69% (7,045 kWh) would be sold to the grid. Thus, to meet the household's annual consumption necessities, 5,085 kWh would still have to be bought from the grid (equivalent to 64% of the total annual electricity consumption). This would require an initial investment of 143,442 SEK (12,551 EUR). In the base-case scenario with government subsidies, the project would have initial equity investment of 28,904 SEK, a NPV of 133,730 SEK (11,791 EUR), a payback period of 10.2 years, an IRR of 16.2%, and a LCOE of 0.7577 SEK/kWh (0.0663 EUR/kWh). Even though the LCOE is higher than the current selling price of electricity generated (0.44 SEK/kWh), it is still lower than the current buy price of electricity (1.81 SEK/kWh). In addition, the project has positive NPV and IRR higher than the equity cost of capital (3.36%). This indicates that despite the high LCOE, the project is financially feasible.

If the project is financed with a 100% credit and benefits from government subsidies, the NPV decreases slightly to 128,766 SEK (11,267 EUR) while the payback period, IRR and LCOE increase to 12.2 years, 25.3%, and 0.7809 SEK/kWh (0.0683 EUR/kWh). The opposite movement is observed if the project is fully financed by equity and benefits from government subsidies, the NPV increases to 148,622 SEK (13,004 EUR), while the payback period, IRR and LCOE decreases to 8.9 years, 11.6% and 0.6882 SEK/kWh (0.0692 EUR/kWh). Thus, it is possible to understand that the share of the investment financed by debt does not impact significantly the economics of the project in the current credit conditions. Nonetheless, the current unstable credit environment and hiking interest rates may negatively affect the financials of the project.

In the scenario in which the project is fully financed by equity, but does not benefit from government subsidies, the NPV and IRR decrease to 10,584 SEK (926 EUR) and 4.0%, respectively. The payback period increases to 16.5 years and the LCOE to 0.9043 SEK/kWh (0.0791 EUR/kWh). Thus, the financing method of the investment impacts its economic viability. Indeed, if the project is 100% financed by equity and benefits from government subsidies, it is

possible to maximize its NPV at a lower payback period and LCOE (as cashflows are not used for debt repayments). Nevertheless, the IRR is lower as a higher initial investment is required.

ii. Additional Analysis

a. Scenario Analysis

In this research, the primary factors of concern that may drive the biggest impact on NPV are electricity prices. Indeed, the NPV was increasing with the number of panels and driving the optimal size of the system to the maximum because of relatively low electricity buy price and high sell price (along with government incentives such as the income tax reduction). As such, it is prudent to consider different future trends in electricity prices and their impact on the economics of the project. In effect, it is very unlikely that the conditions in which this analysis was performed will remain constant throughout the entire useful life of the installation. For example, the planned opening of new nuclear reactors in Sweden (Reuters 2023) might contribute to a decrease in future electricity prices. In the contrast, if the conflict between Russia and Ukraine prevails and natural gas prices rise further than expected, then electricity prices could rise even further. Such increase could also be amplified when combined with a dry and cold winter with low wind.

Therefore, four different scenarios were tested for the optimal installation size: *Scenario I*: instead of growing with inflation, electricity prices would decrease by 2% each year; *Scenario II*: electricity prices would grow with inflation until year 5 and then decrease annually by 2%; *Scenario III*: electricity prices would rise by 5% per year in the first five years and then grow with inflation; and *Scenario IV*: electricity buy and sell prices would grow with inflation until year 10, when they would suffer a 30% and 10% drop, respectively, and would then decrease yearly by 2% until year 15. Results can be found in Table 5 below:

Table 5 – Scenario analysis for the optimal installation size

SEK	Scenario									
	Base-case		I		II		III		IV	
Prices	Buy	Sell	Buy	Sell	Buy	Sell	Buy	Sell	Buy	Sell
T = 0	1.81	0.44	1.81	0.44	1.81	0.44	1.81	0.44	1.81	0.44
T= 5	1.98	0.48	1.67	0.41	1.98	0.48	2.20	0.53	1.98	0.48
T= 10	2.18	0.53	1.51	0.37	1.79	0.43	2.43	0.59	1.50	0.47
T = 25	2.94	0.71	1.11	0.27	1.32	0.32	3.27	0.79	1.11	0.35
NPV 375 W	133,730		69,863		88,680		152,023		86,211	

b. Batteries

Battery storage is becoming an increasingly popular addition to solar PV systems. Incorporating a battery in the PV system entails several advantages, as it allows to store the surplus of electricity that is generated by the installation. Indeed, batteries contribute to achieving energy independence, by maximizing self-consumption of energy and building resilience against power shortages. In addition, batteries can help lower energy bills over the long run, and decrease a home's carbon footprint as they minimize the need for fossil fuel-based backup generators.

There are currently two types of battery technologies in the market, lead-acid and lithium. On the one hand, lead-acid batteries are the traditional and most popular choice, as they have lower upfront cost. However, they have shorter useful life (generally 3 to 5 years), require regular maintenance, have lower energy density, and are heavier and bulkier. On the other hand, lithium batteries have longer lifespan (up to 15 years), offer higher energy density, are more compact and lightweight, and have negligible energy losses. As such, even though lithium batteries entail higher cost, they are frequently more cost-effective in the long run due to better performance and lower maintenance requirements. Lithium batteries are then a more environmentally friendly alternative as they minimize batteries disposal.

With this said, when quantifying the value added of a battery in a PV system composed by 26 panels of 375W, it was assumed a lithium battery with useful life of 15 years. The model chosen was Tesla's battery Powerwall 2, as per recommendation of most providers. Indeed, Powerwall 2 was rated as one of the best solar batteries in 2023 (Wigness 2023) (Drolet 2023). This battery has a total usable energy capacity of 13.5 kWh, 7 kW peak power, 100% depth of discharge, and 10 years of warranty. As such, useful life of the battery was assumed to be 10 years. Additionally, Powerwall 2 integrates an inverter within its design. This means that the direct current (DC) generated by the solar system is directly converted into alternating current (AC) by the battery itself, eliminating the need for an additional inverter. It was possible to obtain quotes from Hemsol, with selling price being 79,800 SEK as of December 2023 (excluding subsidies). Since Powerwall's electrical interface itself provides a simple connection to any building, installation is relatively easy. Thus, any additional costs associated with labor, rack or additional necessary cables were ignored. In the base-case scenario, the household benefitted from the government subsidy deducting 50% of the total cost of the battery. Additionally, the household was assumed

to replace the battery in years 10 and 20 of the project, while taking advantage from the green deduction once again. The price of the battery was projected to grow in line with inflation. The flows of the system with the battery were set such that the first priority would be self-consumption (6):

$$(6) \text{ } cons_{HH} = \min (gen, load)$$

The second flow was to charge the battery (if not already full), as follows below (7):

$$(7) \text{ } battery \text{ } level_h = \max (\min (battery \text{ } level_{h-1} + gen - load, battery_{capacity}), 0)$$

If PV panel generation was insufficient to meet demand, electricity could be obtained from the battery (8):

$$(8) \text{ } battery_{HH} = \max (-(battery \text{ } level_h - battery \text{ } level_{h-1}), 0)$$

In case nor PV panel generation nor energy stored in the battery would be enough to cover demand, electricity could be bought from the grid as last resort (9):

$$(9) \text{ } grid_{buy} = load - gen - battery_{HH}$$

In case there was excess electricity relative to the capacity of the battery (13 kWh), the surplus would be injected into the grid in order to maximize revenues (10):

$$(10) \text{ } battery_{sell} = \max (gen - load - (battery \text{ } level_h - battery \text{ } level_{h-1}), 0)$$

Then it was possible to compute the yearly savings and NPV associated with batteries within the PV system. Given that the battery still had 5 years of useful life left at the end of the project, its residual value was calculated following the straight-line depreciation method. So, the household can increase the NPV associated with energy storage if it decides to sell the battery by its residual value at the end of the project.

Table 6 - Total costs, incremental savings and NPV associated with a battery

Battery capacity (kWh)	13.5
Total battery cost (SEK)	175,352
Incremental savings (SEK/year)	12,616
Residual value battery (SEK)	39,900
NPV not selling the battery (SEK)	71,770
NPV selling the battery by residual value (SEK)	111,670

When comparing the NPV of the PV system with (71,770 SEK if not selling the battery or 111,670 SEK if selling the battery) and without a battery (133,730 SEK), it is possible to understand that adding a battery dampens the economics of the project. Even though including a battery decreases the NPV of the project, there could be scenarios in which such decline could still be justified. Some circumstances could be unreliable grid access combined with unstable energy supply. However, Sweden has a stable and reliable electricity grid with delivery security being at 99.986% in 2021 (Energimarknadsinspektionen 2021). So, adding a battery does not add value to the project.

c. Active Energy Management

Active energy management may also improve the financial attractiveness of the project. As such, the potential increase in savings by controlling and optimizing the household usage of electrical appliances, namely the clothes washing machine and the dishwasher, was estimated. To do so, data from a study on the electricity consumption behavior of Swedish households was used (Zimmermann 2009). Any seasonality effects or differences in cycle modes were neglected. For the purpose of the analysis, the household was assumed to have electrical appliances with delay function (i.e., allowing to set a pre-specified time for the machine to start a cycle while delaying the actual start of the operation). Thus, users were assumed to be willing to use that function to concentrate energy usage to the hours where the difference between electricity generated and consumed was higher. According to the data presented below in Table 6, this time period corresponds to between 8 a.m. and 2 p.m. (can also see *Appendix 9*).

Table 7 - Hourly generation of the system, energy consumed, and sold to the grid in an average day of the year (kWh)

Hour of the day	Average (kWh)		
	Generation panels	PV consumed	PV to grid
1	0.00	0.92	0.00
2	0.00	0.91	0.00
3	0.00	0.90	0.00
4	0.02	0.89	0.00
5	0.08	0.90	0.00
6	0.45	0.93	0.00
7	1.27	1.00	0.27
8	2.26	1.06	1.20
9	3.23	1.09	2.14
10	3.74	1.10	2.64
11	3.91	1.10	2.81
12	3.84	1.10	2.74
13	2.82	1.08	1.74
14	3.36	1.09	2.27

15	2.00	1.07	0.93
16	1.18	1.08	0.10
17	0.43	1.09	0.00
18	0.13	1.11	0.00
19	0.05	1.11	0.00
20	0.00	1.09	0.00
21	0.00	1.07	0.00
22	0.00	1.03	0.00
23	0.00	0.99	0.00
24	0.00	0.95	0.00

First, it was assumed that the family would do 230 clothes washing cycles per year, corresponding to a mean annual consumption of 213 kWh. As such, the average electricity consumption per cycle of the washing machine was estimated at 0.93 kWh, and each cycle was predicted to take one hour to complete (Whirlpool 2023). According to data, families are more prone to wash their clothes either from 5 p.m. to 8 p.m. So, it was analyzed the scenario if individuals changed their behavior and washed their clothes at 11 a.m. By doing so, the household could increase its electricity savings by 292 SEK (25.53 EUR), allowing the NPV to be 139,834 SEK (12,236 EUR). The payback period and the IRR would almost remain flat at 9.6 years and 16.9%, respectively.

Regarding the dishwasher, the household was assumed to do 200 cycles per year, equivalent to an average electricity consumption of 236 kWh per year and 1.18 kWh per cycle. Each cycle was estimated to take 2 hours (Whirlpool 2023). According to data, individuals use their dishwashers most of the times between 7 p.m. and 10 p.m. If the family would use the dishwasher at 11 a.m., it could save more 323 SEK (28.29 EUR) and increase its NPV to 140,494 SEK (12,293 EUR) and IRR to 17.0%. The payback period of the investment would decrease to 9.5 years.

If the household optimized the use of both the washing machine and the dishwasher, then it could save 615 SEK (53.82 EUR) on a yearly basis and maximize the NPV of the project to 146,598 SEK (12,827 EUR). The payback period would decrease to 8.9 years and the IRR rise to 17.6%.

With this said, if the household already possesses electrical appliances with the delay function, then it should pursue active energy management in the maximum number of devices possible in order to maximize savings and the NPV of the project. If the family does not own such electrical devices, then it should consider investing in those. In effect, as of the time of this research, it was possible to get both a washing machine and dishwasher with delay function for approximately 10,000 SEK, which is a lower amount than the increase in the NPV driven by optimized consumption behavior (12,868 SEK).

VII. Final Recommendation

All things considered, the recommendation of building a PV system composed by 26 panels of 375W remains in place. For the base-case scenario, the project's NPV, IRR, payback period and LCOE are 133,730 SEK, 16.2%, 10.2 years and 0.7577 SEK/kWh, respectively.

VIII. Limitations

Nonetheless, this analysis features some limitations. First, sizing an optimal PV system is a unique process for every building. It is difficult to derive a general rule given the unique load curve and production potential of each building, which ultimately determines the self-consumption. Secondly, the hourly load profile considered in this analysis refers to the combined consumption profile of all sectors in bidding area SE3 (Stockholm). As such, there is the risk that the household load profile might not exactly match the load profile of all combined sectors.

Lastly, even though all the variables were carefully examined, they were based on non-temporal evidence. However, key inputs of this analysis will most likely change over time, such as supplier quotes, government laws and subsidies, the cost of debt, and equity, or electricity costs. Therefore, despite this study may be deemed accurate based on the facts available as of December 2023, it will most likely become less reliable in the short, medium to long term.

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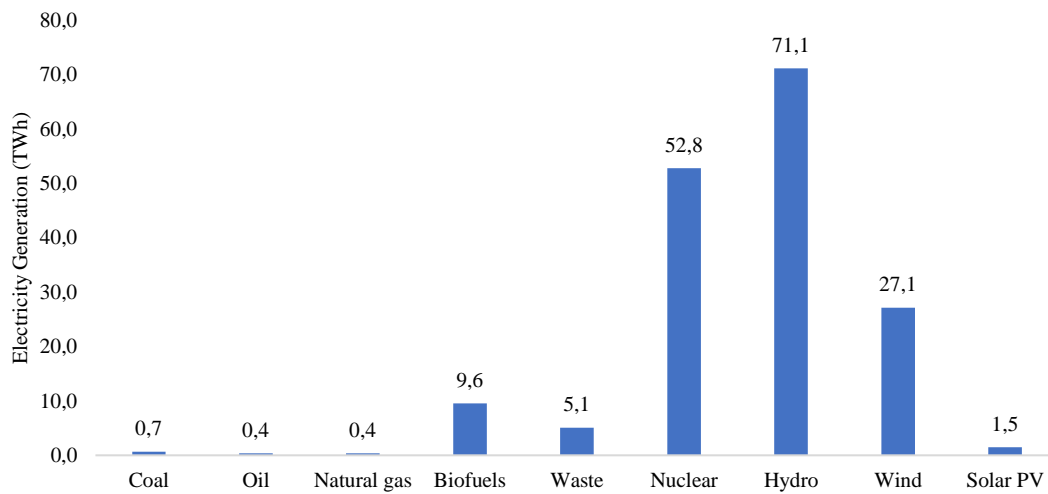
Appendix

Appendix 1 - Swedish Electricity Market Bidding Areas



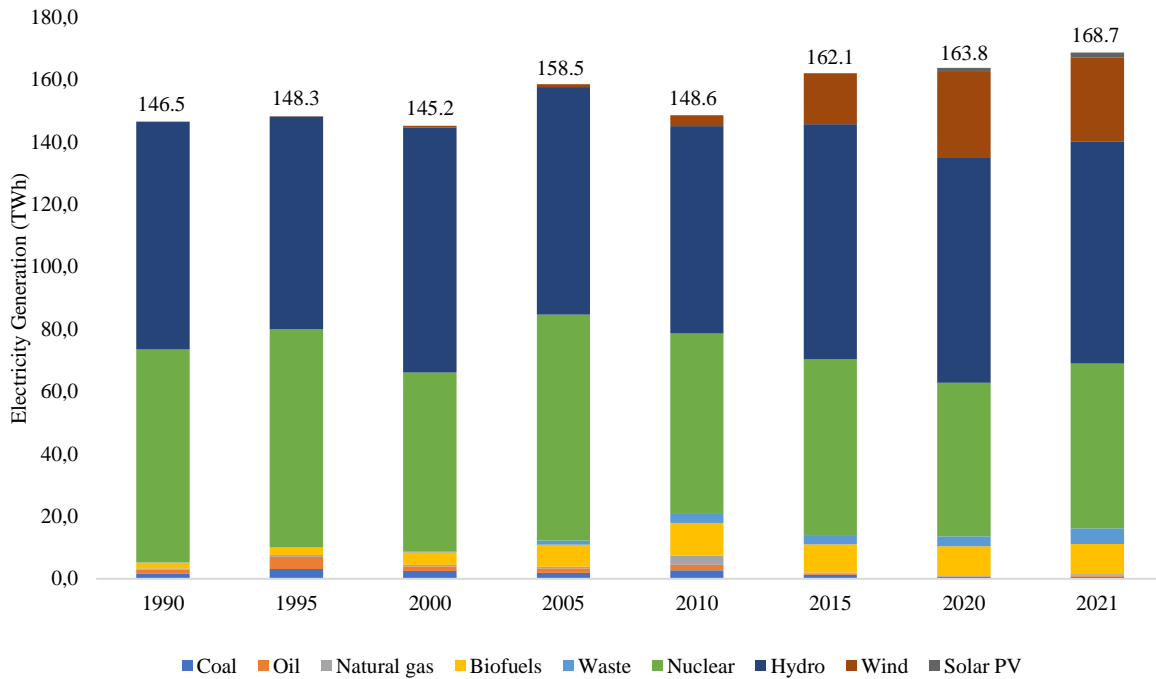
Appendix 2 - Electricity Generation by Source, Sweden 2021 (TWh)

Electricity Generation by Source, Sweden 2021 (TWh)



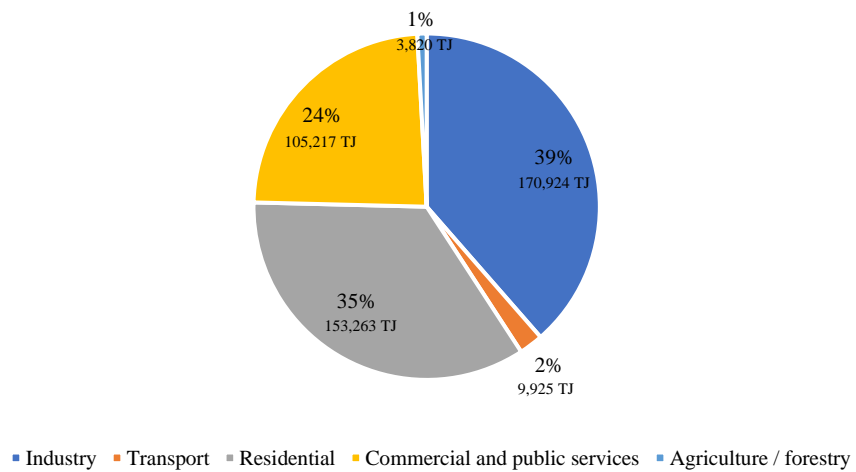
Appendix 3 - Total Electricity Generation, Sweden 1990 - 2021 (TWh)

Electricity Generation by Source, Sweden 1990 - 2021 (TWh)



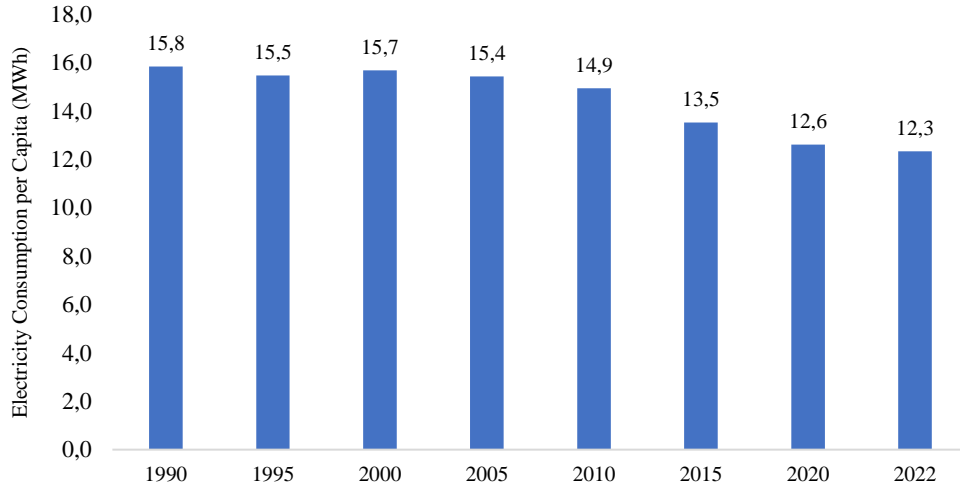
Appendix 4 - Electricity Consumption by Sector, Sweden 2020

Electricity Consumption by Sector, Sweden 2020



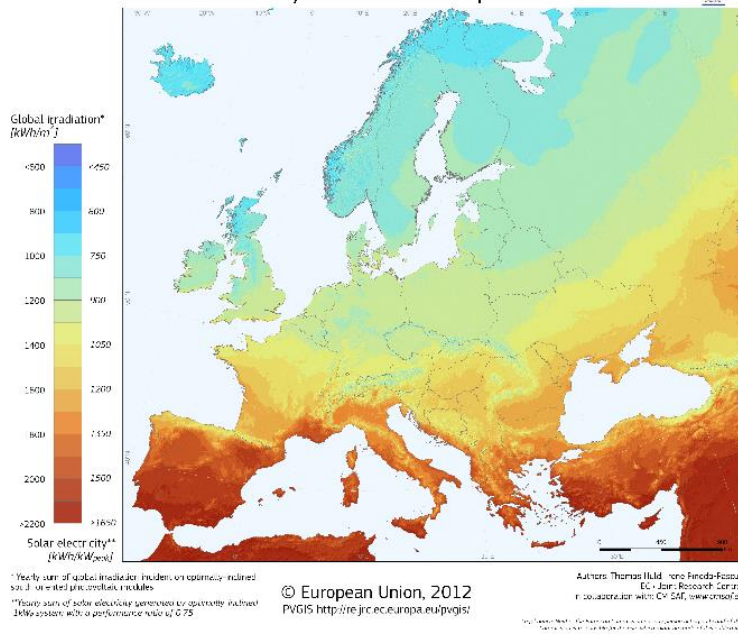
Appendix 5 - Electricity Consumption per Capita, Sweden 1990-2022 (MWh)

Electricity Consumption per Capita, Sweden 1990-2022 (MWh)



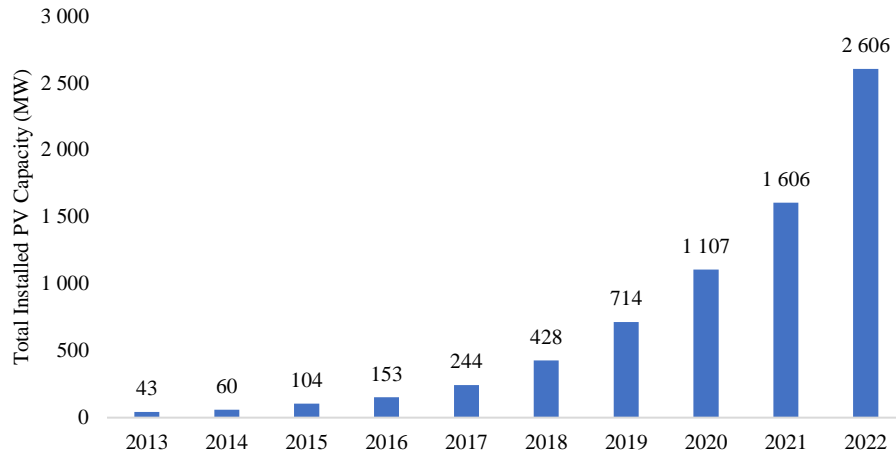
Appendix 6 – Photovoltaic Solar Electricity Potential in European Countries

Photovoltaic Solar Electricity Potential in European Countries



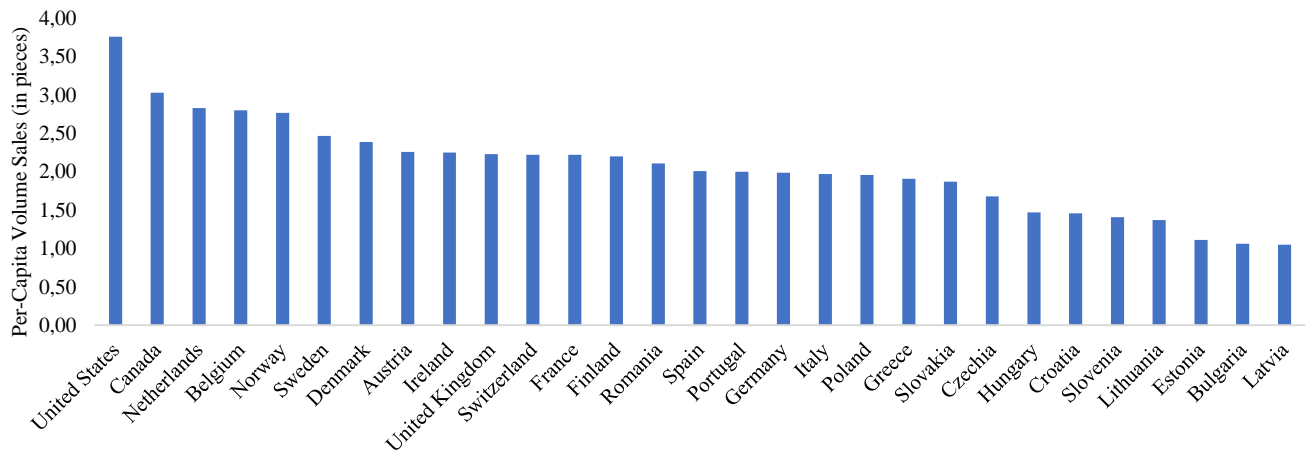
Appendix 7 - Cumulative Solar Photovoltaic Power Capacity Installed in Sweden, 2013-2022 (MW)

Cumulative Solar Photovoltaic Power Capacity Installed in Sweden, 2013-2022 (MW)



Appendix 8 - Per-Capita Volume Sales in the Household Appliances Market Worldwide by Country, 2022 (in pieces)

Per-Capita Volume Sales in the Household Appliances Market Worldwide by Country, 2022 (in pieces)



Appendix 9 – PV Generation, Self-Consumption, and Excess Production in an Average Day (kWh)

PV Generation, Self-Consumption, and Excess Production in an Average Day (kWh)

