Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Engineering Cybernetics

Alexander Berglind

# Assessment of the value of solar PV modules for private consumers in Norway

Master's thesis in Industrial Cybernetics
Supervisor: Sebastien Gros
June 2022

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TTK4900 Engineering Cybernetics, Master´s Thesis

*Alexander Berglind*

supervised by
Prof. Sebastien Gros

Department of Engineering Cybernetics
Faculty of Information Technology and Electrical Engineering
Norwegian University of Science and Technology (NTNU)

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# Abstract

This project aims to assess the value of current solar PV installations for private consumers in Norway to validate the profitability of the installations in conjunction with the power market in Europe.

The spot price is at an all-time high in Norway as of 2021. Future analysis of the power market done by NVE shows that this high is not declining any soon, meaning exploring alternative methods for producing and saving energy is very relevant in today's society.

Solar energy is Norway's fastest-growing renewable energy source, especially in the private market. However, their advertised profitability often rests on the future analysis of possible solar power production in an area and not on historical data from PV systems. To address this, I have assessed by collecting historical house consumption data and solar PV production data from 15 different residences in Norway, then comparing it to the Nord Pool spot price from 2013 to 2021. The results show that the profitability of a PV system is closely linked to the power market. For the PV systems to be economically viable, the spot price must equal the most expensive year ever recorded rather than the least expensive year. The results also showed more value in utilizing the produced power from the PV system for self-consumption rather than selling it to the grid.

This work serves as a foundation for further research in solar PV systems for private residences in Norway. Further research should focus on assessing the data in correspondence with the future of the power market and simulating the outcome based on different scenarios, as well as investigate the values of including batteries in the system of smart management or the house consumption to maximize the value the PV system.

# Sammendrag


Dette prosjektet har som mål å vurdere verdien av solcelleanlegg for private forbrukere i Norge for å validere lønnsomheten til installasjonene sett i sammenheng med kraftmarkedet i Europa.

Spotprisen er på et rekordhøyt nivå i Norge og fremtidig analyser av kraftmarkedet utført av NVE viser at denne høye prisen ikke vil synke med det første, noe som betyr at det å utforske alternative metoder for å produsere og spare energi er svært relevant i dagens samfunn.

Solenergi er den raskest voksende fornybare energikilden i Norge i dag, spesielt innen det private markedet. Deres antatte lønnsomhet hviler ofte på fremtidige analyser av mulig solenergiproduksjon i et område og ikke på historiske data fra solcelleanlegg. For å adressere dette har jeg gjort en vurdering ved å samle inn historiske husforbruksdata og sol energi produksjonsdata fra 15 ulike boliger i Norge, for så å sammenligne det med Nord Pool spotpris fra 2013 til 2021. Resultatene viser at lønnsomheten av et solcelleanlegg er nært knyttet til kraftmarkedet. For at systemene skal være økonomisk levedyktige, må spotprisen tilsvare det dyreste året som noen gang er registrert i stedet for det billigste året. Resultatene viste også at det er mer verdi i å utnytte den produserte kraften fra solcelleanlegget til eget forbruk fremfor å selge den til strømnettet.

Dette arbeidet vil virke som et grunnlag for videre forskning innen solcelleanlegg for private boliger i Norge. Ytterligere forskning bør fokusere på å vurdere dataene i samsvar med fremtiden til kraftmarkedet, og simulere utfallet basert på forskjellige scenarier, samt undersøke verdiene av å inkludere batterier i systemet eller smart styring av husets forbruk for å maksimere verdien av solcelleanlegget.

# Preface

This Master's thesis is the product of my work in the spring of 2022 as the completion of my Master's degree in Industrial Cybernetics at the Norwegian University of Science and Technology (NTNU). The work has been done from 20.01.2022 to 20.06.2021 and is a continuation and extension of my project theses completed in the fall of 2021.

I hope this thesis can serve as a foundation for further research regarding solar PV systems for private residences in Norway. Throughout this project, I learned a lot about writing software, Norway's power market, and solar PV systems. Countless hours have been spent on bug fixes, redoing plots, and calculations in the software, but the results have been exciting, and in the end, it was all worth it. It has been a learning experience and a very gratifying project.

I want to thank Sebastien Gros for supervising this thesis and providing sound guidance when needed. I would also like to thank all the private residences that could provide data and those who could not for offering help and going beyond my expectations to assist me in my project. Lastly, I want to thank Theodor from Otovo AS for helping me retrieve the necessary solar PV production data.

# Acronyms

**AC** Alternating current. 21

**API** Application Programming Interface. 25–27, 55

**CET** Central European Time. 9

**$CO_2$** Carbon dioxide. 10, 13

**CSV** Comma-Separated value. 26

**DC** Direct current. 21

**EU** European Union. 13

**kW** Kilowatt. 14

**kWh** Kilowatt hour. XI, 8, 12, 13, 15, 16, 20, 22, 27–30, 34–36, 42–44, 53

**kWp** Kilowatt peak. XXIX, 6, 20, 34–36, 47, 53

**LCOE** Long Term Cost Concept. 18

**$m^2$** Square meter. XI, XXIX, 8, 29–31

**MWh** Megawatt hour. 9, 10, 28

**NOK** Norwegian Kroner. 6, 9, 10, 14, 16, 22, 27, 28, 42–44, 47, 48, 50, 313–320

**NPV** Net Present Value. 18, 22

**NTNU** Norges Tekniske- og Naturvitenskapelige Universitet. III, 1, 25

**NVE** Norges vassdrags- og energidirektorat. I, II, 3, 13, 52, 54

**PPPP** Public-private-people partnership. 17

**PV** Photovoltaics. I, III, XI–XXXI, 1, 4–6, 15, 17, 18, 20–23, 25, 26, 28–57, 63–320

**SDAC** Single Day-Ahead Coupling. 9

# Contents

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# Chapter 1

# Introduction

*Parts of this chapter are retrieved from my specialization project found in Appendix C.*

## 1.1 Problem description

The problem addressed is formulated as a collaboration between the teaching supervisor representing NTNU, prof. Sebastien Gros, and the student technician carrying out the master project, Alexander Berglind.

### 1.1.1 Objective

The project's objective is to assess the economic value of solar PV installations on private residences in Norway based on their actual power consumption and PV production seen in the context of the Nord Pool power market.

### 1.1.2 Research questions

These research questions are to highlight and give insight into what this project, in the end, will answer.

- What economic effect does a PV system have on a private residence in Norway?
- What type of effect do the variations in the Nord Pool power market have on a PV system in Norway?
- How is the profitability of the PV system affected by self-consumption of the PV production versus selling the PV production to the grid?

### 1.1.3 Tasks

The following tasks are suggested and performed during the project:

- Find and come in contact with private residences in Norway that have a PV installation on their house.
- Collect necessary data to perform the analysis of the PV installations. Which consist of:
  - House consumption from the residences
  - Solar PV production from the residences

  - Historical spot market data

- Calculate, plot, and evaluate the profitability of the PV installation in Python and excel, based on the data gathered.

## 1.2 Background and motivation

This section presents the background and motivation for why this project is essential in today's society. It will include the solar power situation in Norway today and how the development in the power market towards 2040 will be based on analysis done by The Norwegian Resources and Energy Directorate (NVE).

### 1.2.1 Solar power in Norway

Solar power is currently a small part of the power production in Norway, but it is the power generation technology that has the most significant increase. According to data from NVE, Norway's total solar power capacity was 160 MW at the end of 2020. In Figure 1.1 the development of solar power in Norway can be seen, where one can see that there has been a massive increase in the past seven years, mainly solar power connected to the Norwegian power grid. [1]

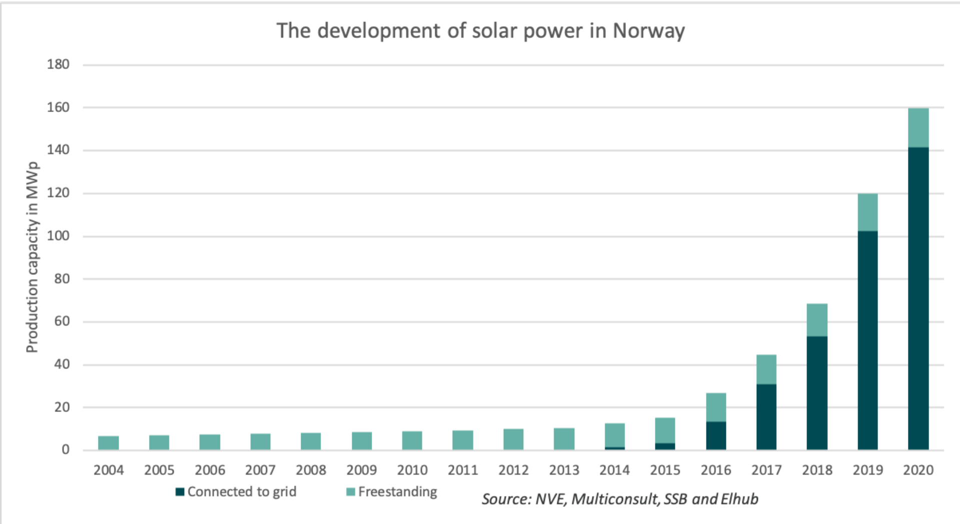



Figure 1.1: Development of solar power in Norway [1]

The potential for solar energy relies on several factors, the most important being the amount of solar irradiance. In Figure 1.2 the potential for the yearly production of solar power in different cities is presented, given the amount of solar irradiance, air temperature, and several other factors. While solar irradiance is lower in Norway than in Central Europe, cooler air temperatures help reduce the loss in the PV system. This results in a potential for PV power production in Kristiansand and Oslo to be at the same level as cities in Germany, which is Europe's largest market for PV power production.[2]

### 1.2.2 The power market

The development in the power market in Europe towards 2040 will to a large degree, be driven by climate policy and technological advancement. A crucial part of climate change involves replacing fossil energy sources with the production and use of renewable energy. A ramification of this is that conditions outside the power market will have an even more significant impact on the power market, as many renewable energy sources are heavily dependent on weather conditions and the increasing price of $CO_2$ which is the result of the European Commission's decision to increase their emission targets. [3] The increase in price of $CO_2$ cause a higher expense in fossil energy production. In addition, trade relations contribute to higher energy prices in countries without fossil power production. [4]

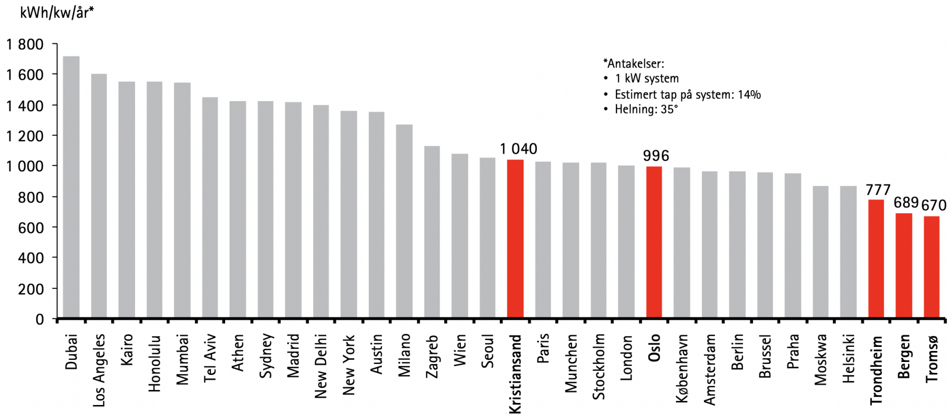



Figure 1.2: Potential for PV power production for chosen cities [2]

## 1.3 Scope and limitations

This project is an extension of the specialization project, completed in the fall of 2021, where only one residence was considered and analyzed. This project aims to verify the results in the specialization project by performing the same analysis on 15 different homes in Norway.

### 1.3.1 Limitations

As a consequence of the difficulty in acquiring the necessary data from private residences in Norway, Chapter 4 will be thoroughly explained in detail, as recommended by my advisor.

Most of the PV data collected in this project were with the help of Otovo AS, as explained in Section 4.2.1, where the data through a script provided by Otovo that communicated with the inverts from the residences. Because of connection issues discussed in Section 3.2 the data collected from Otovo will sometimes deviate from the actual PV production the residences have, but the overall picture remains the same.

The results and conclusions drawn in this thesis are limited by the number of residents that took part and the number of years of available data they had.

## 1.4 Structure of this report

This report is divided into six chapters, excluding the introduction, followed by references and appendices. The second chapter introduces the background for the thesis needed to understand the objectives and methodology of the project, which includes information about the residences that took part in the project, how the Nord Pool power market works, the current power consumption situation in Norway, and different aid schemes available for solar power in Norway. The third chapter presents a literature review from other studies and Master's theses to give an insight into the research done, and it will show relevant theory in solar panel installations and theory regarding assessing the value of a PV system. The fourth chapter presents the methodology used in the project regarding the contact with the residences, the data collection, and the data processing and calculations. Then the results are shown in the fifth chapter, and a discussion of the results is presented in Chapter 6. The end of the report, chapter 7, concludes the report with a summary, conclusion, and recommendations for further work.

# Chapter 2

# Background

*Parts of this chapter are retrieved from my specialization project found in Appendix C.*

This chapter presents the necessary background to understand where the different data used in the analyses originate and how the data is presented. First, the residences used in the project are presented with information about their PV systems and homes. Then the spot price is explained through the Nord Pool power market. Then a section on the power consumption in Norway, where the power supplier and power company related to the case study is presented. Then different aid schemes for solar power in Norway and finally, the environmental impact energy has on society will be presented.

## 2.1 The residences in the project

This section presents the residences participating in the project. To preserve the resident's anonymity, each residence has been denoted by a number used throughout the report, and their locations have been limited to their respective municipalities.

### 2.1.1 The residences PV system

The PV installations for each house vary in size and nominal power based on the installed PV-panels. Therefore, the cost of the PV system installation and subsidy received for each residence will vary more because this involves variable costs. The installation cost depends on, for example, the supplier of the PV-system and the installers. In addition, the subsidy varies from year to year, which is explained in Section 2.4.1. In Table 2.1 all this information is presented for each residence, as well as the number of years of collected data for this project.

Table 2.1: Overview of the PV installations from the residences that took part in the project. With the number of panels for each residence, the nominal power of their PV installation, the gross cost of the entire installation, the subsidy they received, and the years of available data that have been analyzed.

| **House** | **PV panels** | **Nominal power (kWp)** | **Gross cost (NOK)** | **Subsidy (NOK)** | **Years of data** |
|---|---|---|---|---|---|
| **01** | 42 | 12.6 | 184 000 | 26 500 | 2021, 2020 |
| **02** | 20 | 5.7 | 94 500 | 14 500 | 2021, 2020 |
| **03** | 25 | 8 | 115 000 | 18 000 | 2021 |
| **04** | 12 | 3.54 | 76 768 | 14 425 | 2021, 2020 |
| **05** | 26 | 8.32 | 124 029 | 17 900 | 2021 |
| **06** | 28 | 9.72 | 165 581 | 22 150 | 2021, 2020 |
| **07** | 40 | 11.6 | 196 625 | 22 000 | 2021, 2020 |
| **08** | 50 | 14.5 | 260 000 | 56 000 | 2021, 2020 |
| **09** | 20/34[a] | 6/10.2 | 140 000 | 15 000 | 2021, 2020 |
| **10** | 28 | 8.12 | 124 029 | 17 900 | 2021, 2020 |
| **11** | 30 | 8.5 | 131 000 | 26 000 | 2021, 2020 |
| **12** | 22 | 5.94 | 96 530 | 14 000 | 2021, 2020 |
| **13** | 8 | 2.36 | 52 208 | 12 950 | 2021, 2020 |
| **14** | 20 | 6 | 118 607 | 17 500 | 2021, 2020 |
| **15** | 27 | 8.235 | 125 000 | 25 000 | 2021, 2020 |

[a]Increased the number of panels from 20 to 34 in August of 2020

### 2.1.2 General information about the residences

The general location of each residence can be seen in Figure 2.1, with global irradiation marked to indicate the PV power potential for each residence. In Table 2.2 general information about each residence is listed to give an indication and understanding of the PV power potential by listing where in Norway the house is and the house's consumption based on the residence's size and some additional information.

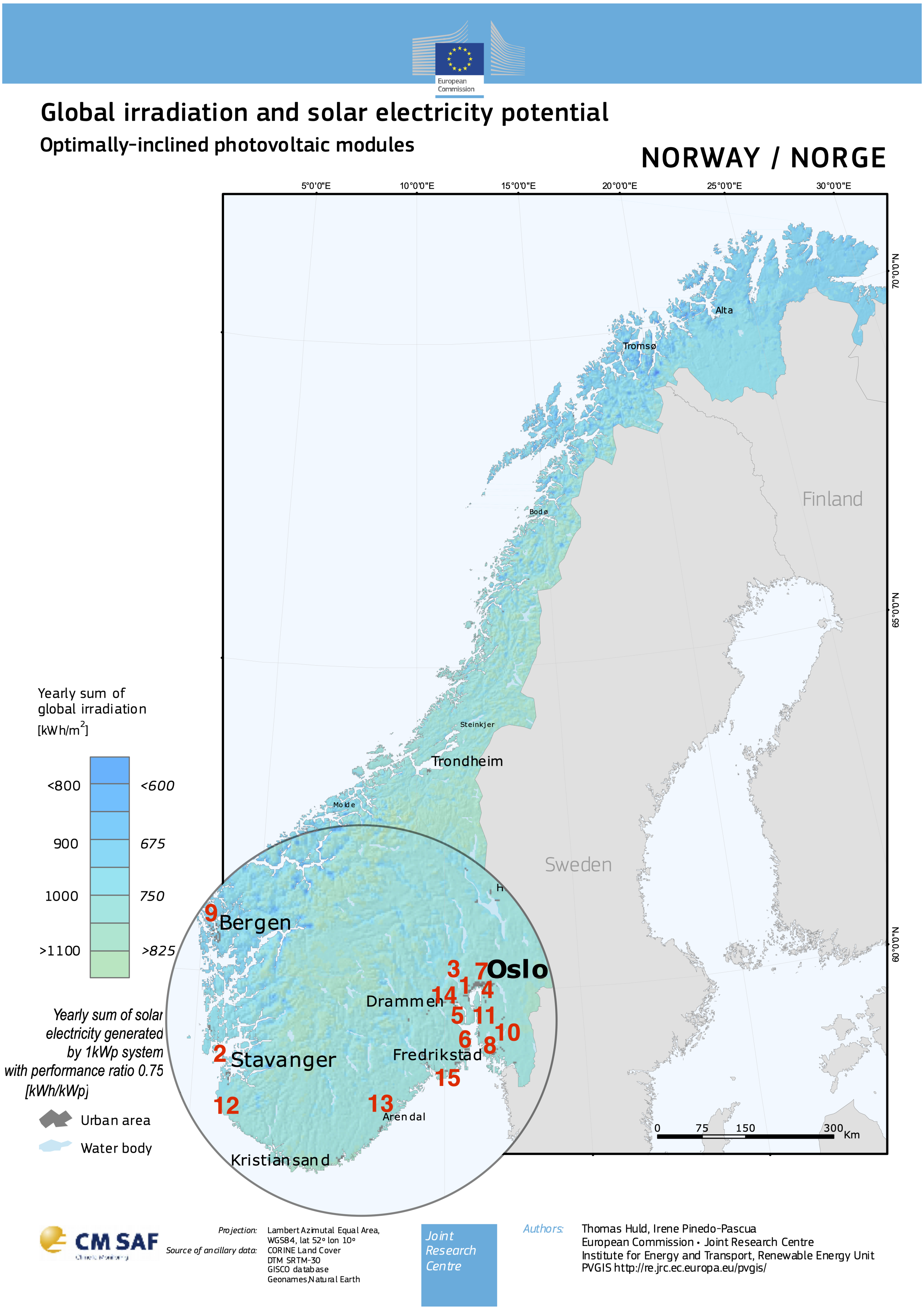



Figure 2.1: Map of irradiation and solar electricity potential in Norway with optimally-inclined photovoltaic modules with the 15 residences in this project marked by a number. Adapted from [5].

Table 2.2: General information about each residence in the project. Includes their limited location in Norway, the size of the residence, and additional information that can impact the consumption of each house.

| House | Location | Size of residence | Info about residence |
|---|---|---|---|
| **01** | Asker Municipality in Viken County | 357 $m^2$ | Heating: Water source heat pump, floor heating cables and pellets fireplace.<br>Other: one electric car. |
| **02** | Randaberg Municipality in Rogaland County | 220 $m^2$ | Heating: two heating pumps, floor heating, and electric heating.<br>Other: one electric car and set up for mining cryptocurrency that uses 3.6 kWh per day. |
| **03** | Hole Municipality in Viken County | 210 $m^2$ | Heating: Air-to-air heat pump and floor heating cables |
| **04** | Oslo Municipality in Oslo County | 205 $m^2$ | Heating: electric heater |
| **05** | Holmestrand Municipality in Vestfold and Telemark county | 127 $m^2$ | Heating: heating pump and floor heating cables |
| **06** | Horten Municipality in Vestfold and Telemark county | 150 $m^2$ | Heating: heating pump, electric heater, and fireplace |
| **07** | Oslo Municipality in Oslo county | 280 $m^2$ | Heating: ground-to-water heating pump |
| **08** | Fredrikstad Municipality in Viken county | 159 $m^2$ | Heating: heating pump and wood-burning fireplace |
| **09** | Alver Municipality in Vestland county | 120 $m^2$ | Heating: Floor heating and electric heater |
| **10** | Fredrikstad Municipality in Viken county | 192 $m^2$ | Heating: heating pump and floor heating cables.<br>Other: two electric cars and a heat recovery system for a shower that saves approximately 1200 kWh per year. |
| **11** | Vestby Municipality in Viken county | 164 $m^2$ | Heating: air-to-air heating pump and floor heating cables |
| **12** | Eigersund Municipality in Rogaland county | 184 $m^2$ | Heating: air-to-water heating pump |
| **13** | Arendal Municipality in Agder county | 160 $m^2$ | Heating: solar thermal collector to floor heating, radiator, and wood-burning fireplace |
| **14** | Asker Municipality in Viken county | 178 $m^2$ | Heating: air-to-air heating pump and floor heating cables |
| **15** | Skien Municipality in Vestfold and Telemark county | 148 $m^2$ | Heating: heating pump, floor heating cables, and electric heater |

## 2.2 Nord Pool

Nord Pool is a power market where the electricity prices for 16 European countries are decided. It is a power market, named the day-ahead market, where customers trade in energy for the following 24 hours in a closed auction to determine the hourly spot price for each zone. Figure 2.2, shows a map of the bidding zones for the Nord Pool power market. [6] Where Norway is typically divided into five bidding zones. This division is due to bottlenecks in the transmission systems, so the orders are matched to maximize the social welfare while network constraints provided by transmission system operators are taken into consideration.[7]

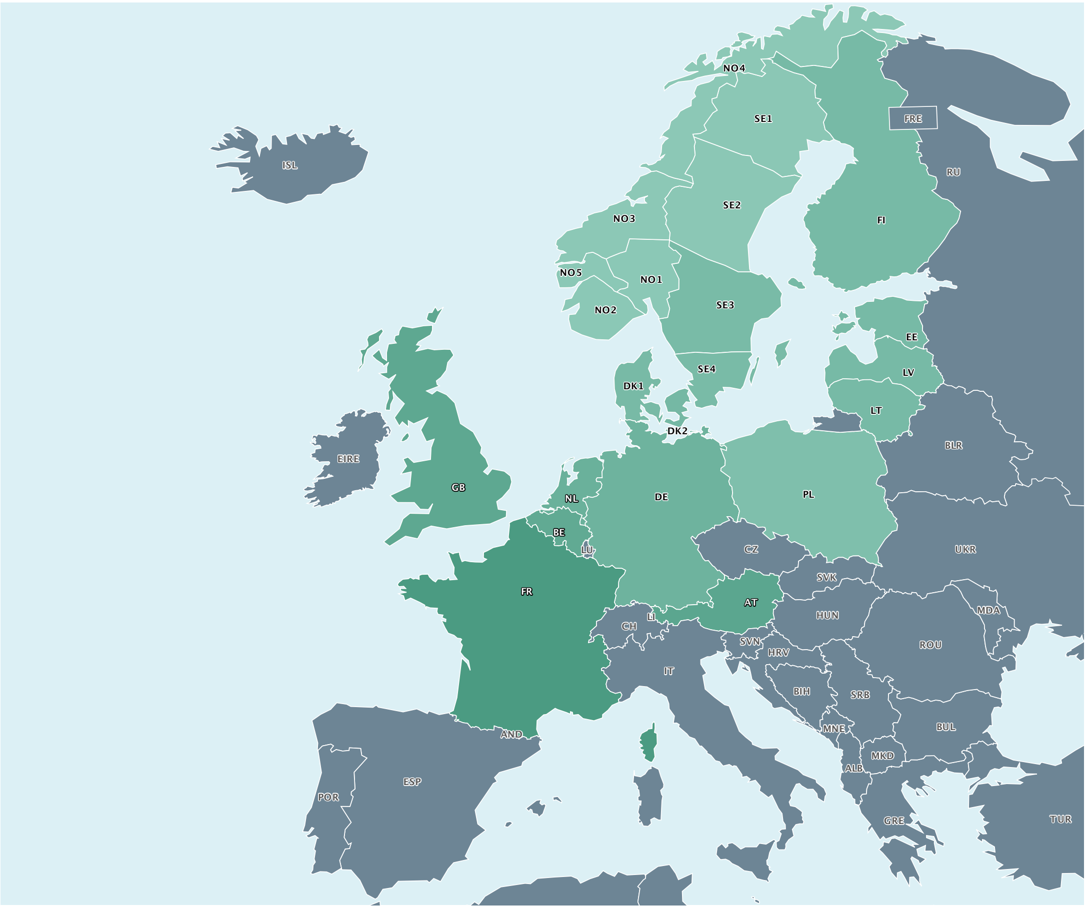



Figure 2.2: Map over bidding zones in the Nord Pool power market [6]

The way the day-ahead market works is that each day at 10:00 Central European Time (CET), the available capacities on the transmission lines between and within the bidding zones are published, where hourly prices for the next day are possible to bid on, and the buyers and sellers have until 12:00 CET to finalize their bids. Then through a pan-European market coupling process called Single Day-Ahead Coupling (SDAC), each submitted order is then matched with other orders from the surrounding markets in Europe through an algorithm called Euphemia. Finally, the hourly prices are typically announced to the market at 12:45 CET for the following day. [7]

### 2.2.1 Spot price

The spot price from the power market depends mainly on supply and demand, where the primary role of the market price is to establish an equilibrium between the two. But other factors may also impact the price, such as weather or power plants having trouble producing to their full capacity. [8]

Norway's average spot price in 2020 was 116 Norwegian kroner (NOK) per megawatt hour (MWh). This is the lowest yearly price ever recorded on the power market in Norway. The low prices resulted from reasonable access to supply in combination with lower demand than usual. In addition, heavy rain, snow in the mountains and good wind conditions produced record high power. 2020 was also the warmest year ever recorded in Norway, which meant less heating, which often stands for half the electricity bill. [8]

For the following year, 2021, the average price was 634 NOK/MWh, the highest yearly price ever recorded on the power market. The reason for this high cost was the result of, among other things, extreme energy prices on the continent that led to high prices in the Nordic countries; because of the close European connection, the gas prices quadrupled, and the $CO_2$-prices doubled during the year. Furthermore, unusually little rainfall during the second half of 2021 led to less "fuel" for the hydropower plants, and a freezing winter led to high energy consumption for private residences. [8]

By using Norway as an example, if the weather forecast predicts heavy rain for the following days, hydropower plants will expect a high power production leading to a high level of supply, this in return will often lead to low spot prices. But, if it predicts low temperatures, consumers and suppliers expect high demand, often pushing the spot price up. This model serves society well, when the cost of power goes up, it also becomes clear where there are issues on the grid. Meaning it is easy to identify where production or capacity is lacking since one can see where there is too high demand compared to production supply. [9]

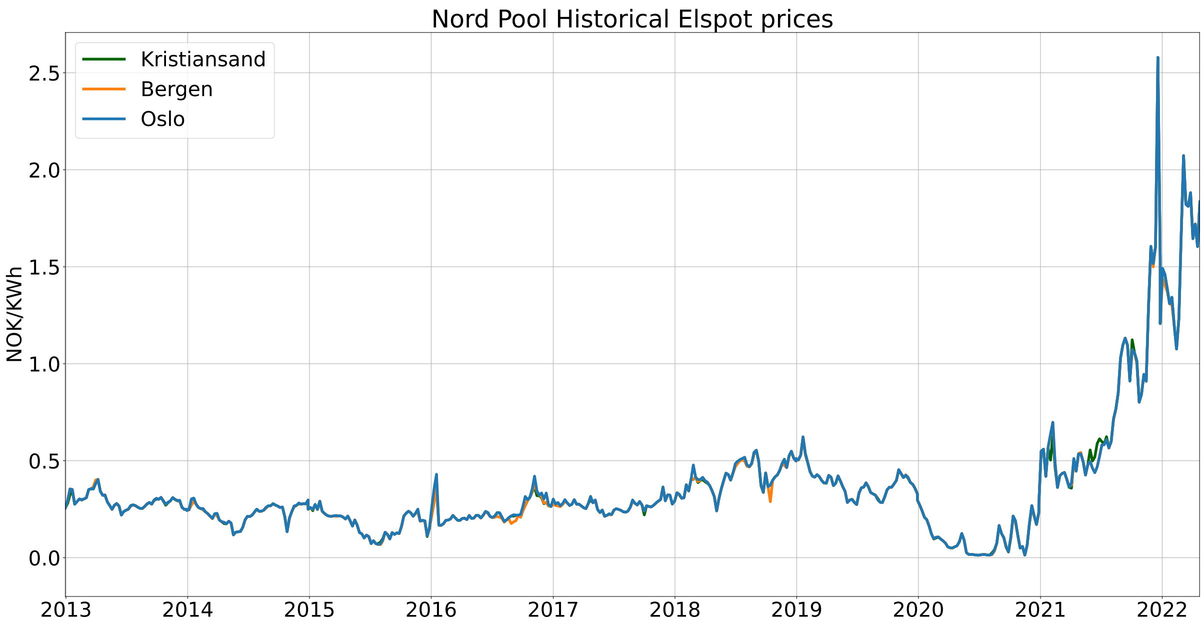



Figure 2.3: The weekly average spot price for energy from the Nord Pool power market for Oslo (zone NO1), Kristiansand (zone NO2), and Bergen (zone NO5) from 2013-mid 2022.

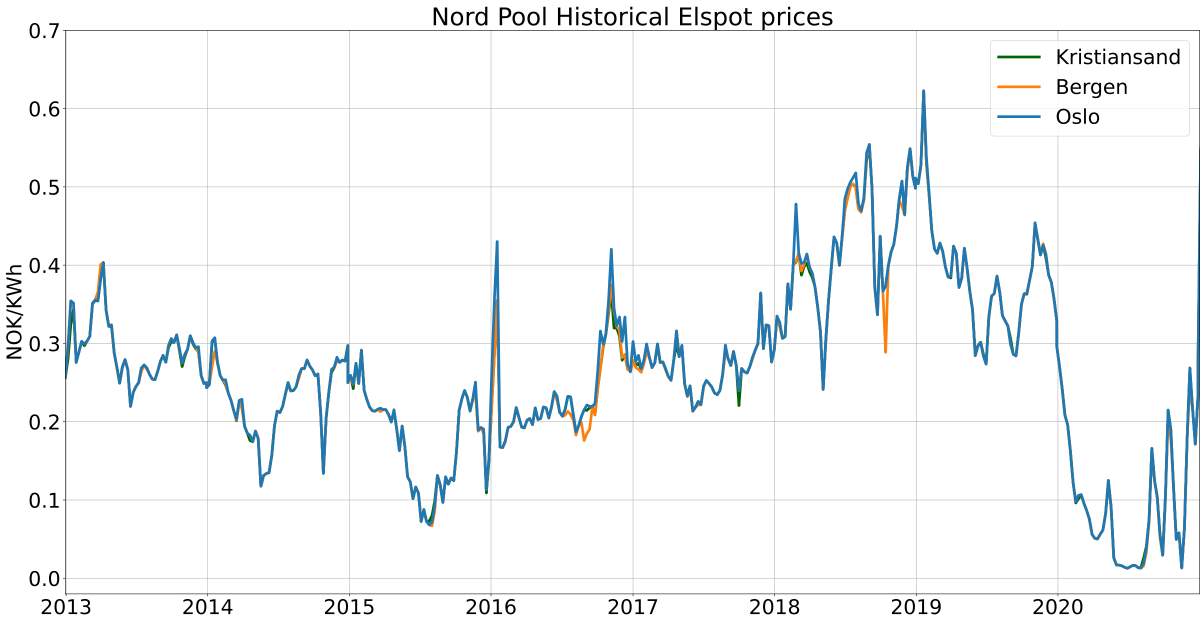



Figure 2.4: The weekly average spot price for energy from the Nord Pool power market for Oslo (zone NO1), Kristiansand (zone NO2), and Bergen (zone NO5) from 2013-2020 to get a more detailed view of the power prices.

Figure 2.3, shows the weekly average price from the Nord Pool spot market for the three zones applicable for this project. The three zones are NO1 (Oslo), NO2 (Kristiansand), and NO5 (Bergen). To get a more apparent view of the fluctuations in the spot price Figure 2.4, shows the weekly average price from the Nord Pool spot market from 2013-2020, not including the peak from 2021.

## 2.3 Power consumption in Norway

The electricity bill in Norway consists of three parts divided between the power company and power supplier. The first part is the power consumption, where the consumer pays for the electricity used during that period. The second part is nettleie, where the consumer pays a fee based on the electricity consumption during that period, which goes to the operation and maintenance of the power grid in the consumer's area. The third part is government taxes, where the consumer pays for statutory fees, including certificates. Finally, on top of the power consumption and nettleie, there is value added tax (VAT) from the Norwegian government. The first and third part comes from the power companies, and the second part comes from the power supplier who owns the power grid. [10]

The choice of power company and power agreement is an open choice in Norway. Consumers can have a fixed-, variable- or spot-based power agreement. The choice of power supplier is, on the other hand, a restricted choice since power suppliers have a monopoly on their respective areas. [10]

### 2.3.1 Power suppliers and nettleie in Norway

In Norway today, there are approximately 100 power suppliers that handle the transmission of electricity from power plants to the end consumer. The power grid operation within a geographical area is a natural monopoly because it is not socioeconomically rational for several companies to develop competing power grids in the area. The power suppliers thus have a monopoly on their services within their area, resulting in strict regulations from the government. [11] In Table 2.4, an overview of the largest power suppliers in Norway can be seen.

The nettleie for different areas varies. In Figure2.5, the nettleie from the relevant counties regarding this project are plotted from 2013 to 2021.

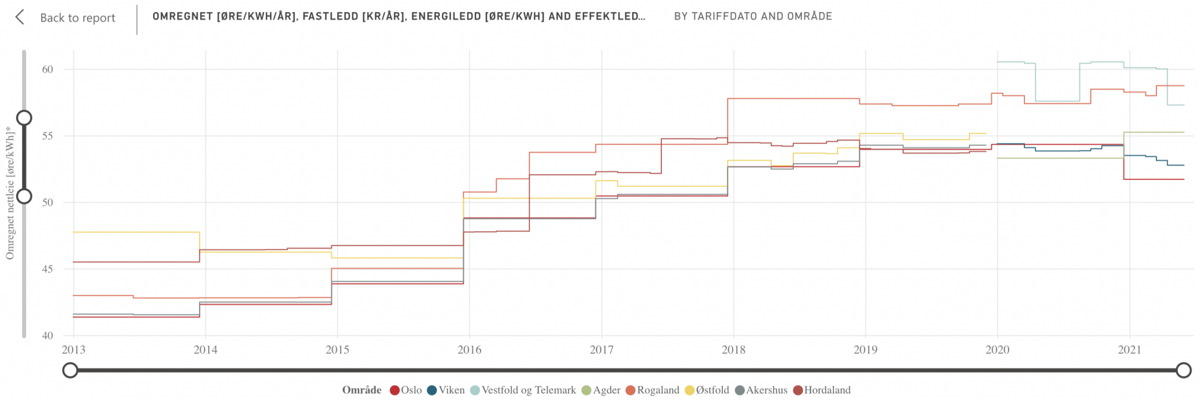



Figure 2.5: A plot of the statistics of the Norwegian nettleie from chosen counties from the period 2013 to 2021 [11]

In Table 2.3, the average nettleie in Norway determined by Statistics Norway can be seen. [12] Which strongly correlates with the average in Figure 2.5.

Table 2.3: The average yearly nettleie for all of Norway from 2013 to 2021. [12]

| | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** |
|---|---|---|---|---|---|---|---|---|---|
| **Netteleie (øre/kWh)** | 45.9 | 46.4 | 49.5 | 54.6 | 54.6 | 56.5 | 55.1 | 55.3 | 54.6 |

### 2.3.2 Power companies in Norway

In 1990, Norway passed a new energy law that opened up competition in the power market. This led to the Norwegian consumers being among the first in the world to choose their electricity supplier freely. In addition, the possibility of selecting an electricity supplier based on price or other relevant considerations opened up competition between the power suppliers. [13] Most of the participants in this project use the power company Tibber.

#### Tibber

Tibber is a Norwegian power company offering only an hourly spot price agreement. This means that the spot price the consumer pays follows the market price from the Nord Pool power market, with a surcharge of maximum 1 øre/kWh to cover statutory fees and VAT. So, when the price in the power market decreases, the consumer pays less for power, and if it increases, the consumer pays more. [14]

### 2.3.3 Elhub

Elhub is a national database developed by Statnett, where they collect information from consumers, power companies, and power suppliers to simplify a former chaotic communication pattern.[15] All consumers in Norway have a metering point where consumption and production are measured and stored in

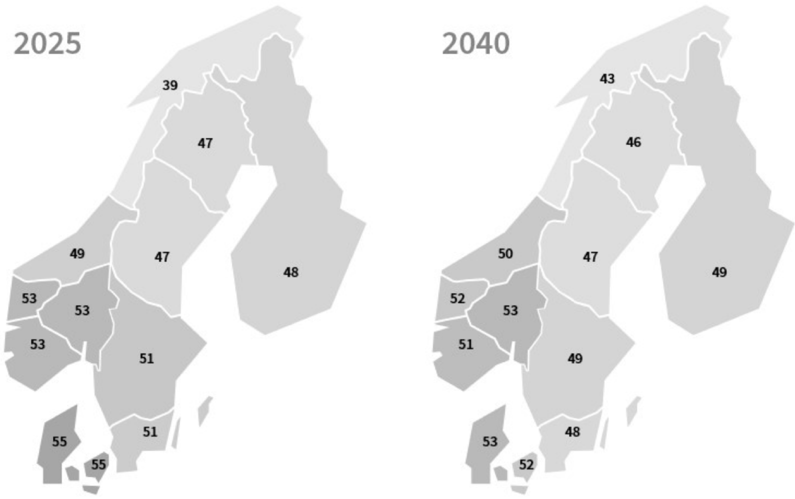



Figure 2.6: The development in power prices in the Nordic countries from 2025 to 2040 in øre/kWh [18]

Elhub. The consumer can log in to Elhub through the power companies website, where they can control and provide access to stored data. [16]

### 2.3.4 The future of the power market

In line with EU's emission target for 2030 and their proposals for change in regulations to achieve this [17], this has contributed to a significant increase in $CO_2$-prices which has given apparent effects on the power prices in Norway for the past year. [18] 2020 was a year with a lot of rainfall and record low power prices. In 2021 we saw the opposite. Low precipitation and little reservoir filling, together with an increase in gas and coal prices, have contributed to record high power prices in the south of Norway through the autumn of 2021. Rapid weather changes combined with high costs of thermal energy production have clearly shown how prices can fluctuate in a weather-based system. [18]

The development in the power market in Europe towards 2040 will mainly be driven by climate policy and technological development. A crucial part of climate change is replacing fossil energy sources with the production and use of renewable energy, leading to more integration of the energy and power sector. Conditions outside the power market will thus have an even more significant impact on the power market. [18]

According to a power market analysis by NVE in [18], the power price will increase slightly from 2025 to 2030. Rising gas and $CO_2$ costs and increased exchange capacity between the continent and the other Nordic countries contribute to this. In addition, the assumption is that the Norwegian power surplus will gradually decrease during this period. In the analysis, the average power price in Norway will fall somewhat between 2030 and 2040, despite the fact that gas and $CO_2$ prices continue to rise. The cost of power decreases the most in the south of Norway. An important reason is the assumption of a significantly higher share of renewable energy in Europe by 2040. With such a development, Norway will in the future import reasonable power from these countries. The assumption that wind and solar power development in Norway will noticeably increase after 2030 also contributes to the average price decreasing towards 2040. In Figure 2.6, the development in the power prices in the Nordic countries from 2025 to 2040 can be seen, showing how the difference in power prices in Northern Norway compared to Southern Norway will even out. [18]

## 2.4 Aid schemes for solar power in Norway

Norway has several aid schemes to support investment in renewable energy sources. In this section, the procedures regarding solar panel installations are presented.

### 2.4.1 Enova

Enova is a state enterprise founded in 2001 to contribute to the reorganization of energy consumption and production to help reduce greenhouse gas emissions and develop energy and climate technology. Enova is meant to help businesses and private individuals to invest in the newest and most climate-friendly technologies, where Enova infuses over NOK 3 Billion of public resources each year into these solutions.[19] Through the Enova Subsidy, support was given to 9115 projects in 2020, where electricity generation was the individual measure that received the most grants, with almost 18 percent of all the contributions. The generation of electricity in households is mainly linked to installing solar PV modules in one's house.[20]

If a private residence decides to install solar PV modules on their house, through the Enova Subsidy, the installation itself will provide NOK 7,500 in support. The rest of the aid will depend on the nominal effect the installation has, where one will receive 2000 NOK per kW installed effect, up to 20 kW. This results in a total maximum support of NOK 47 500 for installing solar PV modules on one's house.[21]

### 2.4.2 Plusskunde

A plusskunde is a consumer that both use and produce electricity, where they push the excess power they produce into the grid. The consumer must settle an agreement with a power company, where the power company can set requirements for the connection to ensure their grid system is in line with current regulations. The current regulations are that for an end user with consumption and production behind the connection point, the input power at the connection point cannot at any time exceed 100 kW. The plusskunde arrangement means that the consumer cannot, in principle, resell the power to other end users or participate in the power market but must sell the surplus power to a power supplier. For the consumer to sell their surplus of energy, they must choose a power supplier that handles both production and consumption. [22]

#### Plusskunde power suppliers

When consumers produce more power than they use, the excess gets automatically pushed into the grid. The power supplier's tariffs the contribution of this surplus production to reduced grid losses; in Table 2.4, an overview of the largest power suppliers and the tariff they offer are presented. The power supplier may demand a construction contribution from the consumer if the surplus of power they produce exceeds the limit of the grid, leading to the need to improve it.

Table 2.4: Overview of the largest power suppliers in Norway and the tariff they offer for pushing excess PV power into the grid. [23]

| **Power supplier** | **Area in Norway** | **# Costumers** | **Feed-in Tariff** |
|---|---|---|---|
| Elvia | Oslo and Viken counties | 936 834 | -3.9 øre per kWh in the summer and -7 øre per kWh in the winter [24] |
| Tensio | Trøndelag county | 268 282 | Tariff = Excess PV production (kWh) × spot price × marginal loss rate (6.5% winter daytime, 6% winter nighttime/weekend, 5% rest of the year) [25] |
| BKK Nett | Vestlandet county | 253 556 | Tariff = Excess PV production (kWh) × spot price × marginal loss rate (7% winter daytime, 6% winter nighttime/weekend, 4% rest of the year) [26] |
| Skagerak Nett | Vestfold, Grenland and Hjartdal in Telemark and Svelvik in Viken county | 209 091 | -5 øre per kWh [27] |
| Agder Energi Nett | Agder county | 207 830 | -4 øre per kWh [28] |
| Lyse Elnett | South Rogaland county | 153 907 | -4 øre per kWh [29] |
| Arva | Nordland and Troms counties | 118 506 | -10 øre/kWh [30] |
| Norgesnett | The municipalities of Askøy, Fredrikstad (not Onsøy), Hvaler, Nesodden, Røyken in Asker, Enebakk and Ski in Nordre Follo | 97 721 | Askøy: -1.50 øre per kWh in the winter, -0.6 øre per kWh in the summer. Nordre Follo: -2.18 øre per kWh in the winter, -1.67 øre per kWh in the summer. Fredrikstad: -3.40 øre per kWh in the winter, -2.81 øre/kWh in the summer. [31] |

### Plusskunde power companies

A residence with a PV system is required to choose a power company that handles both consumption and production. [22] The power companies offer different deals on the excess power a plusskunde produces. In Table 2.5, an overview of varying power suppliers is presented with the plusskunde agreement they provide and their customer satisfaction rating. The most common deal is selling the excess power according to the Nord Pool power market.

Table 2.5: Overview of different power companies in Norway and the plusskunde offer they have.

| **Power company** | **Plusskunde offer** | **Customer satisfaction**[a] |
|---|---|---|
| Tibber | Nord Pool spot price. The consumer earns the same amount per kWh in surplus as Tibber would have to pay from the power market[b]. [33] | 83.0 |
| Gudbrandsdal Energi | Nord Pool spot price minus 1 øre per kWh. [34] | 72.4 |
| LOS | Nord Pool spot price. The consumer earns the same amount per kWh in surplus as LOS would have to pay from the power market. [35] | 70.5 |
| Lyse | Nord Pool spot price. The consumer earns the same amount per kWh in surplus as Lyse would have to pay from the power market. [36] | 69.0 |
| NTE | Nord Pool spot price. The consumer earns the same amount per kWh in surplus as NTE would have to pay from the power market. [36] | 68.9 |
| Trøndelag Kraft | 1 NOK per kWh up to 5000 kWh. Then the Nord Pool spot price applies. [37] | 61.7 |
| NorgesEnergi | Nord Pool spot price. The consumer earns the same amount per kWh in surplus as NorgesEnergi would have to pay from the power market. [38] | 61.3 |
| Fjordkraft | Nord Pool spot price. The consumer earns the same amount per kWh in surplus as Fjordkraft would have to pay from the power market. [38] | 58.9 |

[a] Based on survey done by EPSI Rating Norge in 2021. Generally, companies with a customer satisfaction score below 60 have great difficulty motivating customers to stay, while results above 75 indicate a strong relationship between supplier and customer. Furthermore, it can be said that differences of 2.5 index points or more are significant. [32]

[b] Meaning the consumer gets paid the spot price at the time multiplied with the number of kWh they push into the grid.

# Chapter 3

# Theory

*Parts of this chapter are retrieved from my specialization project found in Appendix C.*

This chapter presents the relevant theory needed to understand the results of this project. First, a literary review shows previous master theses relating to the subject and their main influences. Then the theory on how solar panel installations work is presented before the theory on how to solve the case of missing values for solar irradiation. Finally, the theory relating to assessing the value of a PV system is presented.

## 3.1 Literature review

Research and different case studies of solar energy have been done before, below are their main results.

- Xue et al. [39] proposed the reason for little use of solar power in Norway for private residences is the high initial costs of photovoltaics and the limited information and awareness of the possible benefits. They believe the main concern for the public sector is the low application of existing incentives, and they propose a model called Public-private-people partnership (PPPP) to overcome these barriers.
- Kjenstadbakk E. [40] does a case study of the effect of integrating a solar PV installation in a housing cooperative in Trondheim, Risvollan. The main results show that with the current unit cost and grid electricity prices, the solar PV systems researched could not match the grid electricity price.
- Veie B. [41] master thesis presents the results of an evaluation of actual load data from industrial, commercial, and residential sectors and actual solar power data from Trondheim to see if it is possible to reduce the strain on the grid in a cost-effective manner. The key results show that there is a potential to both reduce peak load and save money.
- Gjørven S. [42] master thesis investigates how the distribution grid is affected by the increase of installed PV capacity. Because many PV installations in a grid can lead to increased voltage levels and overload the lines and cables, this thesis studied a strong grid, where a capacity of 10 kWp could be installed at each end-user without creating too high voltage levels or power flows.
- Haugstad H. [43] master thesis investigates how the profitability of private small-scale solar PV installations will be affected by the introduction of grid tariffs. This thesis was based on a 3.3 kWp PV installation on the roof of an office building in Oslo and an average household. The thesis

concluded that private solar PV installations would not be profitable even with the support of the time (2019) from Enova.

- Bentsen K. [44] master thesis investigates the accuracy of the simulation program *PVsyst* to see if it gives an accurate estimate of total yield for PV installations in Norway, as well as examines the profitability of PV installations in Norway. The thesis concluded that *PVsyst* had the least accurate estimate of the different simulation programs tested in the thesis, whereas the model designed for this study had the most realistic estimation. The conclusion of the profitability of solar panels was that the LCOE (Long term cost concept) must be at 1.2 NOK/kWh to be profitable in Norway.
- Løvstakken T. [45] master thesis investigates the control and operation of battery storage systems for commercial buildings with and without solar PV installations. In the thesis, the HOMER software is used to calculate the net present cost of different system combinations. It was found that larger PV systems without battery storage were the more profitable solution. For the power consumption-driven optimization, the power peaks were reduced during high demand periods and increased during low demand periods, balancing the power consumption of the building. This did not reduce the costs of energy fees but power fees, where the profit depends on which fees apply.
- Haumann T. [46] master thesis gives a brief look at the performance of PV in Norway, where several Norwegian PV systems are analyzed mainly in terms of annual specific yields. Based on irradiation data from 57 stations located in Norway, the thesis confirmed that annual irradiation in Norway lies at 700 − 1000 kWh/m2. The thesis concluded that a well-designed PV system has great potential also in Norway.
- Østbye M. [47] master thesis challenges the results of the report; "Kostnadsstudie, Solkraft I Norge 2013", published by Enova, through a case study. The thesis concluded with a significantly lower LCOE than Enova and a negative NPV over a lifetime of 25 years.

## 3.2 Solar panel installations

In this section, the theory of how solar panels work is presented. In Figure 3.1, a diagram shows how solar energy is converted from light to electricity for a private residence in six stages. The three first stages are explained in detail in this section to give the necessary basis for terminology used in Section 4 and 5, to give a basic understanding of how solar panels work. Stages 4 and 5 represent the house consumption measured and used for a private residence. Finally, stage 6 illustrates the power grid where one either retrieves needed power for their home or exports the excess energy they produce through their PV system. [48]

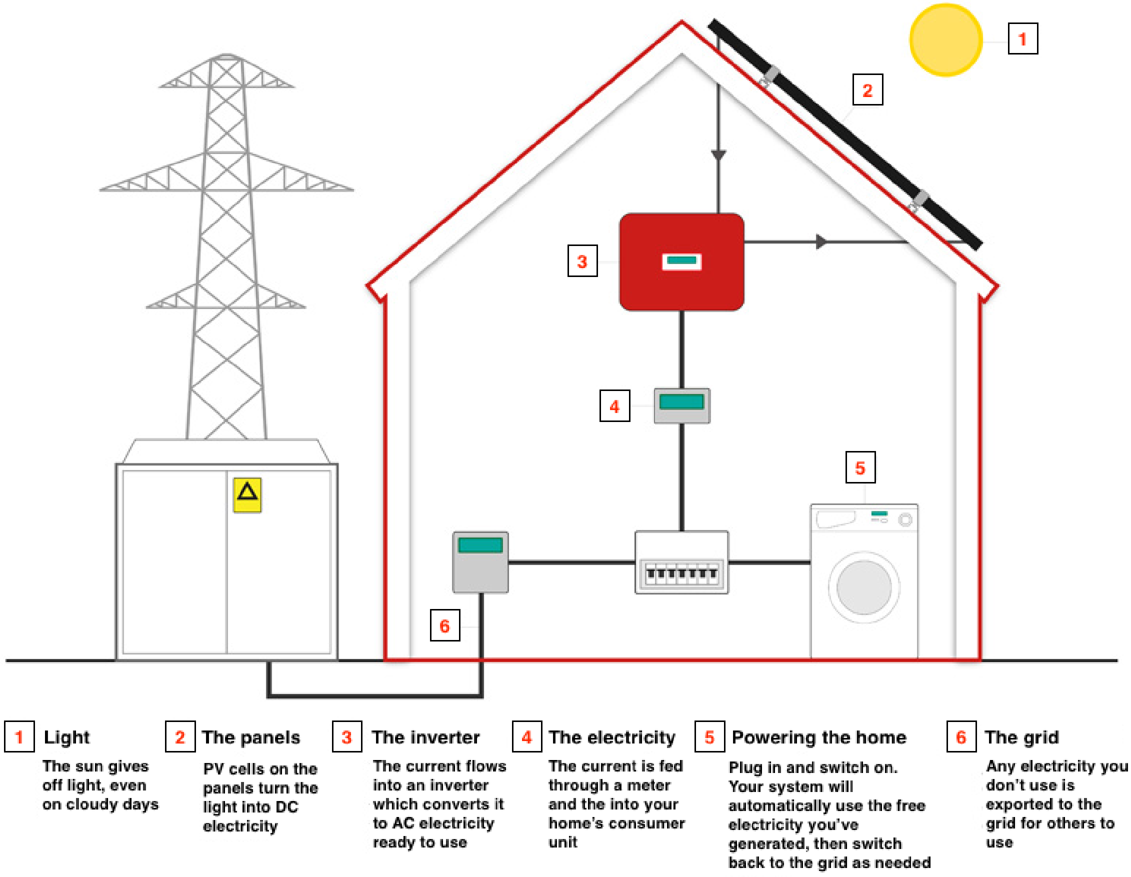



Figure 3.1: A diagram that shows how solar energy is converted into electricity for a home adapted from [48].

### 3.2.1 Solar radiation

Stage 1 on the diagram in Figure 3.1, represents the solar radiation or sunlight, a general term for the electromagnetic radiation emitted by the sun. The amount of solar radiation that reaches any given location on the Earth's surface varies depending on the geographic location, time of day, season, local landscape, and local weather.[49] Some of the sunlight that passes through the atmosphere is absorbed, scattered, and reflected by air molecules, water vapor, clouds, dust, and such, and this is called *diffuse solar radiation*. The sunlight that reaches the Earth's surface without being diffused is called *direct solar radiation*, and the sunlight reflected off a surface is called *reflected solar radiation*, in Figure 3.2, all three are illustrated. Where the sum of the three is the *global solar radiation*. [49] The amount of solar energy that reaches a specific location is called *solar irradiance* and is measured in watts per square meter (W/m$^2$). [50]

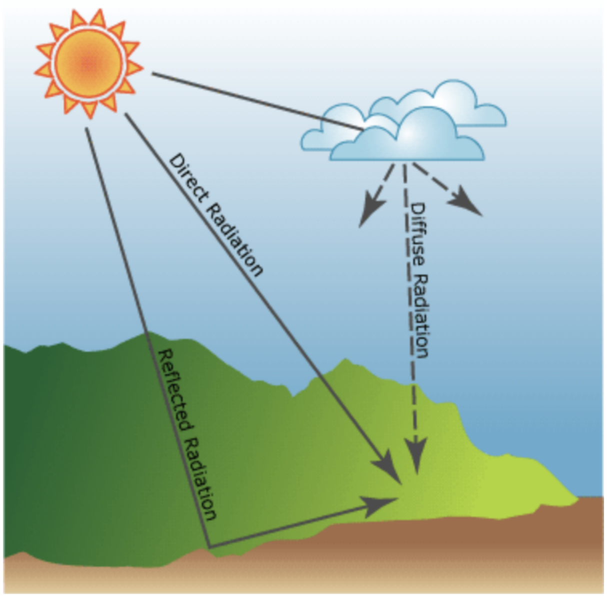



Figure 3.2: A figure of incoming solar radiation that is intercepted as direct, diffuse, and reflected radiation.[51]

### 3.2.2 The solar panels

Stage 2 on the diagram in Figure 3.1, depicts the solar panels or PV system. The PV material and device convert the sunlight into electrical energy. One solar panel consists of many individual PV cells, each producing 1 or 2 watts of power, connected in chains to boost the total power output. [52] A PV system usually delivers 100-170 kWh of electricity per square meter of PV cell area or, in other words, approximately 700-1000 kWh per installed kilowatt peak (kWp) per year. [53] Kilowatt peak is the peak power of the PV system, which is the rate at which they generate energy at peak performance. So, for example, a PV system with a peak power of 3 kWp working at its maximum capacity for one hour will produce 3 kWh of electricity, often called nominal power. [54]

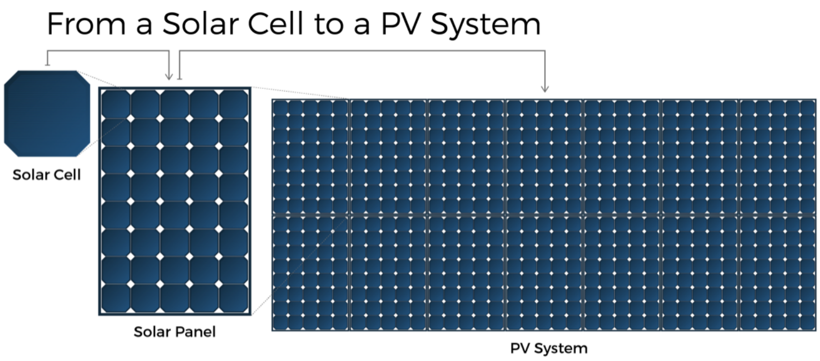



Figure 3.3: Illustration from a single PV cell to a PV system [55]

There are two main groups of PV cells on the market today; silicon and thin-film, where silicon is the most used technology. First, there are monocrystalline cells that are solar cells made from silicon crystallized into a single crystal, where the surface is homogeneous and often black, which means that all light is absorbed in the PV cell. Secondly, there are multi-crystalline cells that consist of several silicon crystal grains, giving the PV cell a characteristic color play on the panel's surface. Monocrystalline cells have a higher conversion efficiency, while multi-crystalline cells require less energy to produce and are therefore cheaper. [56] The conversion efficiency of a PV cell is measured by the percentage of solar energy that hits the panel that is converted into usable electricity. [57] Commercial PV panels, as of now, commonly have a conversion efficiency of 16% to 22.6%. [58]

### 3.2.3 The inverter

Stage 3 on the diagram in Figure 3.1, represents the inverter in the PV system. An inverter is a device that converts direct current (DC) electricity, which PV panels generate, into alternating current (AC) electricity, which the power grid uses. In a household PV system, the inverter performs several functions in addition to converting the solar energy into AC power; it monitors the system and provides a portal for communication with computer networks. [59]

## 3.3 Missing values for solar irradiation

Due to operational issues (e.g., WiFi connection cuts out), the inverter can sometimes have gaps of data missing throughout a day, like solar irradiance weather data from weather stations. In a paper by Mohammad et al., [60] they examined five statistical imputation methods frequently used in missing value analysis for daily solar irradiance series based on two different weather conditions in a tropical climate with 10% to 50% of missing values. The results showed that for cloudy weather with 10% missing data, linear interpolation gave the best estimation for the missing values. [60]

### 3.3.1 Linear interpolation

Given a data set consisting of independent data values, $x_i$, and dependent data values, $y_i$, where $i = \{1, \ldots, n\}$, there is an estimation function $\hat{y}(x)$ such that $\hat{y}(x_i) = y_i$ for every point in the data set. This means that the estimation function goes through the data points. Given a new $x^*$, one can interpolate the function values using $\hat{y}(x^*)$. This $\hat{y}(x)$ is the interpolation function. Unlike regression, interpolation does not require one to have an underlying model for the data, especially when there are many reliable data points. In linear interpolation, the estimated point is assumed to lie on the line joining the nearest points to the left and right. Without the loss of generality if one assumes that the $x$-data points are in ascending order, meaning $x_i < x_{i+1}$, and $x$ is a point such that $x_i < x_{i+1}$, then the linear interpolation at $x$ is: [61]

$$\hat{y}(x) = y_i + \frac{(y_{i+1} - y_i)(x - x_i)}{(x_{i+1} - x_i)} \tag{3.1}$$

## 3.4 Assessing the value of a PV system

This section presents the theory of how one can assess the value and investment of a PV system.

### 3.4.1 Cost of PV-panels per watt peak

One way to evaluate the cost of a PV system is by assessing the installation cost per kilowatt peak installed.

$$\frac{\text{Cost}}{\text{kilowatt}_{peak}} = \frac{\text{Net cost of PV system installation}}{\text{Nominal power}} \tag{3.2}$$

The cost of installing a PV system consists of material and labor. With fewer panels installed, the labor costs will increase, and if you have many panels installed, they will decrease. [62]

### 3.4.2 The hourly cost of power for a residence

Calculating the cost of power for a chosen hour for a residence without a PV-system ($C$) is done by the following equation:

$$\mathrm{C(ts)} = (\mathrm{SP_{tax}(ts)} + \mathrm{NL}) \cdot \mathrm{E_h(ts)} \tag{3.3}$$

Where $SP_{tax}$ (NOK/kWh) is the Nord Pool spot price with tax added from the Norwegian government and the power company, $NL$ (NOK/kWh) is the nettleie cost which is a fixed cost, $E_h$ (kWh) is the hourly house consumption, and $ts$ is the corresponding timestamp. A residence with a PV-system installed will lower their cost of power and sometimes even generate proceeds, the hourly cost calculations with a PV-system ($C_{PV}$) then becomes:

$$\mathrm{C_{PV}(ts)} = \begin{cases} (\mathrm{SP_{tax}(ts)} + \mathrm{NL}) \cdot \Delta(\mathrm{ts}), & \text{if } \Delta > 0 \\ (\mathrm{SP(ts)} \cdot \Delta(\mathrm{ts})) + (\mathrm{FIT} \cdot \Delta(\mathrm{ts})), & \text{if } \Delta < 0 \end{cases} \tag{3.4}$$

Where *SP* (NOK/kWh) is the Nord Pool spot price, *FIT* (NOK/kWh) is the power suppliers feed-in tariff a residence get when pushing power into the grid and $\Delta$ is given by following equation:

$$\Delta(\mathrm{ts}) = \mathrm{E_h(ts)} - \mathrm{E_{PV}(ts)} \tag{3.5}$$

Where $E_{PV}$ (kWh) is the hourly power production from the PV-system.

### 3.4.3 Payback time

The payback time for a PV system is the time required to cover the initial investment cost. It is only a simplistic measure and returns the number of years needed for the PV system to pay itself off. Payback time does not take into account the time value of money and does not measure profitability or include price inflation. [63] The payback time read as:

$$\text{Payback time} = \frac{\text{Total cost of PV system - tax credits, grants and subsidies}}{\text{Annual profit from PV system}} \tag{3.6}$$

Where *annual profit from the PV system* comes from the annually produced kilowatt hours from the PV system times the electricity price.

### 3.4.4 Net present value

The Net Present Value (NPV) is a method for appraising long-term projects using the time value of money, where it compares the present value of money today to the current value of money in the future, taking inflation and returns into account. If NPV $>$ 0, the investment will be profitable; if NPV $<$ 0, the investment will be unprofitable, and if NPV $=$ 0, the investment would break even [64]. In this context, the PV system would go past its lifetime before it would start to make money. The NPV can be calculated from [65]:

$$\mathrm{NPV} = -\mathrm{S} + \frac{\mathrm{Q_1}}{(1+i)} + \frac{\mathrm{Q_2}}{(1+i)^2} + \cdots + \frac{\mathrm{Q_N}}{(1+i)^N} = -\mathrm{S} + \sum_{j=1}^{N} \frac{\mathrm{Q_j}}{(1+i)^j} \tag{3.7}$$

The variable $i$ represents the nominal interest rate, which is the monetary price that allows different economic quantities to be referred to each other, when transferred periodically over time, to the initial year of investment. [65] $S$ represents the initial cost of the PV system and can be expressed by Equation (3.8):

$$\mathrm{S} = \mathrm{C_{gen}} + \mathrm{C_{inv}} + \mathrm{C_{inst}} - \mathrm{C_{sub}} = \mathrm{C_{system}} - \mathrm{C_{sub}} \tag{3.8}$$

Where $C_{gen}$ represents the cost of the PV panels, $C_{inv}$ is the cost of the inverter, $C_{inst}$ is the cost of the installation, and the sum of the three is $C_{system}$. Because the inverter has, at worst, an expected lifespan of 10 years, the inverter cost ($C_{inv}$) should be multiplied by 3. $C_{sub}$ is the possible financial subsidy on the initial cost. [65]

$Q_j$ represents the difference between the cash input generated by the investment and the payment or cash output the investment requires for a certain instance in time (year $j$) [65], this is expressed by Equation 3.9:

$$\mathrm{Q_j} = (\mathrm{Cash\ input}_j) - (\mathrm{Cash\ output}_j) = (\mathrm{p_b} \cdot \mathrm{E_{PVaut}} + \mathrm{p_s} \cdot \mathrm{E_{PVinj}}) - (\mathrm{C_{O\&M}} + \mathrm{C_{ins}} + \mathrm{C_{Fin}}) \tag{3.9}$$

Where $p_b$ and $p_s$ represent the price of the energy bought from and sold to the grid, respectively. $E_{PVaut}$ represents the energy produced by the PV system that is automatically consumed by the house, and $E_{PVinj}$ is the energy produced by the PV system that is sold to the grid. $C_{O\&M}$, $C_{ins}$, and $C_{Fin}$ are the annual costs connected to operation and maintenance, insurance, and financing. [65]

### 3.4.5 Selling all PV production

Selling all the PV production one produces through their private PV systems are in some countries more favourable than using it to self-consumption. In Spain it is allowed and also permitted to sell all production from ones PV system. [65] The results will be a modified version of Equation (3.4), which becomes:

$$\mathrm{Income_{PV}} = \mathrm{SP(ts)} \cdot \mathrm{E_{PV}(ts)} + \mathrm{FIT} \cdot \mathrm{E_{PV}(ts)} \tag{3.10}$$

# Chapter 4

# Method

*Parts of this chapter are retrieved from my specialization project found in Appendix C.*

This chapter presents the methods used to achieve this project's results. It includes the communication process with the participants who shared their data, the software used for the project, and how the data was processed to obtain the results.

## 4.1 Getting residences for the project

The process of finding residences for the project was done by using different social media platforms. A post was created describing the purpose of the master project and that help from private individuals was needed, see Figure 4.1. This post was published in several Facebook groups regarding renewable energy for private residences in Norway. The most prominent response was in a group named "Solceller og Alternativ Energi", with 16 900 members. [66]


Figure 4.1: The post that was published on social media platforms to get volunteers for the project.

The same post was also published on the social media platform LinkedIn [67] and on renewable energy forums online [68], but with less response. In total, 63 volunteers made initial contact to offer help, and 15 were able to deliver the necessary data for the project.

### 4.1.1 The correspondence

The correspondence with the volunteers was done through mail, with initial contact made through Facebook Messenger. The first mail was sent as a formal mail introducing the master thesis and NTNU, with a focus on the goal of the project and how they could contribute. Most volunteers were eager to help and had a positive attitude towards the project. The communication was usually about how they could extract the necessary data for the project. Since many had different inverters, the data extraction in the right granularity was often problematic without enforcing too much work on the volunteers.

## 4.2 Data gathering

This section presents how the data was collected for the project and processed into usable data.

### 4.2.1 Solar data

The gathering of solar data for this project came with several obstacles, mainly because of different suppliers and accessibility to the data required to carry out the project. The solar inverters are connected to a web application or mobile application where the consumer can monitor the production of their PV system. Still, the possibility to download historical data in hourly granularity for more than a day at a time was minimal and needed private login credentials.

#### Solar data from Otovo

Most of the volunteers in the project used the company Otovo AS as the supplier for their PV system. Through a contact person at Otovo AS and the approval of the volunteers, a Python script was used to communicate with Otovo's application programming interface (API) and retrieve the solar data from the residences. Unfortunately, the API could only handle a year's worth of data at a time before a time-out error would occur, so this process was repeated several times for every residence to get all the data.

The dataset retrieved was a snapshot of the energy production at intervals of 5 minutes and 10 minutes throughout a day, in watts. To convert this into kilowatt hours, to match the other data, the Python package *pandas* and the function *resample* with mean were used to transform the granularity into hourly data. The Python function summed up all the values for each hour and divided it by the total number of values in the hour.

Since the connection with the inverter only happens when there is PV production, the dataset will not have any values for the nighttime. Therefore, because of a missing connection or bad connection with the inverter, some days in the dataset had gaps of missing data, measured to approximately 2-3% based on a test with one of the houses with data from Otovo and daily data from the inverters web application. As discussed in Section3.3, linear interpolation was used to fill in the missing data. Daily production values were retrieved directly from the inverters web application to verify that the interpolation and resampling with the mean function worked. Finally, the data from Otovo was resampled into daily values. The comparison can be seen in Figure 4.2, where the plot on top shows how closely they correlate. The histogram at the bottom shows the frequency of difference in daily values, where the mean absolute value was calculated to be 0.4.

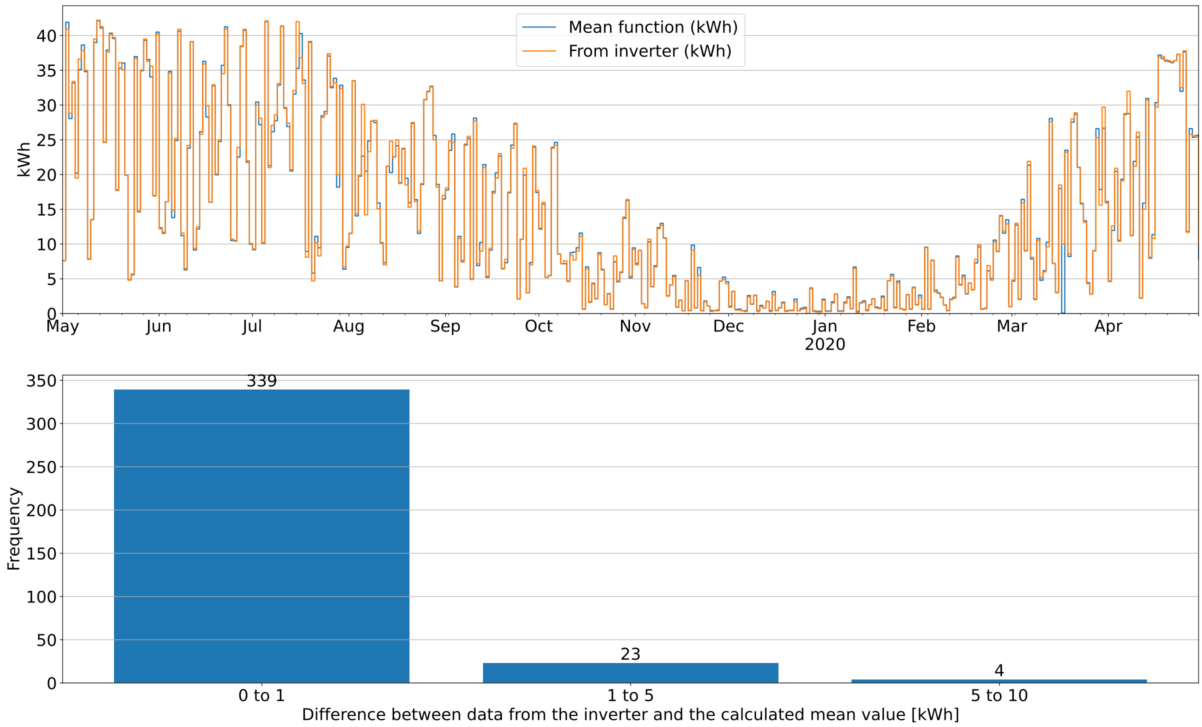



Figure 4.2: Plot and histogram of the daily values retrieved from Otovo compared to directly from the inverter to verify the usage of interpolation and resampling to fill in the missing data in the PV production.

**Solar data from Solaredge**

For the residences with a Solaredge inverter, a script was used that communicated with the Solaredge API and retrieved the hourly data comprised in a JSON file which was then converted to a comma-separated value (CSV) file. The data contained an hourly timestamp and the solar energy in Wh produced during that hour.

### 4.2.2 House consumption data

The consumption data for the residences were collected in three different ways based on the availability of data. First, for homes with a PV system installed, the whole or part of their consumption is covered by their production, resulting in the power they buy from the grid not equal to their actual house consumption. To get the exact house consumption, the excess PV production, pushed to the grid, is subtracted from the gross PV production, then added to the house consumption that the power company show.

For the residences that had Tibber as a power supplier, the data could be downloaded directly from their API through a Python script or a google sheet developed by Tibber [69]. For the remaining residences, the house consumption data was retrieved from Elhub with their permission.

### 4.2.3 Spot data

The hourly spot price used in this project is retrieved from the Nord Pool power market, explained in Section 2.2. The aim was to recover ten years of hourly spot data to use in the calculations to get a more extensive time perspective over the results. A Python script was used to communicate with Nord Pool to retrieve the hourly data condensed into pickle files. Here an issue arose when the earliest hourly dataset the script was able to return was from 2019. The solution was to download the historical market data directly from the Nord Pool website, where hourly data in excel-files was available back to 2013 at the earliest.[70] So, the hourly spot price data used in the project is from 2013 to 2021.

### 4.2.4 Nettleie

The nettleie from power suppliers is a fixed cost and varies from area to area. The nettleie for the different areas relevant to this project is presented in Figure 2.5. Since there is a slight variation in nettleie cost for the various counties, the average nettleie for each year between 2013 to 2021 was used, which can be seen in Table 2.3.

### 4.2.5 Plusskunde

The plusskunde parameter is divided into two parts: the plusskunde relation the consumer has with the power company and the plusskunde relation the consumer has with their power suppliers, called the feed-in tariff.

The Nord Pool spot price is used for the plusskunde parameter connected to the power company. This means the consumer earns the same amount per kilowatt hour they push into the grid as the power company would gain from the power market. Some power companies offer a start-up deal, offering, for example, 1 NOK/kWh for the first 5000 kWh, then switch over to the Nord Pool spot price. But since this is a limited offer, and as seen in Table 2.5, where the most popular power companies are listed, the standard is using the Nord Pool spot price.

Then for the feed-in tariff that the power suppliers give, -4 øre/kWh is used since this is the most common deal, and most of the residences in this project receive this. In Table 2.4, an overview of the largest power suppliers in Norway is presented, where the different deals also can be seen.

## 4.3 Data processing and calculations

How the data gathered was used and how the calculations for the result were done will be presented here in chronological order so that it can conveniently be replicated at a later time by anyone if needed.

### 4.3.1 Software

The data gathering, calculations, and illustrations made in this project were done using Python.

### 4.3.2 Spot price

Two different Python functions were made to process the spot market data: one to handle the data from the pickled file that was retrieved directly from the Nord Pool API and one to process the excel-file that had to be downloaded from their website. Both functions returned dictionaries containing timestamps for the hourly data and the spot price for the corresponding time, both with and without VAT. However, the raw data from the files, both the pickle file and the excel file, had one missing value between 02:00-03:00 at a date at the end of March for each year, which was assumed to be a maintenance gap. Therefore, a for-loop was implemented in the Python script to counteract this, which iterated through the list, finding missing data and replacing them with the mean of the previous and following value.

Two modifications were needed to be applied to the raw data to return it to the desired form. First, all the values had to be divided by 1000 to turn them from NOK/MWh to NOK/kWh. For the spot price that included tax, each value had to have 25% added, then another addition of 0.01 NOK, explained in Section 2.3.2.

### 4.3.3 House consumption, PV production, and the delta variable

Three python functions were created to handle the different data to process the house consumption data from Tibber, Elvia, and Elhub and the PV production data. The functions returned the data as dictionaries containing timestamps for the hourly data and the corresponding house consumption, PV production, and the delta variable.

The house consumption data contained the grid consumption and the excess PV production sold to the grid. As explained in Section 4.2.2, to get the actual house consumption, the grid consumption had to be added to the total PV production and then subtracted by the excess PV production sold to the grid. To ensure the correct values were added together with the corresponding timestamps, a Python function was made that correlated the indices to match.

The delta variable, the difference between the house consumption and the PV production, was processed through the same functions. When the delta variable was greater than zero, the house consumption was greater than the PV production at that hour, which meant that the resident had to buy power from the grid. When the delta variable was less than zero, the house consumption was less than the PV production at that hour, which meant that the resident sold the excess power to the grid. When the delta variable was equal to zero, the house consumption matched the PV production, and the resident neither bought nor sold any power and would break even at that hour.

### 4.3.4 The hourly cost of electricity with and without the PV installation

To get the hourly cost of electricity with and without the PV installations, a Python function was created that took in the house consumption, the delta variable, and the spot price with and without tax as arguments. Then, the Python function designed to correlate the indices were applied to ensure the calculations were accurate considering the timestamps. How the calculations for the hourly cost were done can be seen in Section 3.4.2.

### 4.3.5 Selling all PV production

To get how much each residence would make if they chose to sell all their PV production, instead of using it themselves, a Python function was created that took in the hourly PV production and the spot price. The Python function correlated timestamps were also used to ensure they matched up. How the calculations were done can be seen in Section 3.4.5.

# Chapter 5

# Results

This chapter will present the main results from the data gathered in tables and plots. The results are based on house consumption and PV production data for 15 private residences in Norway that have installed solar PV systems.

The chapter is divided into three sections, where the first section presents the house consumption and PV production for each residence, the second section shows a cost analysis of the data in connection with the Nord Pool spot market from the past eight years, and the third section presents the cost and payback time of the PV systems for each residence. For each residence, house consumption data and PV production data have been collected for the years 2020 and 2021, so the results obtained will be presented and divided into the results based on the data collected from 2020 and the data collected from 2021.

The results for each house are presented neatly in different plots to give a visualization of the results. In this section, only the graphs from house number 1 will be presented, accompanied by detailed explanations of each plot. The plots for the remaining houses are found in Appendix A.

## 5.1 House consumption and PV production

This section presents the house consumption and PV production for the 15 residences participating in the project. The results will be divided by the year of collected data, meaning first the data collected from 2020 is presented, then the data collected from 2021 is shown before a summary of all the results is presented.

### 5.1.1 House consumption

The house consumption data for the 15 residences participating in the project is presented in Table 5.1. The table shows the consumption for each house with and without the PV system present and the total reduction in grid consumption each residence had. The data is presented as yearly average consumption per square meter to be easier to compare the different homes since they vary in size.

#### 2020

The lowest average house consumption for 2020 was residence number 7, the second largest residence in the project, with an average consumption of 60.1 kWh/m$^2$ per year with the PV installation. The highest average house consumption was residence number 9, the smallest residence in the project, with an average consumption of 187.5 kWh/m$^2$ per year. The most significant decrease in grid consumption due to the PV system was residence number 8, the residence with the largest PV system installed, which had a reduction of 36.2%.

Out of all the residences, the average house consumption without a PV system was 135.9 kWh/m$^2$ per year and 111.9 kWh/m$^2$ per year with the PV system, which is an average reduction in consumption of 17.7% in total.

**2021**

The lowest average house consumption for 2021 was residence number 7, the second largest residence in the project, with an average consumption of 65.9 kWh/m$^2$ per year with the PV installation. The highest average house consumption was residence number 5, the second smallest residence in the project, with an average consumption of 311.9 kWh/m$^2$ per year. The most considerable decrease in grid consumption due to the PV system was residence number 8, the residence with the largest PV system installed, which had a reduction of 35.1%. The residences compared to each other can be seen in Figure 5.1.

Out of all the residences, the average house consumption without a PV system was 147.2 kWh/m$^2$ per year and 122.4 kWh/m$^2$ per year with the PV system, which is an average reduction in consumption of 16.9% in total.

In Figure 5.2, the correlation between reduced house consumption and the size of the installed PV system for each residence is presented. Where the linear trend shows that the larger the systems are, the higher the reduction in house consumption is.

Table 5.1: Average yearly house consumption per m$^2$ for each residence with and without PV system and the total reduction in grid consumption as a result of the PV system.

| **House** | **Without PV (kWh/m$^2$/yr)** | | **With PV (kWh/m$^2$/yr)** | | **Reduction** | |
|---|---|---|---|---|---|---|
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **01** | 114.3 | 109.5 | 97.1 | 93.9 | -15% | -14.3% |
| **02** | 120.5 | 95.1 | 102.2 | 77.8 | -15.2% | -18.2% |
| **03** | N/A | 84.3 | N/A | 68.3 | N/A | -19% |
| **04** | 107.1 | 125.3 | 96.9 | 116.6 | -9.5% | -6.9% |
| **05** | N/A | 344.1 | N/A | 311.9 | N/A | -9.4% |
| **06** | 149.4 | 141.6 | 115.5 | 109.9 | -22.7% | -22.4% |
| **07** | 79.6 | 84.5 | 60.1 | 65.9 | -24.5% | -22% |
| **08** | 114.8 | 115 | 73.2 | 74.6 | -36.2% | -35.1% |
| **09** | 227.3 | 199.7 | 187.5 | 142.7 | -17.5% | -28.5% |
| **10** | 157.1 | 188.1 | 137.3 | 166.3 | -12.6% | -11.6% |
| **11** | 193.1 | 199.5 | 163.4 | 171.5 | -15.4% | -14% |
| **12** | 115.7 | 103.9 | 99.4 | 87.5 | -14.1% | -15.8% |
| **13** | 123.9 | 129.1 | 110.3 | 116.8 | -11% | -9.5% |
| **14** | 147.2 | 166.3 | 124.7 | 143.9 | -15.3% | -13.5% |
| **15** | 116.1 | 121.2 | 87 | 93.7 | -25.1% | -22.7% |
| **Avg.** | **135.9** | **147.2** | **111.9** | **122.4** | **-17.7%** | **-16.9%** |

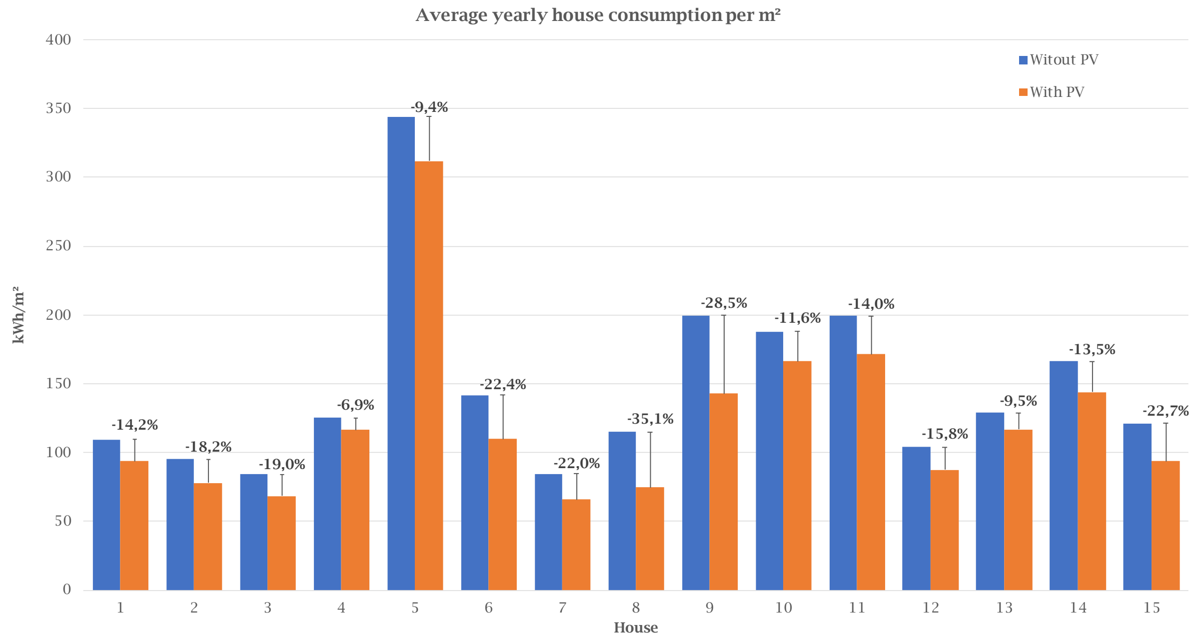



Figure 5.1: Average yearly house consumption per m$^2$ for each residence with and without a PV system, using data from 2021.

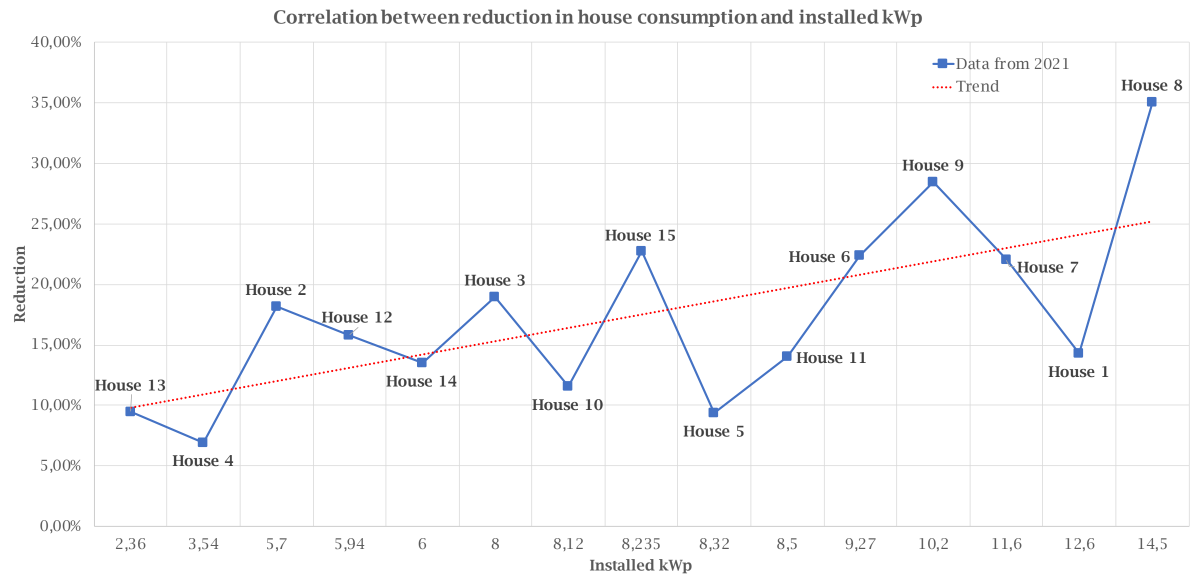



Figure 5.2: Correlation between the reduction in house consumption for each residence and the size of the installed PV system, using data from 2021.

### House consumption plots

In Figure 5.3, the house consumption data for 2021 from House 1 is shown. The line graph in the figure shows how the PV system impacts the consumption data and PV system over time. The blue line represents the consumption without a PV system, and the orange line represents the actual consumption with the PV system. One can see that the PV system has the most significant impact during the spring and summer months, with little to almost no effect during the fall and winter months. The line gr shows the daily data and the weekly simple moving average (SMA) to eliminate peaks and more clearly represent the data. The histogram in Figure 5.3, shows the frequency of daily consumption values throughout 2021, where the blue bars represent the daily consumption values without a PV system present, and the orange bars represent the actual daily consumption values with the PV system.

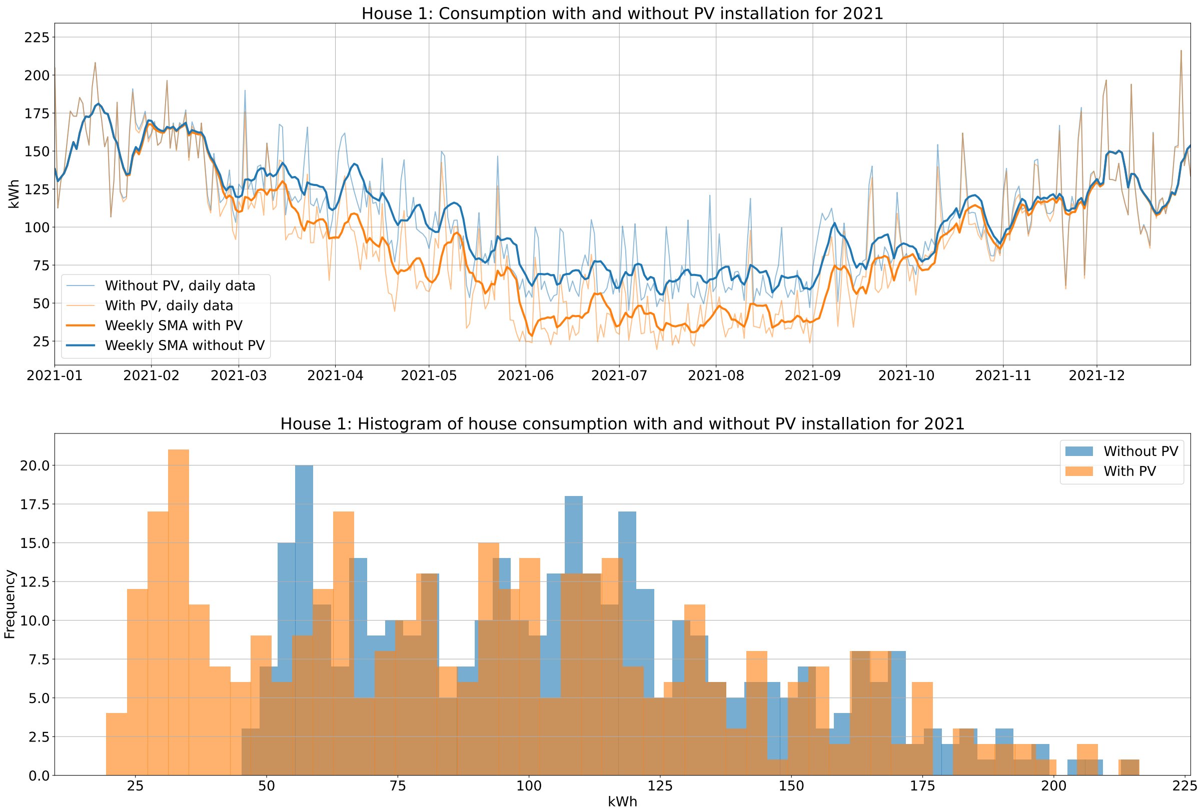



Figure 5.3: Daily house consumption with and without a PV system for 2021 from House 1. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represent the values with the PV system and the blue represents the values without the PV system.

In Figure 5.4, the monthly house consumption for 2021 from House 1 is shown in a bar graph. Here it is easier to see the impact of the PV system for each month of the year, substantiating the claim that the PV system has the most considerable effect during the spring and summer months. In Figure 5.5, the total house consumption accumulated over 2021 is shown for House 1. These plots for the rest of the residences can be found in Appendix A.

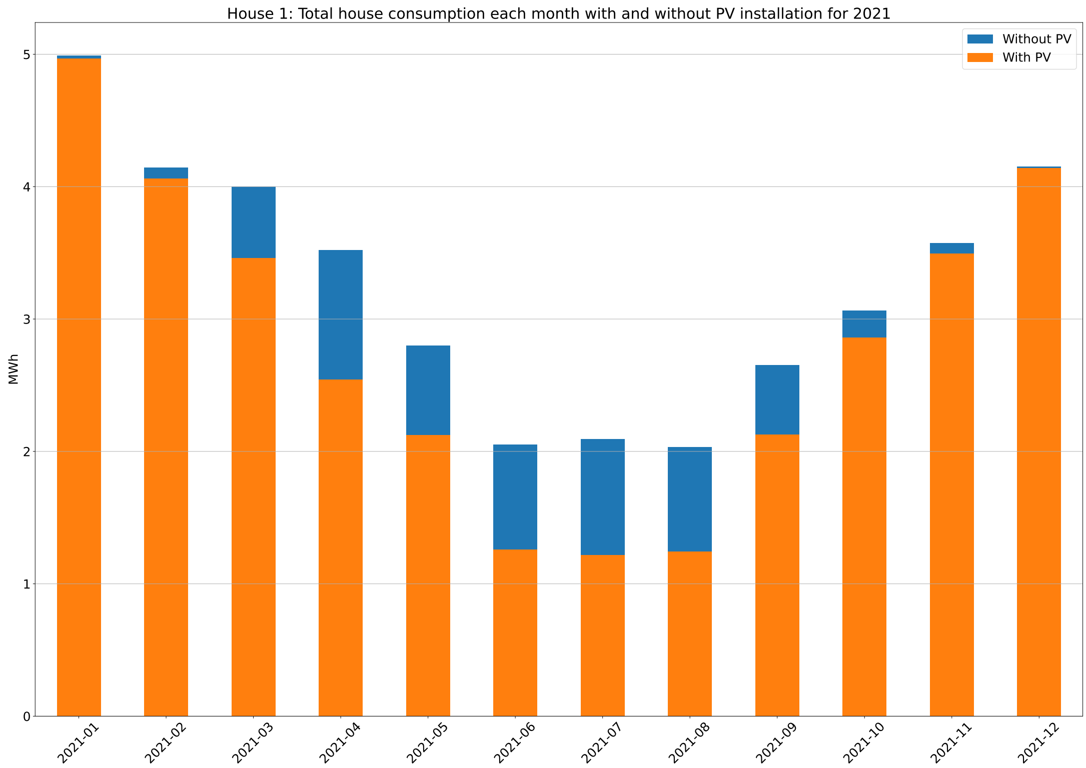



Figure 5.4: Monthly house consumption for House 1 with and without a PV system for 2021.

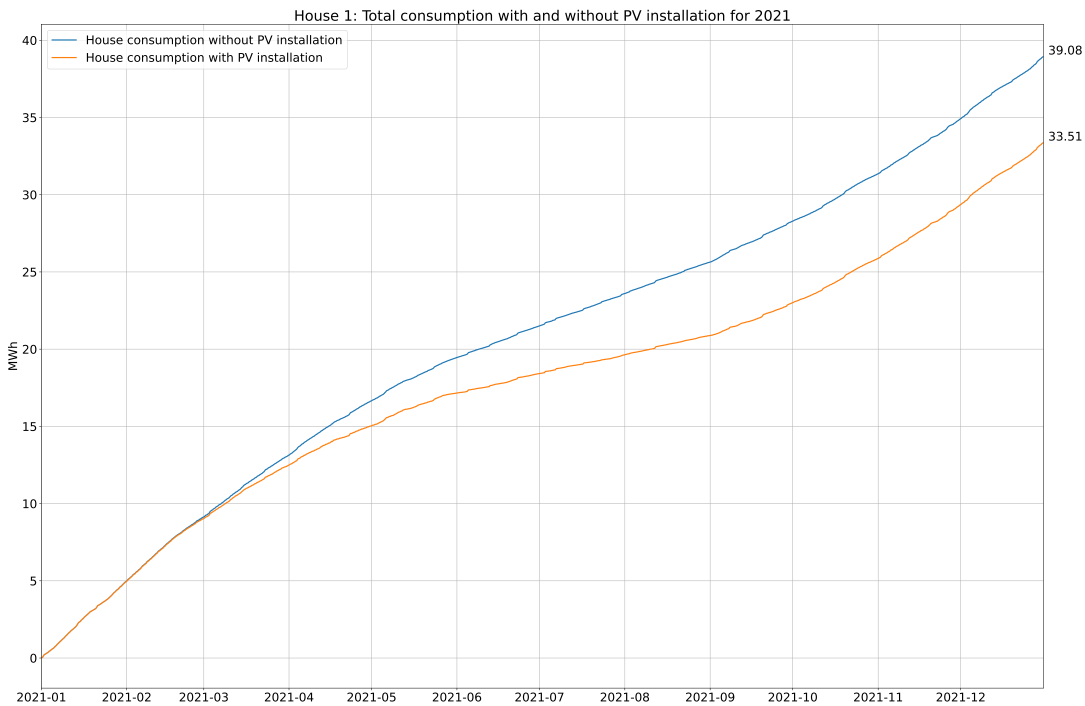



Figure 5.5: Total house consumption for House 1 with and without a PV system accumulated over 2021

### 5.1.2 Solar PV production

The solar PV production for the 15 residences that took part in this project is presented in Table 5.2. The table shows the yearly average production per kilowatt peak installed, the yearly average sold production per kilowatt peak installed, and the percentage of the production self-consumed by the residences. Since the homes have different sizes on their PV system installations, the data is presented as yearly production in kilowatt hours per kilowatt peak installed effect to give a better basis for comparison. The difference in PV production from the collected data from 2020 and 2021 will vary a little, mainly based on the weather conditions for the year.

**2020**

The highest average production for 2020 came from residence number 13, the residence with the smallest PV system located in Agder county, which had a yearly average production per kilowatt peak installed of 1131.4 kWh/kWp per year. The lowest average production for 2020 came from residence number 10, located in Viken county, which had a yearly average production per kilowatt peak installed of 673.7 kWh/kWp per year. The residence with the highest self-consumption rate was residence number 13, which used 82% of the power the PV system produced. The residence with the lowest self-consumption rate was residence number 8, with the largest PV system located in Viken county, where they used 27.6% of the power the PV system produced.[1]

Out of all the residences, the average production per kilowatt peak installed was 867.4 kWh/kWp per year, where on average, 56.8% was used for self-consumption, and the rest was sold to the power grid.

**2021**

Residence number 13 had the highest average production for 2021, with 1025.4 kWh/kWp per year. The lowest average production for 2021 came from residence number 5, located in Vestfold and Telemark county, with 574.5 kWh/kWp per year. Residence number 5 was also the residence with the highest self-consumption rate of 85.6%. The residence with the lowest self-consumption rate was again residence number 8, with 30.5%. The residences compared to each other can be seen in Figure 5.6.

[1] Residence 15 is listed in Table 5.2, as the residence with the lowest self-consumption rate for 2020, but this residence is missing two months of PV data from 2020, which is why it is exempt here.

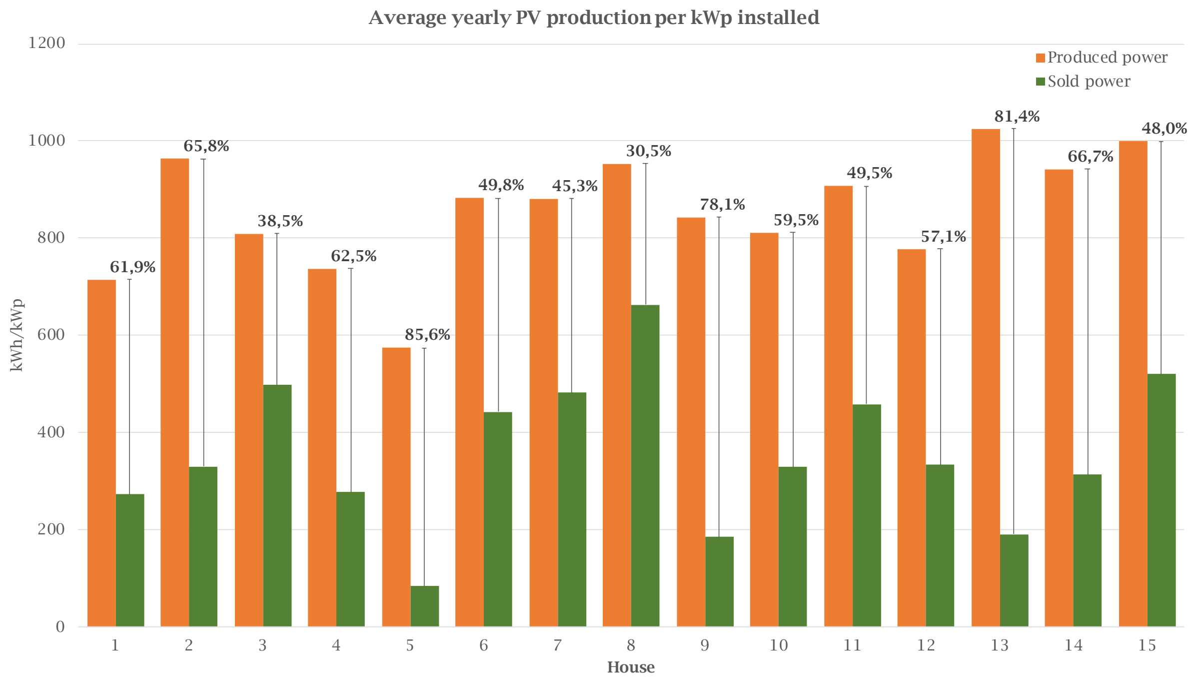



Figure 5.6: Average yearly PV production for each residence, the amount they sold, and percentage of self-consumption, based on data from 2021.

Out of all the residences, the average production per kilowatt peak installed was 852.9 kWh/kWp per year, where on average, 58% was used for self-consumption, and the rest was sold to the power grid, the distribution can be seen in Figure 5.7.

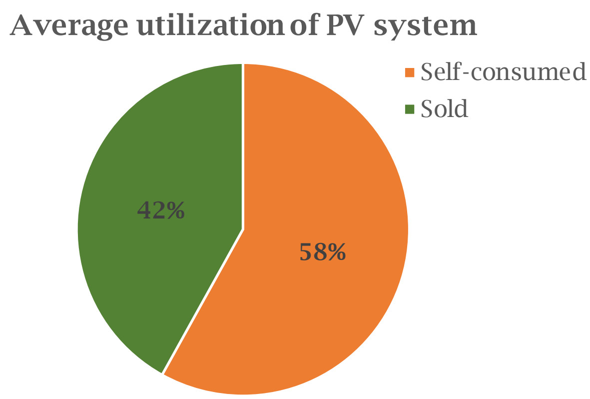



Figure 5.7: Average utilization of the PV systems for all the residences, based on data from 2021.

Table 5.2: Average yearly PV production per kWp installed for each residence, the amount of excess production sold to the grid, and the percentage that went to self-consumption.

| House | Produced (kWh/kWp/yr) | | Sold (kWh/kWp/yr) | | Self-consumption | |
|---|---|---|---|---|---|---|
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **01** | 767.5 | 714.3 | 279.4 | 272.2 | 63.6% | 61.9% |
| **02** | 880.7 | 963.2 | 198.3 | 329.8 | 77.5% | 65.8% |
| **03** | N/A | 808.8 | N/A | 497.5 | N/A | 38.5% |
| **04** | 776.8 | 737.3 | 276.8 | 276.8 | 64.4% | 62.5% |
| **05** | N/A | 574.5 | N/A | 82.9 | N/A | 85.6% |
| **06** | 906.4 | 881.7 | 448.6 | 442.4 | 50.5% | 49.8% |
| **07** | 915.5 | 881 | 509.5 | 481.9 | 44.3% | 45.3% |
| **08** | 974.5 | 953.1 | 705.5 | 662.8 | 27.6% | 30.5% |
| **09** | 820.2 | 843.1 | 175.3 | 184.3 | 78.6% | 78.1% |
| **10** | 673.7 | 811.6 | 357.1 | 328.8 | 47% | 59.5% |
| **11** | 974.1 | 907.1 | 474.1 | 457.7 | 51.3% | 49.5% |
| **12** | 735.7 | 777.8 | 306.4 | 333.3 | 58.4% | 57.1% |
| **13** | 1131.4 | 1025.4 | 203.4 | 190.7 | 82% | 81.4% |
| **14** | 983.3 | 941.7 | 375 | 313.3 | 61.9% | 66.7% |
| **15** | 735.9 [a] | 999.4 | 564.7 | 519.7 | 23.3% | 48% |
| **Avg.** | **867.4** | **852.9** | **374.9** | **358.3** | **56.8%** | **58%** |

[a] This dataset is missing PV production data from 2020.04 to 2020.06

### Solar PV production plots

In Figure 5.8, the PV production from House 1 for 2021 is shown to give a visualization of the production throughout the year. The data is presented as daily values and weekly SMA on top to eliminate peaks and provide a better plot. In Figure 5.9, the hourly PV production throughout 2021 is shown. Here, one can see the hour with the highest production measured at 9.88 kWh at the end of June for House 1. In Figure 5.10, the excess PV production automatically sold to the grid is plotted through daily values and weekly SMA for House 1. In Figure 5.11, the total PV production and the excess sold to the grid are summed up for each month in 2021 for House 1. And in Figure 5.12, the total PV production and surplus sold to the grid are cumulated over 2021 for House 1. These plots for the rest of the residences can be found in Appendix A.

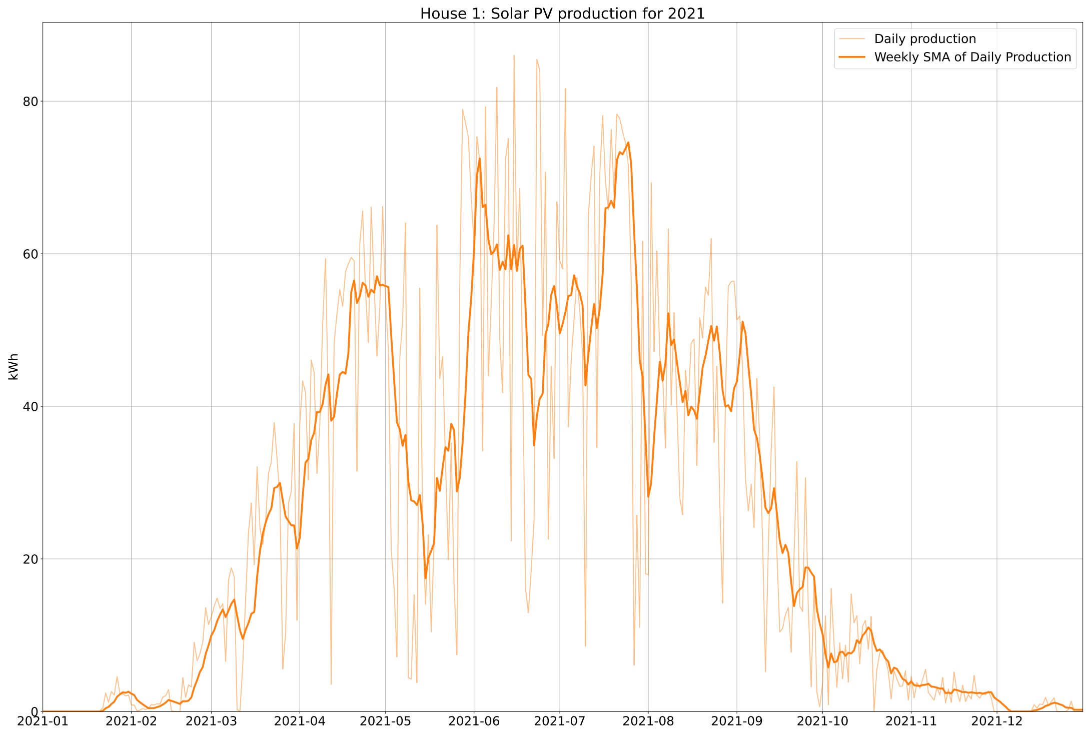



Figure 5.8: Daily PV production and weekly SMA for House 1 in 2021.

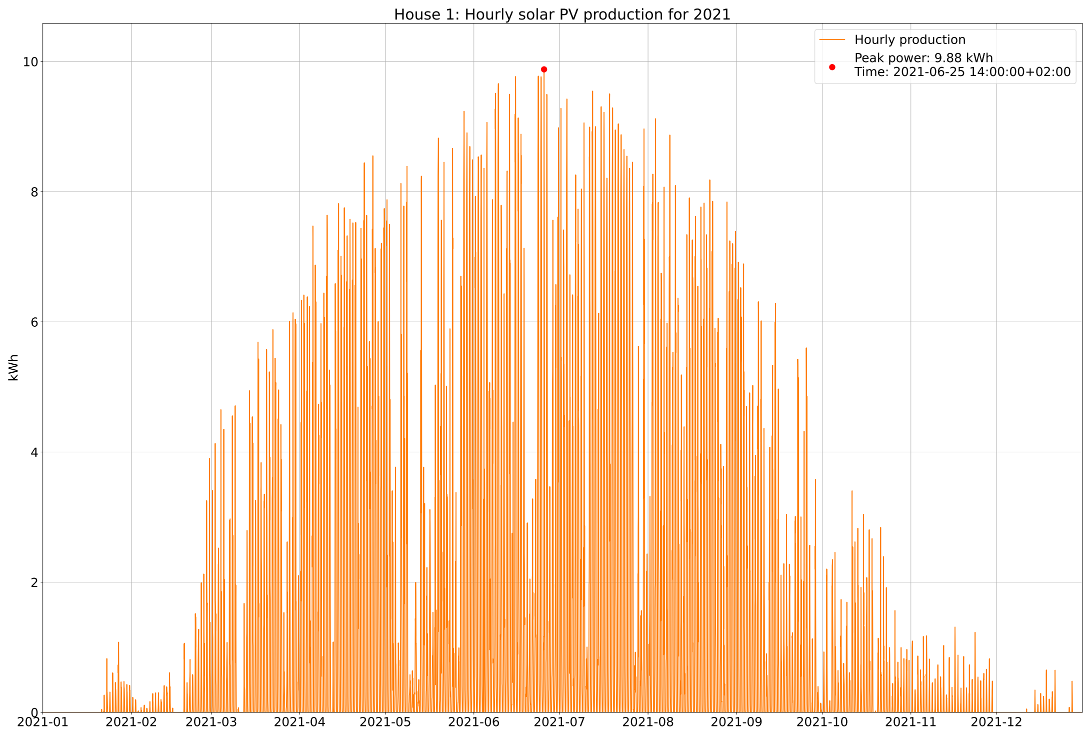



Figure 5.9: Hourly PV production for House 1 in 2021.

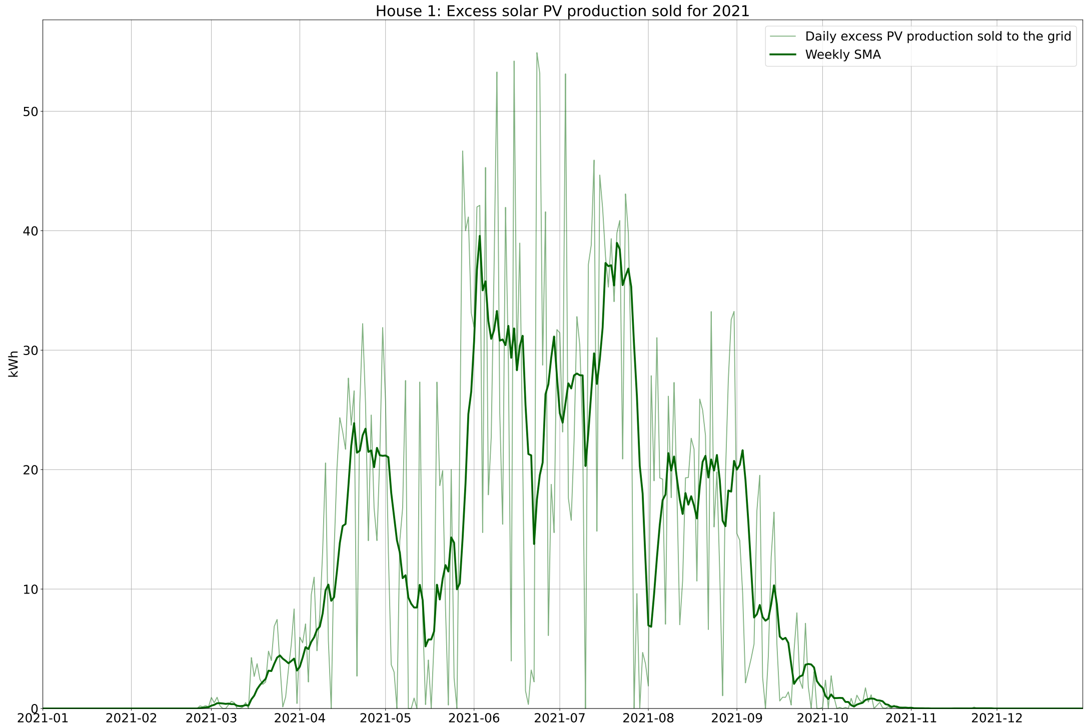



Figure 5.10: Daily excess PV production sold to the grid and weekly SMA for House 1 in 2021

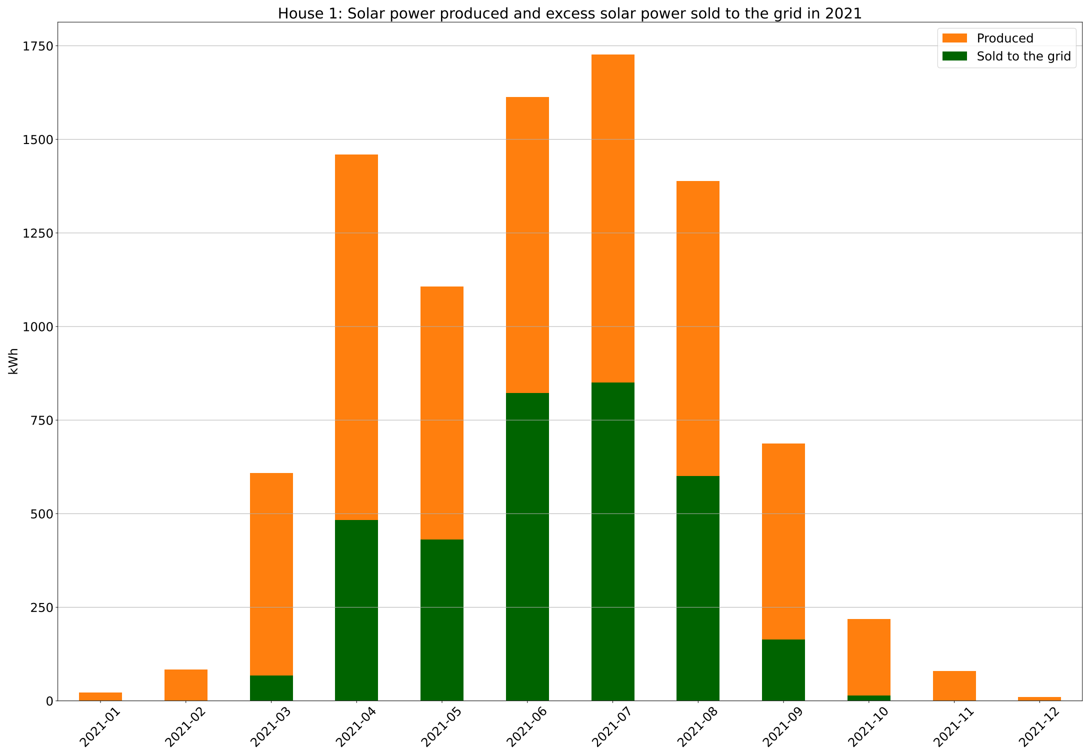



Figure 5.11: Total solar PV production and excess production sold to the grid for each month in 2021 from House 1.

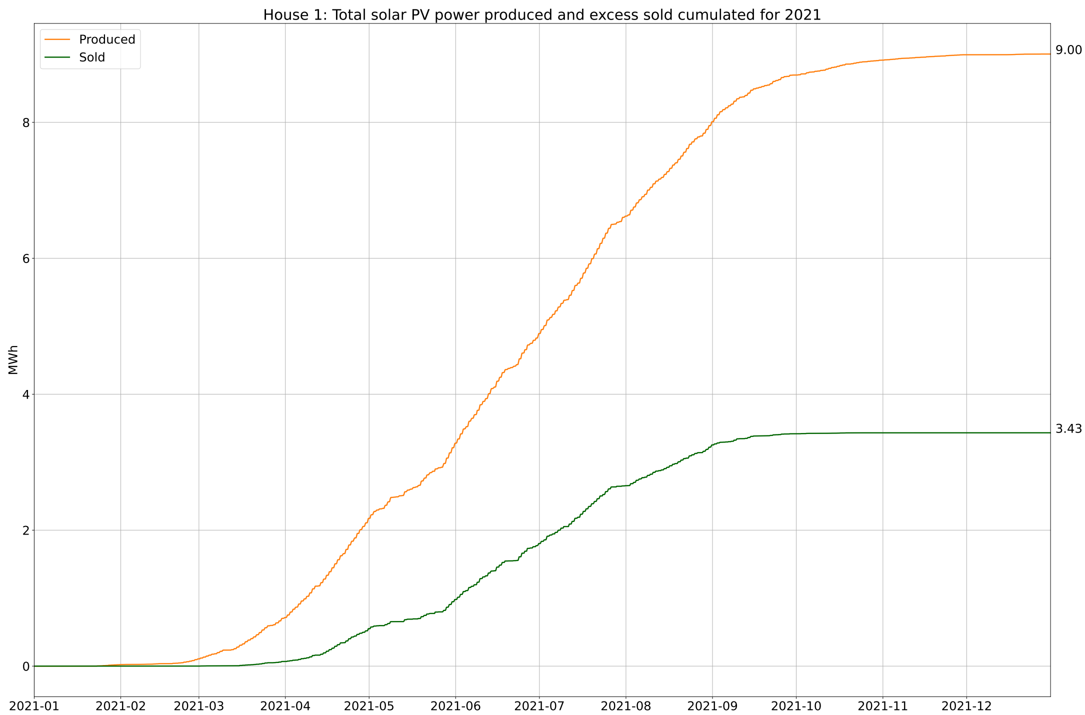



Figure 5.12: Total solar PV production and excess production sold cumulated over 2021 from House 1

### 5.1.3 Delta variable

The difference in the house consumption and the PV production at every hour is called the delta variable. See Section 3.4.2, for elaboration on how this variable is calculated. In Figure 5.13, this variable is plotted for House 1 for 2021 as a line plot and histogram. The plot is used to visualize how often the residence's pv system produces more power than the residence itself consumes. The red dotted line in the plot represents the energy equilibrium of the consumption in the house. Whenever the hourly delta values cross this dotted red line, it means that at that hour, the residence produced more energy with their PV system than their house was using. Whenever the hourly delta values are above the dotted red line, it means that at that hour, the house consumption was larger than the production of the PV system. The bottom plot of Figure 5.13, is a histogram to show the distribution and frequency of the different hourly delta values. This plot for the rest of the residences can be found in Appendix A.

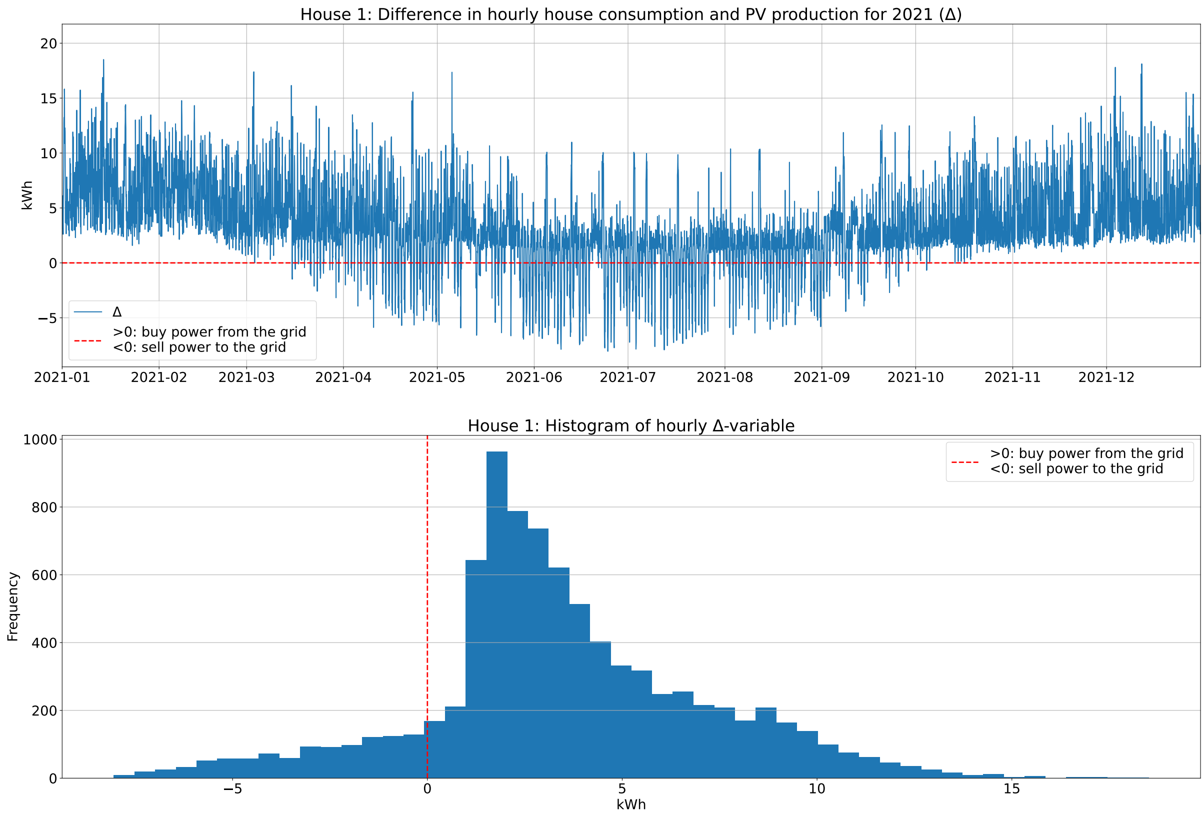



Figure 5.13: The delta variable plotted for House 1. It shows the difference in house consumption and PV production at every hour to better visualize when the residence produces more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence.

### 5.1.4 House consumption and PV production

To provide an overall picture of the house consumption (simulated without the presence of a PV system) versus the PV production, they are both plotted together here in Figure 5.14, for House 1. This plot for the rest of the residences can be found in Appendix A.

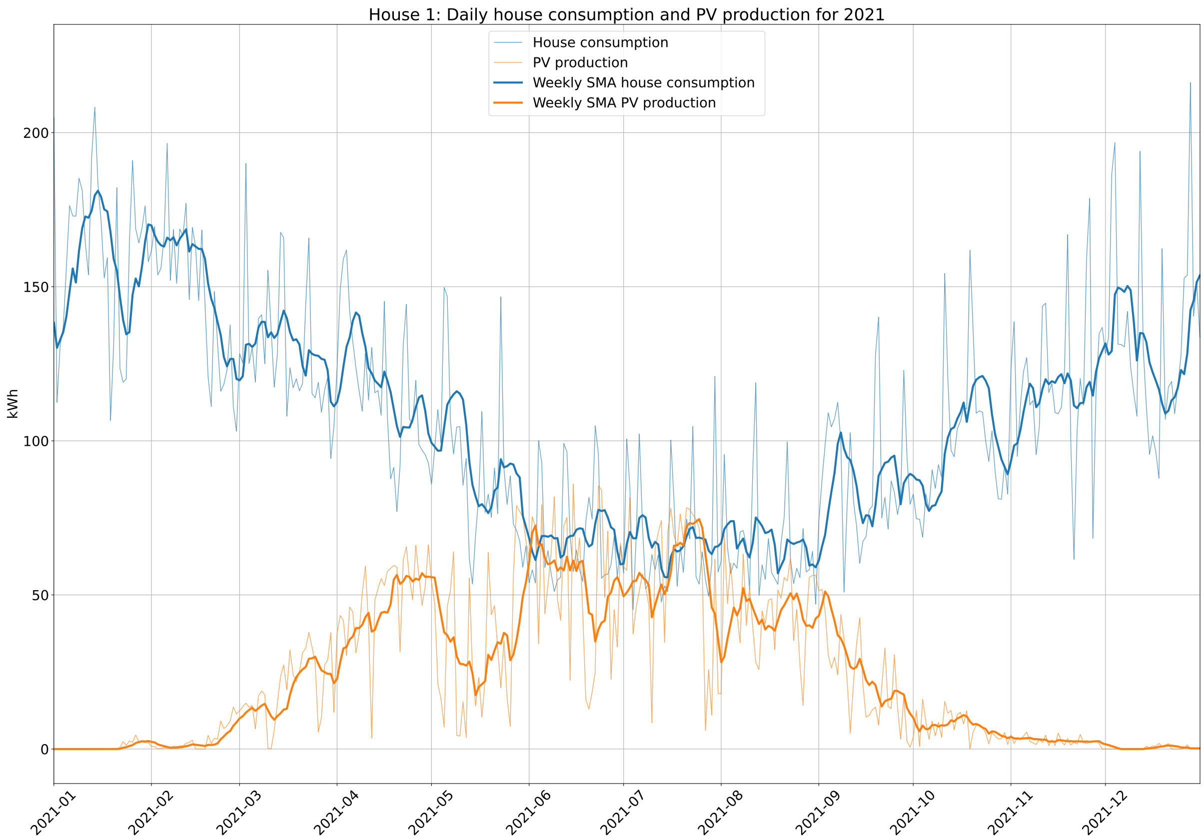



Figure 5.14: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

## 5.2 Cost of power with and without a solar PV system

This section will present the cost of power for each residence, the actual price with the PV system present, and the simulated cost without the PV system present, by using the data collected from each home and matching it up with the spot price from different years to see the effect it has[2]. How the specific calculations are done can be read about in Section 3.4.2. The variation in the Nord Pool spot price can be seen in Figure 2.3, in Section 2.2.1, where the year with the highest cost of power was 2021, and the year with the lowest power price was 2020. Each year of data collected from the residences is used in the cost calculations. Only the main results from these calculations will be presented here. The rest of the results can be found in Appendix B. To provide a better basis for comparison, the total cost calculated for each year is divided by the total house consumption for each residence, with the data for the corresponding year.

### 5.2.1 The average cost of power with and without a solar PV system

In this section, the average cost of power for each residence is presented, with and without a solar PV system. In Table 5.4, the average cost of power using the house consumption data and PV production data from 2021 is shown, where the year with the most expensive power (2021) and the year with the least expensive power (2020) are listed to show how much the spot price impacts the cost of energy.

**The year with the lowest spot price (2020)**

The cost of power without a PV system varies from 0.68 NOK/kWh to 0.72 NOK/kwh for the year with the least expensive energy price, making the average 0.70 NOK/kWh. The cost of power with a PV system varies from 0.42 NOK/kWh to 0.67 NOK/kWh, making the average 0.57 NOK/kWh. The price reduction due to the PV system varies in line with the installation size, showing an average price reduction of 18.6%.

**The year with the highest spot price (2021)**

The cost of power without a PV system varies from 1.46 NOK/kWh to 1.60 NOK/kWh for the year with the most expensive energy price, making the average 1.50 NOK/kWh, which is over twice as much as the year with the least expensive energy price. The cost of power with a PV system varies from 0.63 NOK/kWh to 1.48 NOK/kWh, making the average 1.17 NOK/kWh. The average price reduction for the year with the highest energy price was a reduction of 22%.

**The average cost of power based on the mean of yearly cost**

For each residence, the yearly cost of power, based on their actual consumption and PV production from 2020 and 2021, has been calculated based on the Nord Pool spot price from the past nine years to see the change in cost based on just the fluctuation in the power market. In Table 5.3, these calculations are shown from House 1, where each year of collected data from the house is used to calculate the simulated cost for the years 2013 up to and including 2021 based on the energy spot price for the given year, these calculations for the remaining residences can be found in Appendix B.

In Table 5.5, the mean value of the nine years of simulated costs is presented for all the residences. The average power price without a PV system is the same for the collected data from 2020 and 2021, at 0.93 NOK/kWh. The average cost of power with a PV system is also the same at 0.73 NOK/kWh, which is a reduction in the average price of 21.5%.

[2]The added taxes from the government and the nettleie cost is also included in these energy calculations, but they are considered to be fixed costs.

Table 5.3: Yearly cost of power for House 1, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for 2013-2021 based on the energy spot price for the given year.

| House 1 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK)** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 33 817 | 32 601 | 27 293 | 26 604 | 6524 | 5998 |
| **2014** | 30 686 | 29 676 | 25 126 | 24 559 | 5561 | 5117 |
| **2015** | 29 811 | 28 792 | 24 623 | 24 073 | 5188 | 4719 |
| **2016** | 34 876 | 33 588 | 28 598 | 27 847 | 6278 | 5742 |
| **2017** | 36 214 | 34 904 | 29 467 | 28 733 | 6747 | 6171 |
| **2018** | 44 008 | 42 356 | 35 174 | 34 116 | 8833 | 8239 |
| **2019** | 42 808 | 41 361 | 34 924 | 34 168 | 7885 | 7194 |
| **2020** | 28 276 | 27 226 | 23 808 | 23 204 | 4468 | 4022 |
| **2021** | 61 379 | 59 460 | 50 794 | 49 709 | 10 584 | 9751 |
| **Avg.** | **37 986** | **36 663** | **31 090** | **30 335** | **6896** | **6328** |

Table 5.4: Average cost of power for each residence, using their house consumption and PV production data from 2021, compared to the Nord Pool spot price for the year with the lowest average power price (2020) and the year with the highest average power price (2021), and the price reduction caused by the PV system.

| **House** | **Cost without PV (NOK/kWh)** | | **Cost with PV (NOK/kWh)** | | **Price reduction** | |
|---|---|---|---|---|---|---|
| | **Lowest price year** | **Highest price year** | **Lowest price year** | **Highest price year** | **Lowest price year** | **Highest price year** |
| **01** | 0.70 | 1.52 | 0.59 | 1.27 | -15.7% | -16.4% |
| **02** | 0.70 | 1.48 | 0.57 | 1.17 | -18.6% | -21% |
| **03** | 0.71 | 1.48 | 0.57 | 1.07 | -19.7% | -27.7% |
| **04** | 0.72 | 1.60 | 0.67 | 1.48 | -6.9% | -7.5% |
| **05** | 0.68 | 1.48 | 0.62 | 1.34 | -8.8% | -9.5% |
| **06** | 0.70 | 1.47 | 0.53 | 1.03 | -24.3% | -29.9% |
| **07** | 0.70 | 1.51 | 0.53 | 1.06 | -24.3% | -29.8% |
| **08** | 0.69 | 1.46 | 0.42 | 0.63 | -39.1% | -56.9% |
| **09** | 0.68 | 1.46 | 0.50 | 1.02 | -26.5% | -30.1% |
| **10** | 0.69 | 1.49 | 0.60 | 1.29 | -13% | -13.4% |
| **11** | 0.69 | 1.51 | 0.59 | 1.23 | -14.5% | -18.5% |
| **12** | 0.70 | 1.48 | 0.58 | 1.19 | -17.1% | -19.6% |
| **13** | 0.69 | 1.53 | 0.63 | 1.38 | -8.7% | -9.8% |
| **14** | 0.70 | 1.52 | 0.60 | 1.30 | -14.3% | -14.5% |
| **15** | 0.70 | 1.49 | 0.52 | 1.02 | -25.7% | -31.5% |
| **Avg.** | **0.70** | **1.50** | **0.57** | **1.17** | **-18.6%** | **-22%** |

Table 5.5: Average cost of power for each residence, using their house consumption and PV production data from 2020 and 2021, compared to their average yearly cost from 2013-2021.

| **House** | **Cost without PV (NOK/kWh)** | | **Cost with PV (NOK/kWh)** | | **Price reduction** | |
|---|---|---|---|---|---|---|
| | **Data from 2020** | **Data from 2021** | **Data from 2020** | **Data from 2021** | **Data from 2020** | **Data from 2021** |
| **01** | 0.93 | 0.94 | 0.76 | 0.78 | -18.3% | -17% |
| **02** | 0.92 | 0.93 | 0.77 | 0.73 | -16.3% | -21.5% |
| **03** | N/A | 0.94 | N/A | 0.70 | N/A | -25.5% |
| **04** | 0.95 | 0.96 | 0.85 | 0.88 | -10.5% | -8.3% |
| **05** | N/A | 0.92 | N/A | 0.83 | N/A | -9.8% |
| **06** | 0.94 | 0.93 | 0.68 | 0.67 | -27.7% | -28% |
| **07** | 0.94 | 0.94 | 0.63 | 0.66 | -33% | -29.8% |
| **08** | 0.93 | 0.93 | 0.47 | 0.47 | -49.5% | -49.5% |
| **09** | 0.92 | 0.92 | 0.75 | 0.64 | -18.5% | -30.4% |
| **10** | 0.93 | 0.93 | 0.80 | 0.80 | -14% | -14% |
| **11** | 0.93 | 0.93 | 0.75 | 0.78 | -19.4% | -16.1% |
| **12** | 0.92 | 0.93 | 0.77 | 0.75 | -16.3% | -19.4% |
| **13** | 0.93 | 0.93 | 0.82 | 0.84 | -11.8% | -9.7% |
| **14** | 0.94 | 0.94 | 0.78 | 0.79 | -17% | -16% |
| **15** | 0.94 | 0.94 | 0.71 | 0.65 | -24.5% | -30.9% |
| **Avg.** | **0.93** | **0.93** | **0.73** | **0.73** | **-21.5%** | **-21.5%** |

In Figure 5.15, one can see the gain for each residence, using their house consumption data and PV production data from 2021, based on the year with the lowest spot price (2020) and the year with the highest spot price (2021). Where it shows the difference in gain based on only the spot price, where the lowest difference was an increase of 120%, and the highest difference was an increase of 213%.

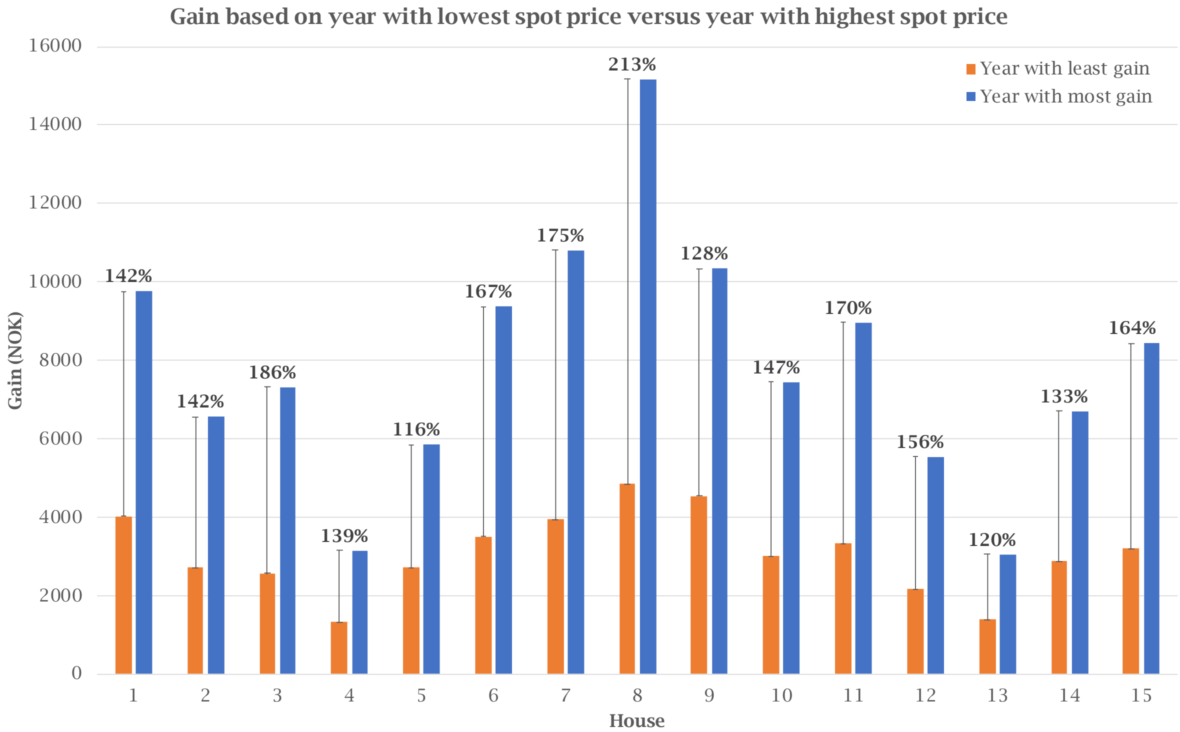



Figure 5.15: The gain for each residence using the data from 2021, based on the year with the lowest spot price versus the year with the highest spot price.

### Plots showing the cost of power over time

The yearly cost of power for each year between 2013 up to and including 2021, with and without the presence of the PV system, for House 1 is presented in Figure 5.16. Here is the house consumption and PV production data from 2021 from House 1 used, where the only variable for each year is the fluctuation in the power price for that given year. This plot for the rest of the residences can be found in Appendix A.

In Figure 5.17, the hourly energy cost for House 1 in 2021 is presented, with the PV system present in blue and without in orange. The red dotted line represents the distinction between when one is buying power from the grid and when one is selling the excess they produce to the grid. This plot for the rest of the residences can be found in Appendix A.

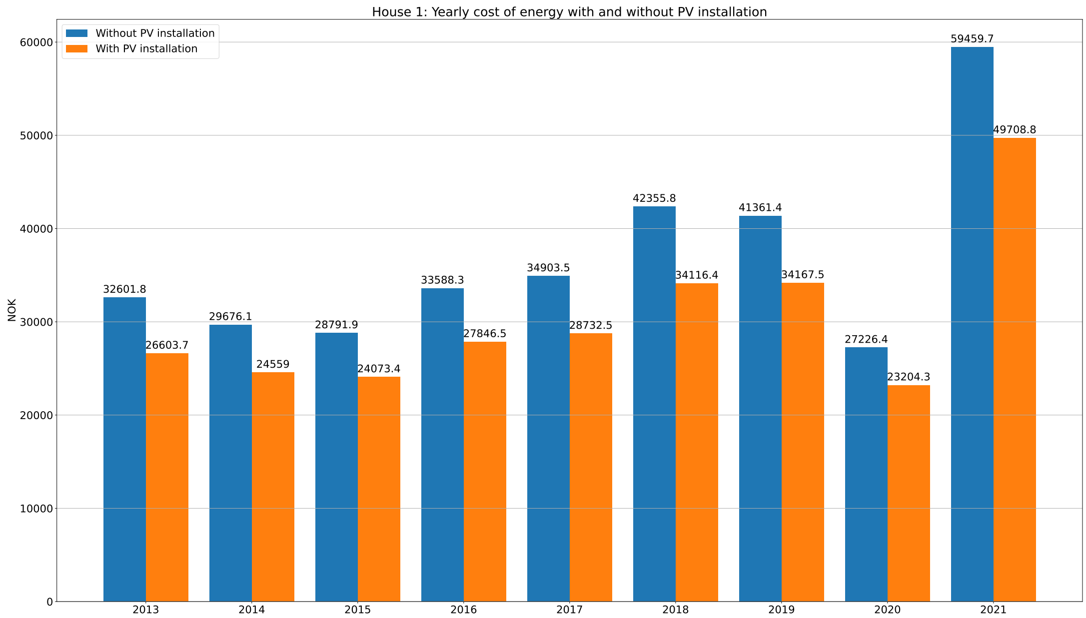



Figure 5.16: Yearly cost of energy for House 1, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

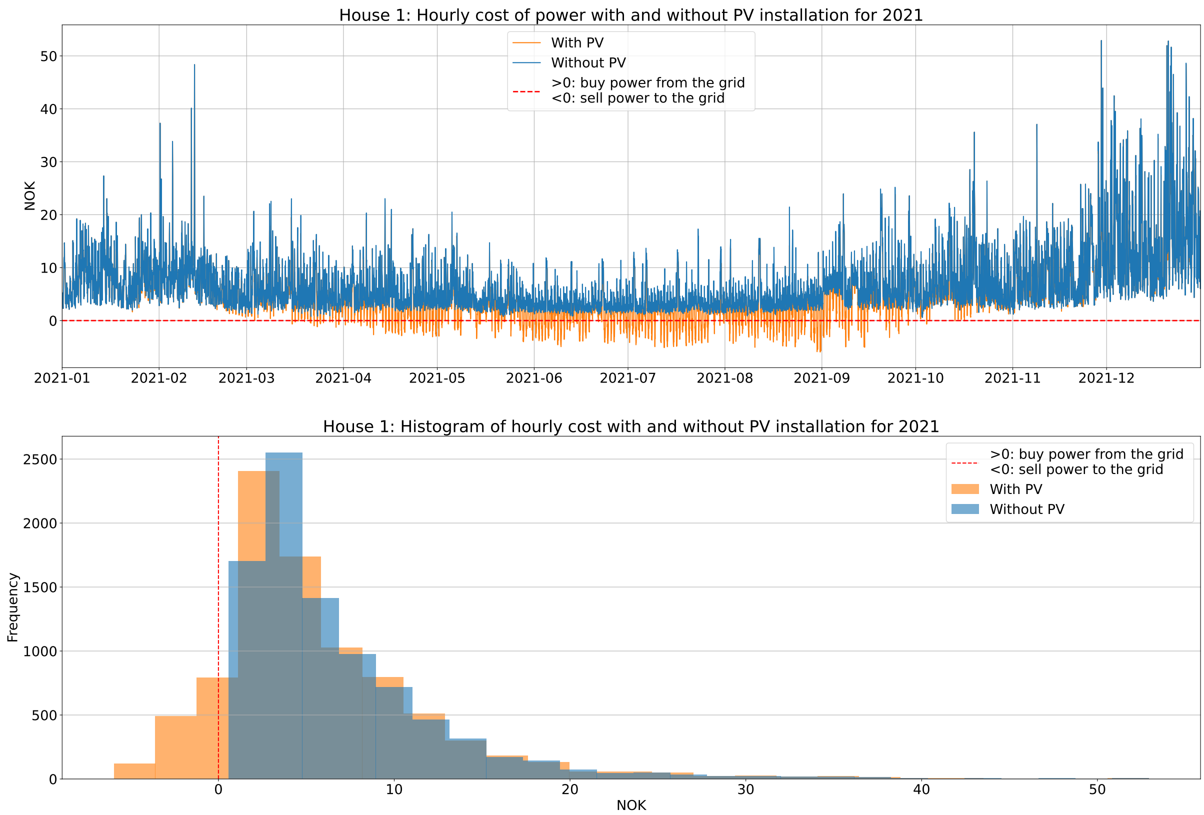



Figure 5.17: Hourly cost of energy for House 1 with and without a PV system present for 2021.

## 5.3 Cost analysis of the PV systems and their profitability

This section presents the cost analysis of the PV installation for each residence. First, we show the cost of the PV systems per kilowatt peak installed; this gives a reasonable ground of basis for comparing the different systems. Then the payback time for each system is presented based on the cost analysis done in the previous section. Then the net present value for each system is shown to evaluate economic gain.

### 5.3.1 Cost of PV system per kilowatt peak installed

To provide a good ground of basis for comparing the different PV systems installed at the 15 residences, the cost is presented per kilowatt peak installed at the residence. The results can be seen in Figure 5.6. The home with the lowest cost per installed nominal effect is residence number 9, with a price of 13 726 NOK/kWp, and the residence with the highest cost per installed nominal effect is residence number 13, which is also the residence with the smallest PV system. In Figure 5.18, the gross cost of each system per installed nominal effect versus the size of the PV system is presented to visualize better how the size of the installed PV system affects the price, where the red dotted line is the trend found in the result. The trend shows that the cost of the system is more expensive for small and large systems, where the optimal size based on this data seems to be around 8 kWp, the increase in cost as the system grows larger is most likely due to the need of extra solar inverters which are expensive.

Table 5.6: The cost of the PV installations for each residence per installed nominal effect for each residence.

| House | Gross cost of system (NOK/kWp) | Cost of system with subsidy (NOK/kWp) |
|---|---|---|
| **01** | 14 603 | 12 500 |
| **02** | 16 579 | 14 035 |
| **03** | 14 375 | 12 125 |
| **04** | 21 686 | 17 611 |
| **05** | 14 907 | 12 756 |
| **06** | 17 035 | 14 756 |
| **07** | 16 950 | 15 054 |
| **08** | 17 931 | 14 069 |
| **09** | 13 726 | 12 255 |
| **10** | 15 275 | 13 070 |
| **11** | 15 412 | 12 353 |
| **12** | 16 251 | 13 894 |
| **13** | 22 122 | 16 635 |
| **14** | 19 768 | 16 851 |
| **15** | 15 179 | 12 143 |
| **Avg.** | **16 787** | **14 007** |

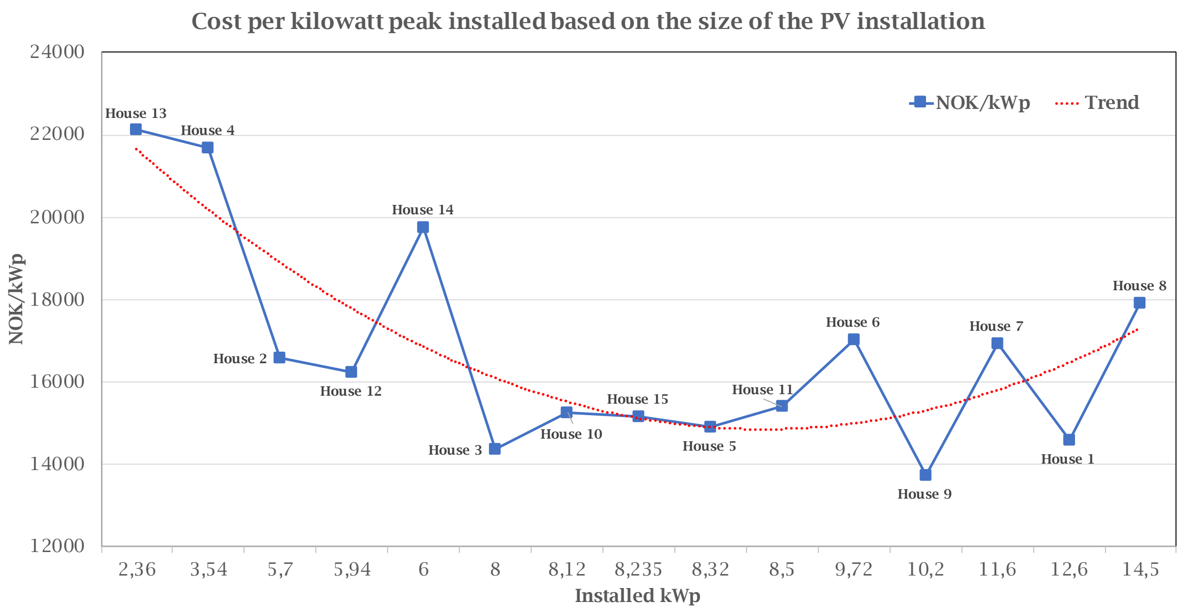



Figure 5.18: The gross cost of the PV systems per installed kilowatt peak based on the size of the PV system.

### 5.3.2 Payback time

In Table 5.7, the payback time for the PV system for each residence is presented. How the payback time is calculated can be read about in Section 3.4.3. The payback time shown in this table is based on if the gain was constant for every year. So, the first two columns after the house number are based on the year for each residence with the least gain, the following two columns are based on the year for each residence with the most gain, and the last two columns are based on the average out of all the years. A comparison between all the residences using the data from 2021 can be seen in Figure 5.19.

For example, with the data collected for House 1 from 2020, if all the years theoretically had a gain of 4468 NOK, it would take 35 years before they broke even on the investment made in the PV system; this would be the worst-case scenario. The best case scenario would be a gain of 10 584 NOK annually, which would only require 15 years before they would break even. Using the data from 2020 and calculating the yearly gain from 2013 and up to and including 2021 (as seen in Table 5.3), the average gain would be 6896 NOK based on the data from 2020. If this gain were constant, it would require 23 years before the investment in the PV system broke even.

Here one can see the effect the spot price has on the profitability of the PV system, where the year with the least gain also corresponds to the year with the lowest spot price (2020), and the year with the most profit corresponds to the year with the highest spot price (2021). So if theoretically, every year had the spot price that was in 2020, it would take these 15 residences an average of 35-37 years before they would break even on their investment. But if theoretically, every year had the spot price that was in 2021, it would take these 15 residence an average of 15-17 years before they would break even. This shows that the payback time will double from the worst to the best year. On average, out of the mean value of the nine years of calculated gain for each residence, it would take 23-24 years before they would break even on their investment.

Table 5.7: The payback time, in years, for the PV installation for each residence in this project. The payback time calculated here is based on if the gain was the same every year, the first and second column after the house number is based on if the gain was from the least profitable year, and the third and fourth is if the gain was from the best year. Finally, the fifth and sixth column is based on the average gain from the nine years calculated for each residence.

| | Payback time (years) | | | | | |
|---|---|---|---|---|---|---|
| | The year with least gain | | The year with most gain | | Average of all years | |
| **House** | **Data from 2020** | **Data from 2021** | **Data from 2020** | **Data from 2021** | **Data from 2020** | **Data from 2021** |
| **01** | 35 | 39 | 15 | 16 | 23 | 25 |
| **02** | 29 | 30 | 13 | 12 | 20 | 20 |
| **03** | N/A | 38 | N/A | 13 | N/A | 23 |
| **04** | 41 | 47 | 19 | 20 | 29 | 31 |
| **05** | N/A | 39 | N/A | 18 | N/A | 27 |
| **06** | 37 | 41 | 15 | 15 | 24 | 25 |
| **07** | 41 | 44 | 16 | 16 | 26 | 27 |
| **08** | 37 | 42 | 15 | 13 | 24 | 24 |
| **09** | 38 | 28 | 17 | 12 | 26 | 19 |
| **10** | 38 | 35 | 17 | 14 | 27 | 23 |
| **11** | 28 | 32 | 12 | 12 | 19 | 20 |
| **12** | 37 | 38 | 17 | 15 | 26 | 25 |
| **13** | 26 | 28 | 12 | 13 | 18 | 20 |
| **14** | 34 | 35 | 15 | 15 | 23 | 23 |
| **15** | 30 | 31 | 15 | 12 | 25 | 19 |
| **Avg.** | **35** | **37** | **15** | **17** | **24** | **23** |

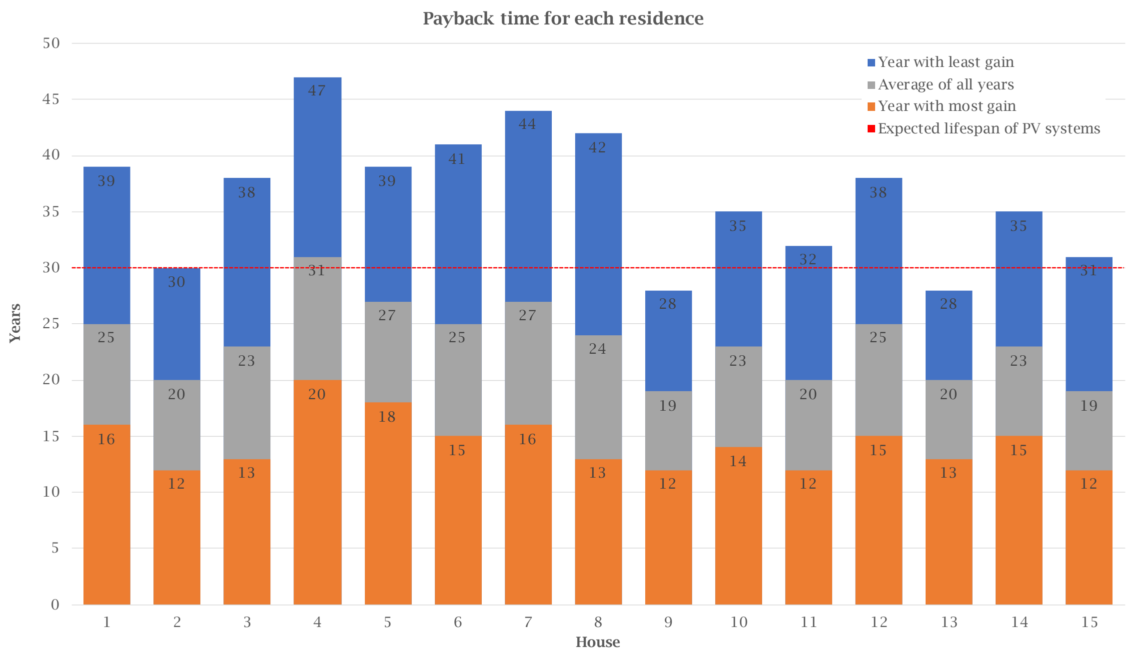



Figure 5.19: The payback time for each residence, based on the year with least gain, most gain and the average out of all the years. Based on the data from 2021.

### 5.3.3 Net present value for the PV system

When calculating the net present value of each PV system, the calculations used can be found in Section 3.4.4. The nominal interest rate used in these calculations is set to be 4% per the Norwegian Ministry of Finance *Rundskriv R* from 2021. [71] A PV system has an expected lifespan of about 30 years, which is used in these calculations of the net present value for each system. The variable $Q_j$ is chosen here to be equal to the yearly gain the system generates, where three different gains will be used here, the gain from the least profitable year, the gain for the best year, and the gain based on the average of all years. These values for every residence can be found in Appendix B.

In Table 5.8, the net present value of the PV systems for each residence is presented, using the data collected from 2020 and 2021. As explained in Section 3.4.4, the net present value for an investment is a method to appraise long-term projects using the time value of money. Based on the parameters set, if all the years the PV system was active theoretically had a gain equal to the least profitable year, then none of the investments would be beneficial. If the gain each year were theoretically similar to the most profitable year, then almost all the investments would be profitable. Based on the average gain over the nine years, none of the investments are profitable.

Table 5.8: The net present value for the PV system for each residence in this project. The calculations here assume a nominal rate of $i = 4\%$ and a period of $N = 30$. $Q_j$ will vary based on the least profitable year, most profitable year, and the average, and is assumed to be constant and with no additional cost attached to it.

| | **Net present value (NOK)** | | | | | |
|---|---|---|---|---|---|---|
| | **The year with least gain** | | **The year with most gain** | | **Average of all years** | |
| **House** | **Data from 2020** | **Data from 2021** | **Data from 2020** | **Data from 2021** | **Data from 2020** | **Data from 2021** |
| **01** | -80 239 | -87 951 | 25 519 | 11 115 | -38 254 | -49 632 |
| **02** | -31 600 | -33 121 | 27 090 | 33 349 | -10 175 | -9 172 |
| **03** | N/A | -52 784 | N/A | 29 457 | N/A | -23 734 |
| **04** | -35 731 | -39 587 | -7026 | -7977 | -25 165 | -27 897 |
| **05** | N/A | -59 354 | N/A | -5161 | N/A | -37 981 |
| **06** | -79 960 | -82 753 | 16 797 | 18 526 | -41 667 | -45 230 |
| **07** | -100 096 | -106 598 | 12 665 | 12 164 | -56 918 | -61 622 |
| **08** | -109 689 | -120 186 | 32 849 | 58 320 | -57 848 | -58 211 |
| **09** | -68 472 | -46 425 | 4915 | 53 782 | -42 482 | -8210 |
| **10** | -57 193 | -54 115 | -94 | 22 489 | -38 880 | -24 891 |
| **11** | -39 809 | -47 539 | 47 256 | 50 058 | -7 387 | -13 110 |
| **12** | -44 194 | -45 145 | 2409 | 13 354 | -27 922 | -24 290 |
| **13** | -12 888 | -45 145 | 2409 | 13 354 | -27 922 | -24 290 |
| **14** | -49 871 | -51 444 | 14 940 | 14 784 | -25 489 | -26 388 |
| **15** | -41 605 | -44 735 | 13 211 | 45 841 | -31 869 | -9736 |

### 5.3.4 Selling all PV production

In Figure 5.20, the gain for each residence, based on the average gain of all years calculated using data from 2021, is presented. Here one can see the difference in gain if a home would choose to sell all the PV production instead of using it for self-consumption, where they would have a decline in gain of 53% on average if they decide to sell all their production instead of utilizing it for self-consumption. This result shows that it is more profitable to use the PV production for self-consumption than to sell it to the grid.

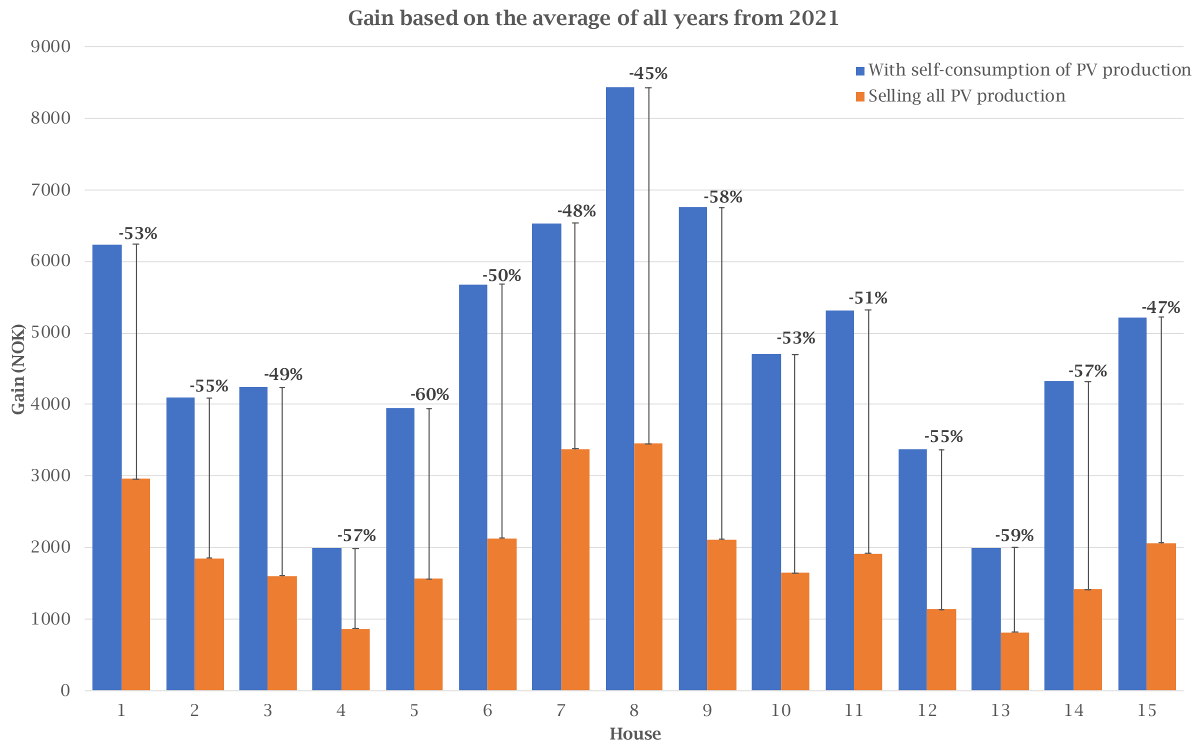



Figure 5.20: The gain for each residence is based on the average gain of all years using the data from 2021. The blue bars represent the gain with regular use, i.e., with self-consumption of the PV production and then selling the excess power to the grid. The orange bar represents the gain if a residence theoretically sold all their PV production.

# Chapter 6

# Discussion

This chapter discusses the results in terms of the research questions raised in the introduction.

## 6.1 The results

The results in this section will be presented in chronological order in coherence with the previous chapter.

### 6.1.1 House consumption and solar PV production

In this section, a short discussion regarding the results of the house consumption and PV production for each residence will be presented.

#### House consumption

The results from the house consumption, with and without the presence of a PV system, coincide with my initial assumptions and the effects seen in my specialization project, that during the winter period, there would be little to no deviation. However, the gap would be more prominent during the spring and summer periods. This result is expected considering that Norway is located far north, where solar irradiation is more significant during the spring and summer periods than during the winter period, resulting in little production from PV systems at that time. This is a disadvantage for most private consumers since their consumption often is higher during the winter and lower during the summer, which is the case for most of the residences in this project. Here we have one to two years of house consumption data from 15 different residences, where the years collected coincidental are the years with the lowest and highest spot price ever recorded in Norway. This could affect the house consumption for the different residences, but based on the numbers from Table 5.1, one can see that there was not a significant difference in consumption for the two years.

Based on the PV systems considered in this project, the results show that there is a correlation between the size of the installed PV system and the reduction in house consumption, as can be seen in Figure 5.2, where it naturally shows that the larger the system is the more percentage reduction in grid consumption are seen.

#### Solar PV production

The solar PV production also coincides with my initial assumption, as discussed in the previous section, with low production during winter and higher production during spring and summer. Almost all the residences were within the production assumption from NVE, where they said that a home in Norway would produce between 650 to 1000 kWh/kWp yearly, the only residence below this limit was residence number 5, which can be caused by missing production data because of connection errors with the inverter or it can be caused by less than optimal placement of the PV system on the house. The only residence above this production assumption is residence number 13, the residence with the smallest PV system and the house located the furthest south, leading to higher solar irradiation throughout the year.

On average, there was a 56% to 58% self-consumption rate, based on all the residences. There is a small correlation between the size of the installed PV system and the self-consumption rate, to do a more thoroughly analysis of this I would require more information about each residence and their consumption habits, this is beyond the scope of this project.

**Delta variable**

The delta variable is just the difference between the house consumption and PV production, but it provides a good picture of the distribution in how much of the PV production is sold to the grid.

## 6.2 Cost of energy with and without a solar PV installation

Based on the preliminary specialization project I did in the fall of 2021, where I analyzed one residence, the results showed that the variation in the spot market significantly impacted the profitability of the PV system. This is confirmed in this project, where one can see in Figure 5.15, that the difference between a year with a low spot price versus a year with a high spot price changes the gain by 153% on average. This result shows a strong correlation between the gain of the PV system and the fluctuation in the spot price.

## 6.3 Cost of the PV systems and their profitability

This section will present a short discussion regarding the results of the cost and profitability of the PV systems.

### 6.3.1 Cost of the PV systems per kilowatt peak installed

The cost per kilowatt peak installed is used to compare the different PV systems in this project. Based on the residences in this project, one can see a correlation between the size of the system and the cost per kilowatt peak installed, as shown in Figure 5.18, where the trend shows a polynomial. The trend indicates that the price per kilowatt peak installed is higher for small and large systems, where it looks like the optimal installation here would be a PV system with an installed nominal effect of 8 kWp.

Most of the residences in this project bought their PV system from the same supplier, with a slight variation in installation time, reinforcing this trend. But to enhance this assumption and verify that this is true, it would be beneficial to collect data from several suppliers in Norway and compare their prices, but this is beyond the scope of this project.

### 6.3.2 Payback time

The payback time of a PV system is one of the most common ways to measure the profitability of a PV system investment. Most suppliers promise a payback time of 15 to 20 years, which, based on this project, is valid if all the years have equally high spot prices as the most expensive year. However, on average, the results here show a payback time of 23 to 24 years, which is unfortunate since most PV systems have an assumed life span of 25 to 30 years.

The results show a strong correlation between the spot price and the payback time, where a PV system owner will profit from high spot prices. But based on the future of the spot market, which can be seen in Section 2.3.4, NVE assumes that the cost of power will increase slightly from 2025 to 2030 but then decline between 2030 and 2040. It will be challenging to assess the actual value of the PV systems since the fluctuation in the spot price depends on many factors. But based solely on the spot price from 2013 to 2021, it shows that most will break even on their investments based on the average gain.

### 6.3.3 Net present value of the PV systems

The payback period is a simplistic measurement to assess the profitability of the PV systems since it does not consider the time value of money. This is where the net present value comes in handy. Here I compare the investment each residence made in their PV system and compare it to if they instead choose to invest the money in, for example, equity fond. Based on average gain, none of the PV systems would be classified as profitable here. There were even some that would not be profitable based on the year with the most gain. But considering that the future of the spot market, based on analysis done by NVE, does not seem to be declining any time soon, an assumption can be made that the price in the future will be quite similar to the year 2021, meaning the investments in a PV system would be profitable.

The downside with net present value is that the picture changes fast based on the nominal rate set, so if I were to lower it, the picture could look very different. In these calculations, I have assumed that the gain is constant for every year, but as discussed, this correlates strongly with the spot prices, and the effect of the PV systems will decline each year.

### 6.3.4 Selling all the PV production

If a residence chooses to sell all their PV production instead of using it for self-consumption, the profitability of the PV system will decline considerably, as seen in Figure 5.20. This result confirms that using the energy in your residence is more profitable than selling it to the grid. Meaning one would more likely be able to earn much more if one were to increase their self-consumption rate. This result is not surprising; when a residence produces more power than they use, they sell the excess to the power company, but the power company will not pay the residence nettleie or taxes for this power, meaning it will be much more beneficial to use the energy than to sell it.

This result provides a good pointer to what should be changed regarding the selling of power to increase the profitability of a PV system for private residences in Norway. It is clear that selling the power to spot price and getting a small nettleie tariff from the power company for all the power one pushes into the grid is inconsistent because of the significant fluctuations in the power market. It would be interesting to do this assessment again with different benefits to increase the profitability by assuming larger tariffs from the power companies or maybe adding a subsidy from the government.

## 6.4 Limitations

The reliability of the collected PV production data is the limitation with the highest effect on the results. Because of the issues discussed in this project, parts of the PV production data for several residences can be flawed. Interpolation has been used to fill in missing data, but this will come with some errors. For example, if the data sets were missing larger parts than just some hours during the day, then the interpolation would not apply, and the production for those days would be set to zero, which will result in some error in the production data. But this did not affect the amount sold to the grid since this data was collected in another way. One can see the error in missing PV production data by looking at the accumulation of produced power throughout the year, where if the amount sold ever exceeds the amount produced, there are missing PV production data. To solve this for others that might try this, I would recommend trying to obtain direct contact with the API of the inverters the different residences have, which will provide much less error.

## 6.5 Aim and tasks of the thesis

This thesis assesses the value of solar PV modules for private residences in Norway.

**The first task** was to come in contact with private residences in Norway that have a PV system installed on their house. This was quite challenging, especially finding homes that had been installed for at least a year. The best contact method was through social media, such as renewable energy blogs, Linkedin, and Facebook.

**The second task** was to collect the necessary data to perform the assessment. The house consumption data from the residences was highly available through many different platforms, depending on the power suppliers the residences had. The easiest way was through the power supplier Tibber, which had an open API to handle this transition. Regarding the PV production data from the residences, this was the most challenging part, mainly due to many different suppliers and difficulty collecting the necessary granularity directly; the help from Otovo was crucial in this part. The historical spot price was easily obtained through a script provided by Sebastien Gros and directly through the Nord Pool website, where historical data was available from 2013.

**The third task** was to organize the data for calculations and plotting to assess the value of the PV systems. The plots provided good visualization of the results for every residence, and the calculations gave reasonable indications for the profitability of the PV system installations for each residence.

**Summing up,** this thesis has answered important questions about the profitability of solar PV modules for private residences in Norway. And hopefully, the data collected can be used to continue this work.

# Chapter 7

# Conclusion

This thesis set out to assess the value of solar PV modules for private consumers in Norway by using house consumption data and PV production data collected from different residences in Norway and the Nord Pool spot price for their respective regions. Specifically, the thesis investigated the economic effect a PV system has on a private residence in Norway, the impact the variations in the Nord Pool power market have on the profitability of a PV system, and how the profitability of the PV system is affected by self-consumption of the PV production versus selling it to the grid.

The project consisted of a considerable amount of research, especially regarding collecting data from the private residences, which was time-consuming and difficult. The main results in this thesis show that:

- Economically speaking, a PV system for a private residence in Norway is not a profitable investment based on the current power market and technology. But if the analysis of the future of the spot market is factual, meaning that the price in the following years will be quite similar to 2021 or higher, then almost all the investments will be profitable.
- The Nord Pool power market has an extensive impact on the profitability of a PV system for private residences in Norway, where the profitability of the PV system increase in line with the increasing price of power.
- There is more value in utilizing the produced power from the PV system for self-consumption than selling it to the grid.

The data collection and findings in this thesis will serve as a good foundation for continued research and investigation in the field of solar PV modules for private consumers in Norway, where the data can be used to investigate methods and simulate scenarios to improve the profitability and thus enhancing the knowledge and interest in solar PV systems to private residences, as well as relieve the pressure on the grid which is beneficial for several parties.

This project's limitations have mainly been collecting the necessary data to complete the analysis. For further work in this area, a recommendation would be to try and systematize and simplify the collection of data, especially the PV production, where it would be beneficial to create scripts that could connect directly to the different inverters to collect the data.

## 7.1 Recommendations for Further Work

The following list is the recommendations I have for further work using the data I have collected and suggestions for other areas that would be interesting to explore:

- Assess the value of including a battery in the systems of these homes by simulating the effect of being able to store energy to use at, for example, a time when the power price is high. This would be interesting based on the results that show that it is much more profitable to use the energy one produces rather than sell it to the grid.
- A couple of the houses in this project have a setup for mining cryptocurrency. So an interesting case would be to include a setup for mining cryptocurrency in the system by using the excess power the PV system produces to power the setup and assess its value.
- Investigate the impact of having smart management of the consumption to maximize the value of the PV system. This could also include a battery pack.
- Using the data collected in this project, simulate the future of the spot market and include the new nettleie tariff that comes into effect in July of 2022. [72]
- Investigate and simulate different scenarios with other possible subsidies and plusskunde arrangements to increase the profitability of the PV systems by using the data collected in this project.
- Develop or test other PV models to verify their results based on the data collected in this project.
- Assess the environmental impact the PV systems have by using the data collected in this project.

# References


[1] Norges vassdrags- og energidirektorat. *40 MW solkraft ble installert i 2020.* URL: https://www.nve.no/nytt-fra-nve/nyheter-energi/40-mw-solkraft-ble-installert-i-2020/. (accessed: 13.10.2021).

[2] D. Zaitsev et al. *Solkraft i Norge - Fremtidige muligheter for verdiskapning.* Accenture and World Wide Fund for Nature, 2020. URL: https://media.wwf.no/assets/attachments/solkraft_i_norge___fremtidige_muligheter_for_verdiskaping1.pdf. (accessed: 28.11.2021).

[3] European Commission. *2020 climate & energy package.* URL: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2020-climate-energy-package_en#ecl-inpage-902. (accessed: 20.10.2021).

[4] H. Birkelund et al. *Langsiktig kraftmarkedsanalyse 2021-2040.* Norges vassdrags- og energidirektorat, Oct. 2021. URL: https://publikasjoner.nve.no/rapport/2021/rapport2021_29.pdf. (accessed: 28.11.2021).

[5] European Commission. *Photovoltaic Geographical Information System.* URL: https://re.jrc.ec.europa.eu/pvg_download/map_index.html. (accessed: 23.04.2022).

[6] Nord Pool. *Nord Pool Day-ahead overview.* URL: https://www.nordpoolgroup.com/maps/#/nordic. (accessed: 25.11.2021).

[7] Nord Pool. *Nord Pool Day-ahead Market.* URL: https://www.nordpoolgroup.com/the-power-market/Day-ahead-market/. (accessed: 25.11.2021).

[8] Energi Norge. *Derfor er strømprisen uvanlig høy i år.* URL: https://www.energinorge.no/fagomrader/strommarked/derfor-er-stromprisen-hoyere-i-ar-enn-i-fjor/. (accessed: 25.11.2021).

[9] Nord Pool. *The power market.* URL: https://www.nordpoolgroup.com/the-power-market/. (accessed: 25.11.2021).

[10] Gjermund Stensrud. *Slik leser du strømregningen din.* URL: https://xn--strm-ira.no/str%C3%B8mregning. (accessed: 26.11.2021).

[11] Norges vassdrags- og energidirektorat. *Nettleiestatistikk.* URL: https://www.nve.no/reguleringsmyndigheten/publikasjoner-og-data/statistikk/nettleiestatistikk/. (accessed: 08.04.2022).

[12] Statistisk Sentralbyrå. *Elektrisitetspriser.* URL: https://www.ssb.no/statbank/table/09387/tableViewLayout1/. (accessed: 18.04.2022).

[13] Regjeringen. *Kraftmarkedet og strømpris.* URL: https://www.regjeringen.no/no/tema/energi/stromnettet/kraftmarkedet-og-strompris/id2076000/. (accessed: 13.04.2022).

[14] Tibber. *Synes du det er forvirrende med de ulike typene strømavtaler.* URL: https://tibber.com/no/magazine/power-hacks/typer-stroemavtaler. (accessed: 26.11.2021).

[15] Elhub. *Om Elhub.* URL: https://elhub.no/en/about-elhub/. (accessed: 18.04.2022).

[16] Elhub. *Elhub for the end user.* URL: https://elhub.no/en/about-elhub/elhub-for-the-end-user/. (accessed: 18.04.2022).

[17] European Commission. *2030 Climate Target Plan.* URL: https://ec.europa.eu/clima/eu-action/european-green-deal/2030-climate-target-plan_en. (accessed: 13.04.2022).

[18] H Birkelund et al. "Langsiktig kraftmarkedsanalyse 2021-2040". In: *Rapport (Norges vassdrags-og energidirektorat)* 29 (2021).

[19] Enova. *About Enova.* URL: https://www.enova.no/about-enova/. (accessed: 29.11.2021).
[20] Enova SF. *Enova Annual Report 2020.* Enova SF, 2020. URL: https://www.enova.no/download?objectPath=/upload_images/F00FA2198797415D9B8FBC7F46F68E2B.pdf. (accessed: 29.11.2021).
[21] Enova. *El-produksjon.* URL: https://www.enova.no/privat/alle-energitiltak/solenergi/el-produksjon-/. (accessed: 29.11.2021).
[22] Norges vassdrags- og energidirektorat. *Plusskunder.* URL: https://www.nve.no/reguleringsmyndigheten/regulering/nettvirksomhet/nettleie/tariffer-for-produksjon/plusskunder/. (accessed: 09.04.2022).
[23] Europower Energi. *Rekkefølgen på de største nettselskapene er stokket om.* URL: https://www.europower-energi.no/nett/rekkefolgen-pa-de-storste-nettselskapene-er-stokket-om/2-1-1003891. (accessed: 10.04.2022).
[24] Elvia. *Plusskunder – innmating av overskuddsproduksjon.* URL: https://assets.ctfassets.net/jbub5thfds15/11lda4HYZ9iHzyz6km5UT1/099ade61c2423fdd3b07fbb5184dc699/Tariffblad_7_1_Plusskunder_Elvia_2022.pdf. (accessed: 10.04.2022).
[25] Tensio. *Nettleiepriser privat gjeldende fra 1. januar 2019.* URL: https://ts.tensio.no/kunde/nettleie-priser-og-avtaler/2019-nettleie-privat. (accessed: 10.04.2022).
[26] BKK Nett. *TARIFFHEFTE BKK KVINNHERAD AS PER 1. JANUAR 2020.* URL: https://static1.squarespace.com/static/53fd9f0ee4b0e1f6ca39c2a7/t/5e0dd7c8a5b0832cb7ae6d6f/1577965512777/-BKKK2020_Tariffhefte_gjeldande_fr%C3%A5_01_01_2020.pdf. (accessed: 10.04.2022).
[27] Skagerak Energi. *NETTLEIETARIFFER FOR PRIVATKUNDER.* URL: https://lede.no/getfile.php/1334515-1610012059/Nett/Filer/Kunde/Priser%20bolig%20og%20fritidsbolig%202021%20-%20feil%20pris.pdf. (accessed: 10.04.2022).
[28] Agder Energi Nett. *Nettleiepriser privatkunde.* URL: https://www.aenett.no/nettleie/tariffer/. (accessed: 10.04.2022).
[29] Lyse Elnett. *Installere anlegg for plusskunde.* URL: https://www.l-nett.no/elinstallator-1/plusskunde/. (accessed: 10.04.2022).
[30] Arva. *Plusskunde.* URL: https://arva.no/plusskunde. (accessed: 10.04.2022).
[31] Norgesnett. *Nettleie for plusskunder.* URL: https://norgesnett.no/nettleie-for-plusskunder/. (accessed: 10.04.2022).
[32] EPSI Norway. *Strømselskapene 2021.* URL: https://www.epsi-norway.org/wp-content/uploads/2021/11/Strombransjen-2021-et-sammendrag.pdf?x86790. (accessed: 10.04.2022).
[33] Tibber. *Selg overskuddet fra solcellene.* URL: https://tibber.com/no/smart-styring/solceller. (accessed: 29.11.2021).
[34] Gudbrandsdal Energi. *Generelle vilkår.* URL: https://www.ge.no/generelle-vilkar. (accessed: 10.04.2022).
[35] LOS. *Avtalevilkår LOS spotpris.* URL: https://www.los.no/strom/spotpris2/vilkar-spotpris/. (accessed: 10.04.2022).
[36] Lyse AS. *Strømavtale til plusskunder.* URL: https://www.lyse.no/strom/pluss. (accessed: 10.04.2022).
[37] Trøndelag Kraft. *Standard kraftleveringsavtale.* URL: https://www.trondelagkraft.no/strom/stromavtaler/solstrom/avtalevilkar/. (accessed: 10.04.2022).
[38] Fjordkraft. *Avtalevilkår mellom kunde og Fjordkraft.* URL: https://www.fjordkraft.no/strom/stromavtale/solkraft/avtalevilkar/. (accessed: 10.04.2022).
[39] Yan Xue, Carmel Margaret Lindkvist, and Alenka Temeljotov-Salaj. "Barriers and potential solutions to the diffusion of solar photovoltaics from the public-private-people partnership perspective – Case study of Norway". eng. In: *Renewable & sustainable energy reviews* 137 (2021). ISSN: 1364-0321.
[40] Emilie Kjenstadbakk. *A Study of How Integration of Solar Photovoltaic Impact a Housing Cooperative in Norway.* 2020. URL: https://hdl.handle.net/11250/2778256.
[41] Bjørnar Veie. *Balancing Solar Energy and Load Consumption given Different Load Consumption Profiles.* 2020. URL: https://hdl.handle.net/11250/2780913.

[42] Signe Eika Gjørven. *Integrasjon av sol i det norske kraftsystemet*. nor. 2018. URL: http://hdl.handle.net/11250/2559920.

[43] Heidi Pegill Haugstad. *Hvordan påvirker effektbaserte nettariffer lønnsomheten for solcelleanlegg i Norge?* nor. 2019. URL: http://hdl.handle.net/11250/2619835.

[44] Kristin Rove Bentsen. *Sammenligning av reell energiproduksjon fra PV-anlegg og estimater fra PVsyst, samt lønnsomhetsvurdering av PV-anlegg i Norge*. nor. 2014. URL: http://hdl.handle.net/11250/221671.

[45] Tonje Løvstakken. *Battery systems for commercial buildings with solar power : Control and operation strategies*. eng. 2019. URL: http://hdl.handle.net/11250/2617616.

[46] Tobias Haumann. *A Brief Look at the Performance of PV in Norway*. eng. 2016. URL: http://hdl.handle.net/10037/10276.

[47] Magnus Østbye. *Cost Evaluation of Integrated Photovoltaic-Solar Cells in Facade of Norwegian Commercial Buildings*. nor. 2014. URL: http://hdl.handle.net/11250/220411.

[48] EvoEnergy. *How do solar panels work?* URL: https://www.evoenergy.co.uk/news-updates/how-do-solar-panels-work-2/. (accessed: 16.03.2022).

[49] U.S. Department of Energy. *Solar Radiation Basics*. URL: https://www.energy.gov/eere/solar/solar-radiation-basics. (accessed: 23.03.2022).

[50] National Aeronautics and Space Administration (NASA). *Solar Irradiance*. URL: https://www.nasa.gov/mission_pages/sdo/science/solar-irradiance.html. (accessed: 24.03.2022).

[51] Esri. *Modeling solar radiation*. URL: https://desktop.arcgis.com/en/arcmap/10.7/tools/spatial-analyst-toolbox/modeling-solar-radiation.htm. (accessed: 24.03.2022).

[52] U.S. Department of Energy. *Solar Photovoltaic Technology Basics*. URL: https://www.energy.gov/eere/solar/solar-photovoltaic-technology-basics. (accessed: 24.03.2022).

[53] Norsk Solenergiforening. *Solceller*. URL: https://www.solenergi.no/solstrm/. (accessed: 29.03.2022).

[54] Evo Energy. *kWp meaning*. URL: https://www.evoenergy.co.uk/news-updates/what-is-a-kwp/. (accessed: 29.03.2022).

[55] Infinite Energy. *What is the Difference Between Solar Panels and Photovoltaic Cells?* URL: https://www.infiniteenergy.com.au/what-is-the-difference-between-a-solar-panel-and-a-photovoltaic-cell/. (accessed: 24.03.2022).

[56] Solenergiklyngen. *Solenergi noe for din kommune?* Solenergiklyngen, 2020. URL: https://www.solenergiklyngen.no/wp-content/uploads/2021/06/veilleder_kompetanse_off_innkjopere_ny.pdf. (accessed: 29.03.2022).

[57] U.S. Department of Energy. *Solar Performance and Efficiency*. URL: https://www.energy.gov/eere/solar/solar-performance-and-efficiency. (accessed: 28.03.2022).

[58] Otovo. *Derfor bør du velge monokrystallinske solceller*. URL: https://www.otovo.no/blog/solcellepanel-solceller/monokrystallinske-eller-polykrystallinske/. (accessed: 28.03.2022).

[59] U.S. Department of Energy. *Solar Integration: Inverters and Grid Services Basics*. URL: https://www.energy.gov/eere/solar/solar-integration-inverters-and-grid-services-basics. (accessed: 29.03.2022).

[60] Noor Bariah Mohamad, Boon-Han Lim, and An-Chow Lai. "Imputation of missing values for solar irradiance data under different weathers using univariate methods". In: *IOP Conference Series: Earth and Environmental Science*. Vol. 721. 1. IOP Publishing. 2021, p. 012004.

[61] Alexandre M. Bayen and Timmy Siauw. "Chapter 14 - Interpolation". In: *An Introduction to MATLAB® Programming and Numerical Methods for Engineers*. Ed. by Alexandre M. Bayen and Timmy Siauw. Boston: Academic Press, 2015, pp. 211–223. ISBN: 978-0-12-420228-3. DOI: https://doi.org/10.1016/B978-0-12-420228-3.00014-2. URL: https://www.sciencedirect.com/science/article/pii/B9780124202283000142.

[62] The Cost Advisor. *Solar panels per Watt peak costs*. URL: https://thecostadvisor.com/priceguide/solar-panels-per-watt-peak-costs/. (accessed: 24.04.2022).

[63] F John Hay. "Economics of Solar Photovoltaic Systems". In: *NebGuide. University of Nebraska. Lincoln Extension. Recuperado em* 7 (2013).

[64] Mohamed Almaktar, Hasimah Abdul Rahman, and Mohammad Yusri Hassan. "Economic Analysis Using Net Present Value and Payback Period: Case Study of a 9kWp Grid-Connected PV System at UTM, Johor Bahru Campus". In: *Progress in Energy and Thermal Sciences*. Vol. 818. Applied Mechanics and Materials. Trans Tech Publications Ltd, Feb. 2016, pp. 119–123. DOI: `10.4028/www.scientific.net/AMM.818.119`.

[65] José L. Bernal-Agustín and Rodolfo Dufo-López. "Economical and environmental analysis of grid connected photovoltaic systems in Spain". In: *Renewable Energy* 31.8 (2006), pp. 1107–1128. ISSN: 0960-1481. DOI: `https://doi.org/10.1016/j.renene.2005.06.004`. URL: `https://www.sciencedirect.com/science/article/pii/S0960148105001667`.

[66] *Facebook group: Solceller og Alternativ Energi*. URL: `https://www.facebook.com/groups/665692520245652/`. (accessed: 15.03.2022).

[67] *LinkedIn*. URL: `https://www.LinkedIn.com`. (accessed: 15.03.2022).

[68] *Futurehome*. URL: `https://forum.futurehome.io`. (accessed: 15.03.2022).

[69] Tibber. *Stuff we respect*. URL: `https://developer.tibber.com/respect`. (accessed: 24.04.2022).

[70] Nord Pool. *Historical Market Data*. URL: `https://www.nordpoolgroup.com/historical-market-data/`. (accessed: 27.11.2021).

[71] Norwegian Ministry of Finance. *Rundskriv R*. URL: `https://www.regjeringen.no/globalassets/upload/fin/vedlegg/okstyring/rundskriv/faste/r_109_2021.pdf`. (accessed: 08.06.2022).

[72] Elvia. *Alt du må vite om ny nettleie for 2022*. URL: `https://www.elvia.no/nettleie/alt-du-ma-vite-om-ny-nettleie-for-2022/`. (accessed: 08.06.2022).

# Appendix A

# Plots

In this part the plots connected to the results will be presented as the first appendix. Each house will have its own section with the plots arranged in the same way for each of them to easier maneuver through the results. These are all the plots that were made from the data gathered, where only the main results will be referenced to in the actual report in the form of tables.

# A.1 House 1

## A.1.1 House consumption

### 2020

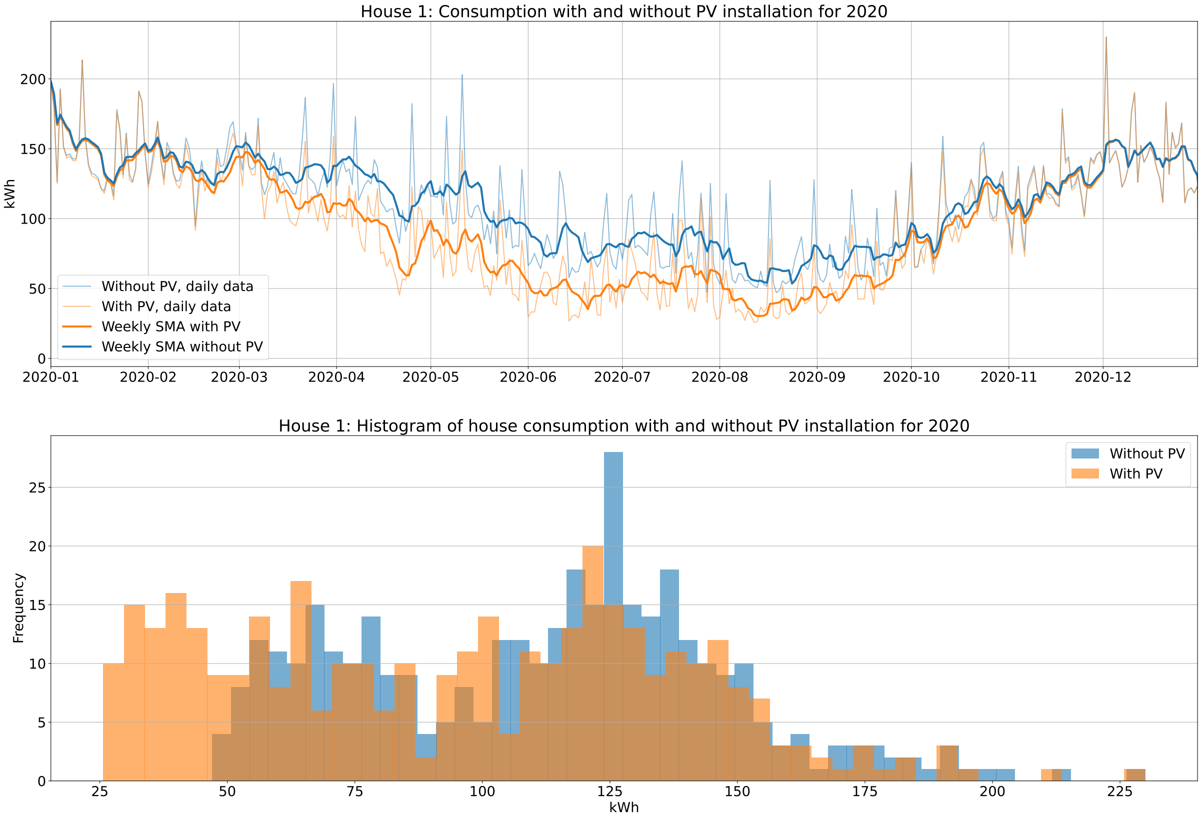



Figure A.1: Daily house consumption with and without a PV system for 2020 from House 1. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

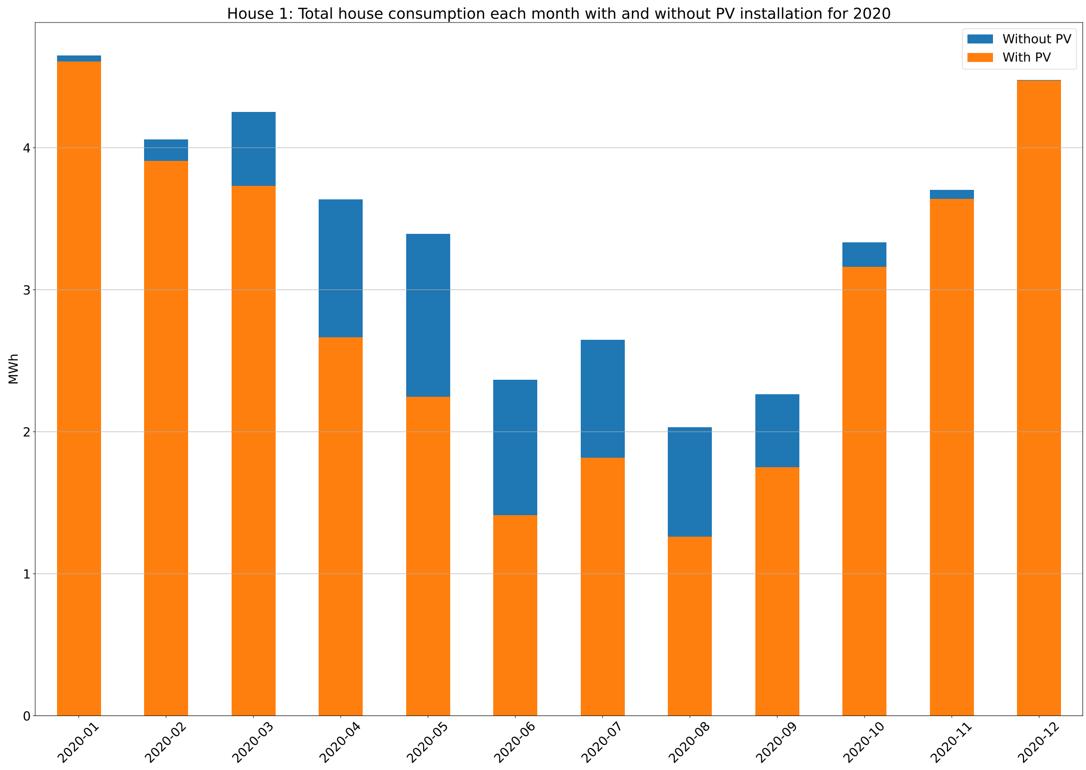



Figure A.2: Monthly house consumption for House 1 with and without a PV system for 2020.

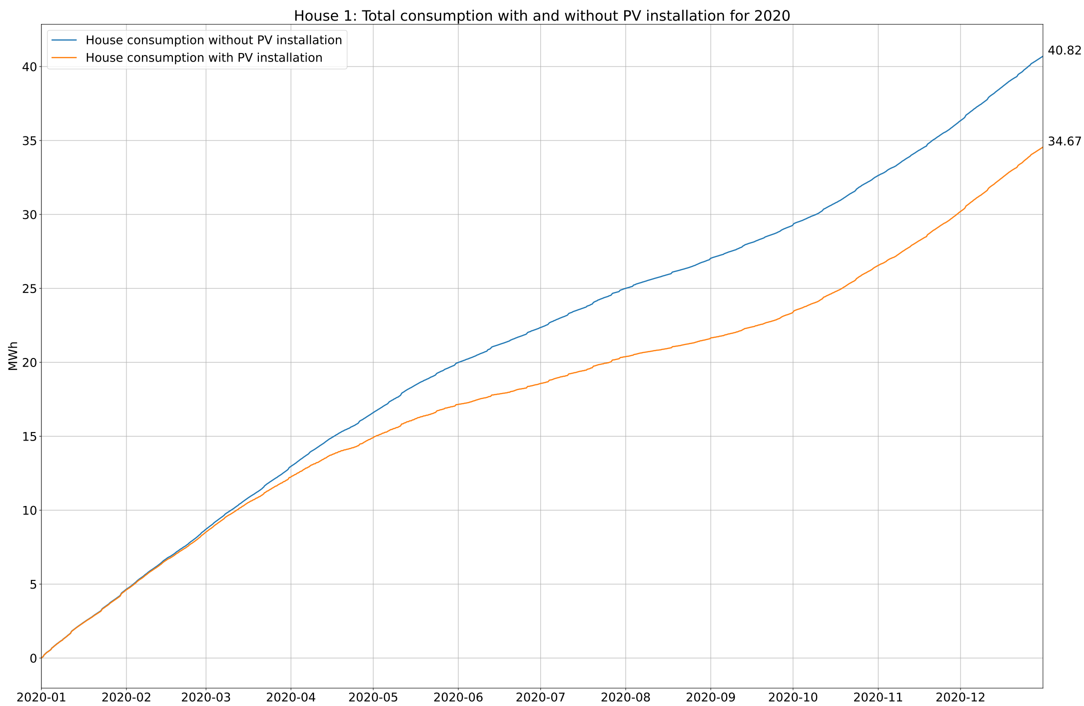



Figure A.3: Total house consumption for House 1 with and without a PV system accumulated over 2020

**2021**

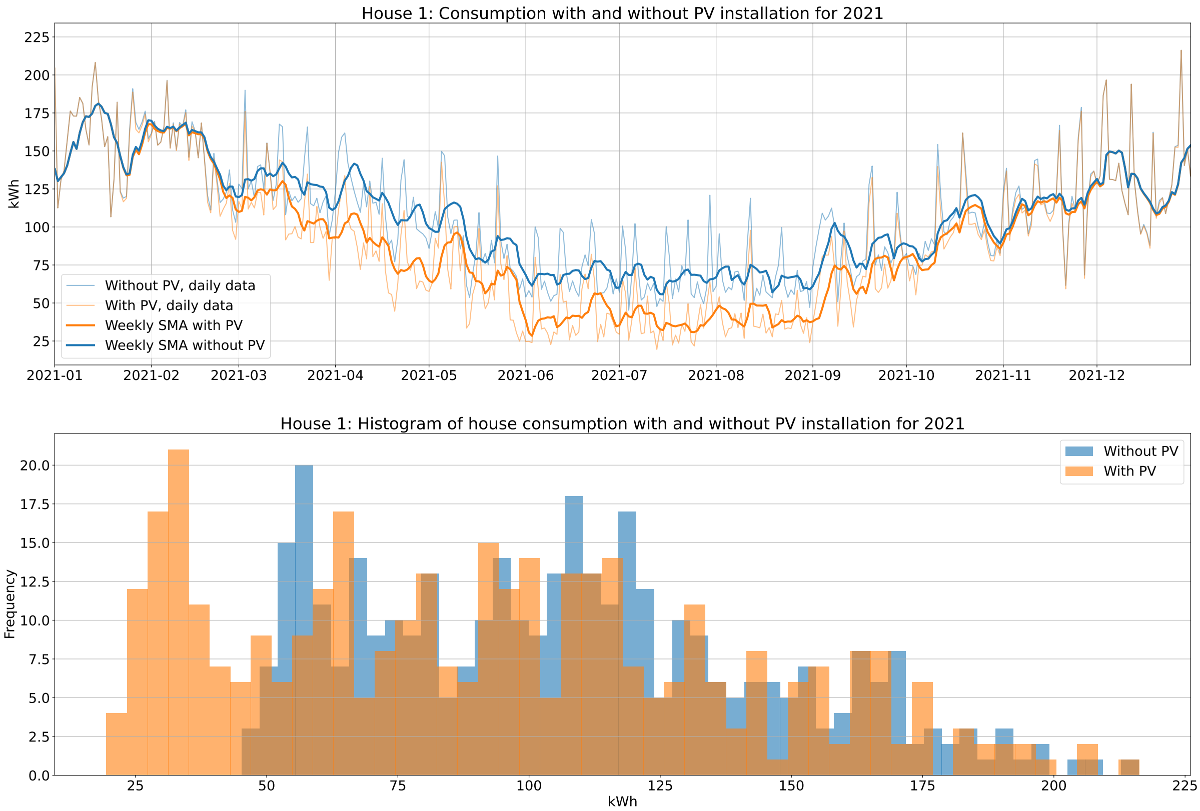



Figure A.4: Daily house consumption with and without a PV system for 2021 from House 1. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

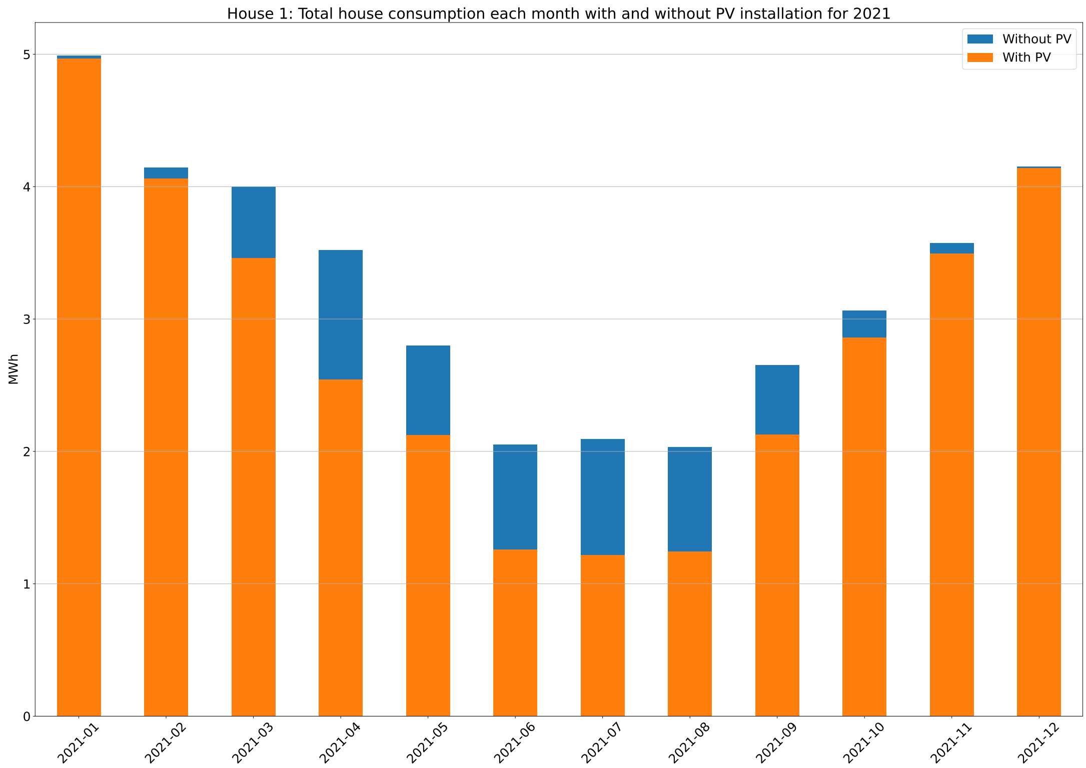



Figure A.5: Monthly house consumption for House 1 with and without a PV system for 2021.

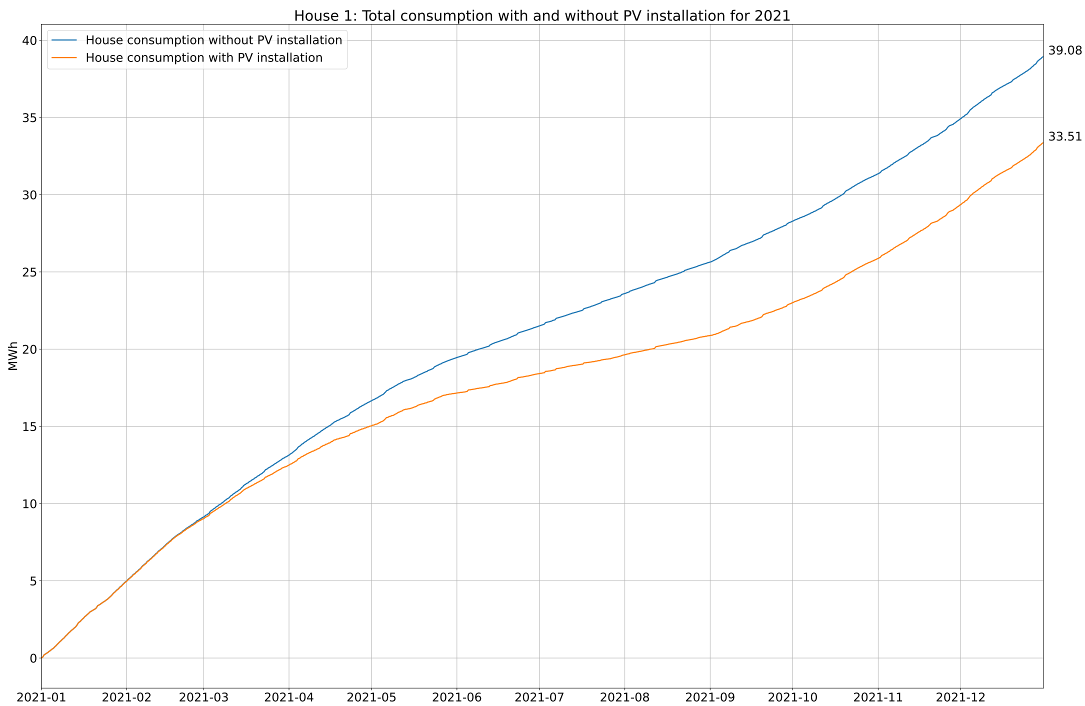



Figure A.6: Total house consumption for House 1 with and without a PV system accumulated over 2021

### A.1.2 Solar PV production

#### 2020

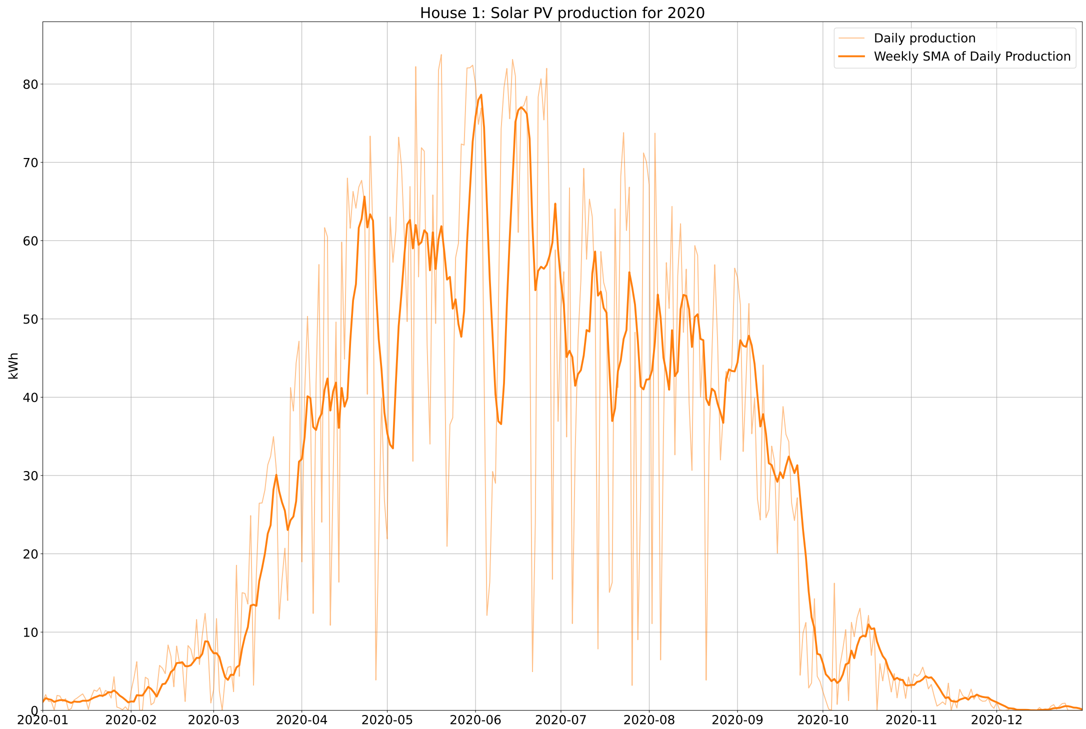



Figure A.7: Daily PV production and weekly SMA for House 1 in 2020.

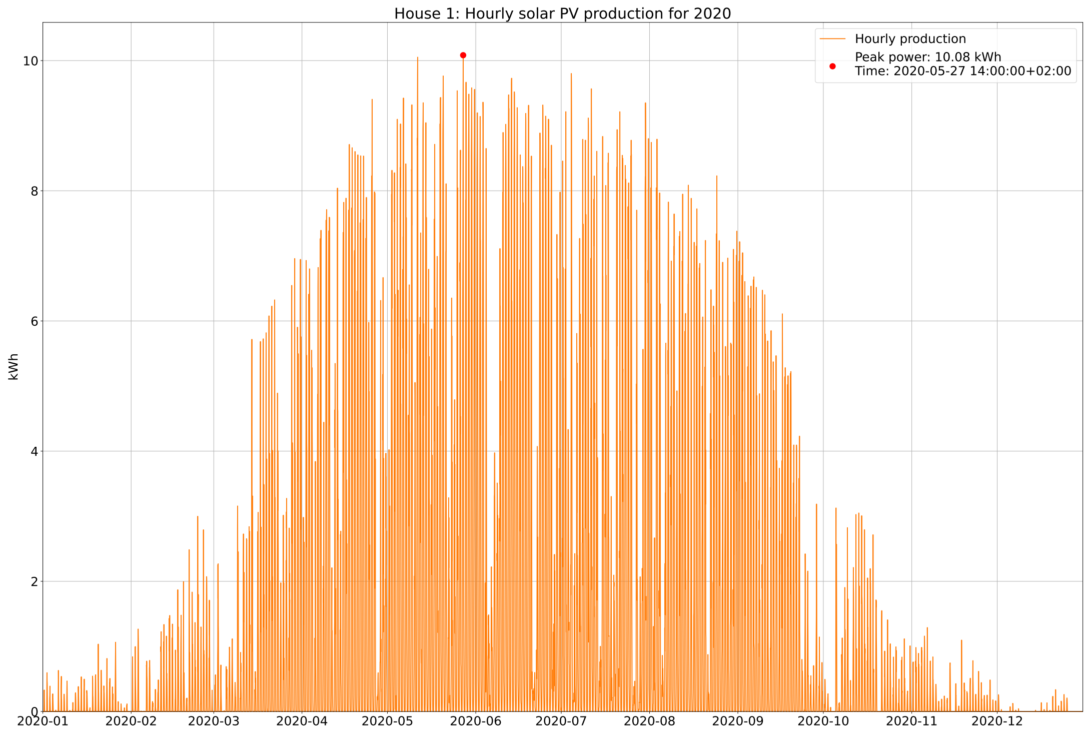



Figure A.8: Hourly PV production for House 1 in 2020.

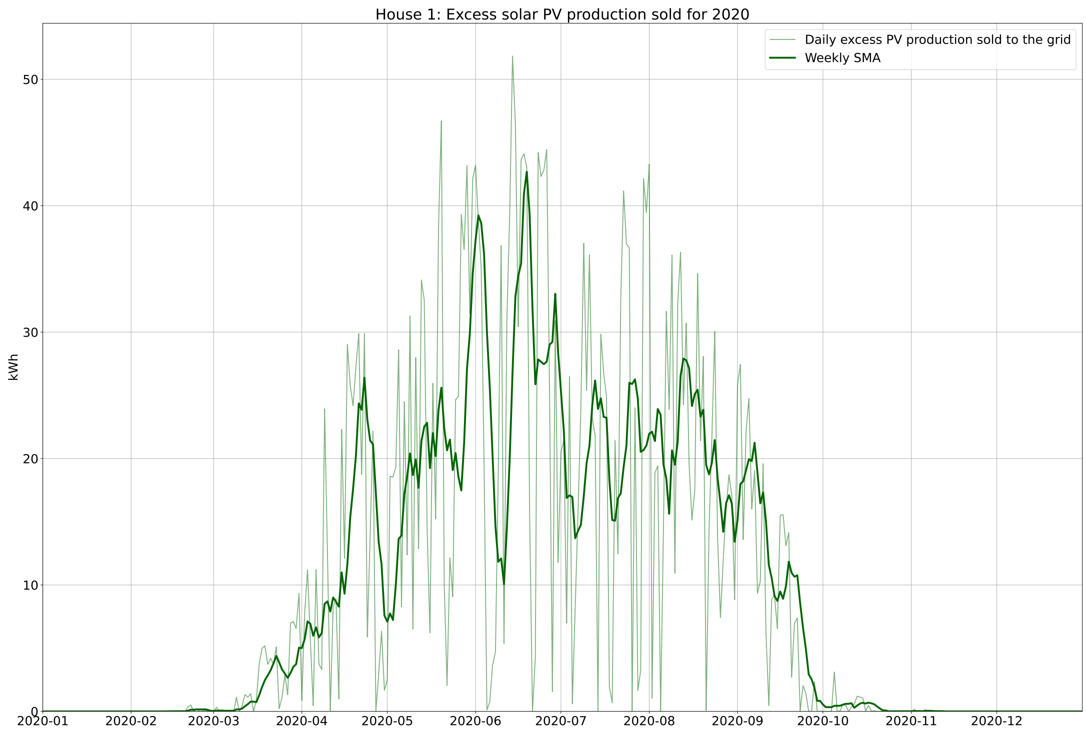



Figure A.9: Daily excess PV production sold to the grid and weekly SMA for House 1 in 2020

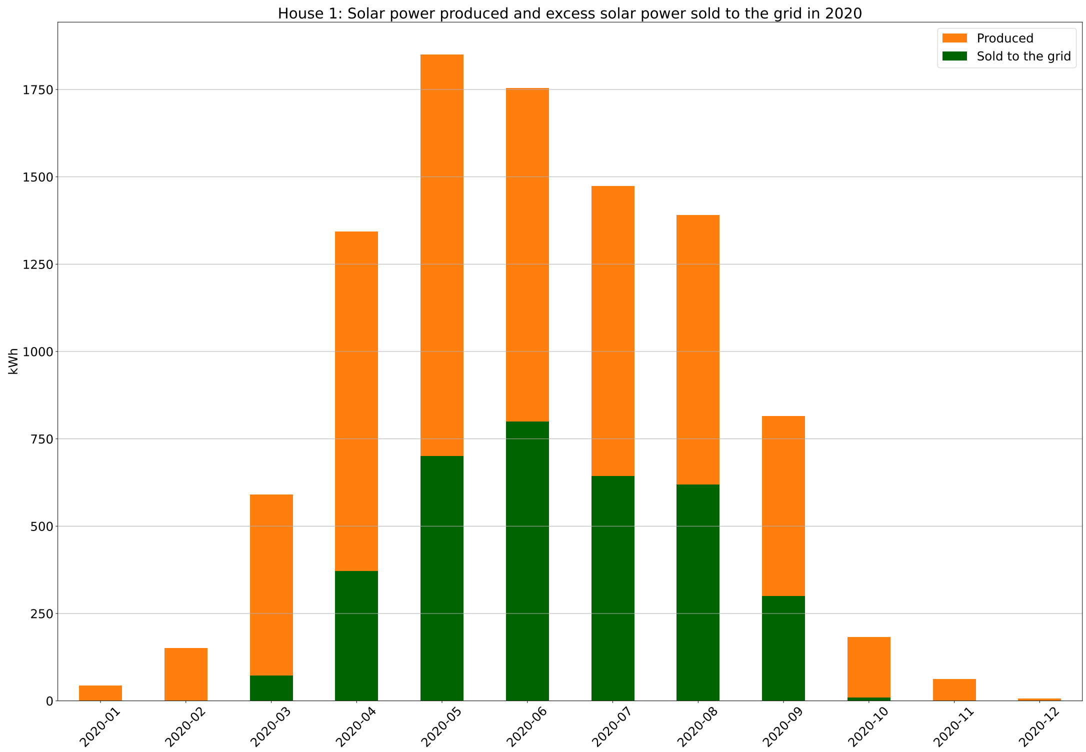



Figure A.10: Total solar PV production and excess production sold to the grid for each month in 2020 from House 1.

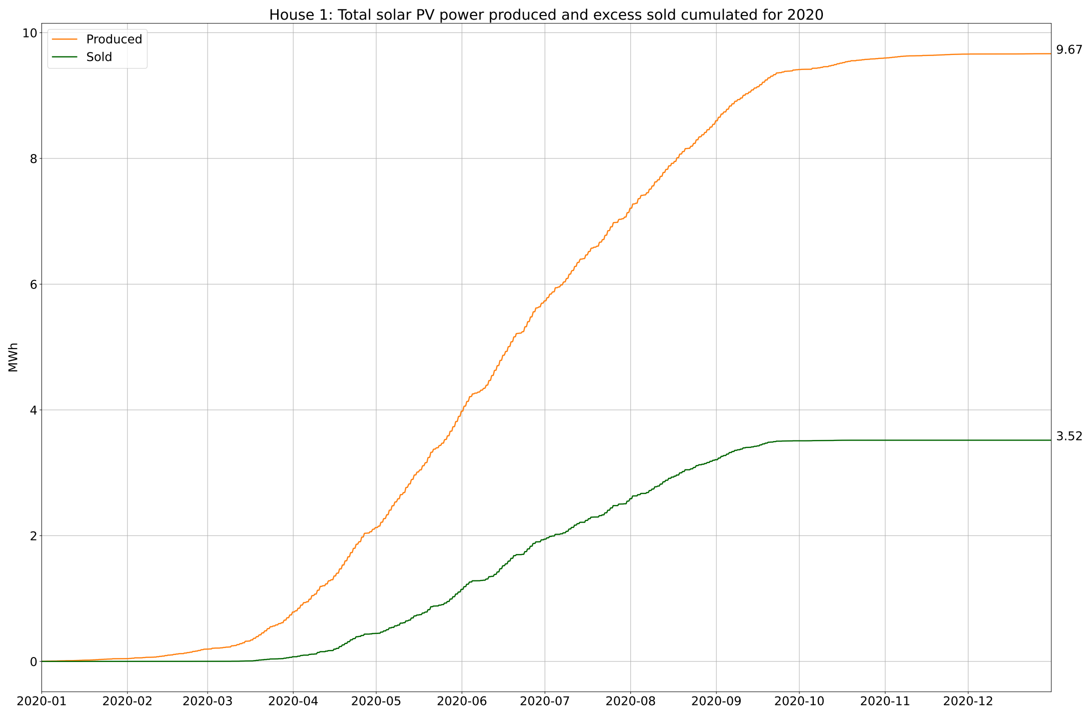



Figure A.11: Total solar PV production and excess production sold cumulated over 2020 from House 1

**2021**

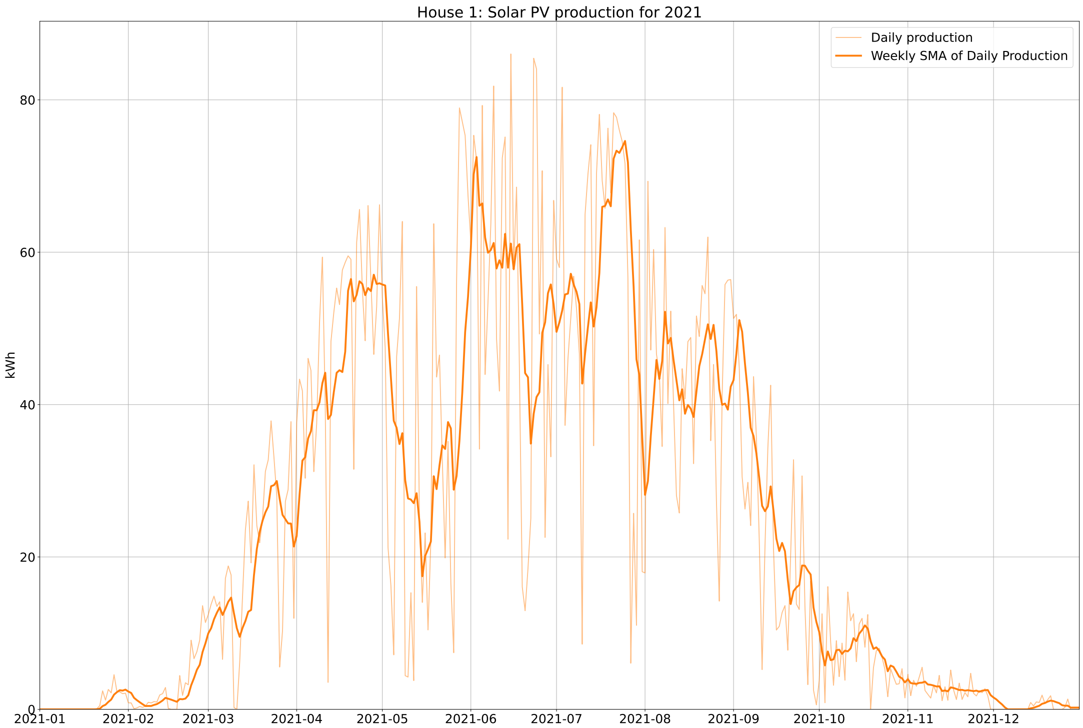



Figure A.12: Daily PV production and weekly SMA for House 1 in 2021.

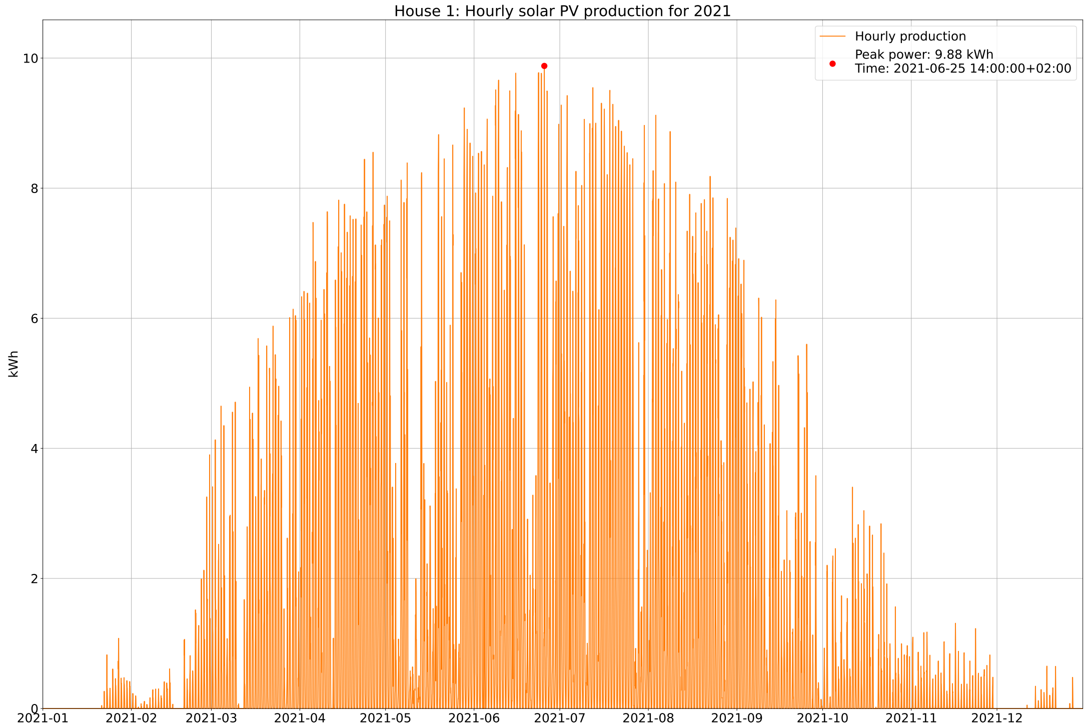



Figure A.13: Hourly PV production for House 1 in 2021.

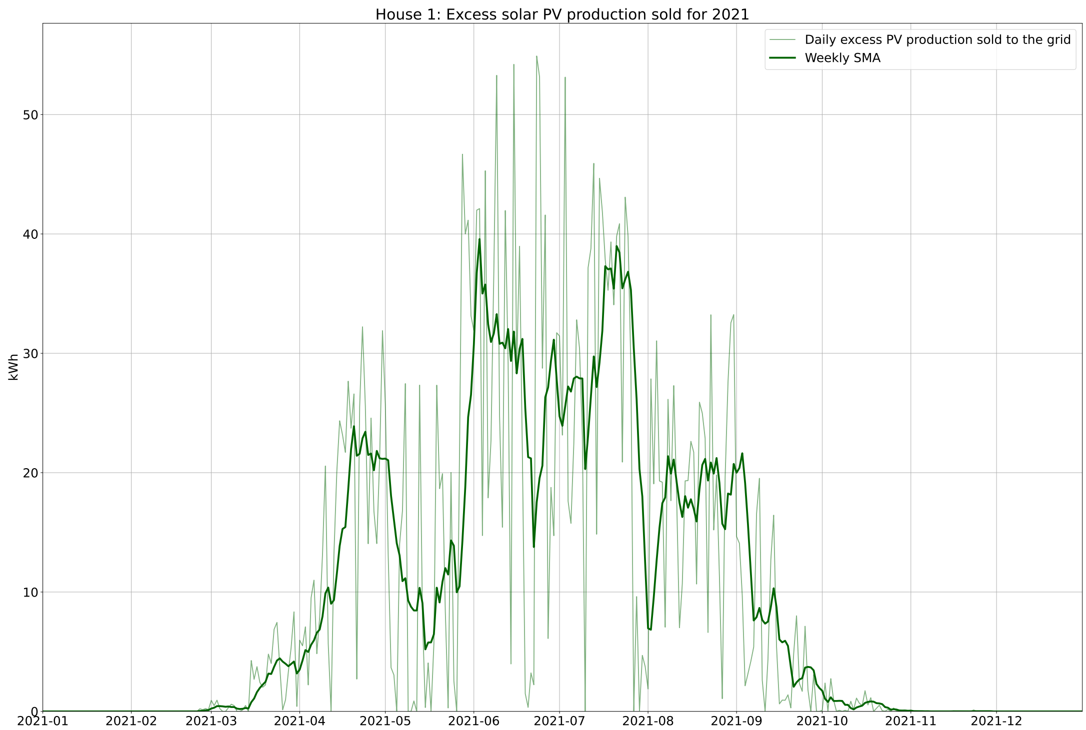



Figure A.14: Daily excess PV production sold to the grid and weekly SMA for House 1 in 2021

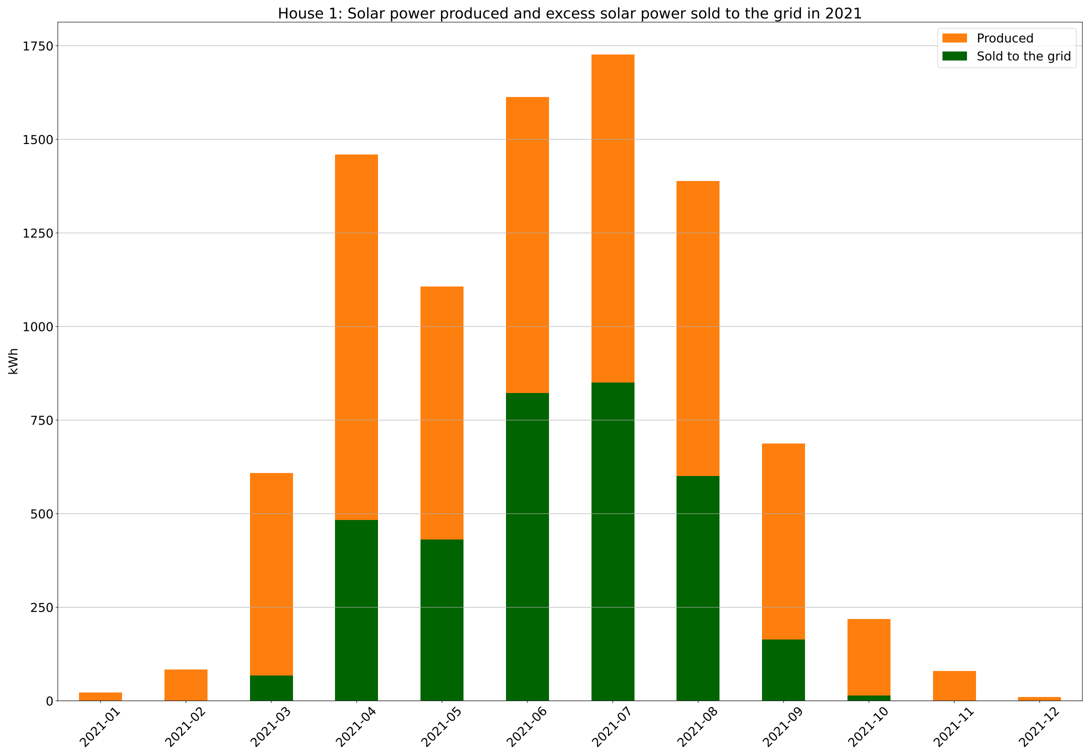



Figure A.15: Total solar PV production and excess production sold to the grid for each month in 2021 from House 1.

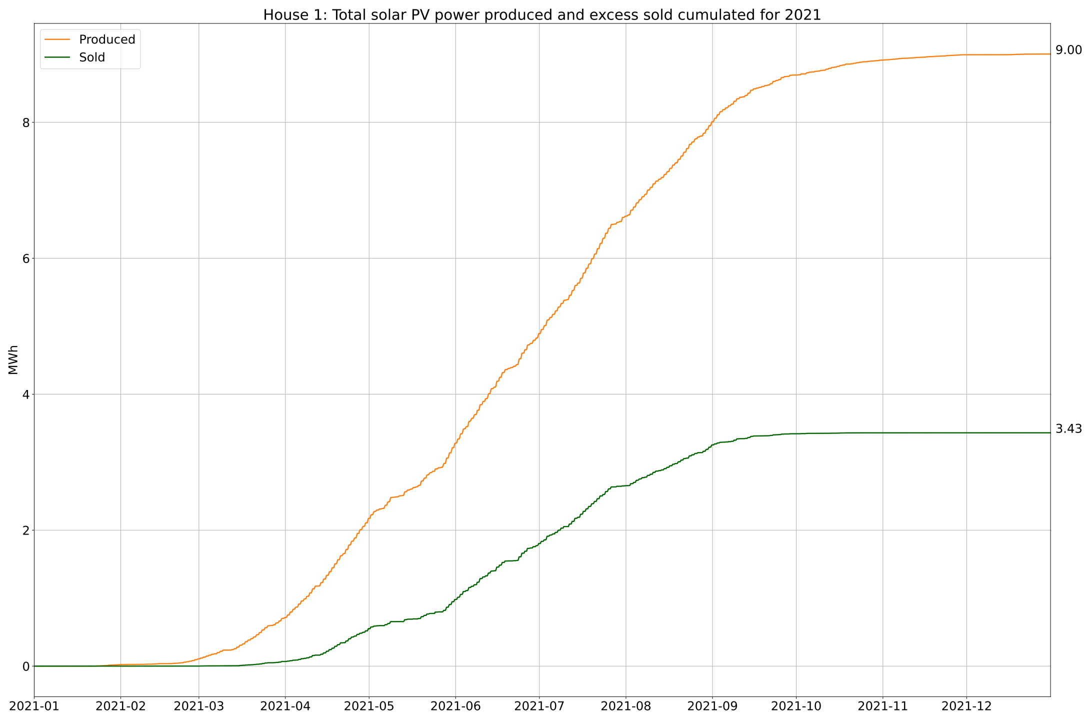



Figure A.16: Total solar PV production and excess production sold cumulated over 2021 from House 1

### A.1.3 Delta variable

#### 2020

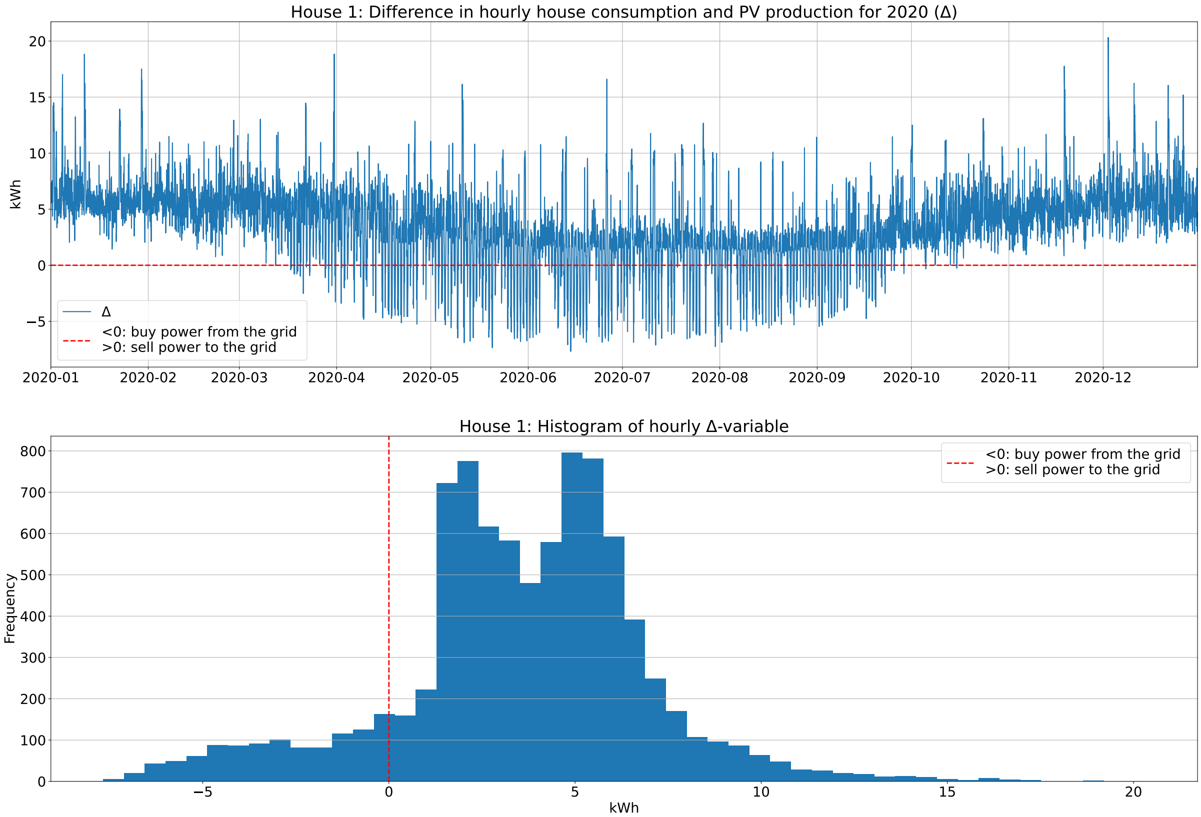



Figure A.17: The delta variable plotted for House 1. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

**2021**

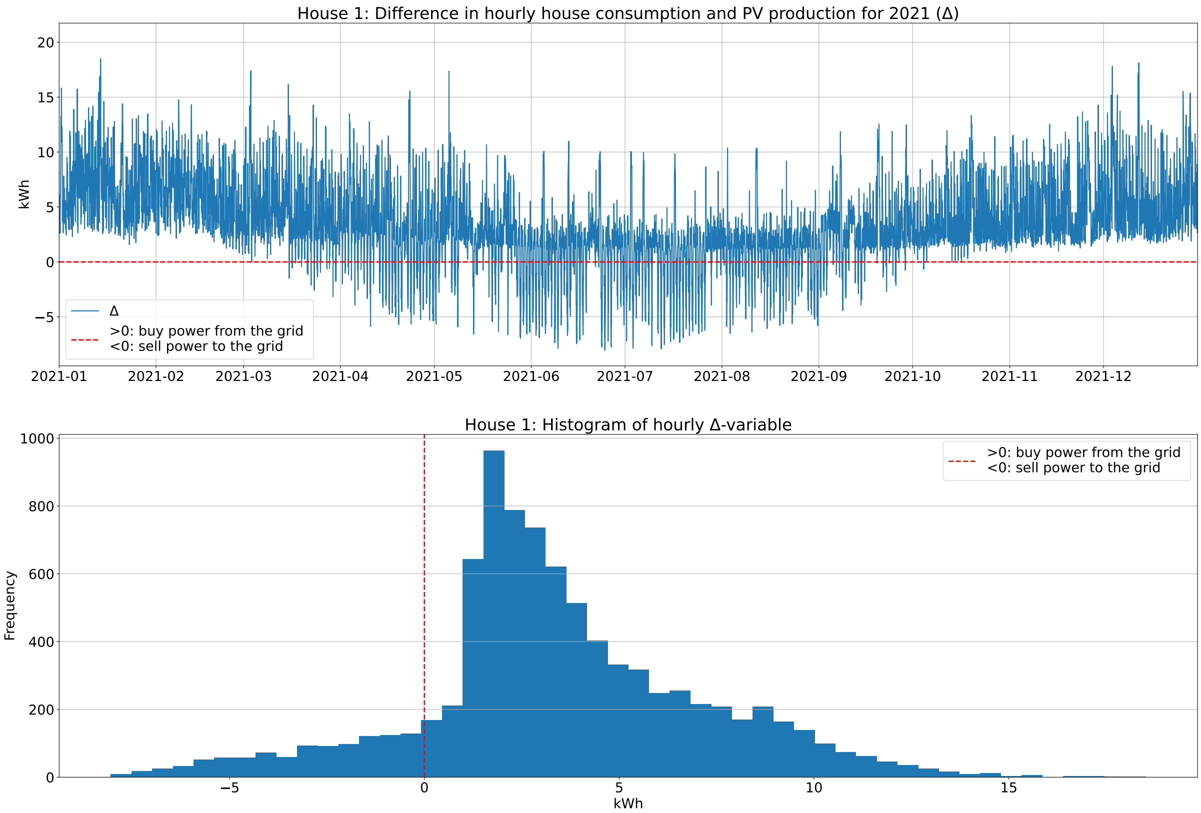



Figure A.18: The delta variable plotted for House 1. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence.

### A.1.4 House consumption and PV production

**2020**

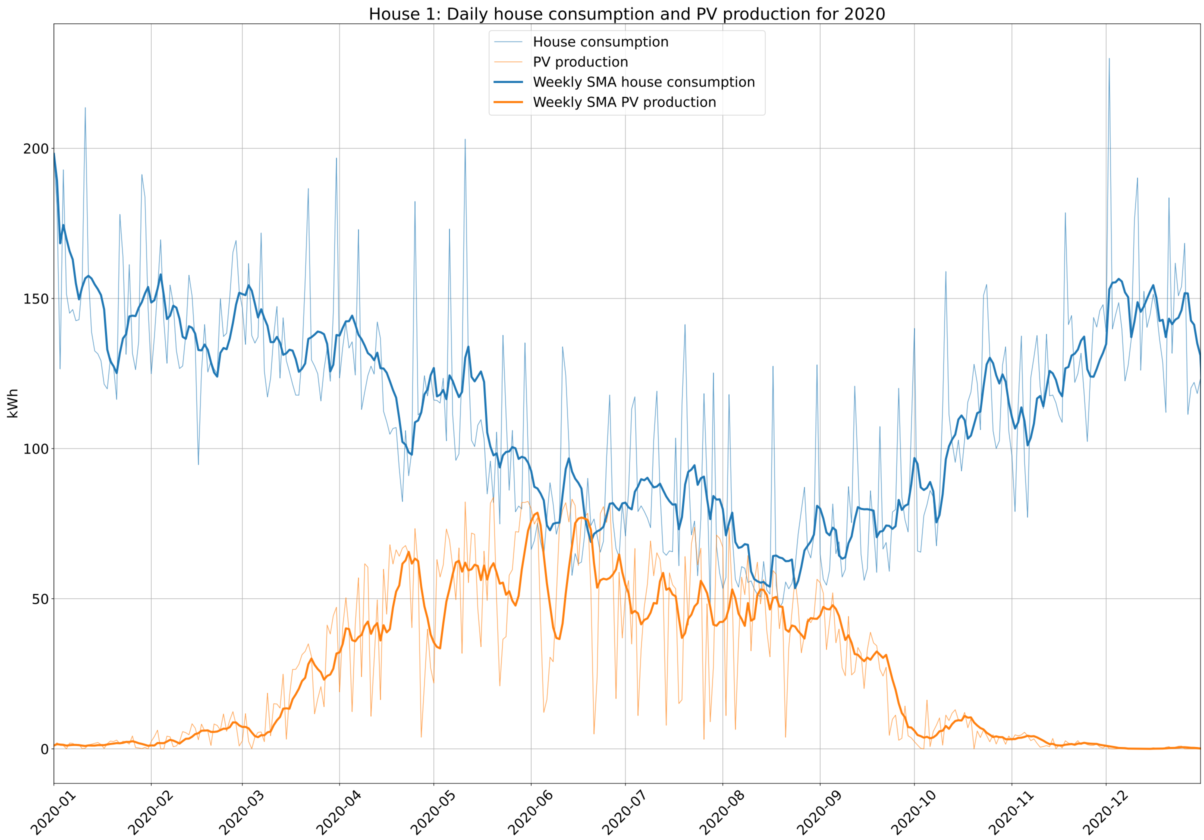



Figure A.19: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

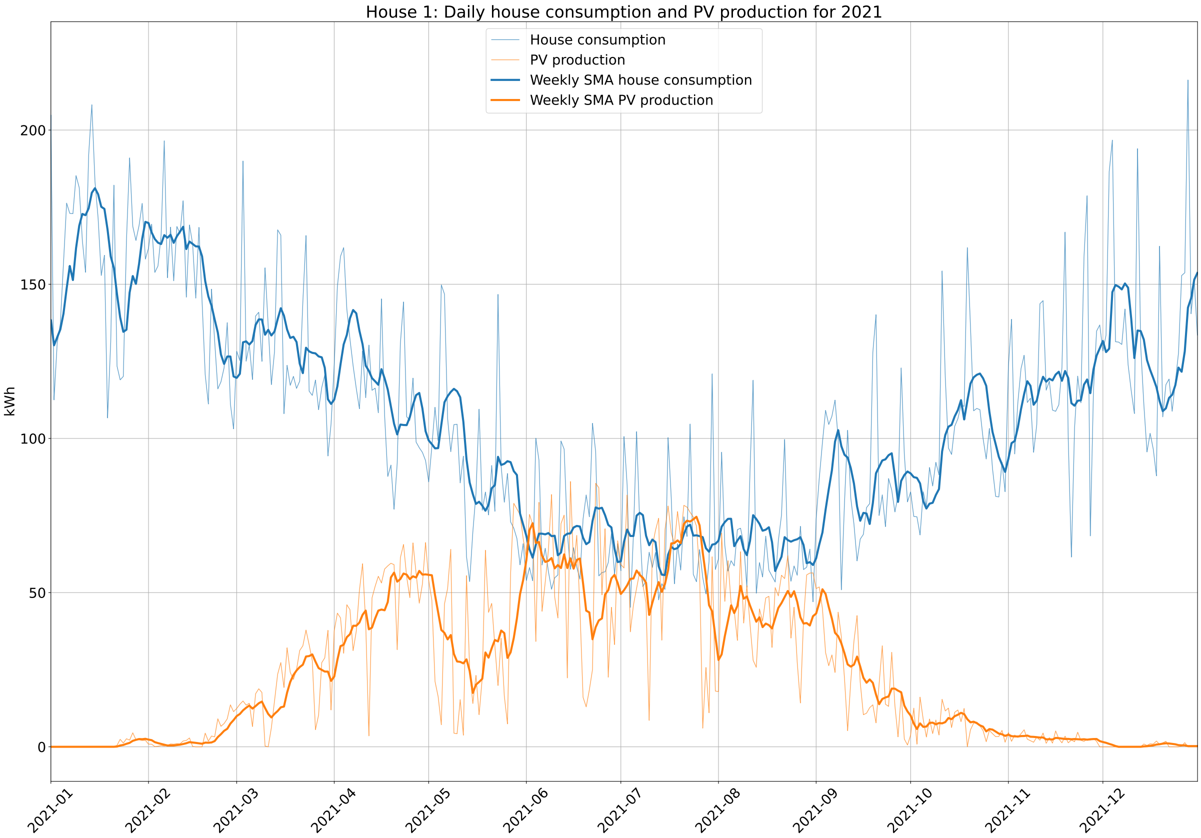



Figure A.20: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.1.5 Cost of energy

#### 2020

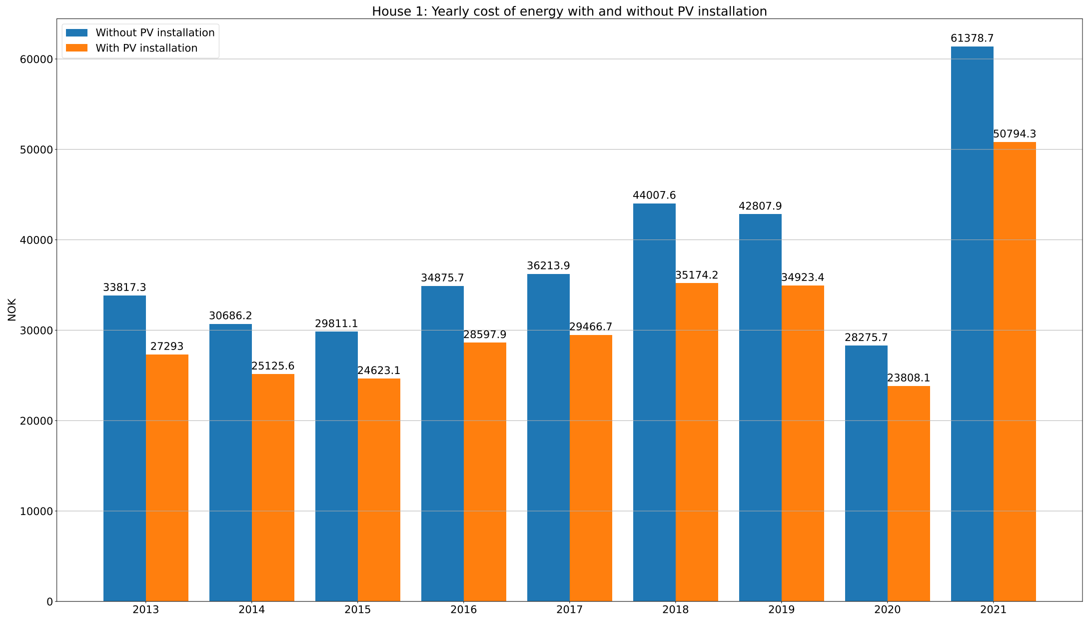



Figure A.21: Yearly cost of energy for House 1, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

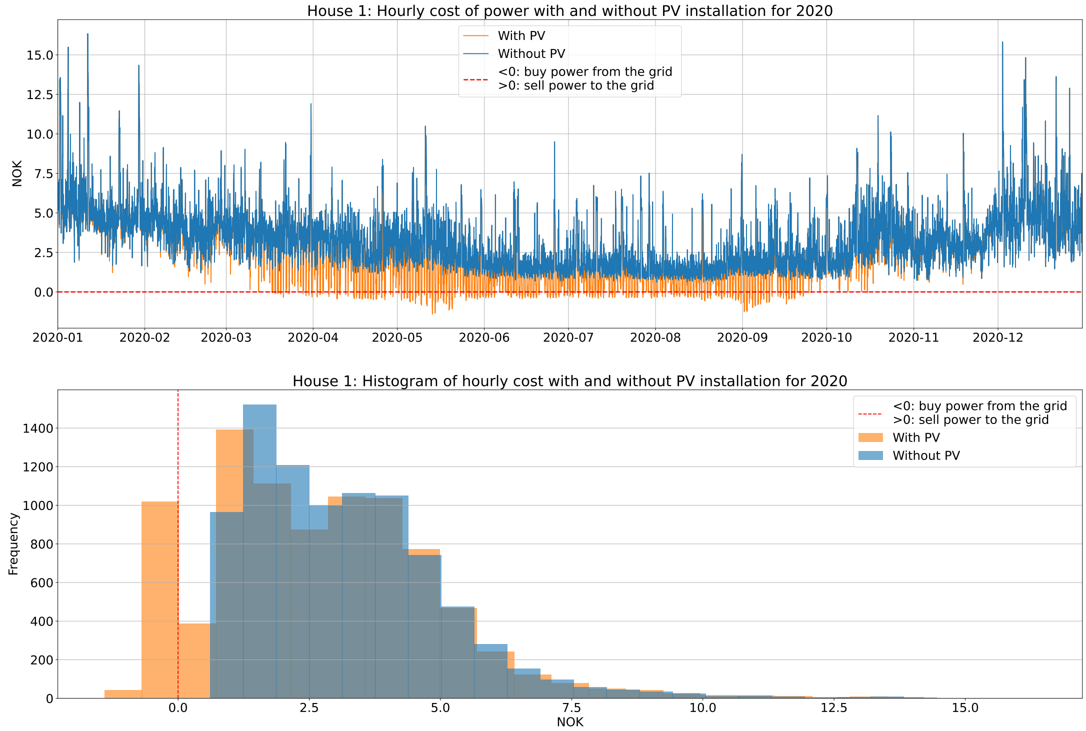



Figure A.22: Hourly cost of energy for House 1 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

**2021**

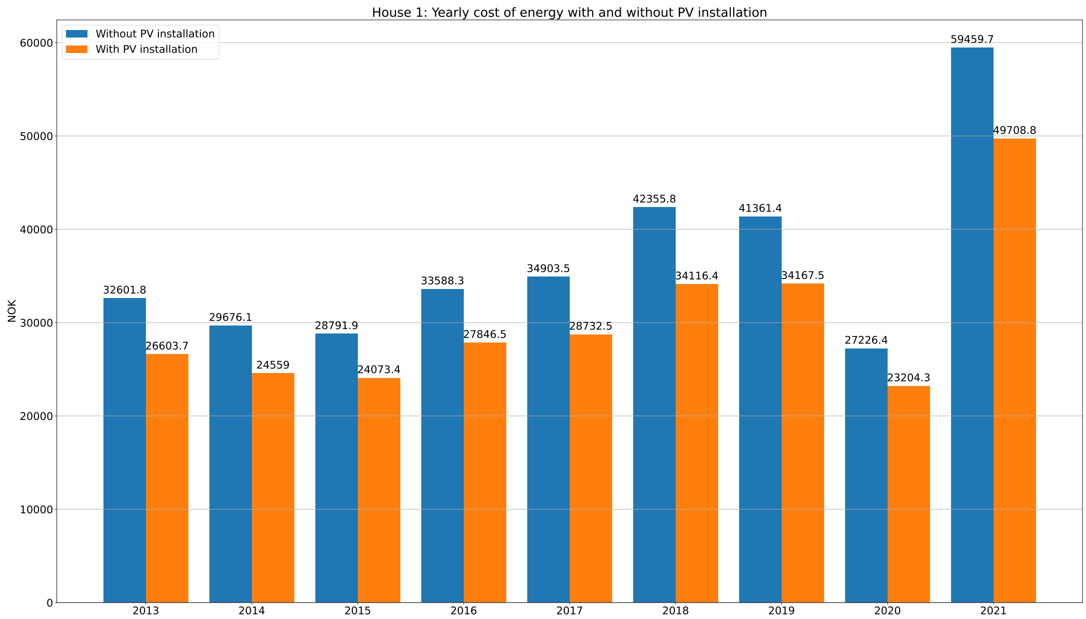



Figure A.23: Yearly cost of energy for House 1, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

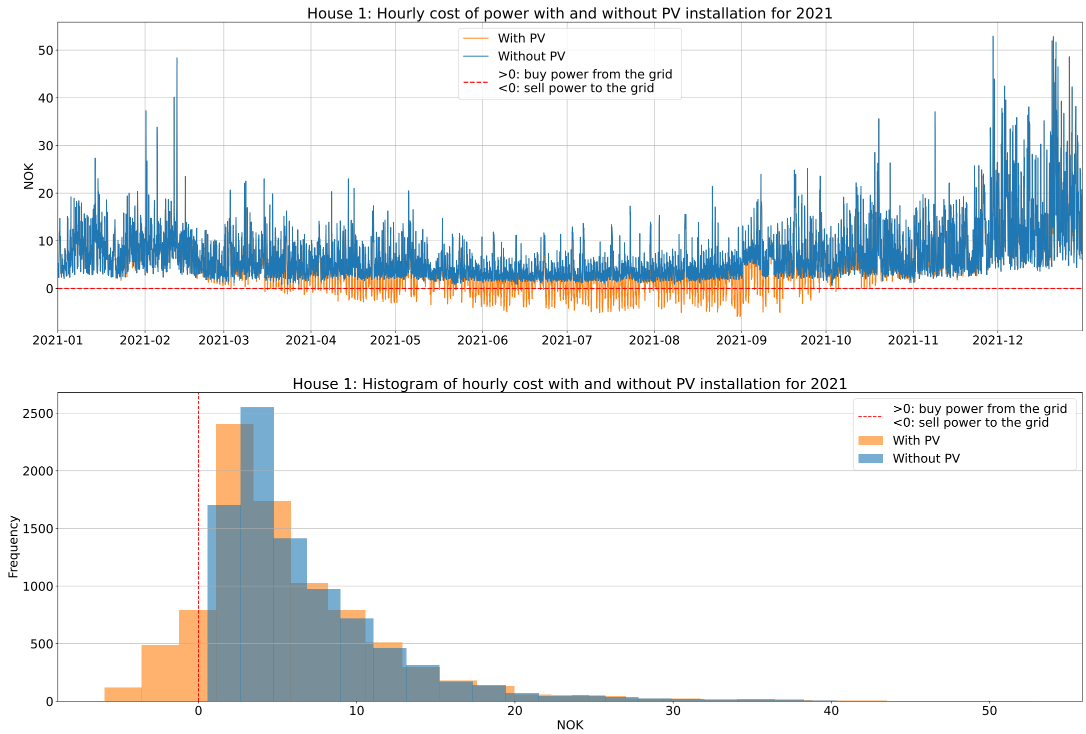



Figure A.24: Hourly cost of energy for House 1 with and without a PV system present for 2021.

## A.2 House 2

### A.2.1 House consumption

**2020**

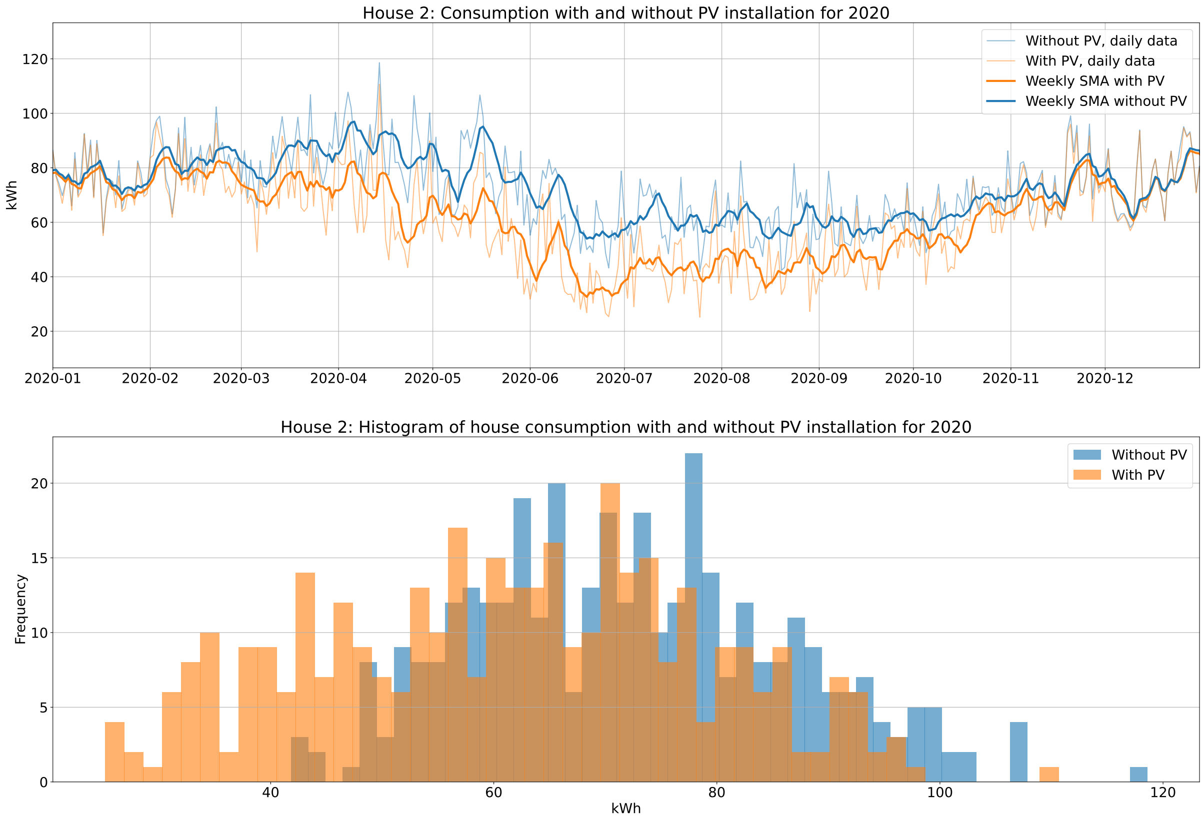



Figure A.25: Daily house consumption with and without a PV system for 2020 from House 2. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

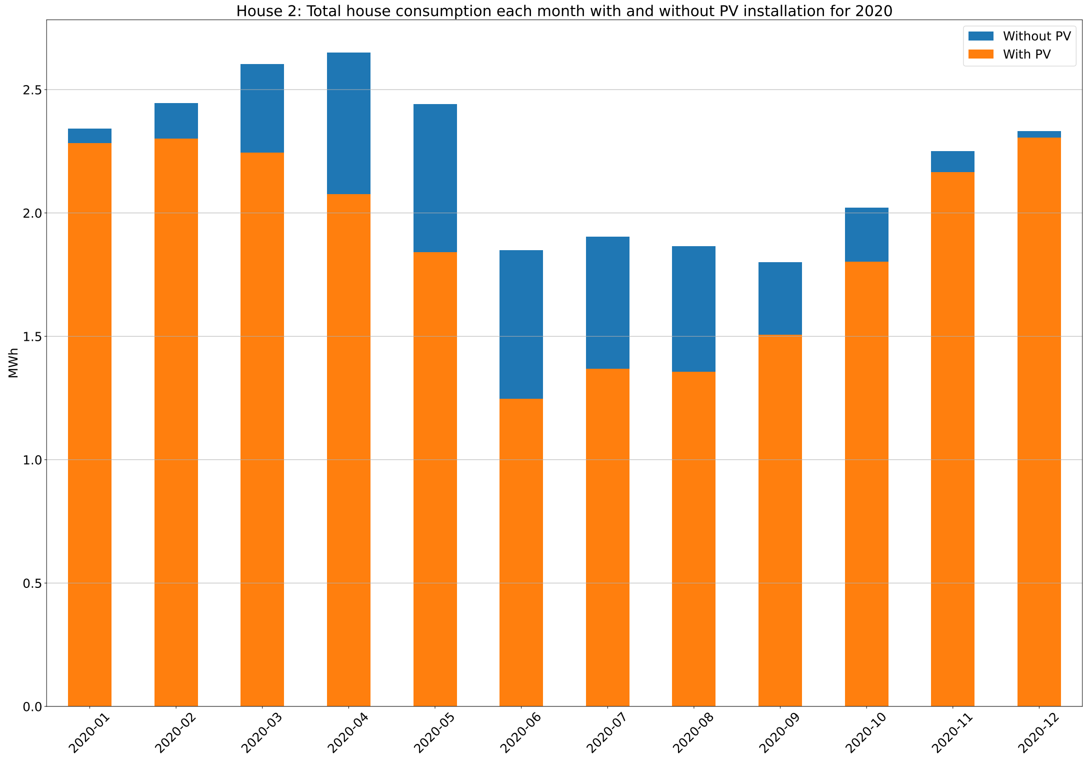



Figure A.26: Monthly house consumption for House 2 with and without a PV system for 2020.

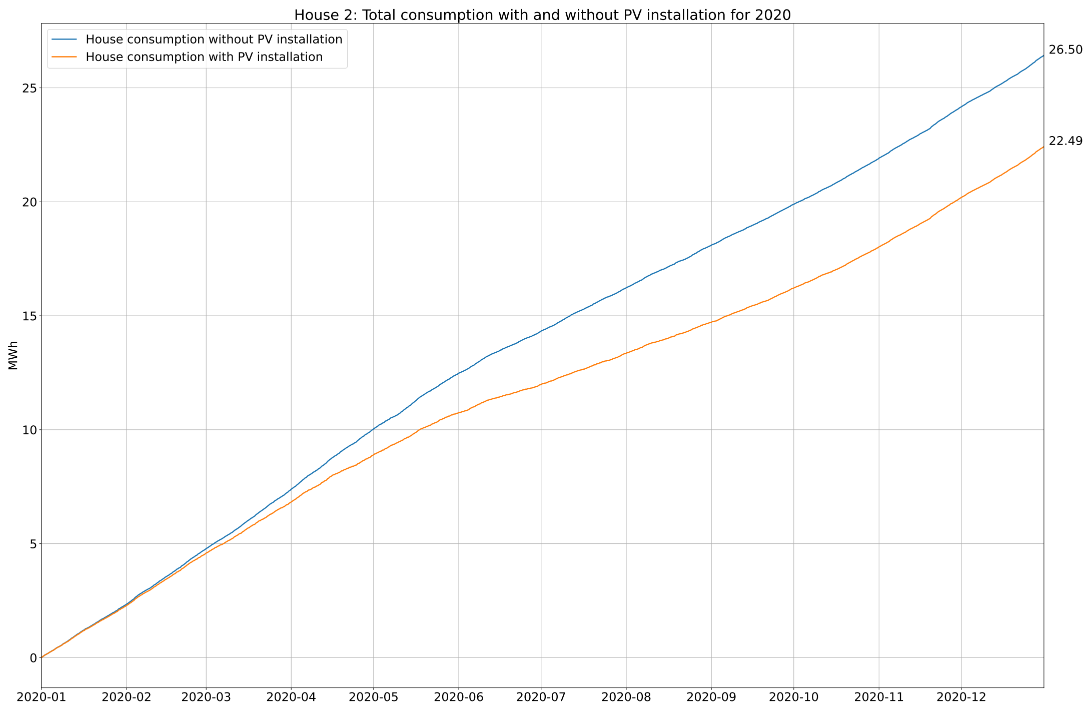
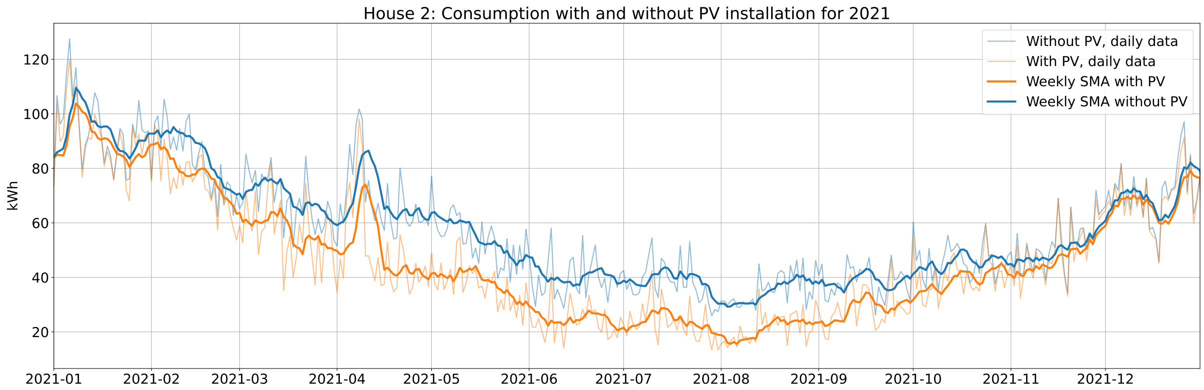



Figure A.27: Total house consumption for House 2 with and without a PV system accumulated over 2020

**2021**



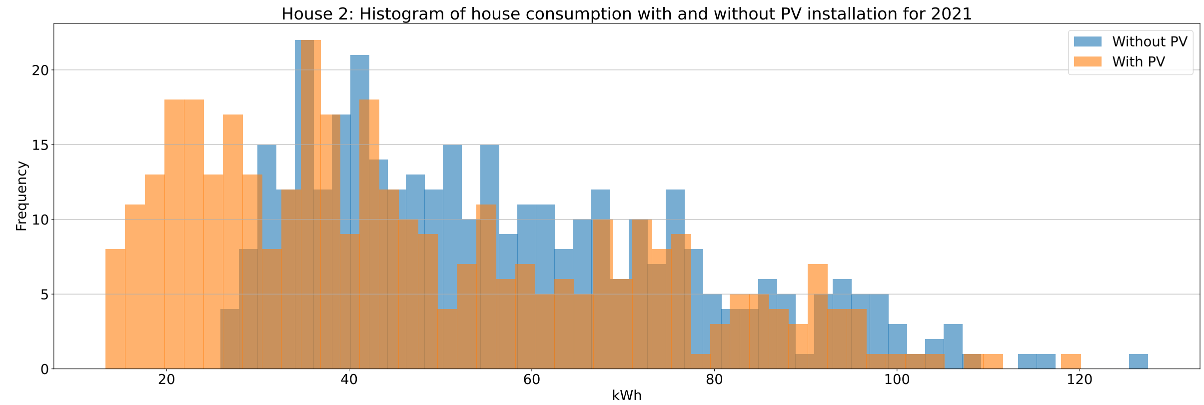




Figure A.28: Daily house consumption with and without a PV system for 2021 from House 2. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

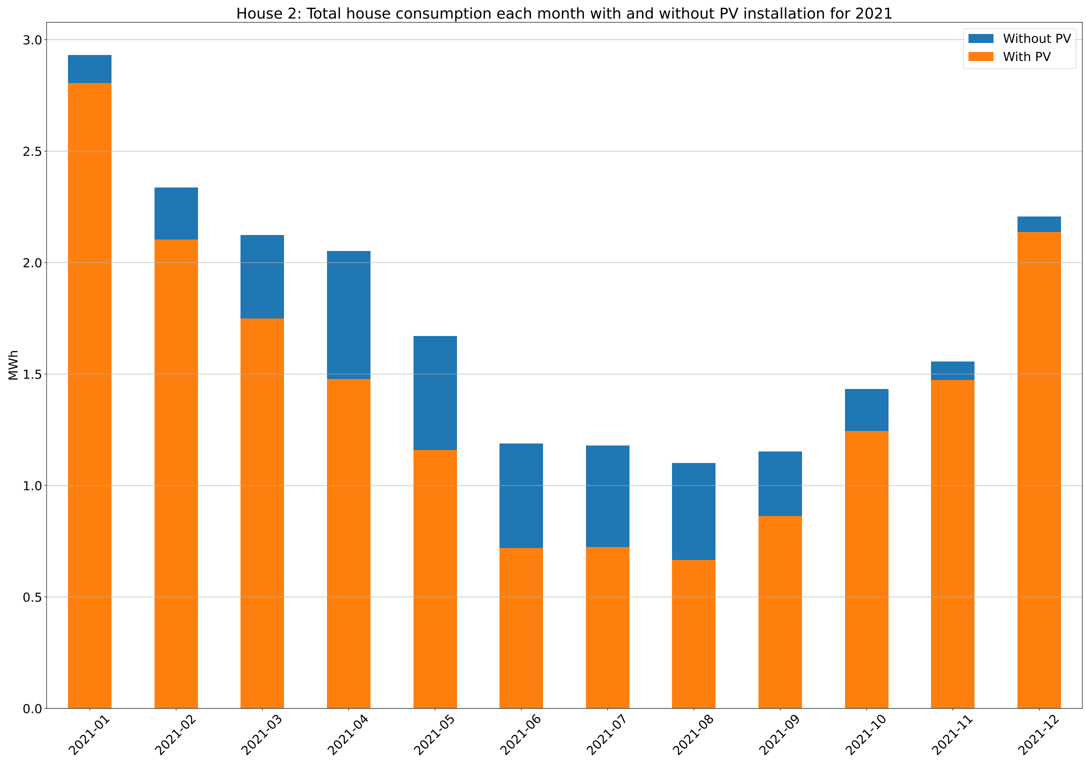



Figure A.29: Monthly house consumption for House 2 with and without a PV system for 2021.

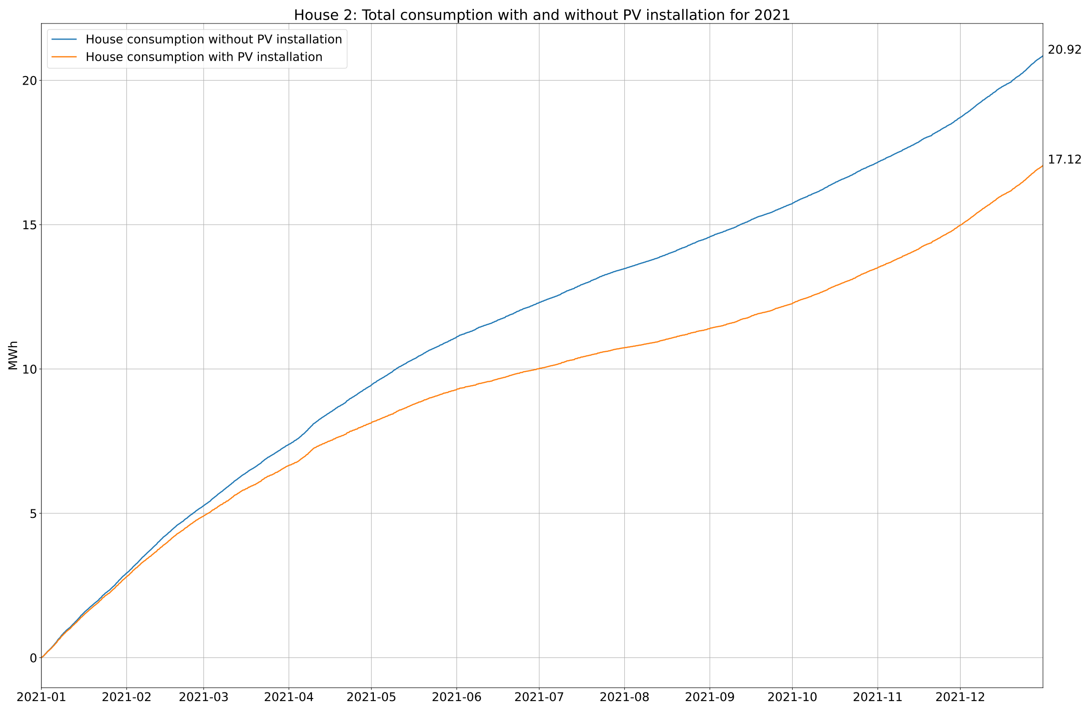



Figure A.30: Total house consumption for House 2 with and without a PV system accumulated over 2021

### A.2.2 Solar PV production

#### 2020

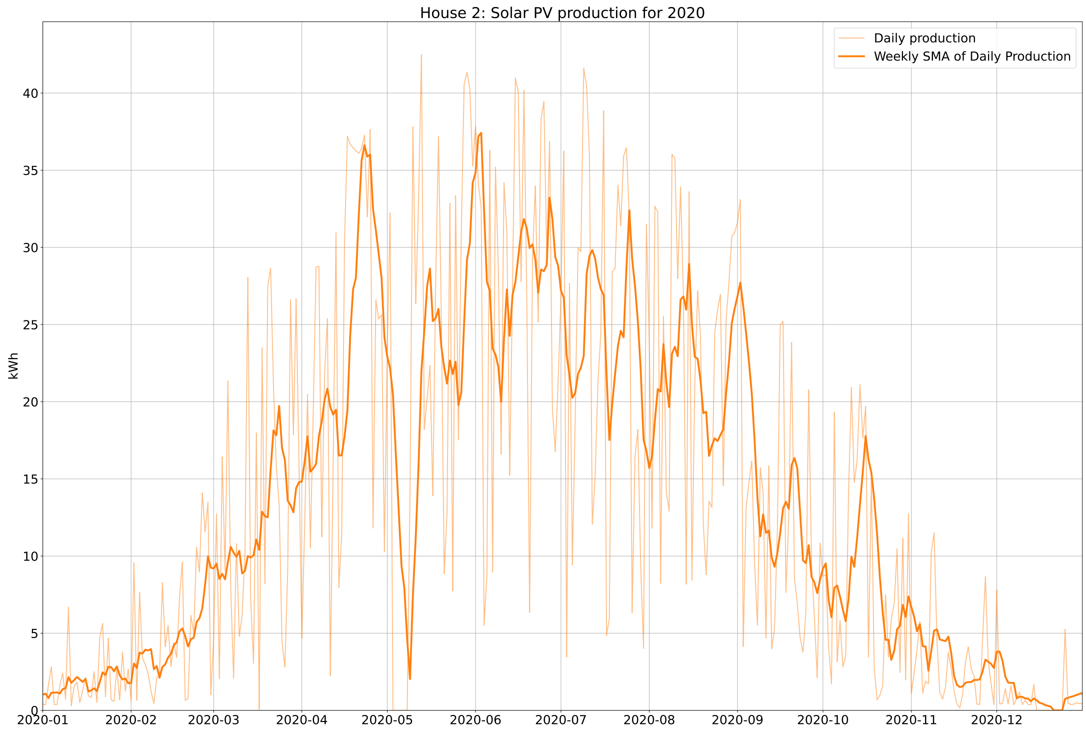



Figure A.31: Daily PV production and weekly SMA for House 2 in 2020.

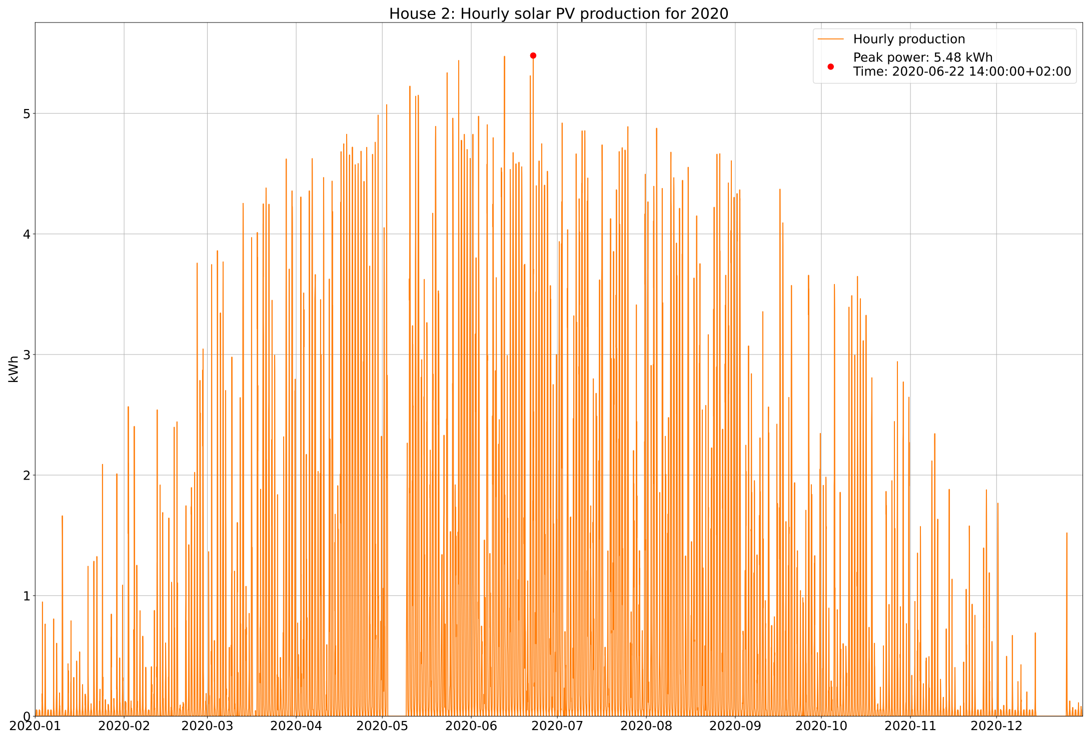



Figure A.32: Hourly PV production for House 2 in 2020.

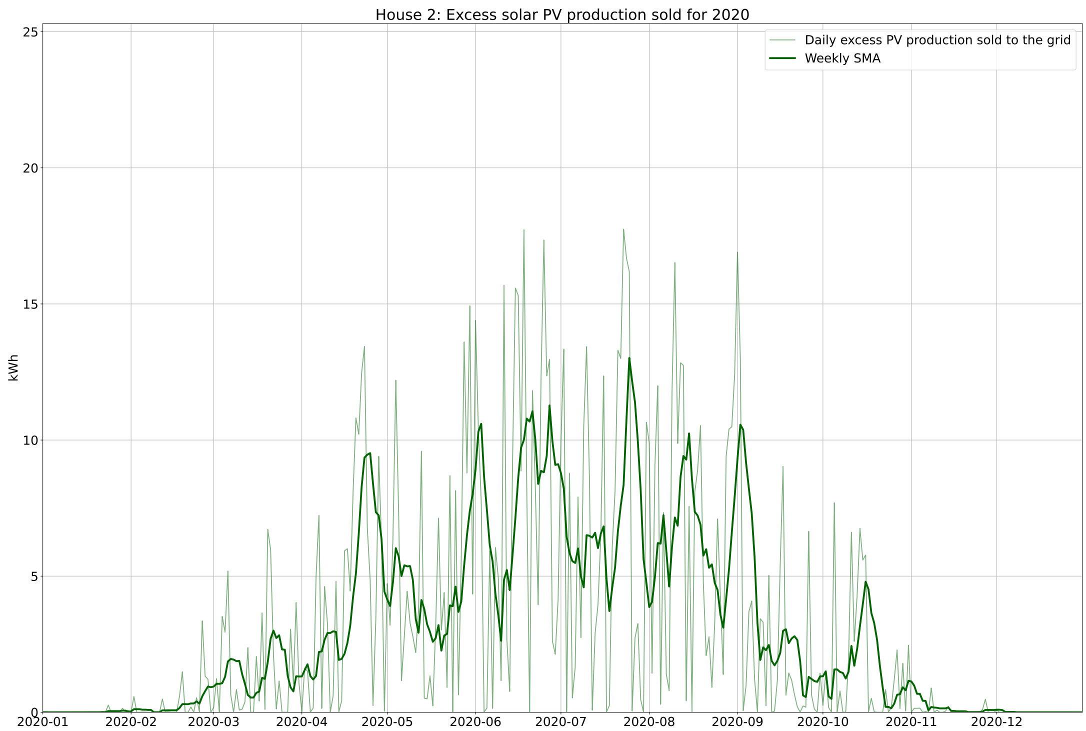



Figure A.33: Daily excess PV production sold to the grid and weekly SMA for House 2 in 2020

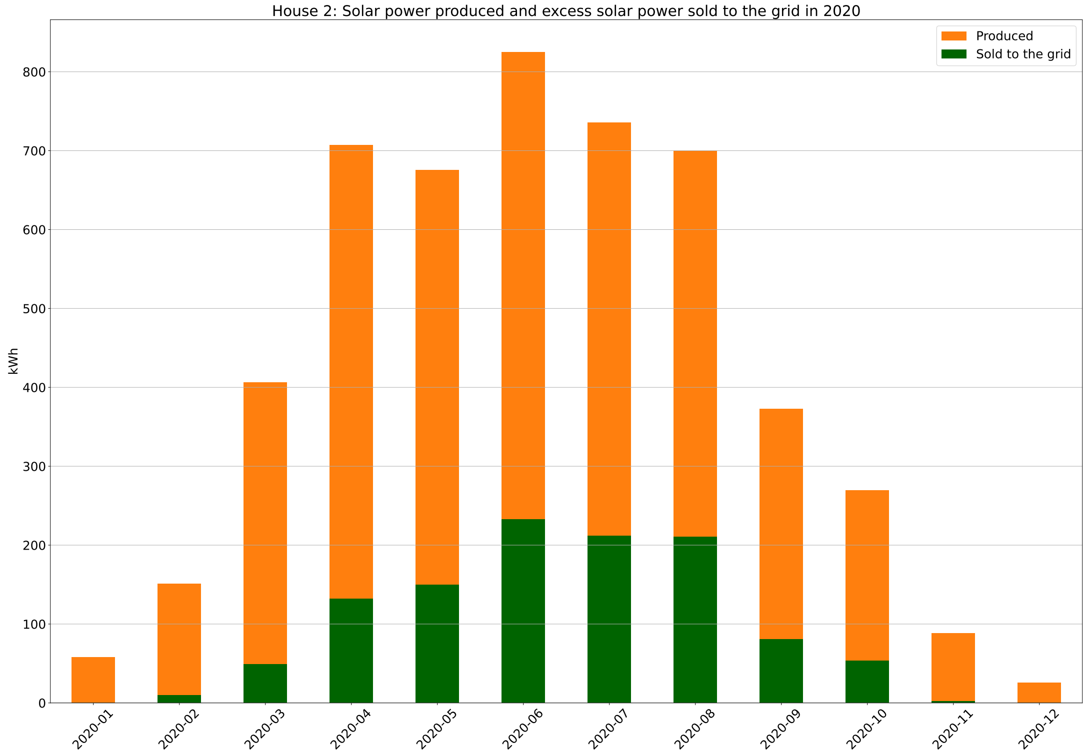



Figure A.34: Total solar PV production and excess production sold to the grid for each month in 2020 from House 2.

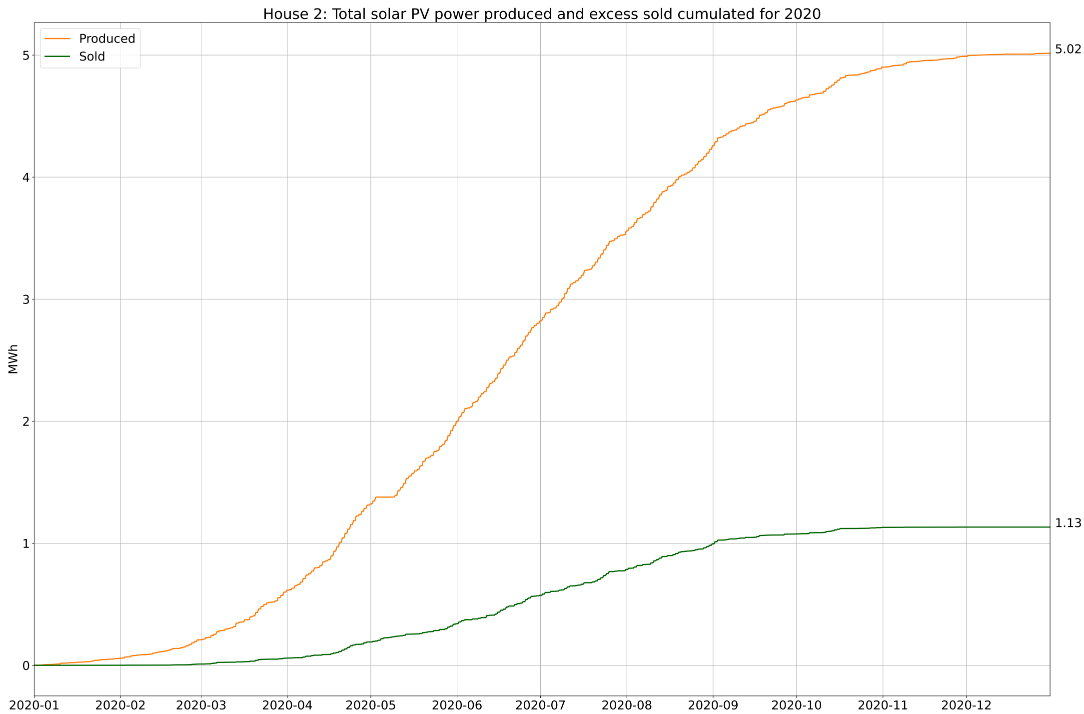



Figure A.35: Total solar PV production and excess production sold cumulated over 2020 from House 2

**2021**

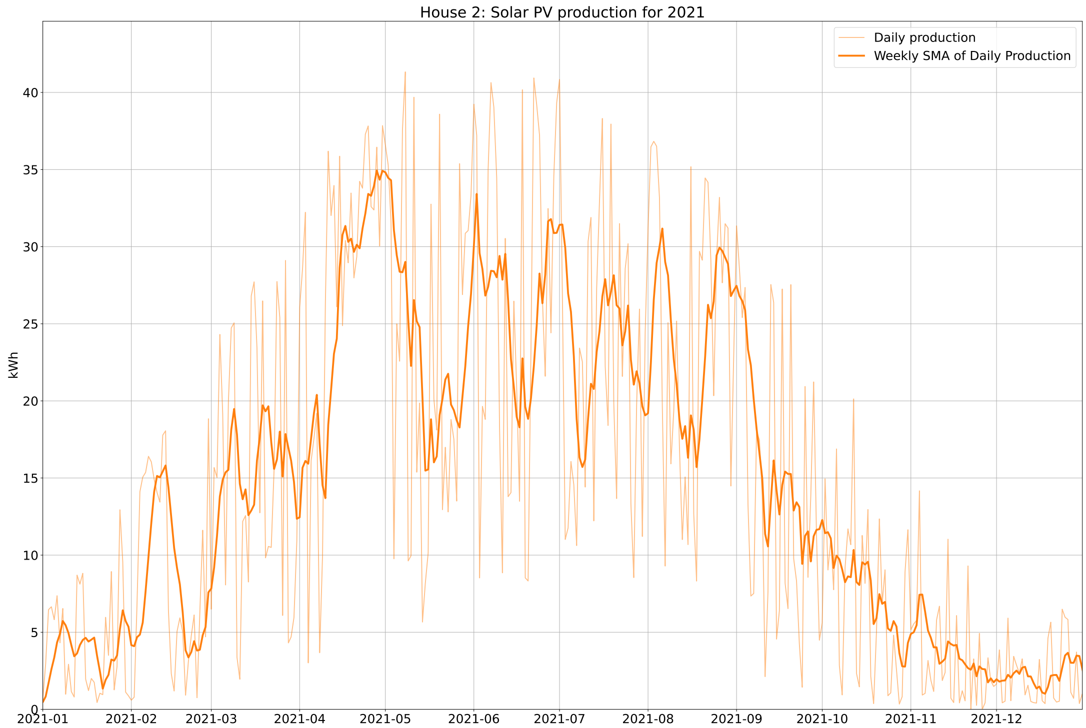



Figure A.36: Daily PV production and weekly SMA for House 2 in 2021.

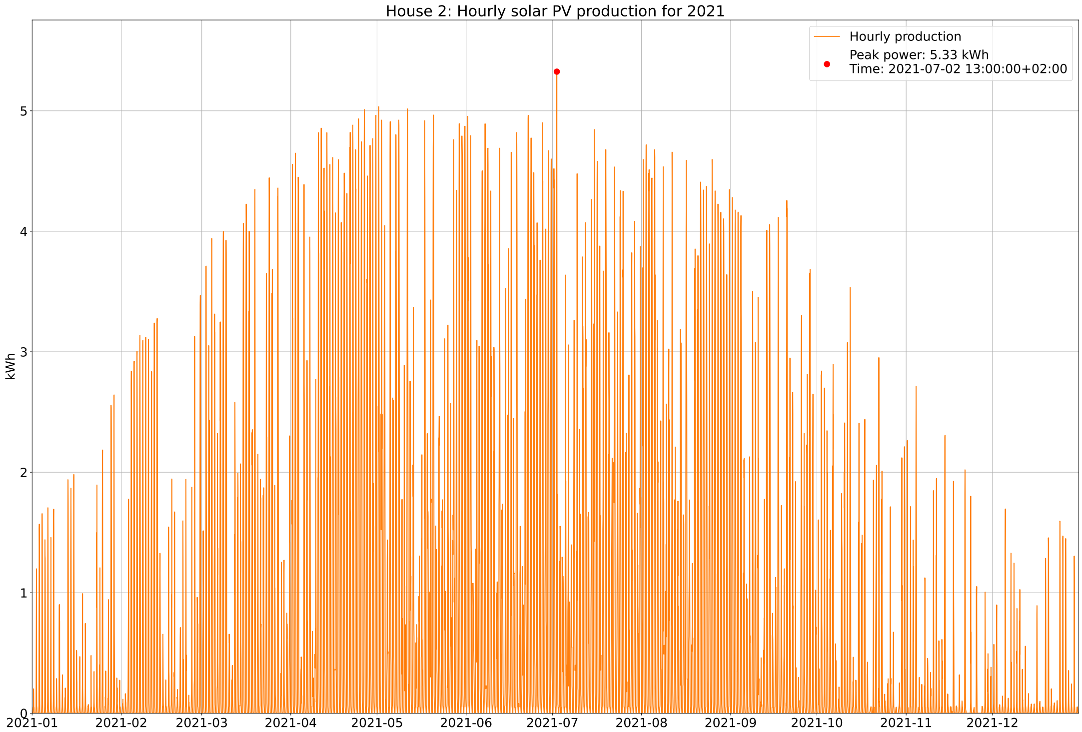



Figure A.37: Hourly PV production for House 2 in 2021.

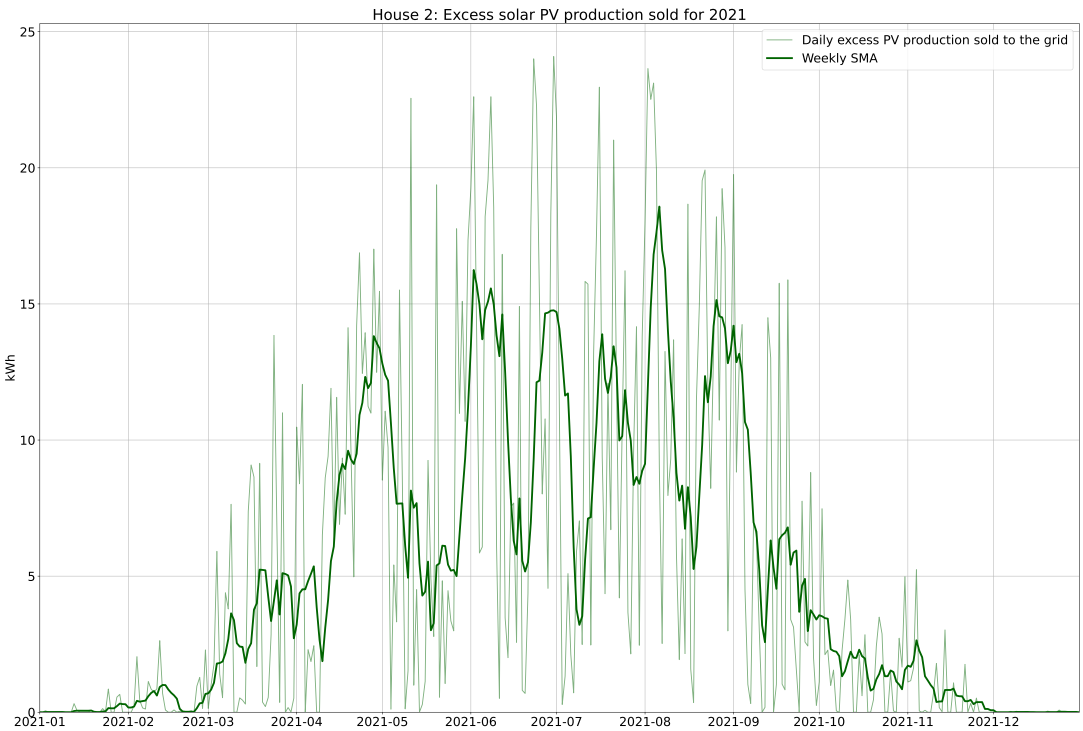



Figure A.38: Daily excess PV production sold to the grid and weekly SMA for House 2 in 2021

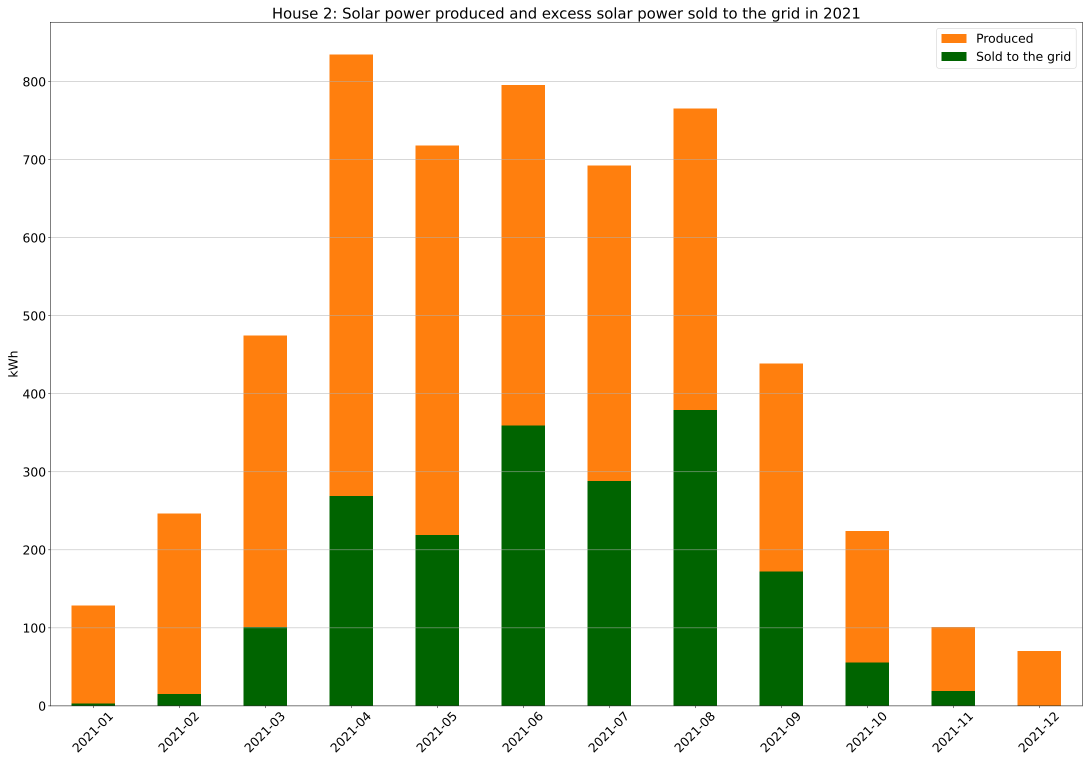



Figure A.39: Total solar PV production and excess production sold to the grid for each month in 2021 from House 2.

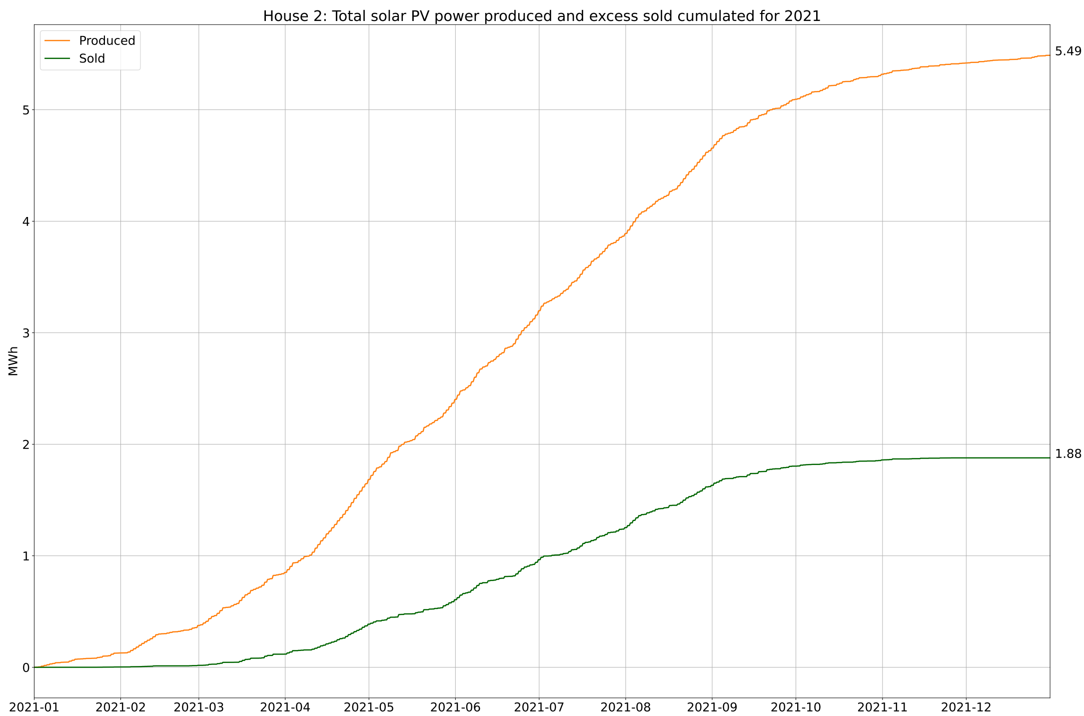



Figure A.40: Total solar PV production and excess production sold cumulated over 2021 from House 2

### A.2.3 Delta variable

#### 2020

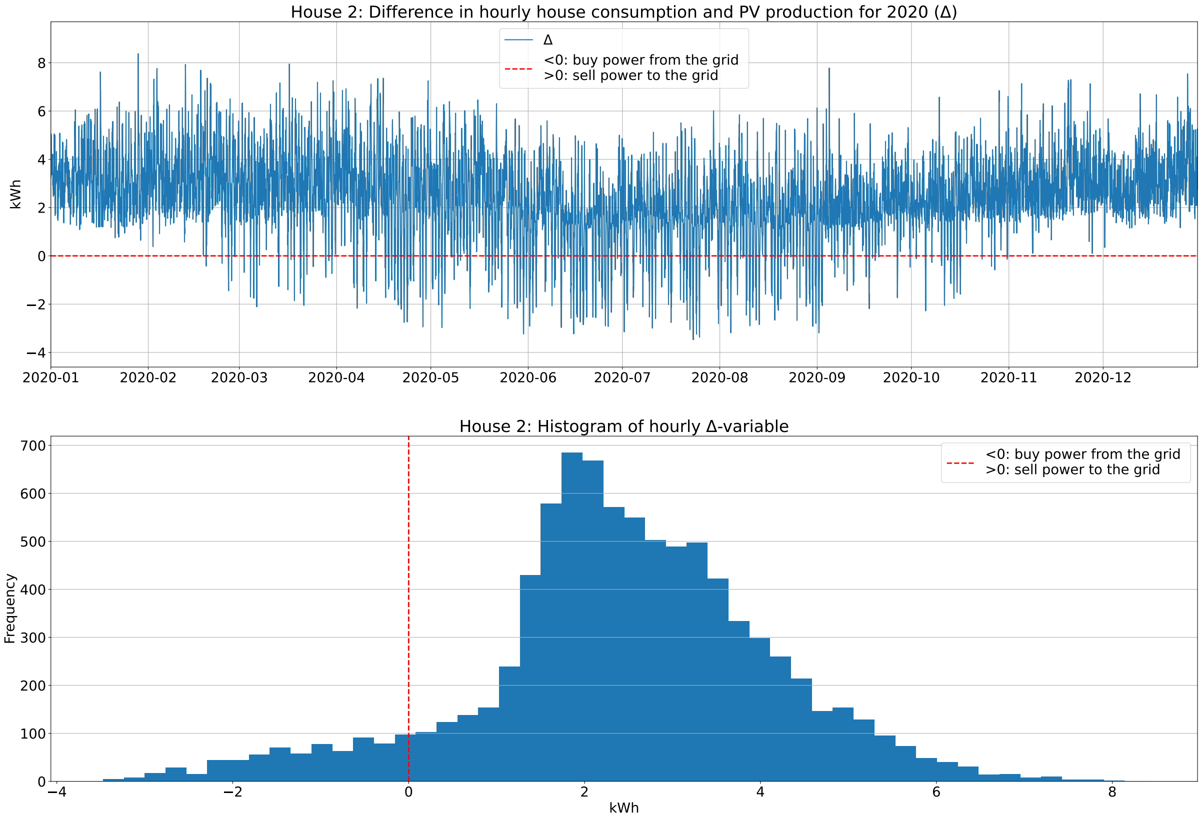



Figure A.41: The delta variable plotted for House 2. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

### 2021

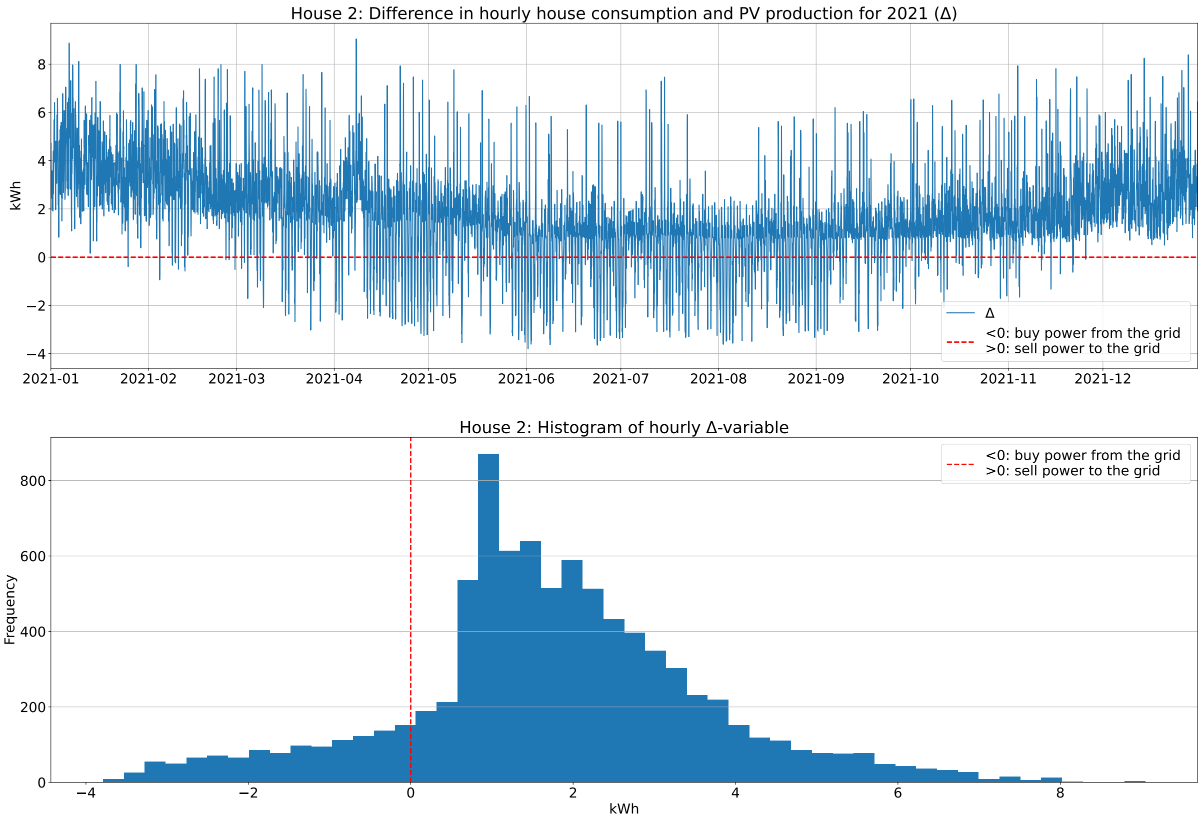



Figure A.42: The delta variable plotted for House 2. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

### A.2.4 House consumption and PV production

#### 2020

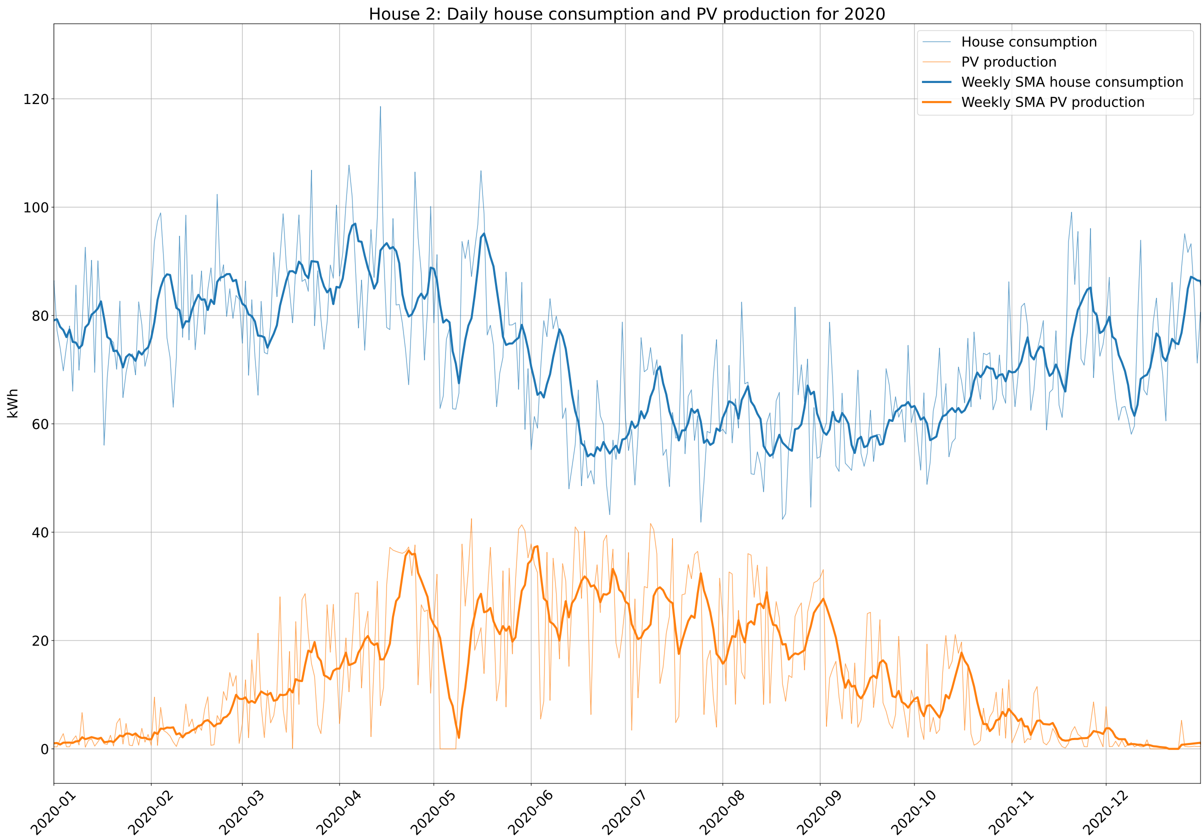



Figure A.43: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

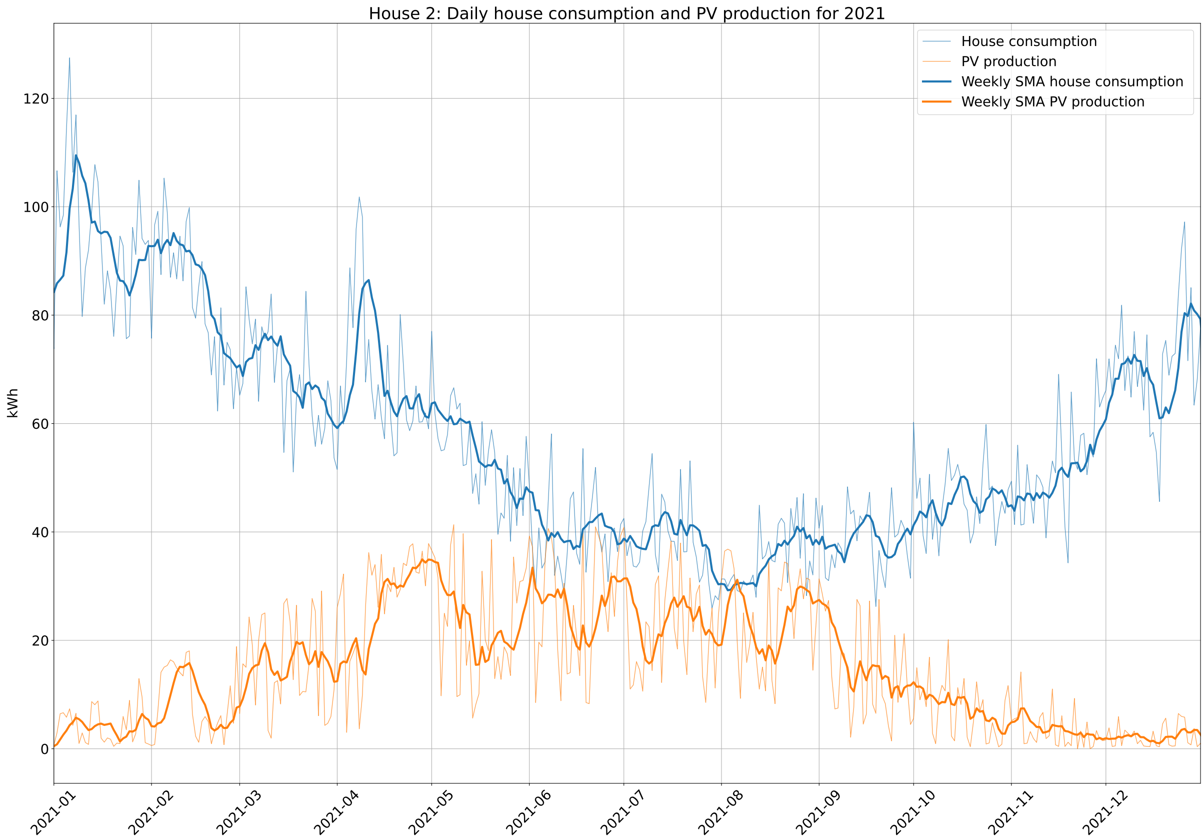



Figure A.44: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.2.5 Cost of energy

#### 2020

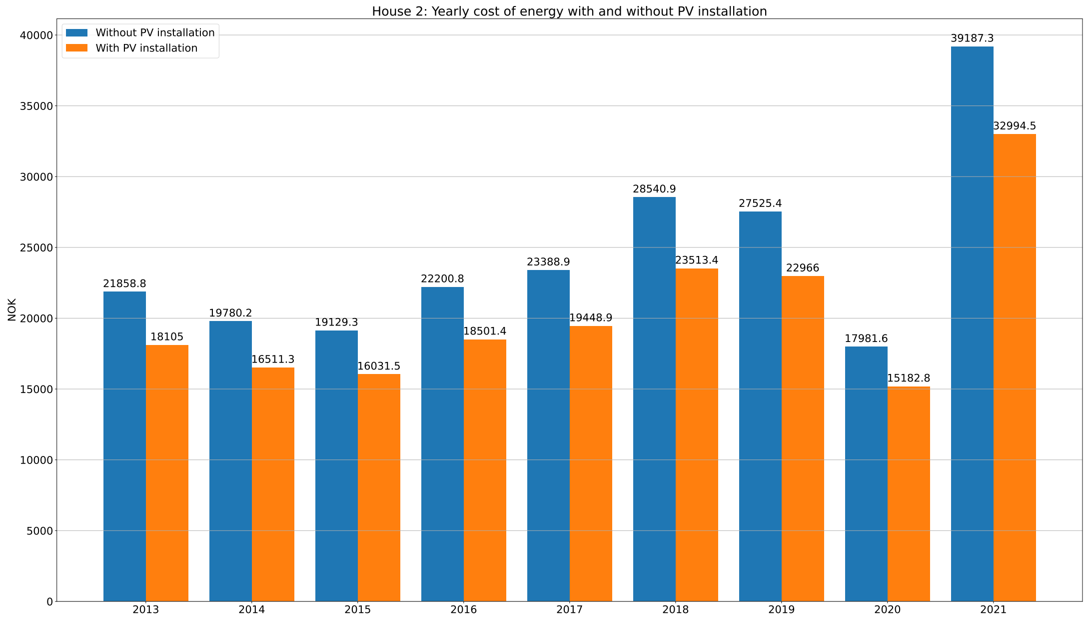



Figure A.45: Yearly cost of energy for House 2, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

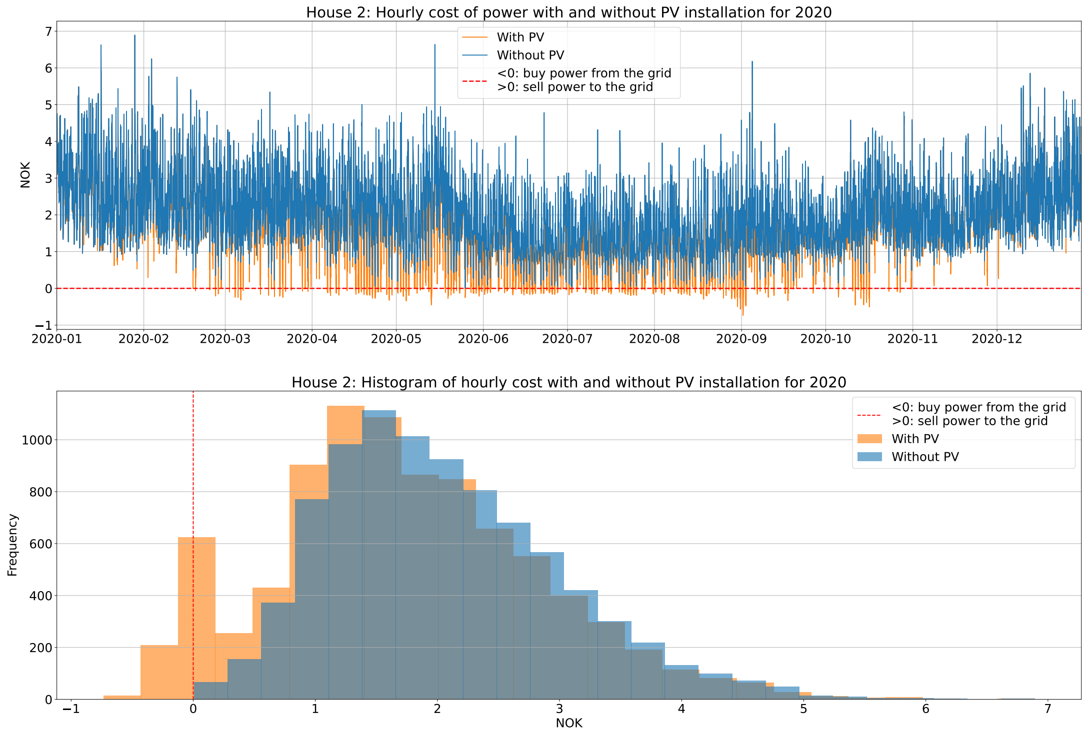



Figure A.46: Hourly cost of energy for House 2 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

**2021**

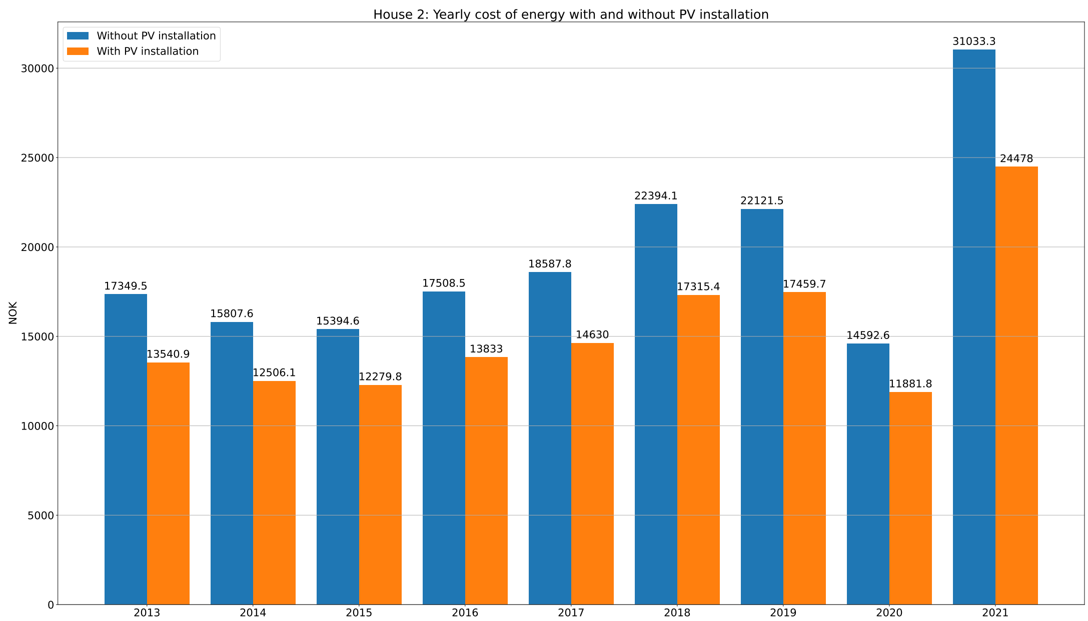



Figure A.47: Yearly cost of energy for House 2, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

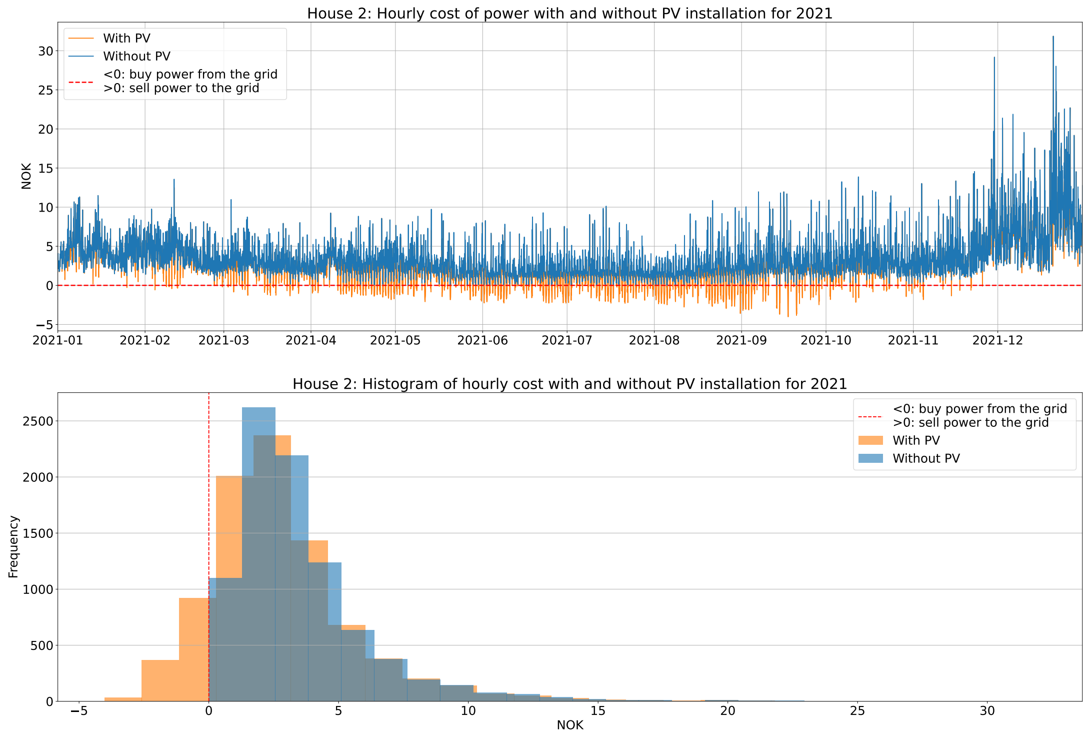
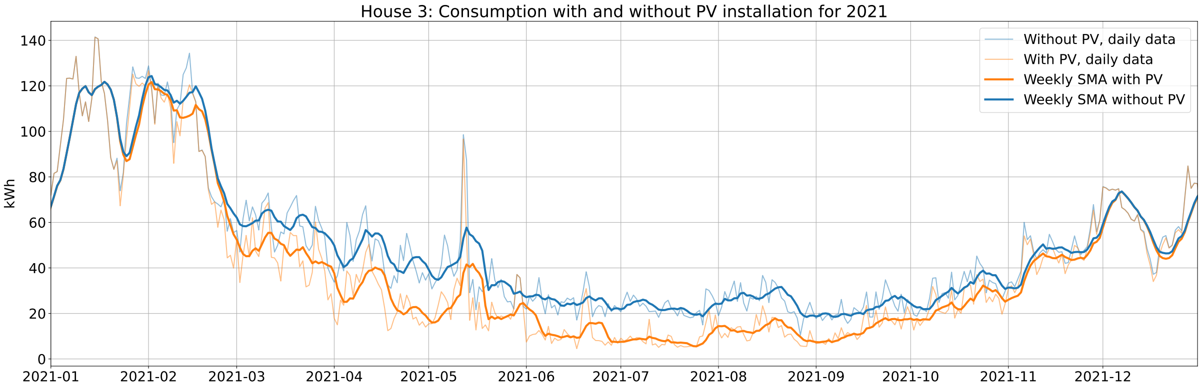



Figure A.48: Hourly cost of energy for House 2 with and without a PV system present for 2021. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

## A.3 House 3

### A.3.1 House consumption

#### 2021



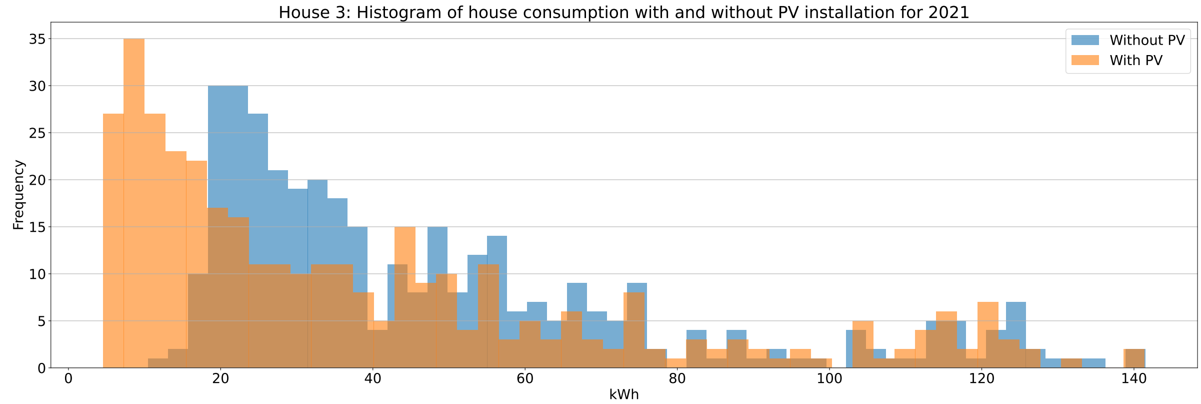




Figure A.49: Daily house consumption with and without a PV system for 2021 from House 3. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

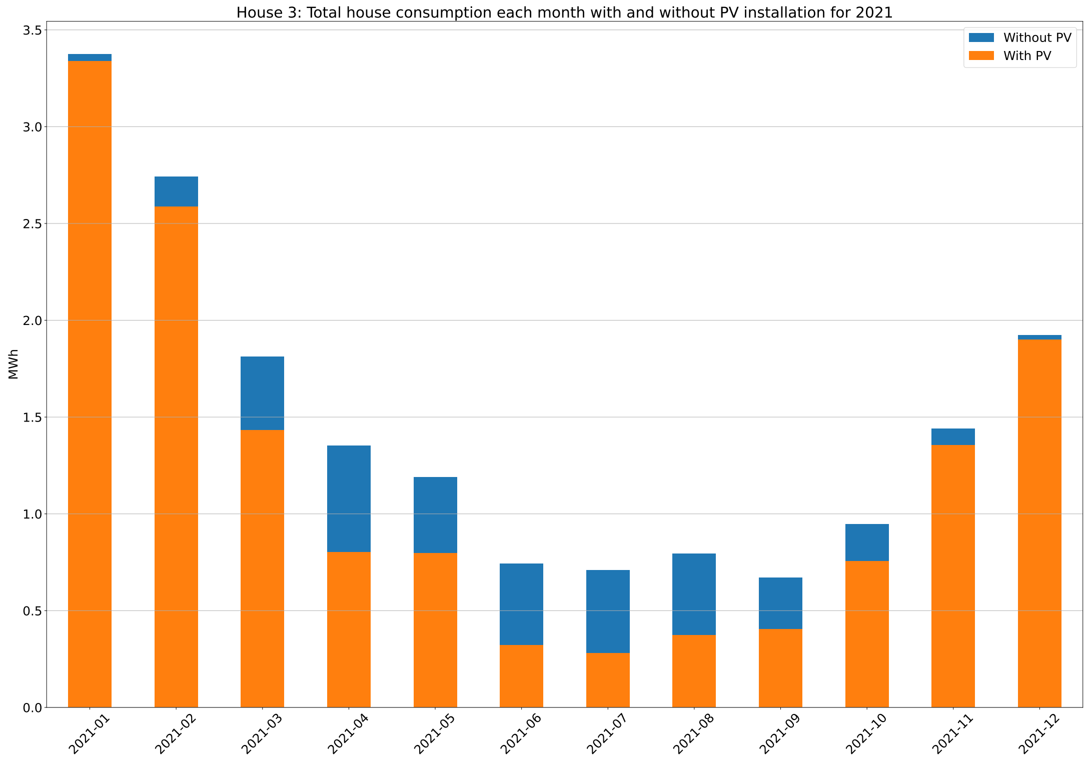



Figure A.50: Monthly house consumption for House 3 with and without a PV system for 2021.

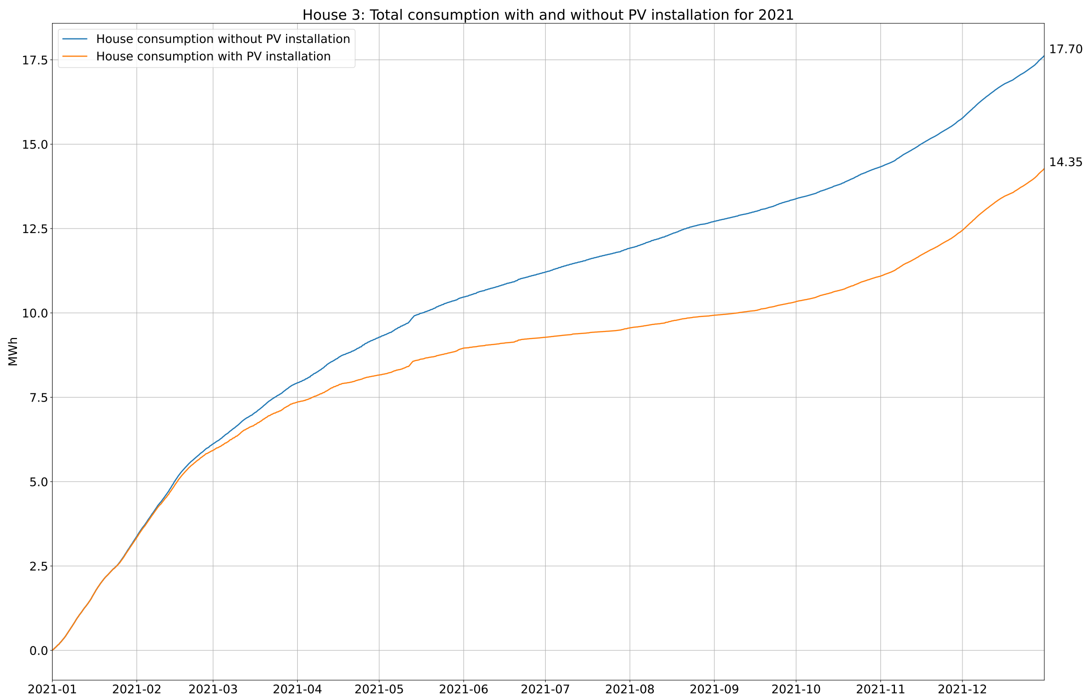



Figure A.51: Total house consumption for House 3 with and without a PV system accumulated over 2021

## A.3.2 Solar PV production

### 2021

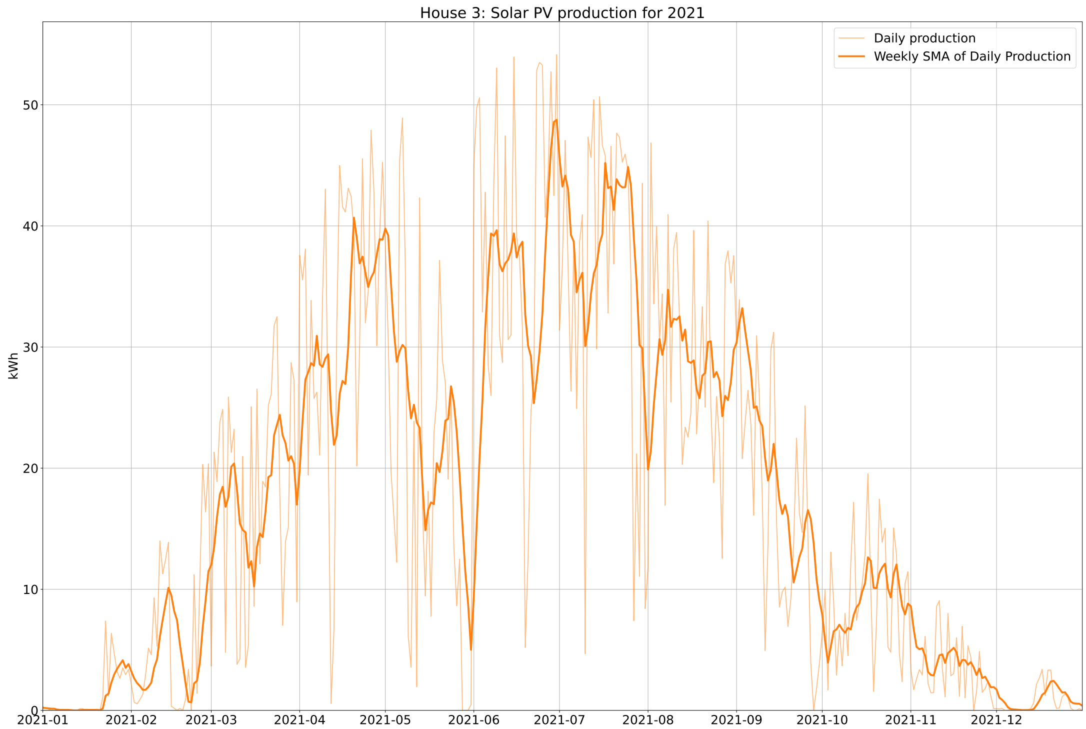



Figure A.52: Daily PV production and weekly SMA for House 3 in 2021.

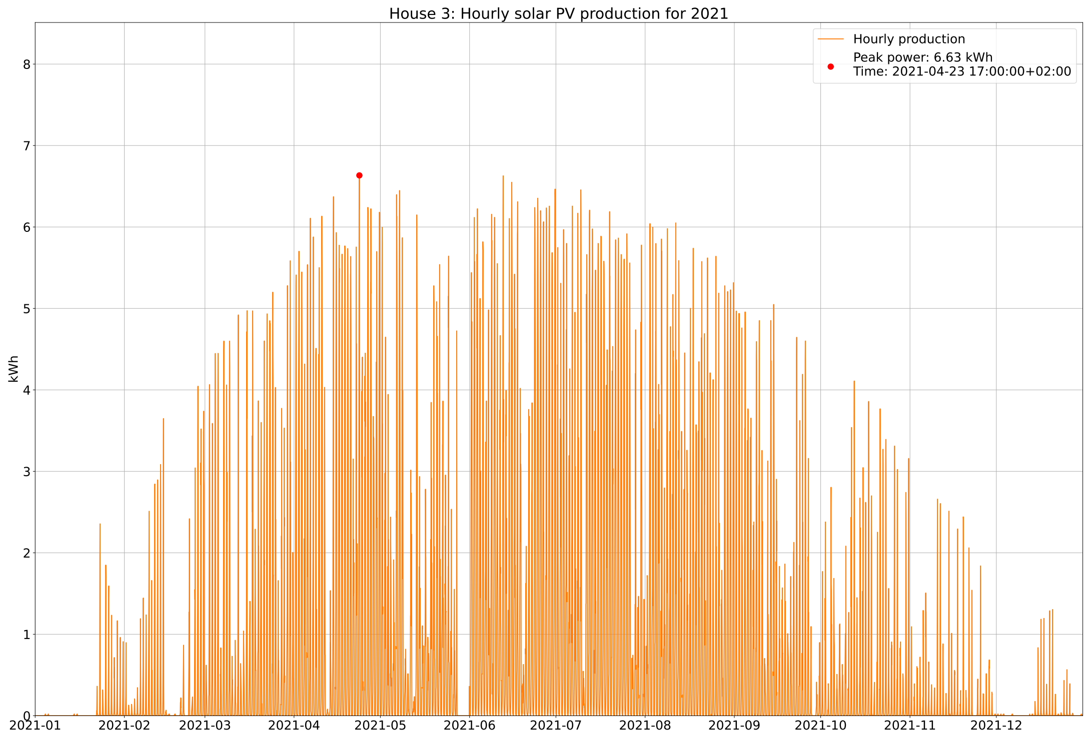



Figure A.53: Hourly PV production for House 3 in 2021.

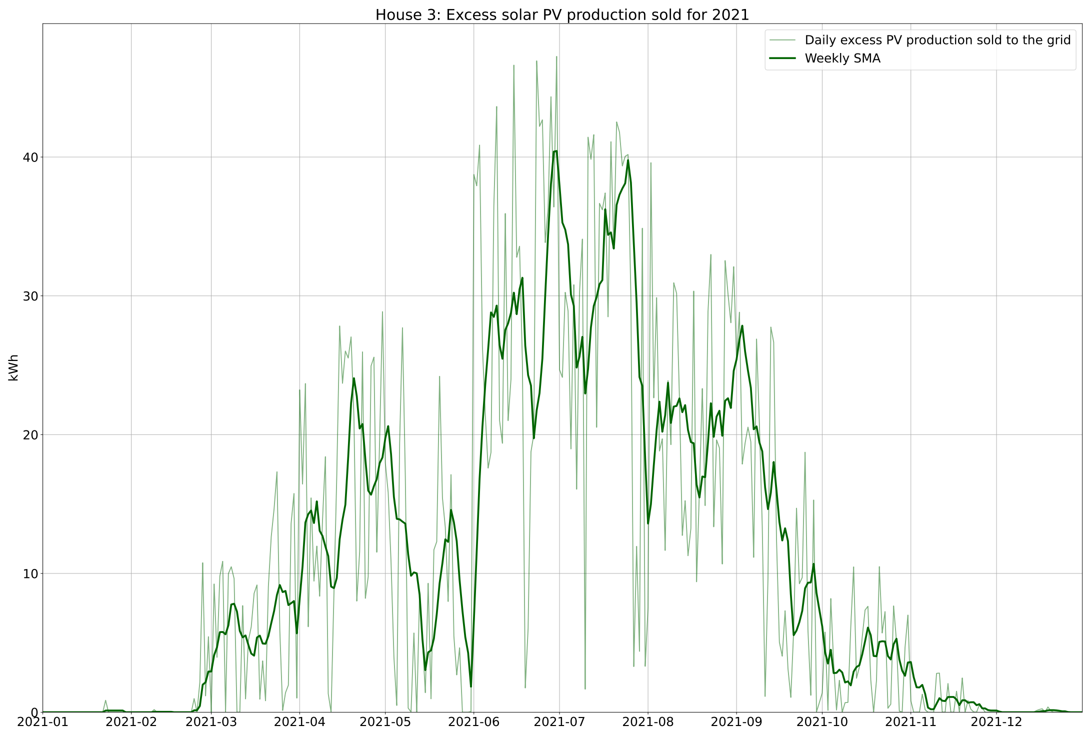



Figure A.54: Daily excess PV production sold to the grid and weekly SMA for House 3 in 2021

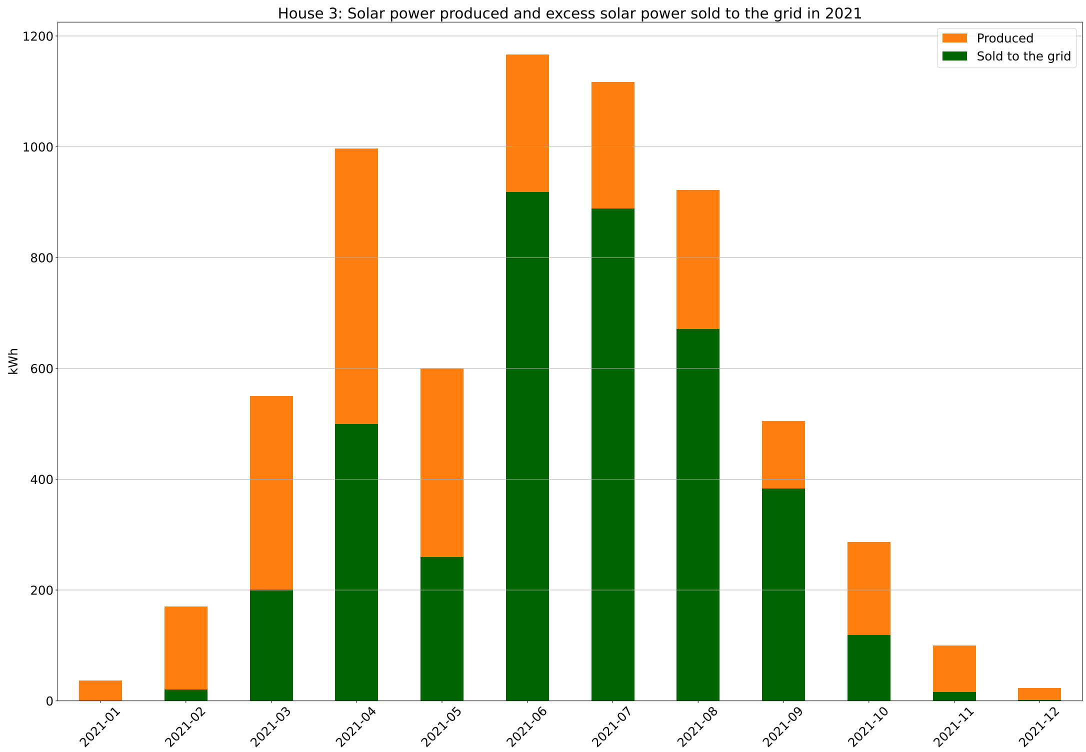



Figure A.55: Total solar PV production and excess production sold to the grid for each month in 2021 from House 3.

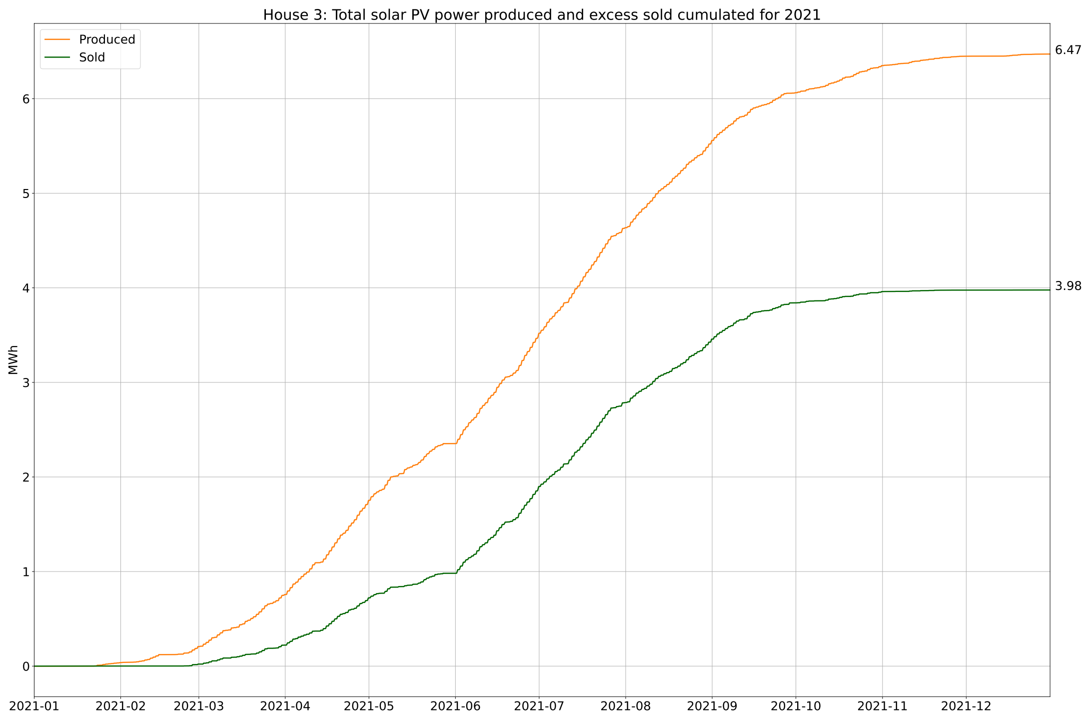



Figure A.56: Total solar PV production and excess production sold cumulated over 2021 from House 3

### A.3.3 Delta variable

#### 2021

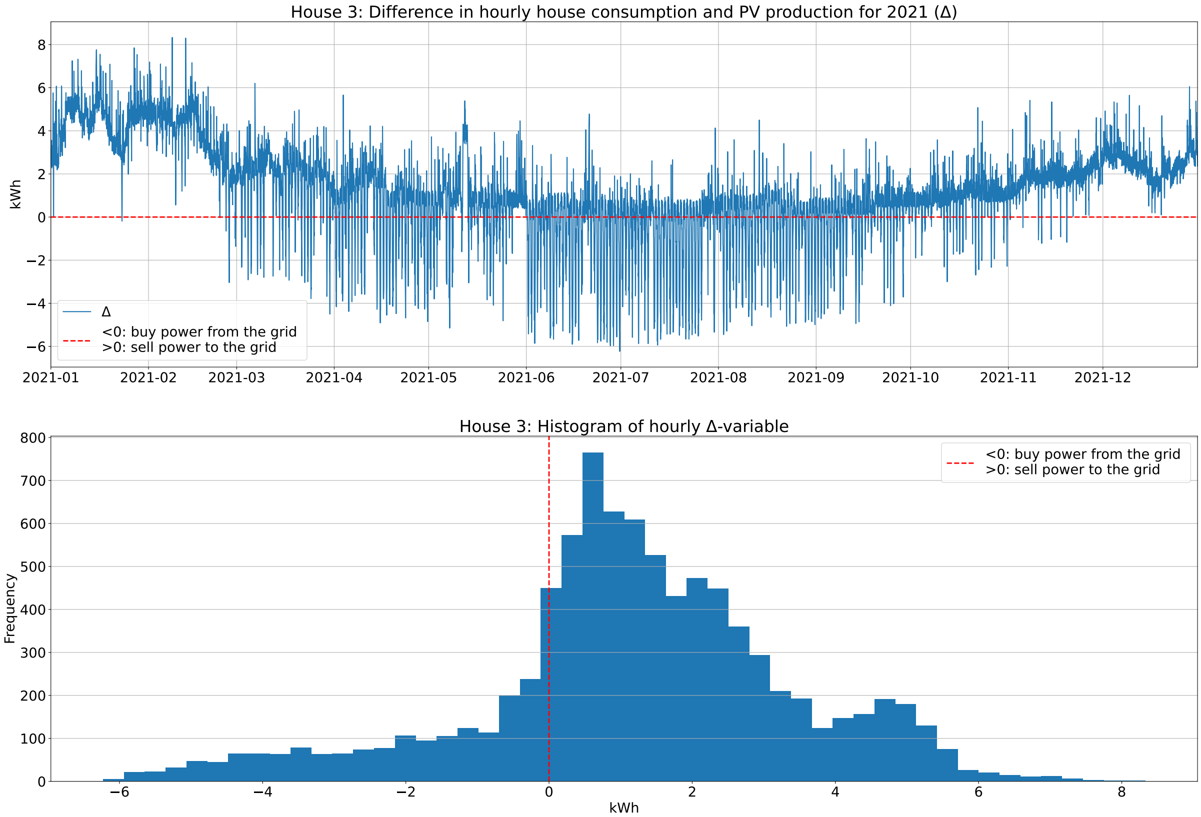



Figure A.57: The delta variable plotted for House 3. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the ”$<$” sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

### A.3.4 House consumption and PV production

#### 2021

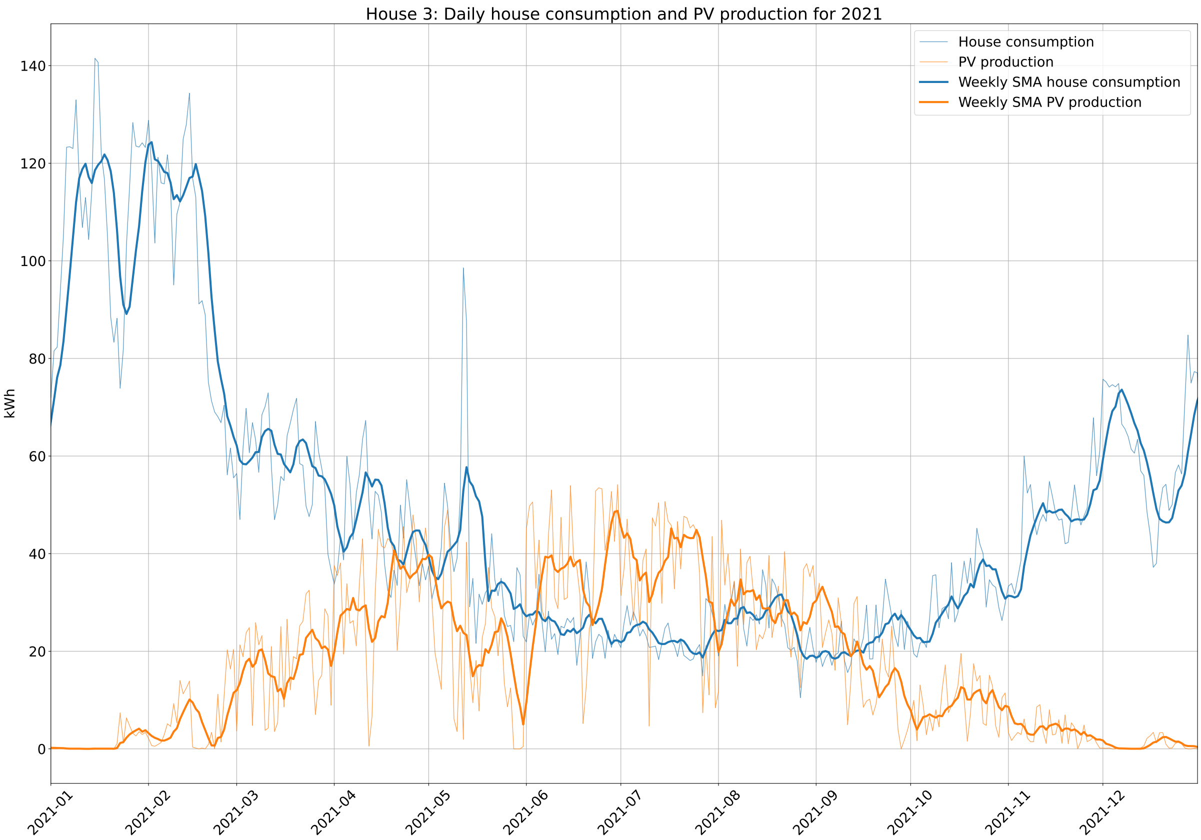



Figure A.58: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.3.5 Cost of energy

#### 2021

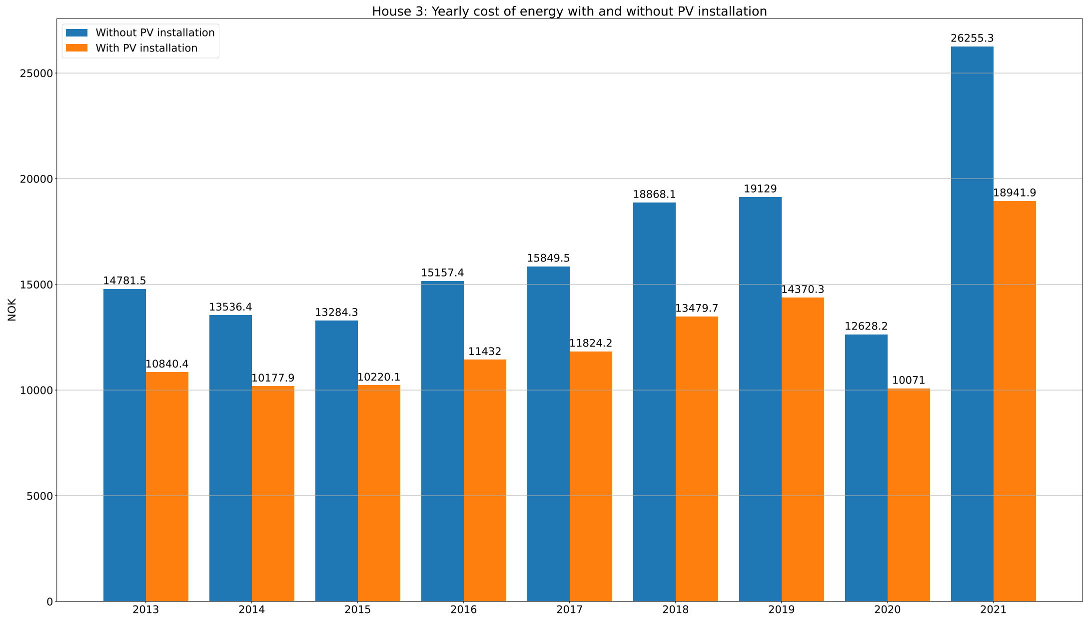



Figure A.59: Yearly cost of energy for House 3, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

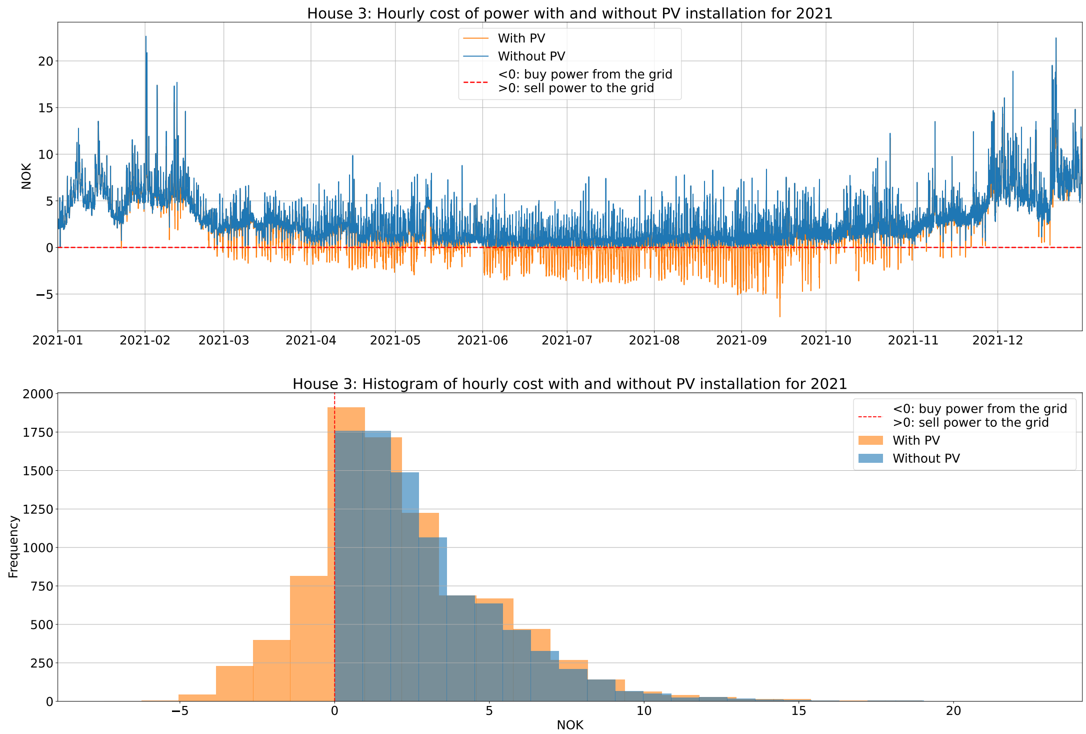
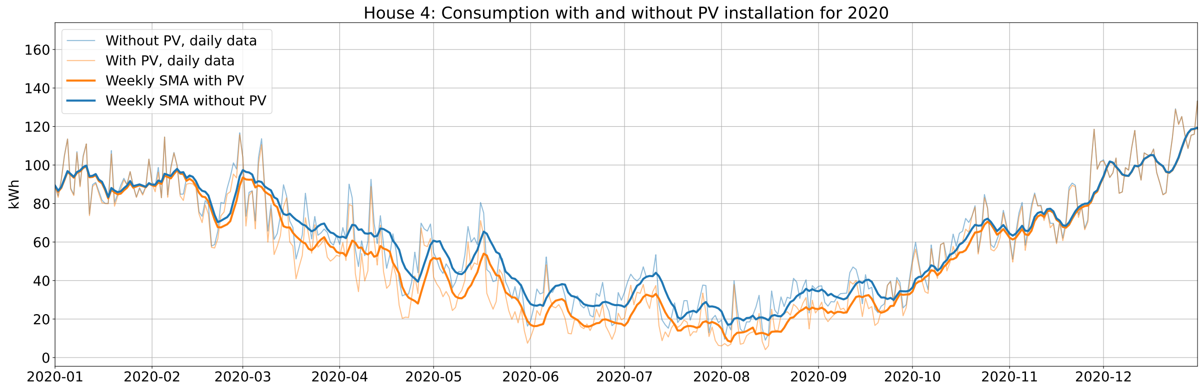



Figure A.60: Hourly cost of energy for House 3 with and without a PV system present for 2021. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$

## A.4 House 4

### A.4.1 House consumption

**2020**



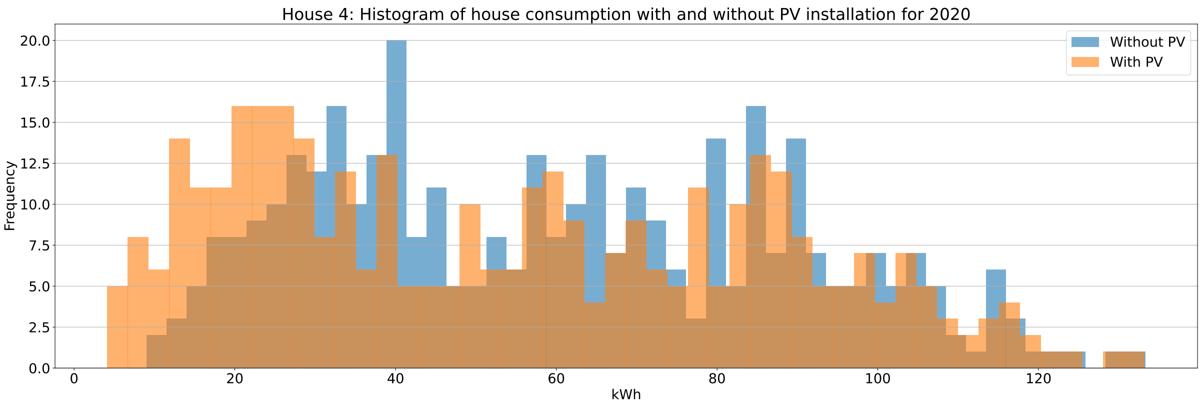




Figure A.61: Daily house consumption with and without a PV system for 2020 from House 4. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

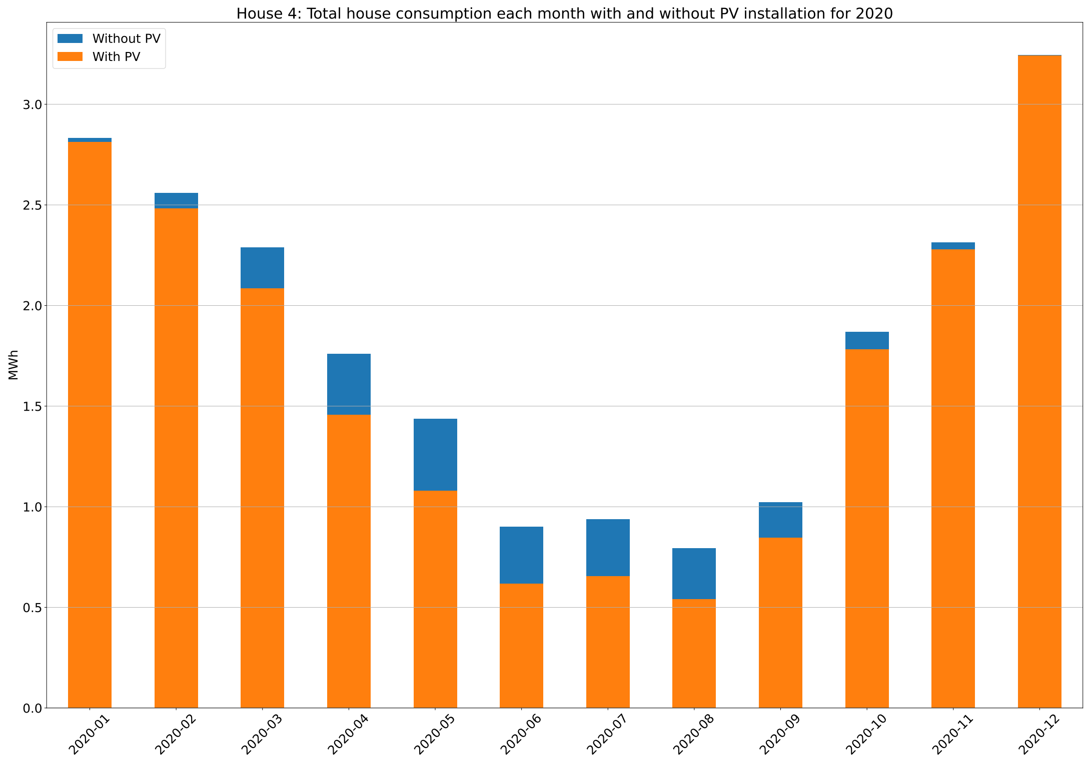



Figure A.62: Monthly house consumption for House 4 with and without a PV system for 2020.

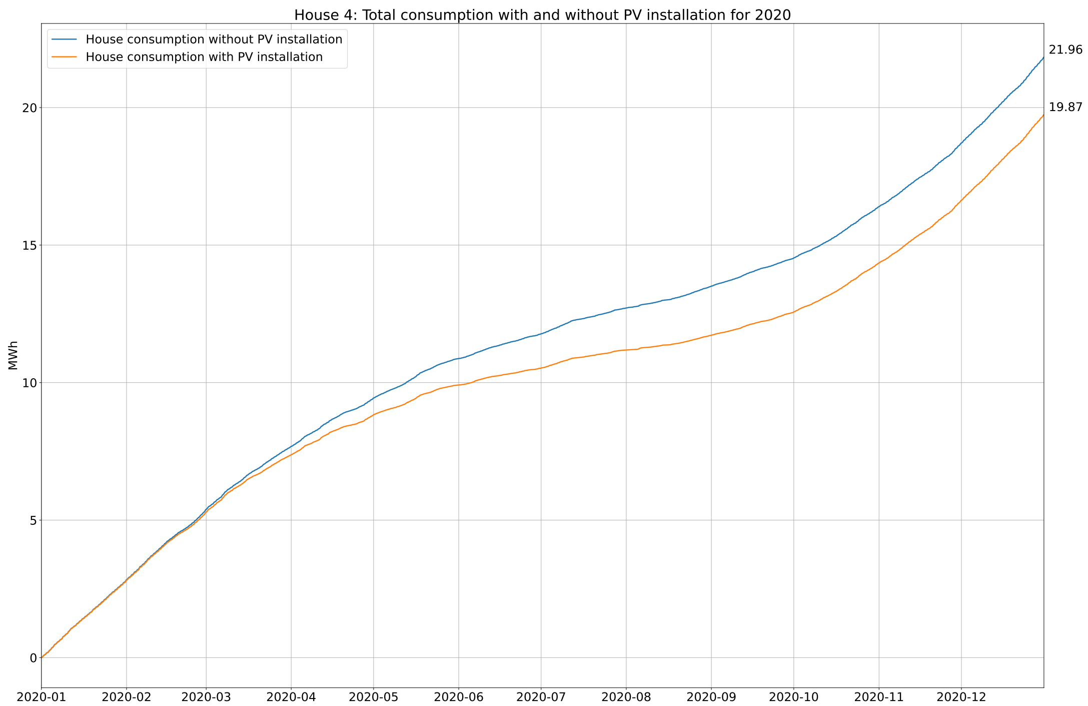



Figure A.63: Total house consumption for House 4 with and without a PV system accumulated over 2020

**2021**

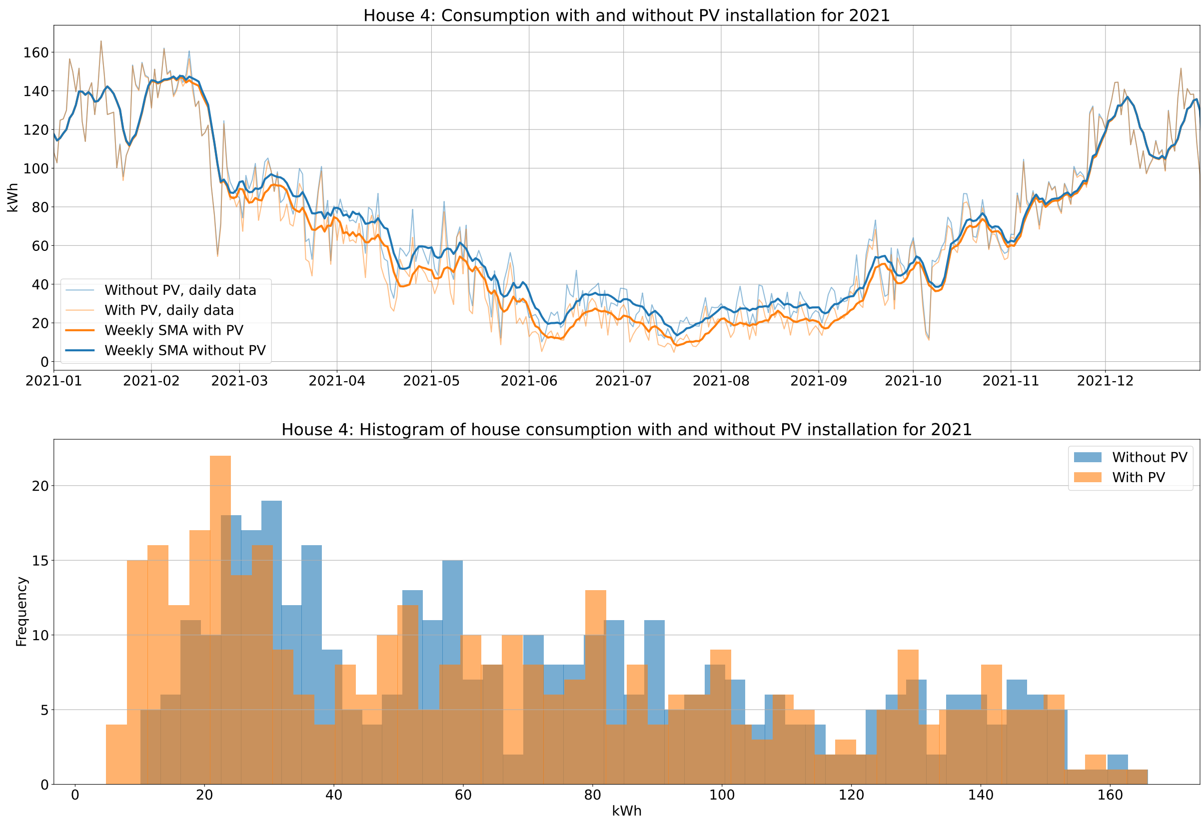



Figure A.64: Daily house consumption with and without a PV system for 2021 from House 1. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

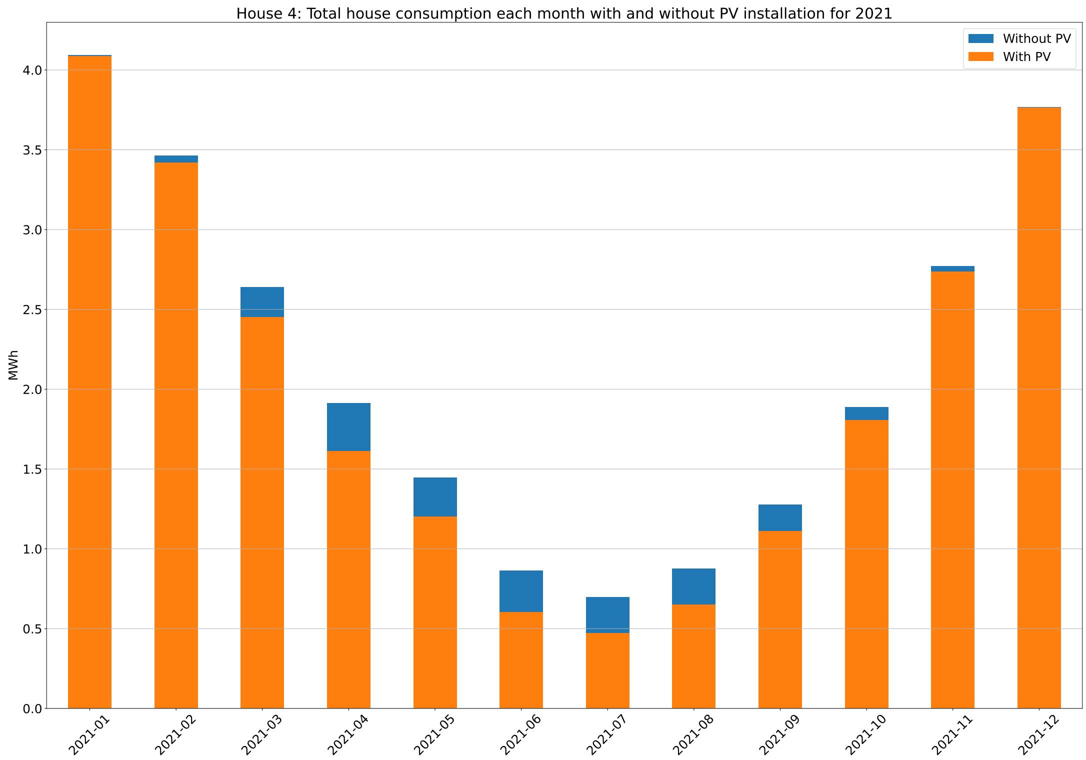



Figure A.65: Monthly house consumption for House 4 with and without a PV system for 2021.

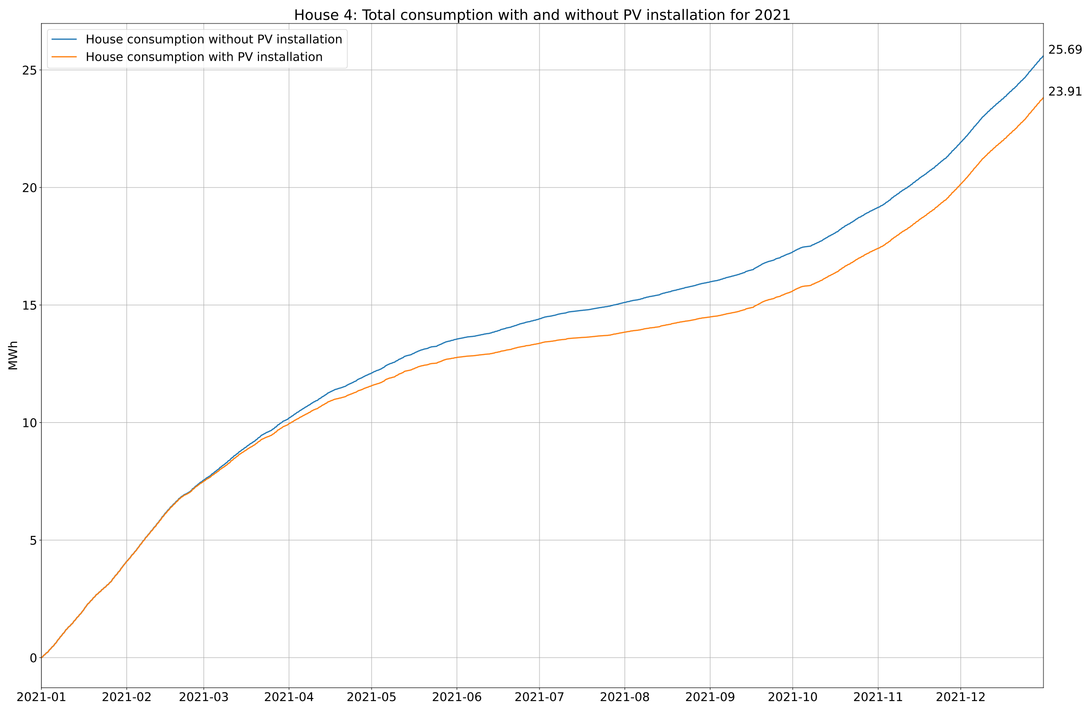



Figure A.66: Total house consumption for House 4 with and without a PV system accumulated over 2021

### A.4.2 Solar PV production

#### 2020

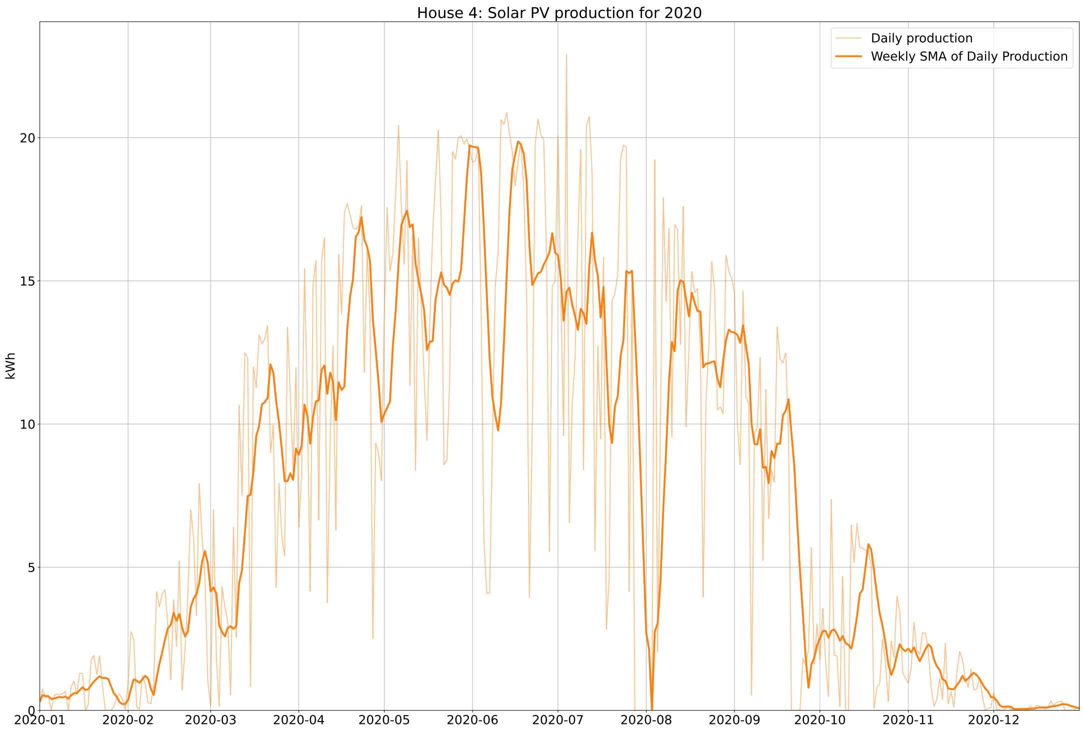



Figure A.67: Daily PV production and weekly SMA for House 4 in 2020.

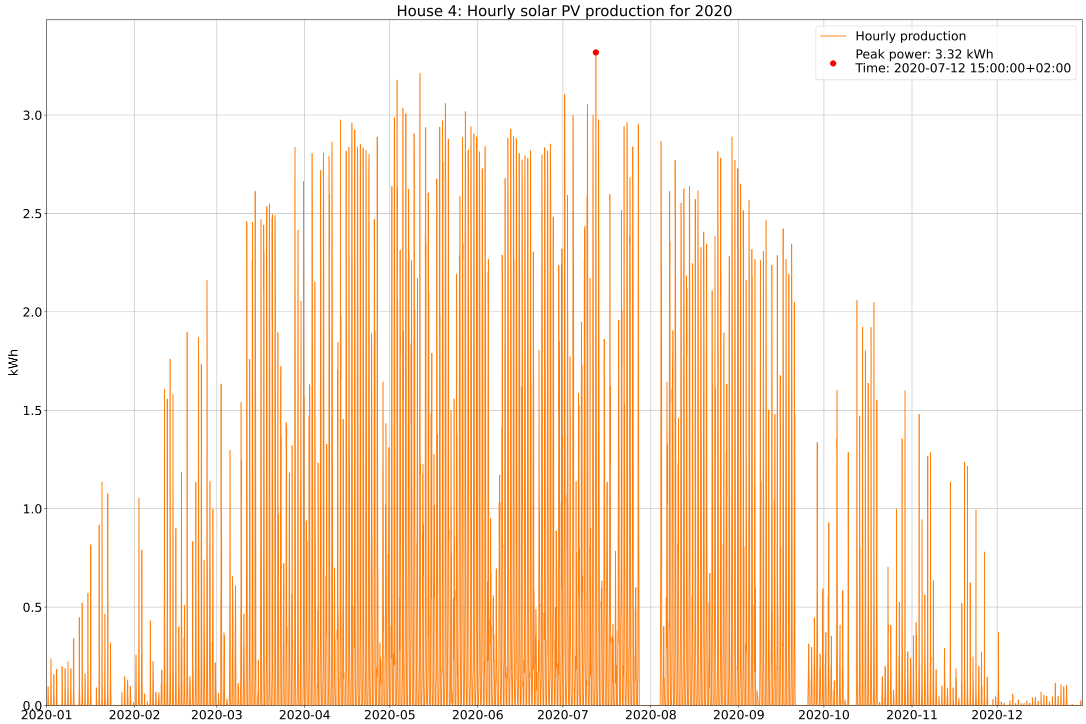



Figure A.68: Hourly PV production for House 4 in 2020.

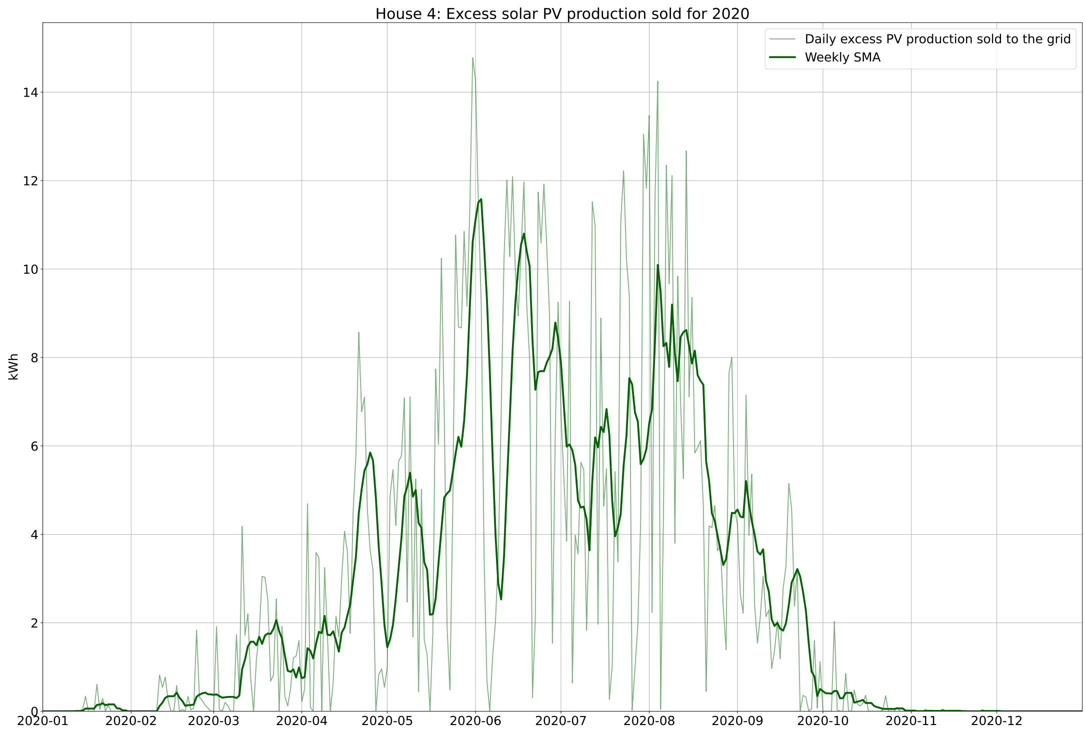



Figure A.69: Daily excess PV production sold to the grid and weekly SMA for House 4 in 2020

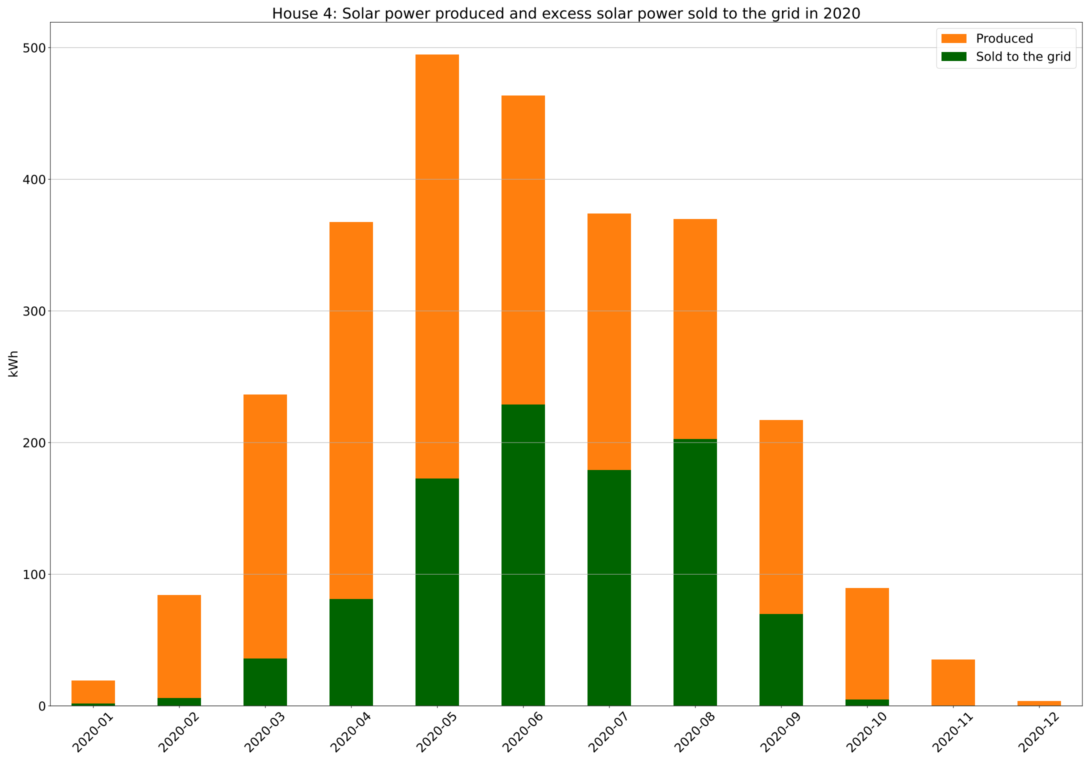



Figure A.70: Total solar PV production and excess production sold to the grid for each month in 2020 from House 4.

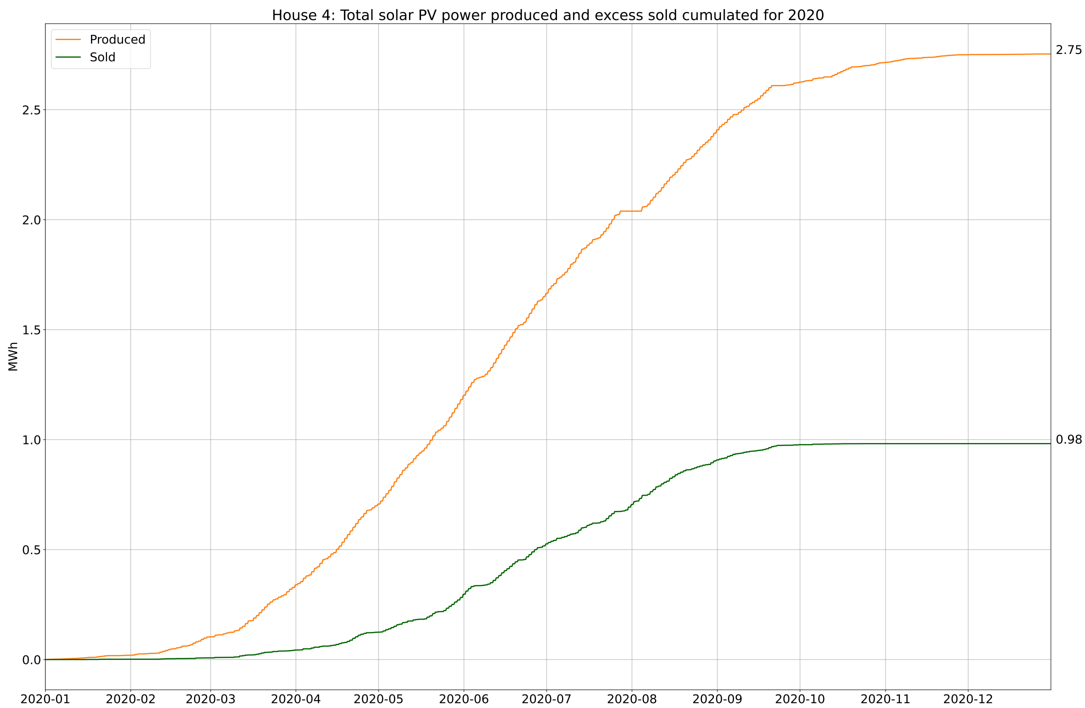



Figure A.71: Total solar PV production and excess production sold cumulated over 2020 from House 4

**2021**

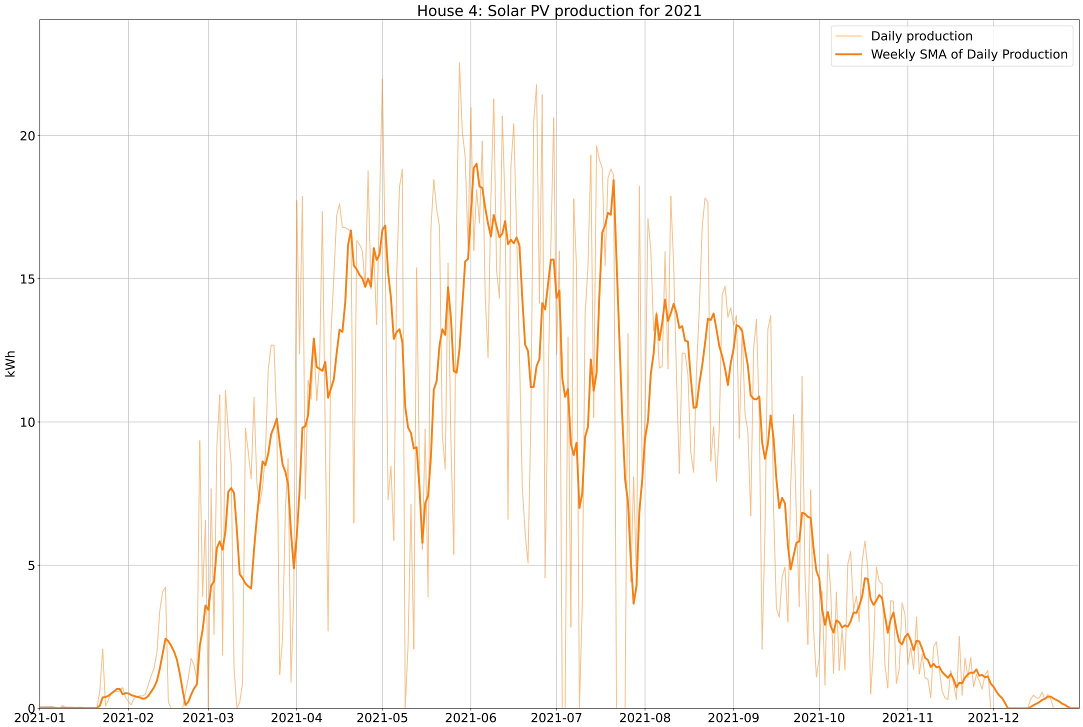



Figure A.72: Daily PV production and weekly SMA for House 4 in 2021.

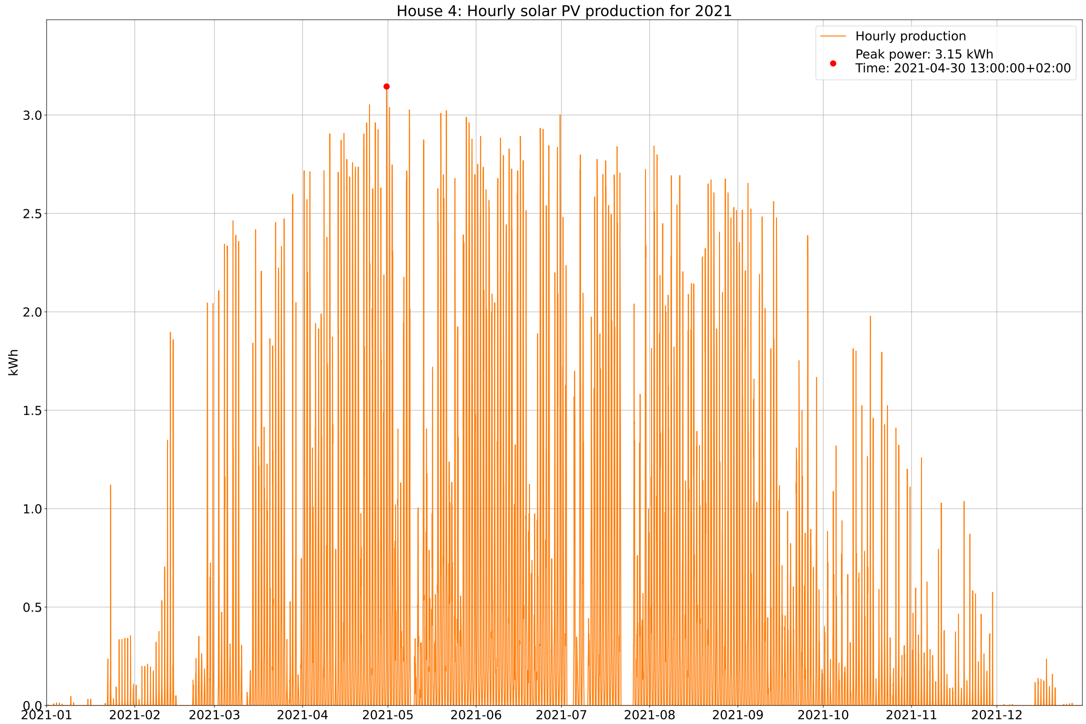



Figure A.73: Hourly PV production for House 4 in 2021.

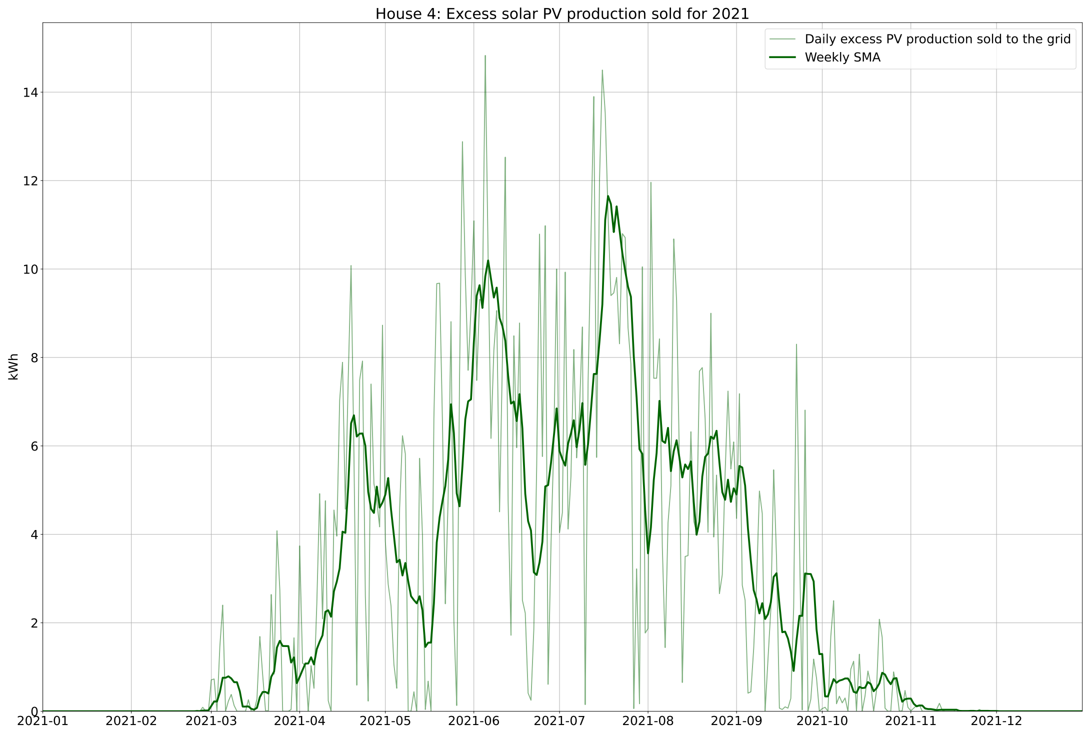



Figure A.74: Daily excess PV production sold to the grid and weekly SMA for House 4 in 2021

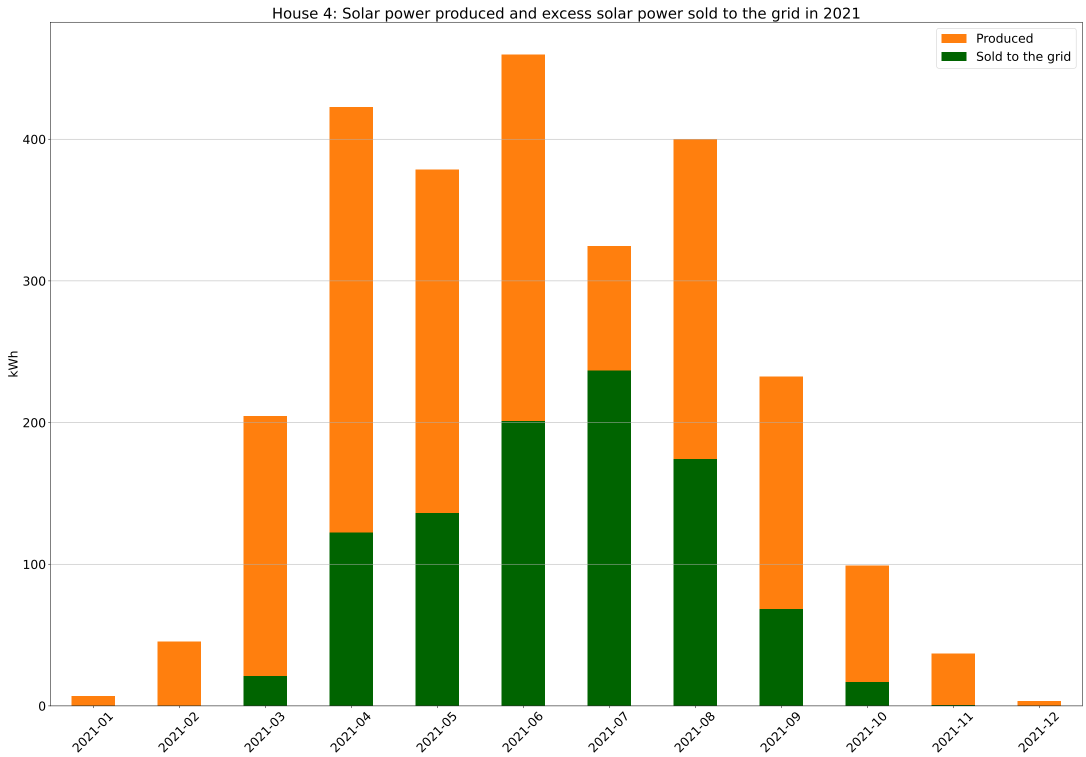



Figure A.75: Total solar PV production and excess production sold to the grid for each month in 2021 from House 4.

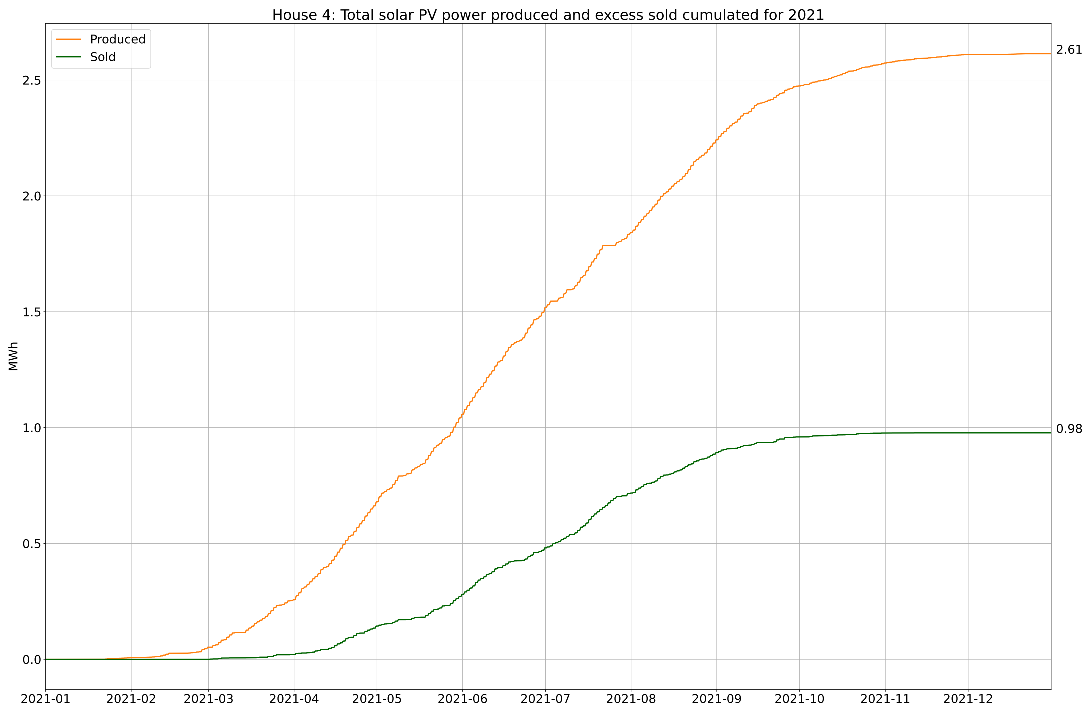



Figure A.76: Total solar PV production and excess production sold cumulated over 2021 from House 4

### A.4.3 Delta variable

#### 2020

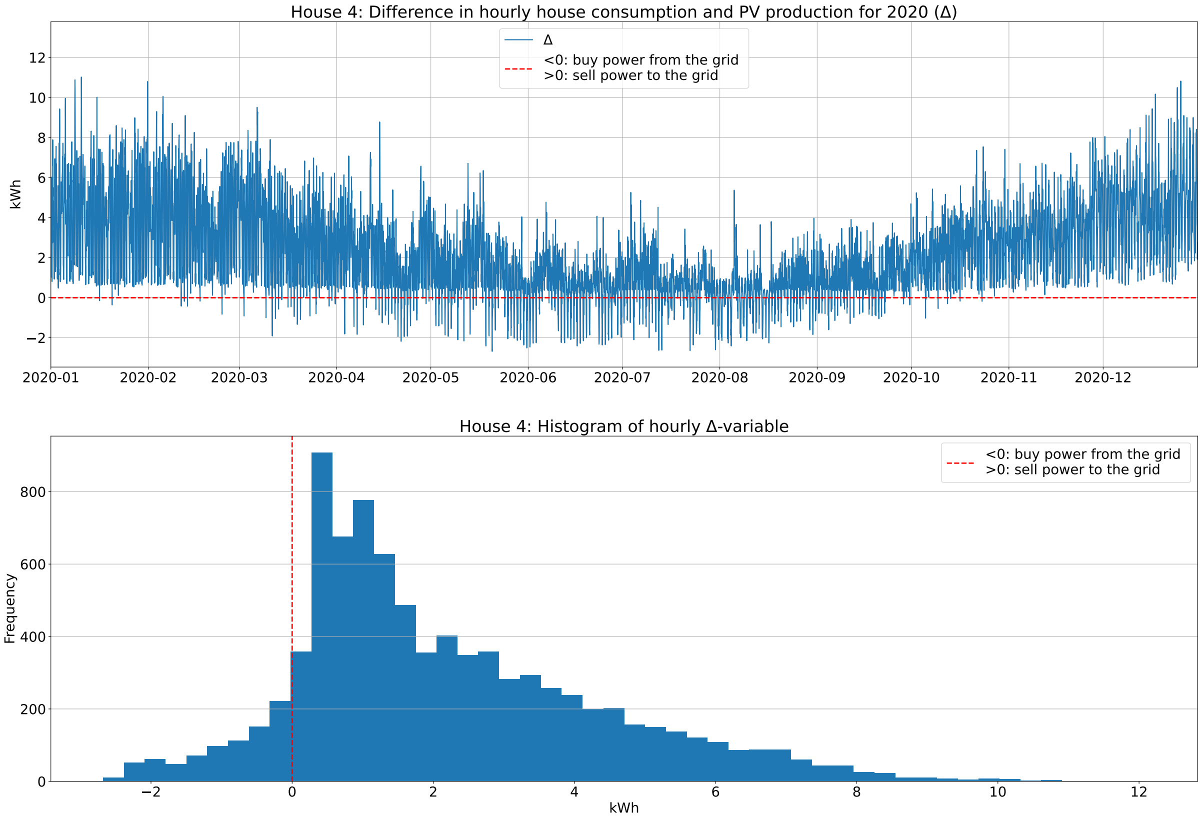



Figure A.77: The delta variable plotted for House 4. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### 2021

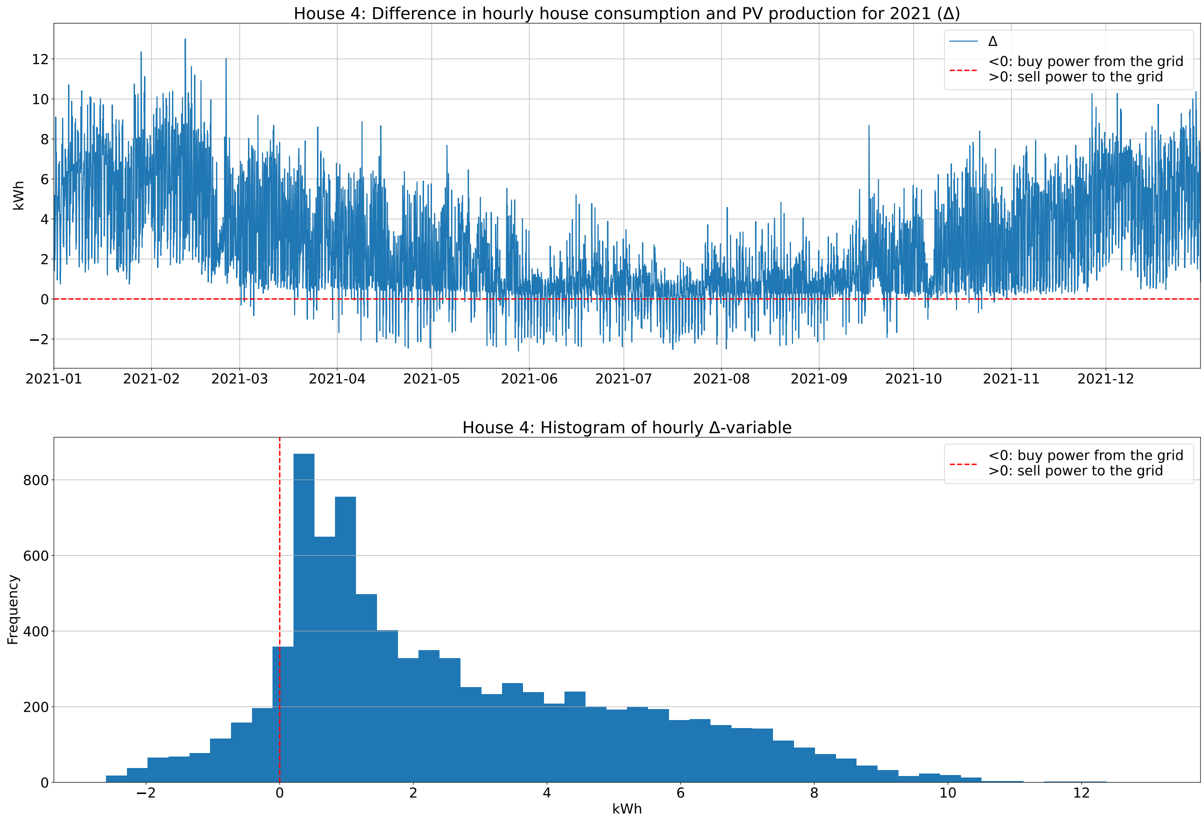



Figure A.78: The delta variable plotted for House 4. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the ”$<$” sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.4.4 House consumption and PV production

**2020**

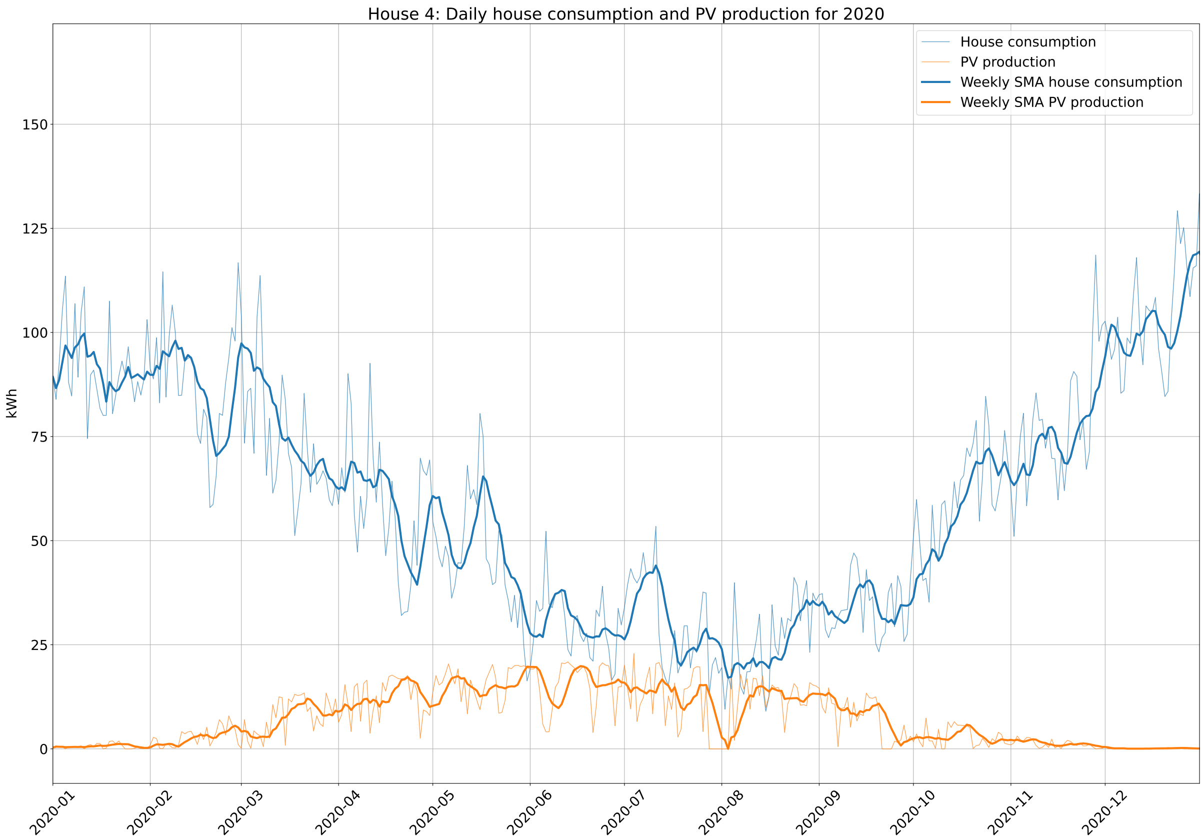



Figure A.79: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

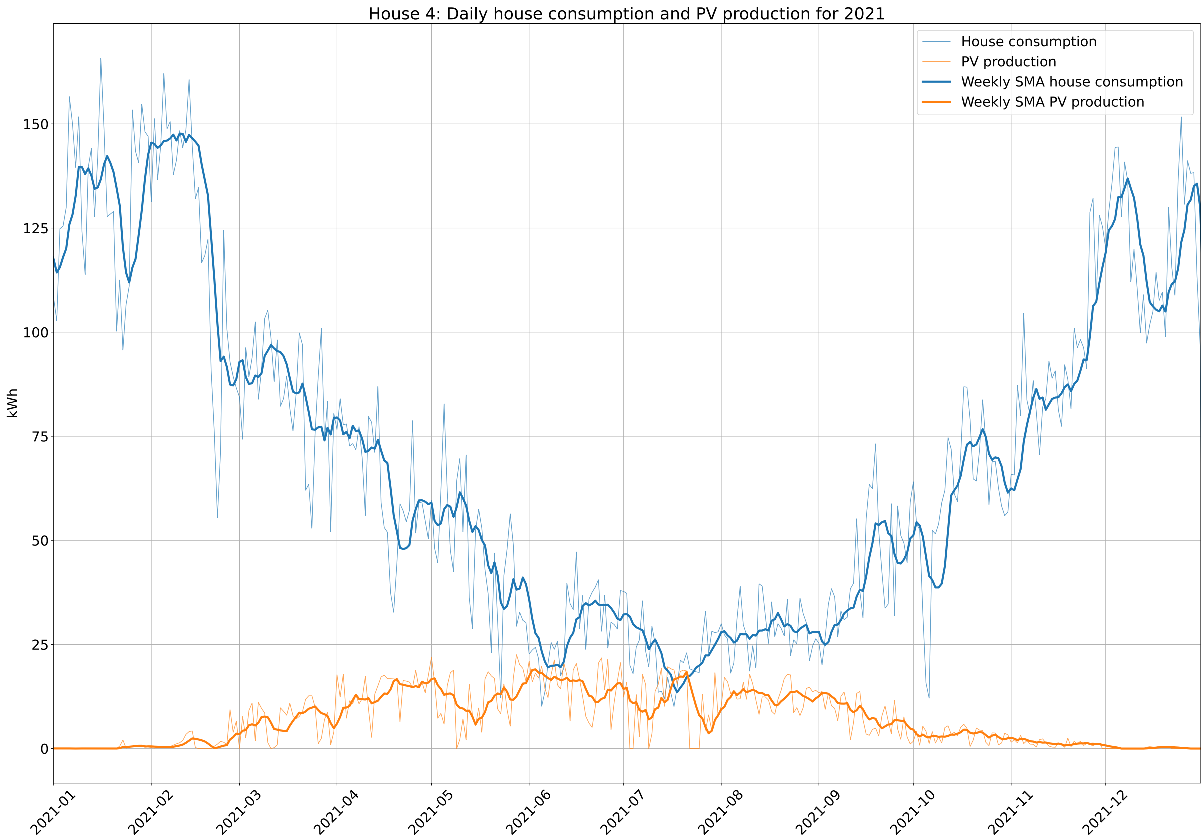



Figure A.80: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.4.5 Cost of energy

#### 2020

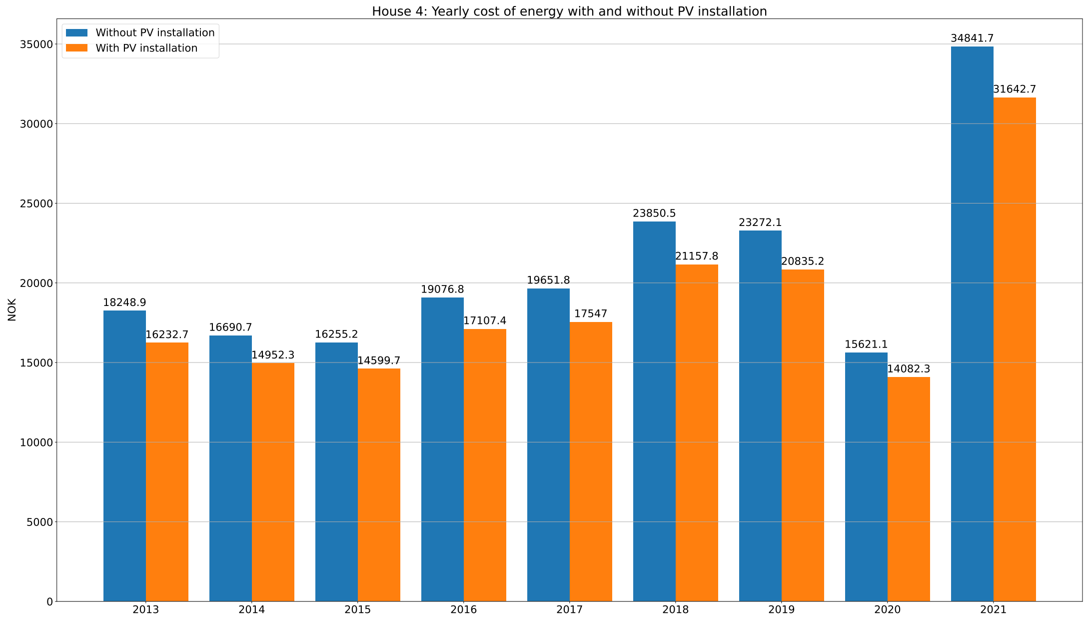



Figure A.81: Yearly cost of energy for House 4, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

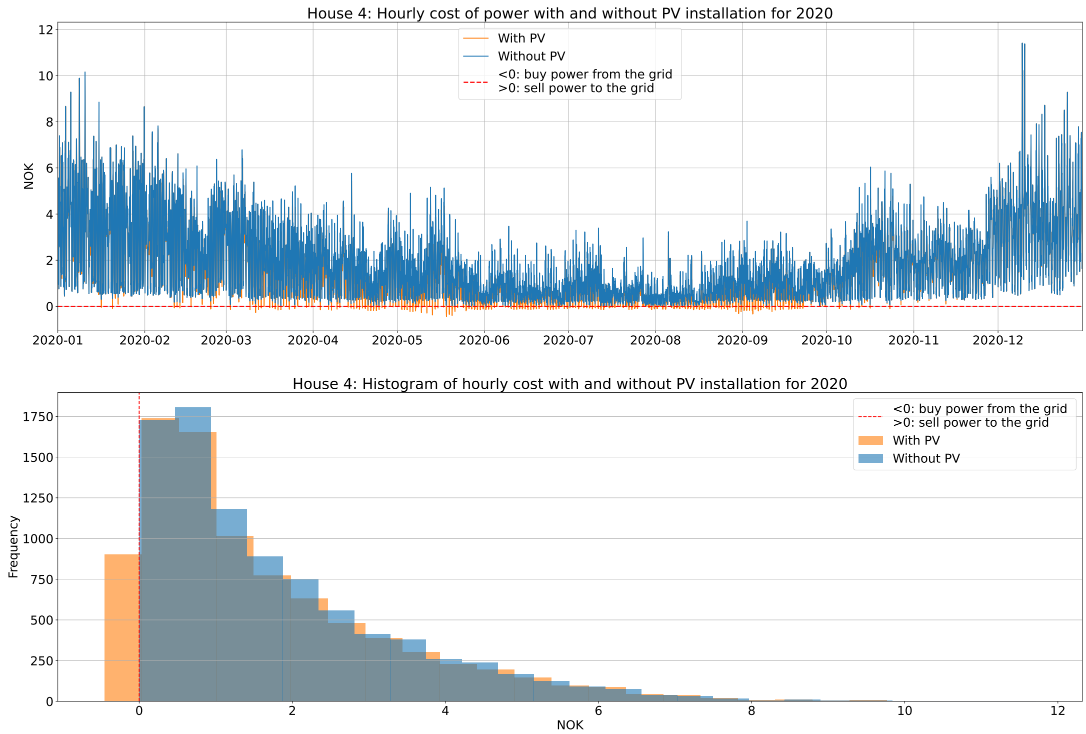



Figure A.82: Hourly cost of energy for House 4 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

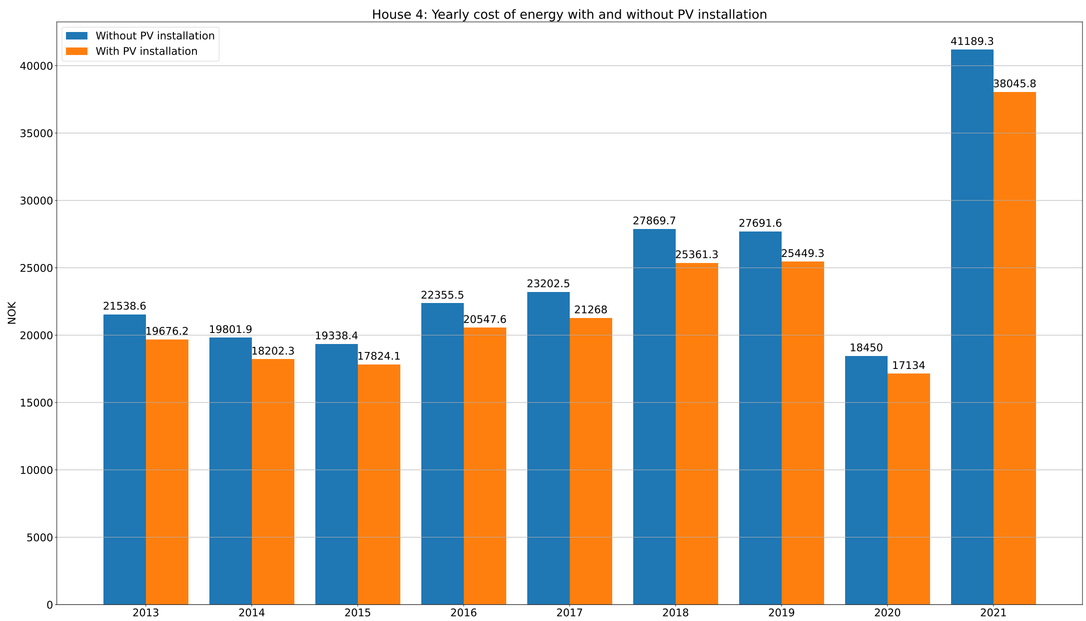



Figure A.83: Yearly cost of energy for House 4, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

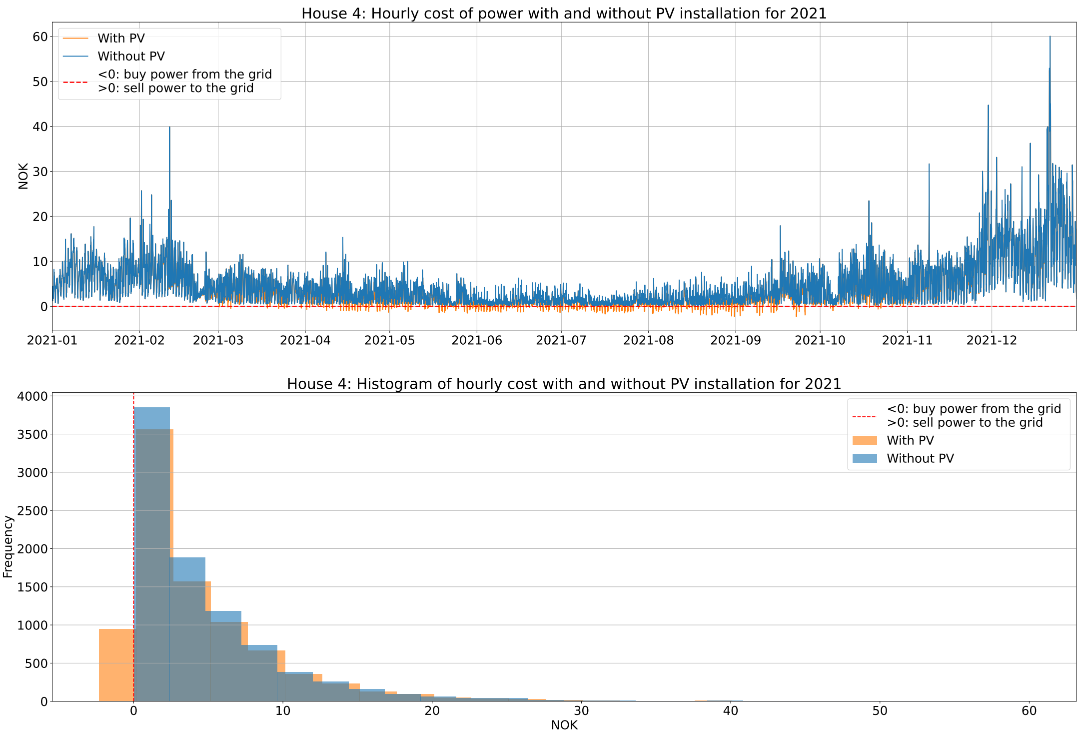
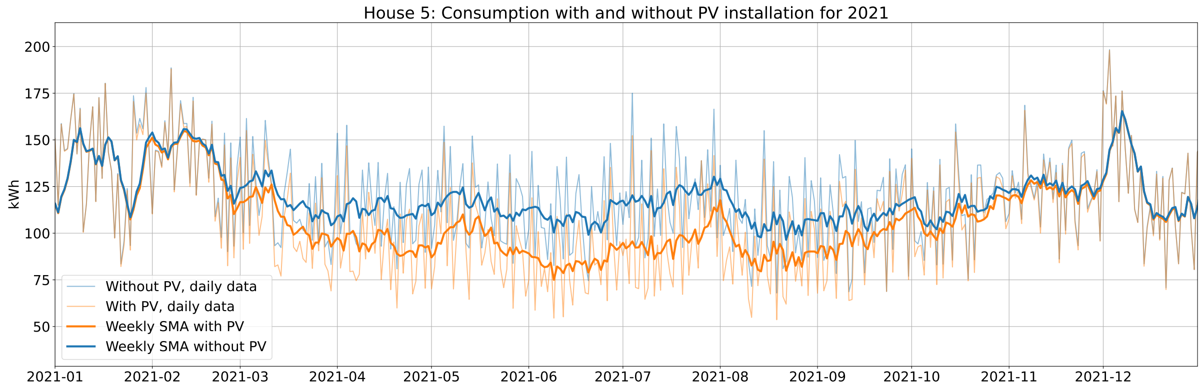



Figure A.84: Hourly cost of energy for House 4 with and without a PV system present for 2021. NB! Due to an small error the ”<” sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.5 House 5

### A.5.1 House consumption

#### 2021



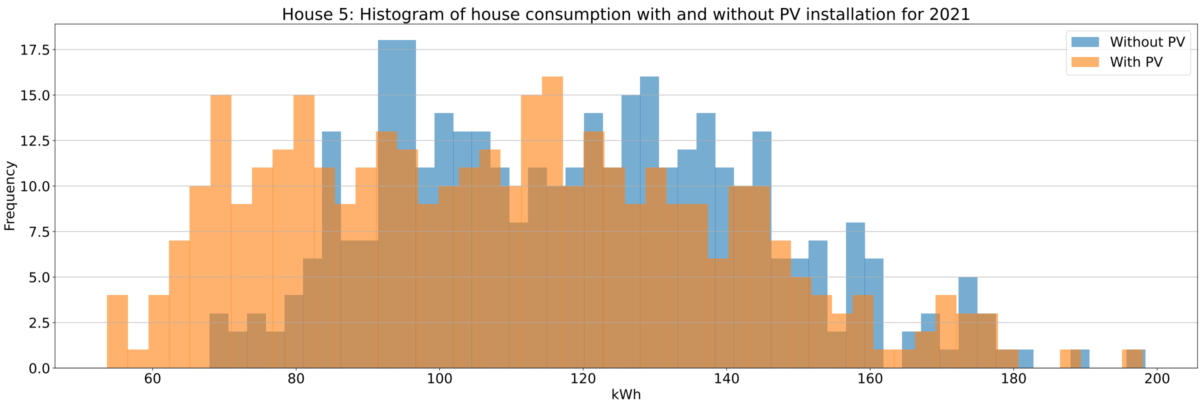




Figure A.85: Daily house consumption with and without a PV system for 2021 from House 5. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

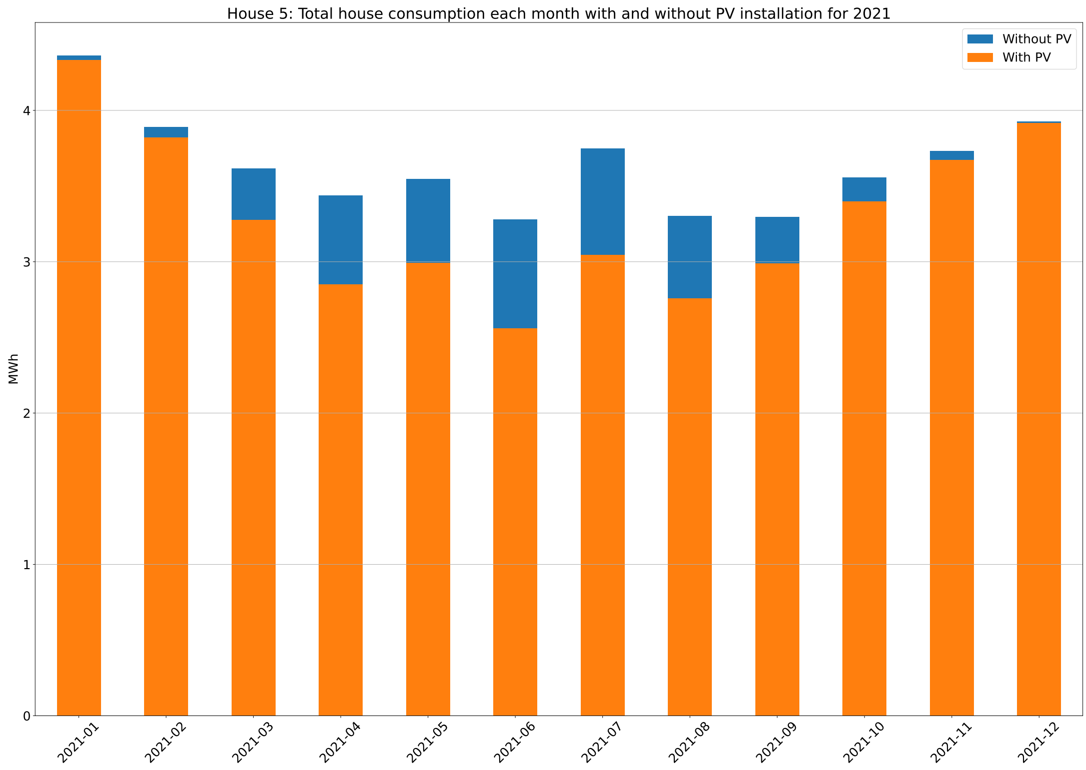



Figure A.86: Monthly house consumption for House 5 with and without a PV system for 2021.

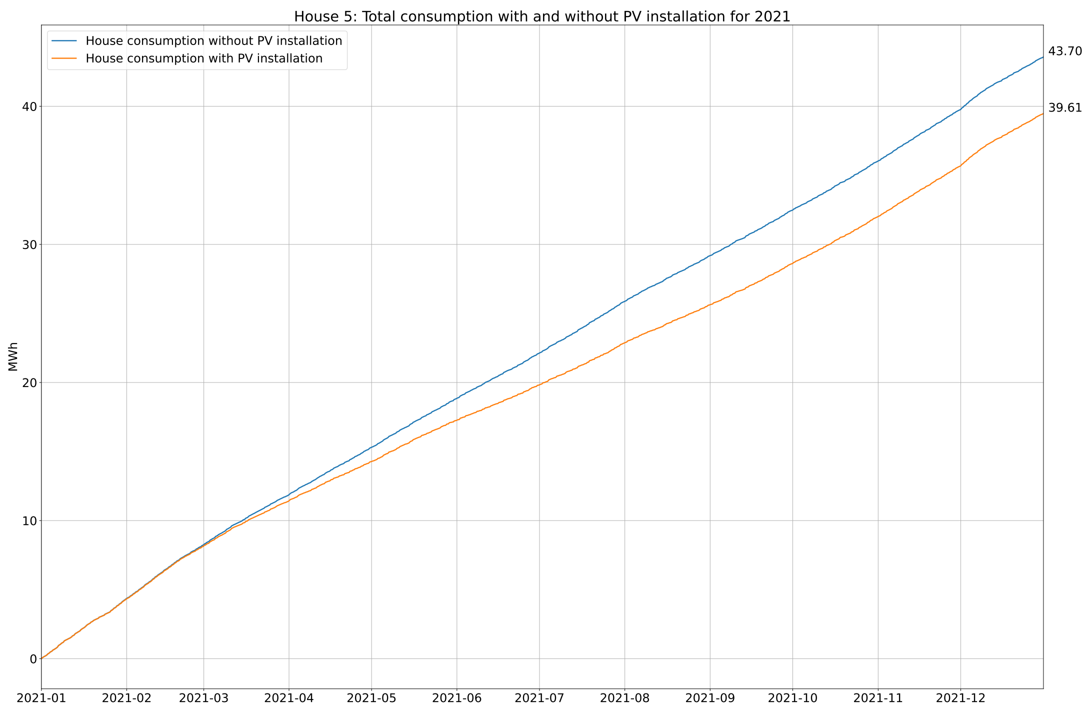



Figure A.87: Total house consumption for House 5 with and without a PV system accumulated over 2021

### A.5.2 Solar PV production

#### 2021

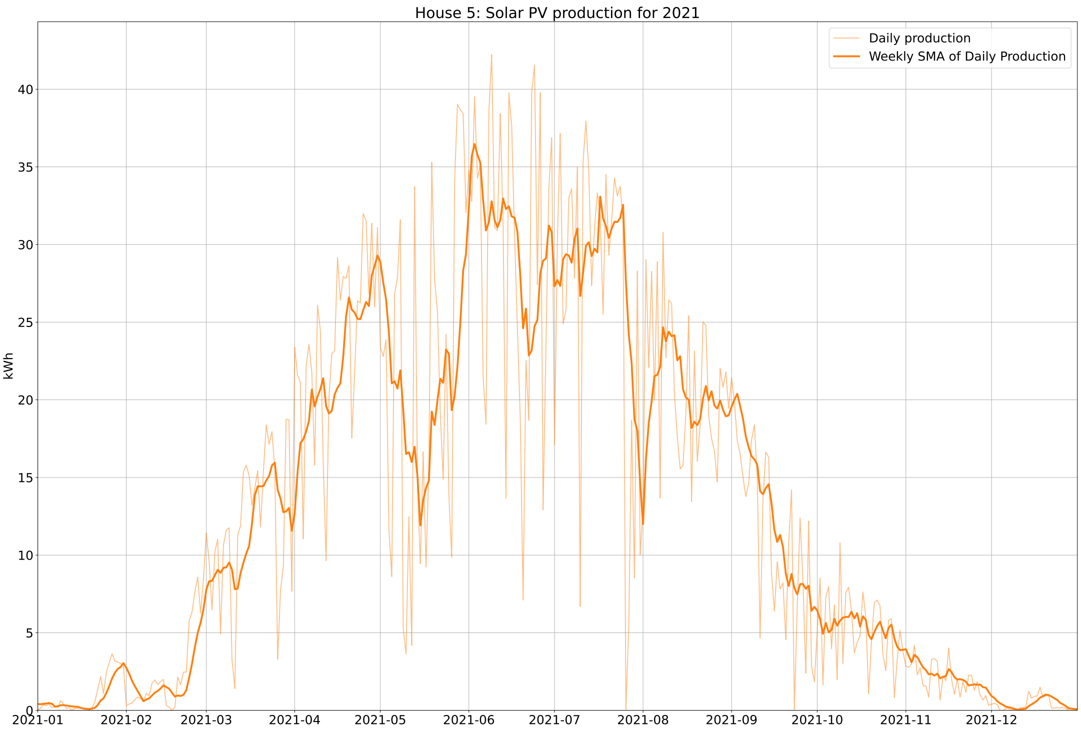



Figure A.88: Daily PV production and weekly SMA for House 5 in 2021.

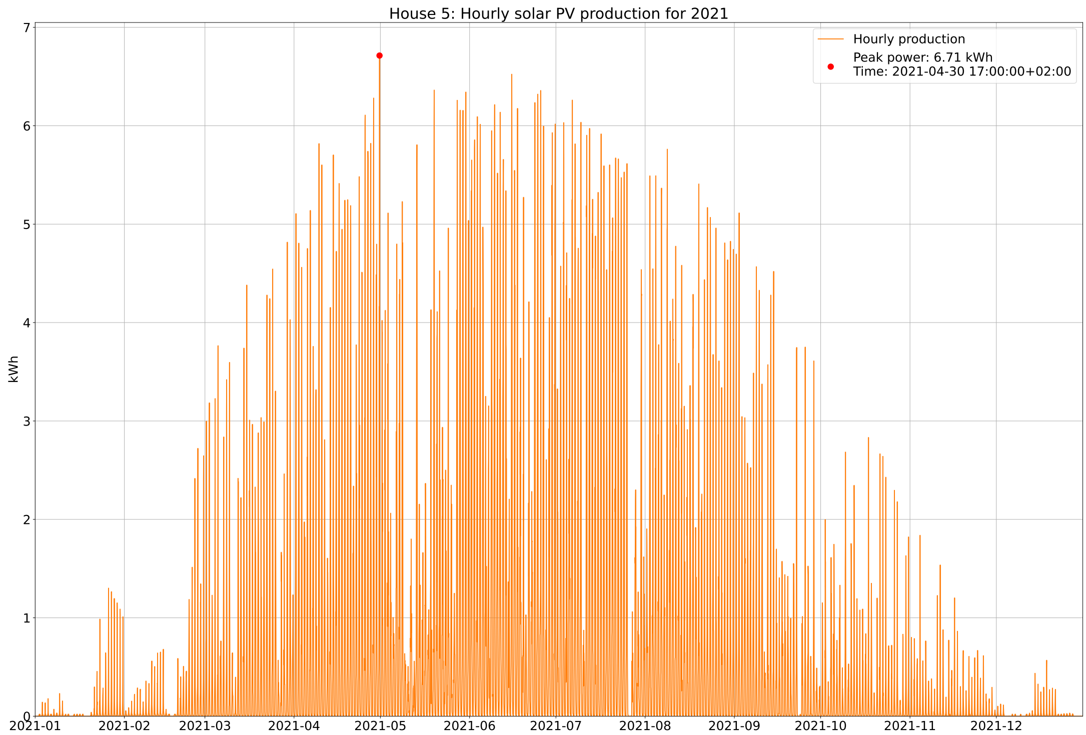



Figure A.89: Hourly PV production for House 5 in 2021.

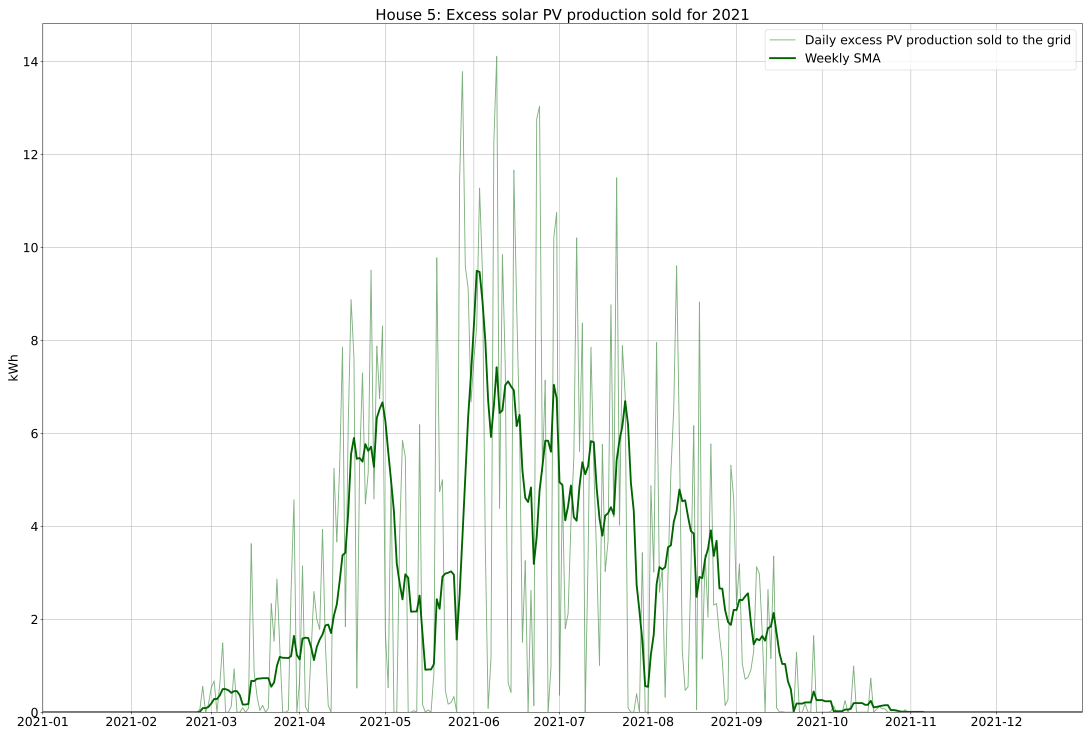



Figure A.90: Daily excess PV production sold to the grid and weekly SMA for House 5 in 2021

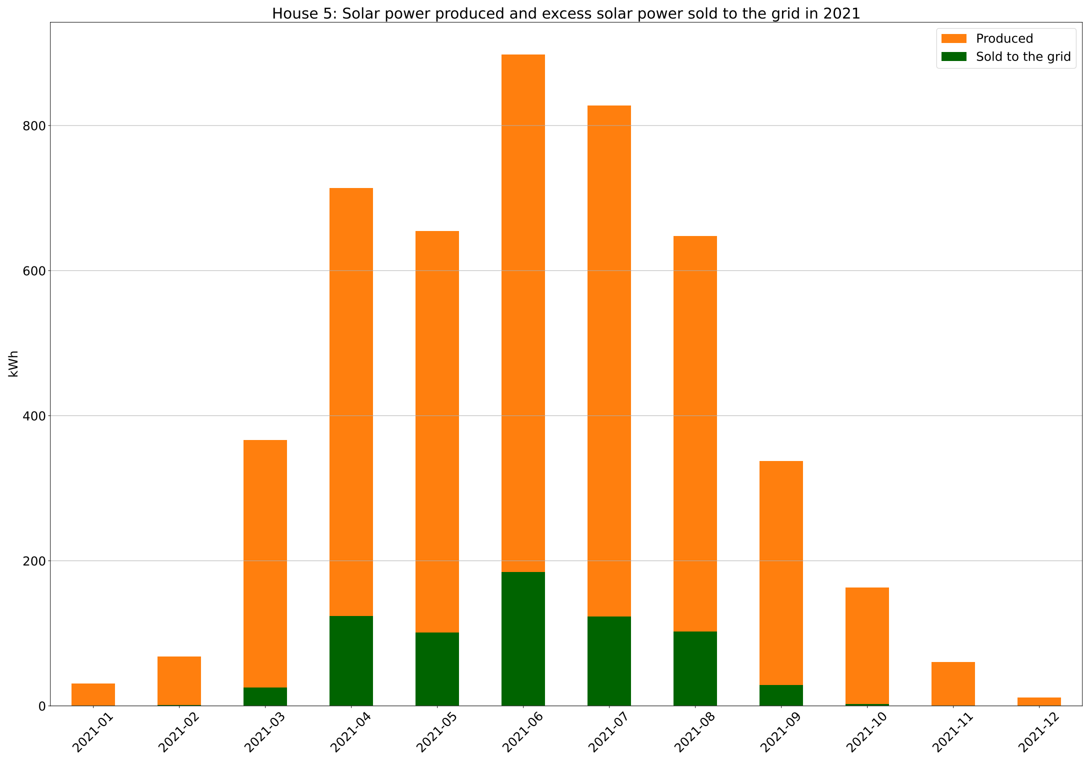



Figure A.91: Total solar PV production and excess production sold to the grid for each month in 2021 from House 5.

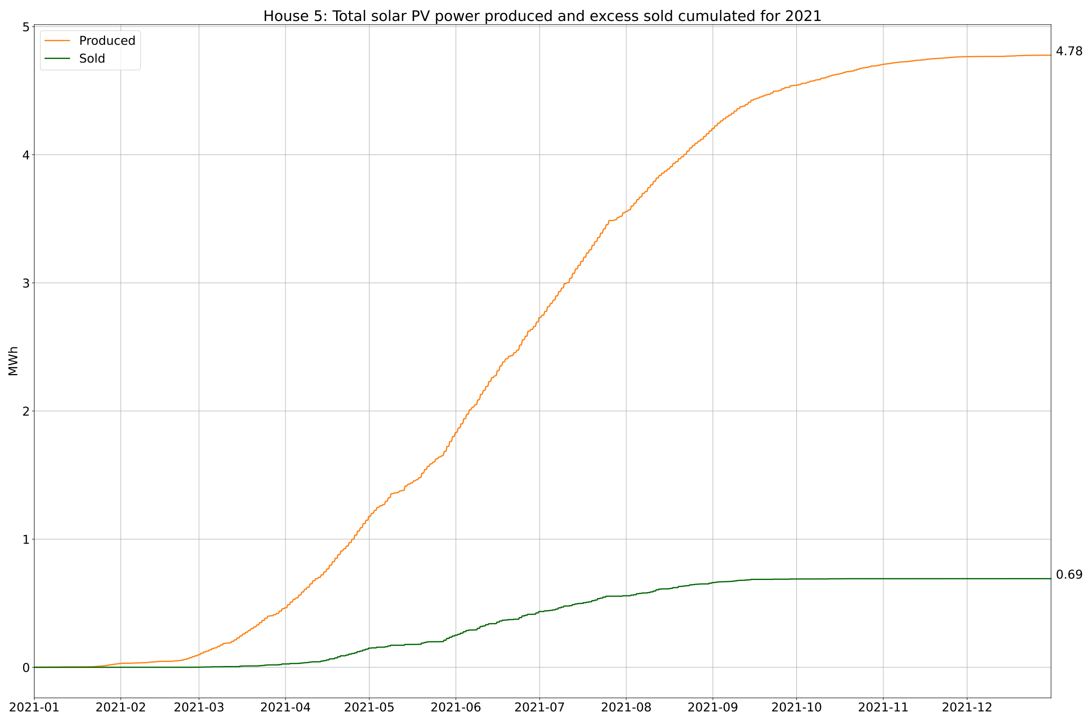
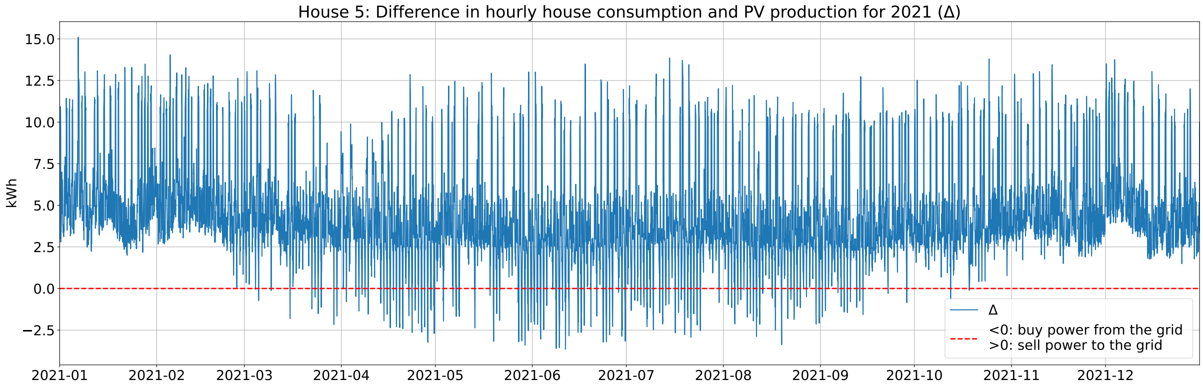



Figure A.92: Total solar PV production and excess production sold cumulated over 2021 from House 5

### A.5.3 Delta variable

**2021**



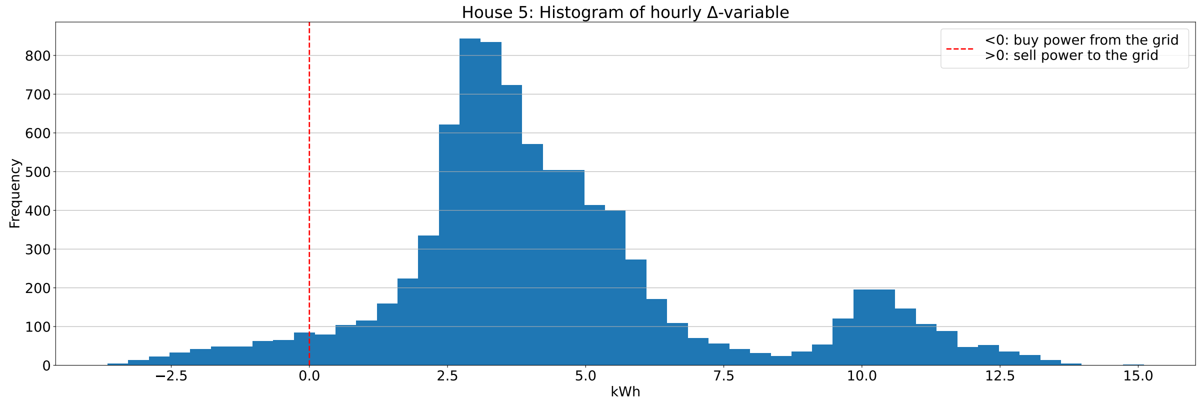




Figure A.93: The delta variable plotted for House 5. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.5.4 House consumption and PV production

#### 2021

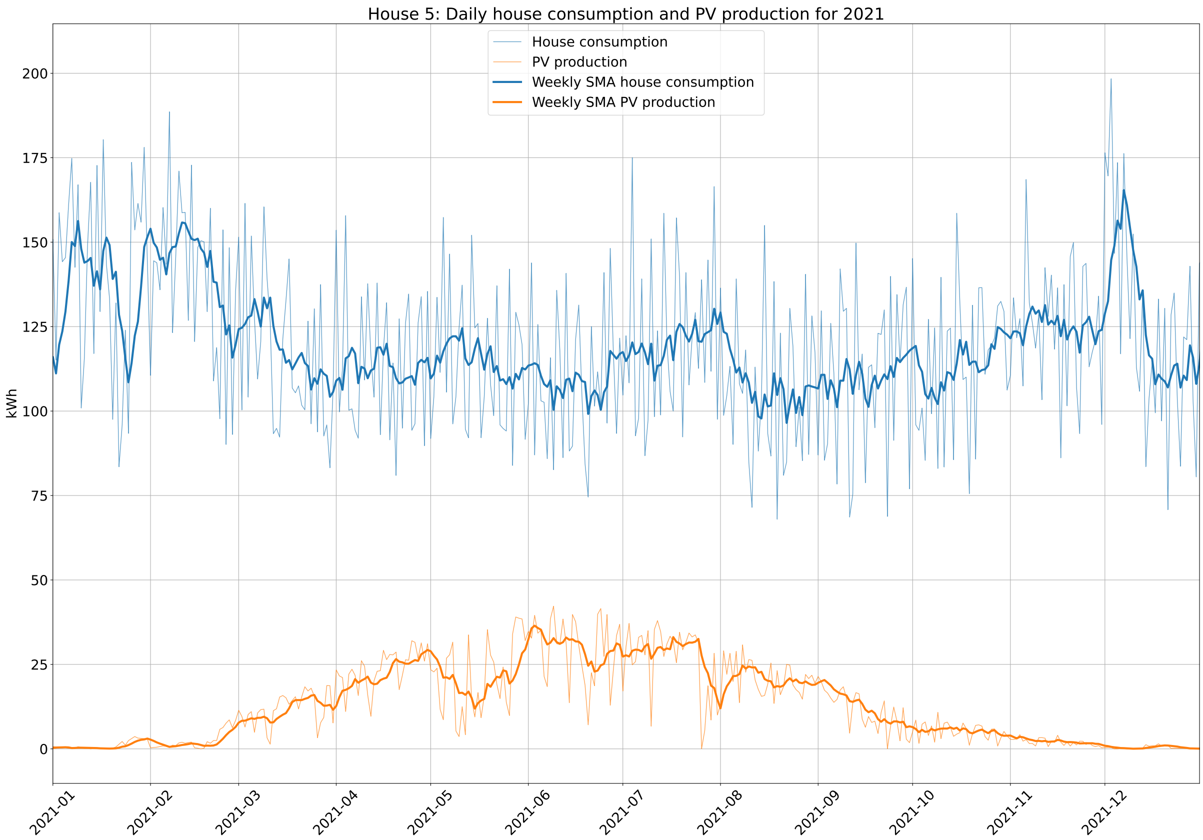



Figure A.94: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.5.5 Cost of energy

#### 2021

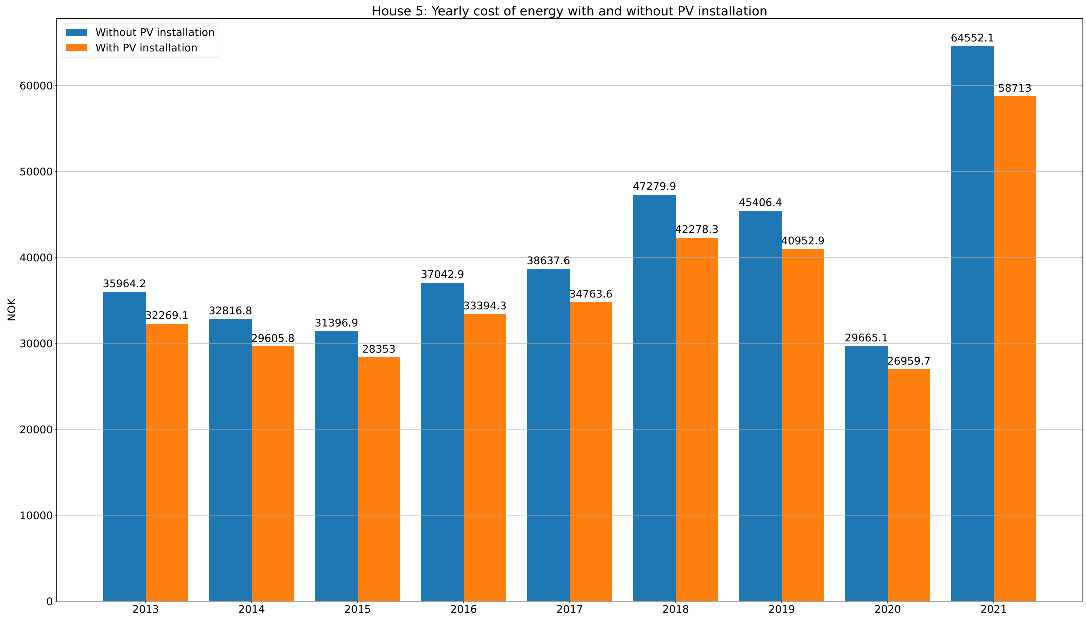



Figure A.95: Yearly cost of energy for House 5, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

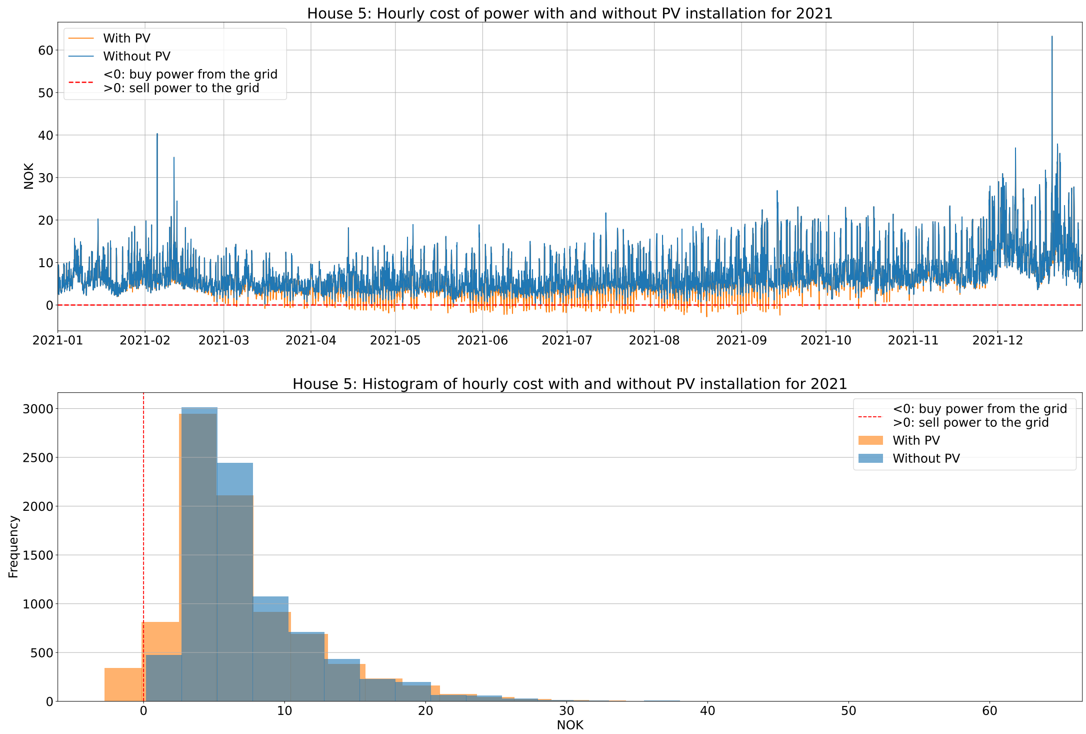
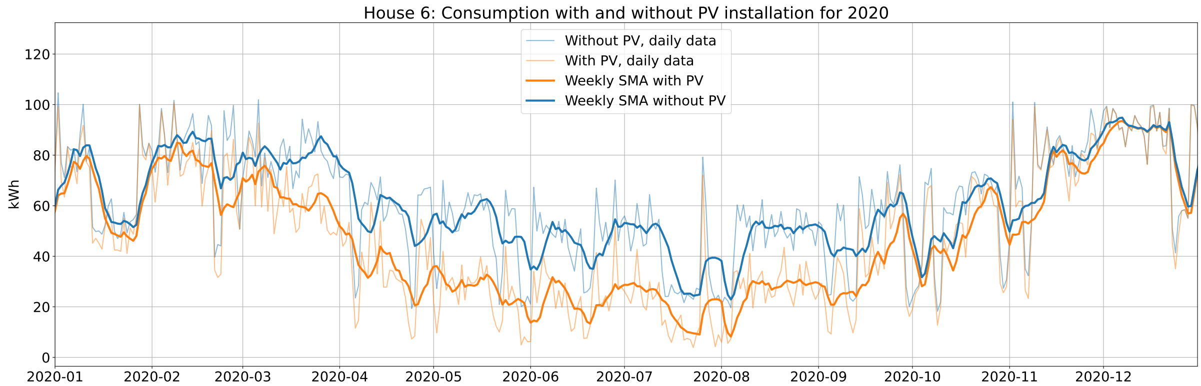



Figure A.96: Hourly cost of energy for House 5 with and without a PV system present for 2021. NB! Due to an small error the ”<” sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.6 House 6

### A.6.1 House consumption

**2020**



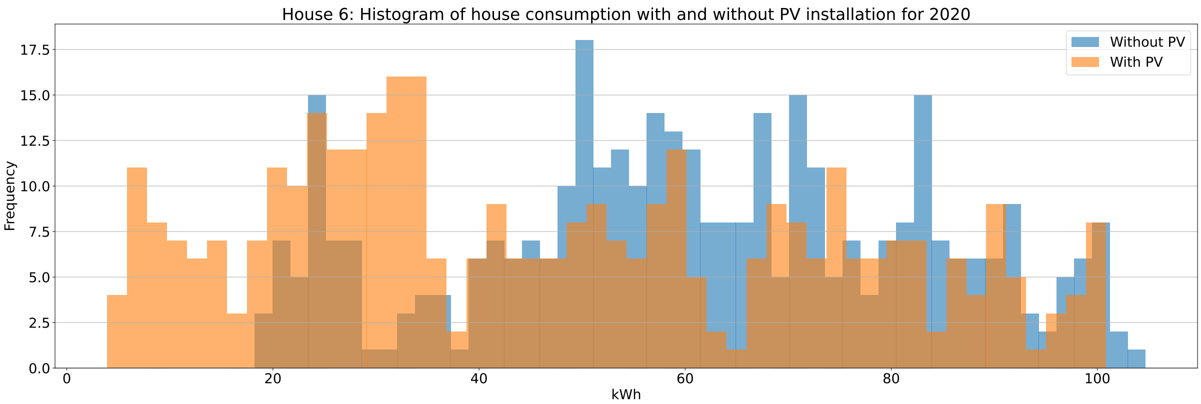




Figure A.97: Daily house consumption with and without a PV system for 2020 from House 6. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

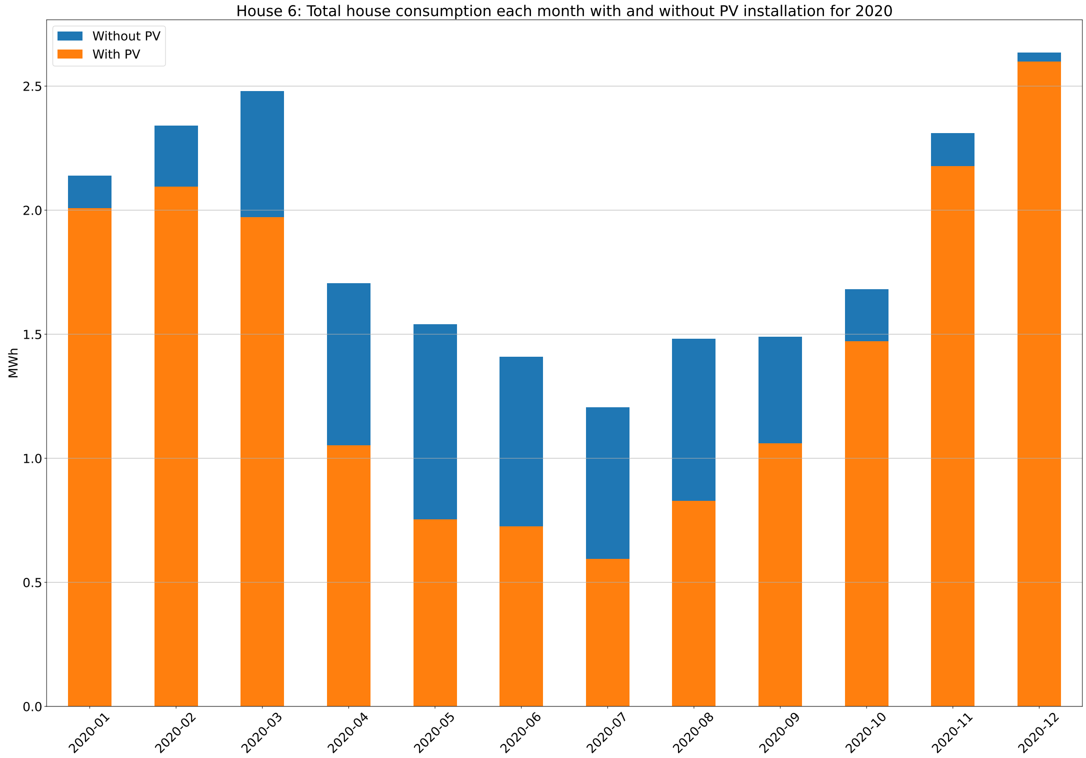



Figure A.98: Monthly house consumption for House 6 with and without a PV system for 2020.

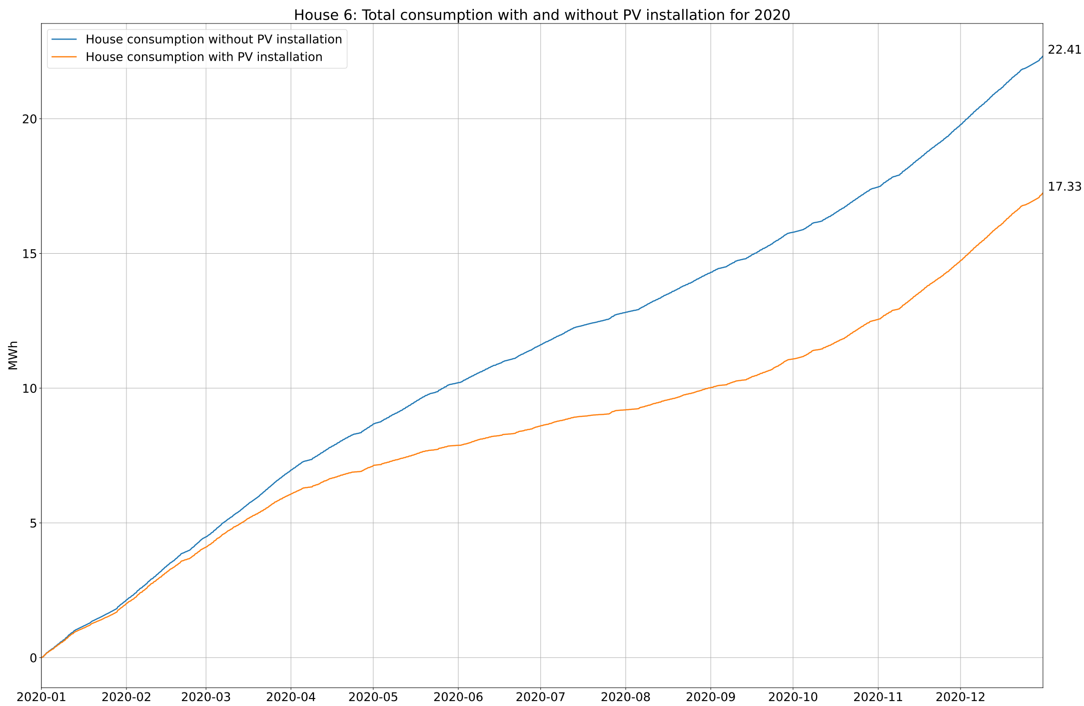



Figure A.99: Total house consumption for House 6 with and without a PV system accumulated over 2020

**2021**

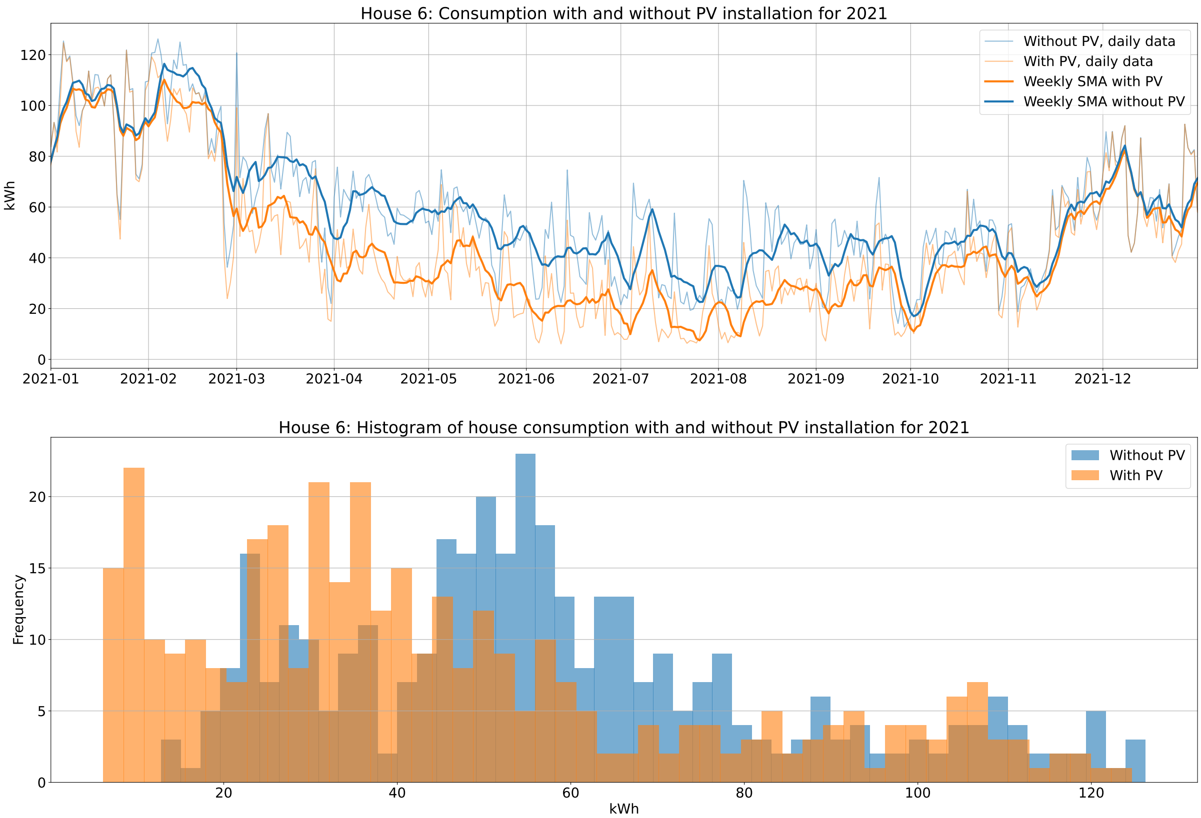



Figure A.100: Daily house consumption with and without a PV system for 2021 from House 6. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

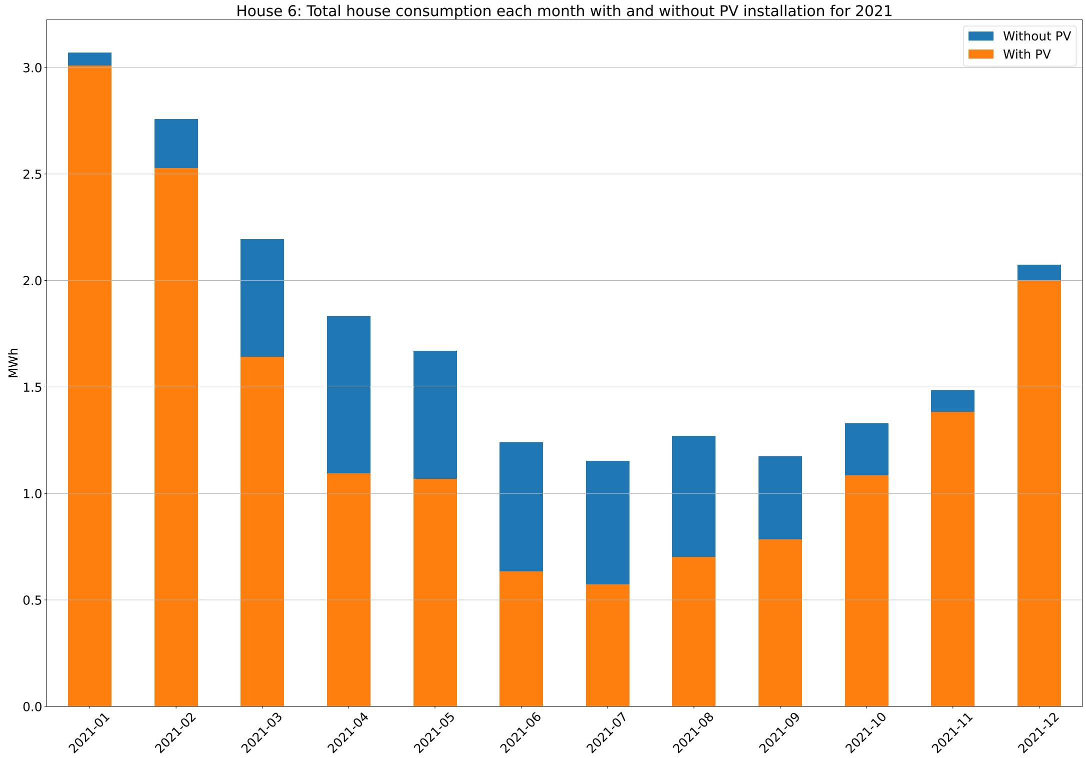



Figure A.101: Monthly house consumption for House 6 with and without a PV system for 2021.

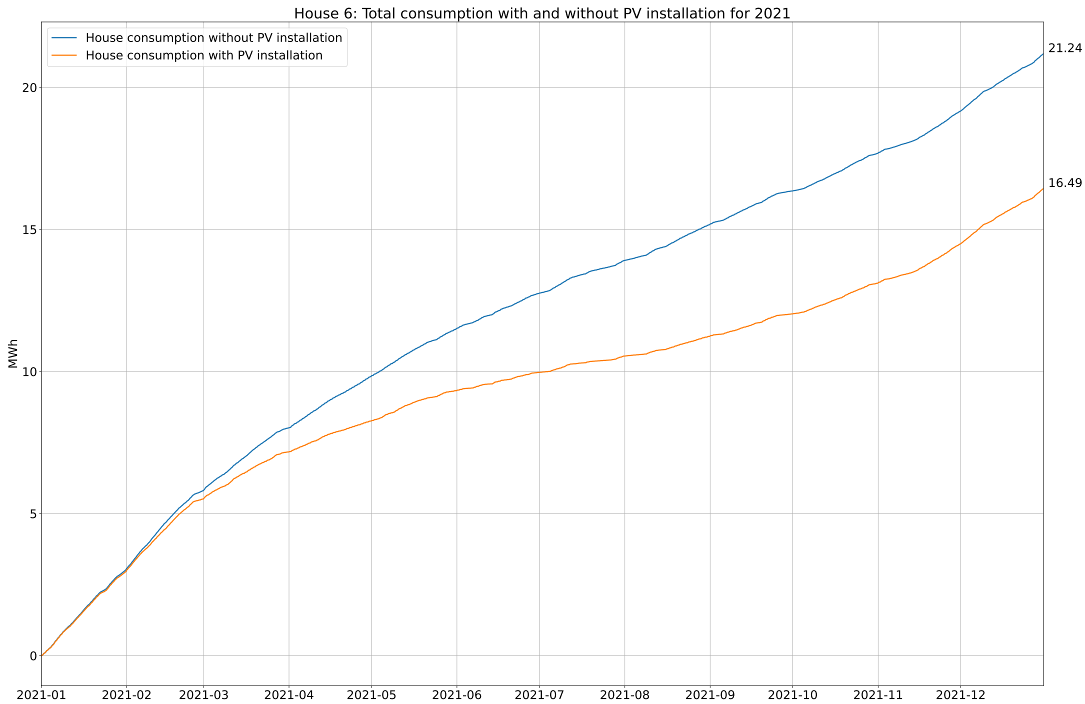



Figure A.102: Total house consumption for House 6 with and without a PV system accumulated over 2021

### A.6.2 Solar PV production

#### 2020

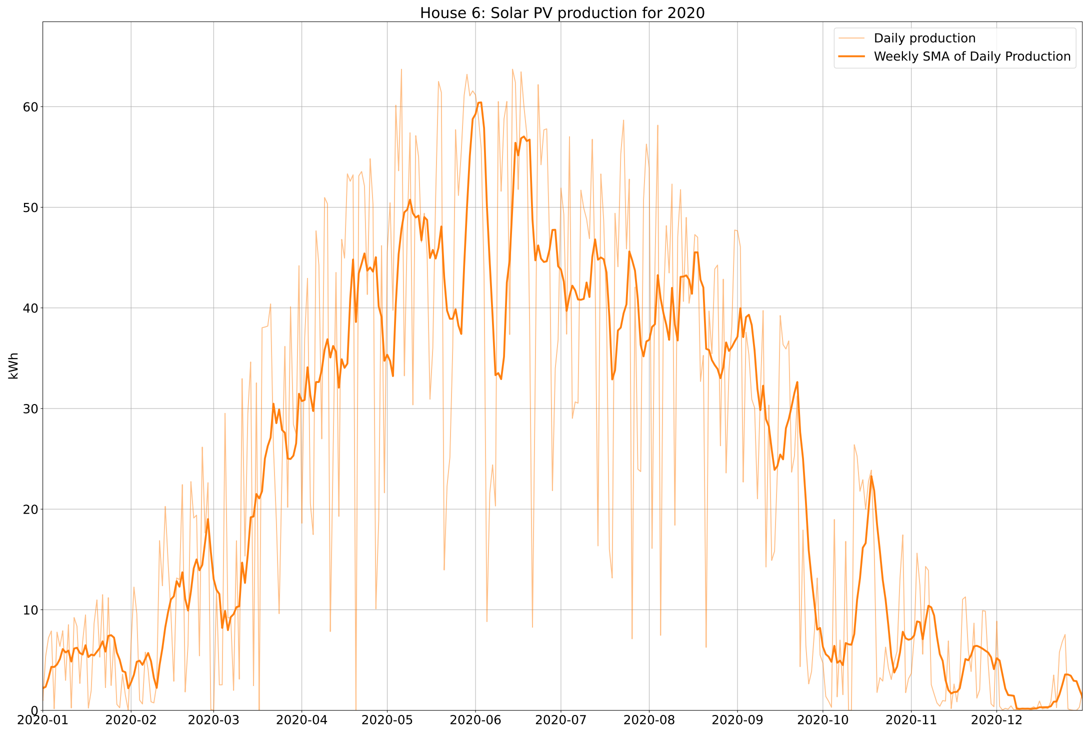



Figure A.103: Daily PV production and weekly SMA for House 6 in 2020.

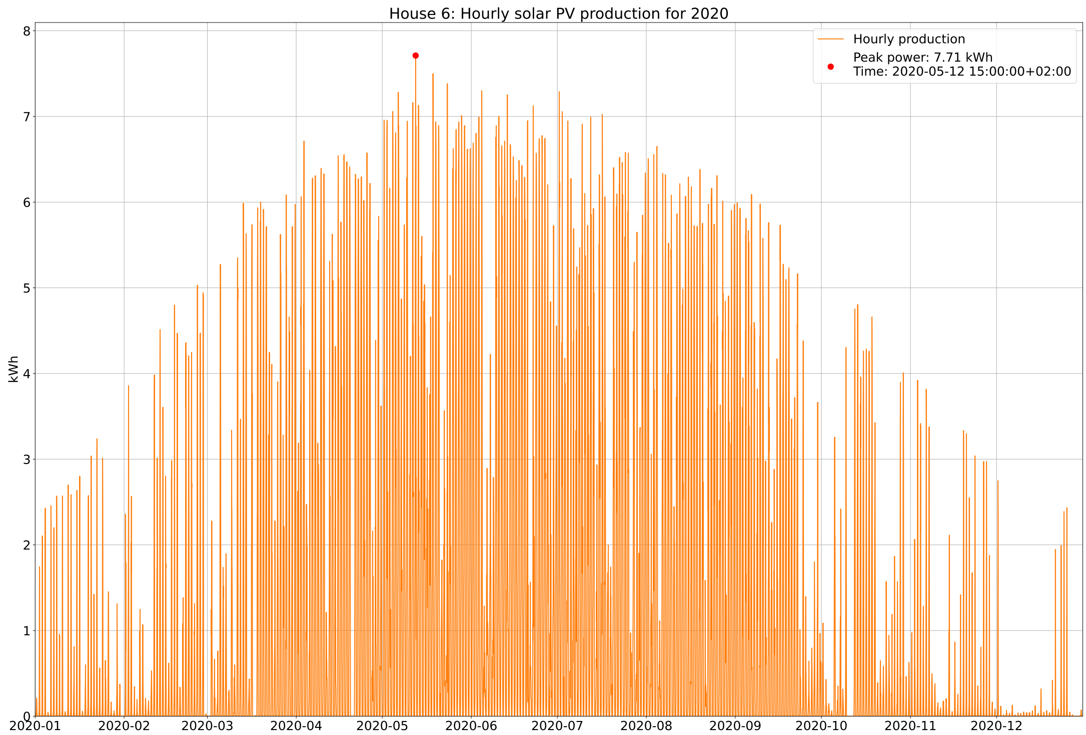



Figure A.104: Hourly PV production for House 6 in 2020.

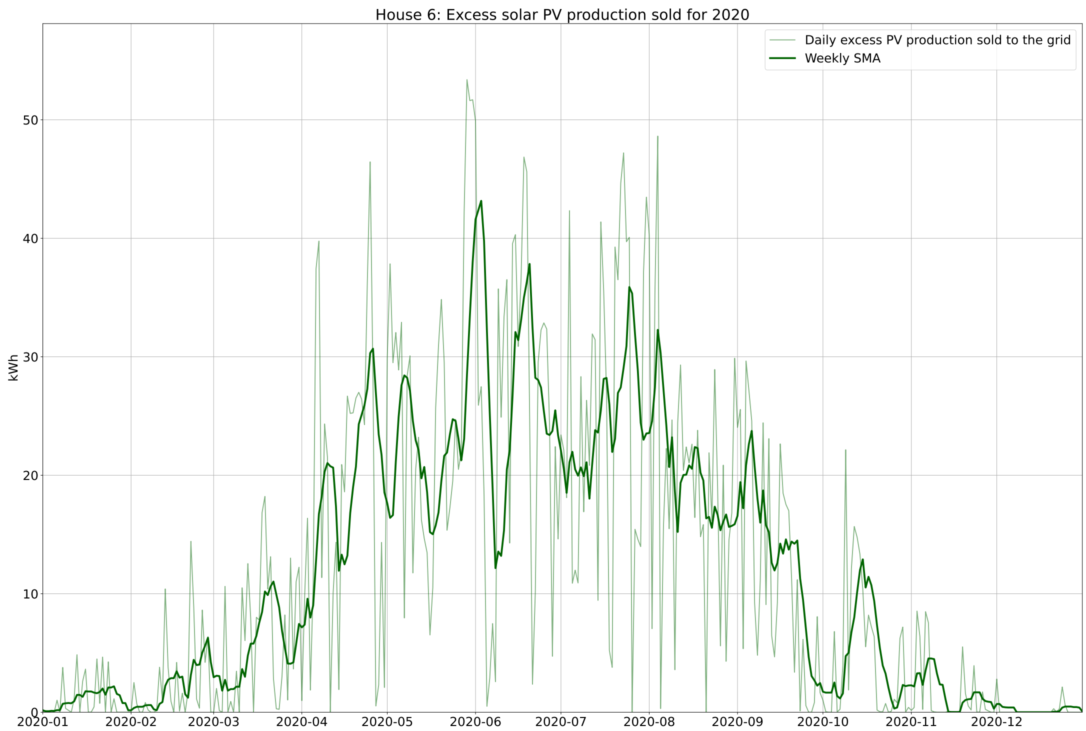



Figure A.105: Daily excess PV production sold to the grid and weekly SMA for House 6 in 2020

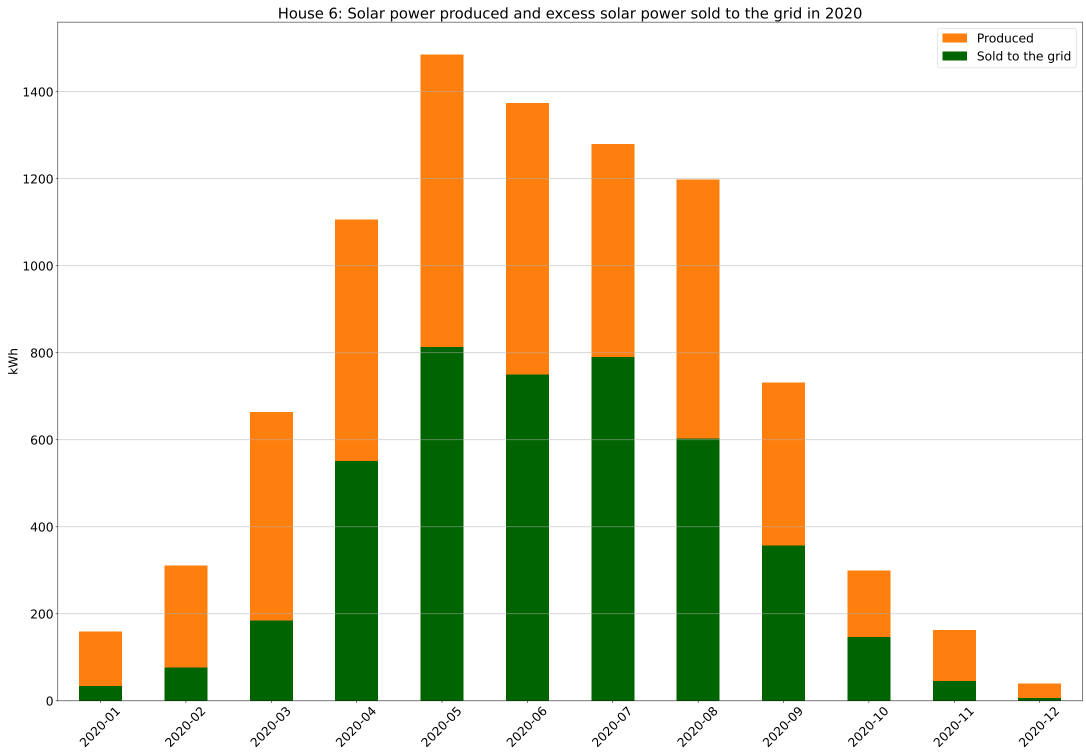



Figure A.106: Total solar PV production and excess production sold to the grid for each month in 2020 from House 6.

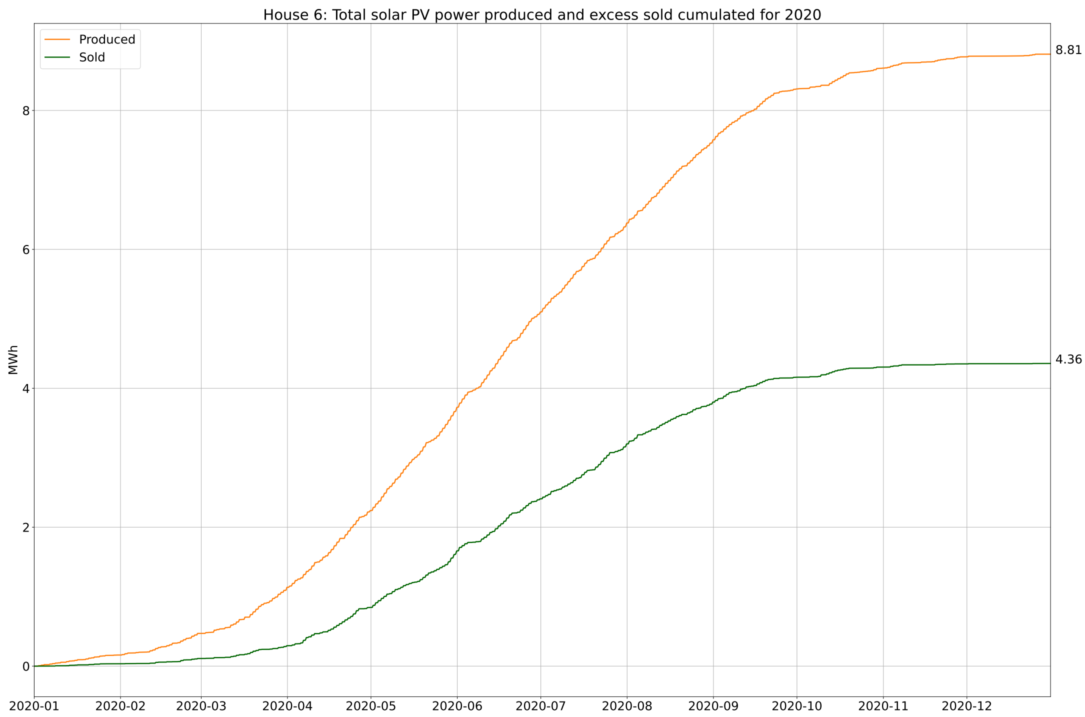



Figure A.107: Total solar PV production and excess production sold cumulated over 2020 from House 6

**2021**

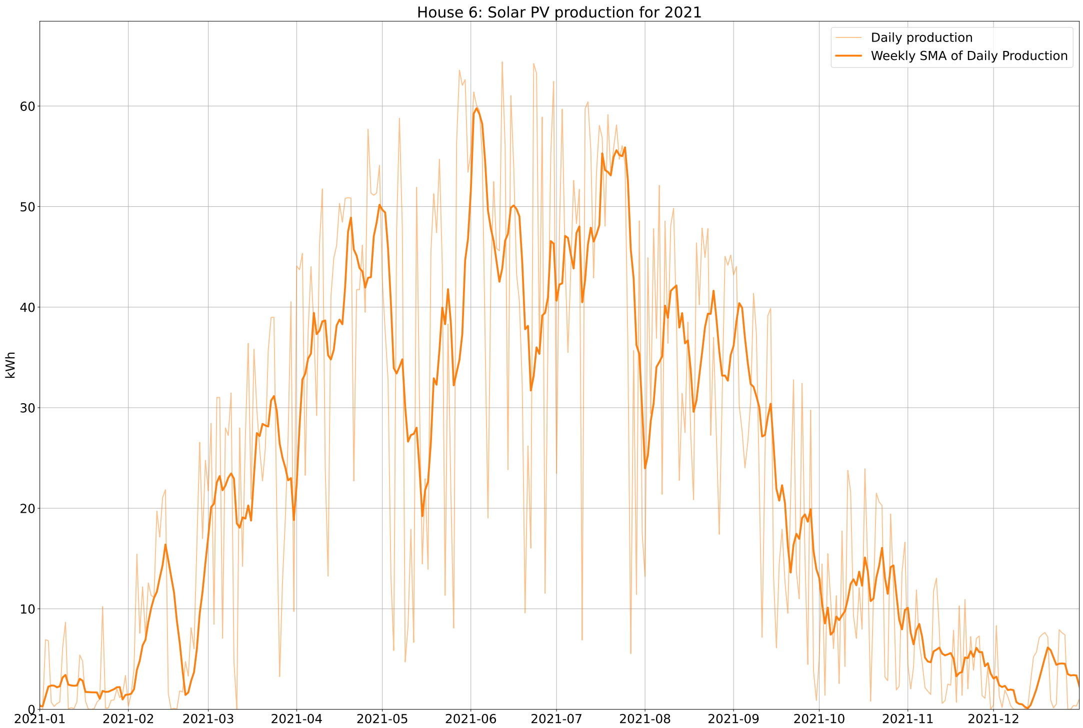



Figure A.108: Daily PV production and weekly SMA for House 6 in 2021.

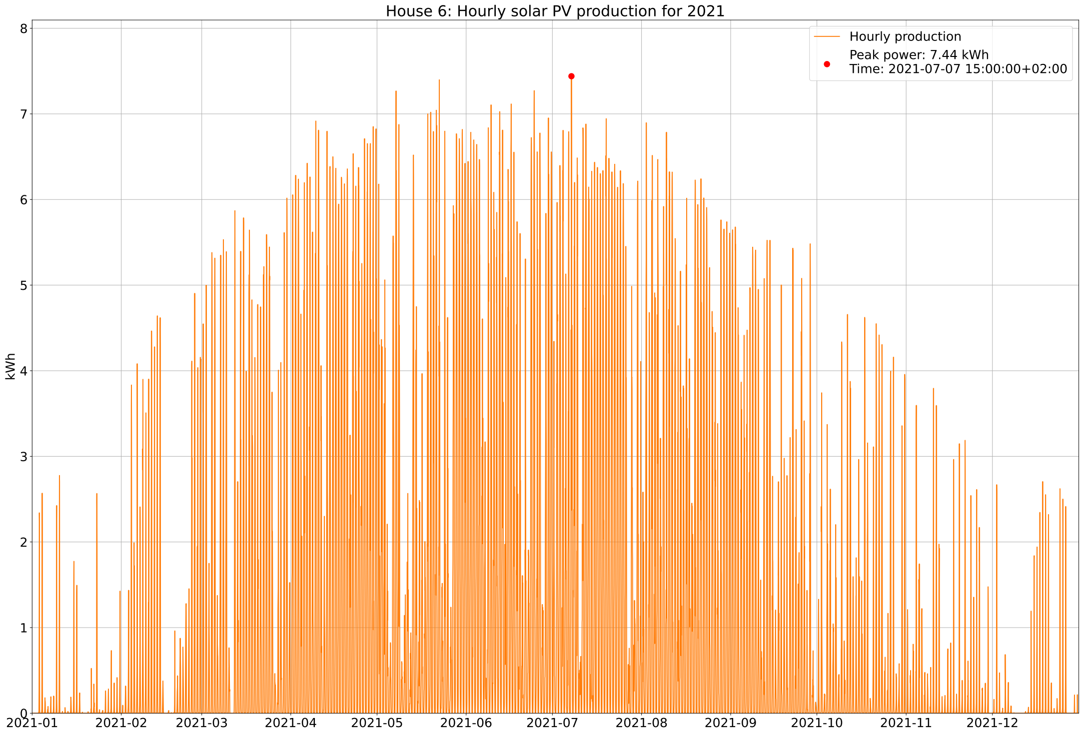



Figure A.109: Hourly PV production for House 6 in 2021.

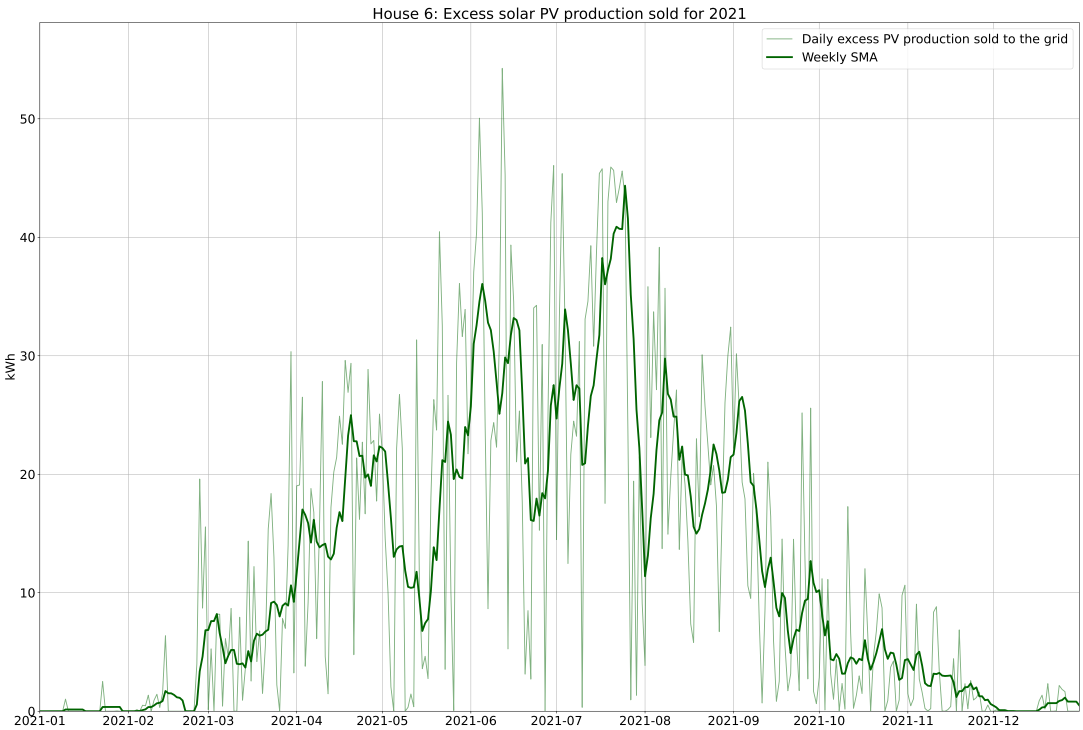



Figure A.110: Daily excess PV production sold to the grid and weekly SMA for House 6 in 2021

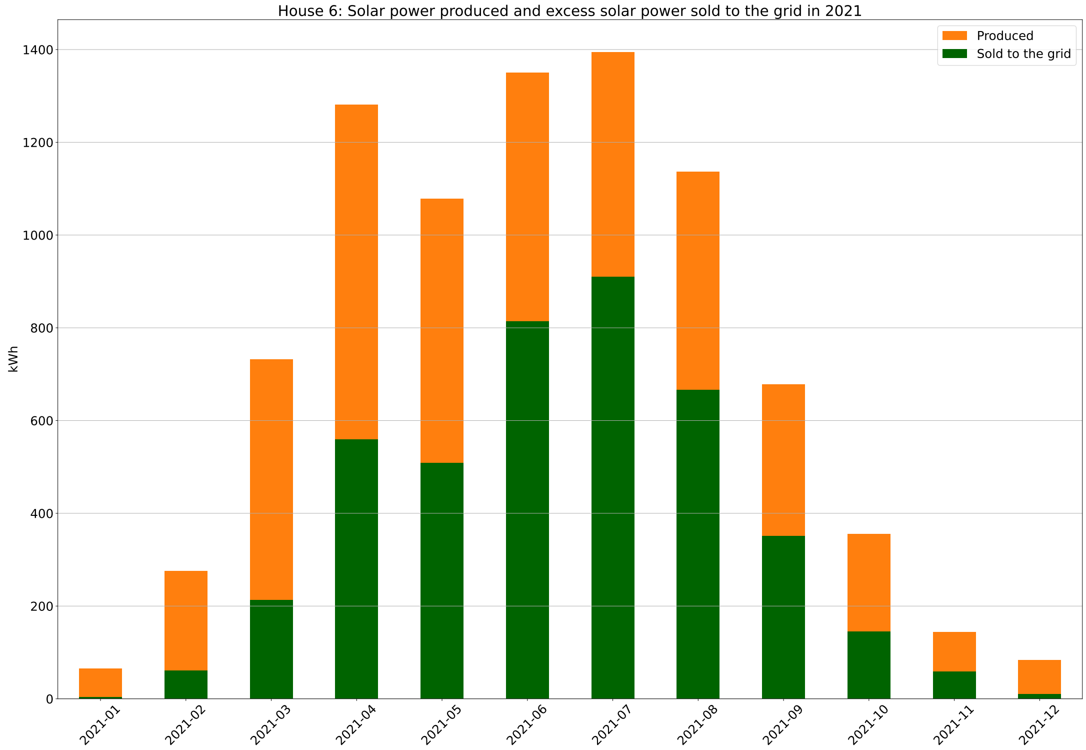



Figure A.111: Total solar PV production and excess production sold to the grid for each month in 2021 from House 6.

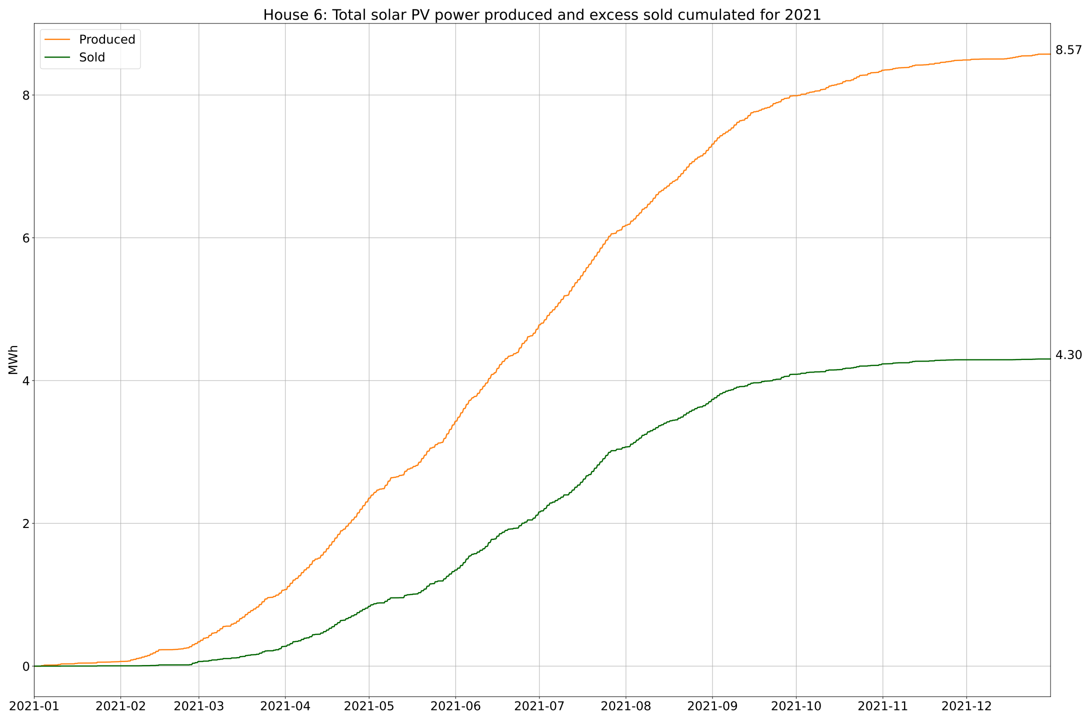



Figure A.112: Total solar PV production and excess production sold cumulated over 2021 from House 6

### A.6.3 Delta variable

#### 2020

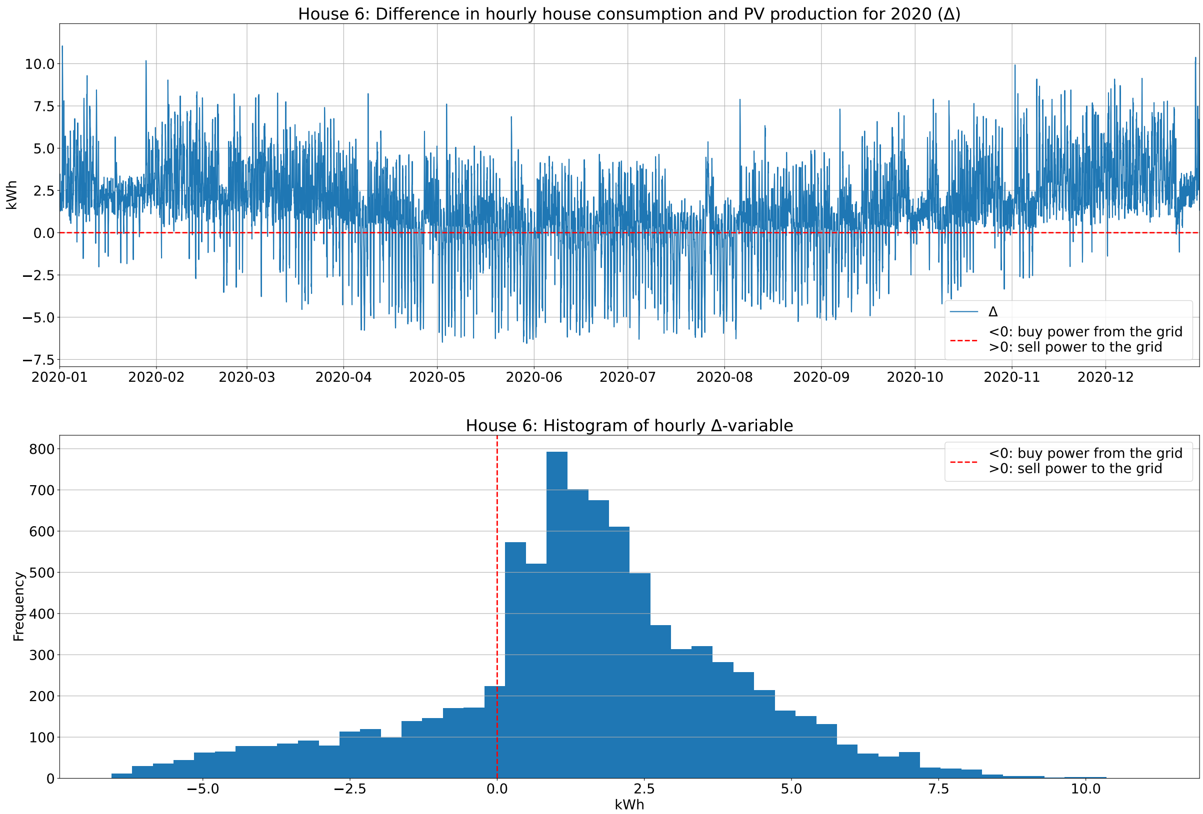



Figure A.113: The delta variable plotted for House 6. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

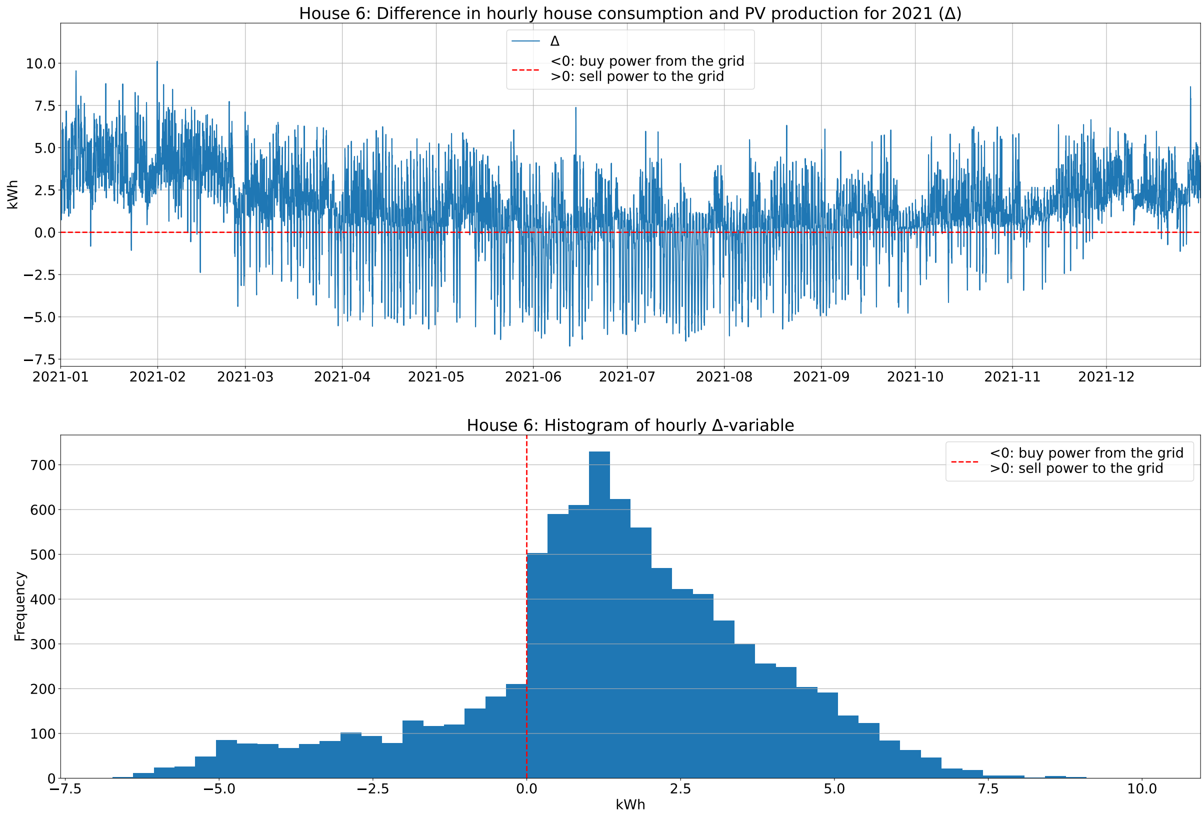



Figure A.114: The delta variable plotted for House 6. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.6.4 House consumption and PV production

#### 2020

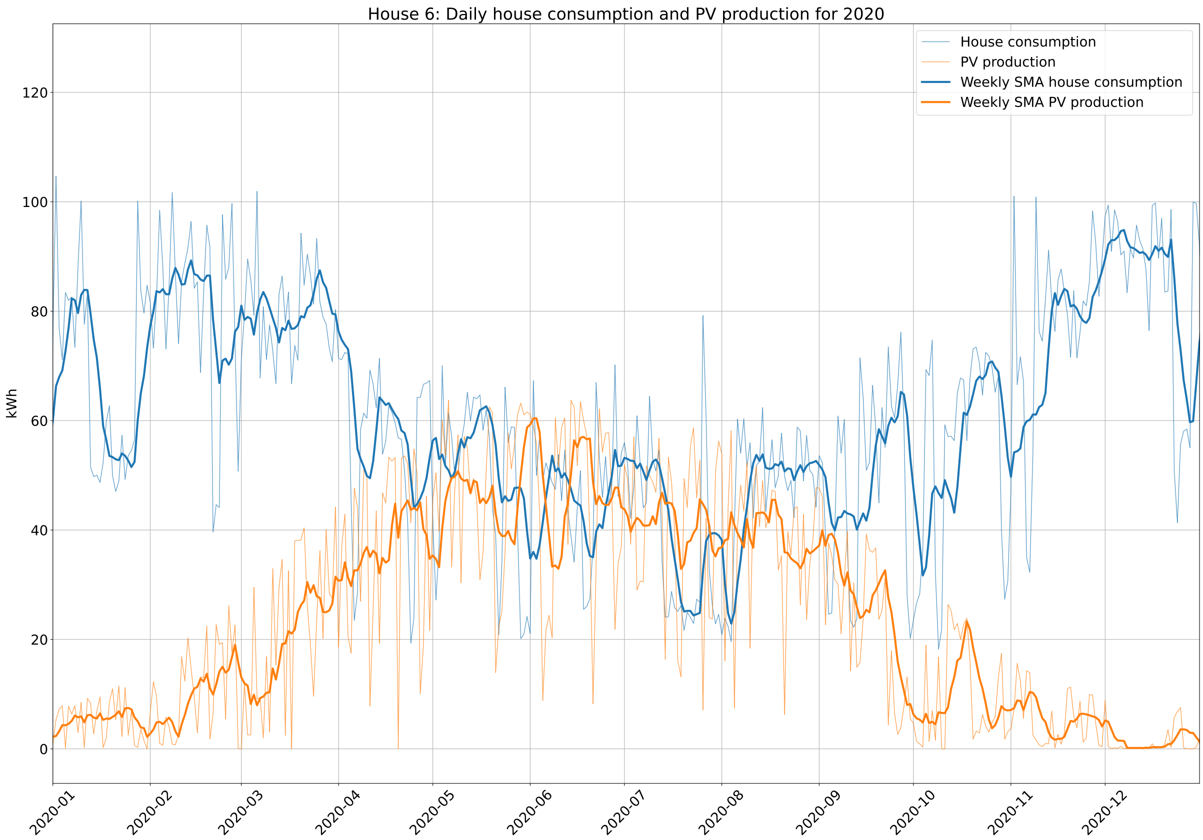



Figure A.115: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

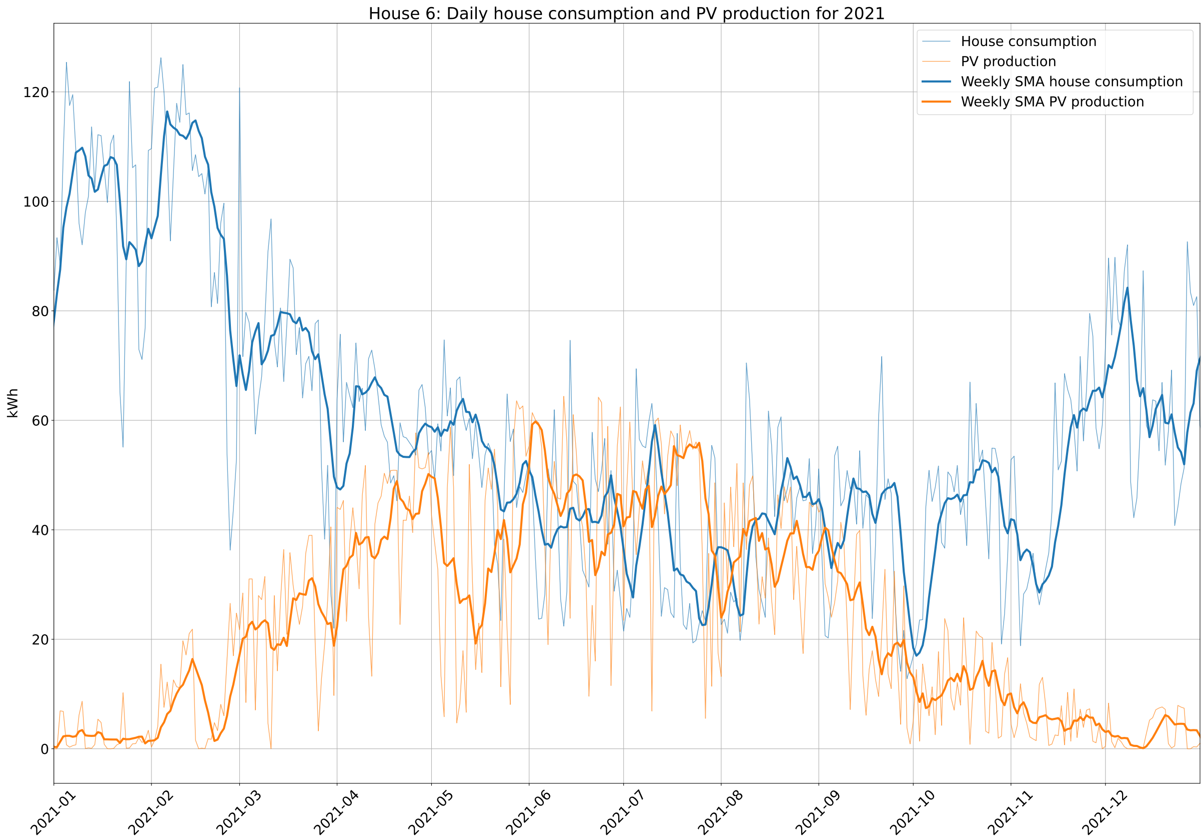



Figure A.116: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.6.5 Cost of energy

#### 2020

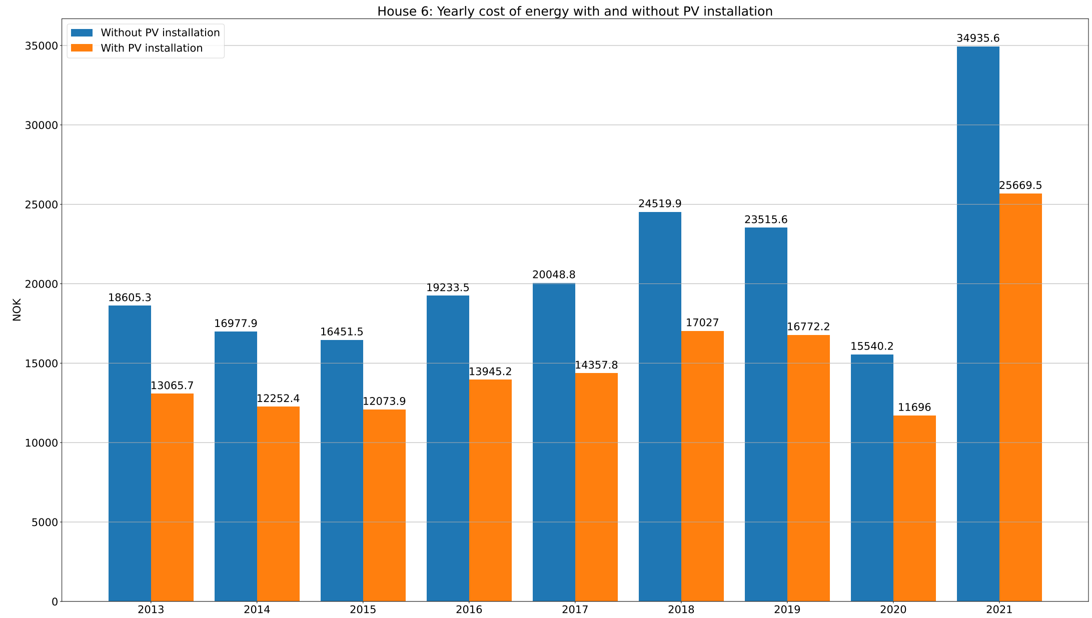



Figure A.117: Yearly cost of energy for House 6, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

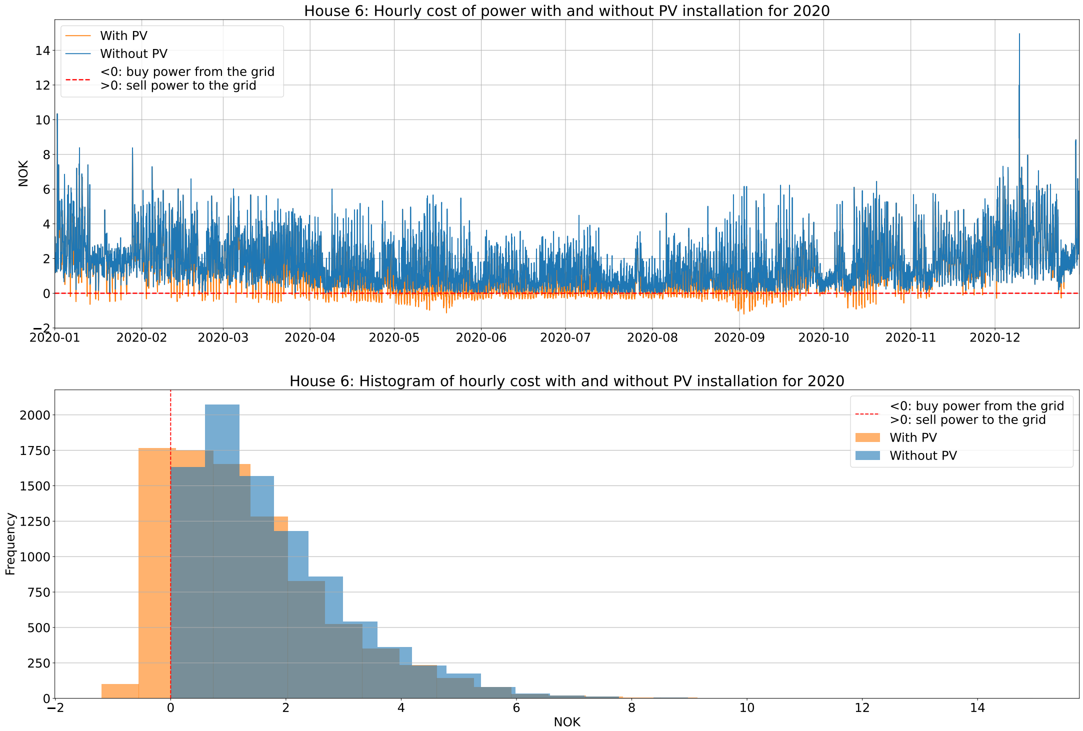



Figure A.118: Hourly cost of energy for House 6 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## 2021

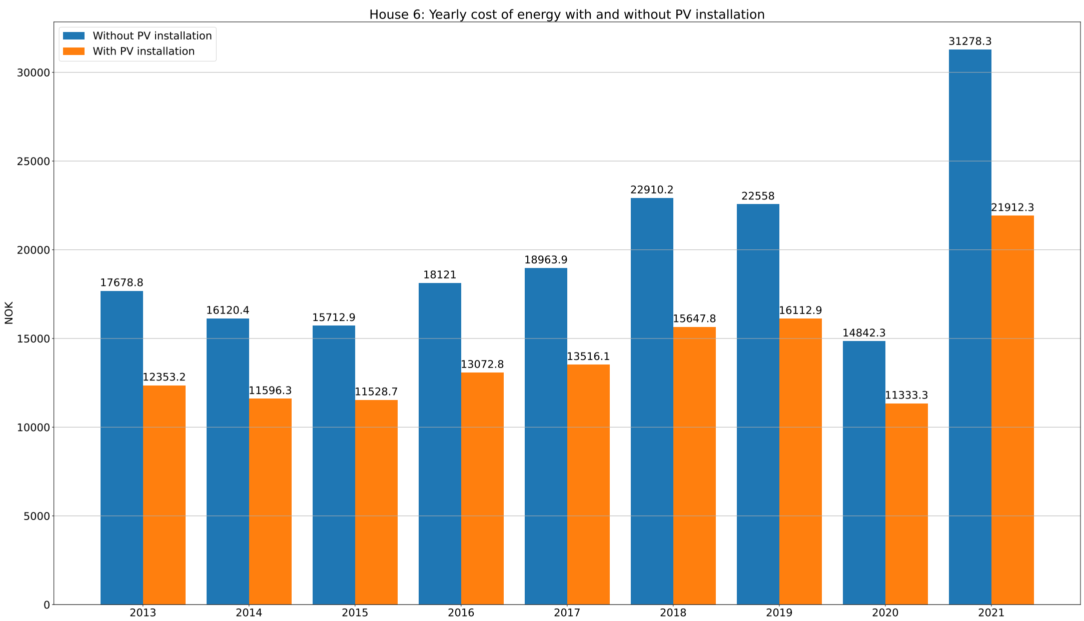



Figure A.119: Yearly cost of energy for House 6, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

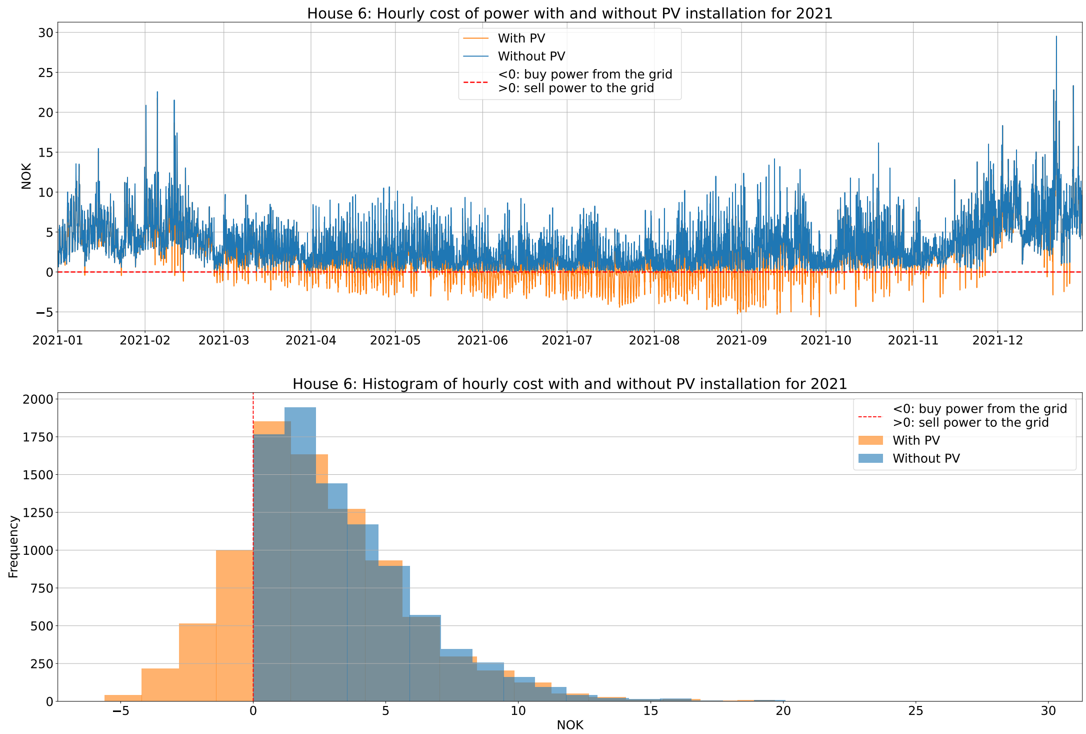
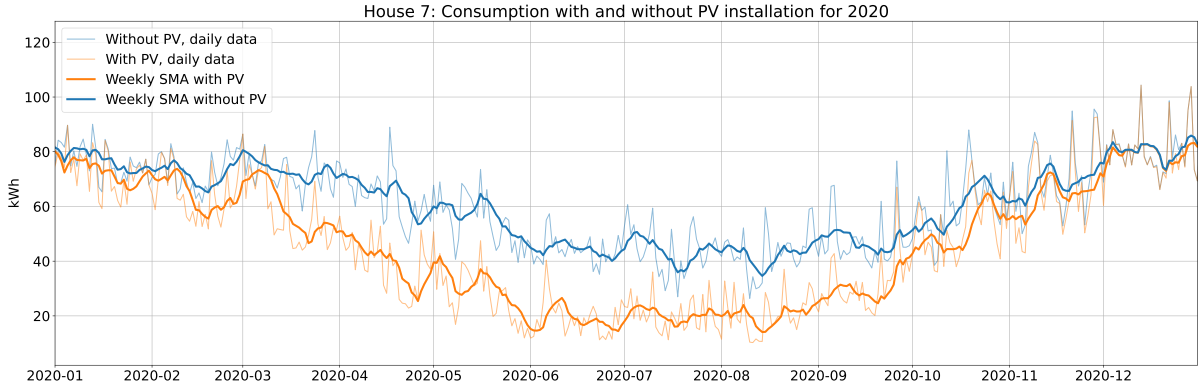



Figure A.120: Hourly cost of energy for House 6 with and without a PV system present for 2021. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.7 House 7

### A.7.1 House consumption

**2020**



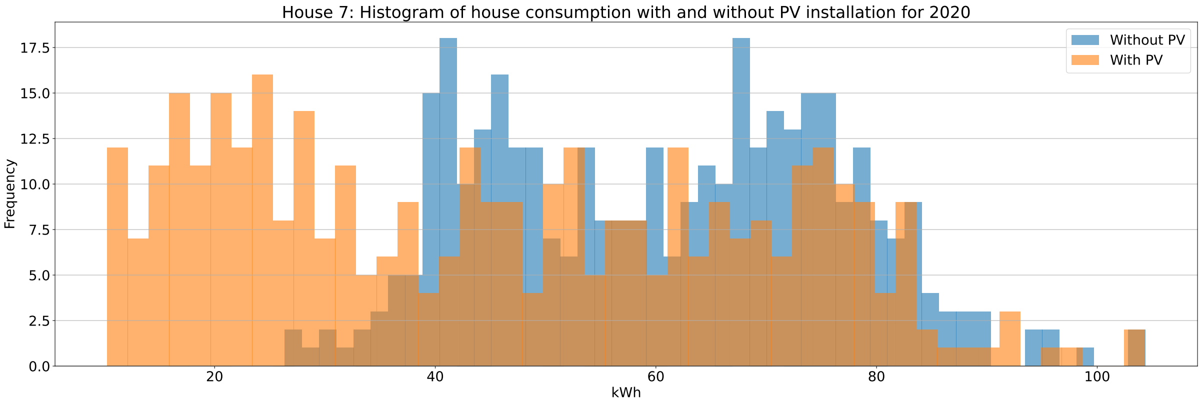




Figure A.121: Daily house consumption with and without a PV system for 2020 from House 7. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

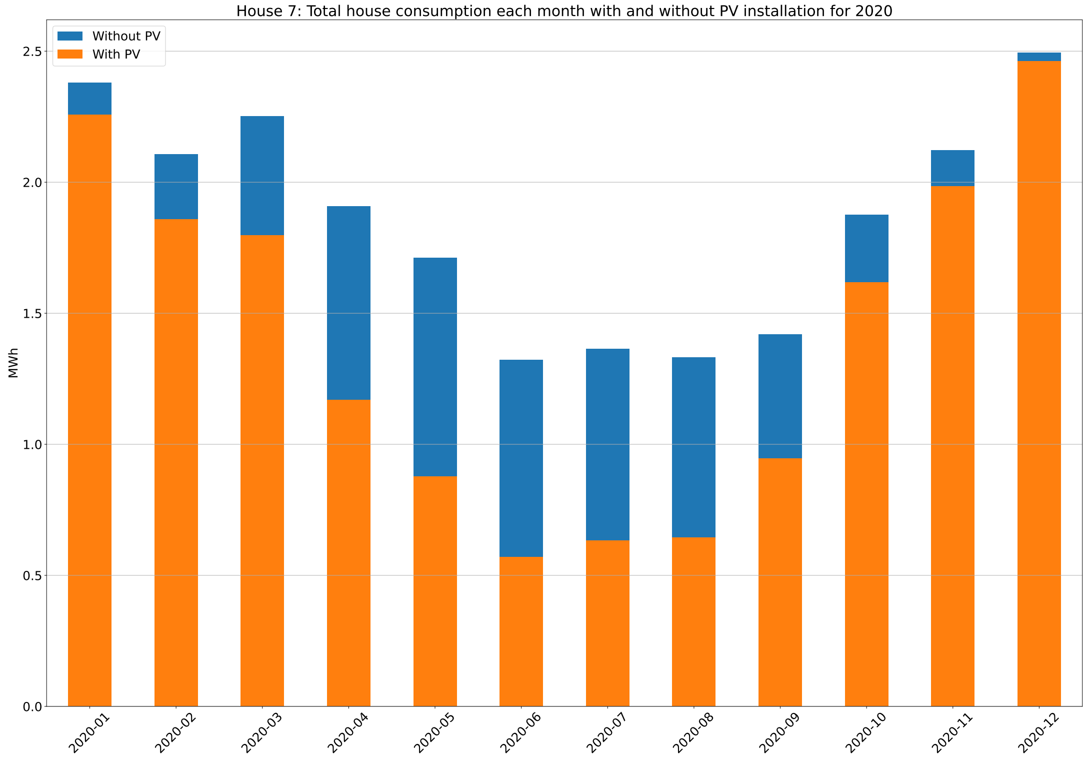



Figure A.122: Monthly house consumption for House 7 with and without a PV system for 2020.

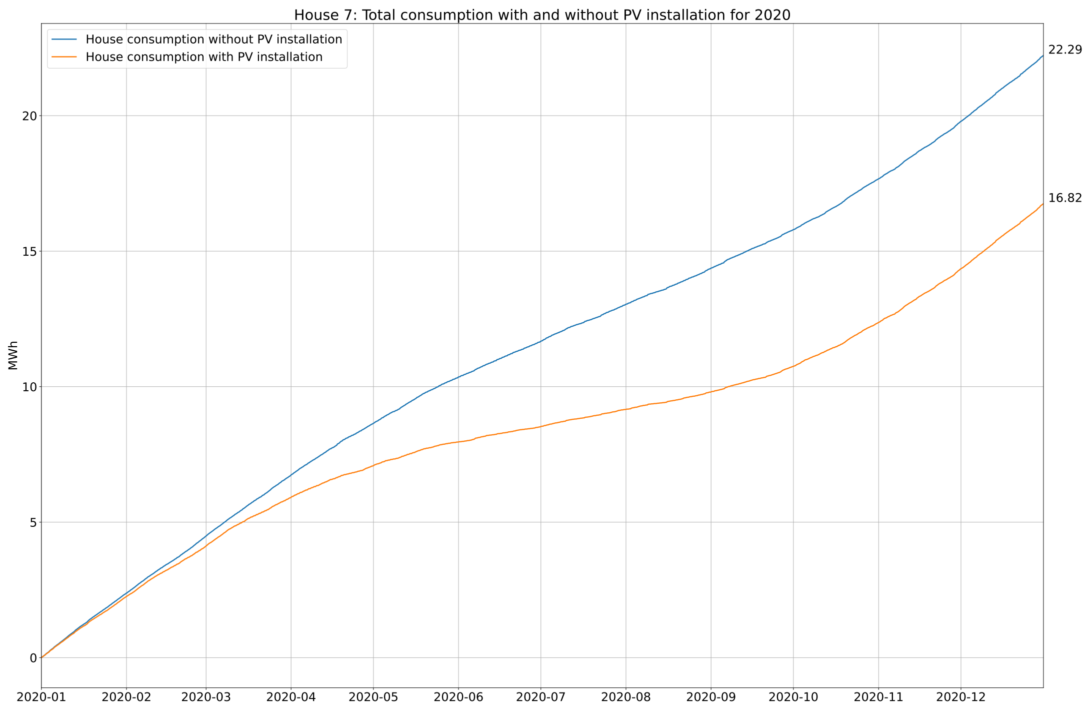
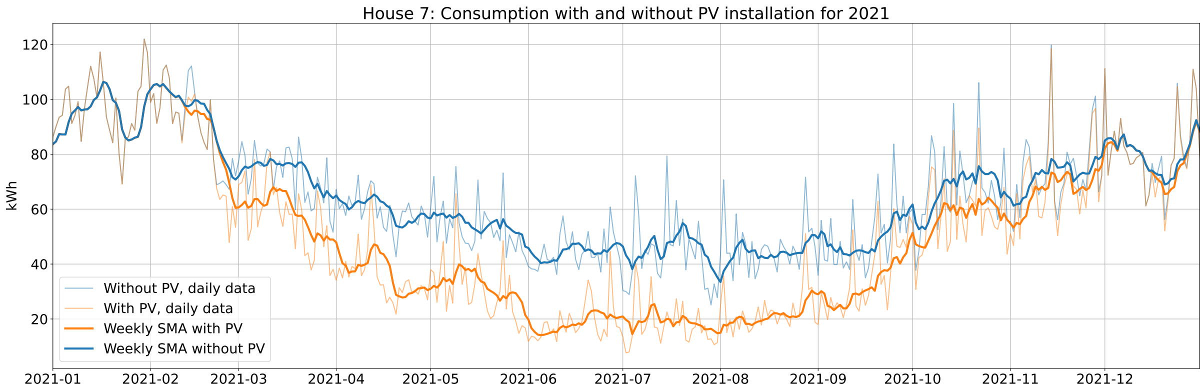



Figure A.123: Total house consumption for House 7 with and without a PV system accumulated over 2020

**2021**



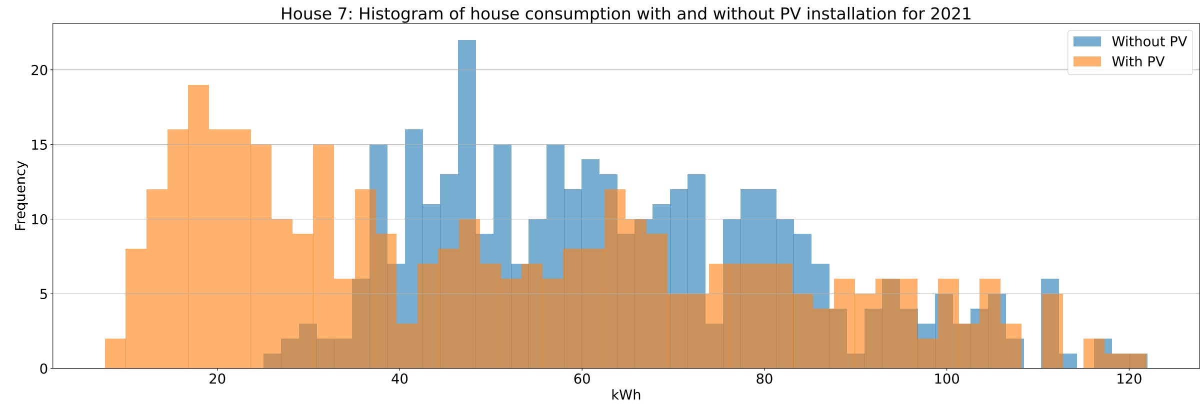




Figure A.124: Daily house consumption with and without a PV system for 2021 from House 7. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

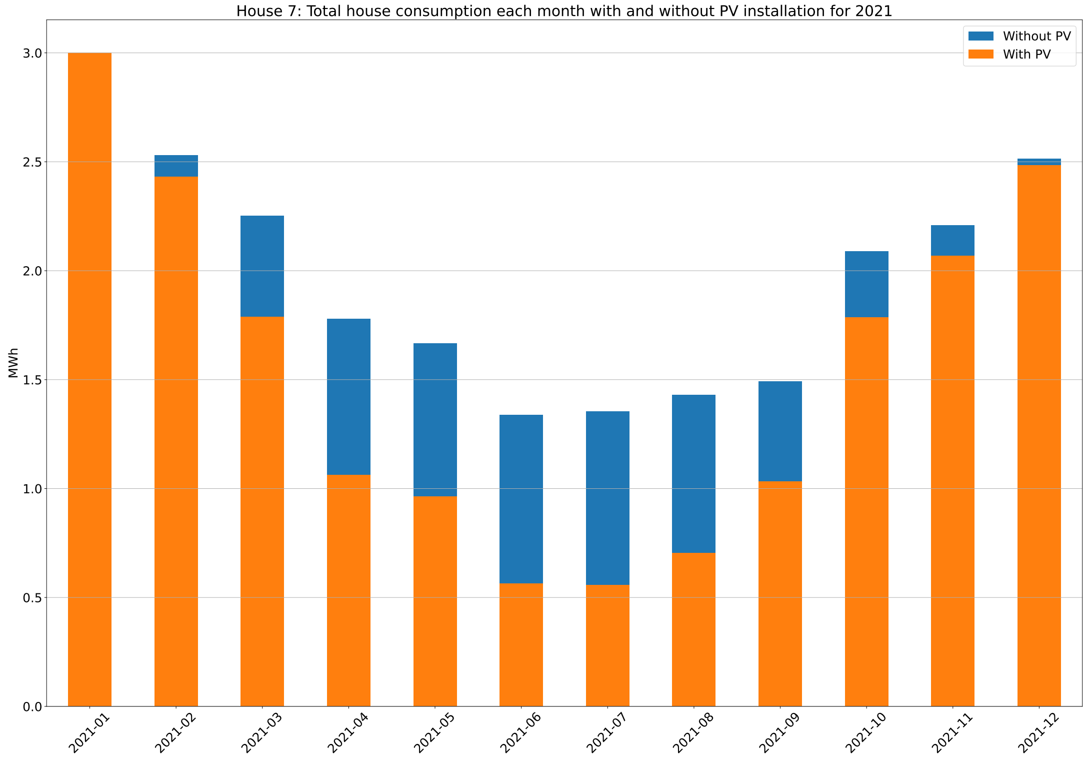



Figure A.125: Monthly house consumption for House 7 with and without a PV system for 2021.

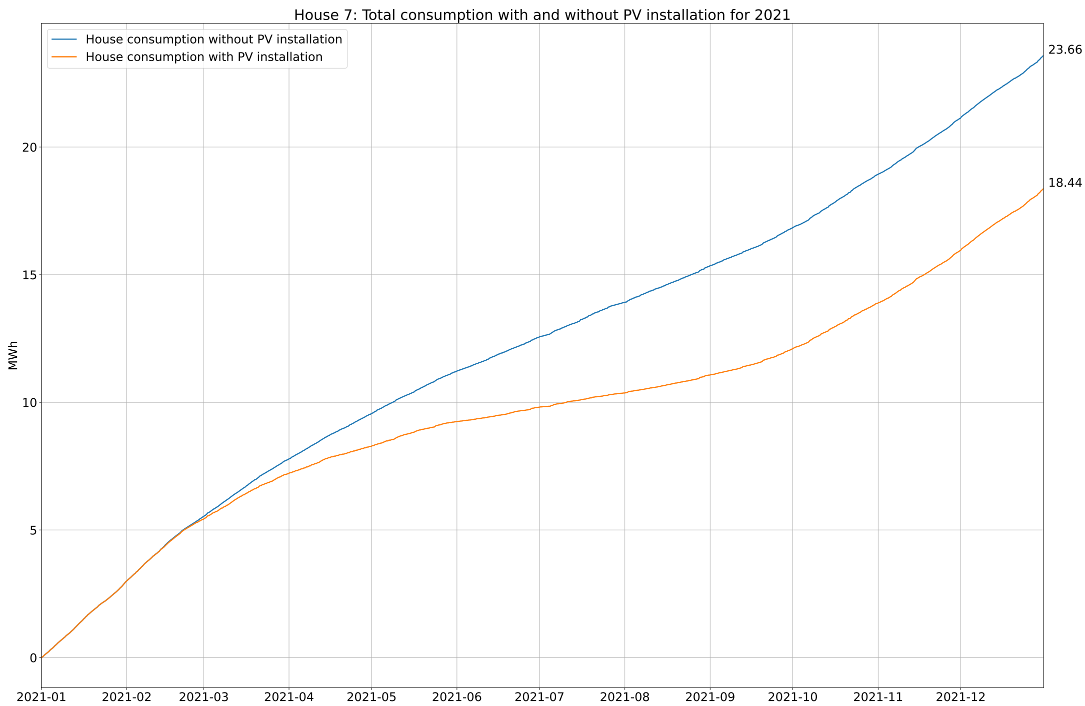



Figure A.126: Total house consumption for House 7 with and without a PV system accumulated over 2021

### A.7.2 Solar PV production

#### 2020

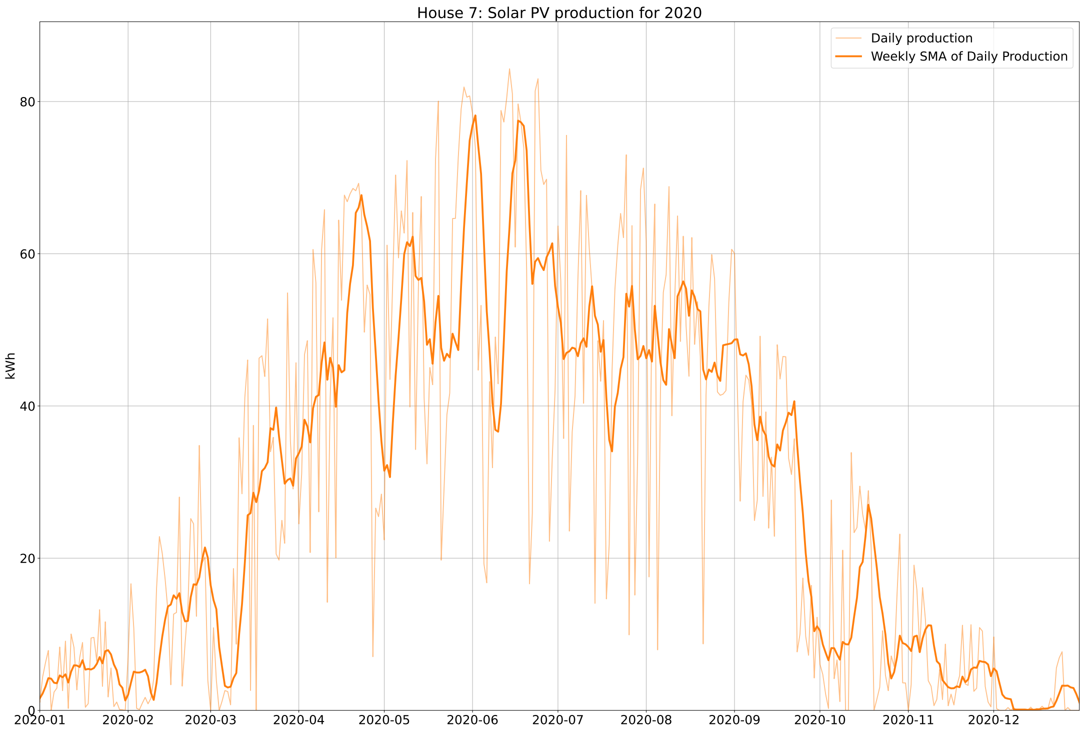



Figure A.127: Daily PV production and weekly SMA for House 7 in 2020.

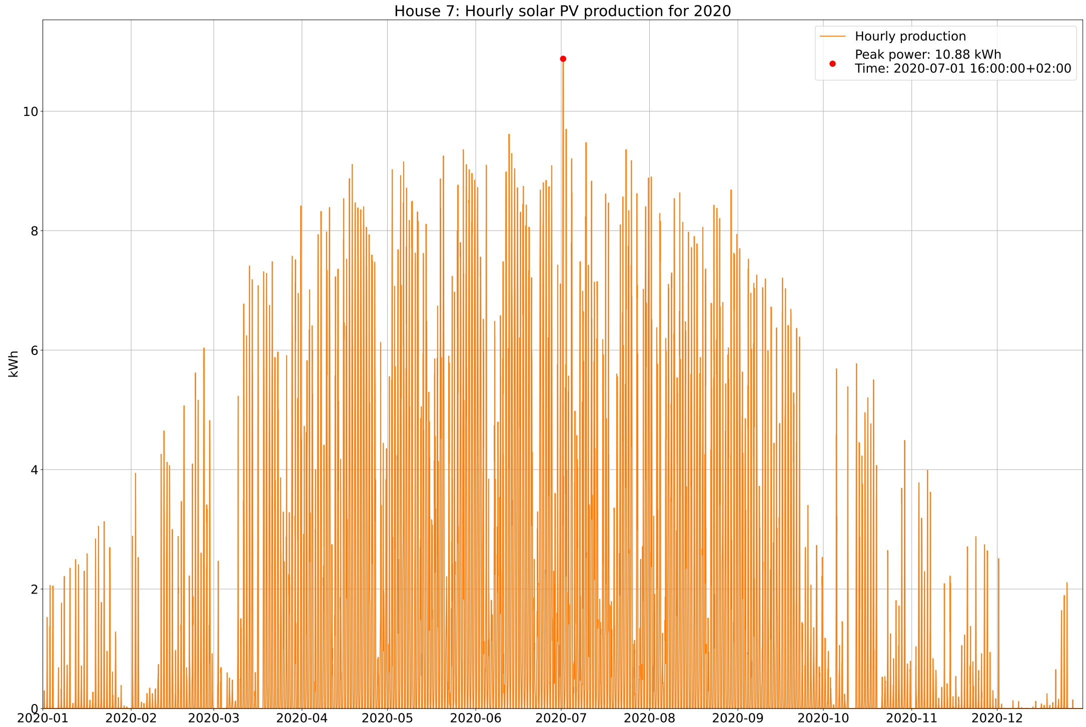



Figure A.128: Hourly PV production for House 7 in 2020.

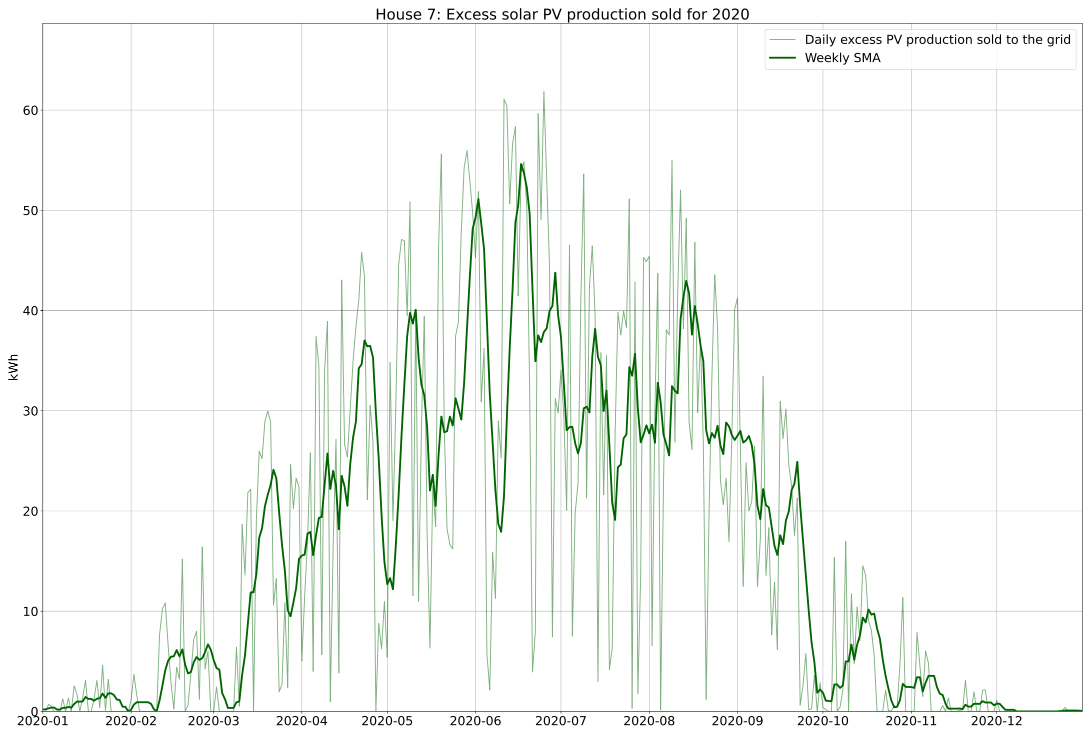



Figure A.129: Daily excess PV production sold to the grid and weekly SMA for House 7 in 2020

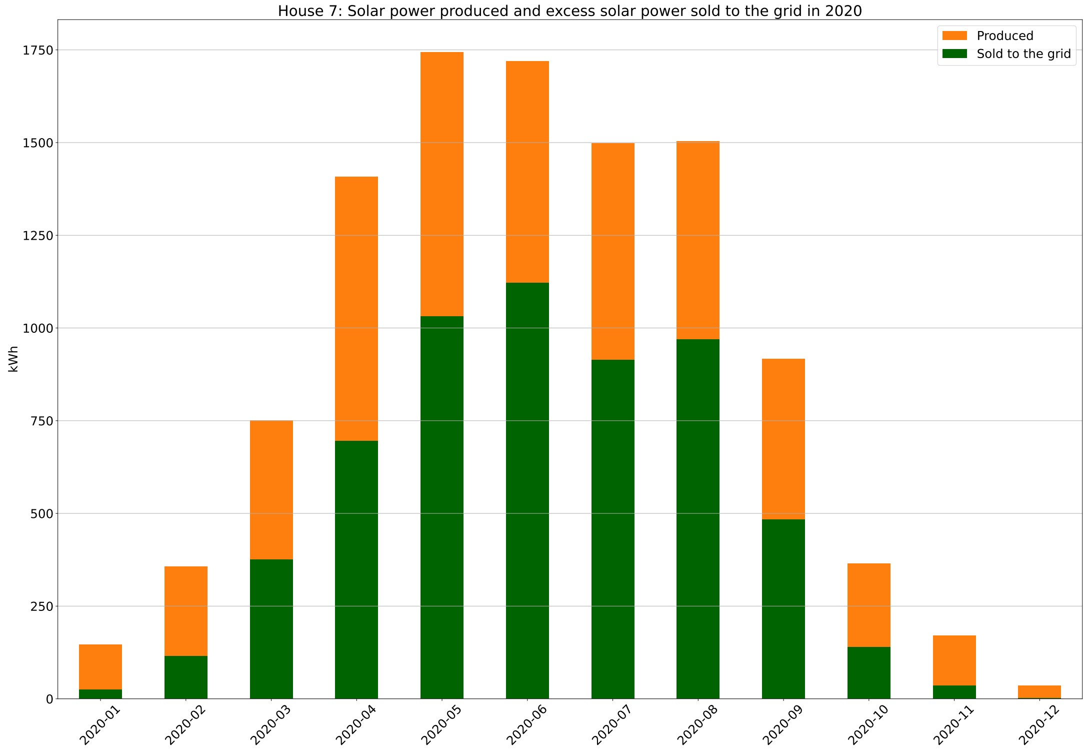



Figure A.130: Total solar PV production and excess production sold to the grid for each month in 2020 from House 7.

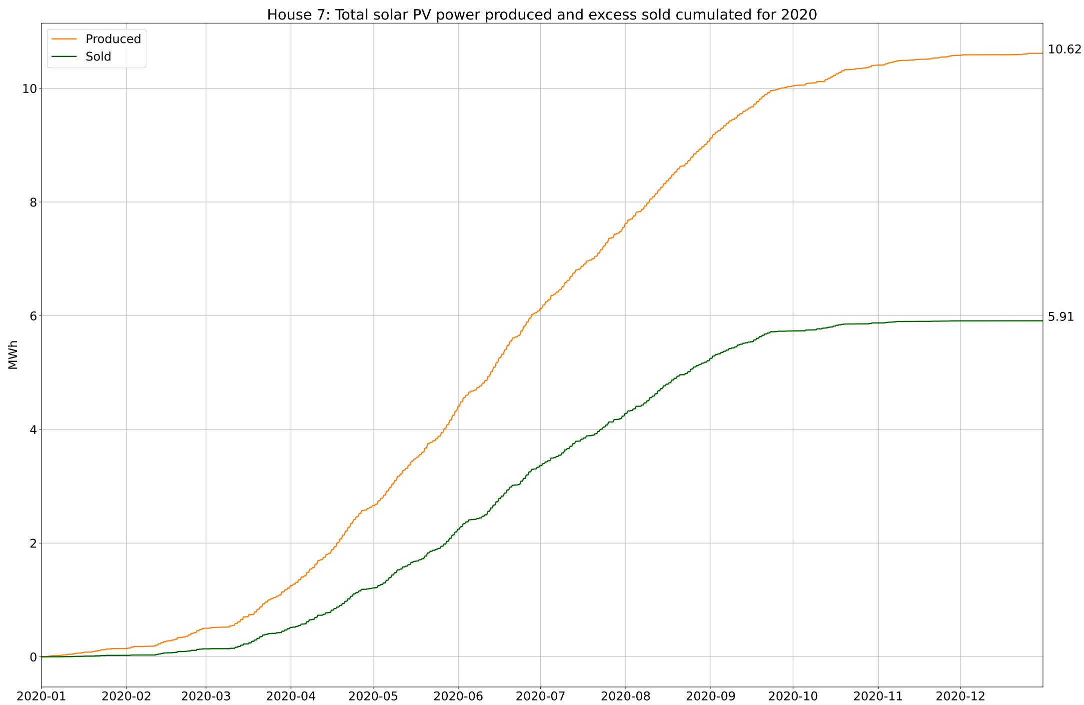



Figure A.131: Total solar PV production and excess production sold cumulated over 2020 from House 7

**2021**

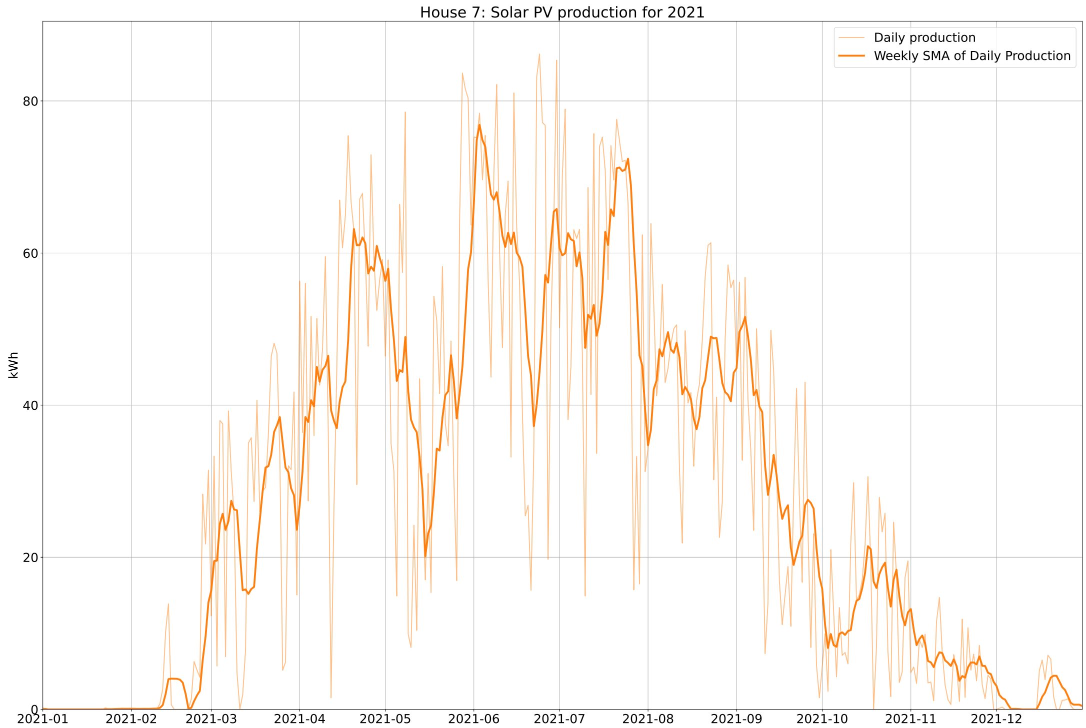



Figure A.132: Daily PV production and weekly SMA for House 7 in 2021.

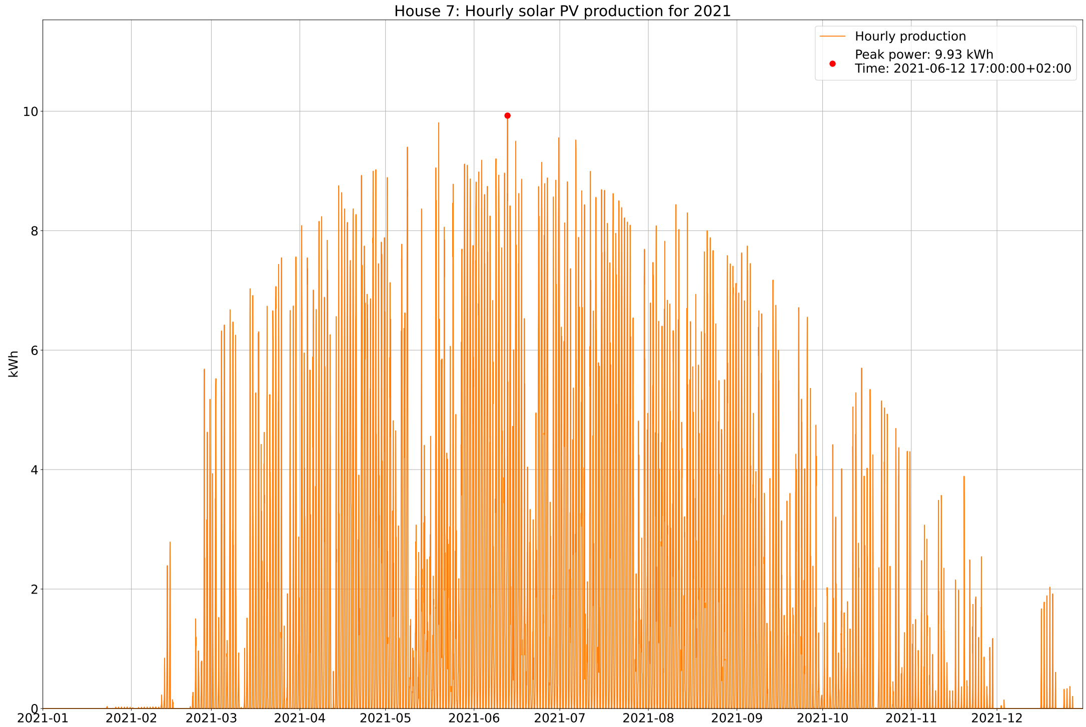



Figure A.133: Hourly PV production for House 7 in 2021.

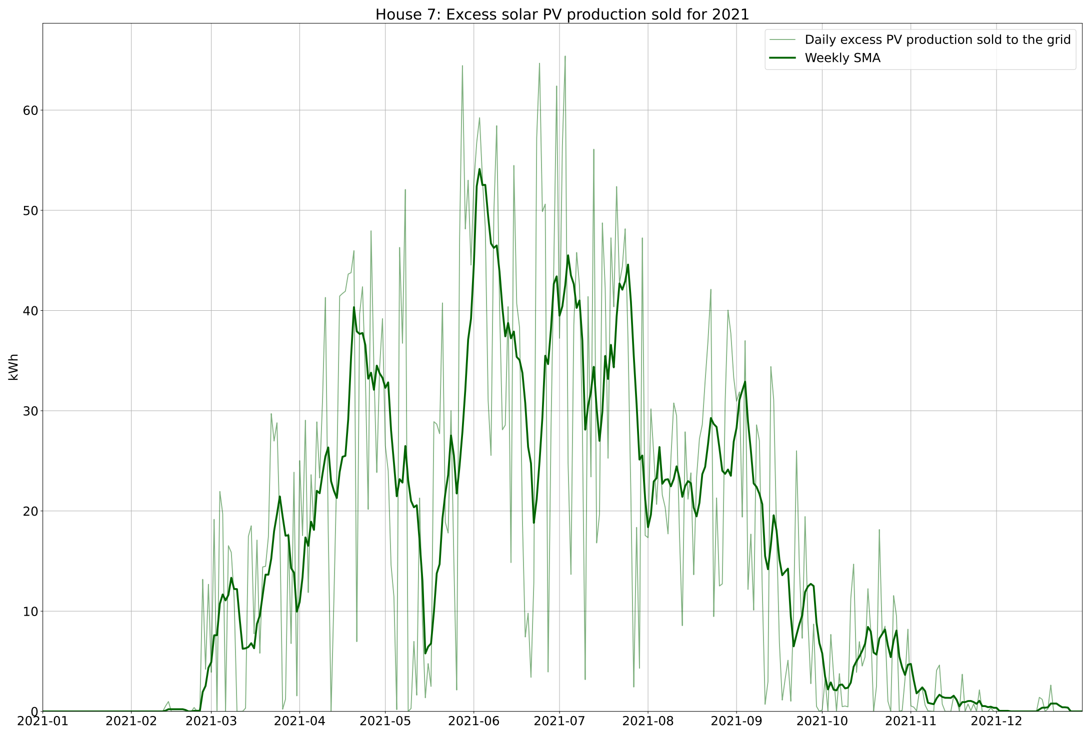



Figure A.134: Daily excess PV production sold to the grid and weekly SMA for House 7 in 2021

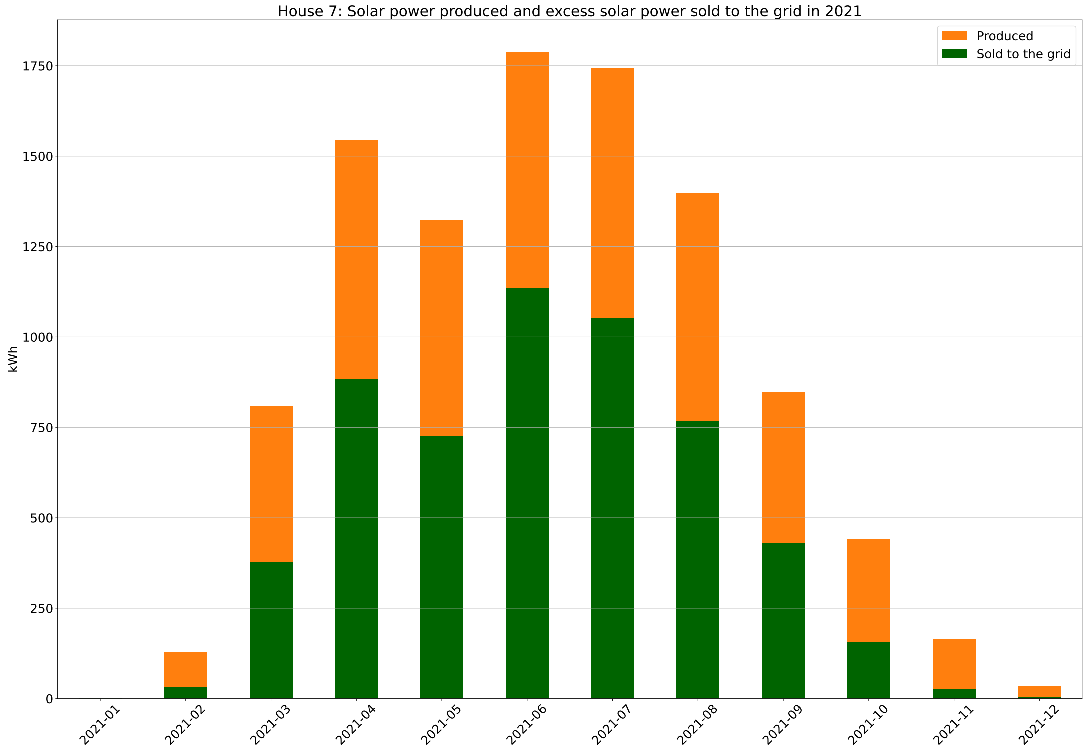



Figure A.135: Total solar PV production and excess production sold to the grid for each month in 2021 from House 7.

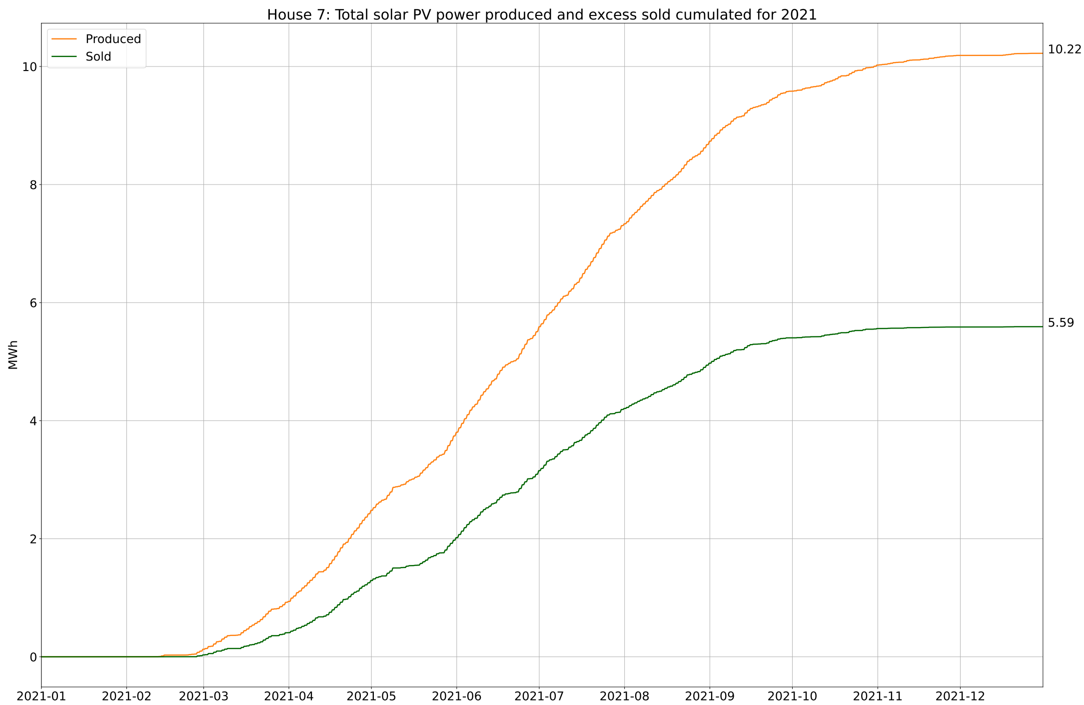



Figure A.136: Total solar PV production and excess production sold cumulated over 2021 from House 7

### A.7.3 Delta variable

#### 2020

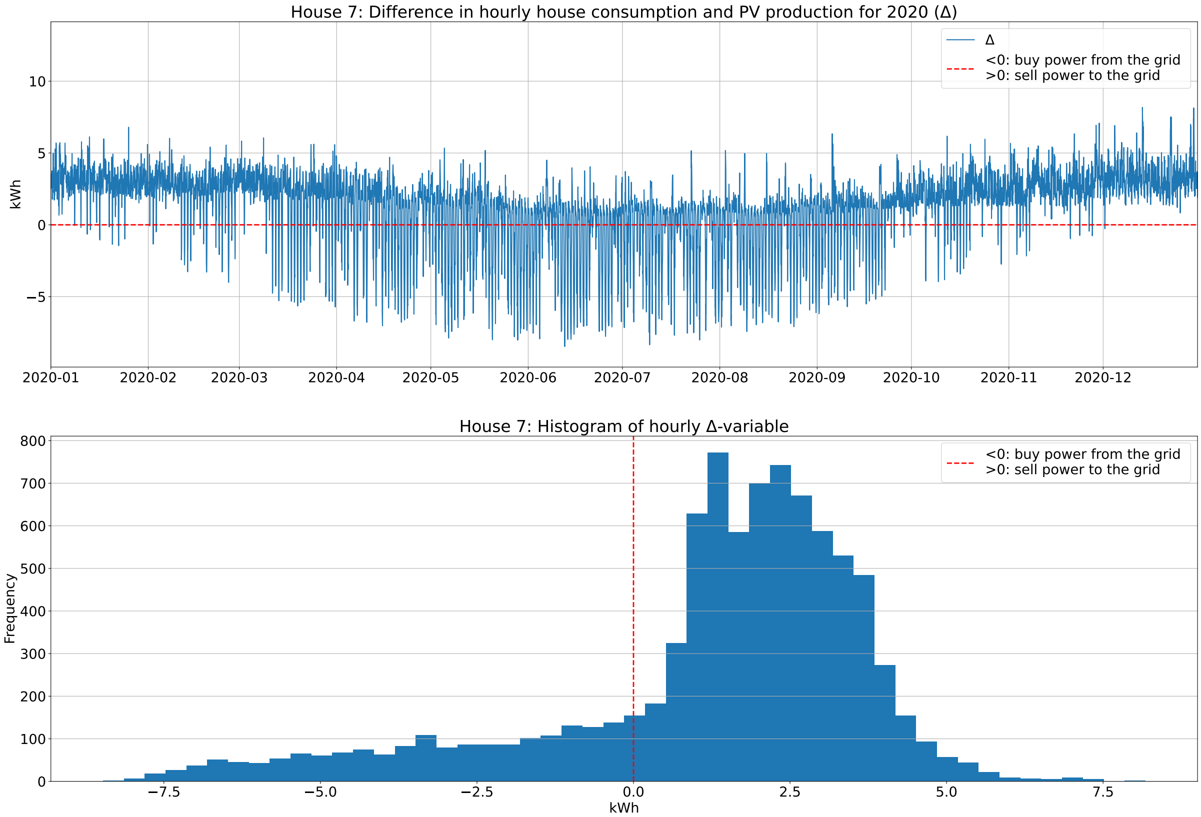



Figure A.137: The delta variable plotted for House 7. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $>0$ and sell when $<0$.

### 2021

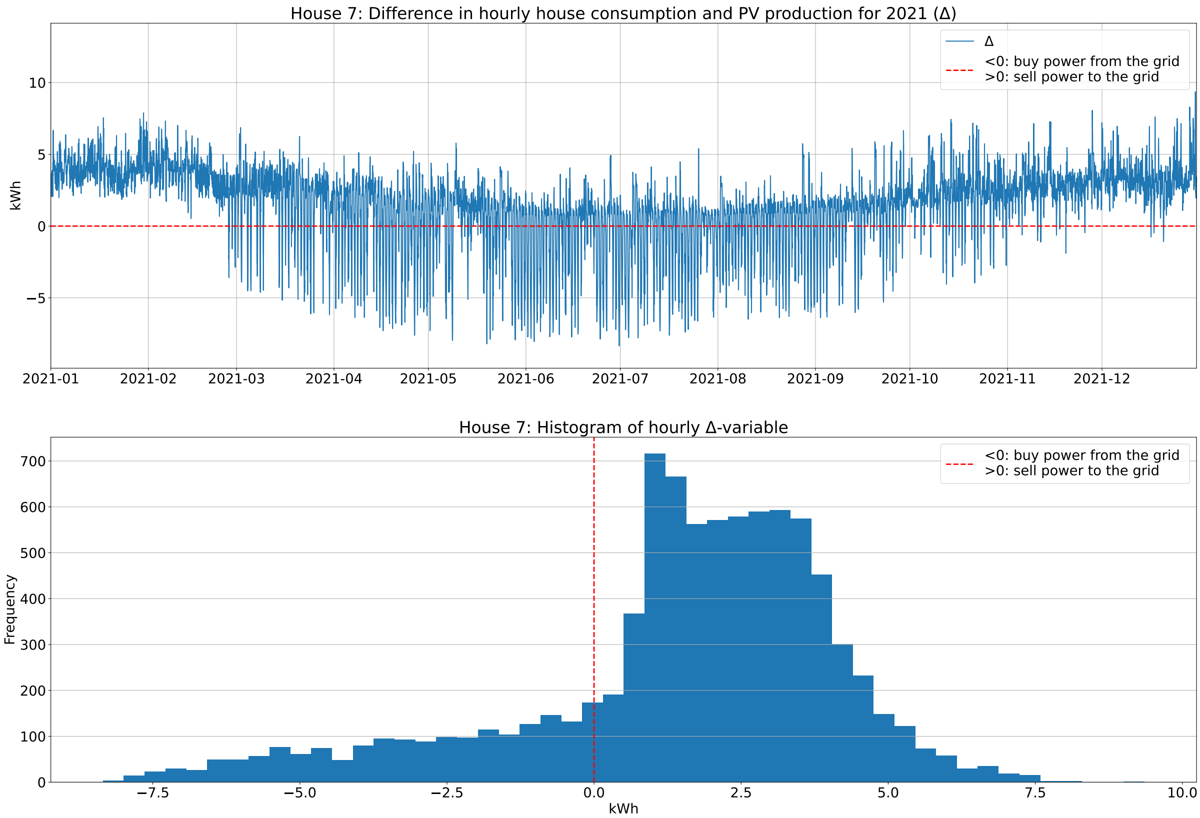



Figure A.138: The delta variable plotted for House 7. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.7.4 House consumption and PV production

### 2020

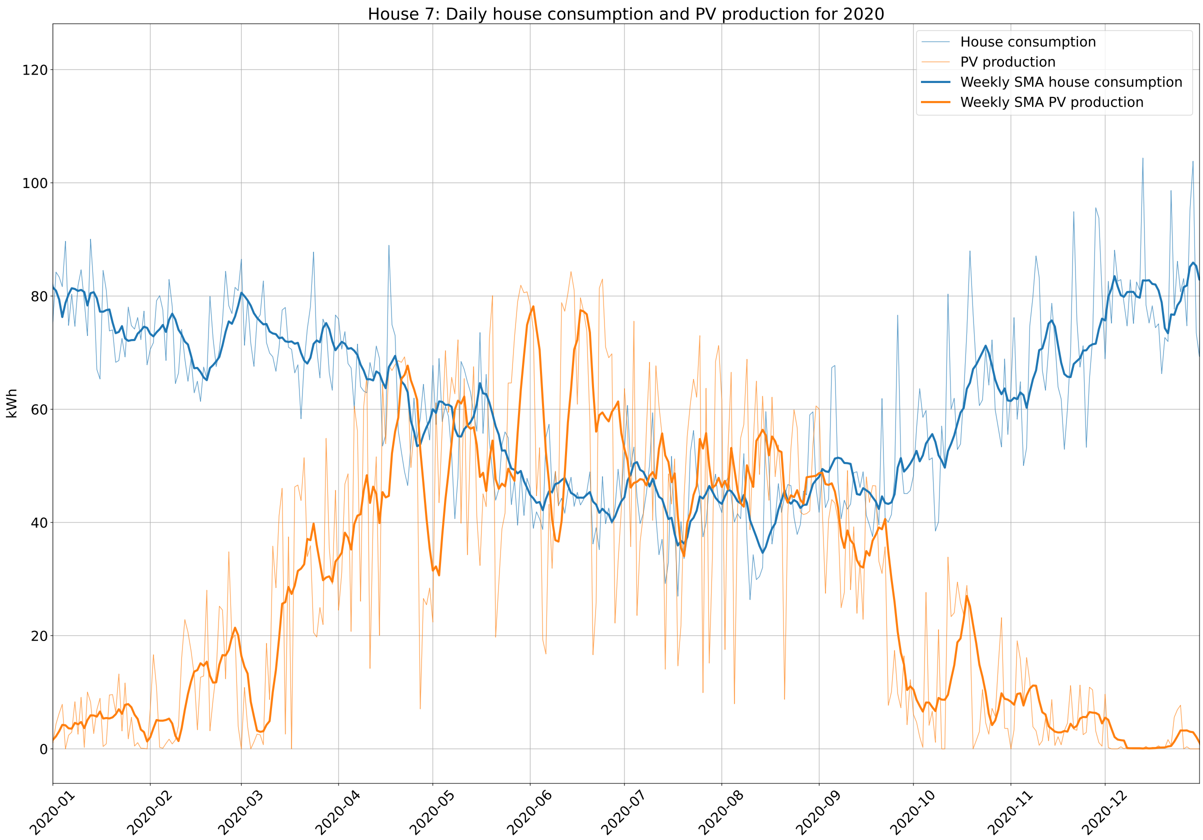



Figure A.139: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

### 2021

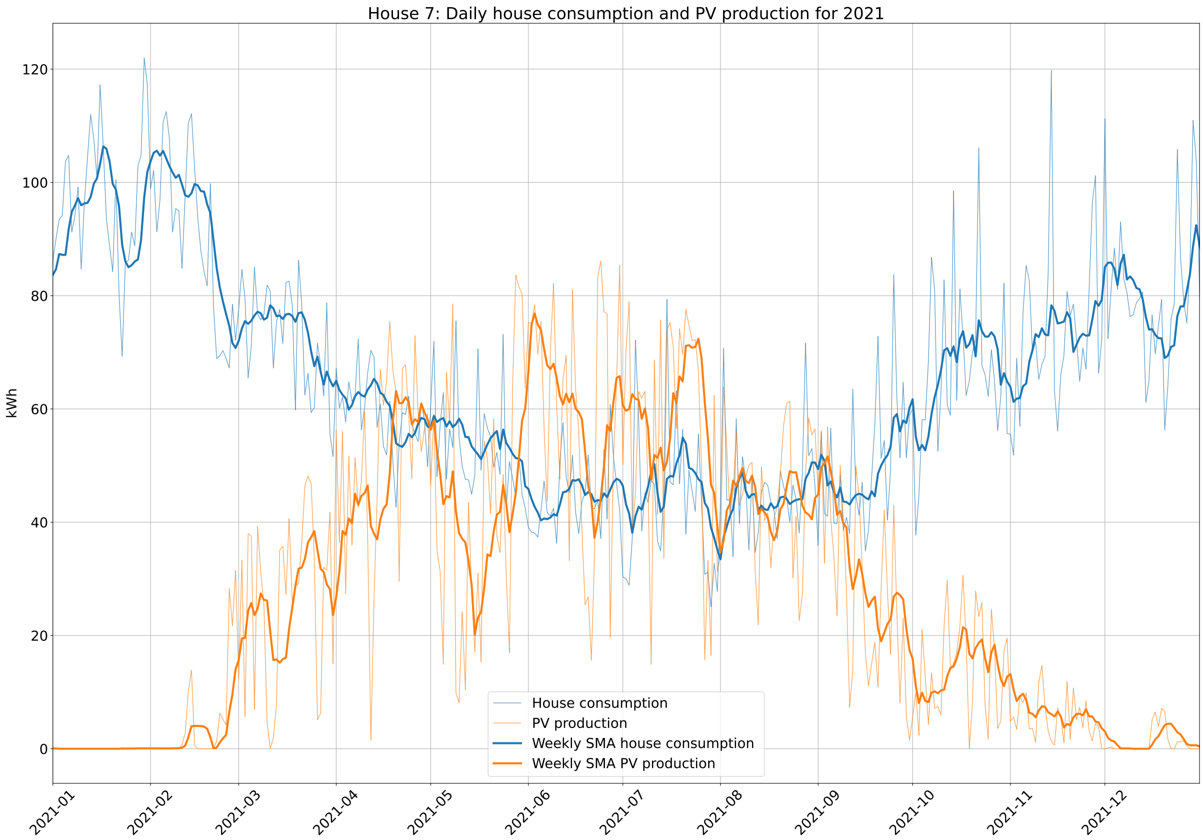



Figure A.140: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.7.5 Cost of energy

#### 2020

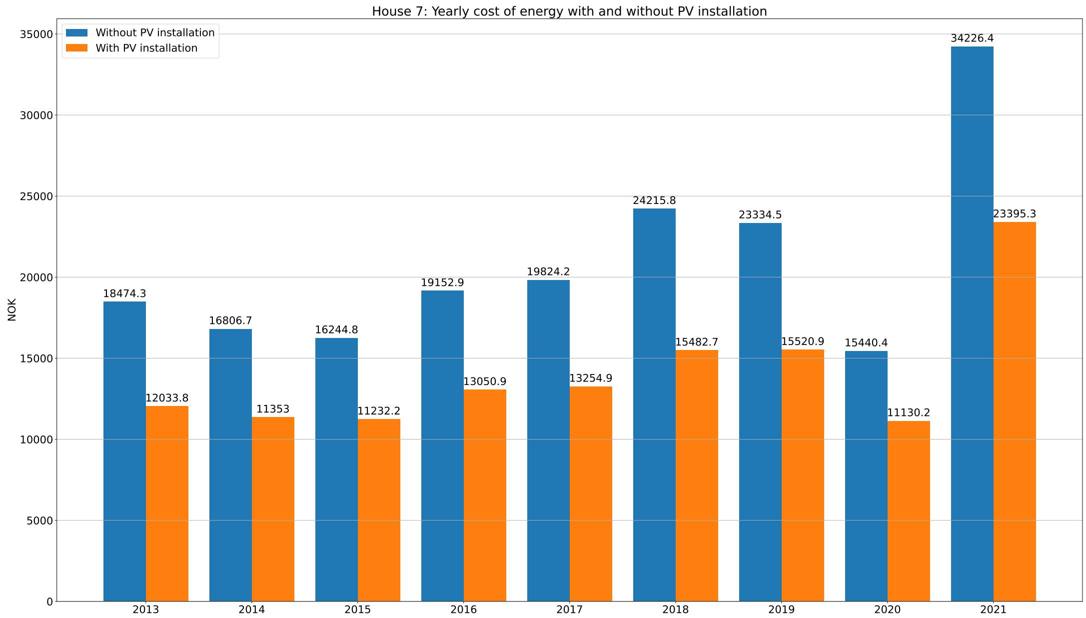



Figure A.141: Yearly cost of energy for House 7, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

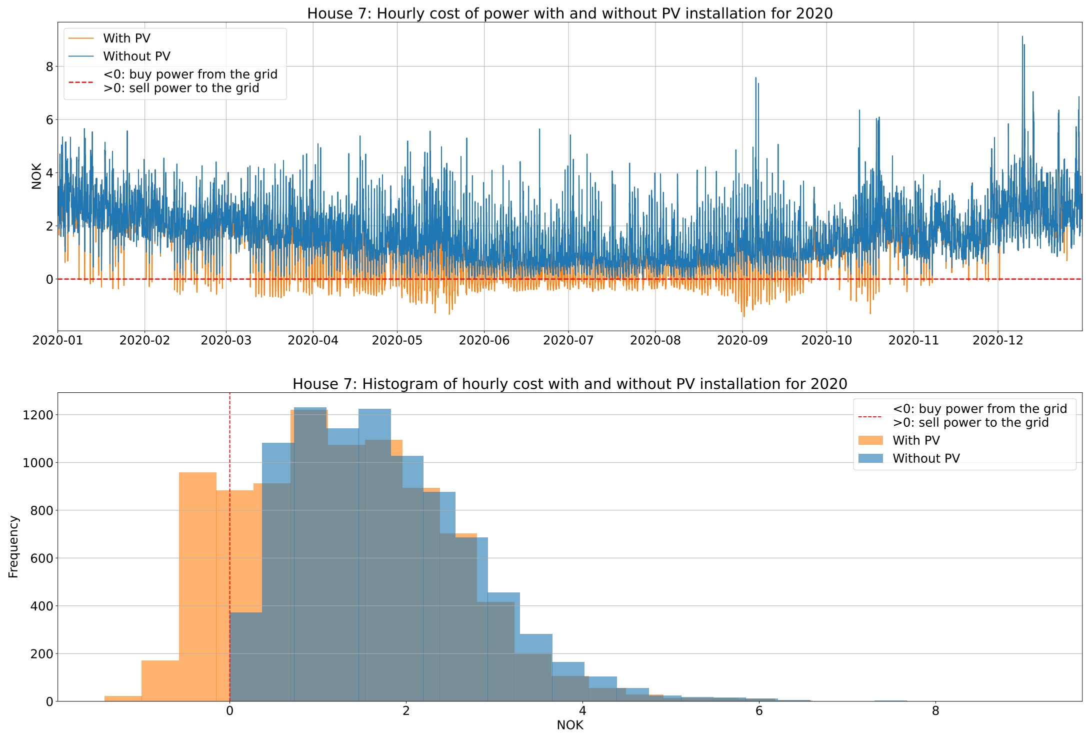



Figure A.142: Hourly cost of energy for House 7 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when > 0 and sell when < 0.

**2021**

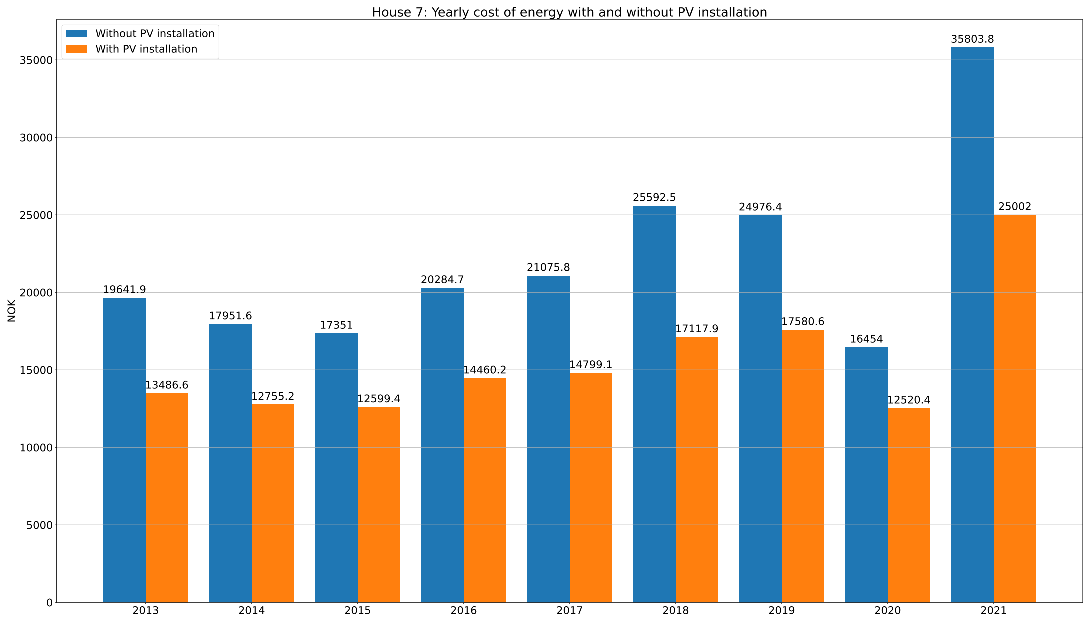



Figure A.143: Yearly cost of energy for House 7, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

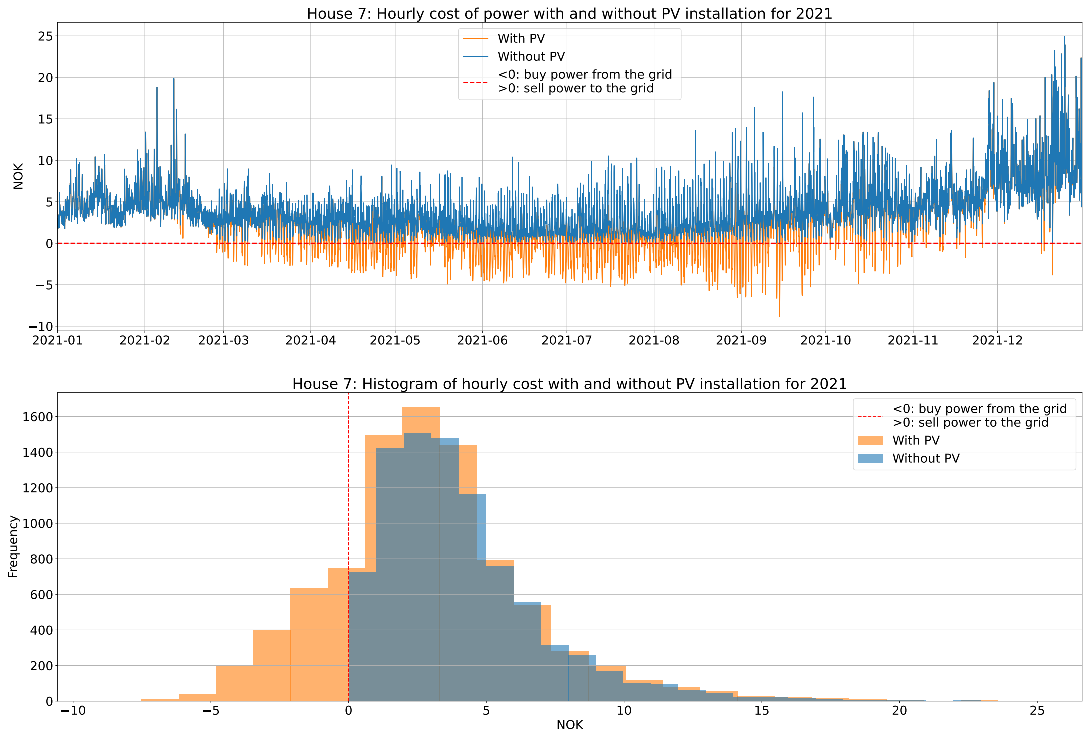
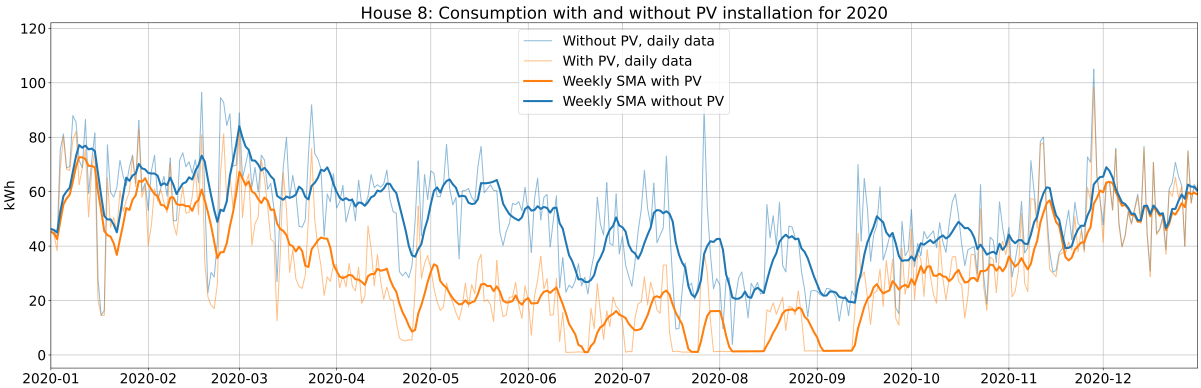



Figure A.144: Hourly cost of energy for House 7 with and without a PV system present for 2021. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.8 House 8

### A.8.1 House consumption

**2020**



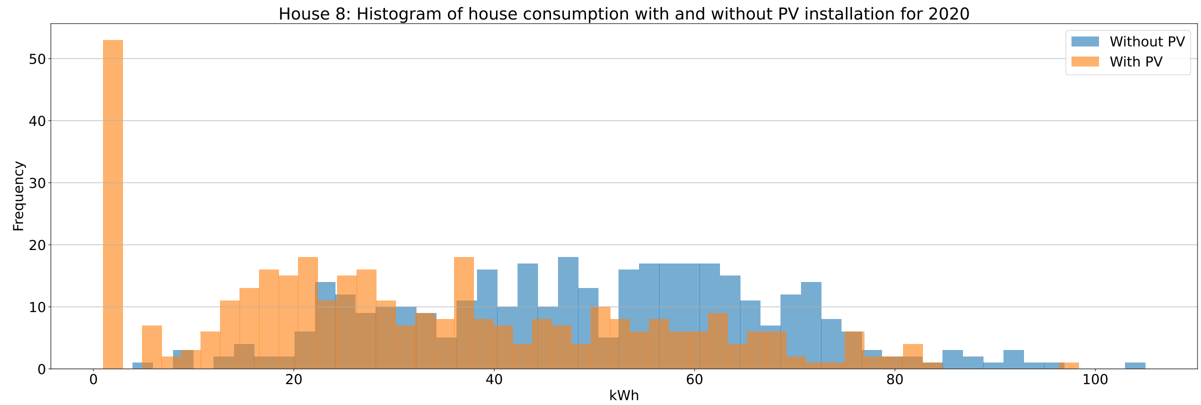




Figure A.145: Daily house consumption with and without a PV system for 2020 from House 8. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

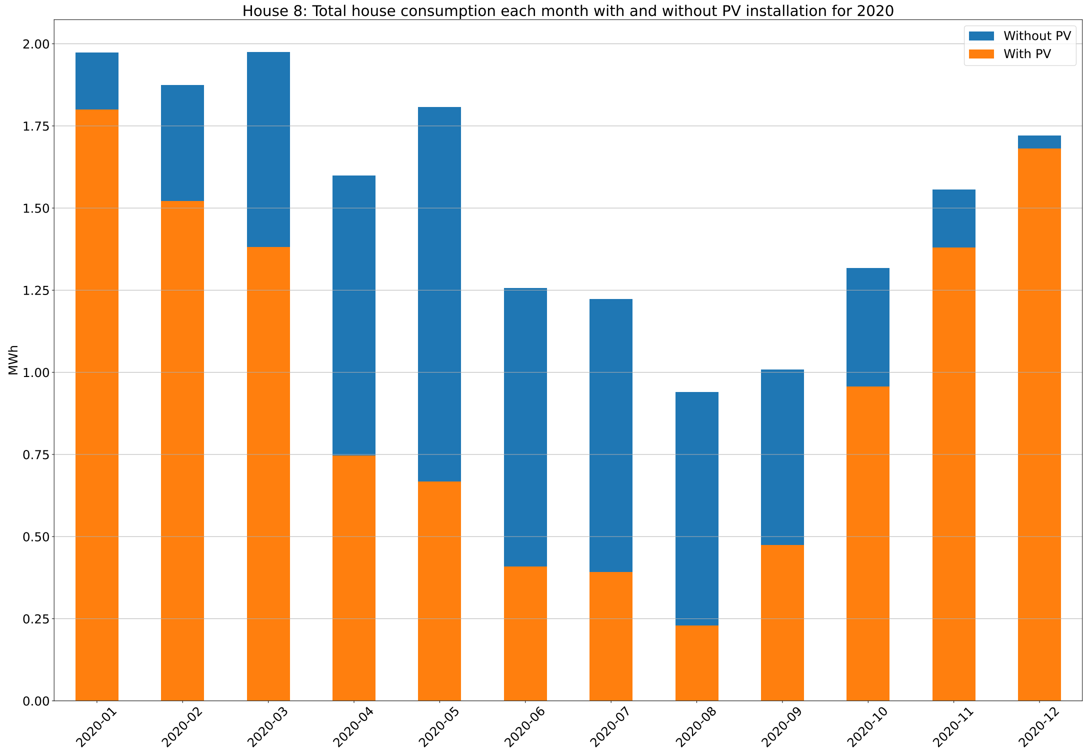



Figure A.146: Monthly house consumption for House 8 with and without a PV system for 2020.

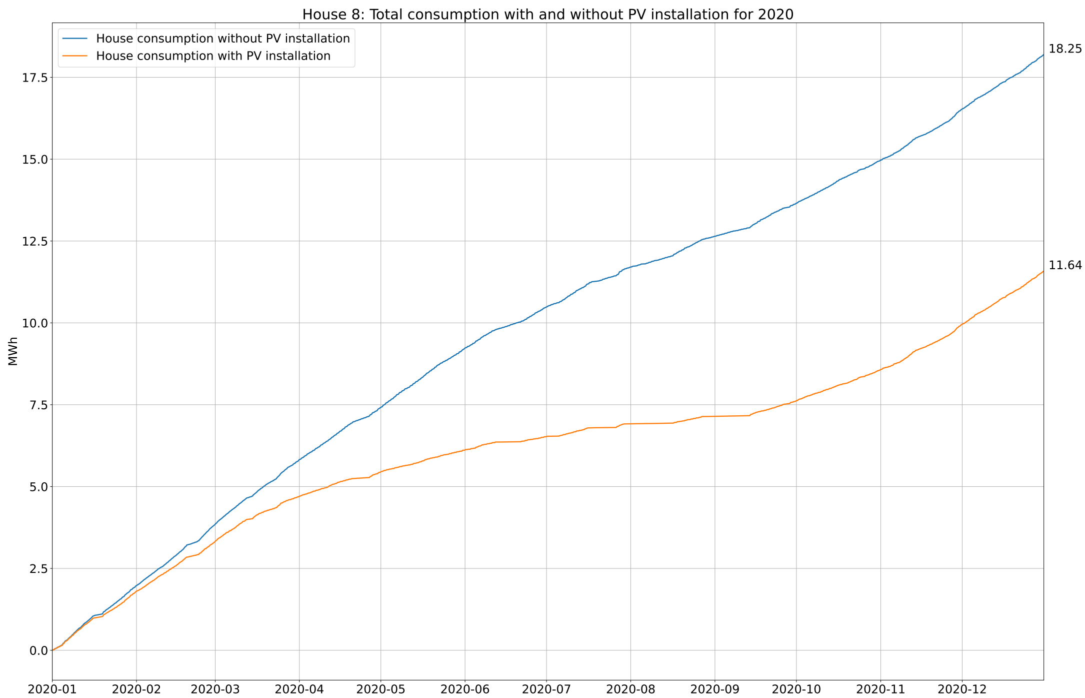
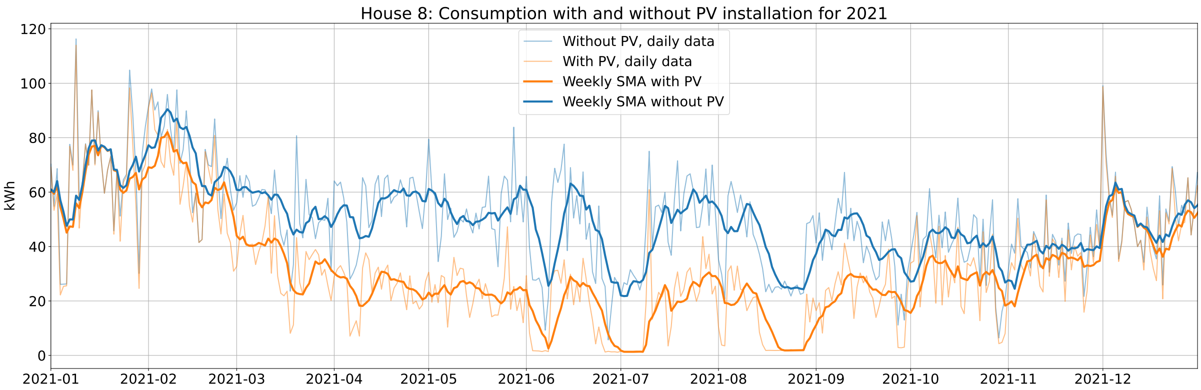



Figure A.147: Total house consumption for House 8 with and without a PV system accumulated over 2020

### 2021



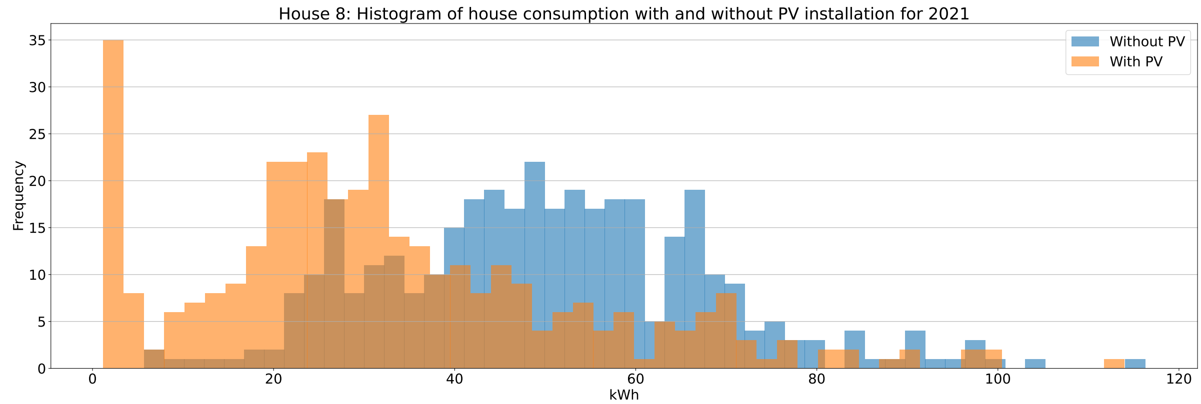




Figure A.148: Daily house consumption with and without a PV system for 2021 from House 8. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

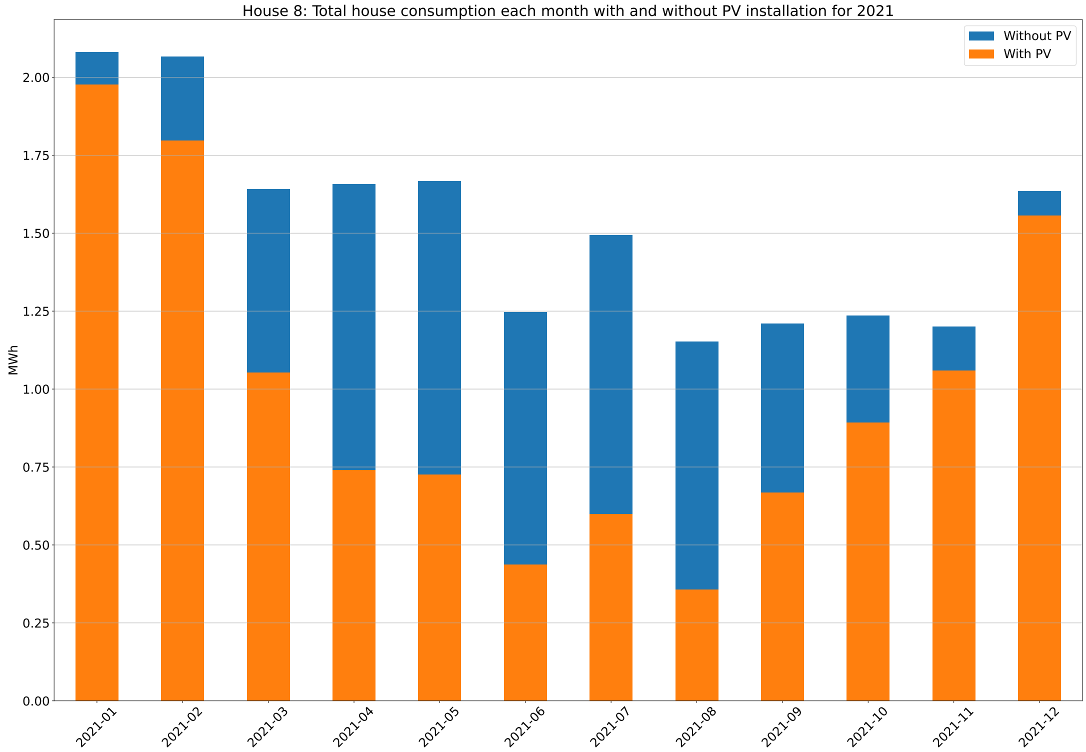



Figure A.149: Monthly house consumption for House 8 with and without a PV system for 2021.

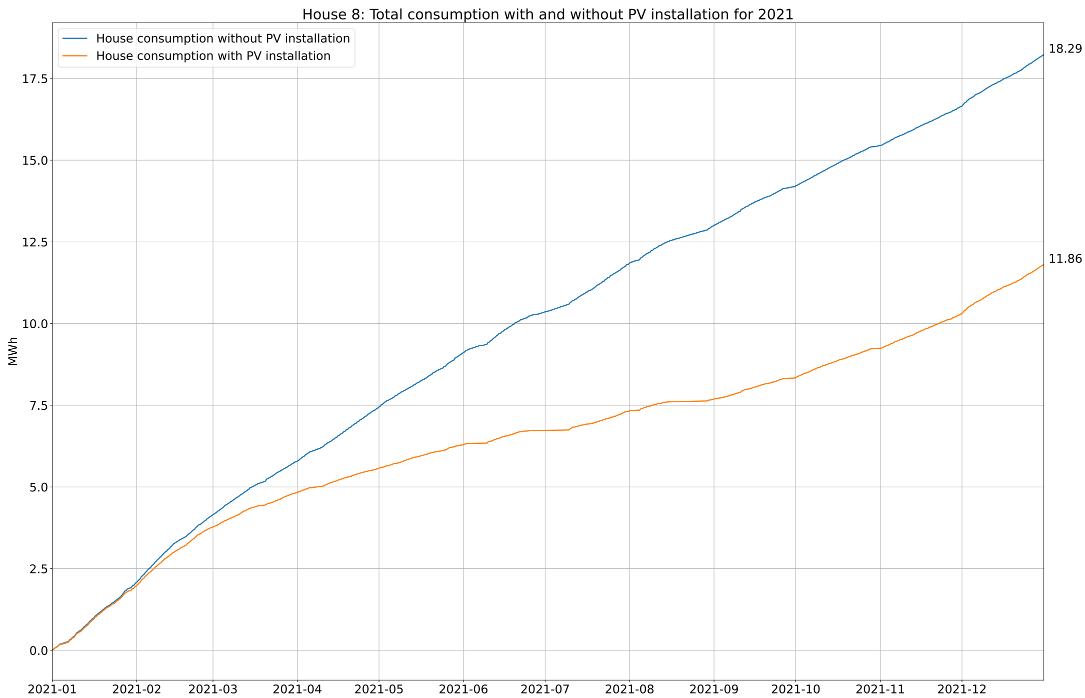



Figure A.150: Total house consumption for House 8 with and without a PV system accumulated over 2021

### A.8.2 Solar PV production

#### 2020

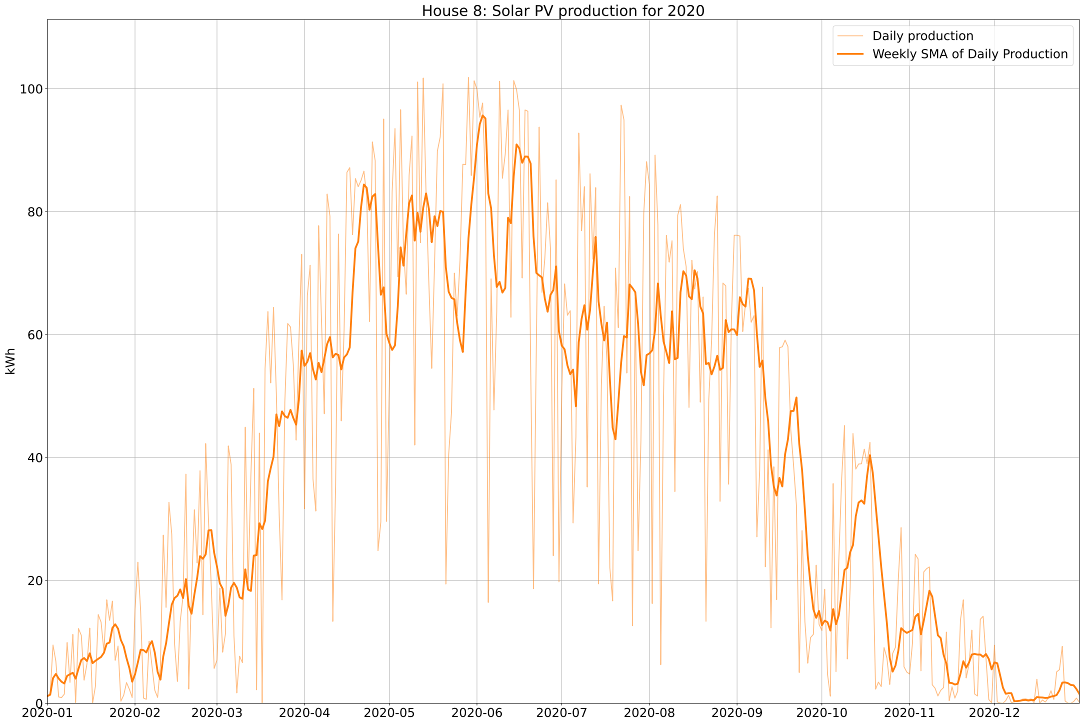



Figure A.151: Daily PV production and weekly SMA for House 8 in 2020.

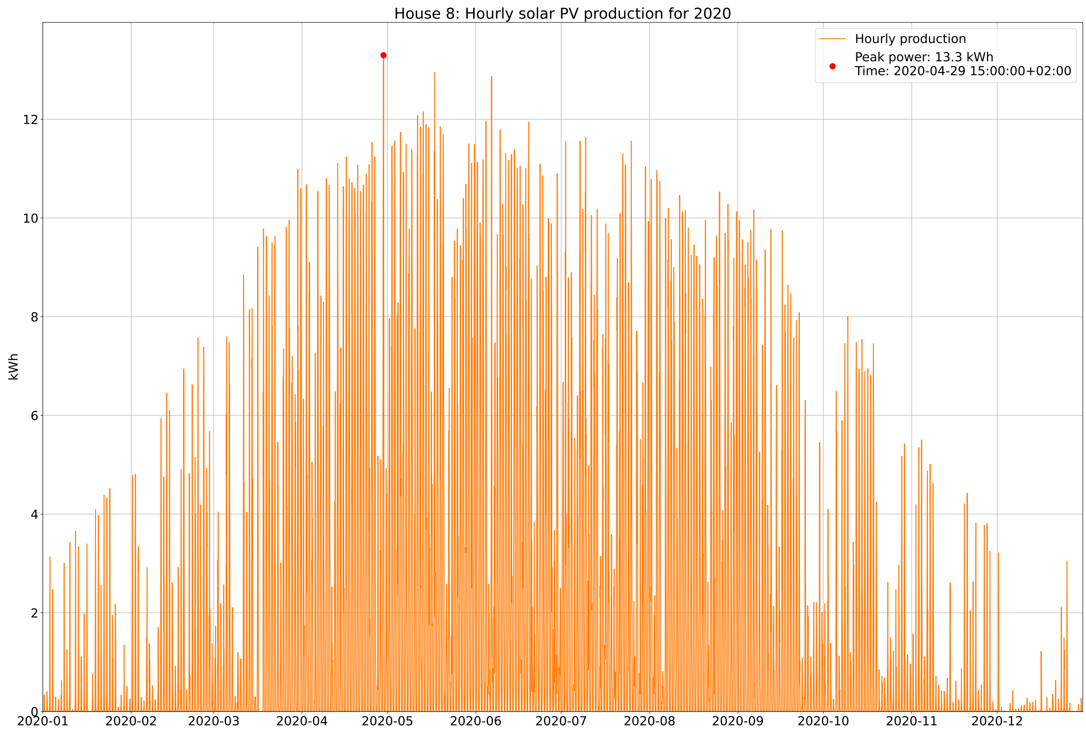



Figure A.152: Hourly PV production for House 8 in 2020.

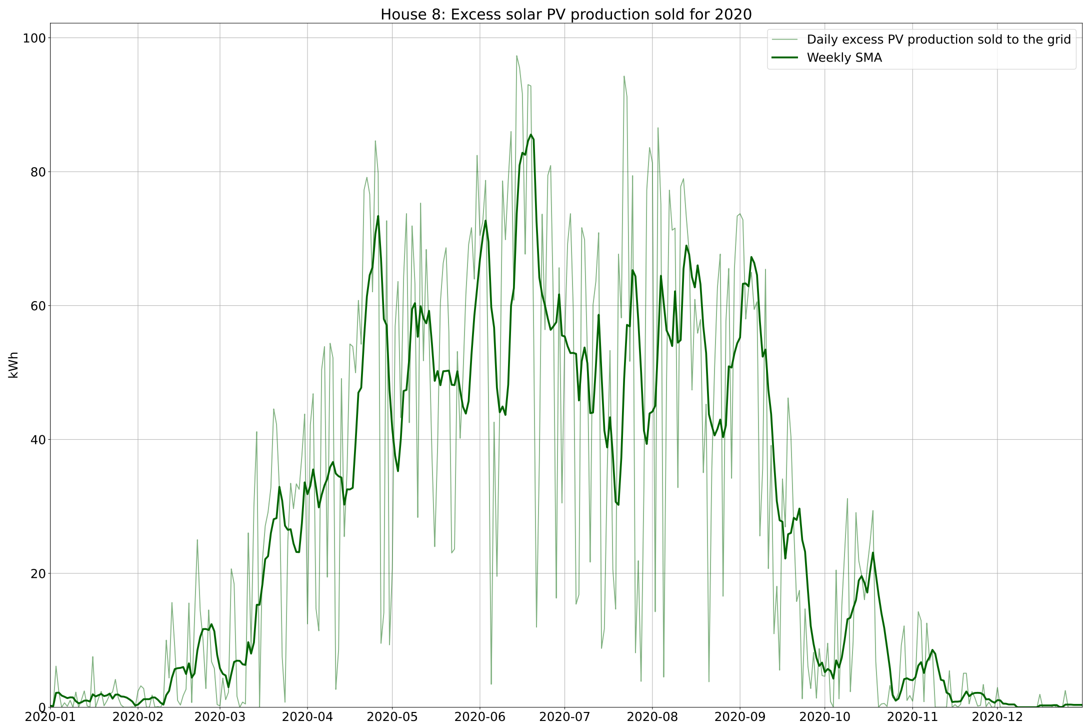



Figure A.153: Daily excess PV production sold to the grid and weekly SMA for House 8 in 2020

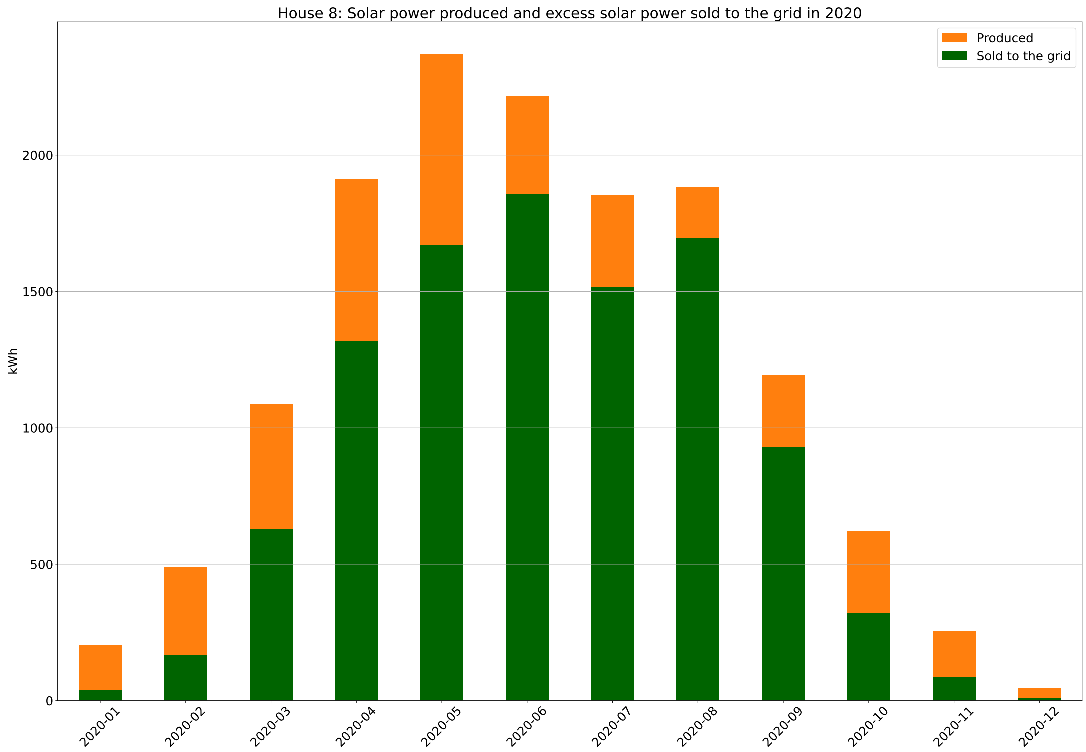



Figure A.154: Total solar PV production and excess production sold to the grid for each month in 2020 from House 8.

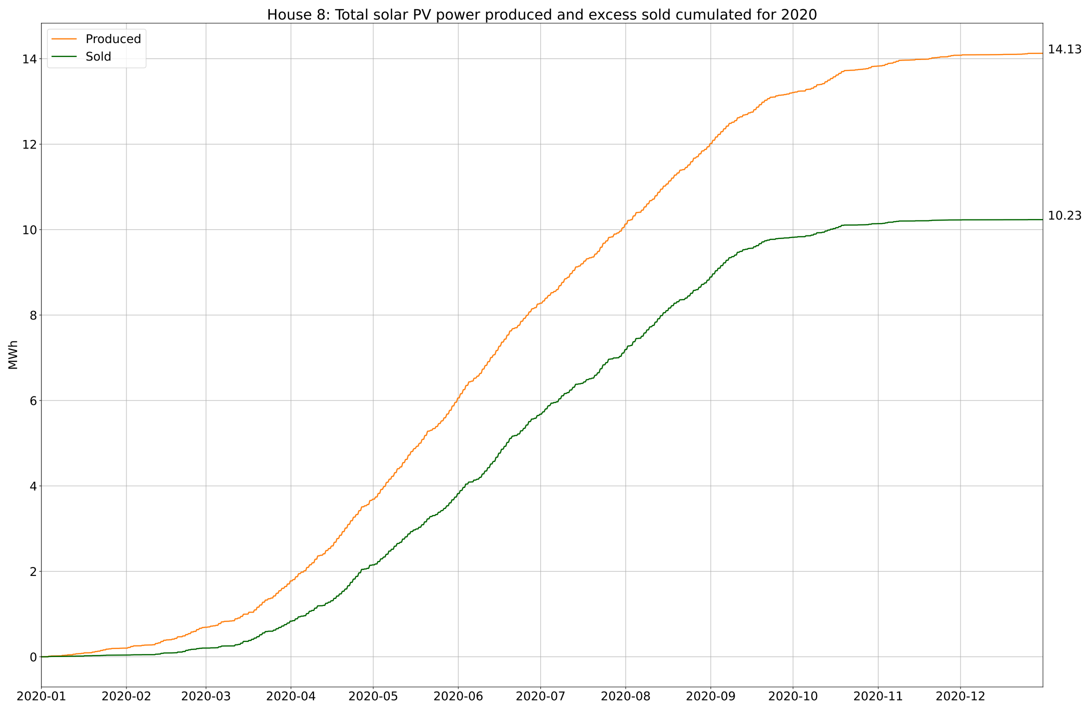



Figure A.155: Total solar PV production and excess production sold cumulated over 2020 from House 8

**2021**

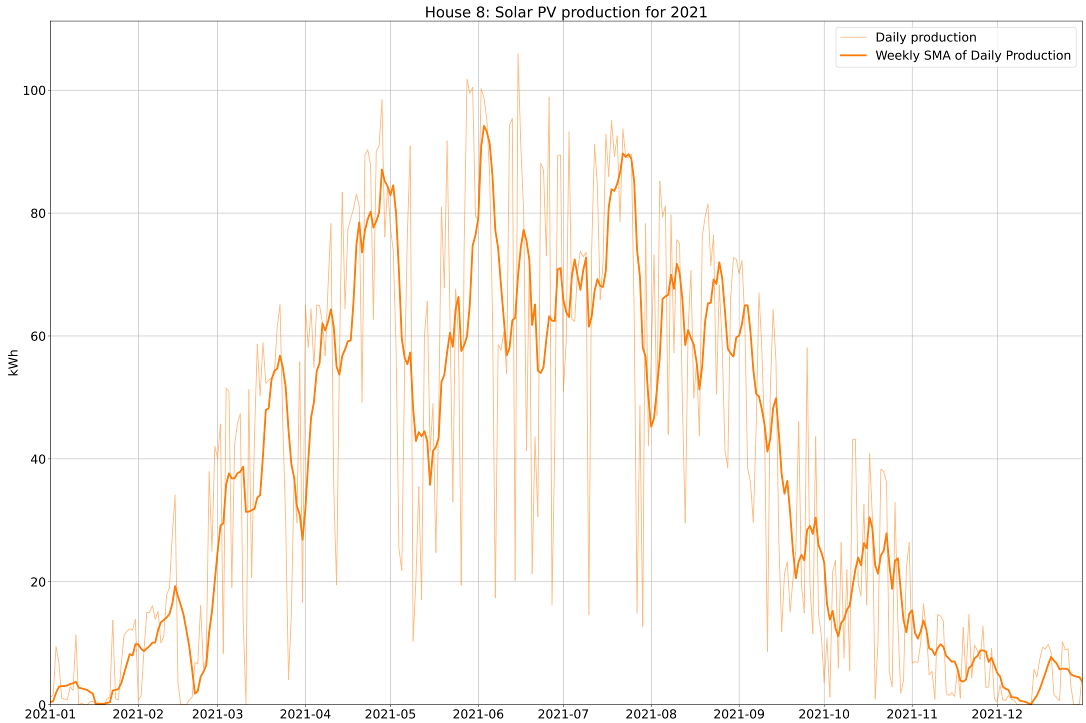



Figure A.156: Daily PV production and weekly SMA for House 8 in 2021.

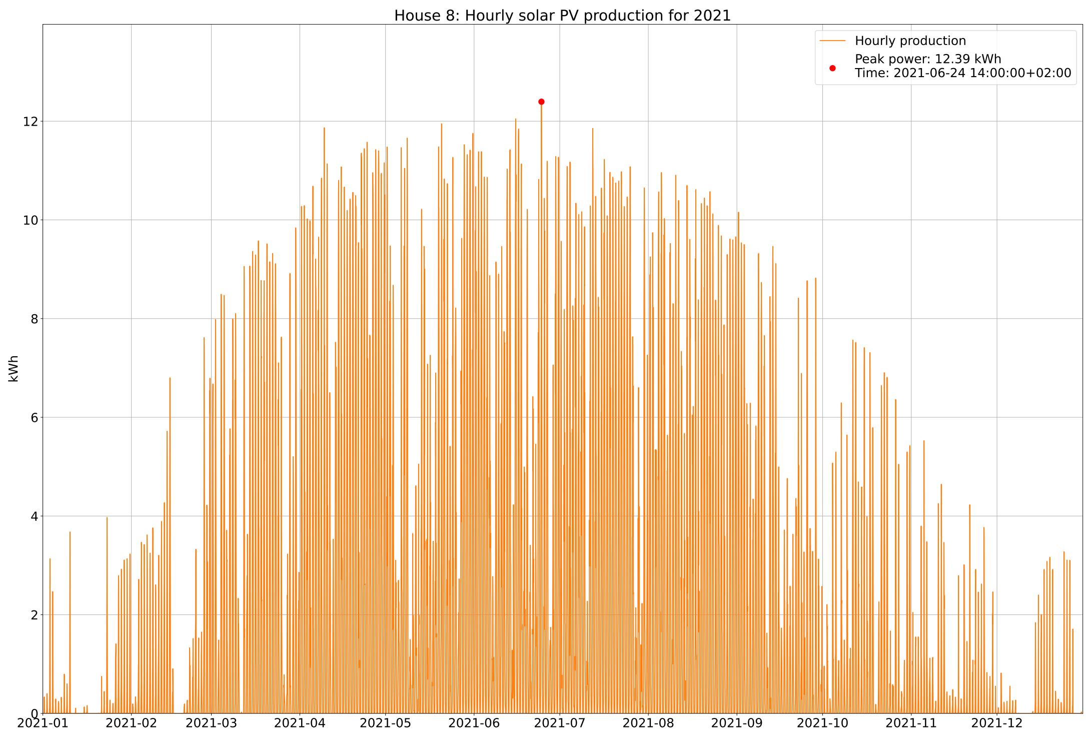



Figure A.157: Hourly PV production for House 8 in 2021.

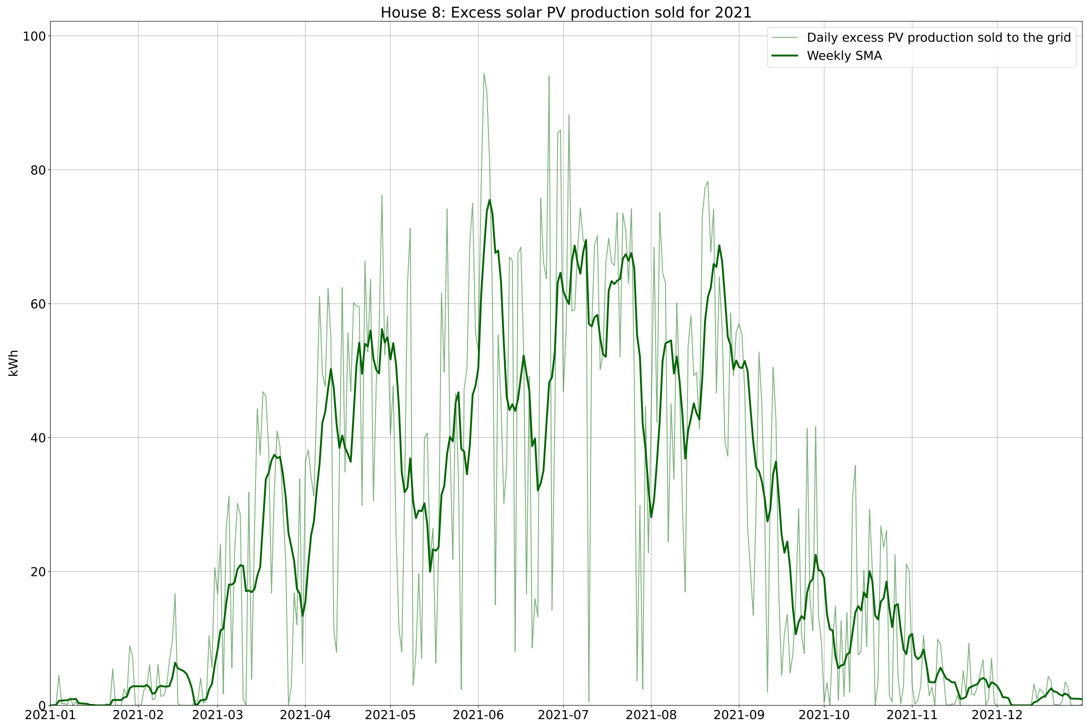



Figure A.158: Daily excess PV production sold to the grid and weekly SMA for House 8 in 2021

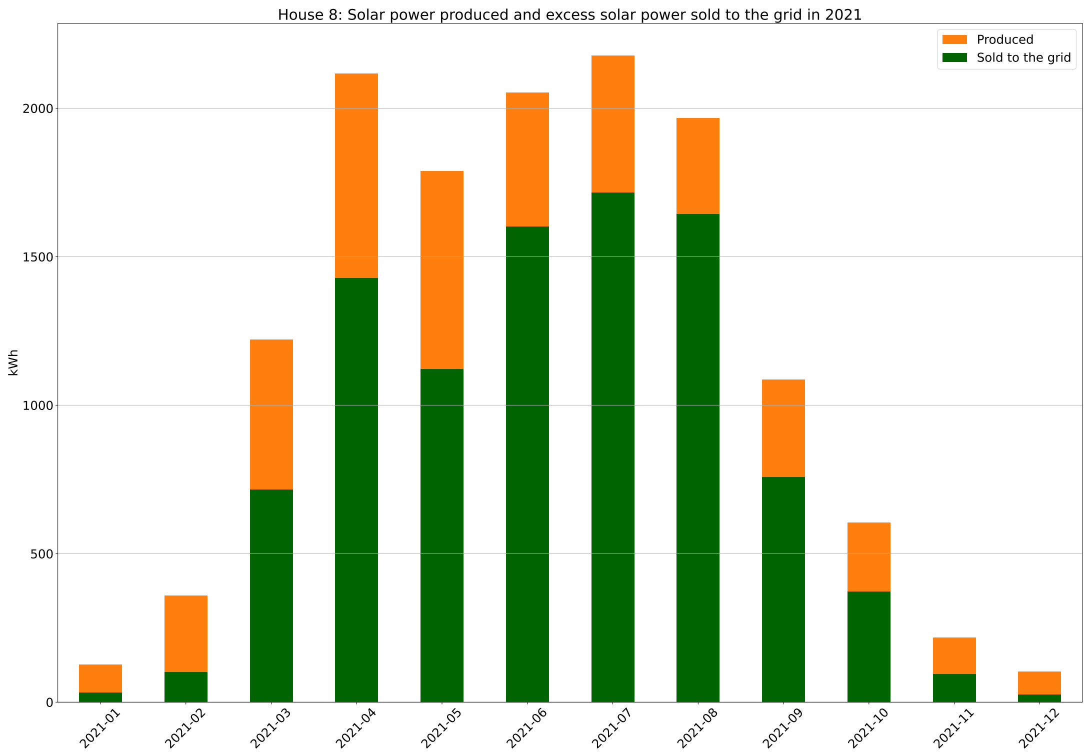



Figure A.159: Total solar PV production and excess production sold to the grid for each month in 2021 from House 8.

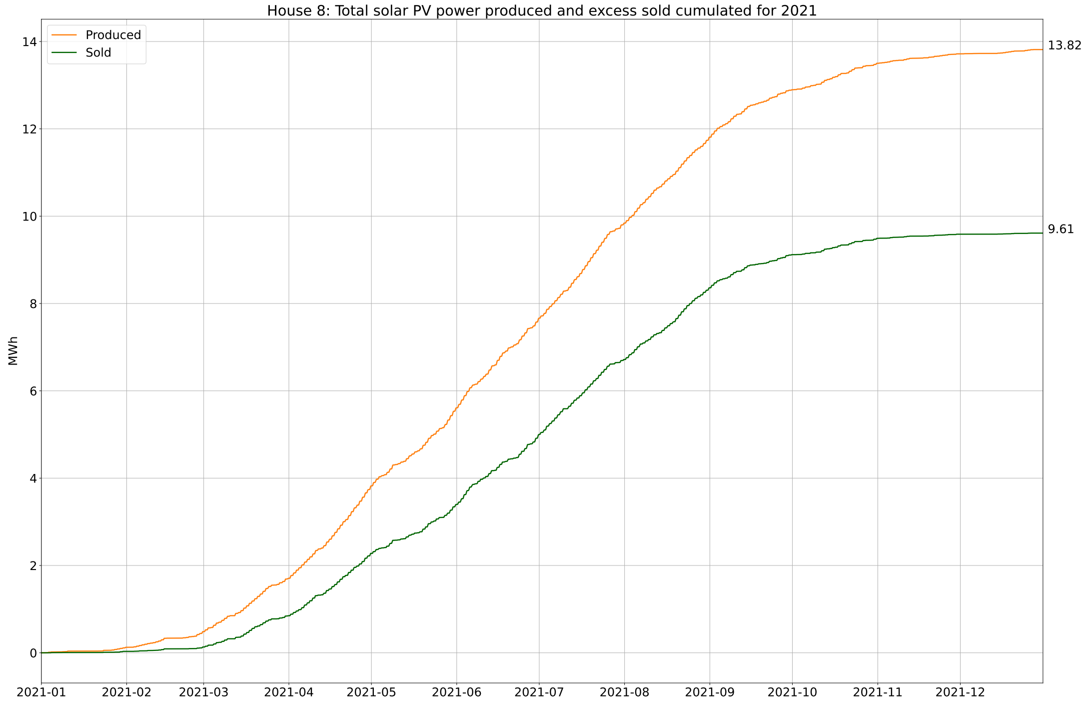



Figure A.160: Total solar PV production and excess production sold cumulated over 2021 from House 8

### A.8.3 Delta variable

#### 2020

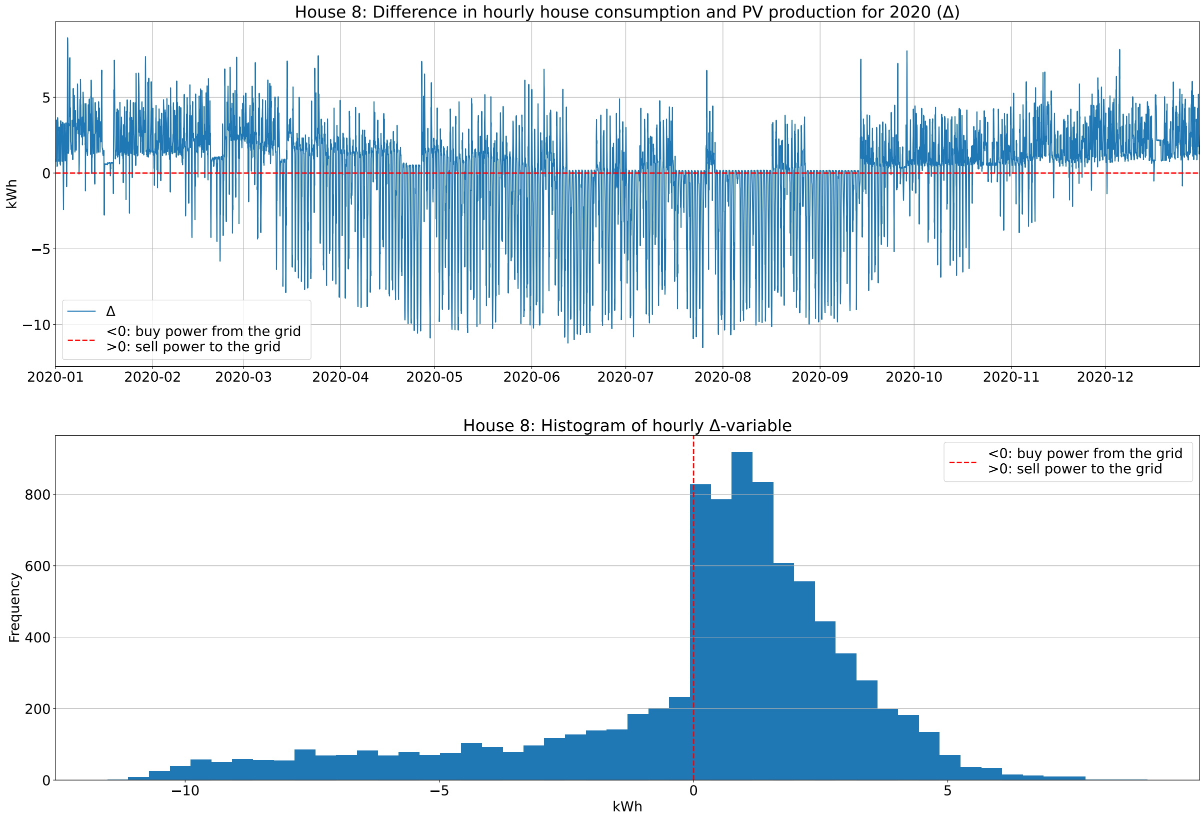



Figure A.161: The delta variable plotted for House 8. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

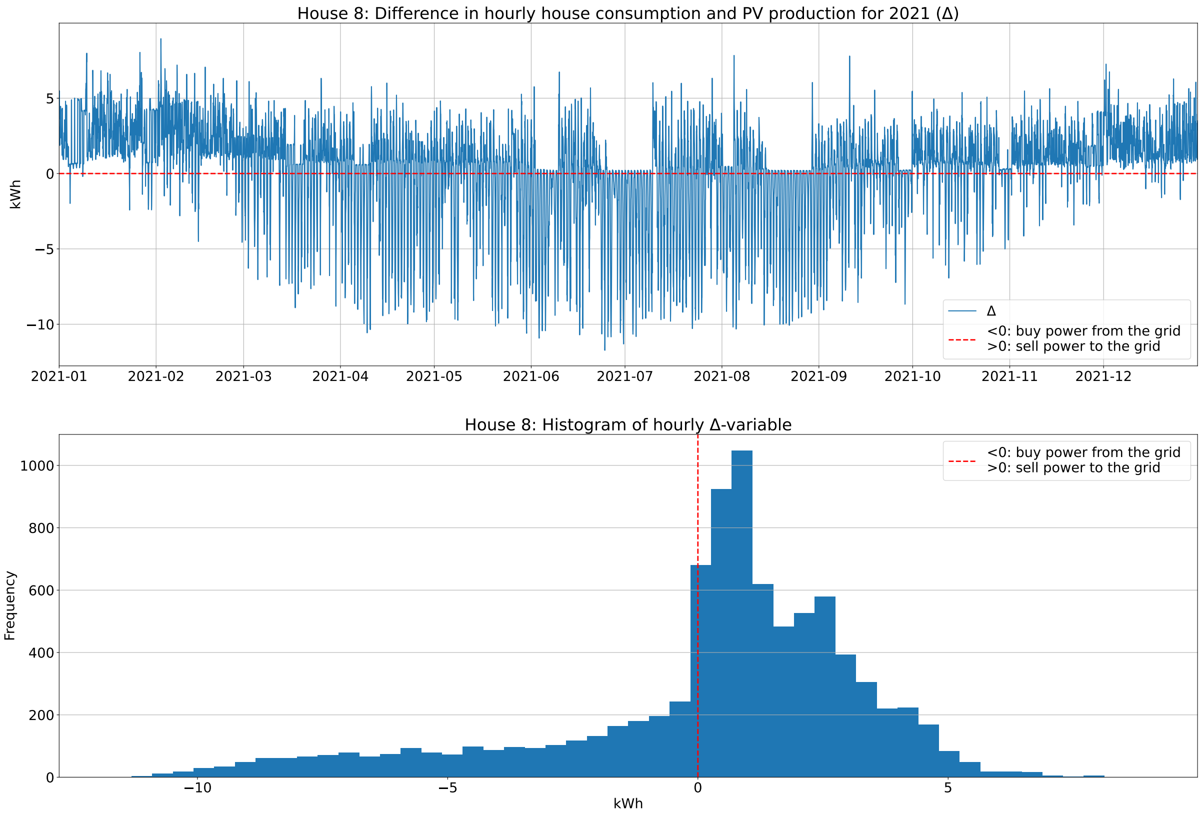



Figure A.162: The delta variable plotted for House 8. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.8.4 House consumption and PV production

**2020**

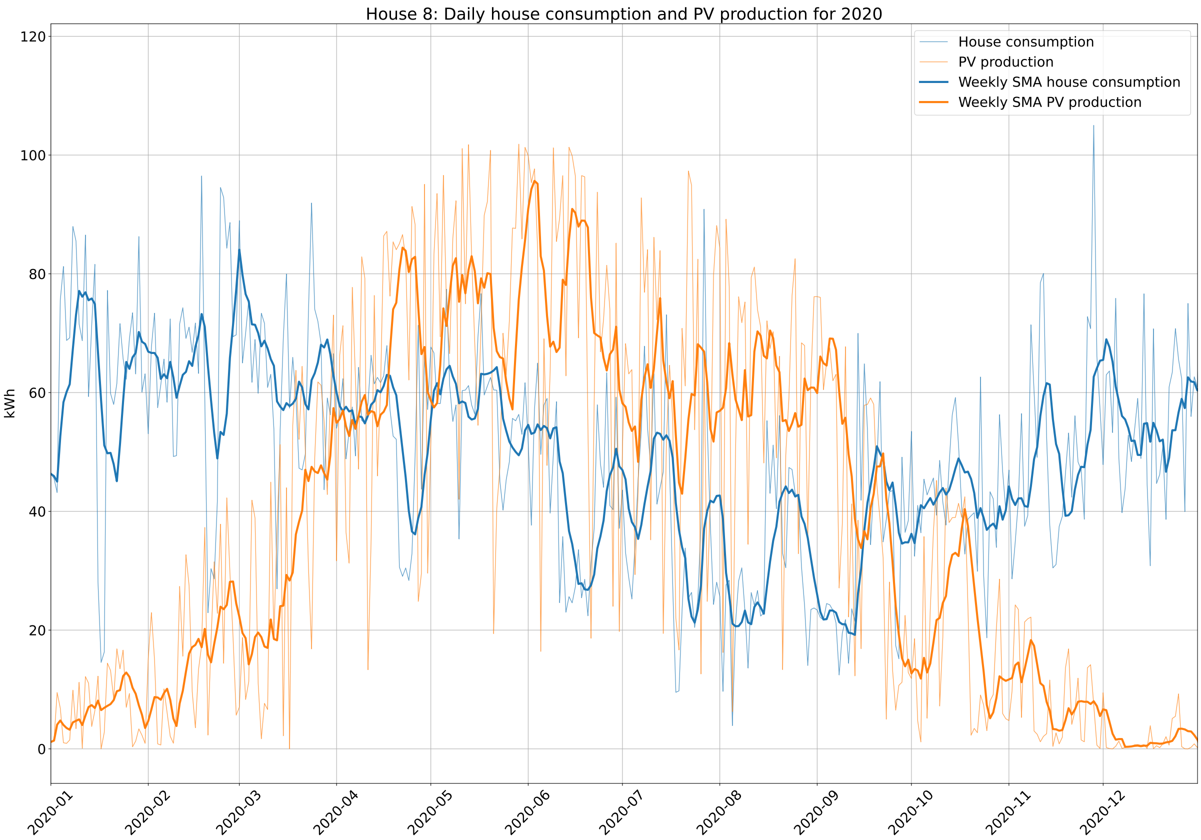



Figure A.163: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

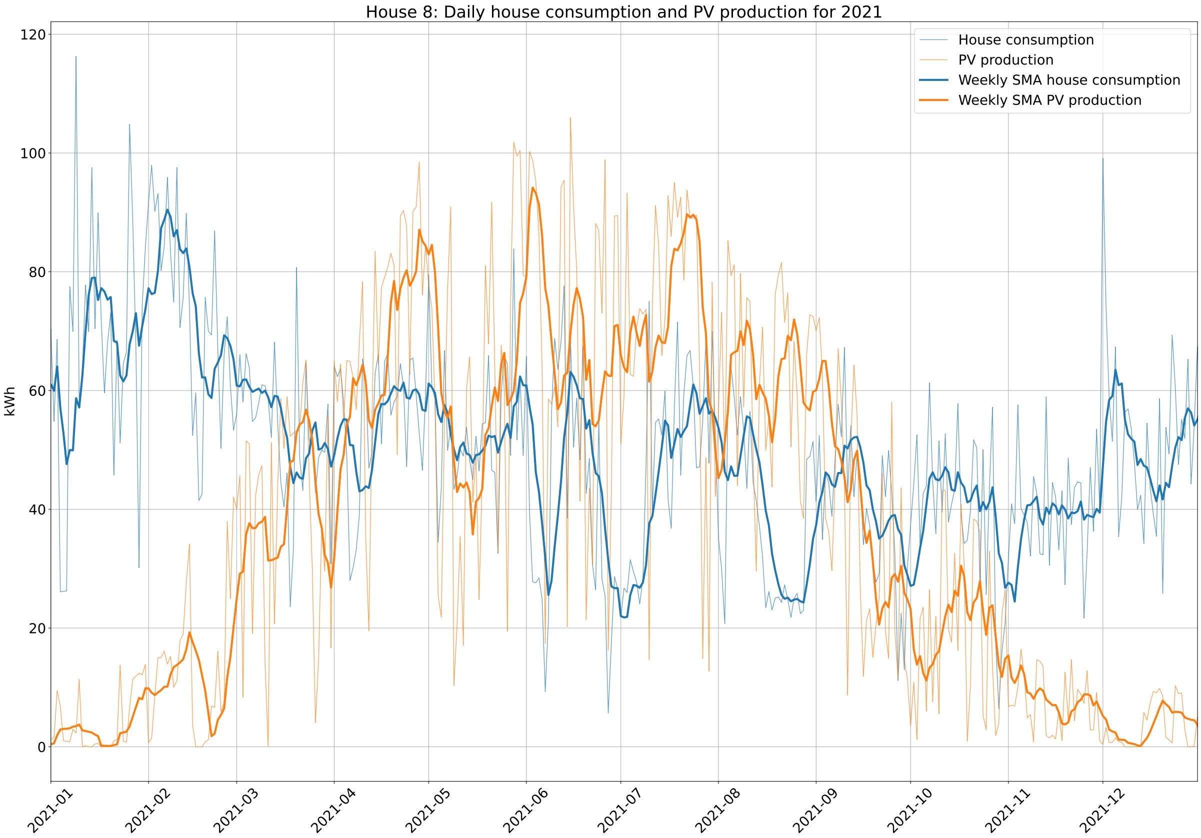



Figure A.164: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.8.5 Cost of energy

#### 2020

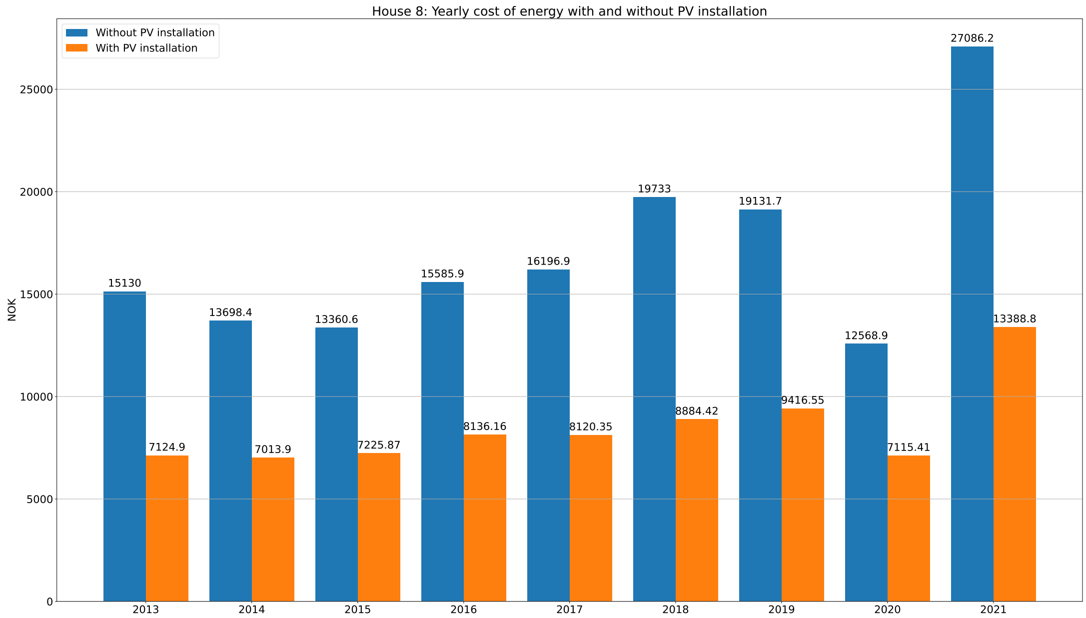



Figure A.165: Yearly cost of energy for House 8, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

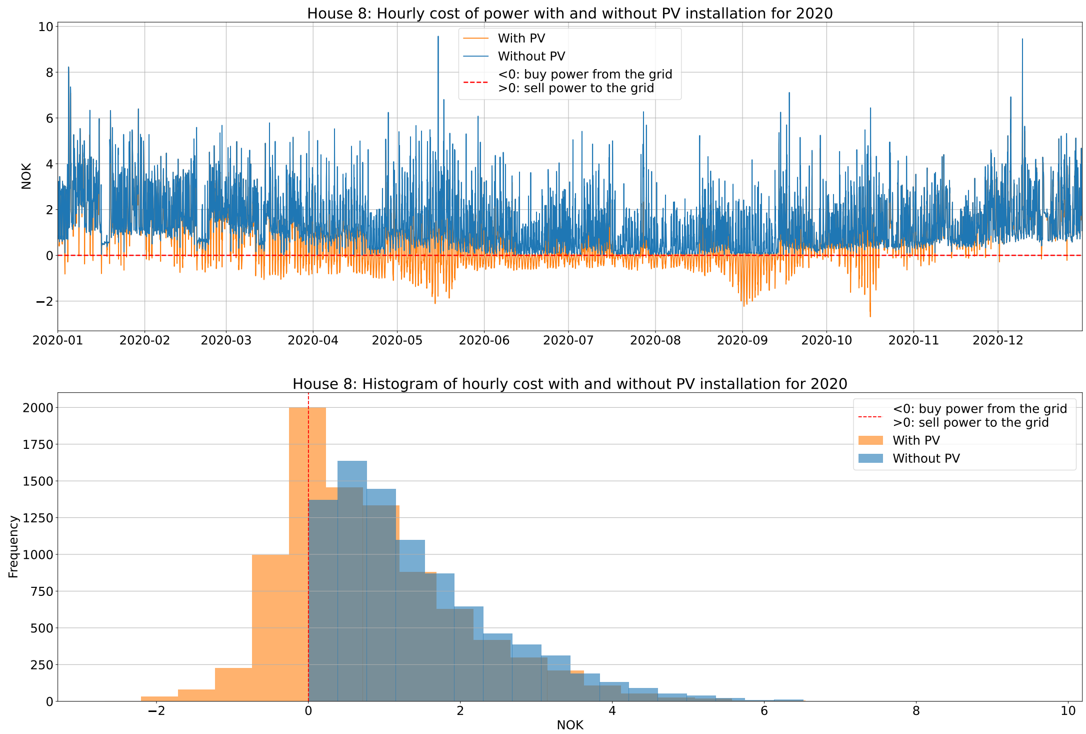



Figure A.166: Hourly cost of energy for House 8 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

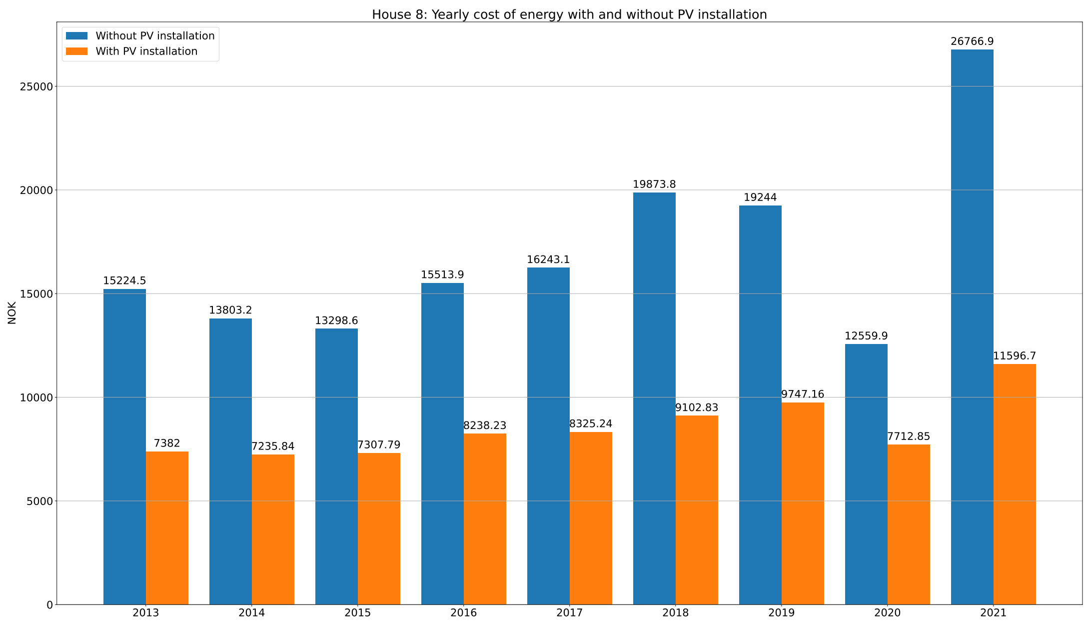



Figure A.167: Yearly cost of energy for House 8, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

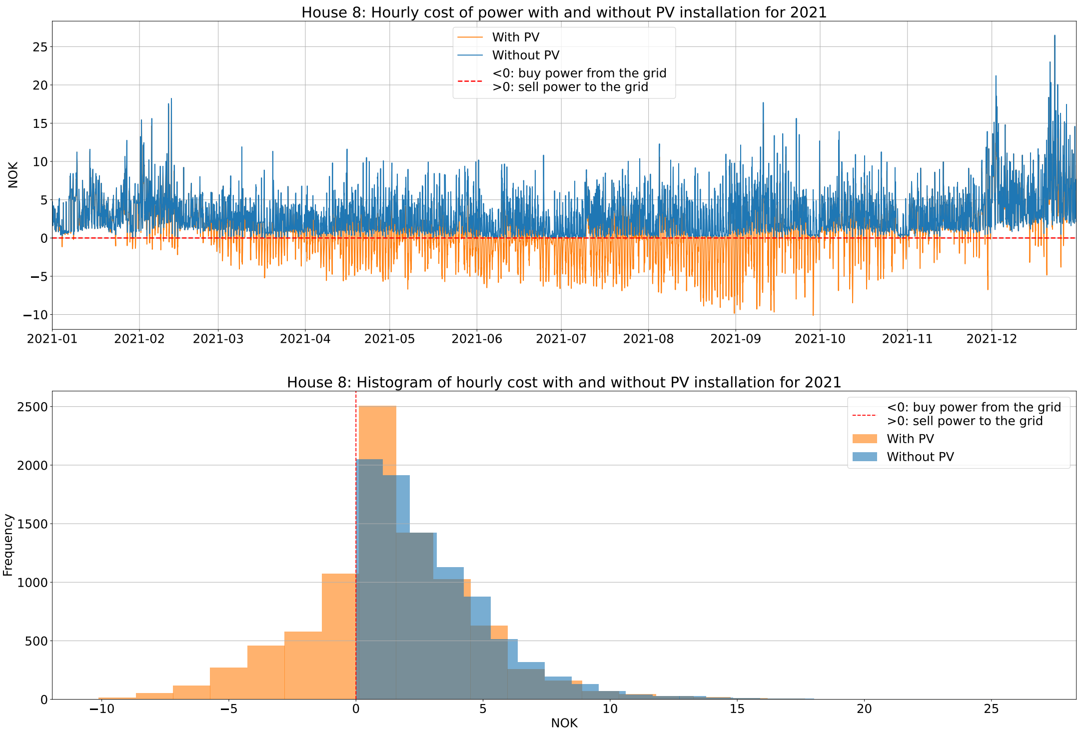



Figure A.168: Hourly cost of energy for House 8 with and without a PV system present for 2021. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.9 House 9

### A.9.1 House consumption

#### 2020

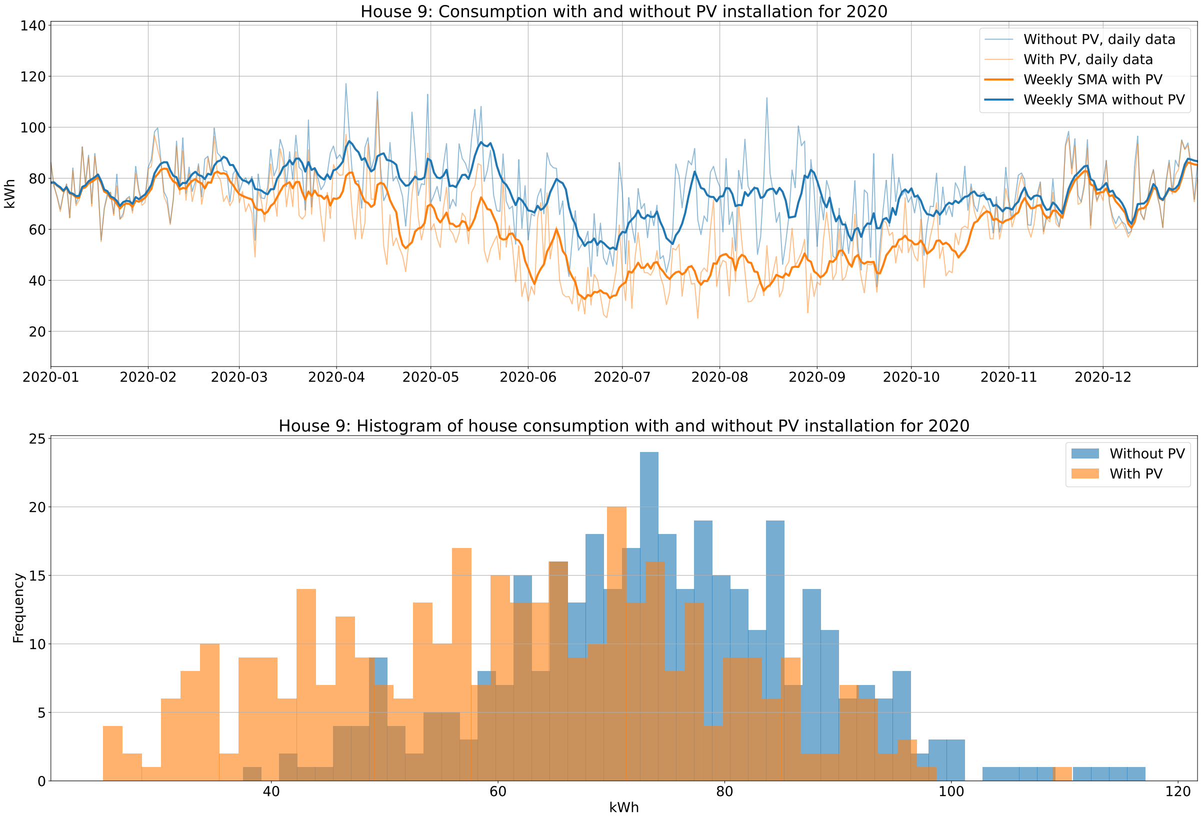



Figure A.169: Daily house consumption with and without a PV system for 2020 from House 9. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

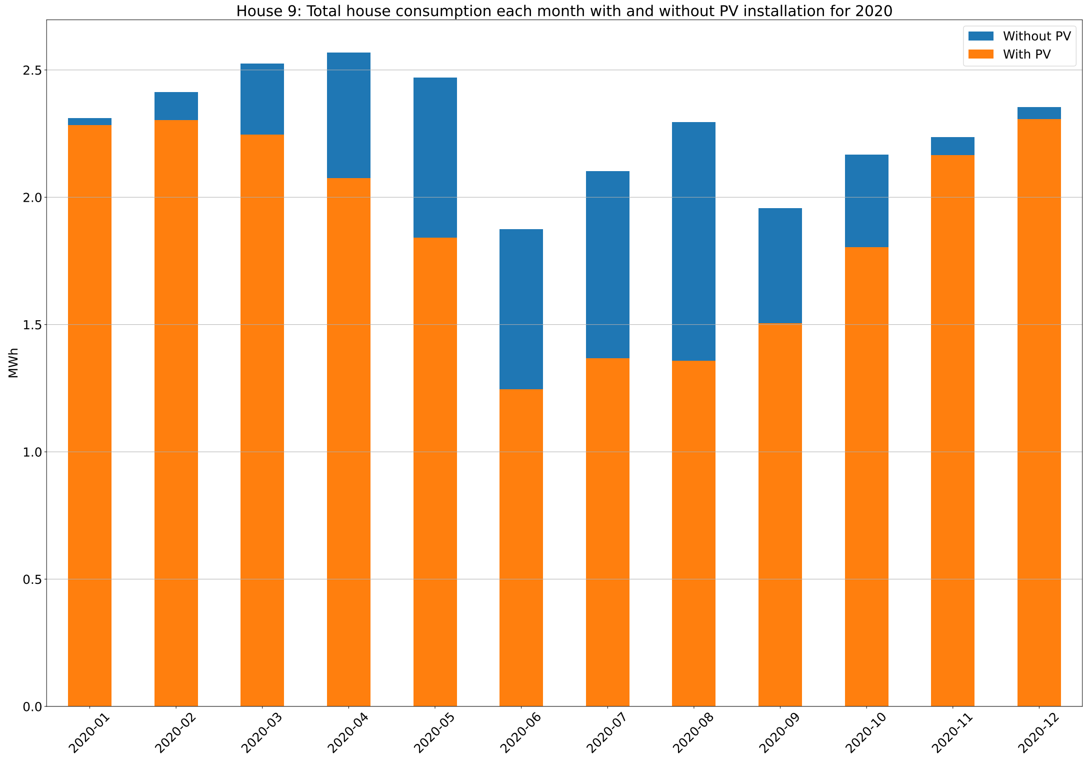



Figure A.170: Monthly house consumption for House 9 with and without a PV system for 2020.

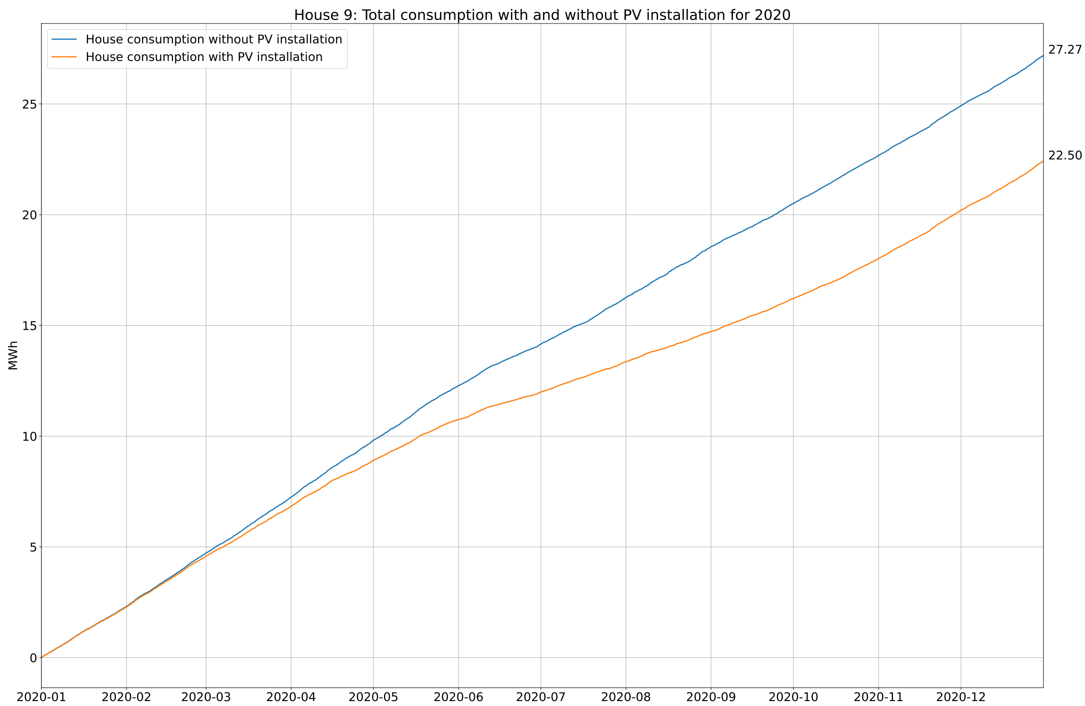



Figure A.171: Total house consumption for House 9 with and without a PV system accumulated over 2020

### 2021

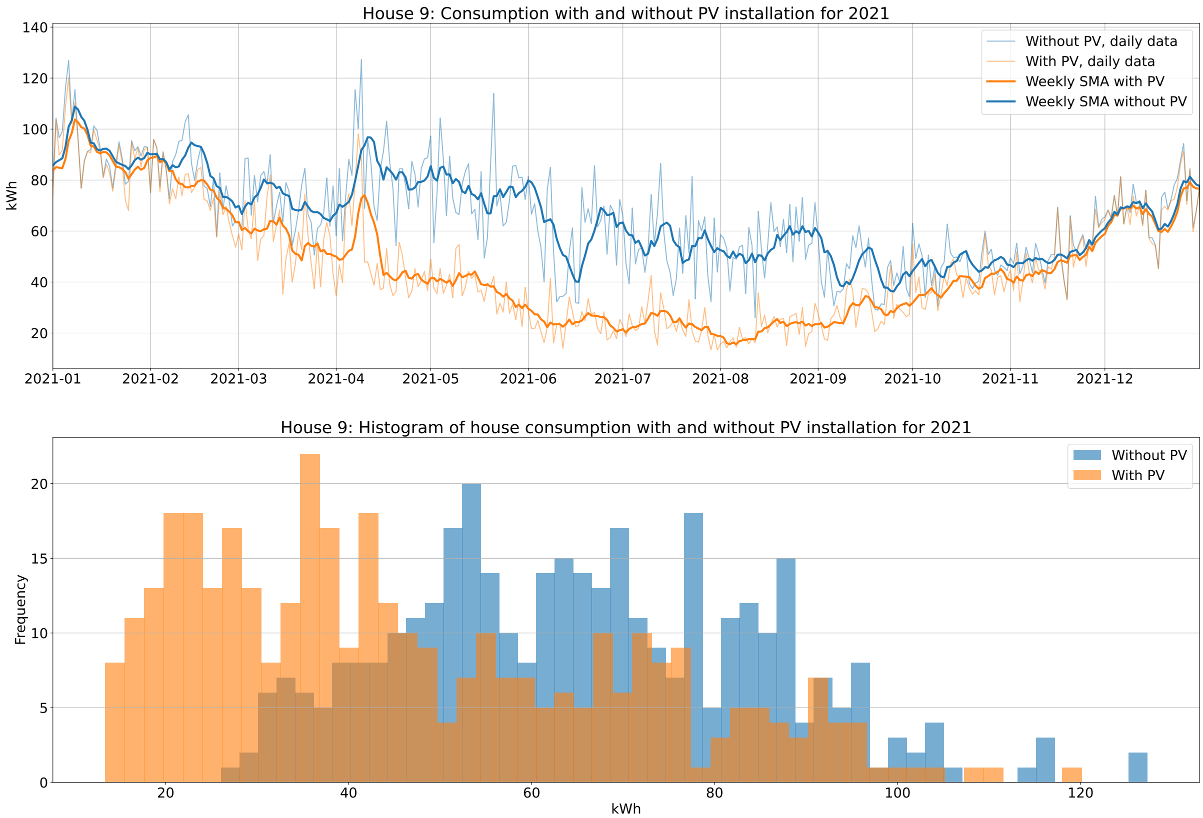



Figure A.172: Daily house consumption with and without a PV system for 2021 from House 9. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

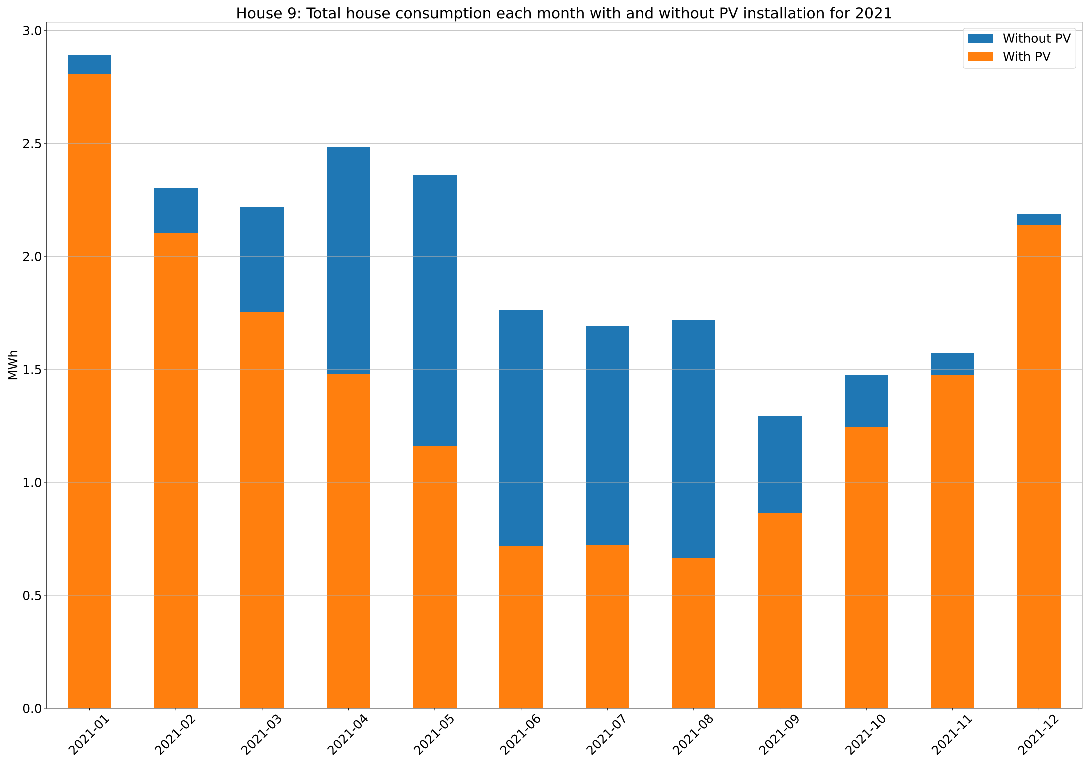



Figure A.173: Monthly house consumption for House 9 with and without a PV system for 2021.

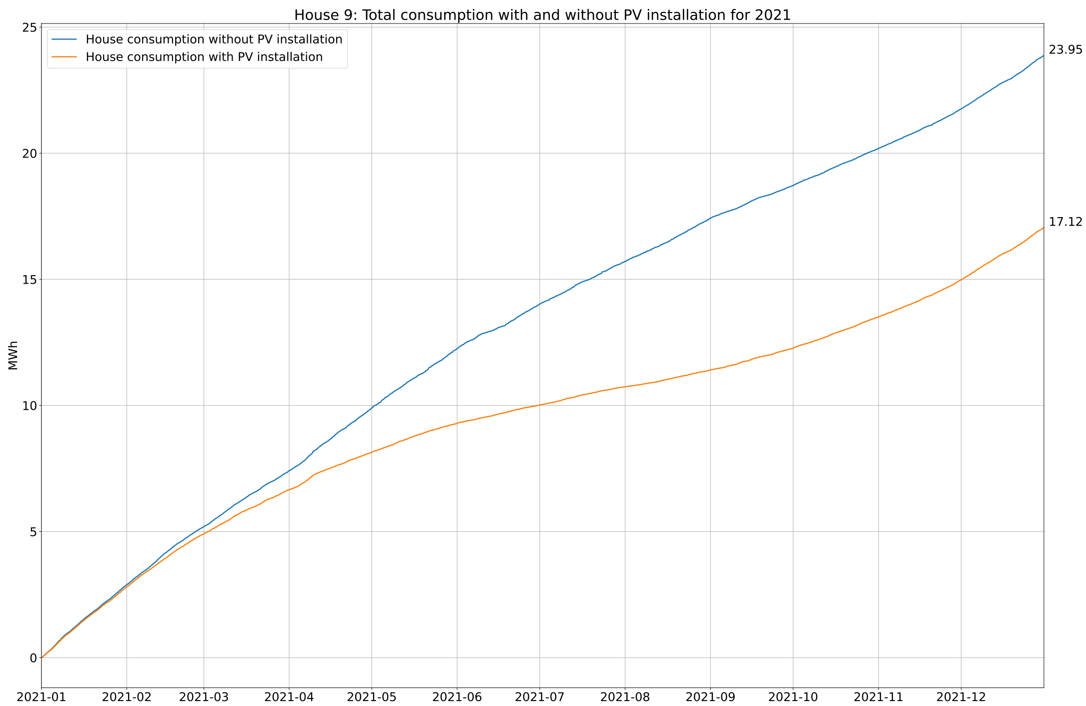



Figure A.174: Total house consumption for House 9 with and without a PV system accumulated over 2021

## A.9.2 Solar PV production

### 2020

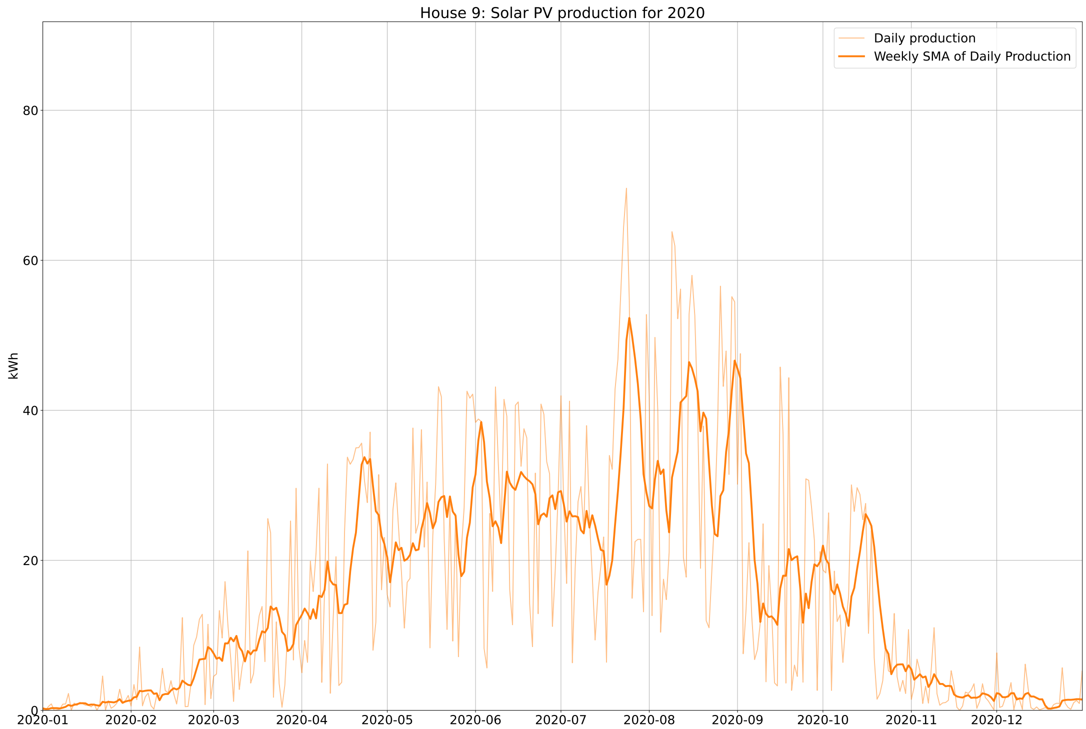



Figure A.175: Daily PV production and weekly SMA for House 9 in 2020.

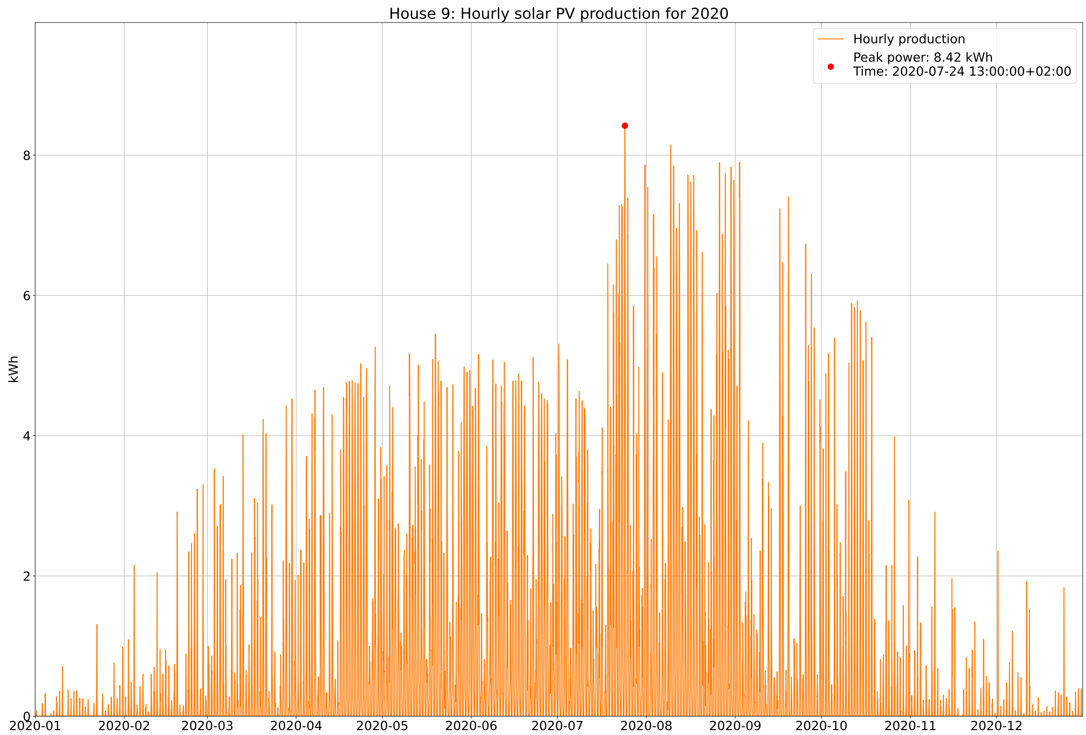



Figure A.176: Hourly PV production for House 9 in 2020.

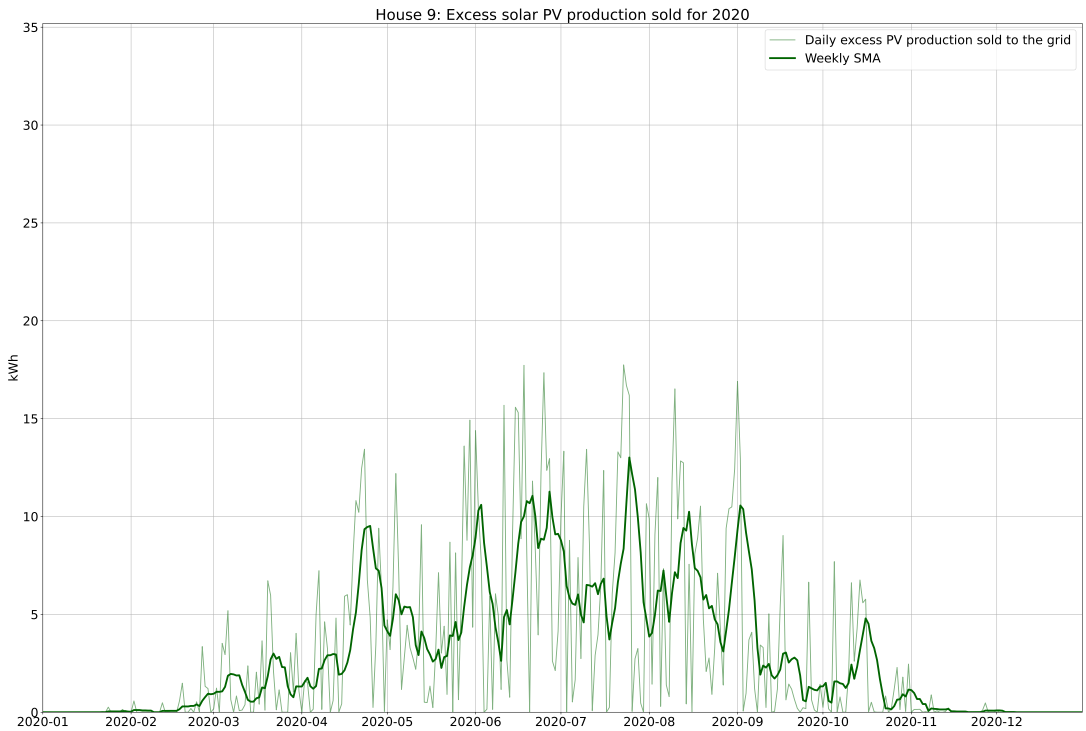



Figure A.177: Daily excess PV production sold to the grid and weekly SMA for House 9 in 2020

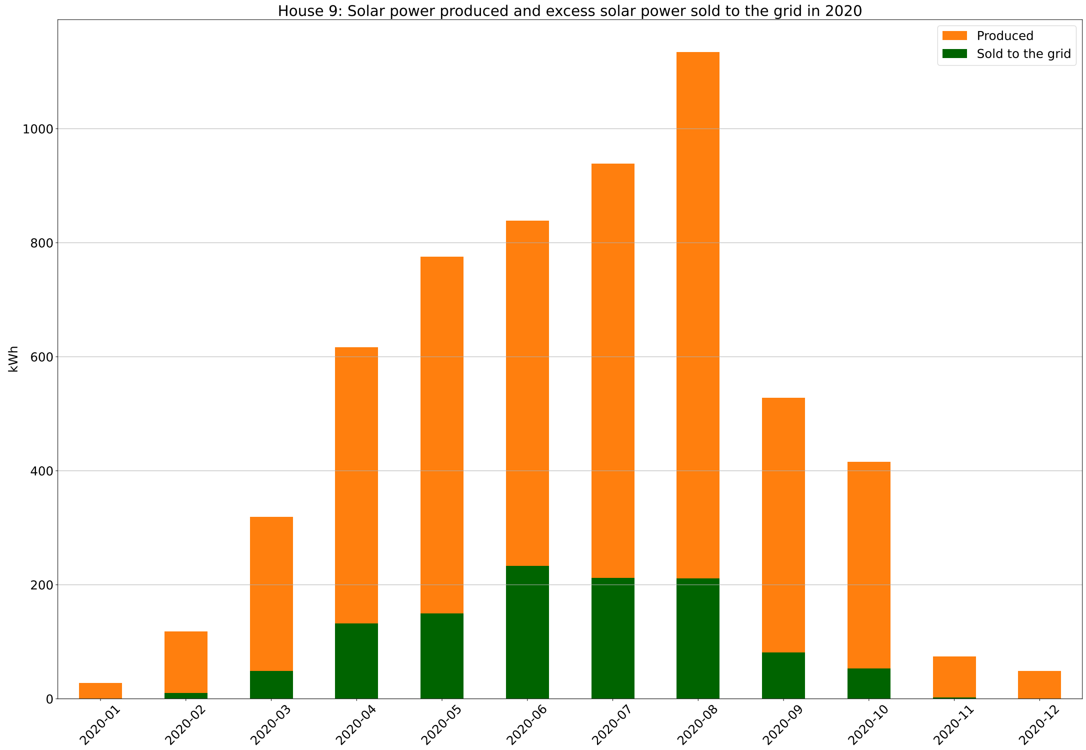



Figure A.178: Total solar PV production and excess production sold to the grid for each month in 2020 from House 9.

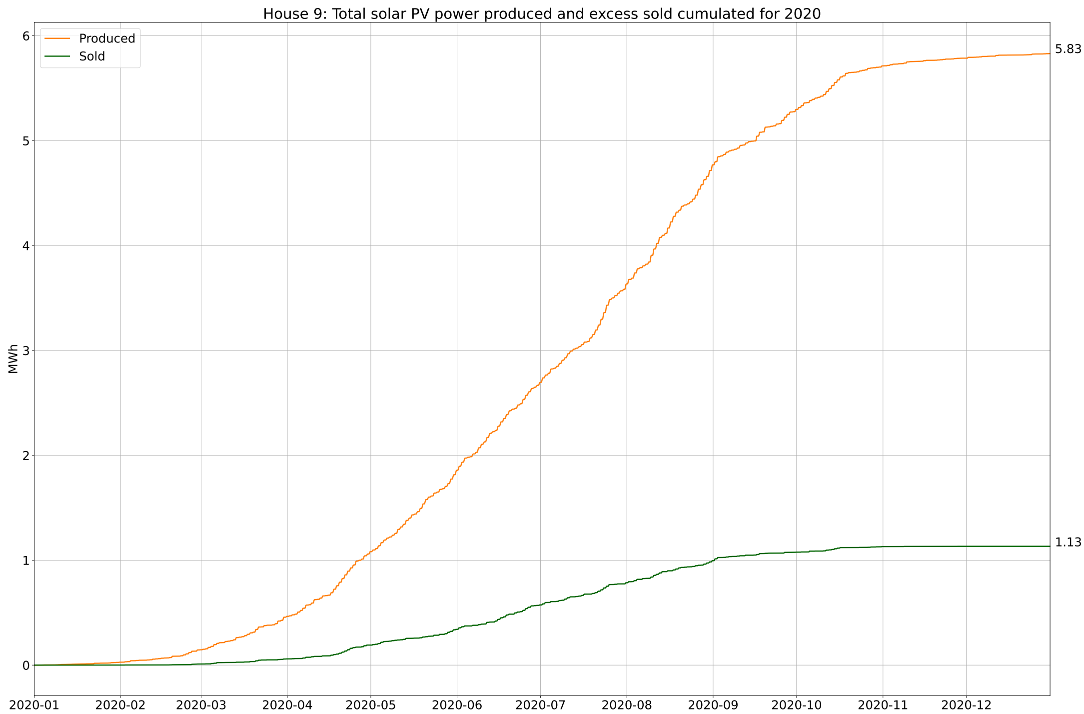



Figure A.179: Total solar PV production and excess production sold cumulated over 2020 from House 9

**2021**

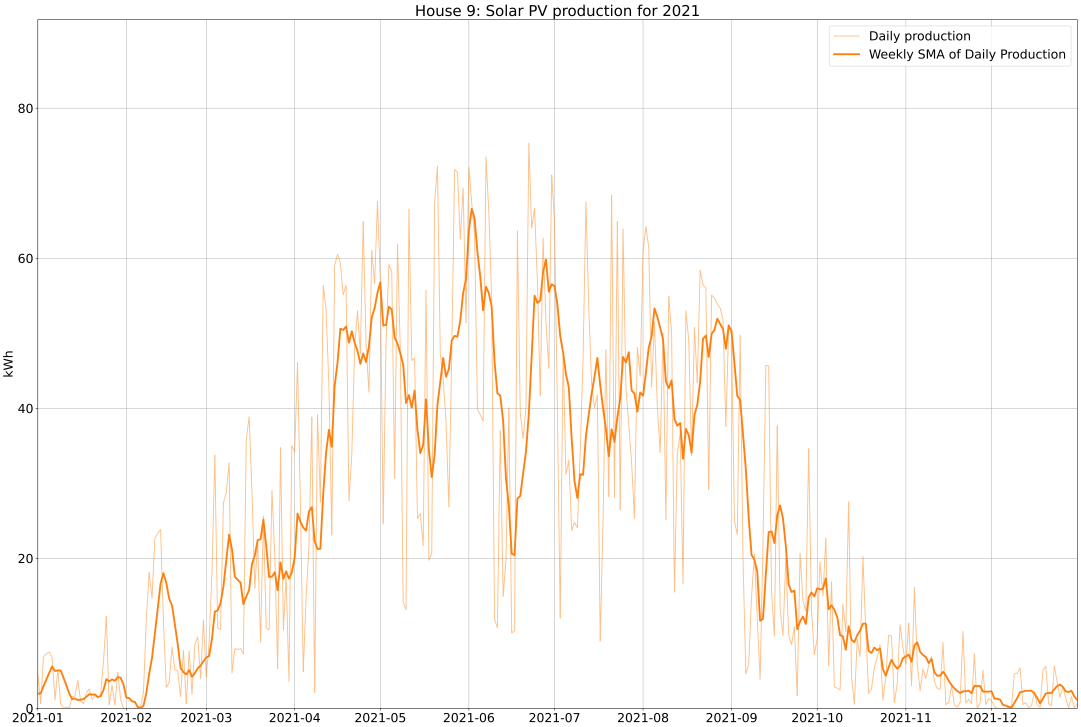



Figure A.180: Daily PV production and weekly SMA for House 9 in 2021.

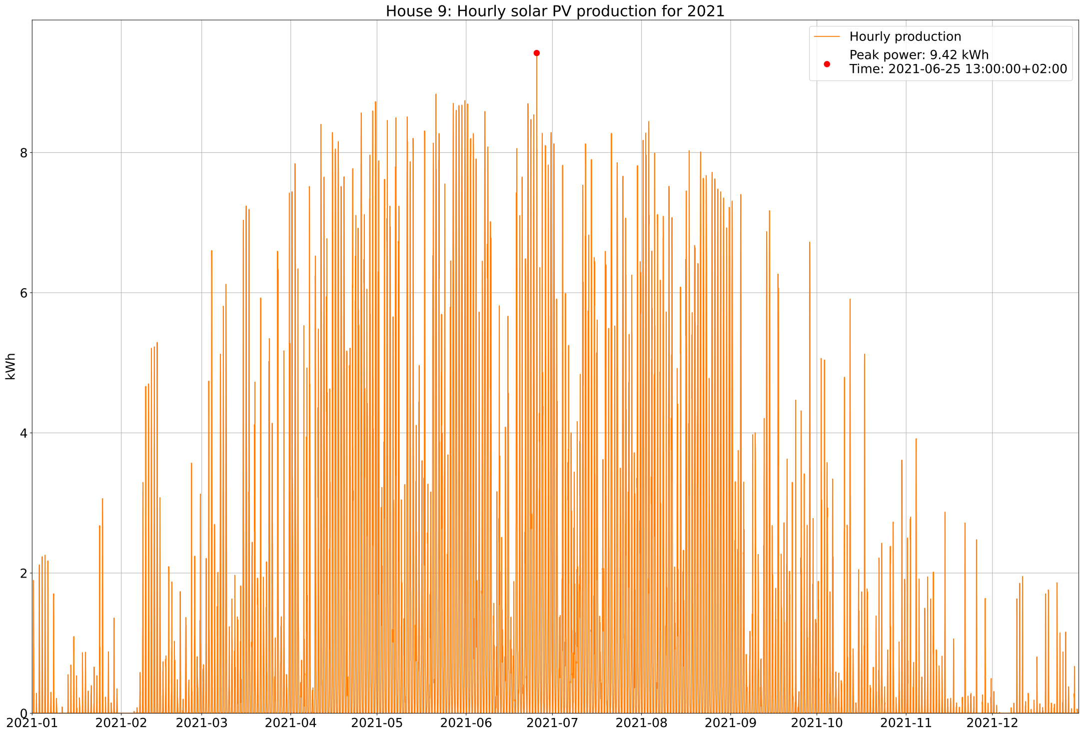



Figure A.181: Hourly PV production for House 9 in 2021.

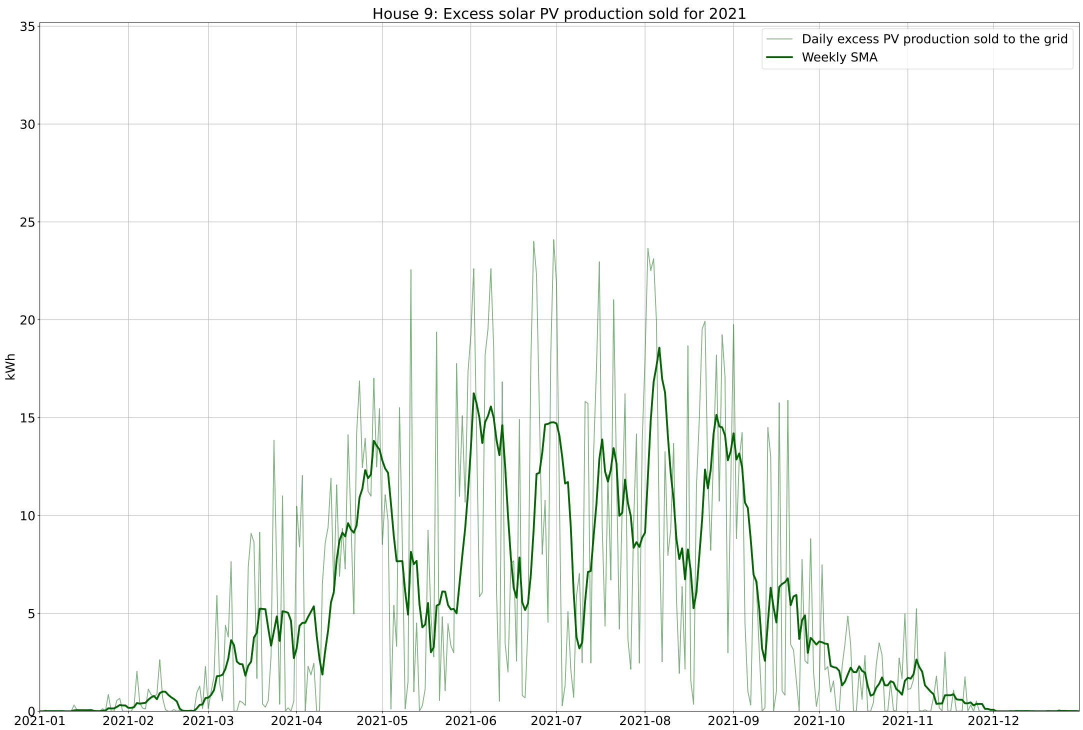



Figure A.182: Daily excess PV production sold to the grid and weekly SMA for House 9 in 2021

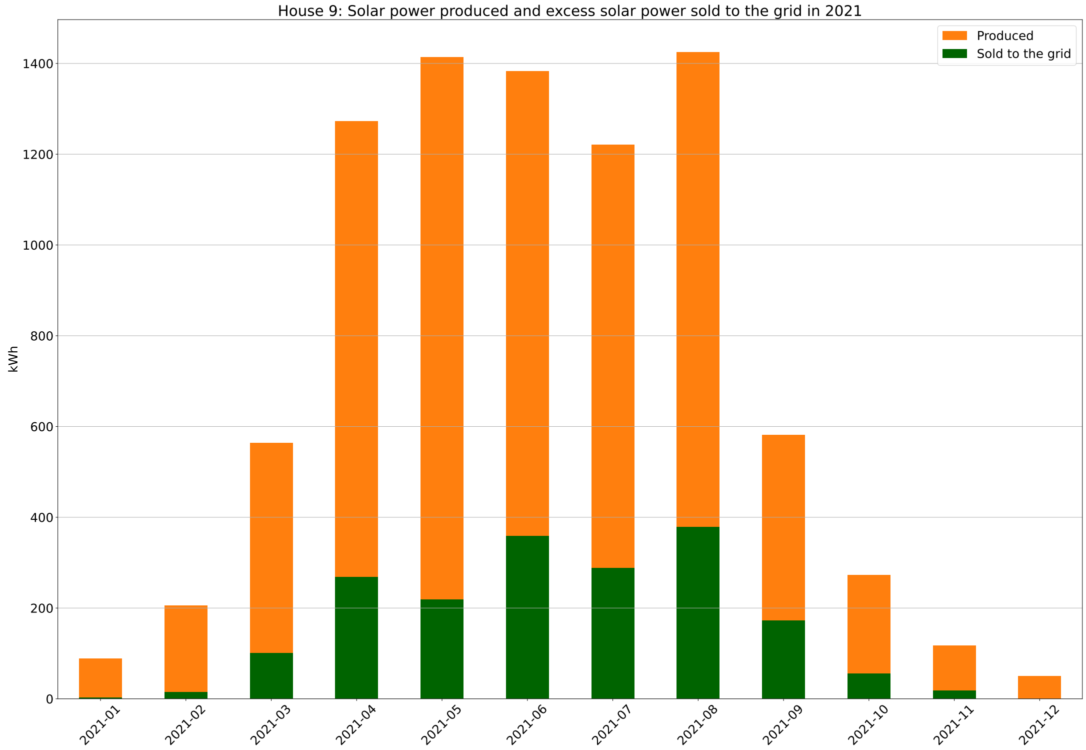



Figure A.183: Total solar PV production and excess production sold to the grid for each month in 2021 from House 9.

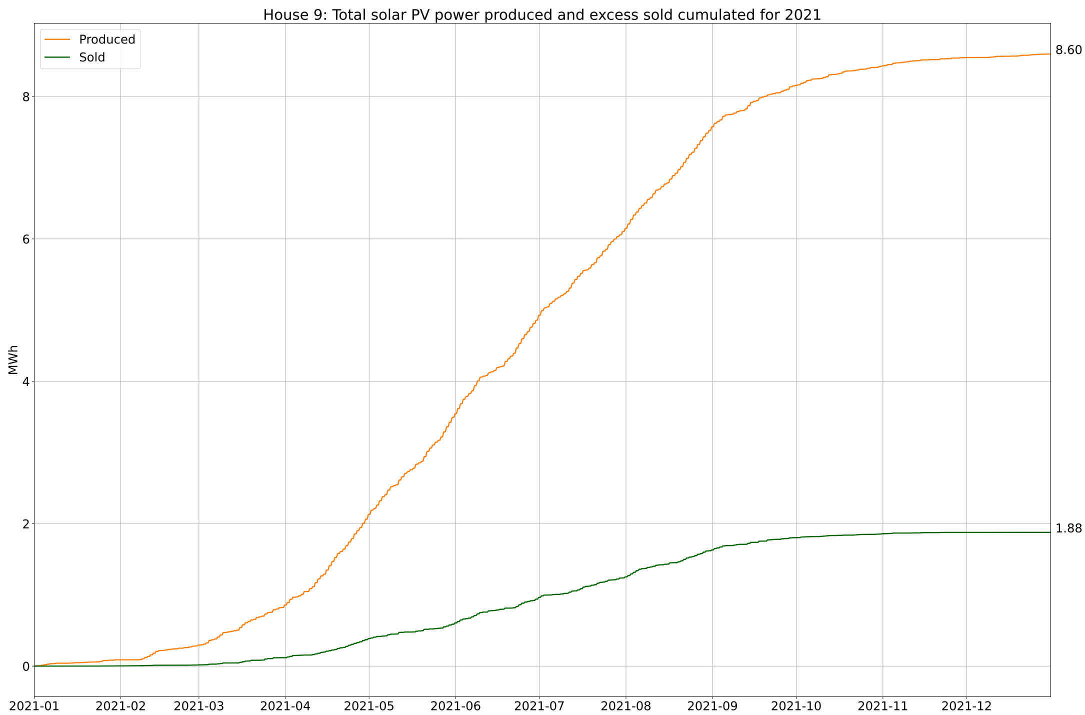
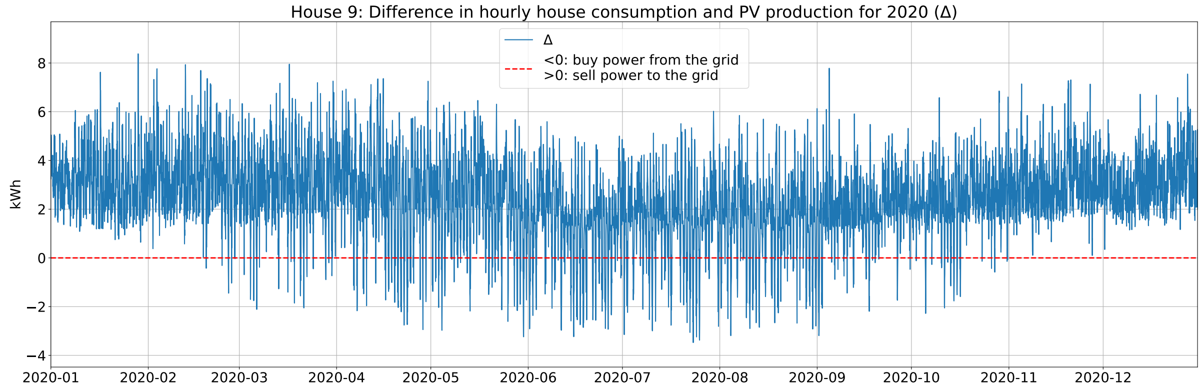



Figure A.184: Total solar PV production and excess production sold cumulated over 2021 from House 9

### A.9.3 Delta variable

#### 2020



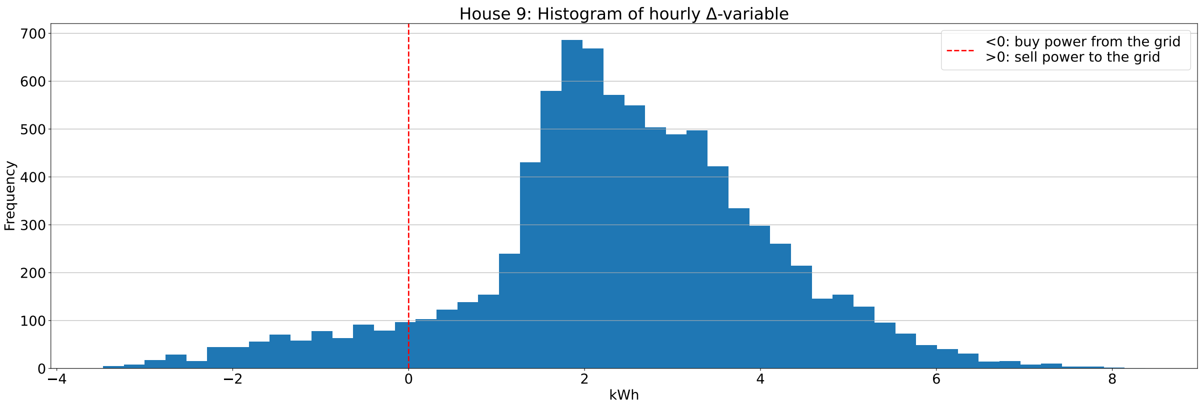




Figure A.185: The delta variable plotted for House 9. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

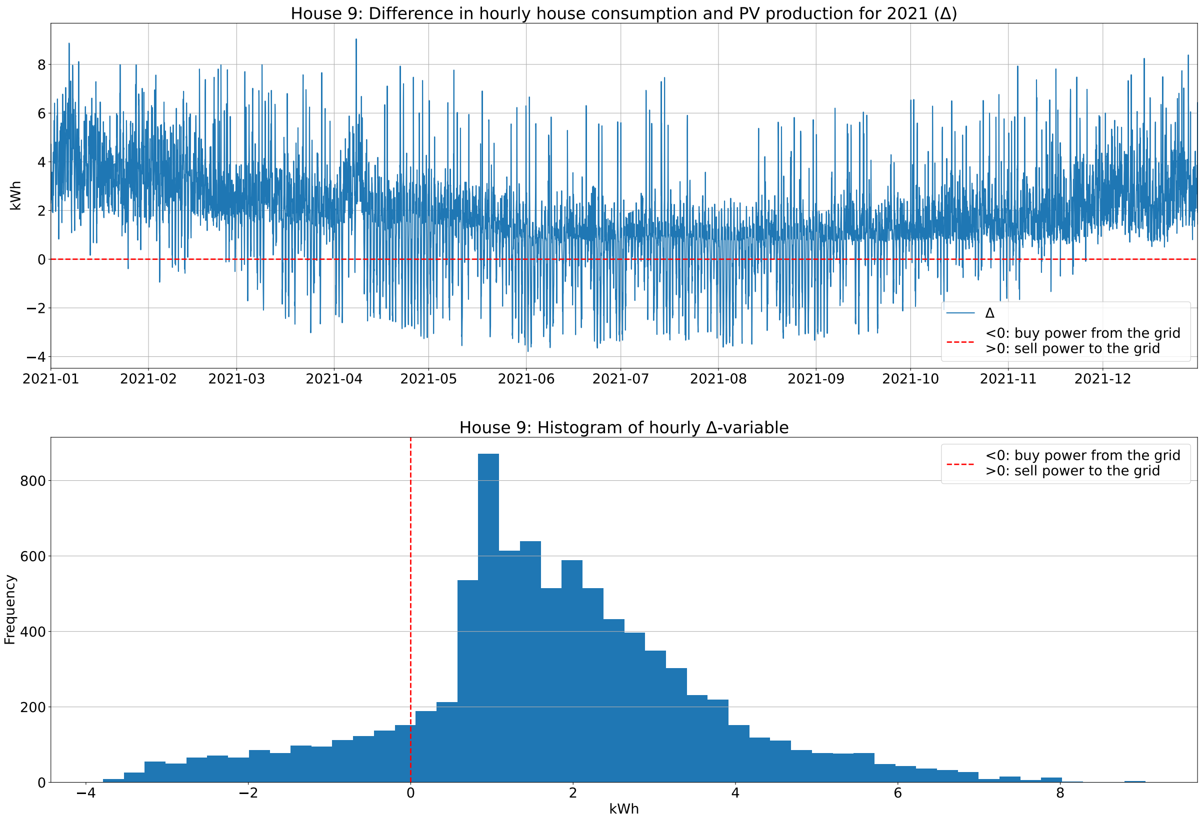



Figure A.186: The delta variable plotted for House 9. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $>0$ and sell when $<0$.

### A.9.4 House consumption and PV production

#### 2020

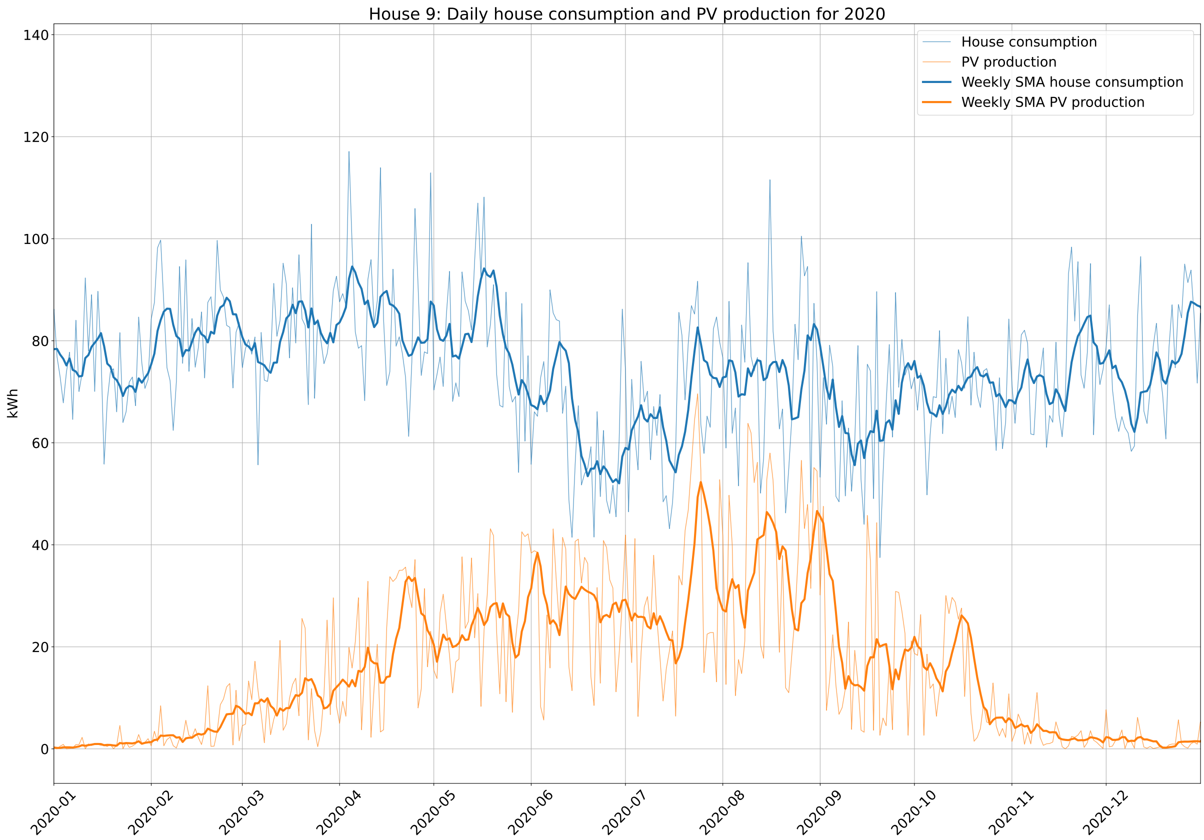



Figure A.187: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

## 2021

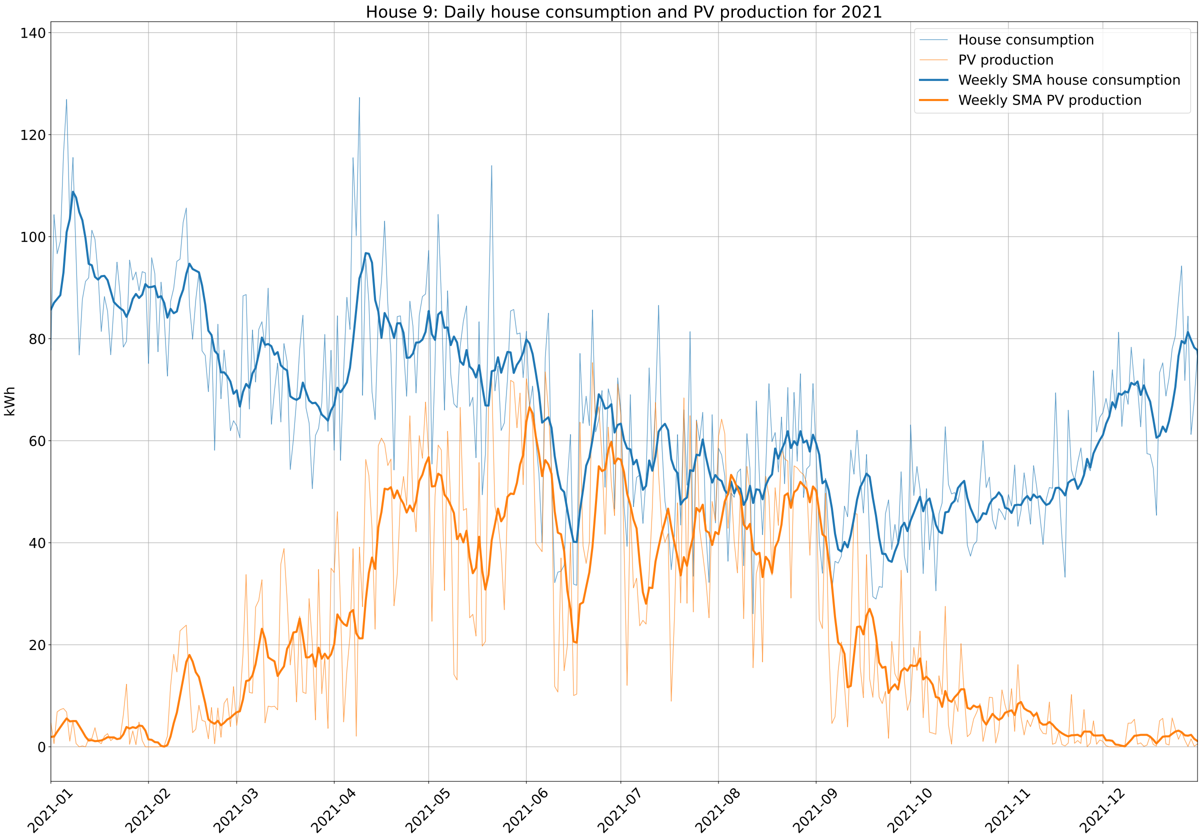



Figure A.188: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.9.5 Cost of energy

#### 2020

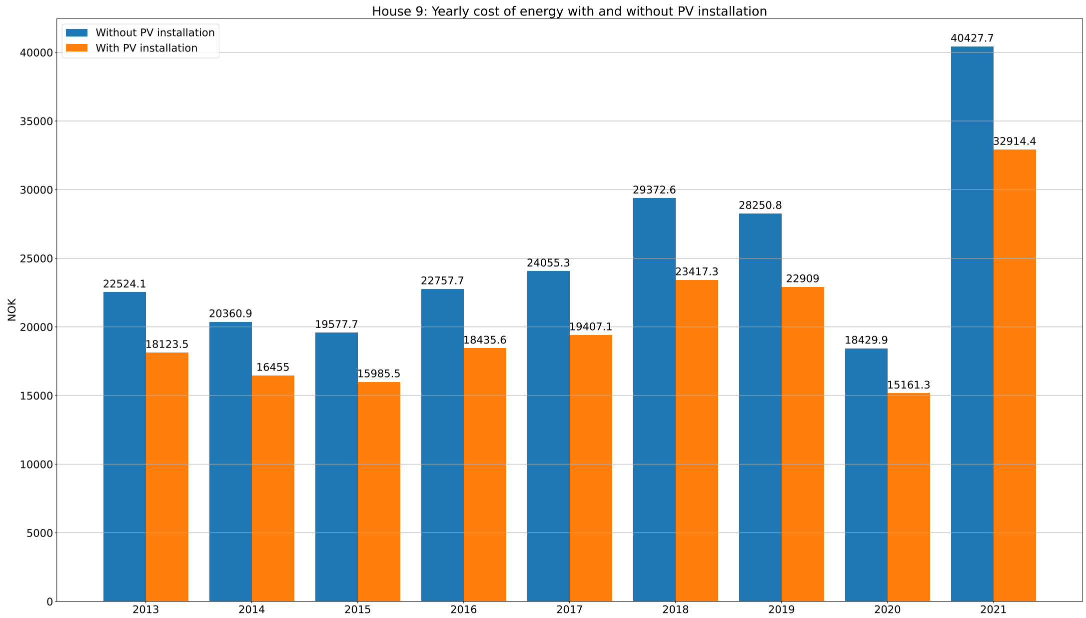



Figure A.189: Yearly cost of energy for House 9, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

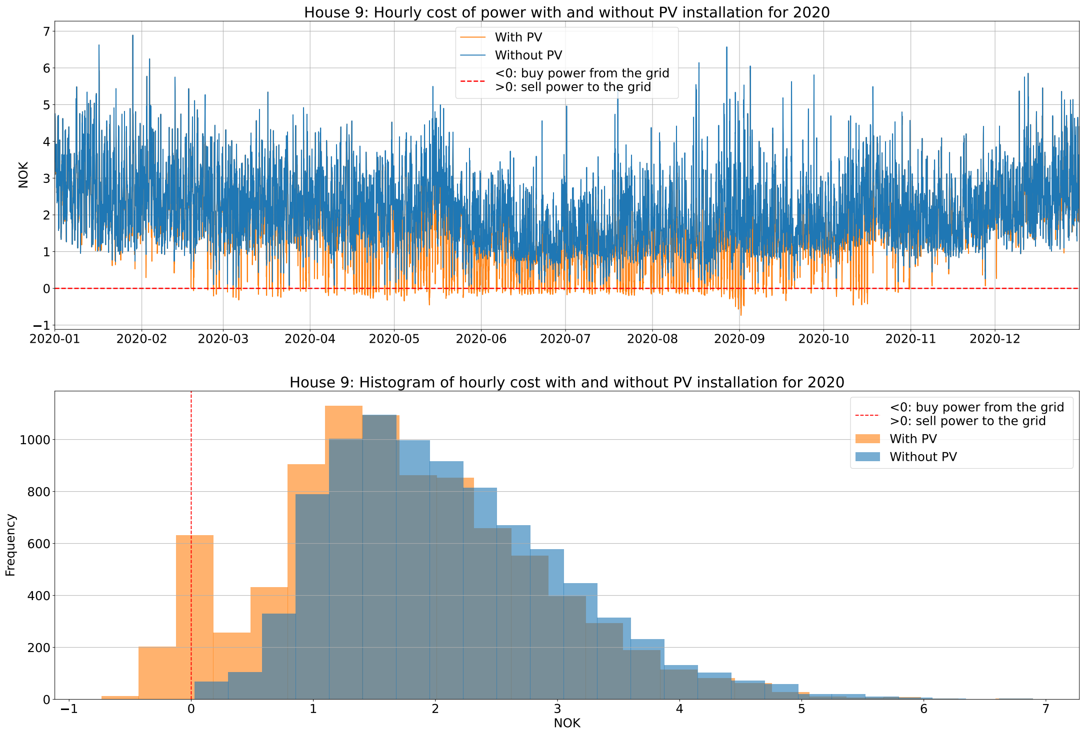



Figure A.190: Hourly cost of energy for House 9 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when > 0 and sell when < 0.

## 2021

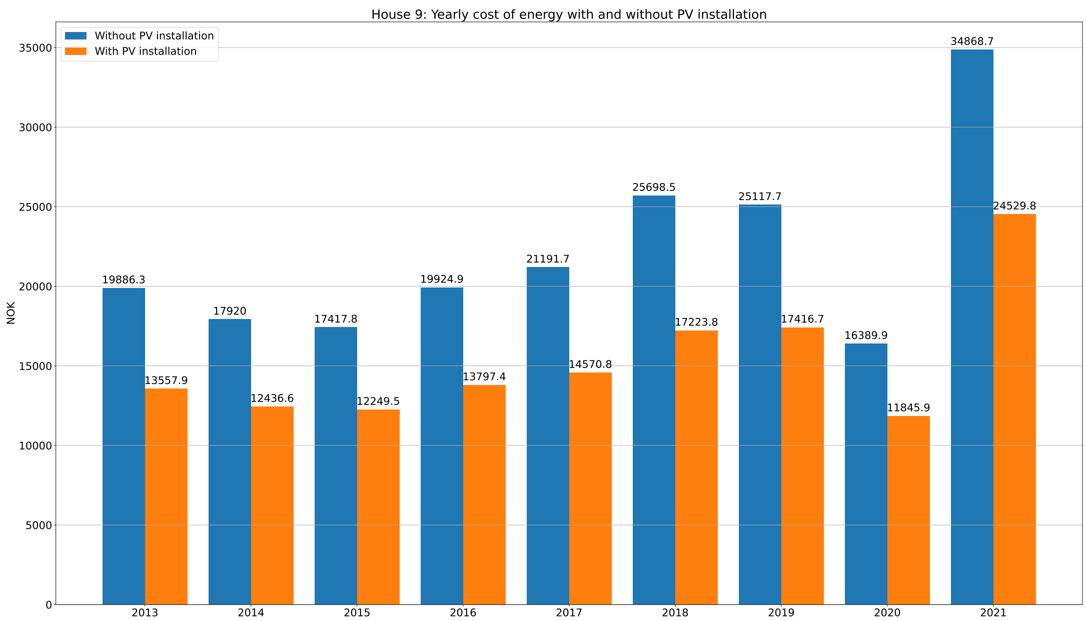



Figure A.191: Yearly cost of energy for House 9, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

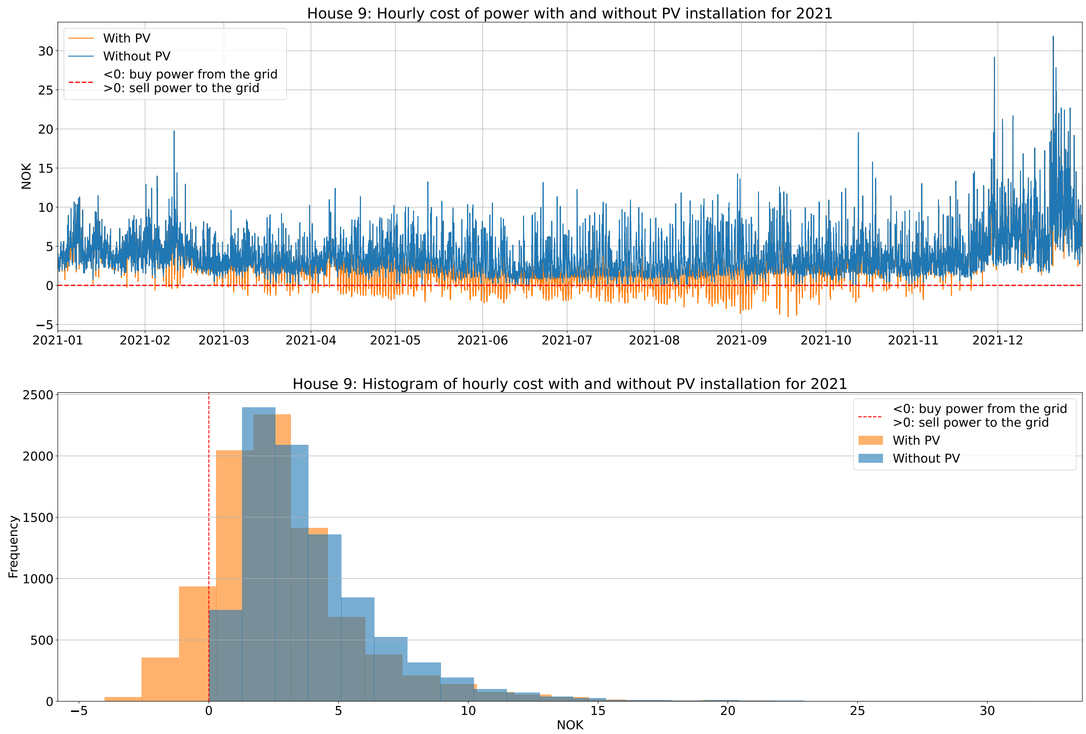



Figure A.192: Hourly cost of energy for House 9 with and without a PV system present for 2021. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

# A.10 House 10

## A.10.1 House consumption

### 2020

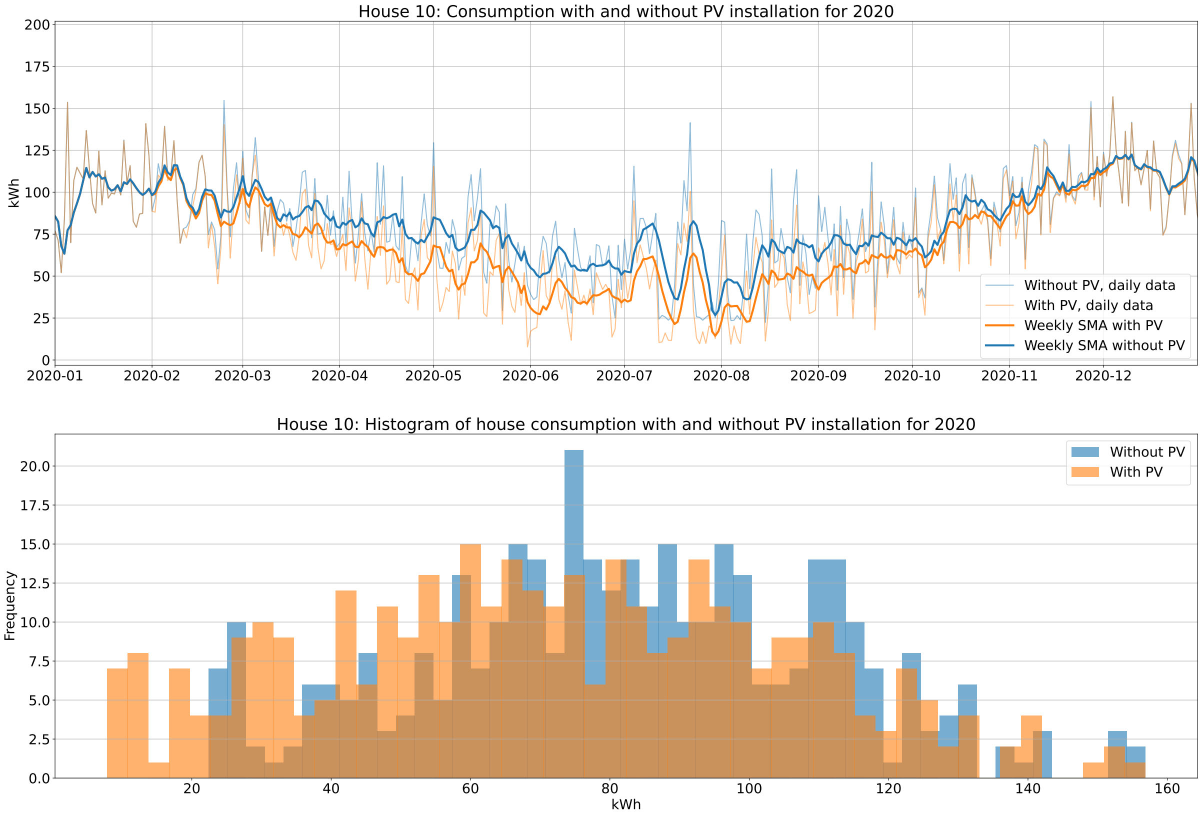



Figure A.193: Daily house consumption with and without a PV system for 2020 from House 10. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

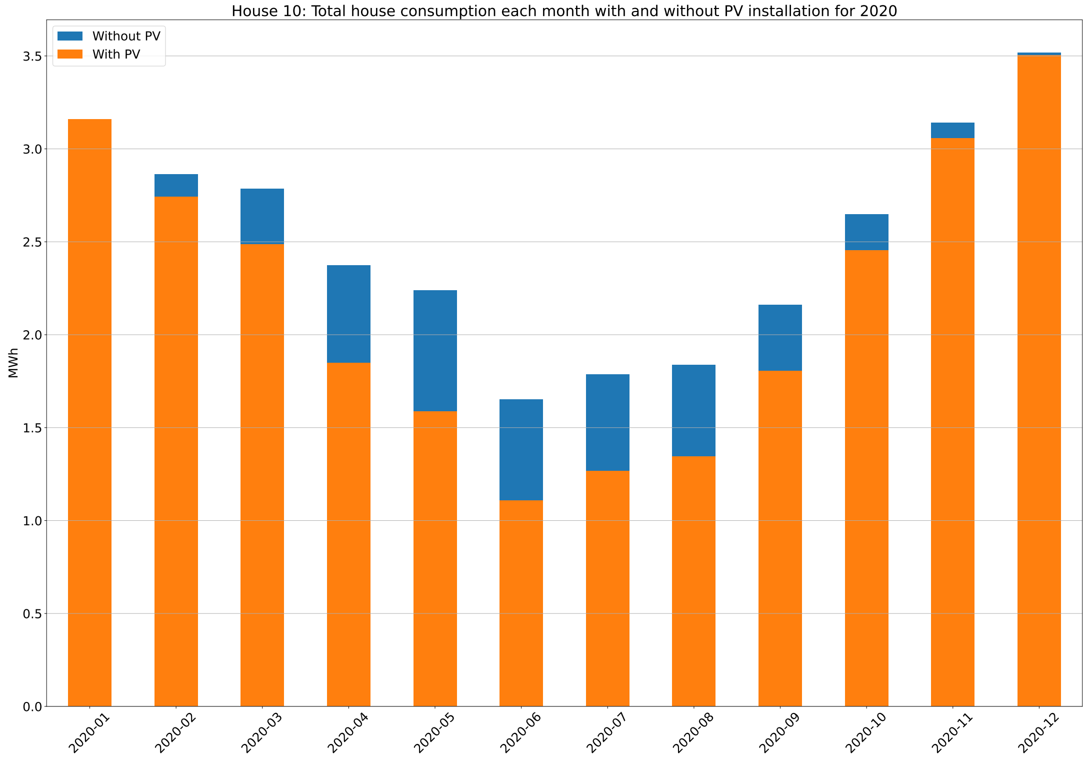



Figure A.194: Monthly house consumption for House 10 with and without a PV system for 2020.

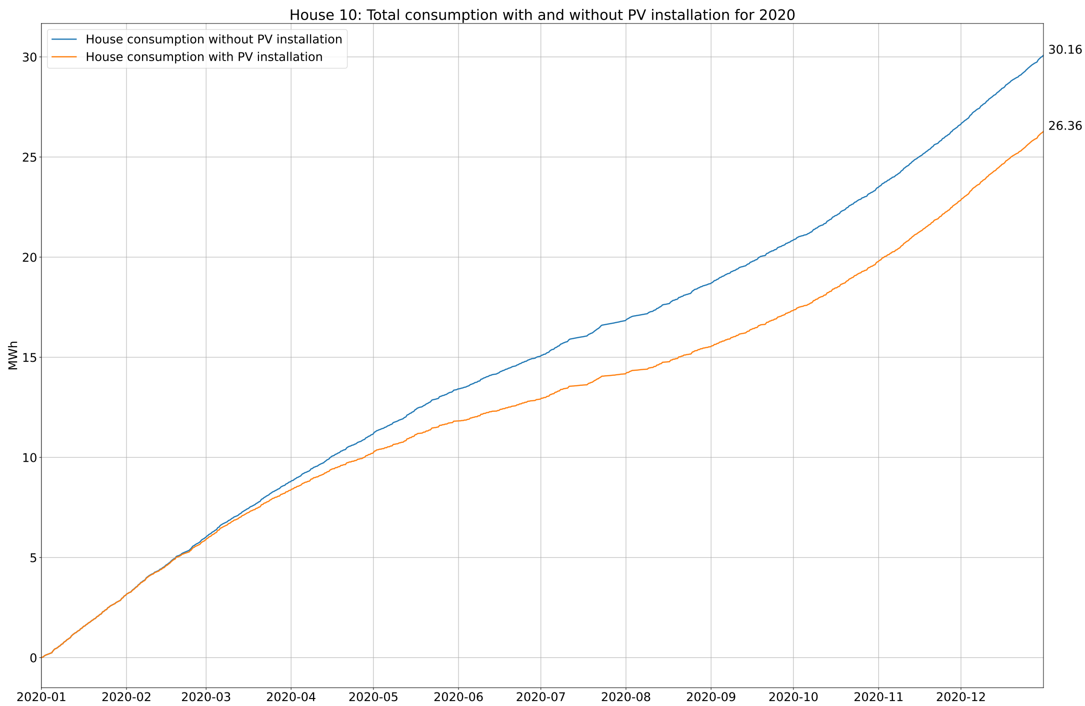



Figure A.195: Total house consumption for House 10 with and without a PV system accumulated over 2020

### 2021

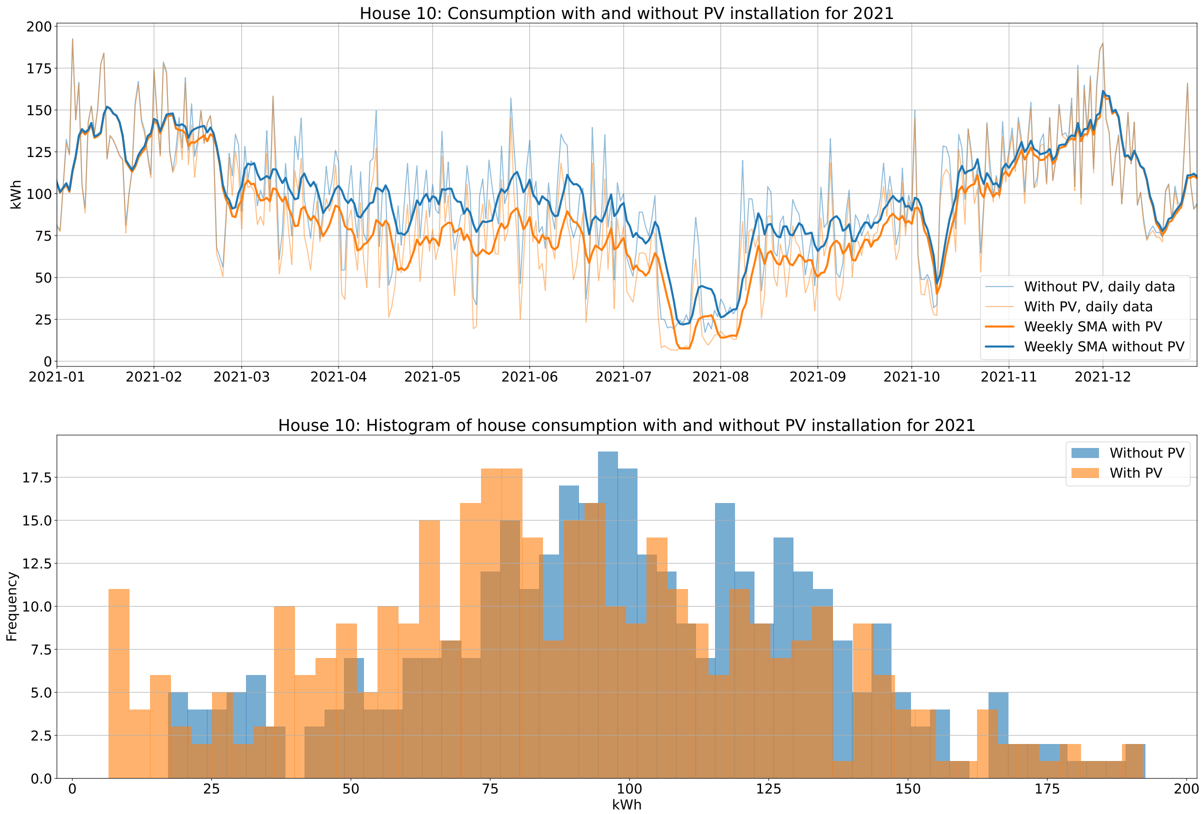



Figure A.196: Daily house consumption with and without a PV system for 2021 from House 10. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

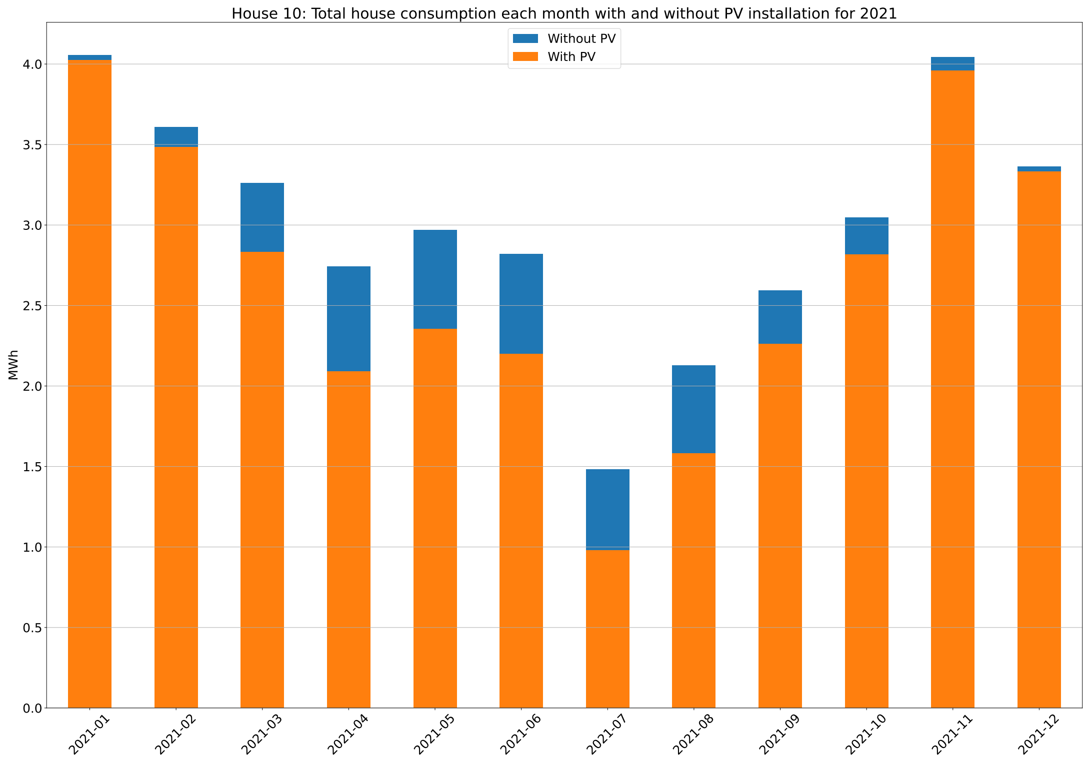



Figure A.197: Monthly house consumption for House 1 with and without a PV system for 2021.

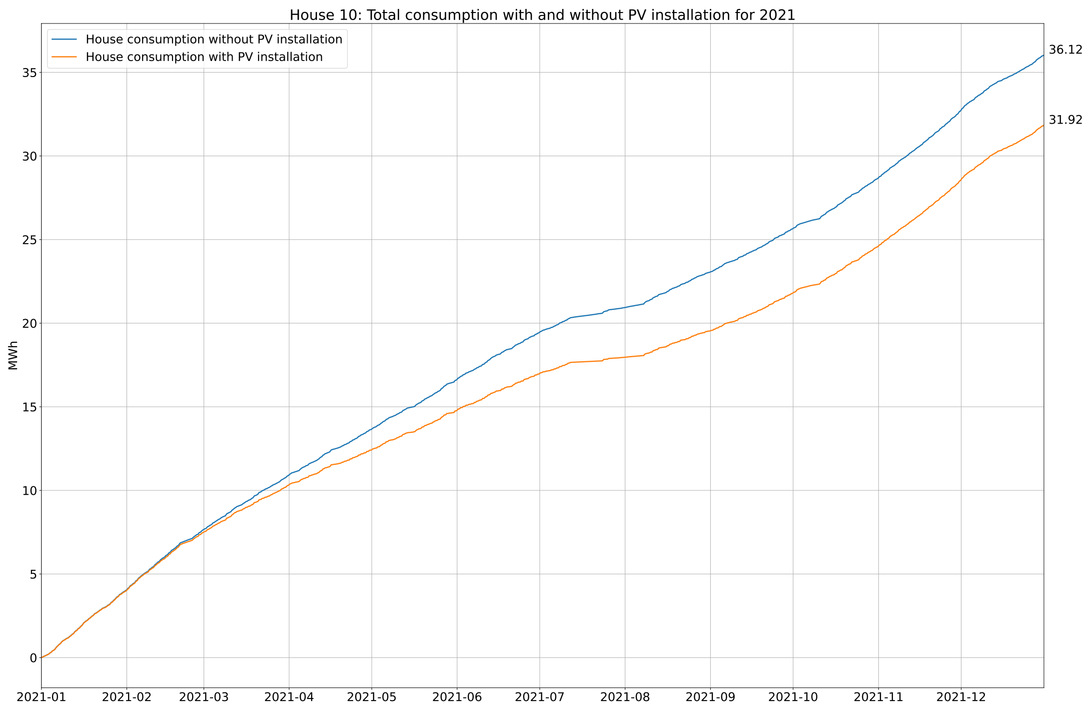



Figure A.198: Total house consumption for House 10 with and without a PV system accumulated over 2021

## A.10.2 Solar PV production

### 2020

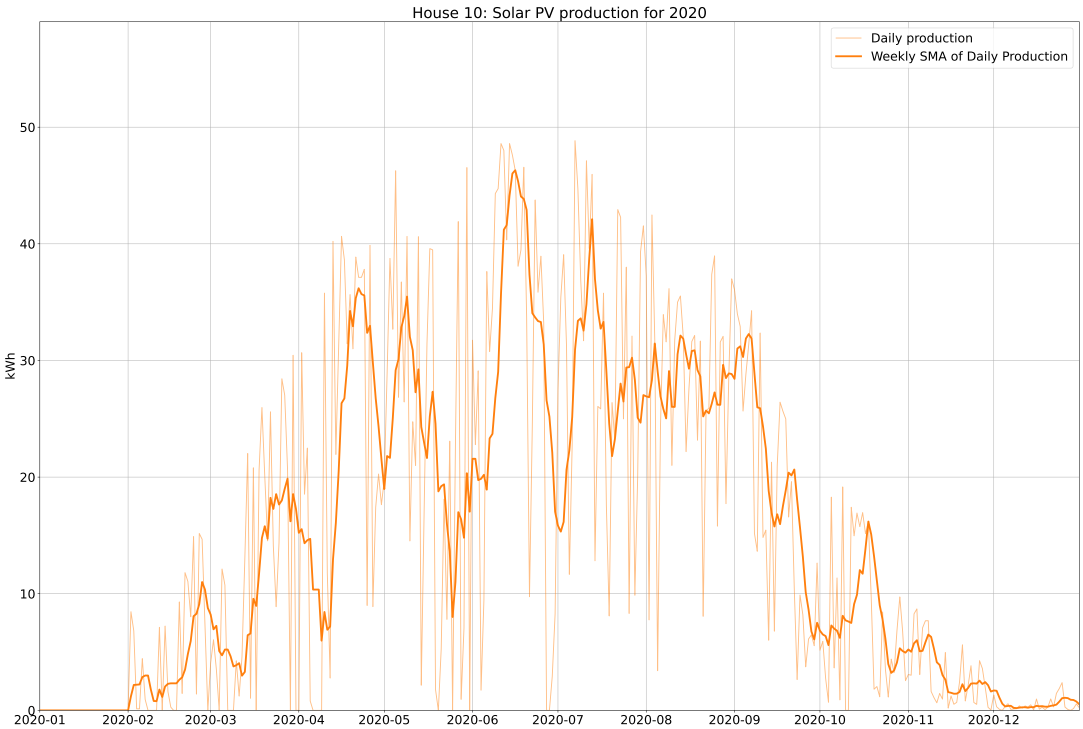



Figure A.199: Daily PV production and weekly SMA for House 10 in 2020.

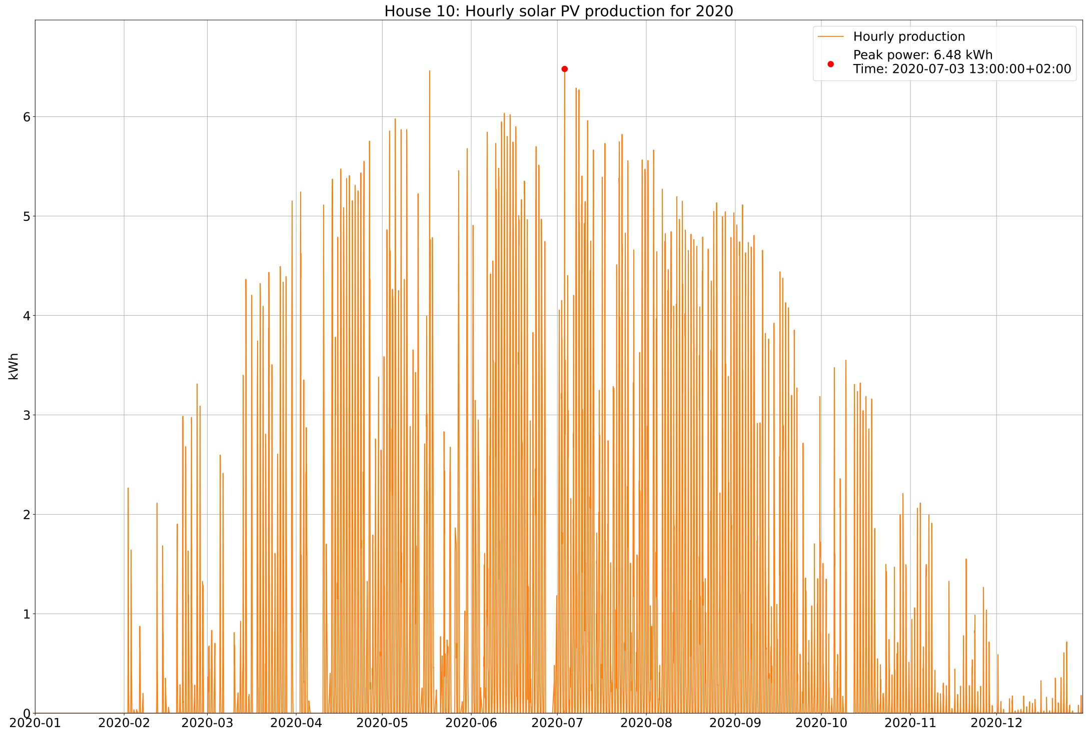



Figure A.200: Hourly PV production for House 10 in 2020.

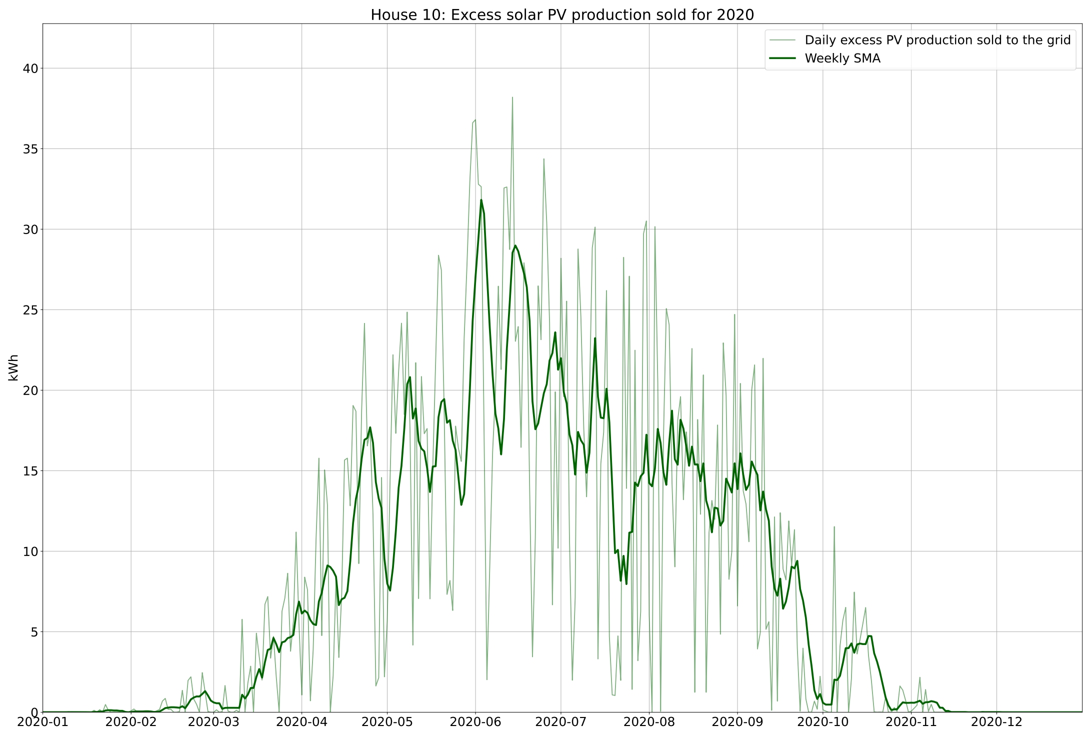



Figure A.201: Daily excess PV production sold to the grid and weekly SMA for House 10 in 2020

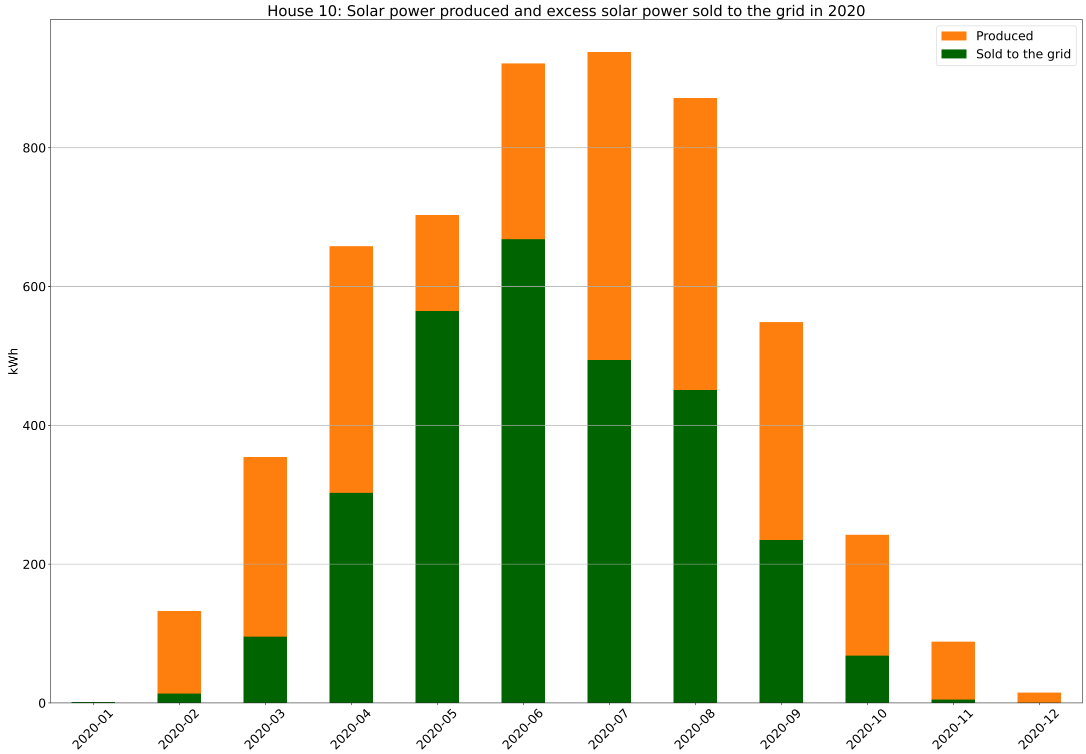



Figure A.202: Total solar PV production and excess production sold to the grid for each month in 2020 from House 10.

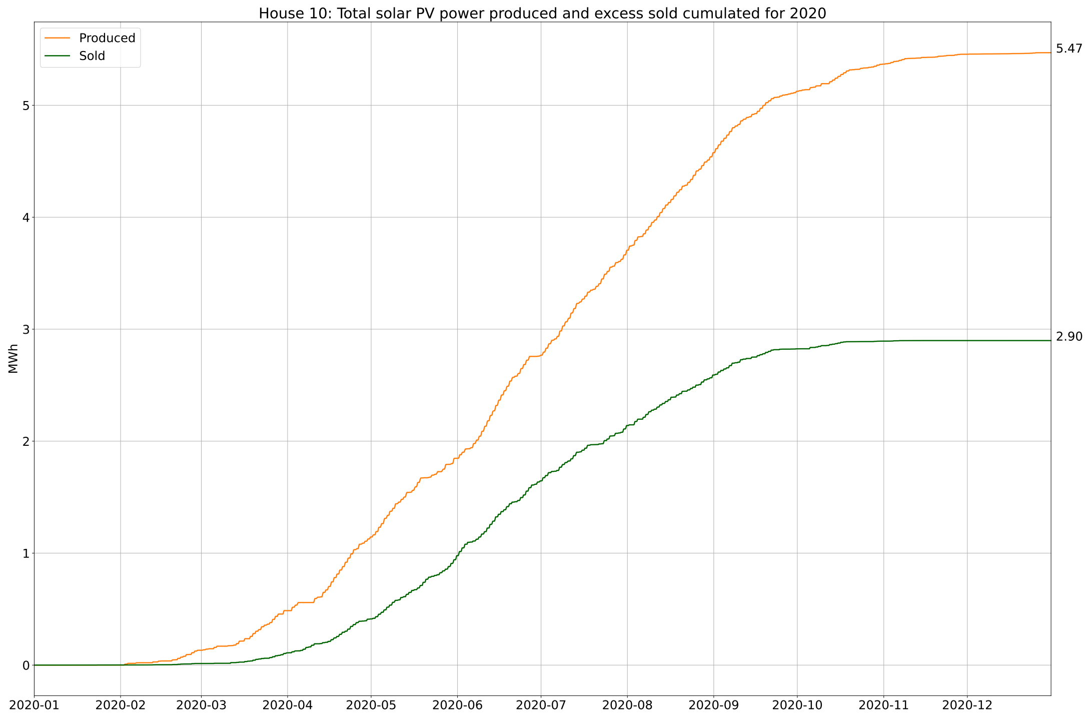



Figure A.203: Total solar PV production and excess production sold cumulated over 2020 from House 10

### 2021

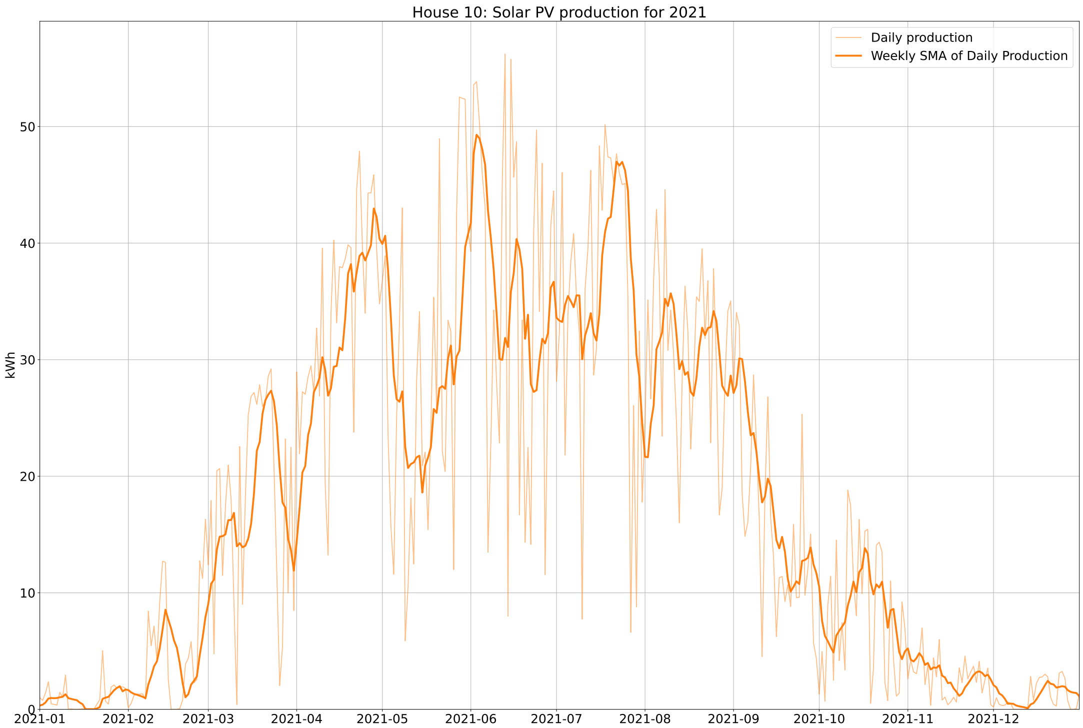



Figure A.204: Daily PV production and weekly SMA for House 10 in 2021.

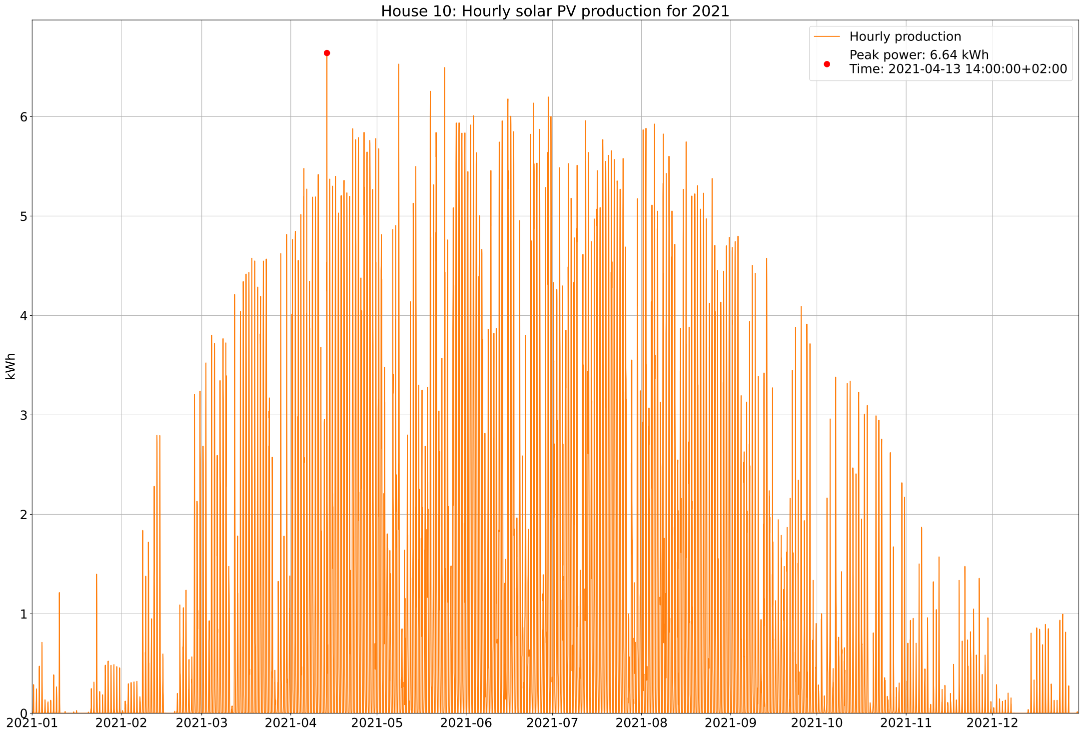



Figure A.205: Hourly PV production for House 10 in 2021.

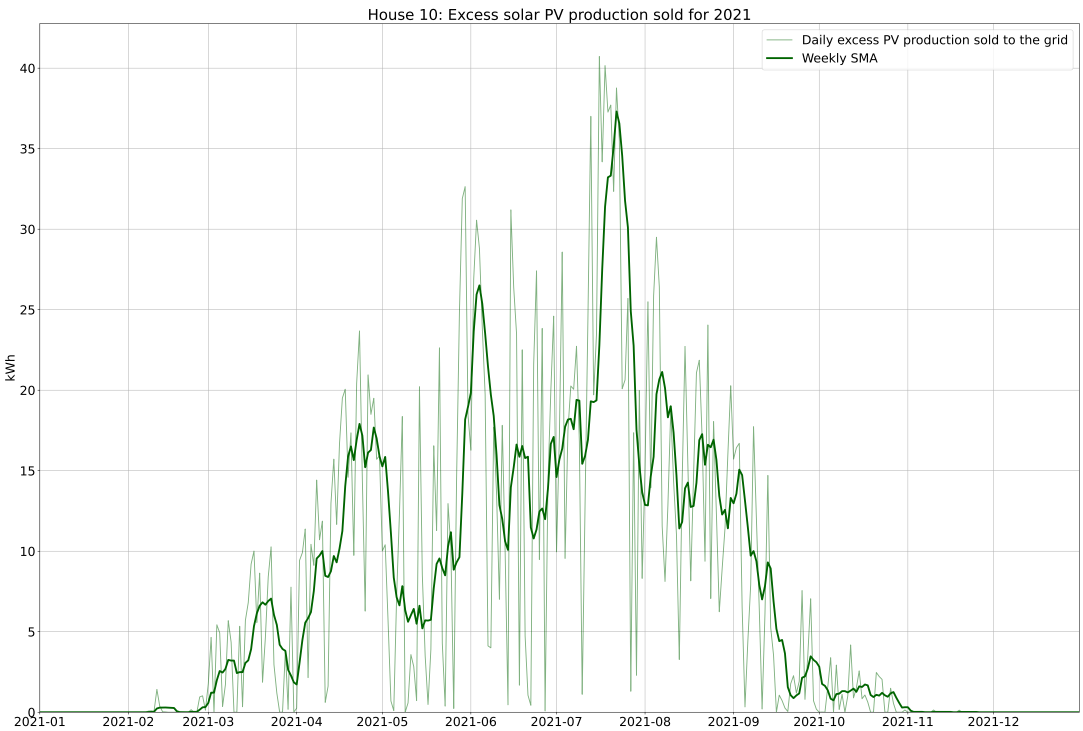



Figure A.206: Daily excess PV production sold to the grid and weekly SMA for House 10 in 2021

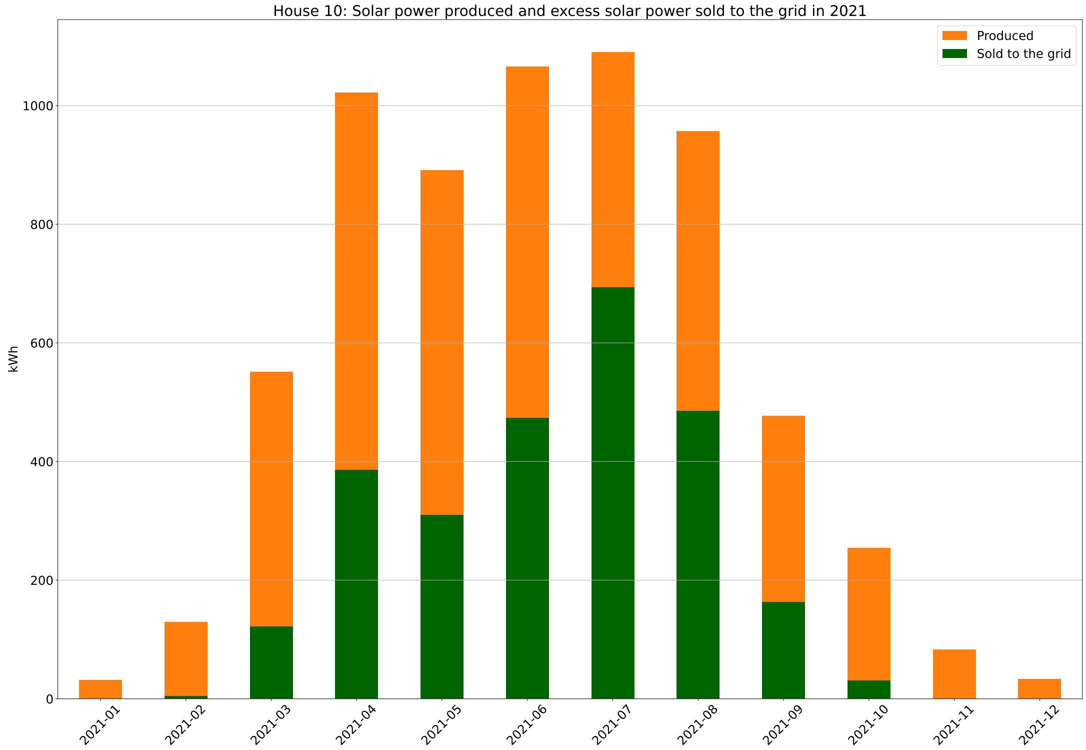



Figure A.207: Total solar PV production and excess production sold to the grid for each month in 2021 from House 10.

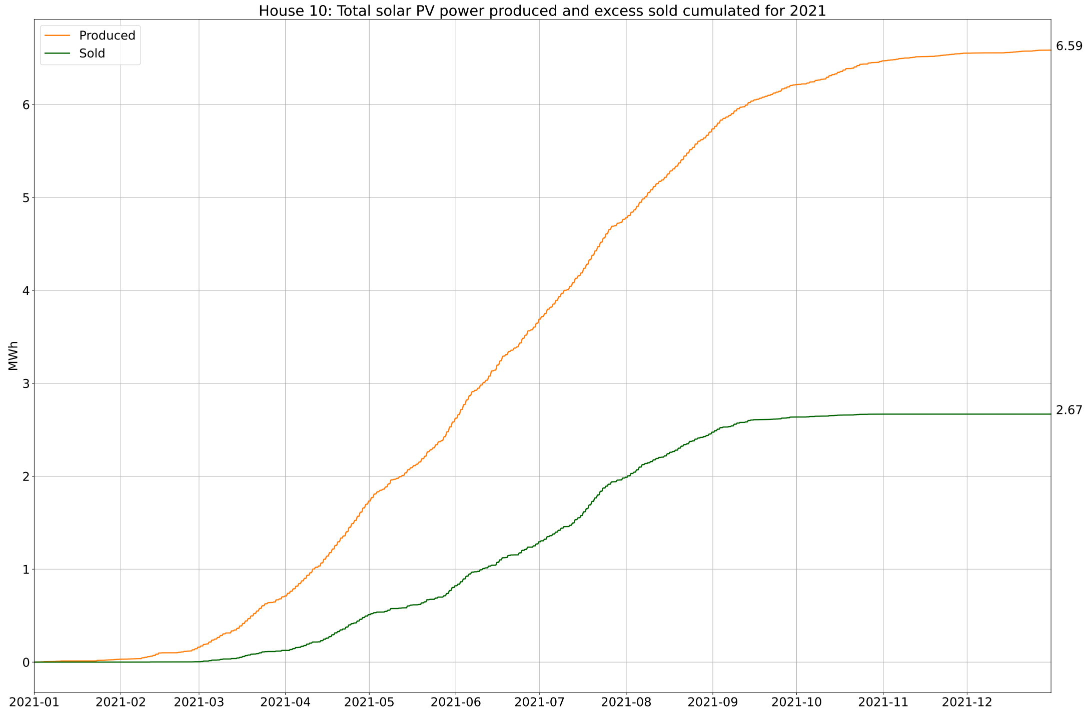



Figure A.208: Total solar PV production and excess production sold cumulated over 2021 from House 10

### A.10.3 Delta variable

**2020**

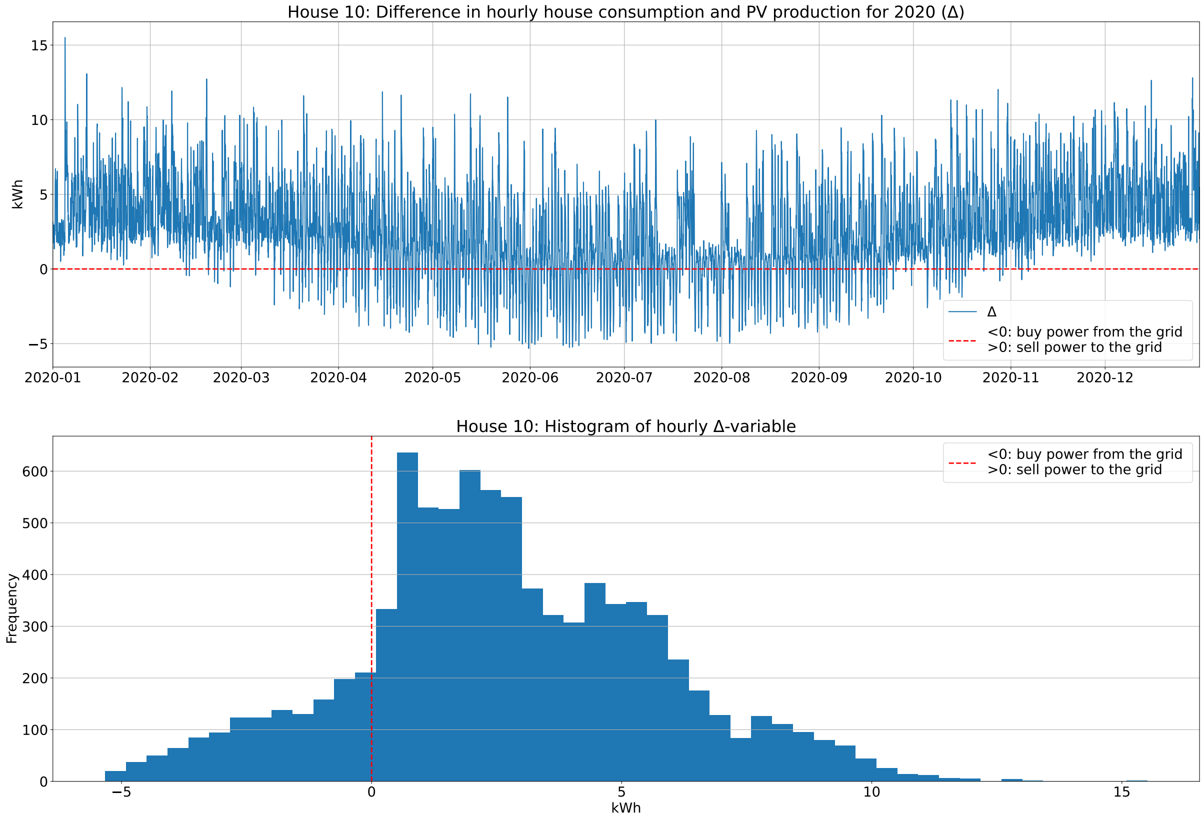



Figure A.209: The delta variable plotted for House 10. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $>0$ and sell when $<0$.

## 2021

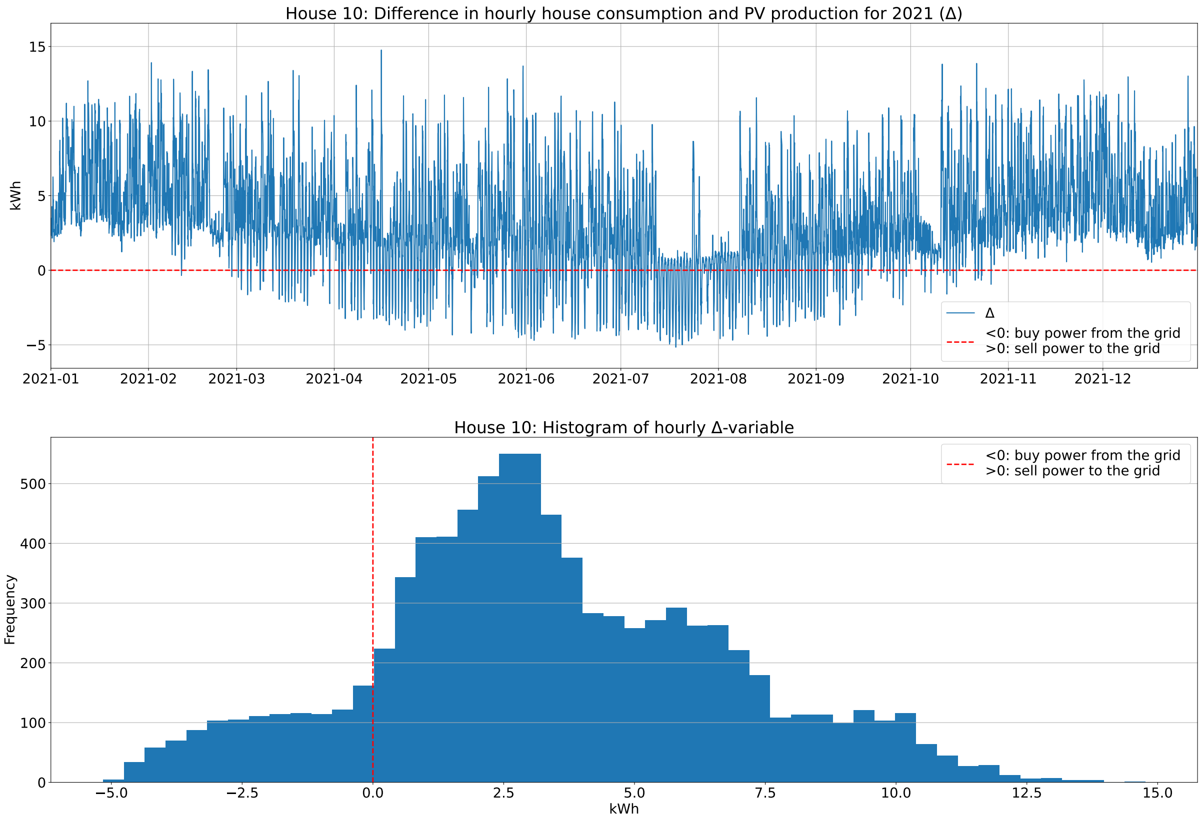



Figure A.210: The delta variable plotted for House 10. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.10.4 House consumption and PV production

**2020**

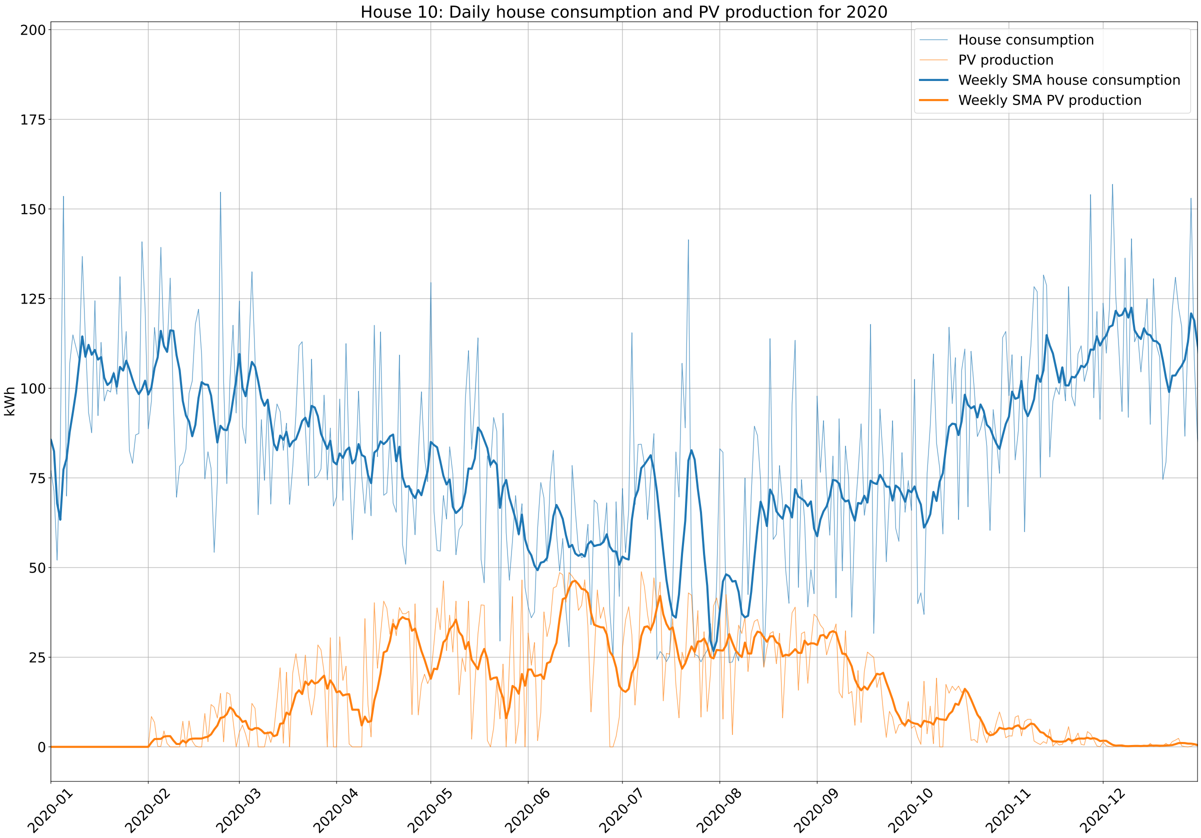



Figure A.211: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

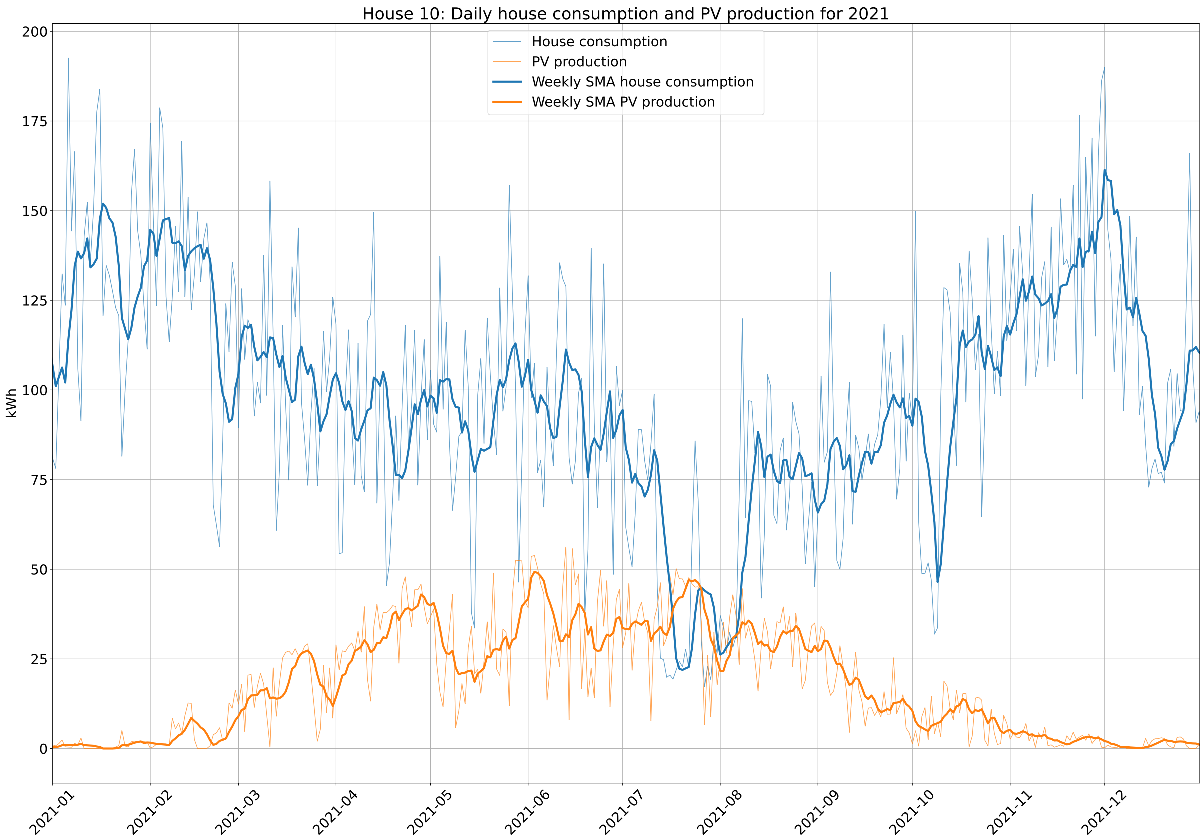



Figure A.212: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.10.5 Cost of energy

#### 2020

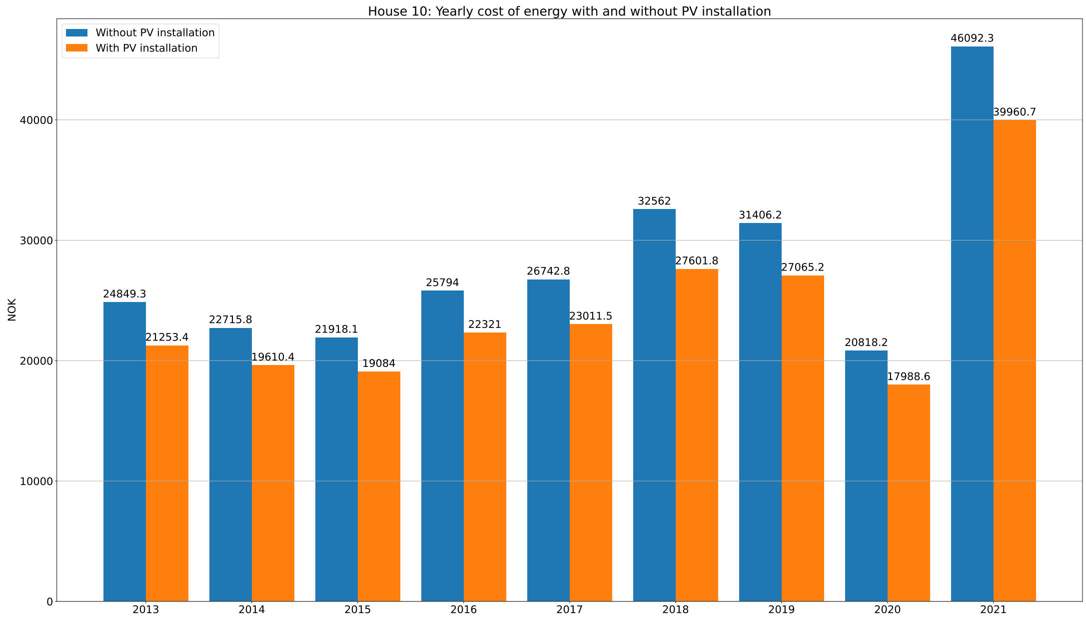



Figure A.213: Yearly cost of energy for House 10, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

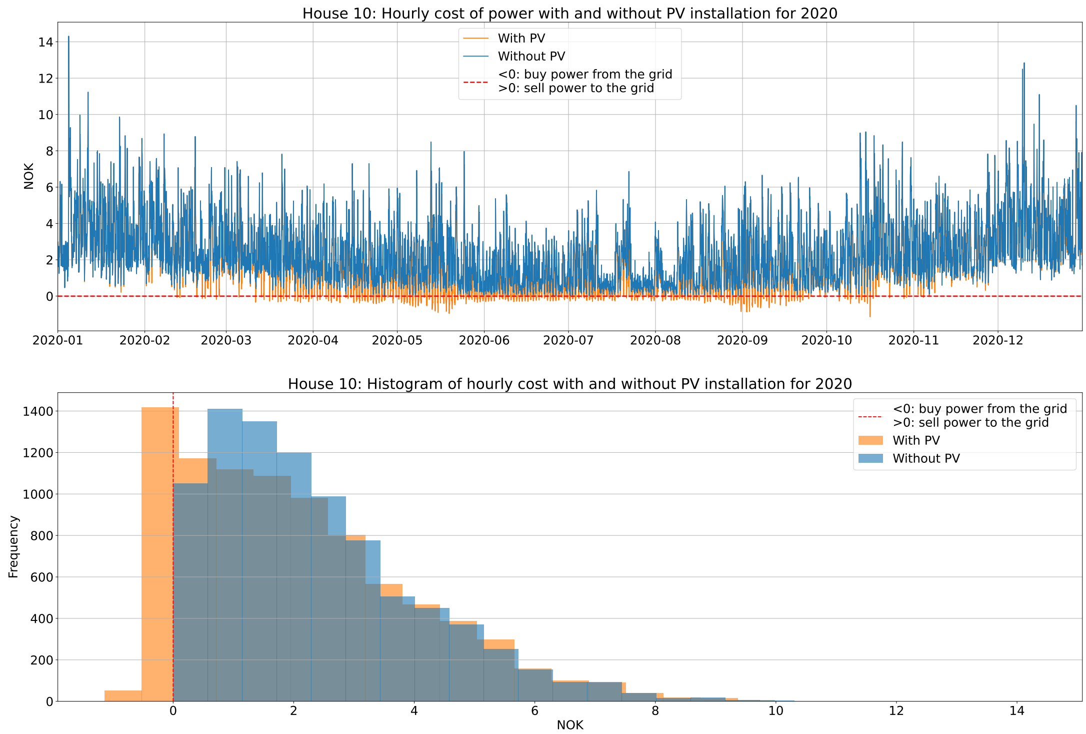



Figure A.214: Hourly cost of energy for House 10 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

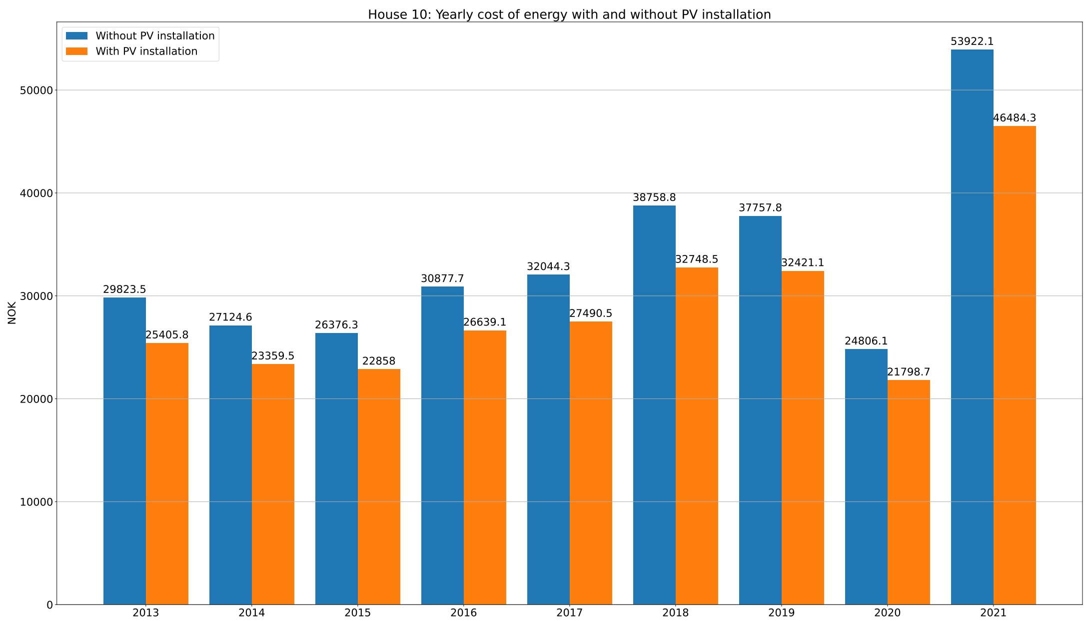



Figure A.215: Yearly cost of energy for House 10, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

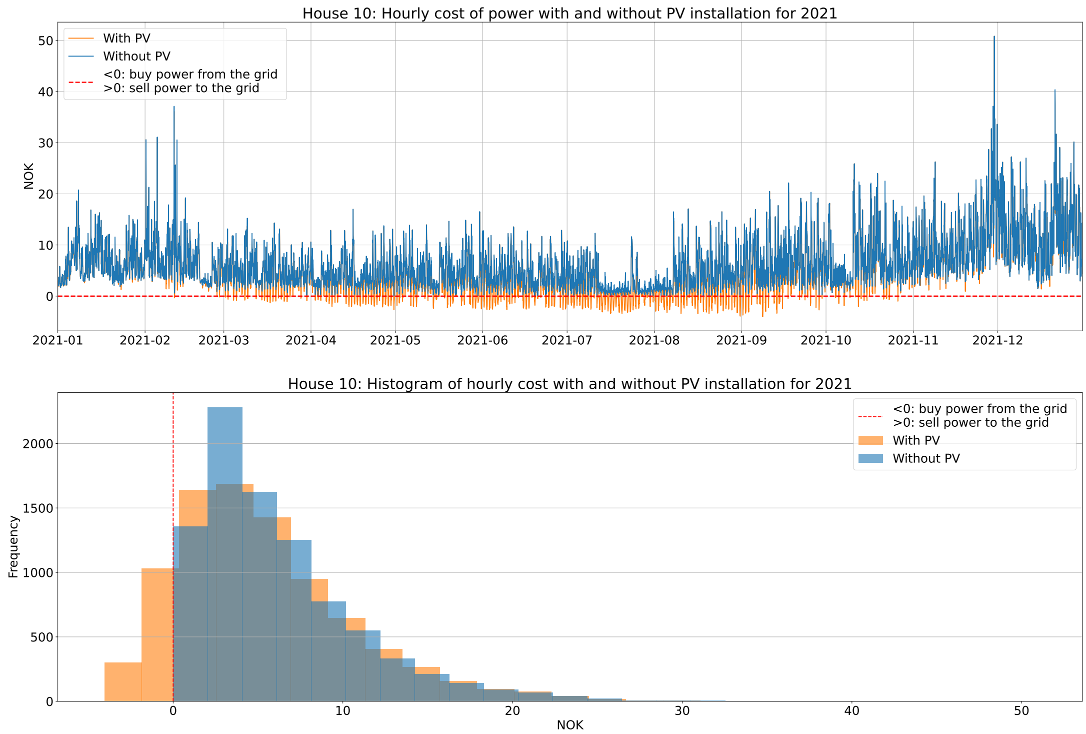



Figure A.216: Hourly cost of energy for House 10 with and without a PV system present for 2021. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

# A.11 House 11

## A.11.1 House consumption

### 2020

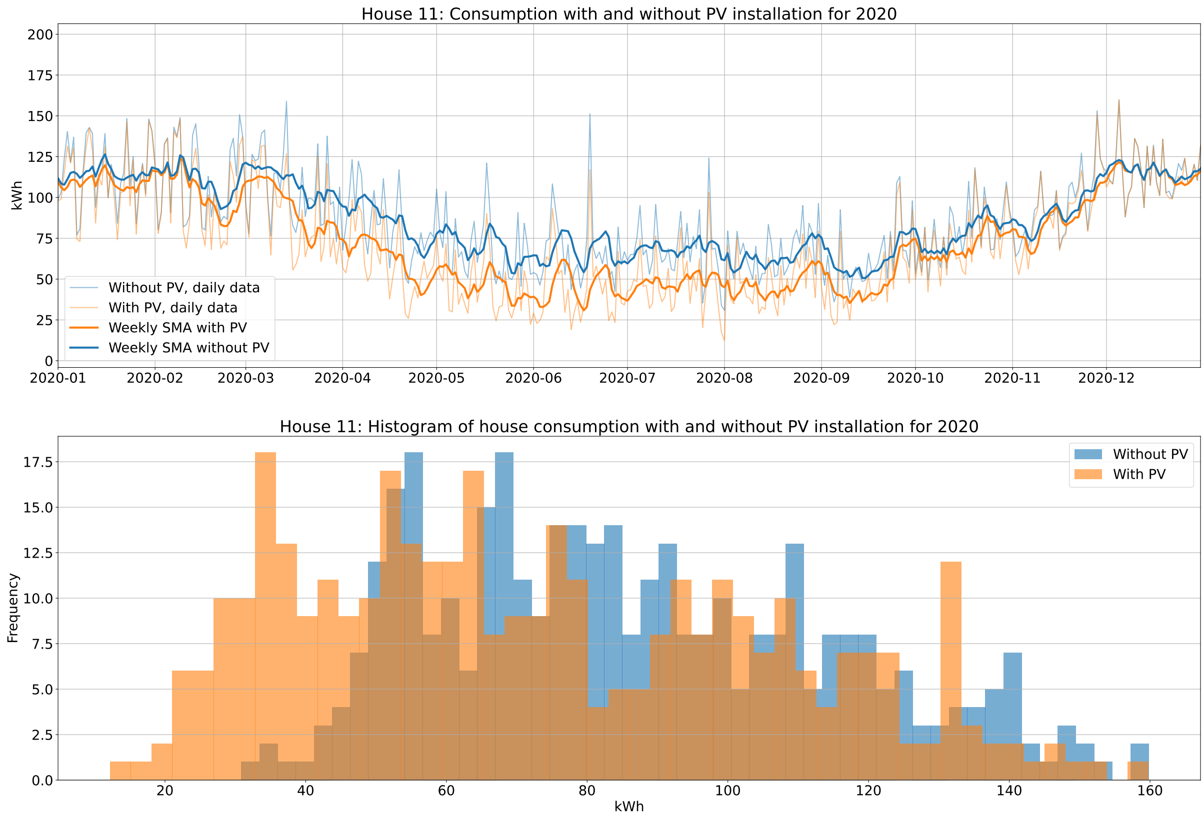



Figure A.217: Daily house consumption with and without a PV system for 2020 from House 11. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

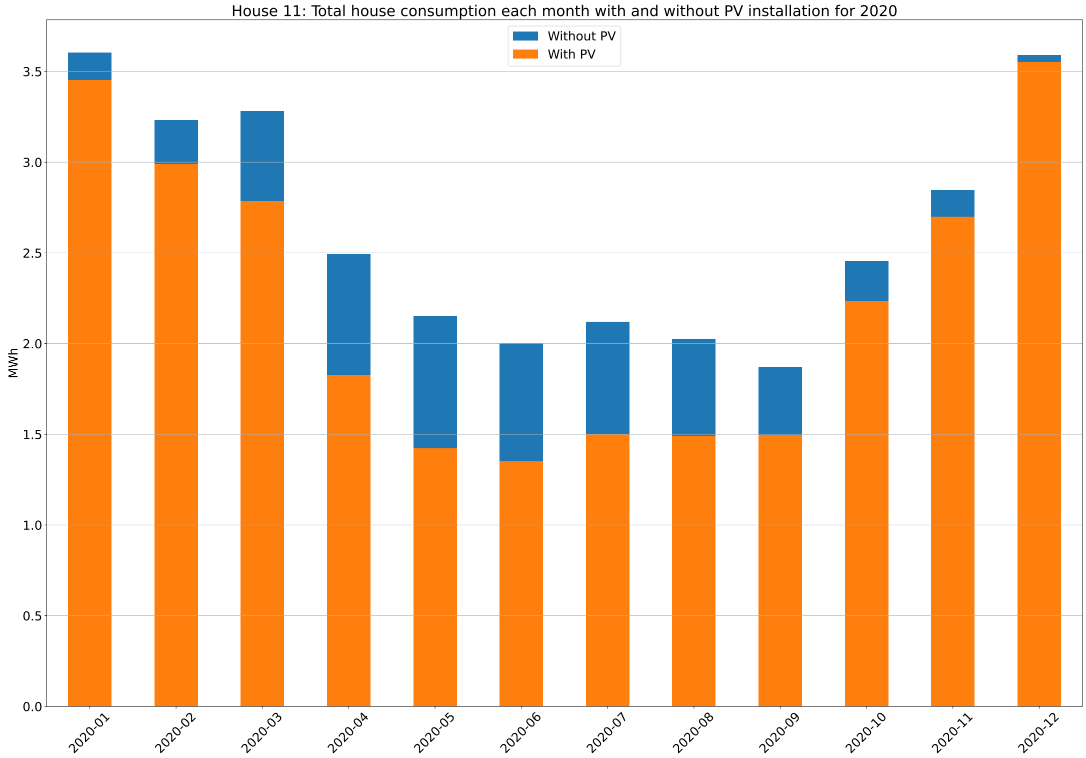



Figure A.218: Monthly house consumption for House 11 with and without a PV system for 2020.

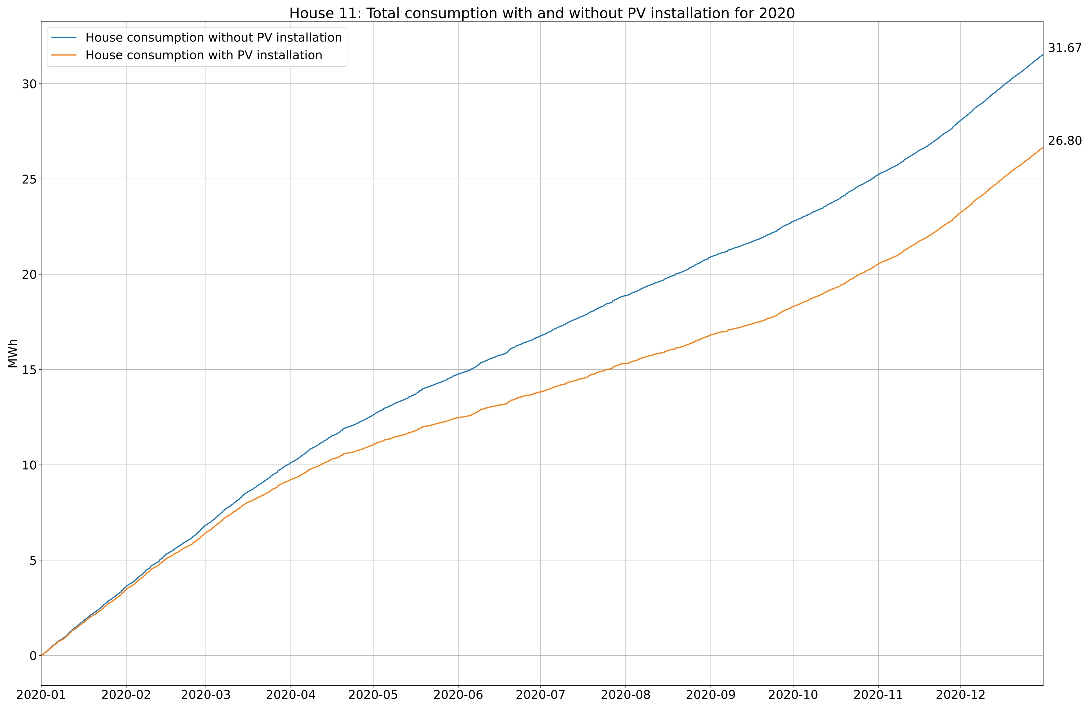
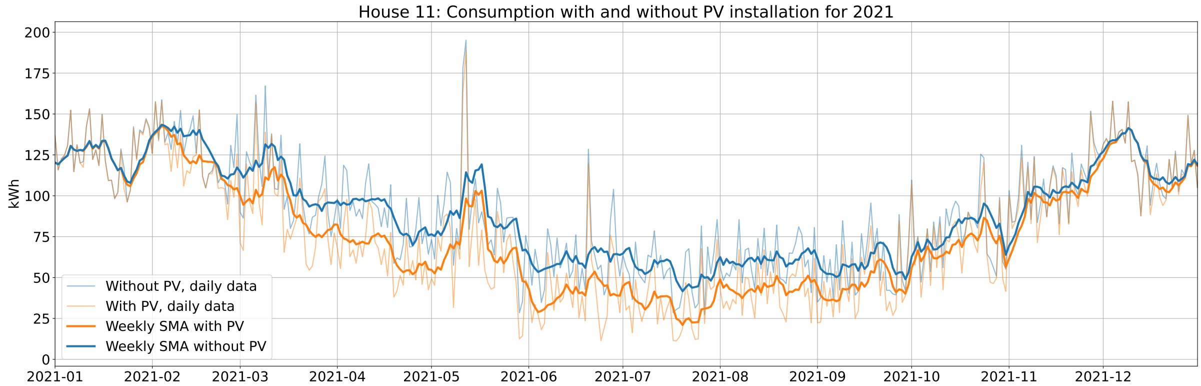



Figure A.219: Total house consumption for House 11 with and without a PV system accumulated over 2020

### 2021



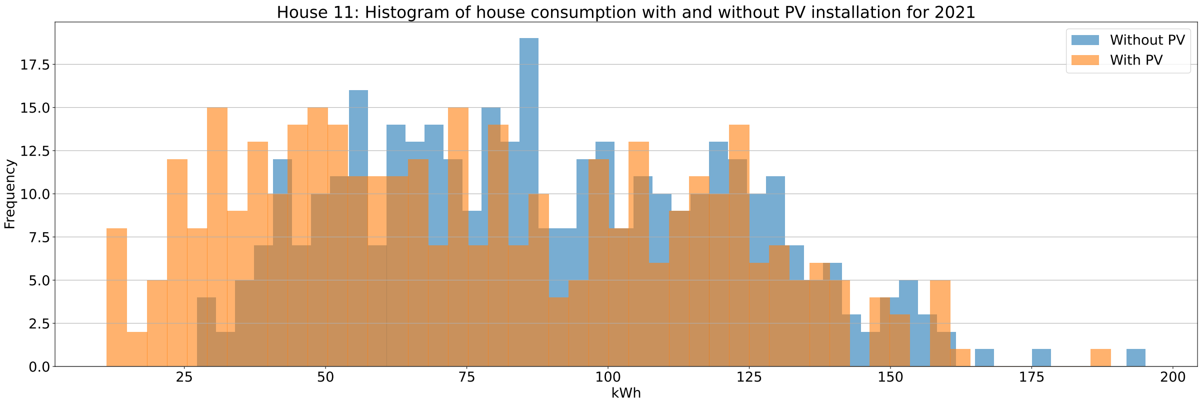




Figure A.220: Daily house consumption with and without a PV system for 2021 from House 11. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

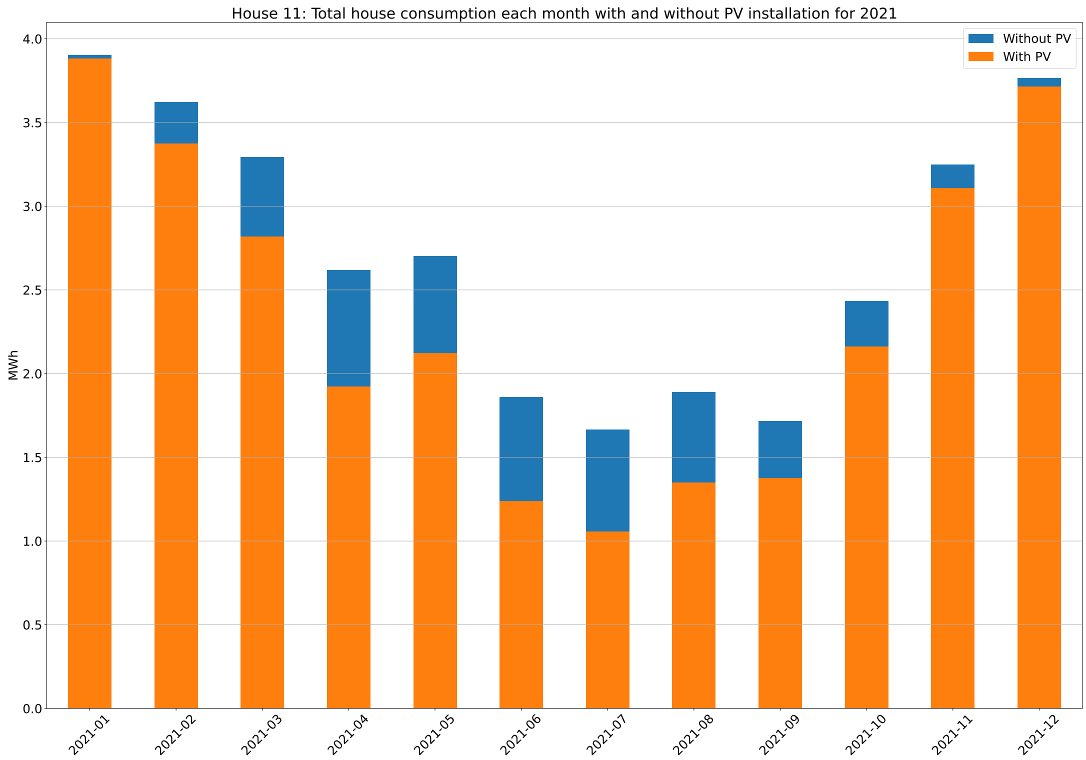



Figure A.221: Monthly house consumption for House 11 with and without a PV system for 2021.

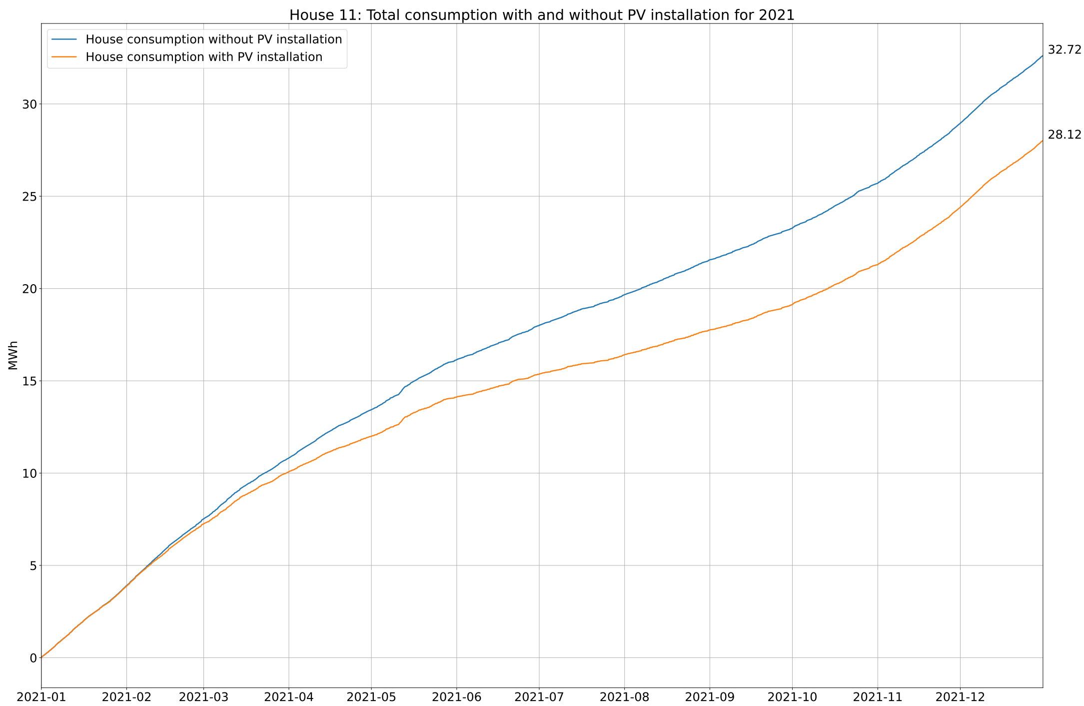



Figure A.222: Total house consumption for House 11 with and without a PV system accumulated over 2021

### A.11.2 Solar PV production

#### 2020

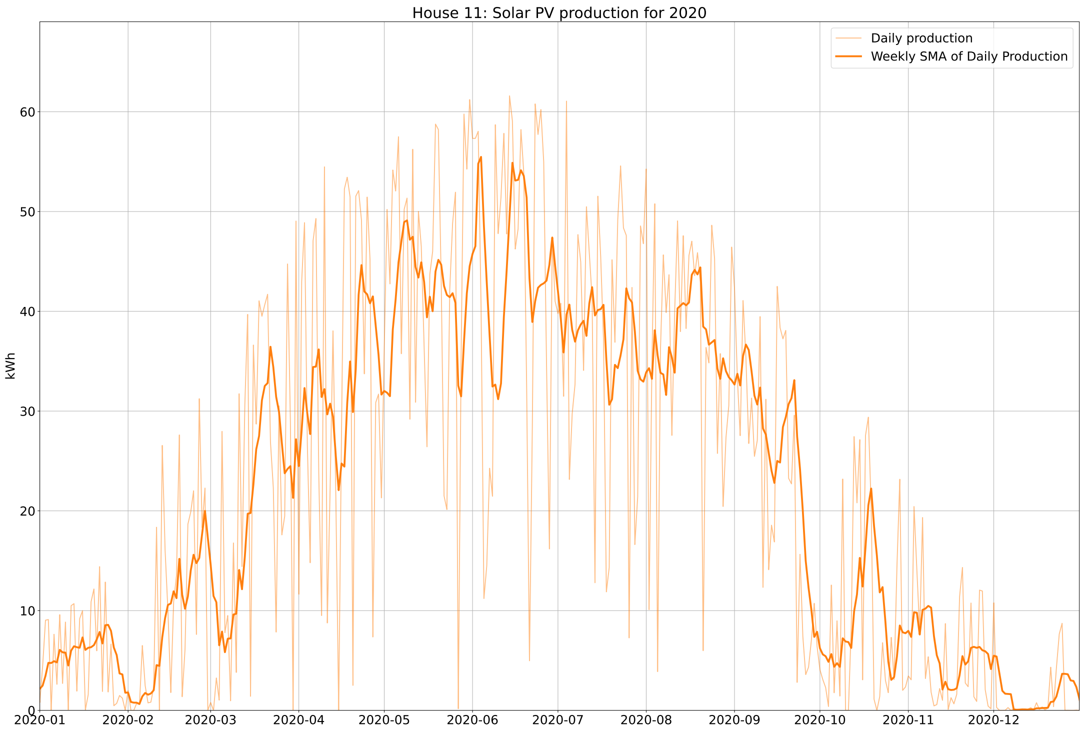



Figure A.223: Daily PV production and weekly SMA for House 11 in 2020.

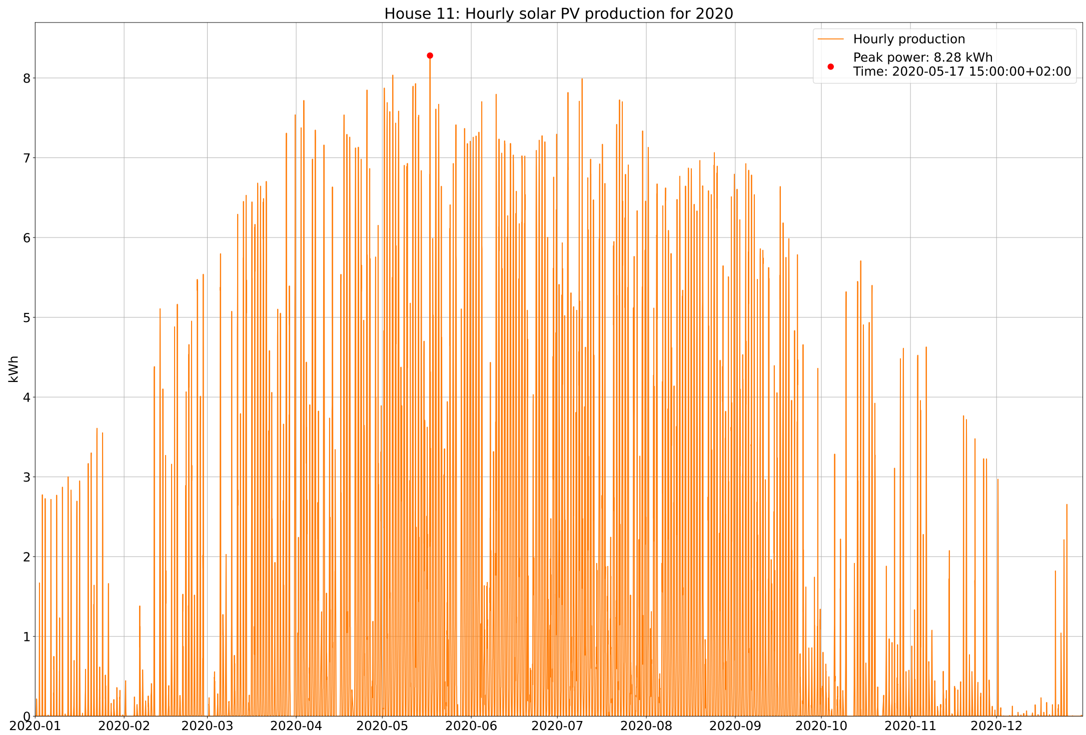



Figure A.224: Hourly PV production for House 11 in 2020.

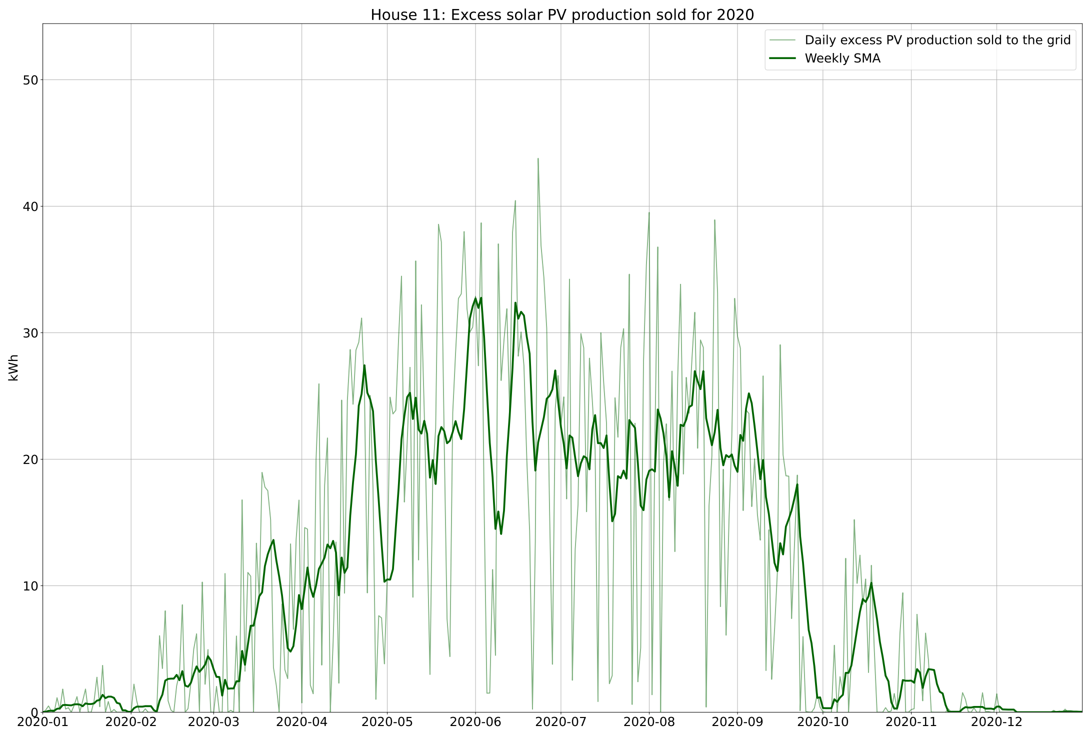



Figure A.225: Daily excess PV production sold to the grid and weekly SMA for House 11 in 2020

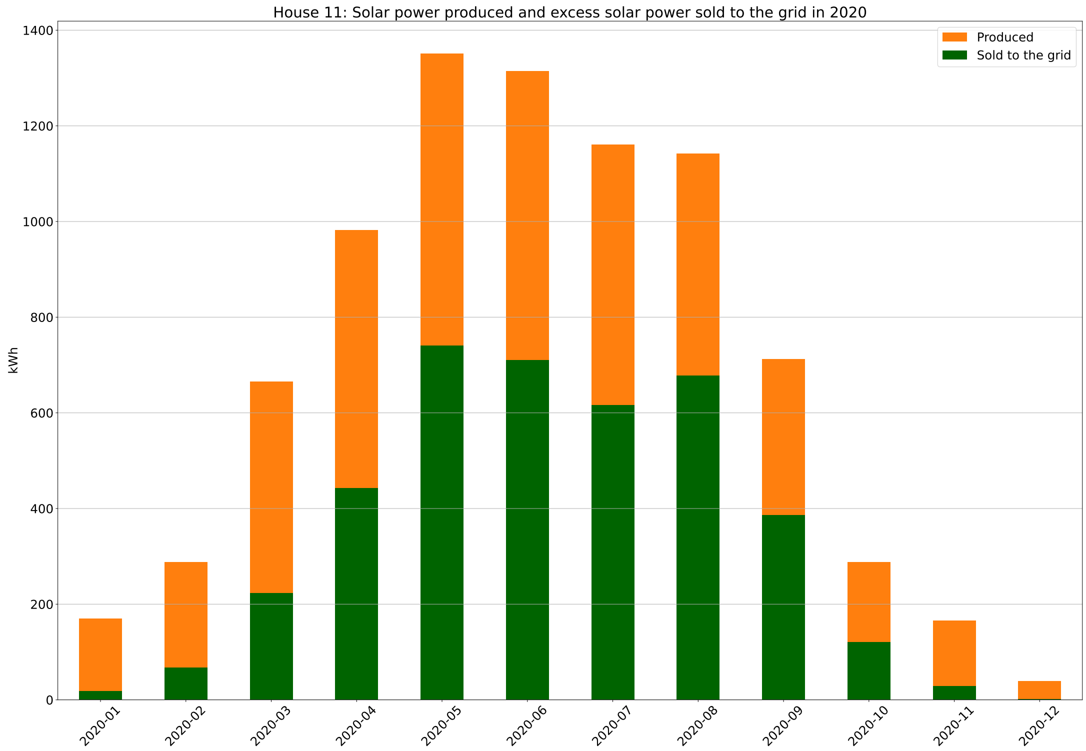



Figure A.226: Total solar PV production and excess production sold to the grid for each month in 2020 from House 11.

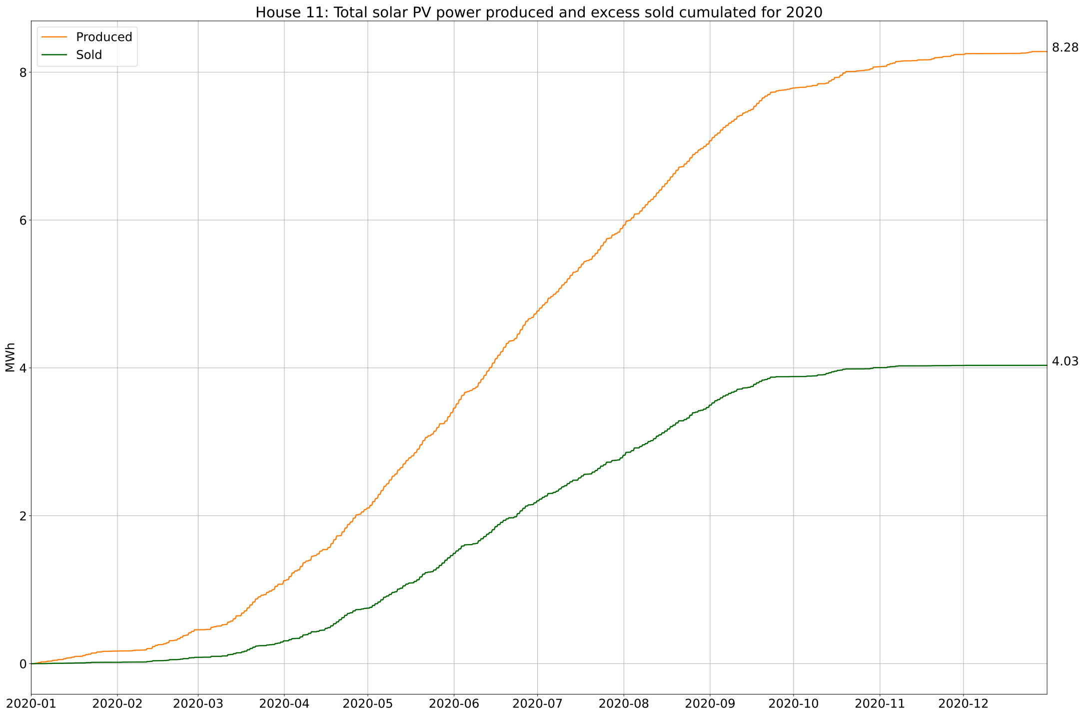



Figure A.227: Total solar PV production and excess production sold cumulated over 2020 from House 11

### 2021

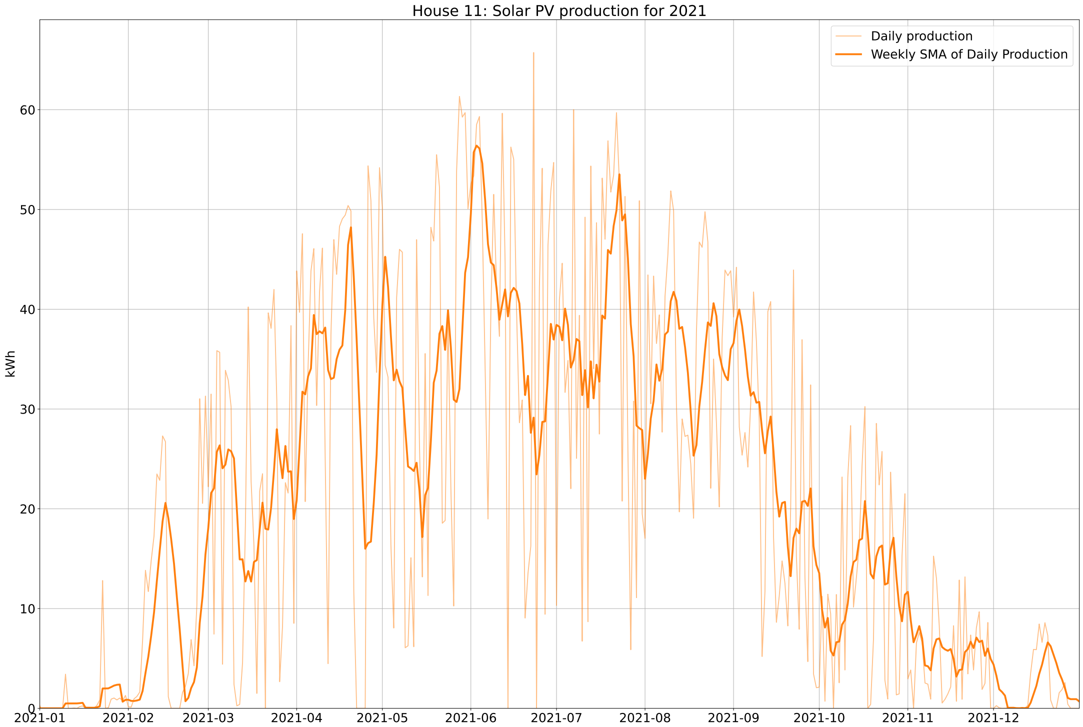



Figure A.228: Daily PV production and weekly SMA for House 11 in 2021.

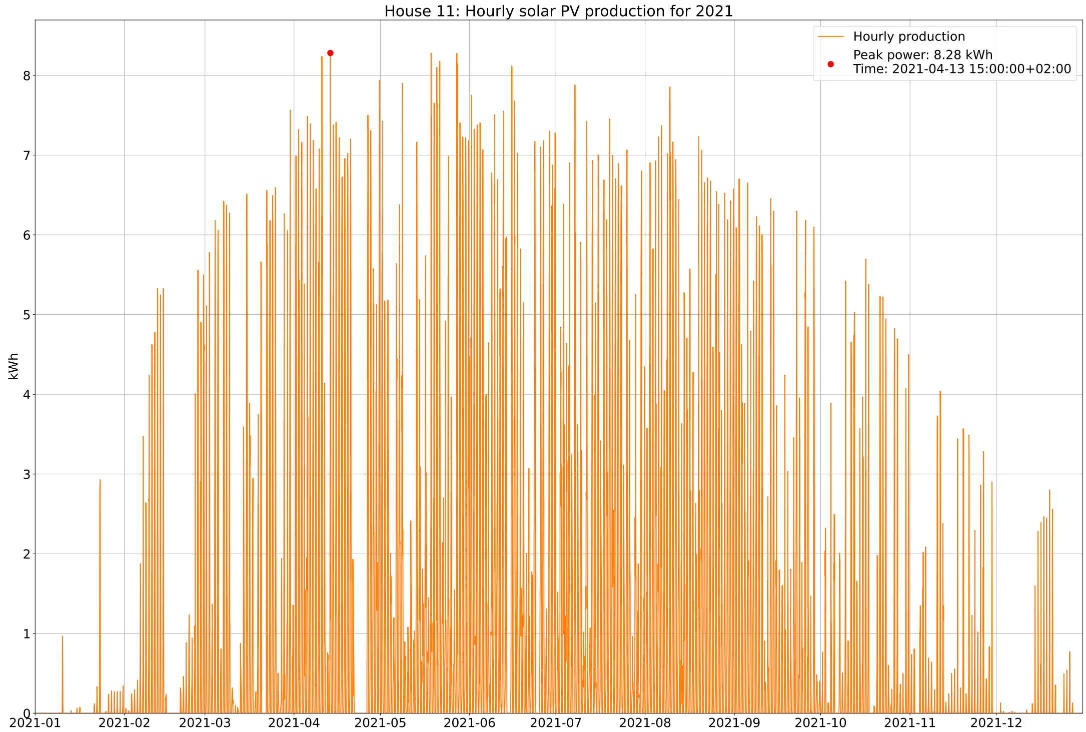



Figure A.229: Hourly PV production for House 11 in 2021.

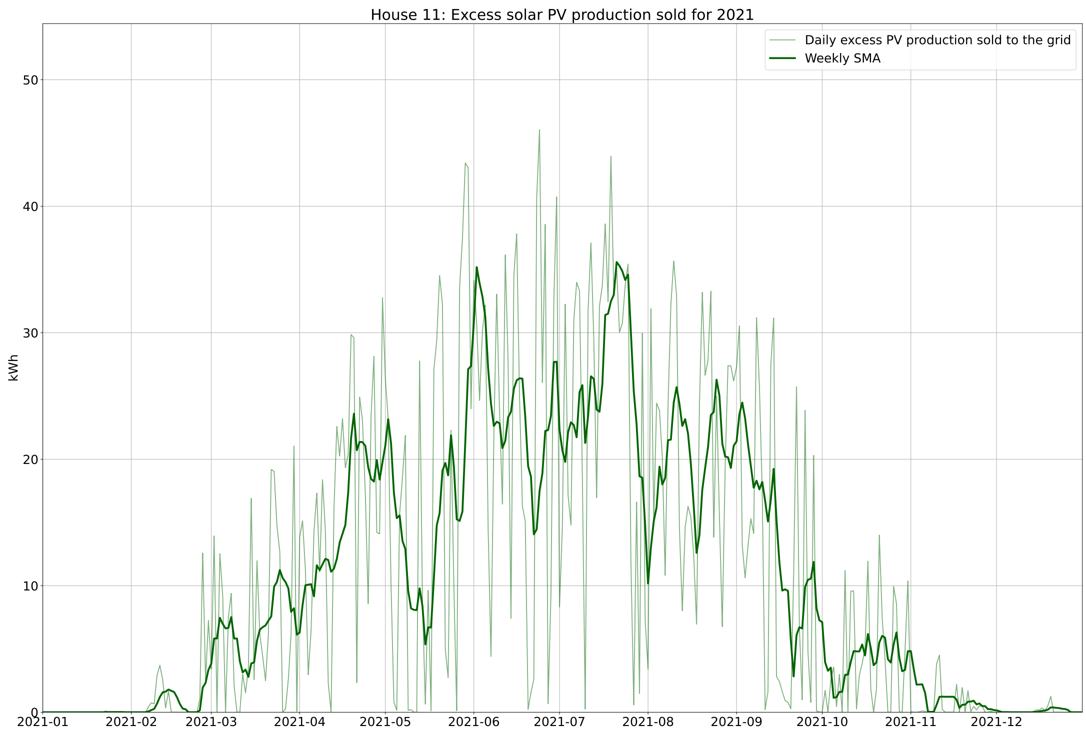



Figure A.230: Daily excess PV production sold to the grid and weekly SMA for House 11 in 2021

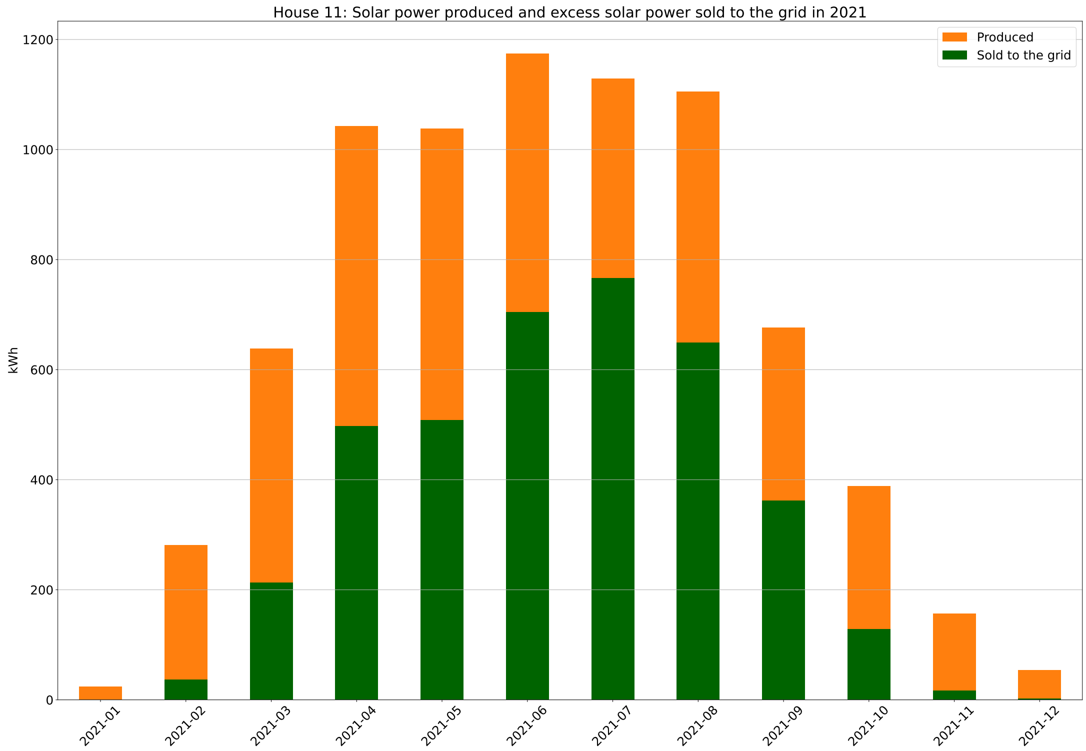



Figure A.231: Total solar PV production and excess production sold to the grid for each month in 2021 from House 11.

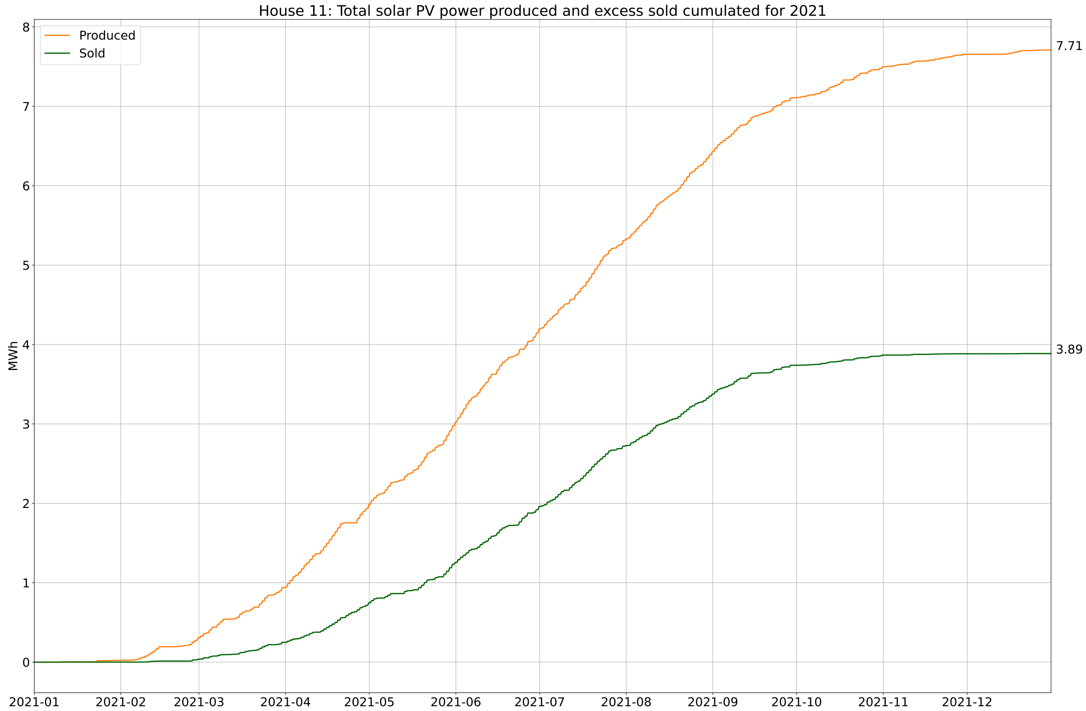
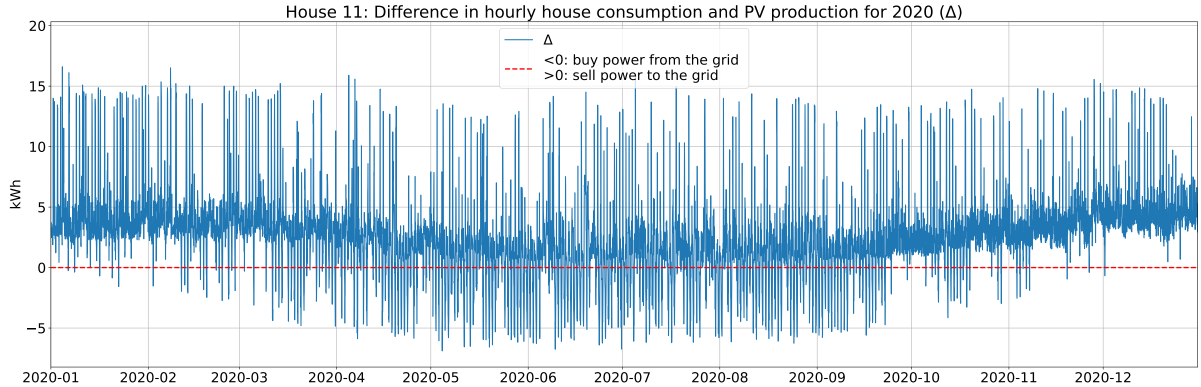



Figure A.232: Total solar PV production and excess production sold cumulated over 2021 from House 11

### A.11.3 Delta variable

#### 2020



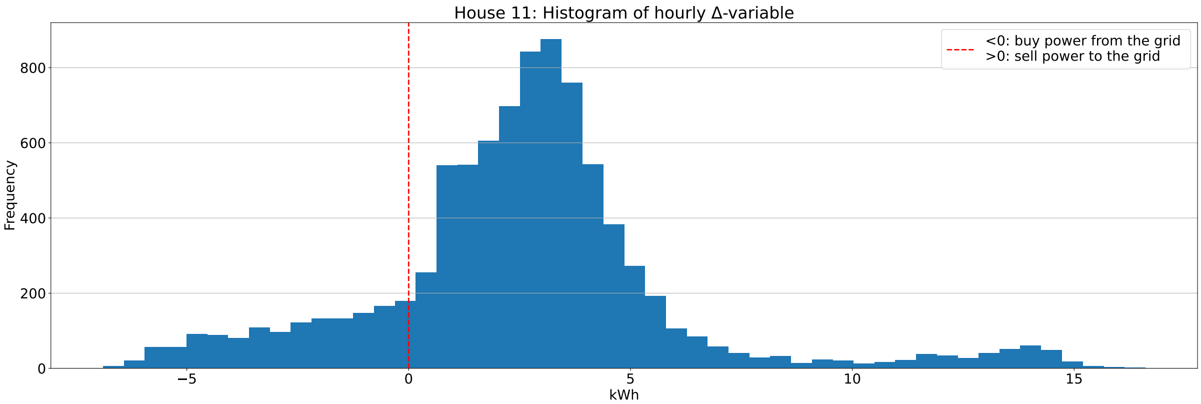




Figure A.233: The delta variable plotted for House 11. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

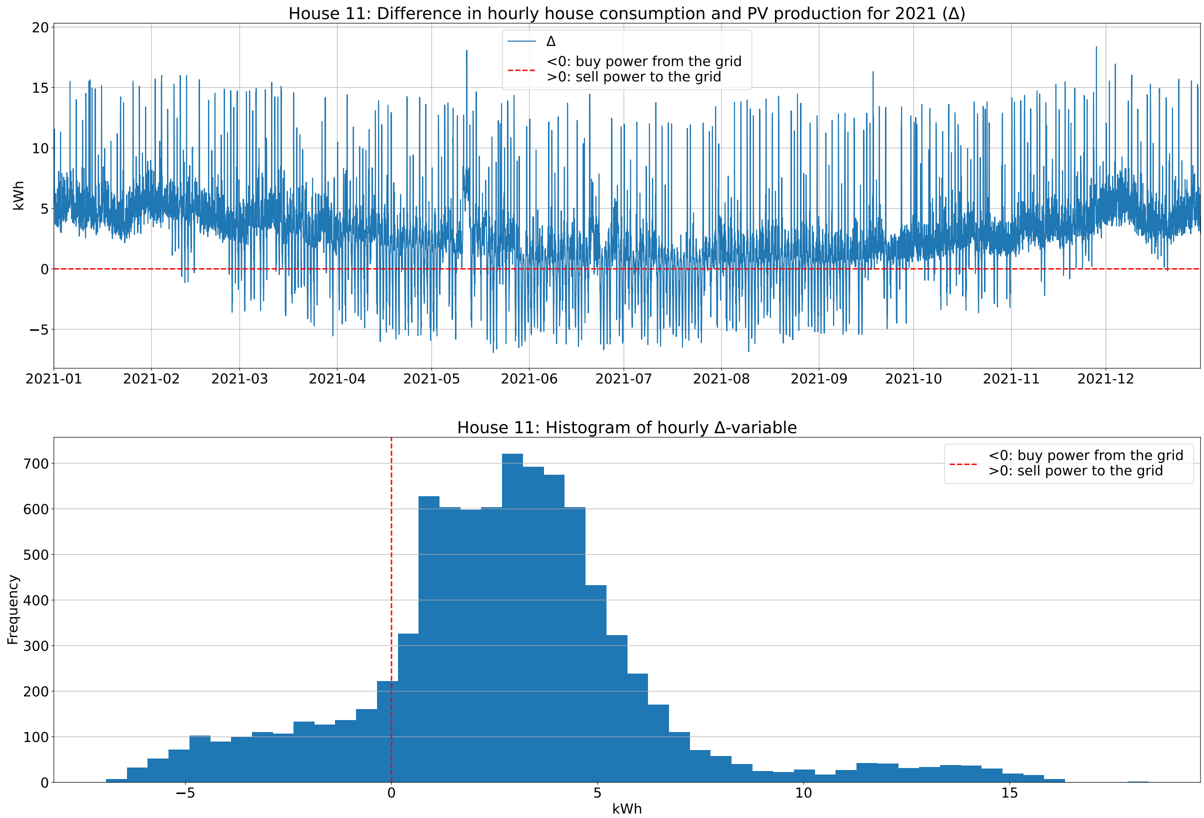



Figure A.234: The delta variable plotted for House 11. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.11.4 House consumption and PV production

#### 2020

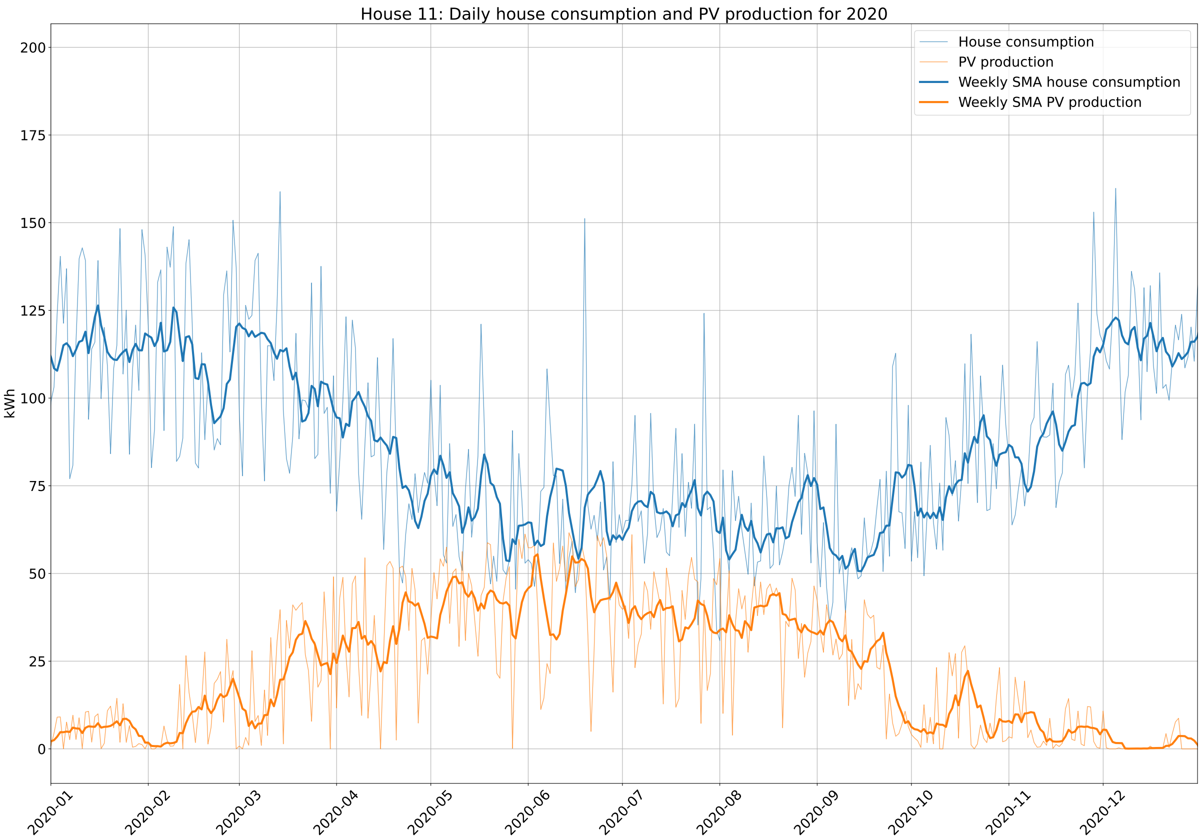



Figure A.235: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

### 2021

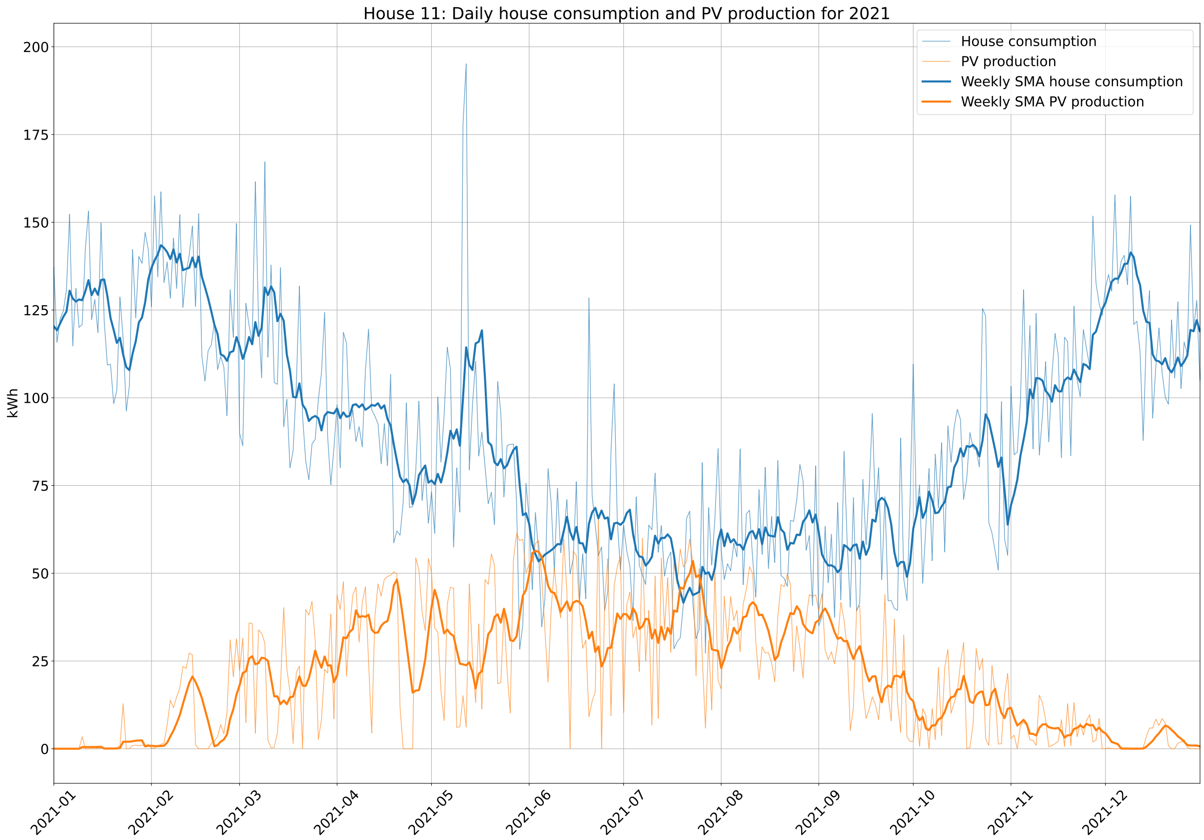



Figure A.236: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.11.5 Cost of energy

#### 2020

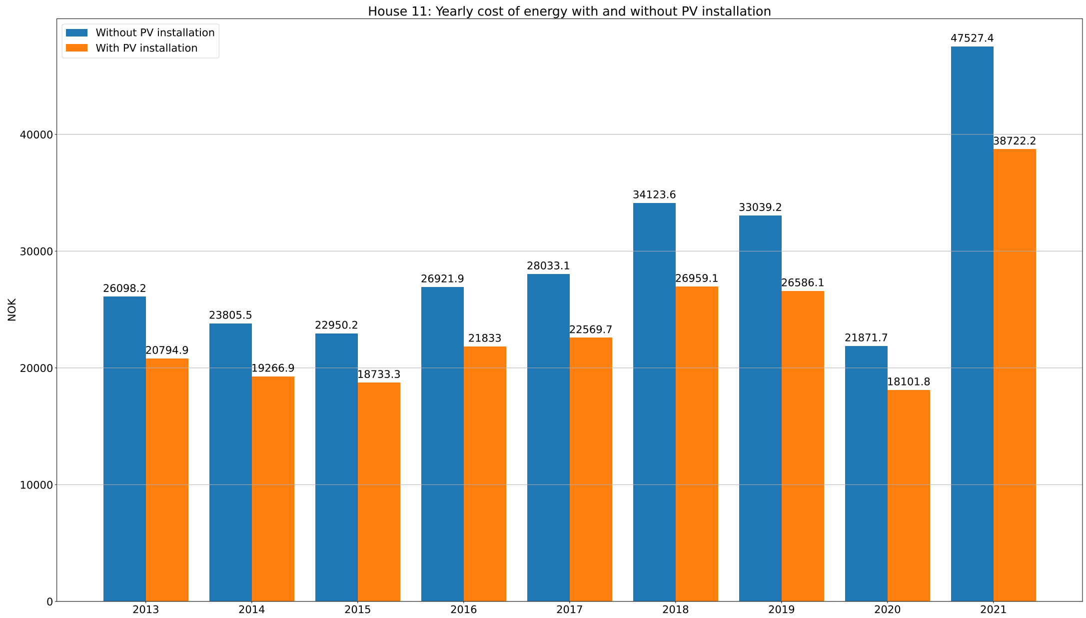



Figure A.237: Yearly cost of energy for House 11, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

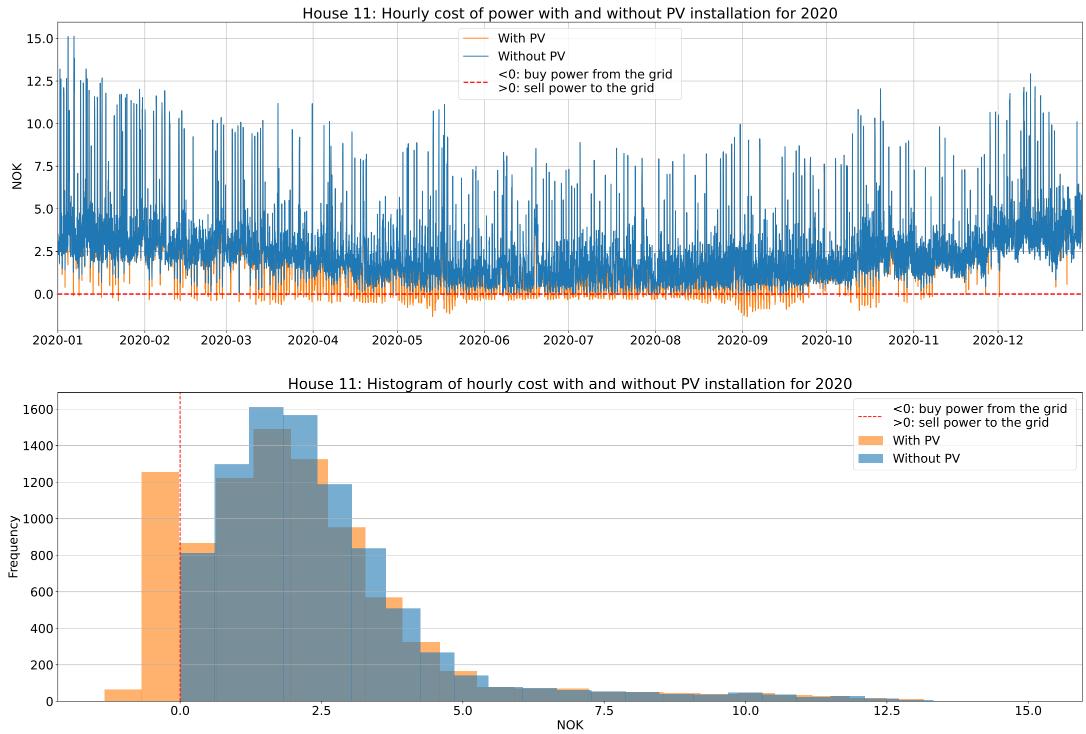



Figure A.238: Hourly cost of energy for House 11 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

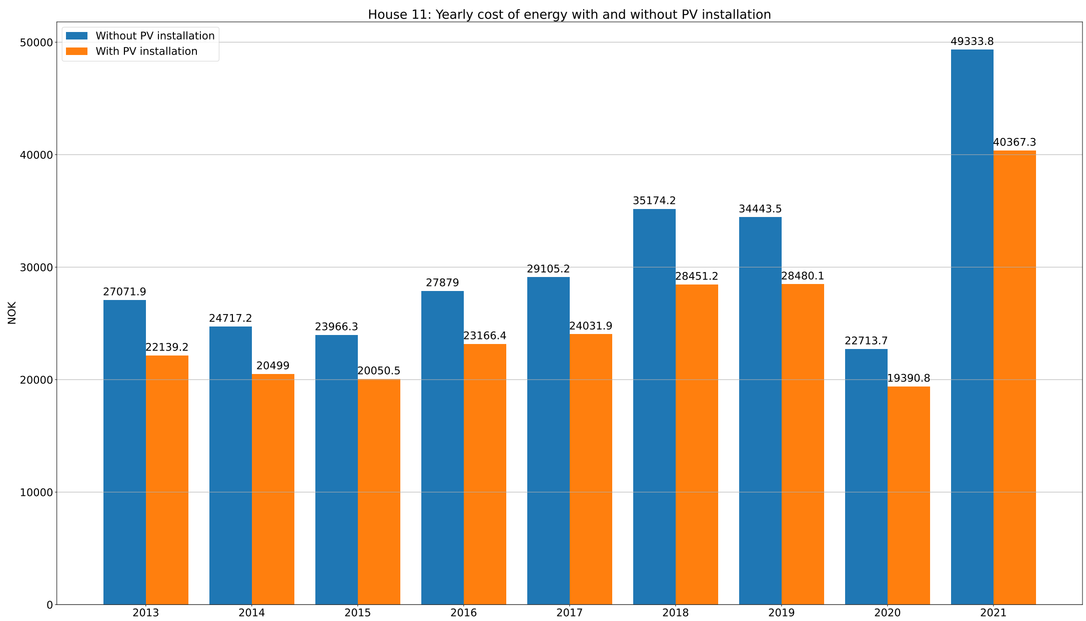



Figure A.239: Yearly cost of energy for House 11, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

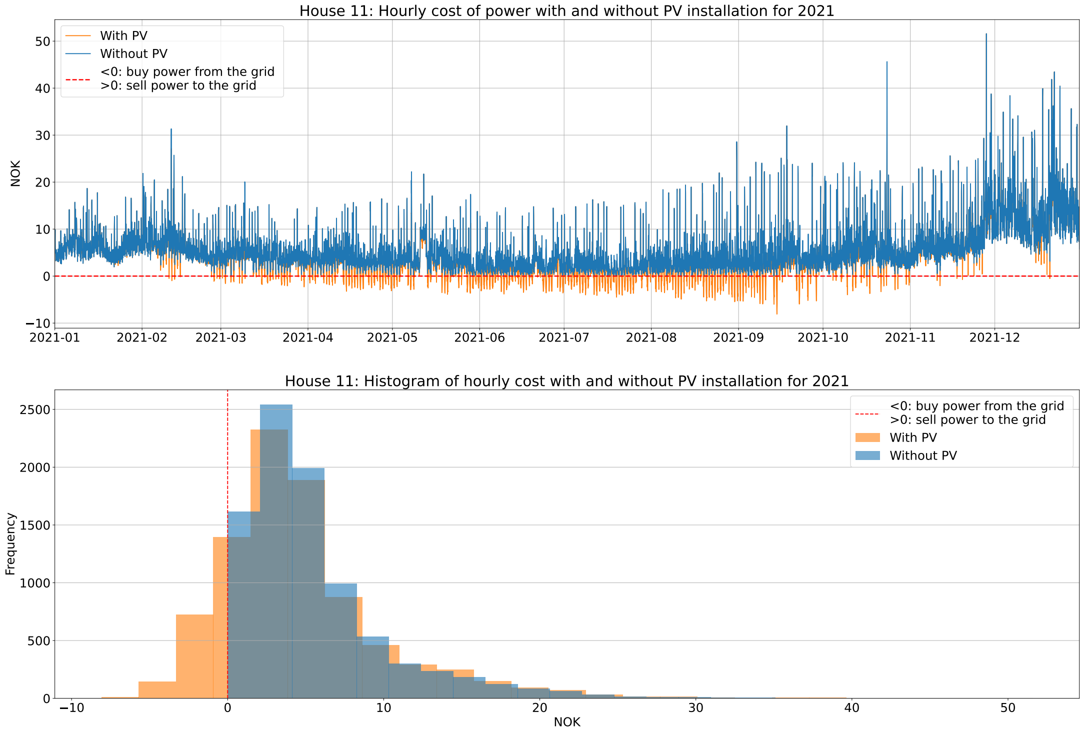



Figure A.240: Hourly cost of energy for House 11 with and without a PV system present for 2021. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.12 House 12

### A.12.1 House consumption

#### 2020

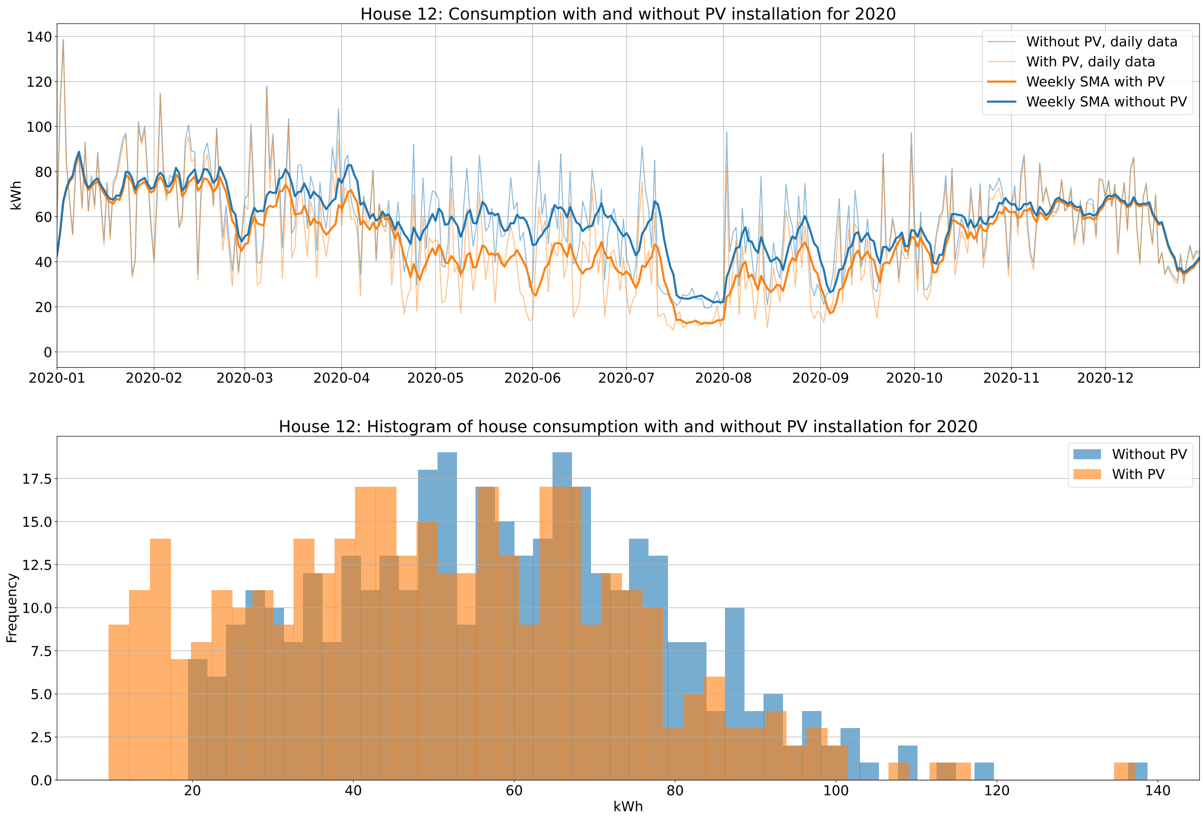



Figure A.241: Daily house consumption with and without a PV system for 2020 from House 12. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

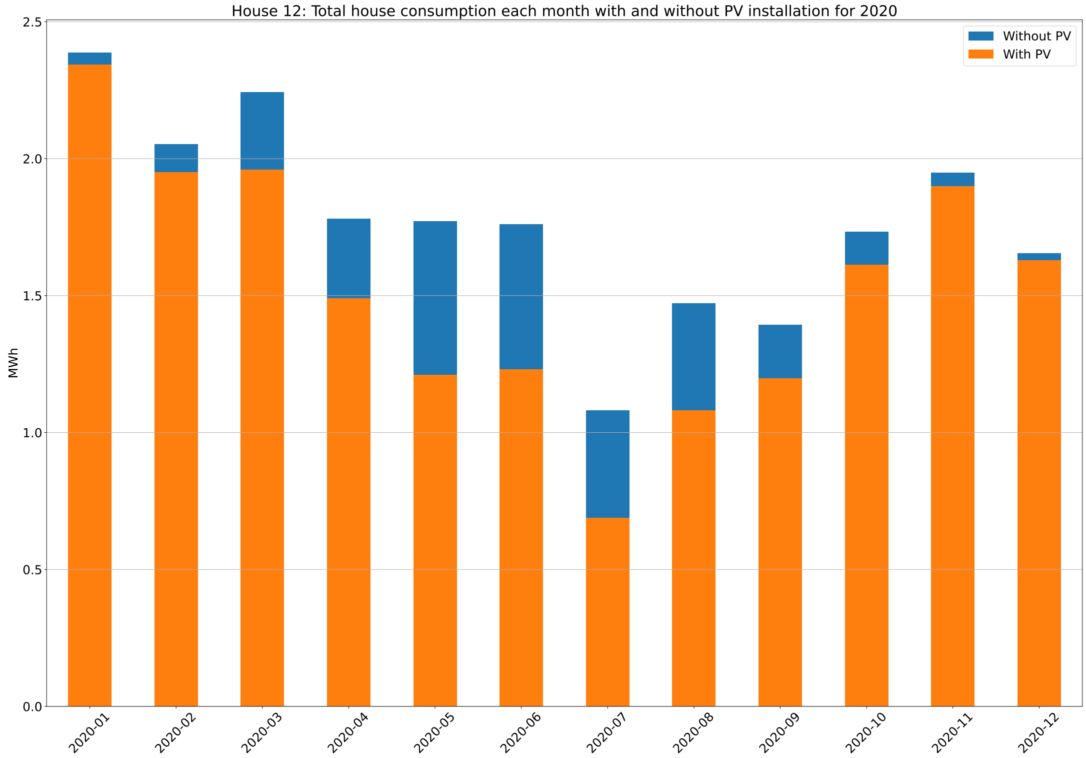



Figure A.242: Monthly house consumption for House 12 with and without a PV system for 2020.

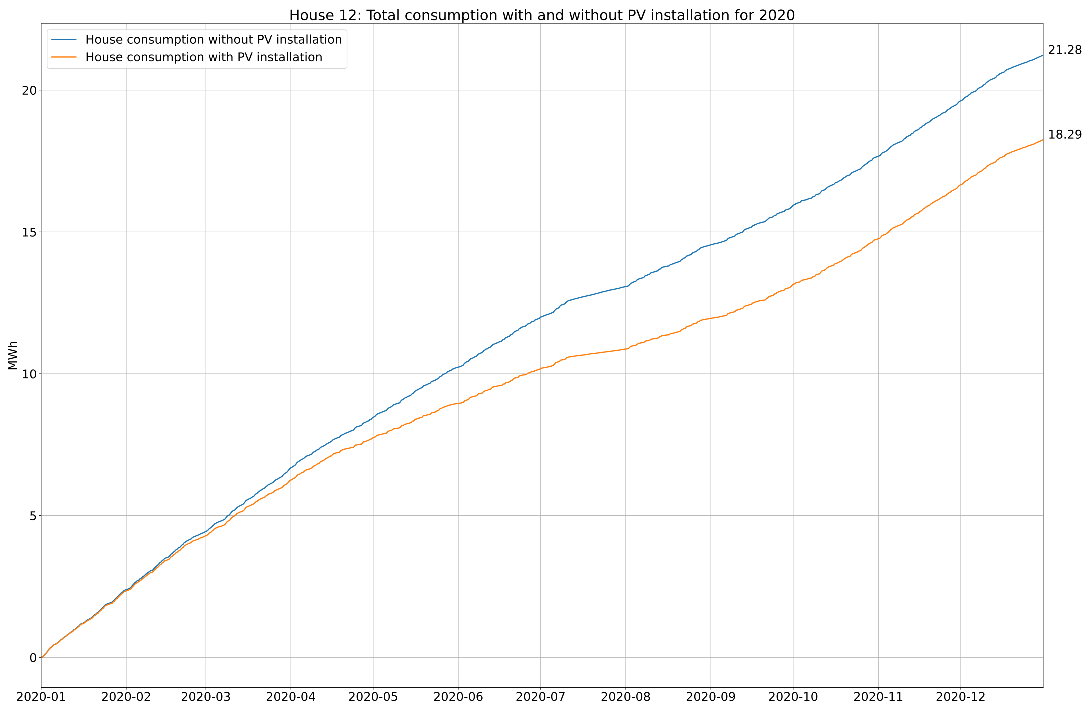



Figure A.243: Total house consumption for House 12 with and without a PV system accumulated over 2020

**2021**

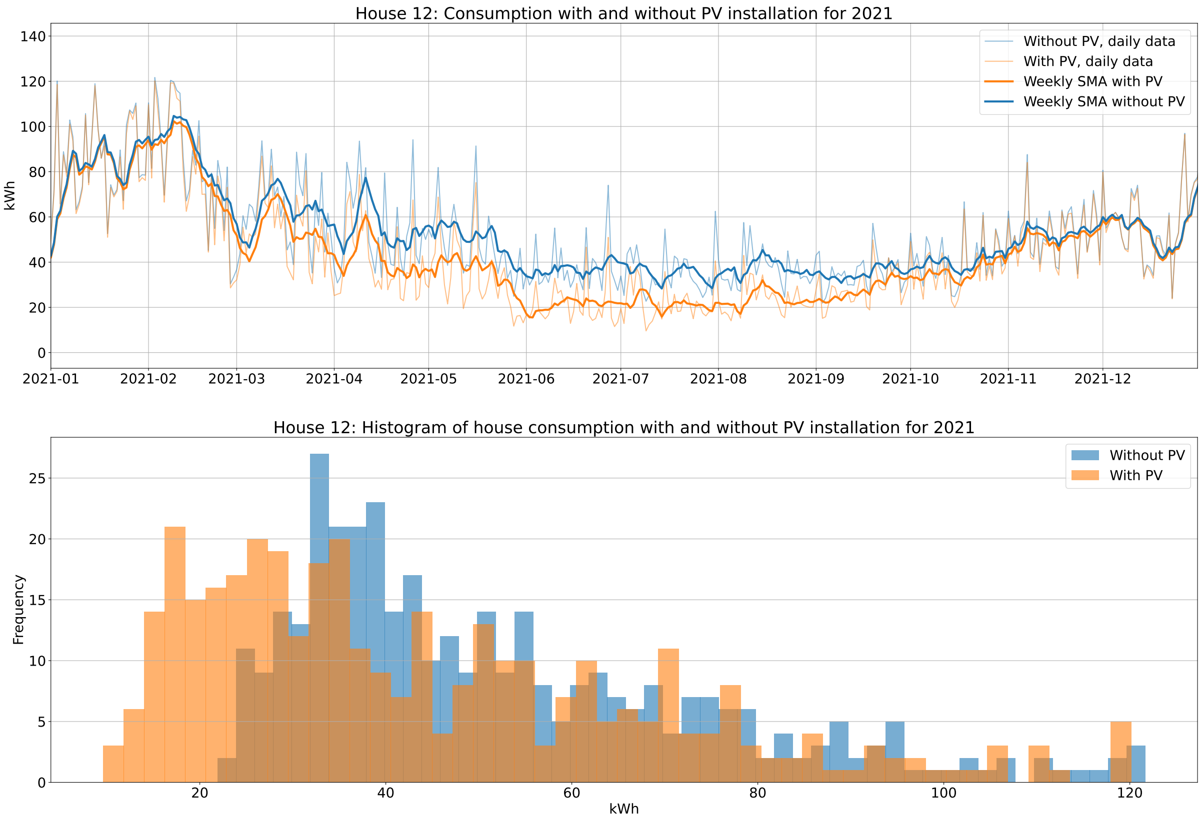



Figure A.244: Daily house consumption with and without a PV system for 2021 from House 12. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

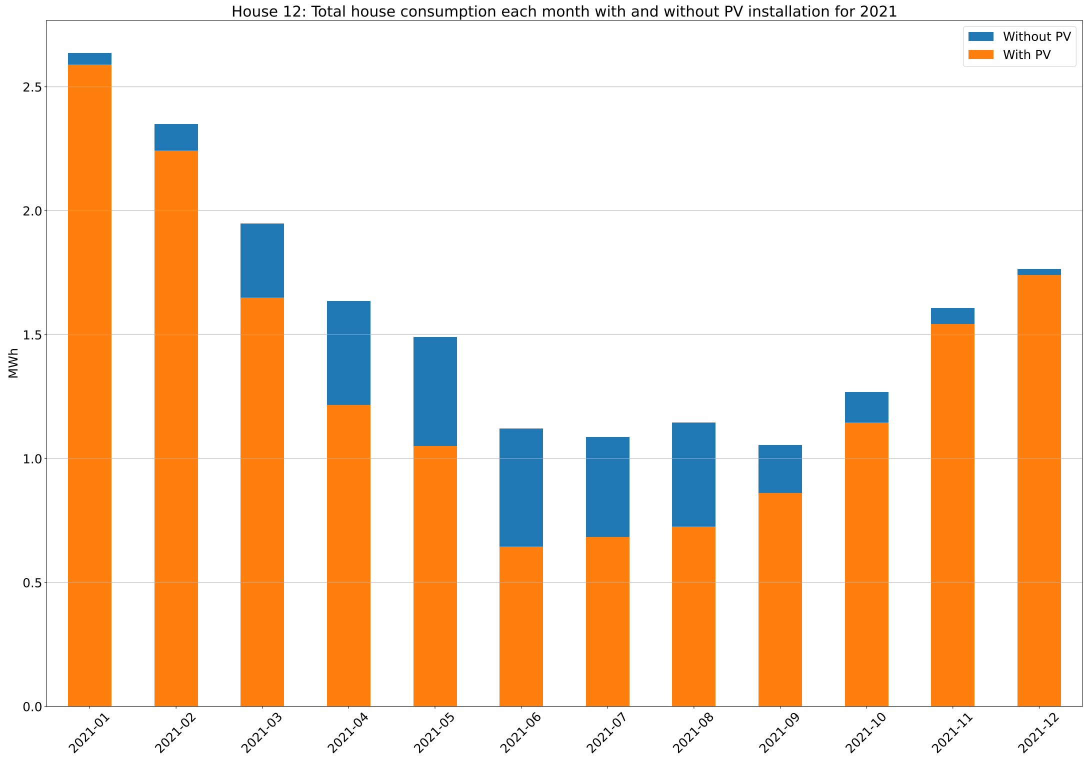



Figure A.245: Monthly house consumption for House 12 with and without a PV system for 2021.

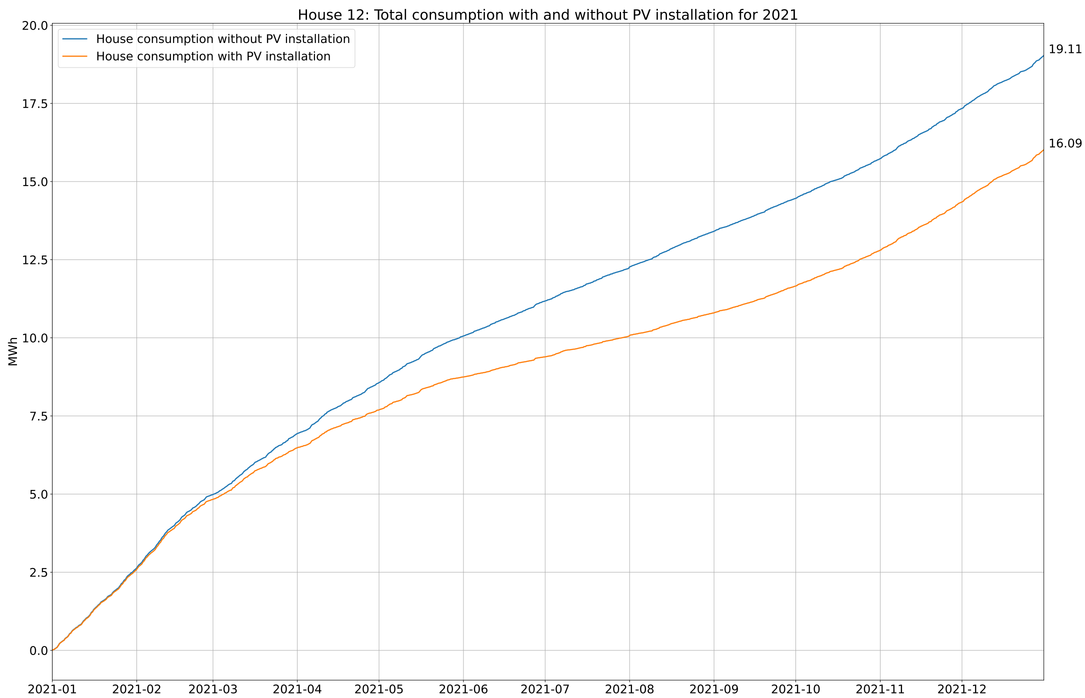



Figure A.246: Total house consumption for House 12 with and without a PV system accumulated over 2021

## A.12.2 Solar PV production

### 2020

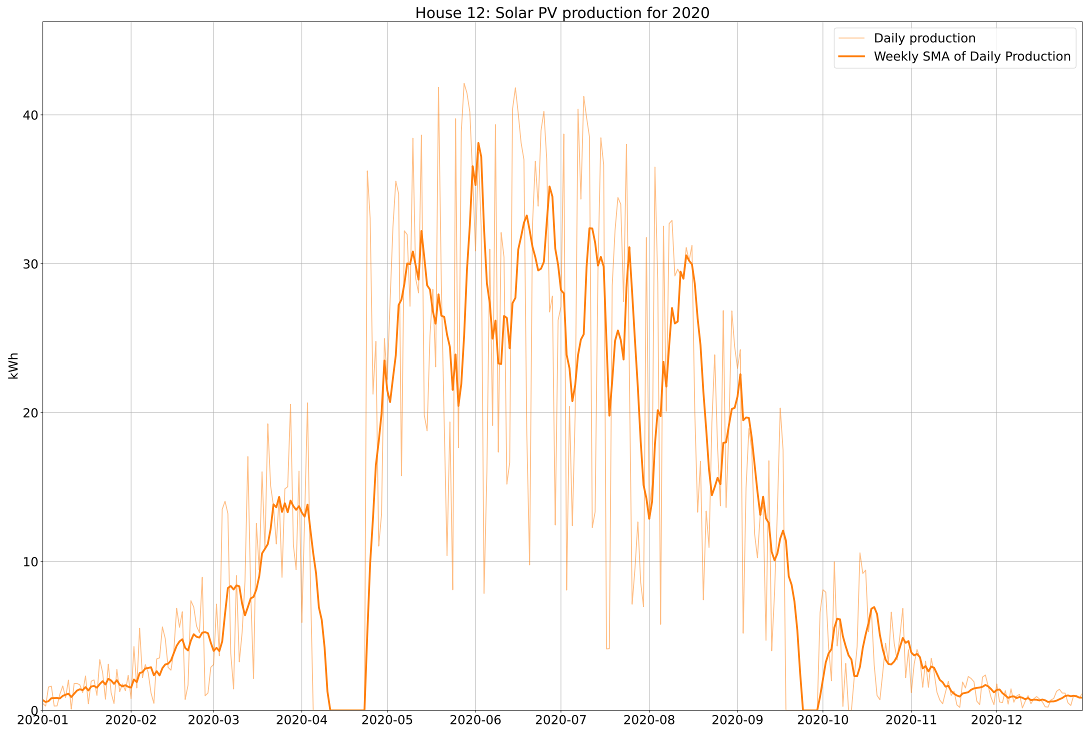



Figure A.247: Daily PV production and weekly SMA for House 12 in 2020.

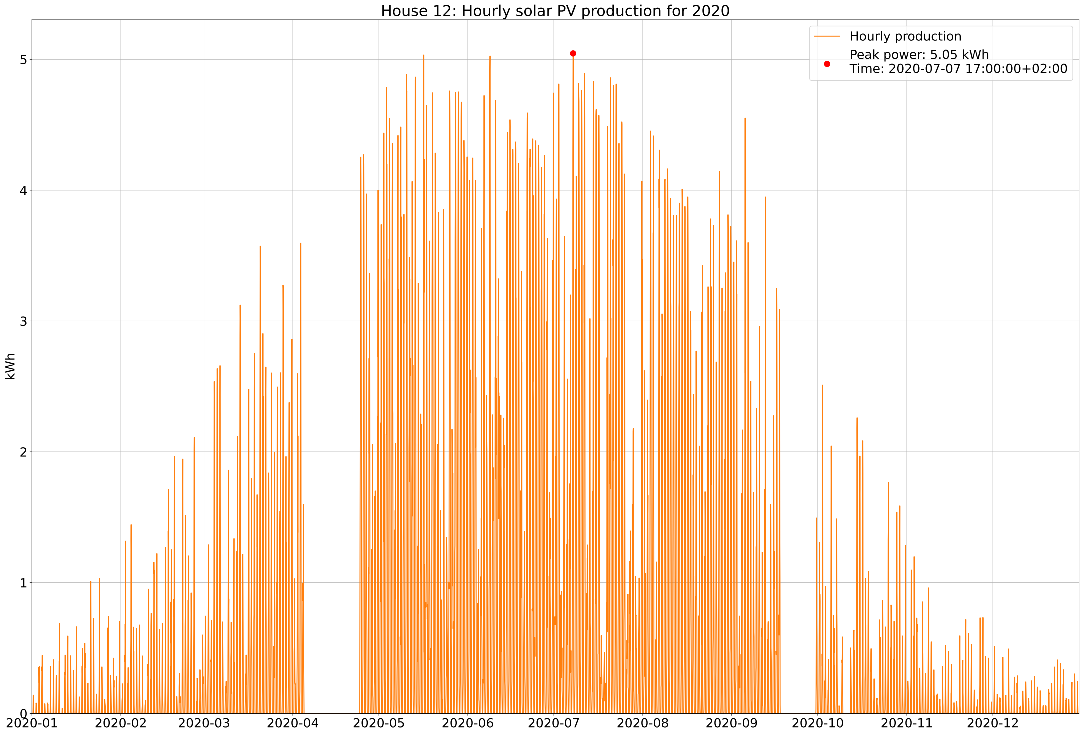



Figure A.248: Hourly PV production for House 12 in 2020.

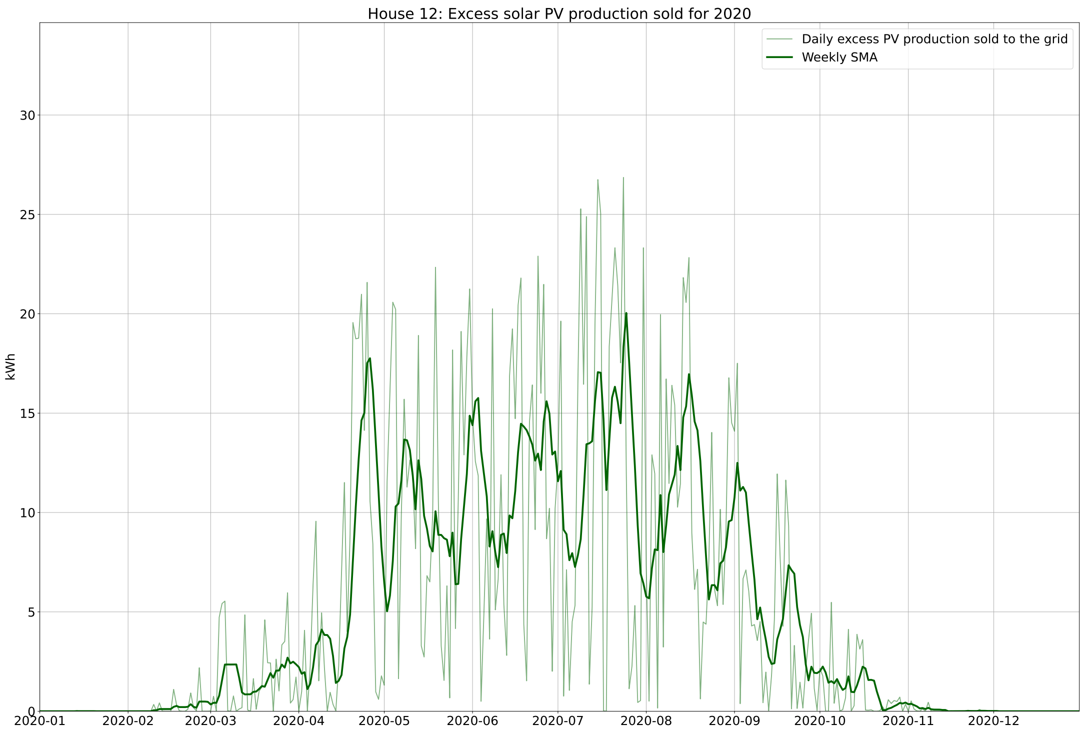



Figure A.249: Daily excess PV production sold to the grid and weekly SMA for House 12 in 2020

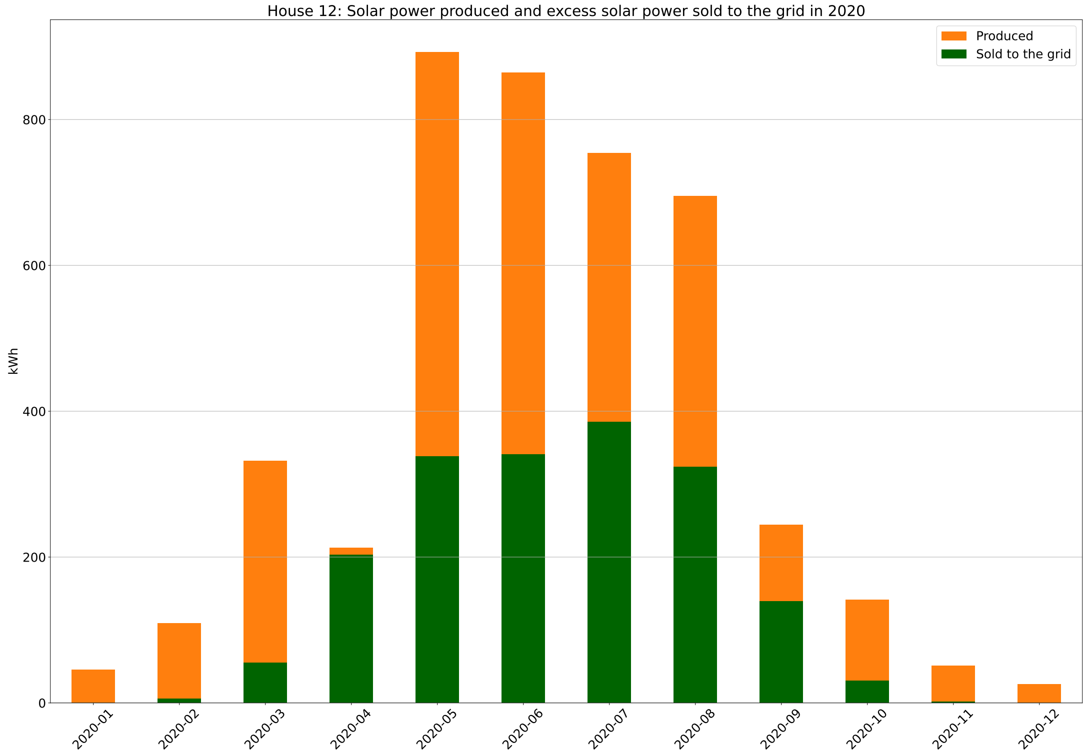



Figure A.250: Total solar PV production and excess production sold to the grid for each month in 2020 from House 12.

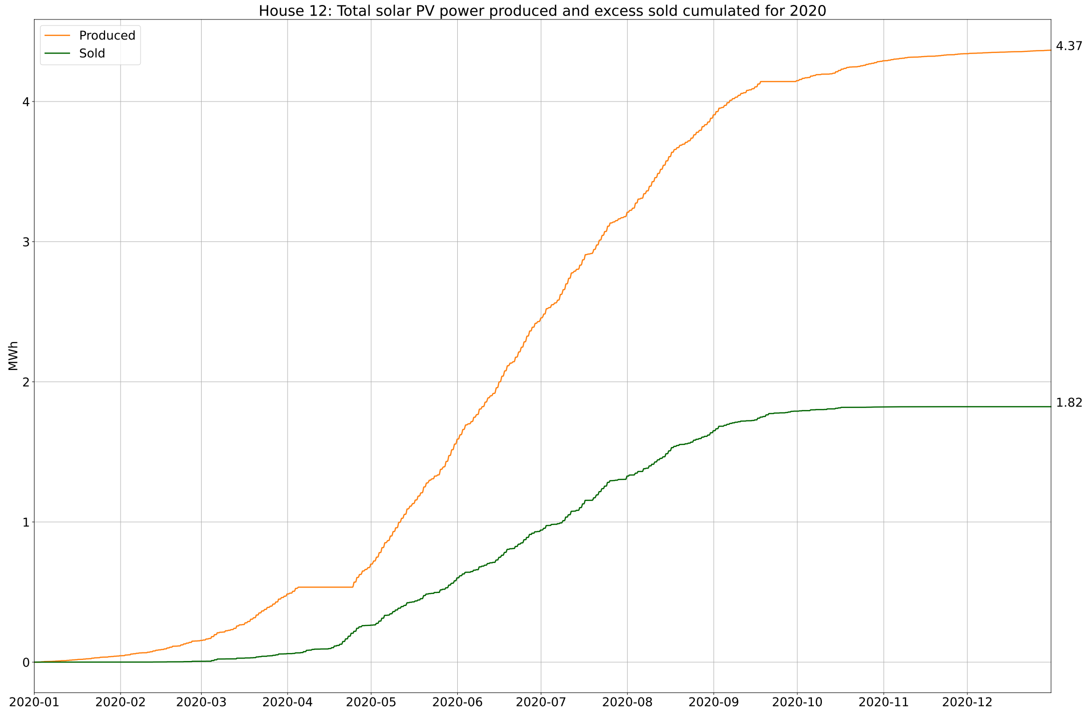



Figure A.251: Total solar PV production and excess production sold cumulated over 2020 from House 12

## 2021

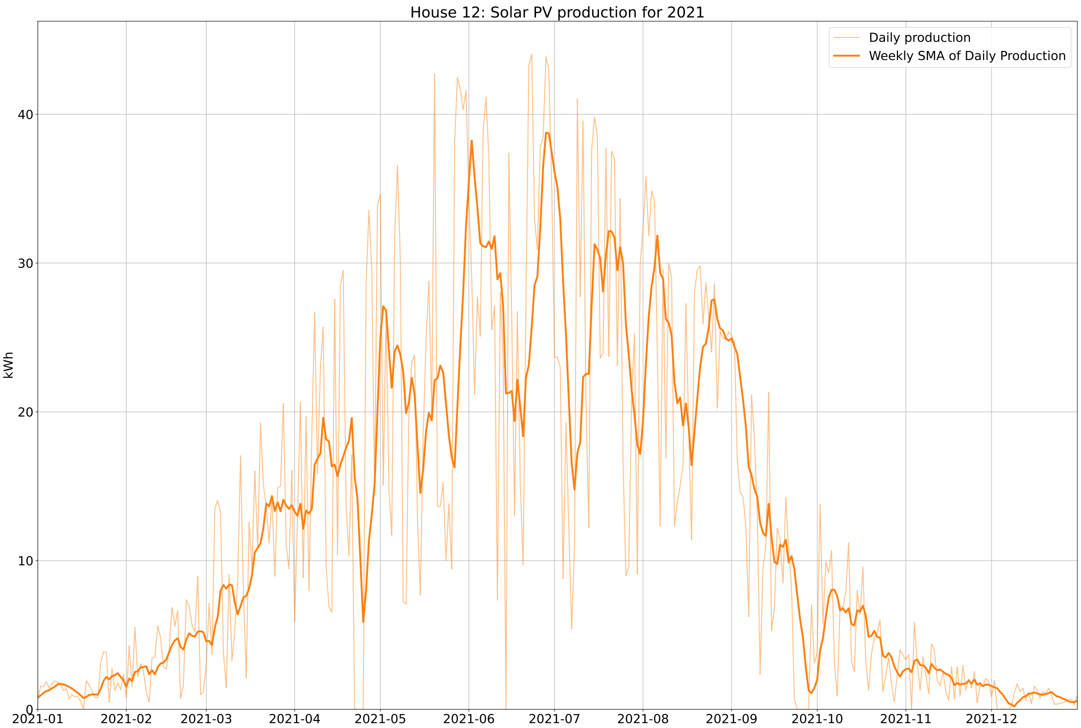



Figure A.252: Daily PV production and weekly SMA for House 12 in 2021.

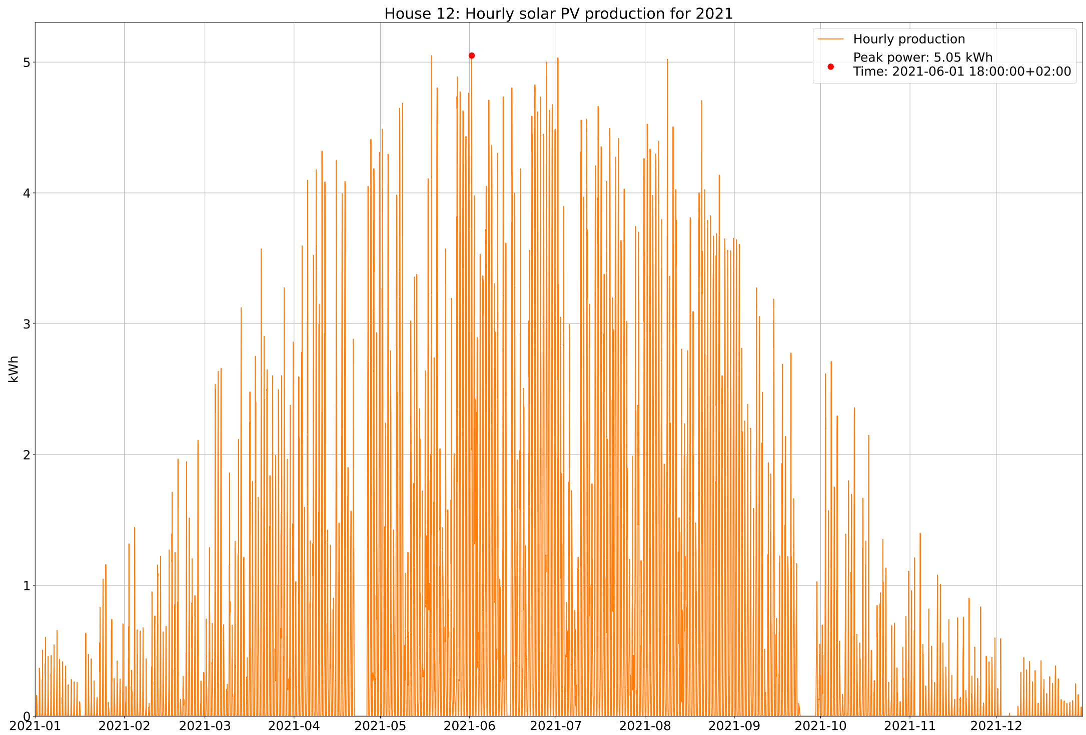



Figure A.253: Hourly PV production for House 12 in 2021.

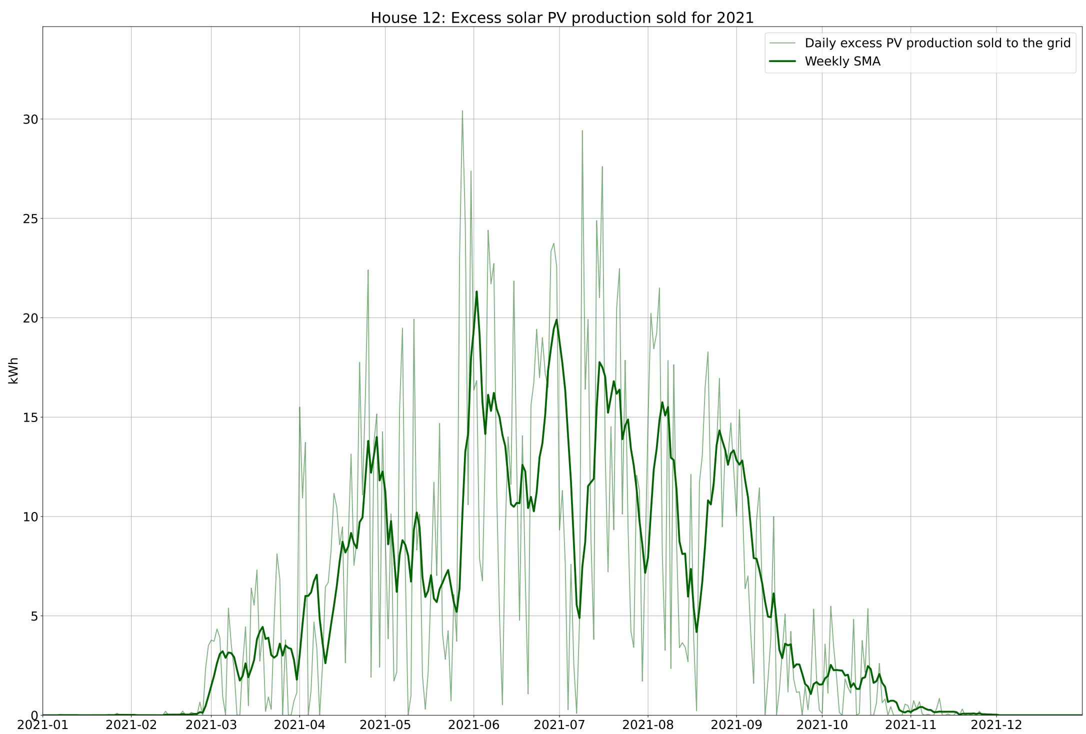



Figure A.254: Daily excess PV production sold to the grid and weekly SMA for House 12 in 2021

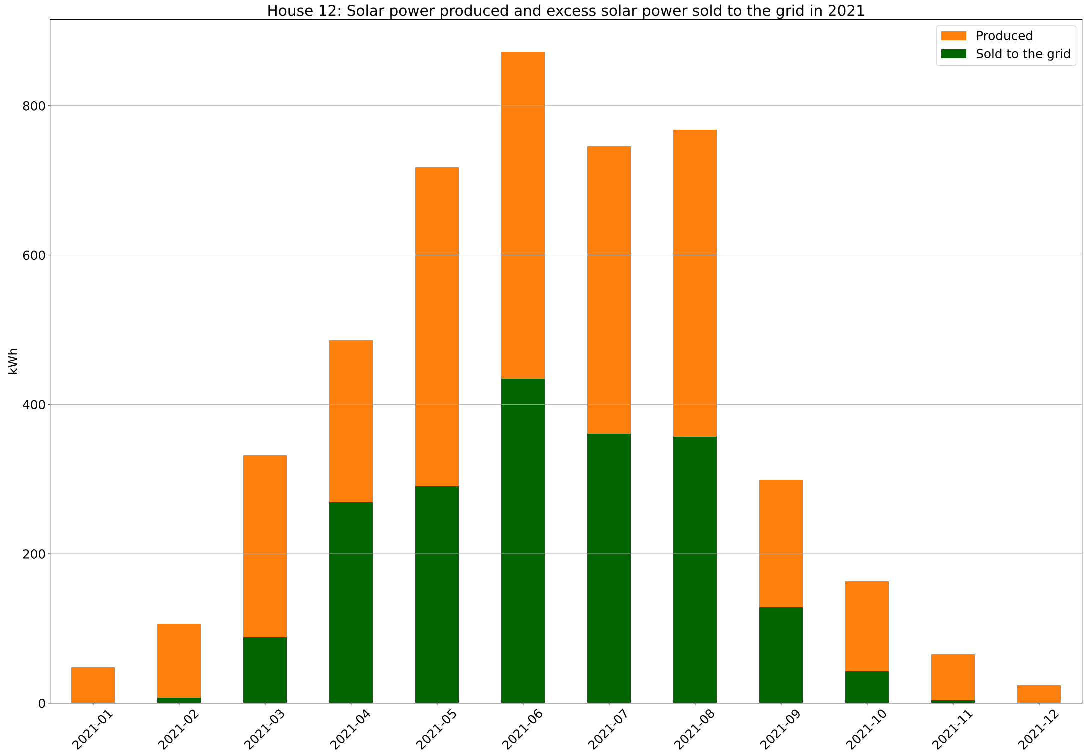



Figure A.255: Total solar PV production and excess production sold to the grid for each month in 2021 from House 12.

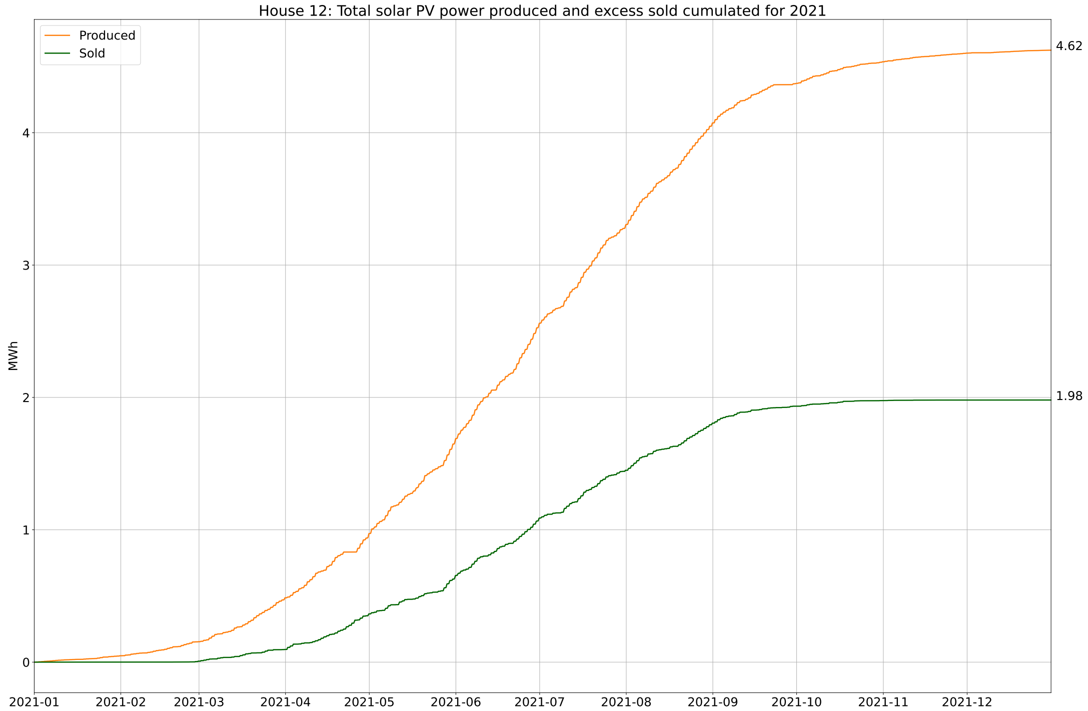
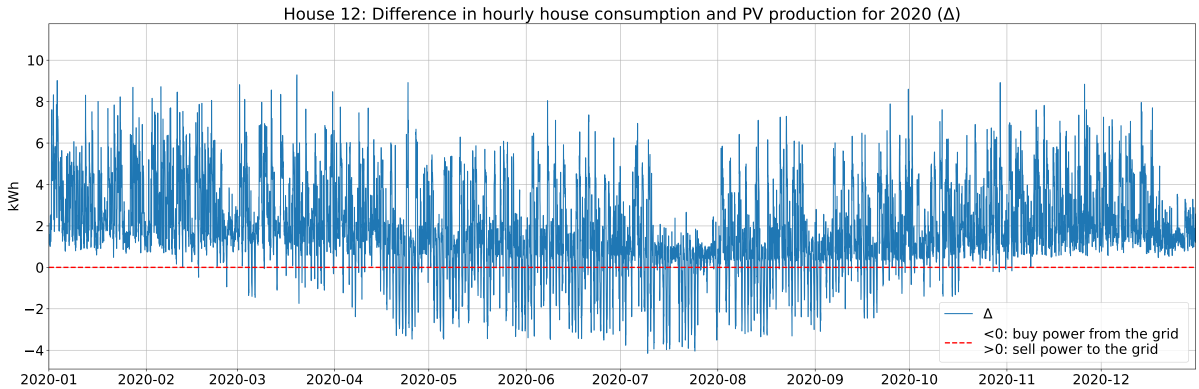



Figure A.256: Total solar PV production and excess production sold cumulated over 2021 from House 12

### A.12.3 Delta variable

#### 2020



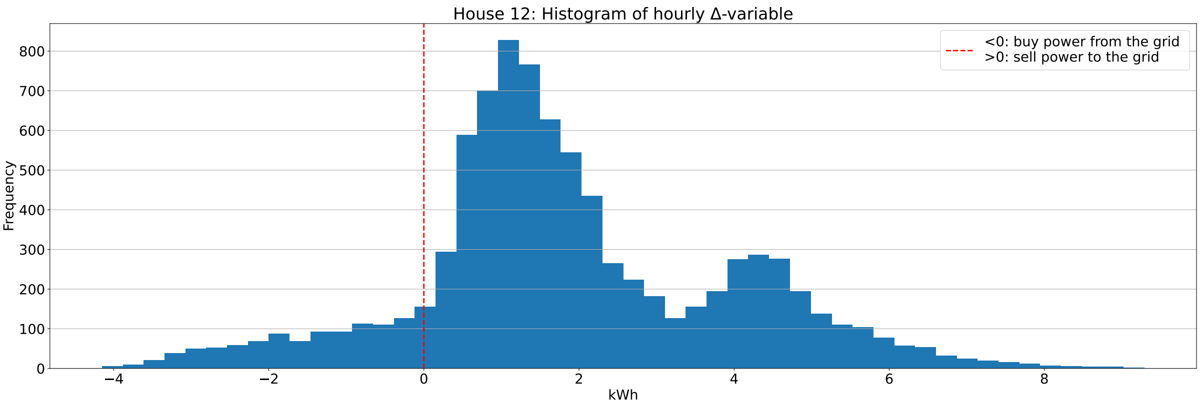




Figure A.257: The delta variable plotted for House 12. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### 2021

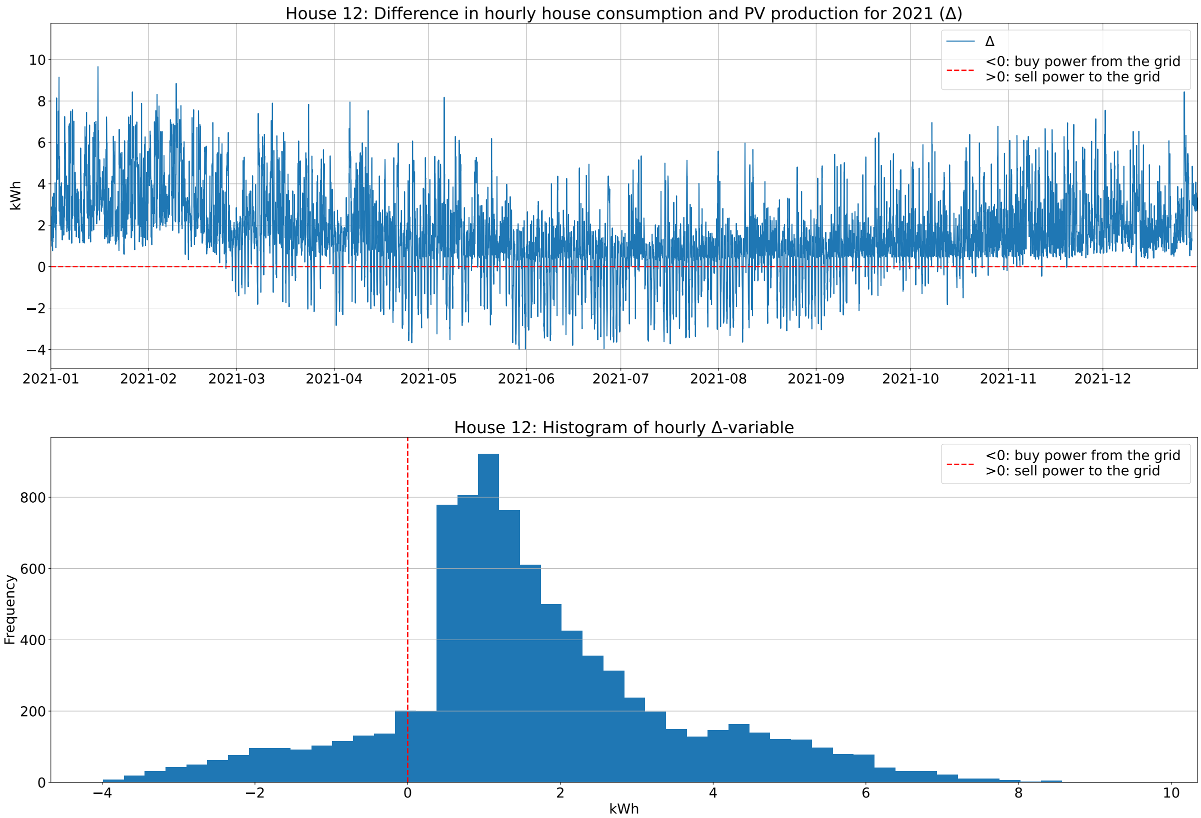



Figure A.258: The delta variable plotted for House 12. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

## A.12.4 House consumption and PV production

### 2020

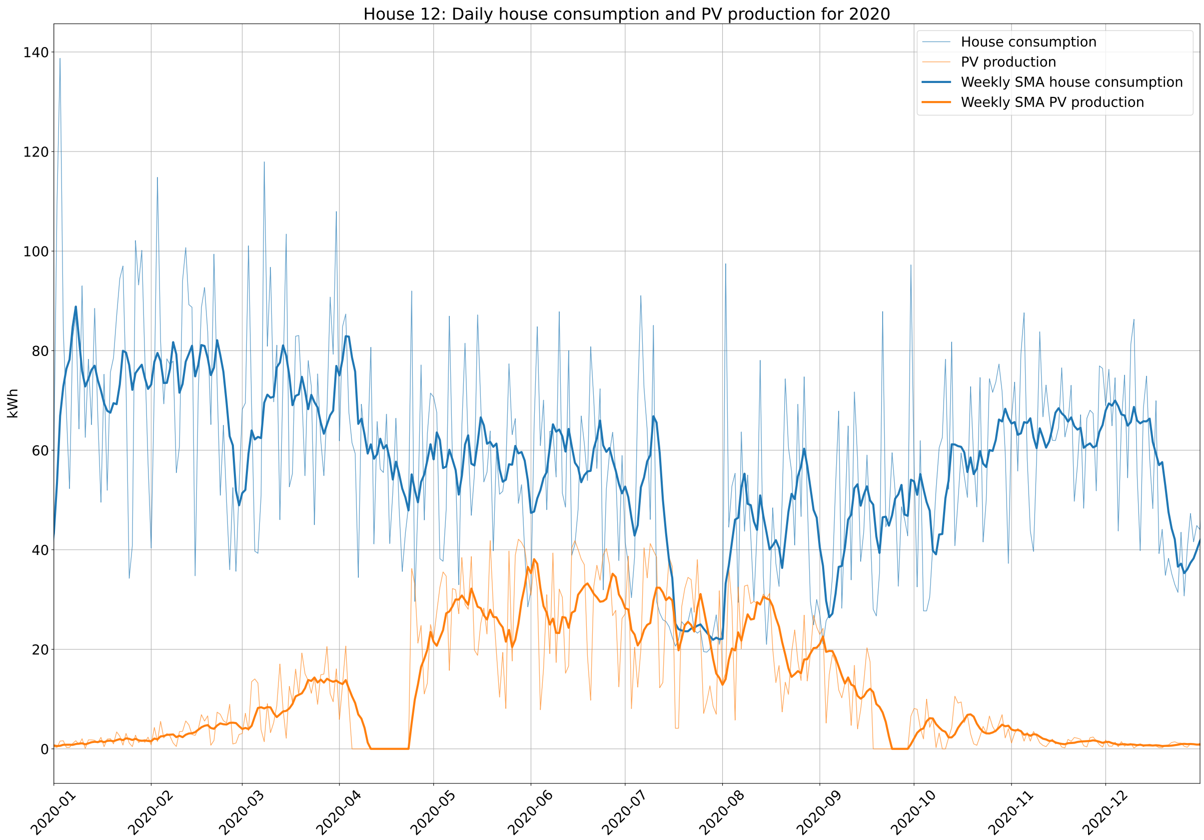



Figure A.259: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

### 2021

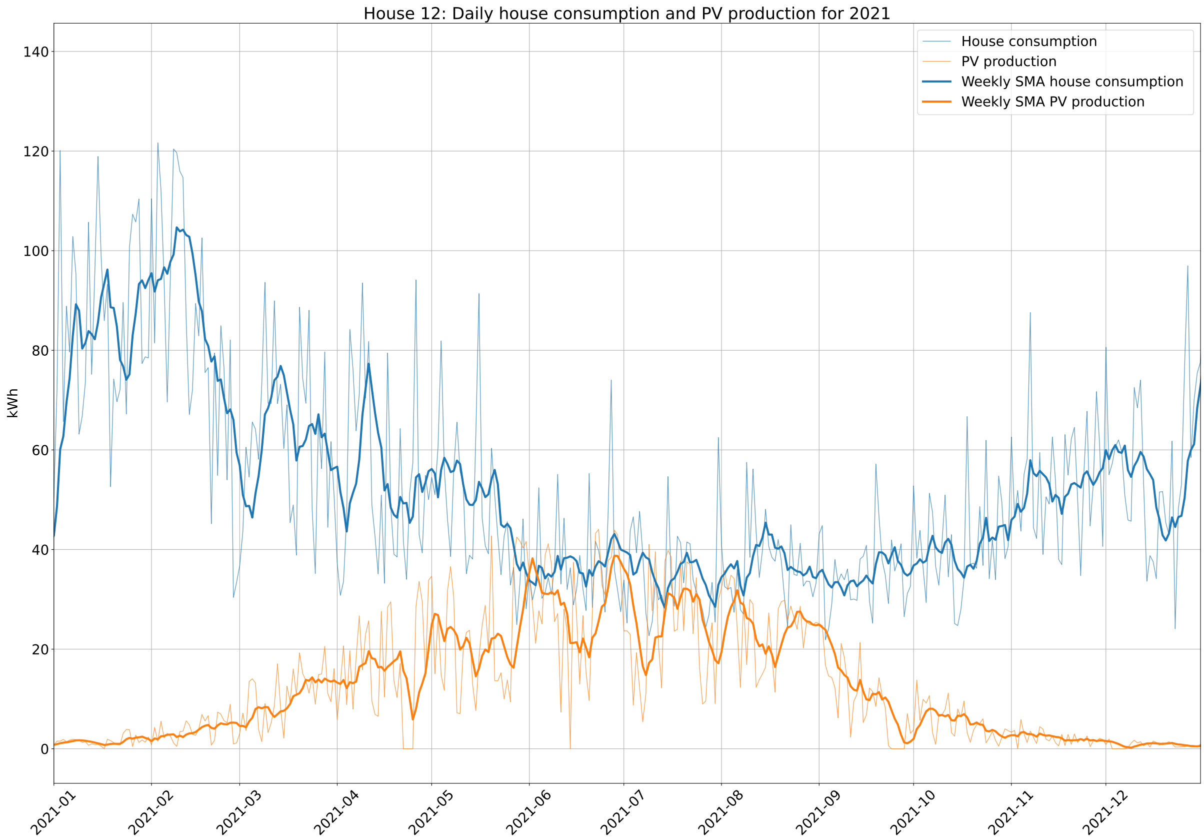



Figure A.260: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.12.5 Cost of energy

#### 2020

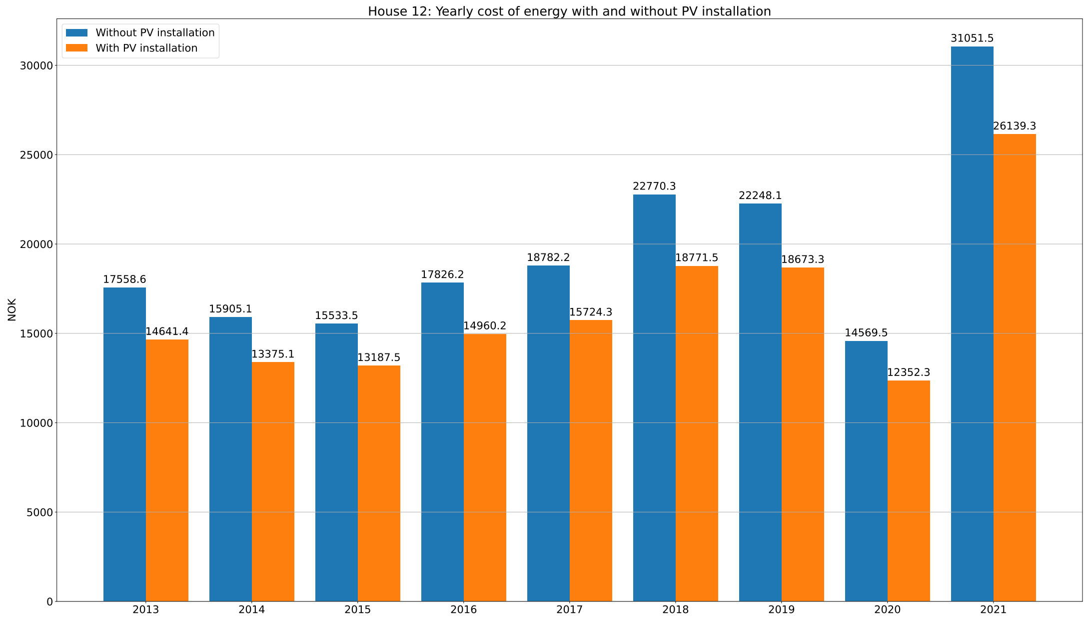



Figure A.261: Yearly cost of energy for House 12, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

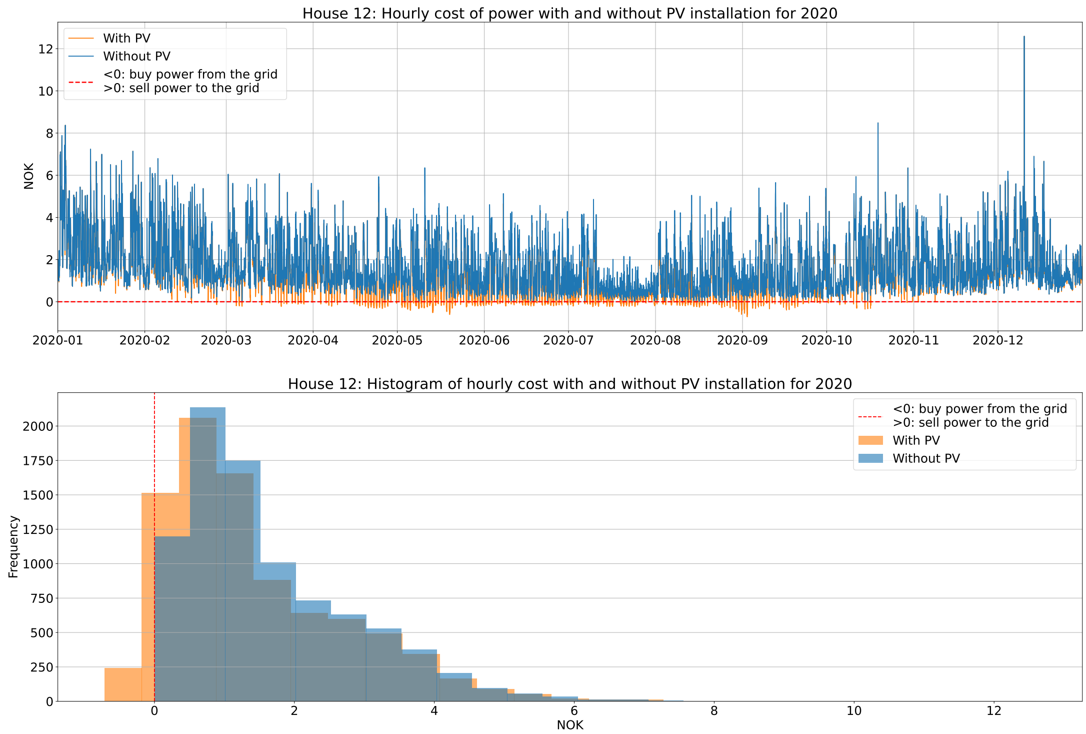



Figure A.262: Hourly cost of energy for House 12 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

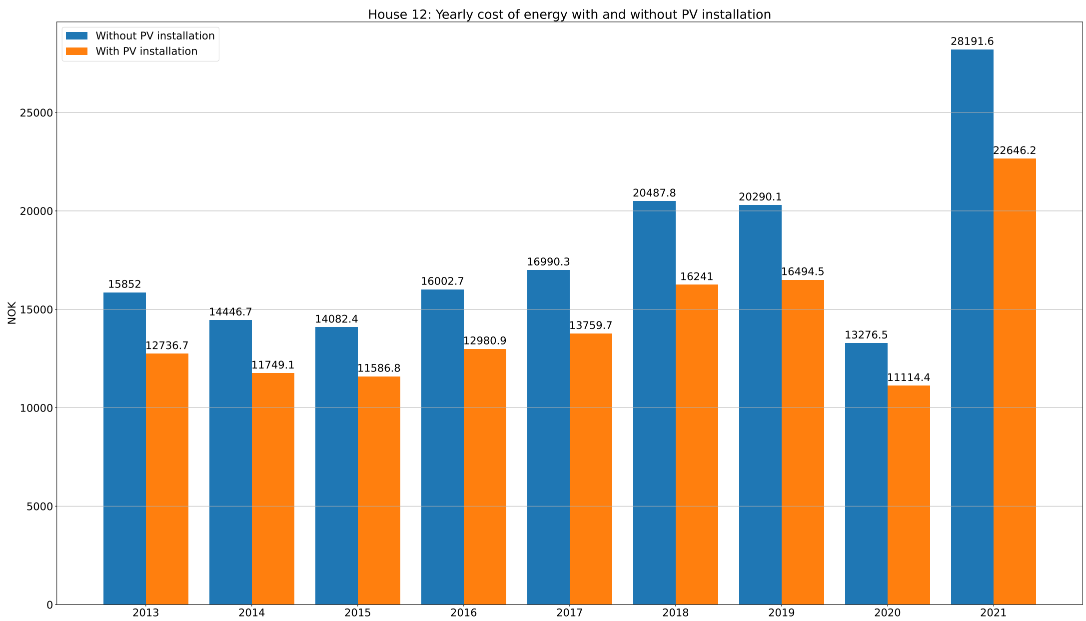



Figure A.263: Yearly cost of energy for House 12, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

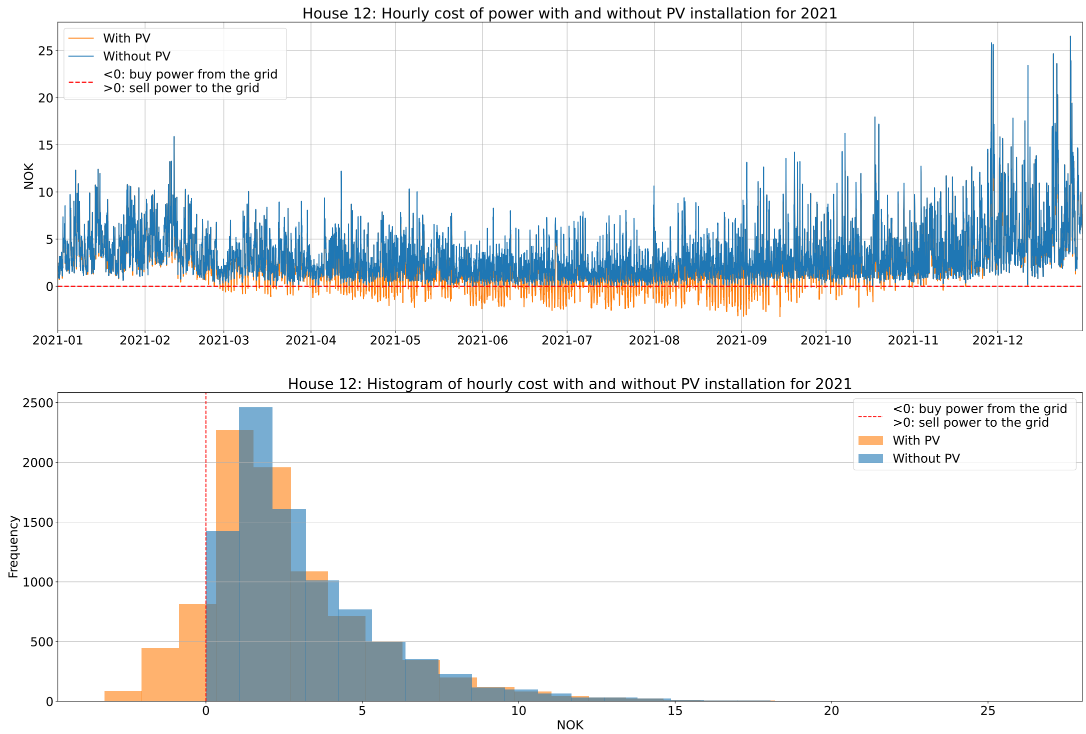
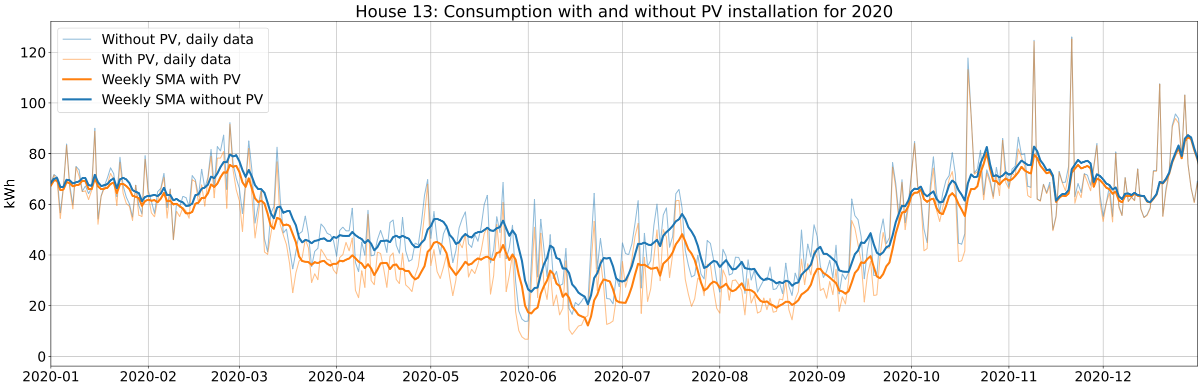



Figure A.264: Hourly cost of energy for House 12 with and without a PV system present for 2021. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

# A.13 House 13

## A.13.1 House consumption

### 2020



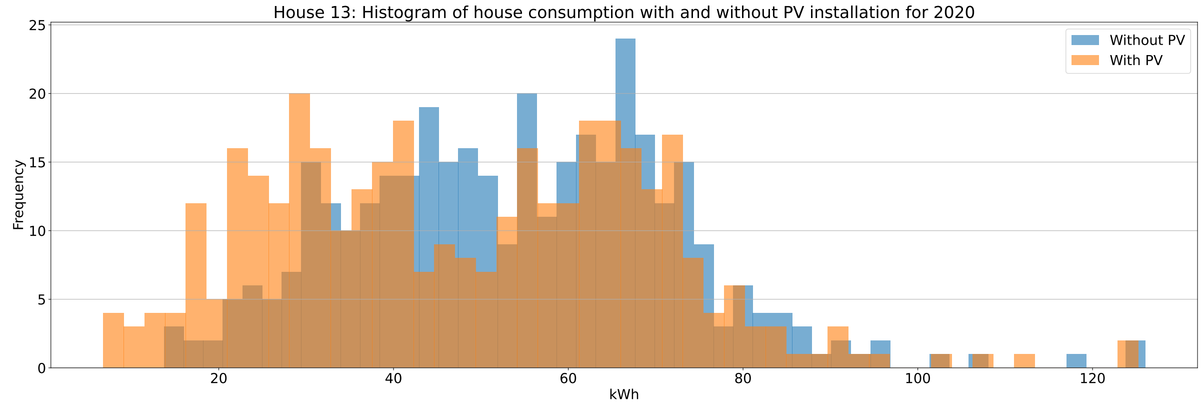




Figure A.265: Daily house consumption with and without a PV system for 2020 from House 13. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

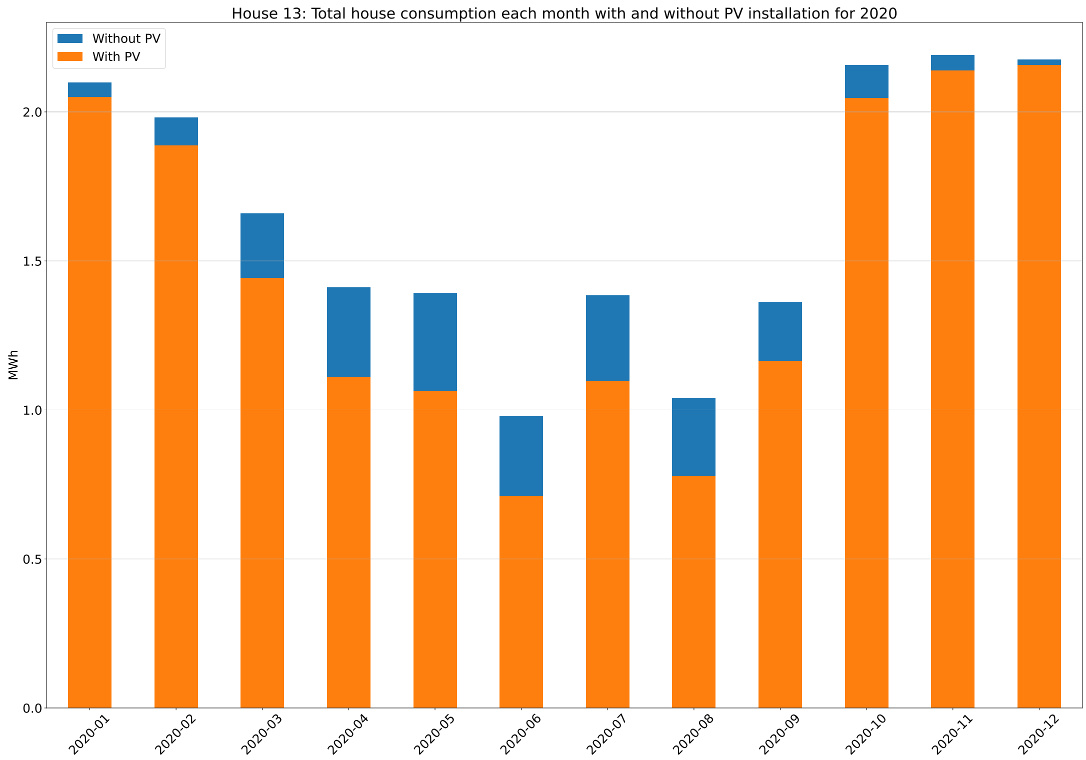



Figure A.266: Monthly house consumption for House 13 with and without a PV system for 2020.

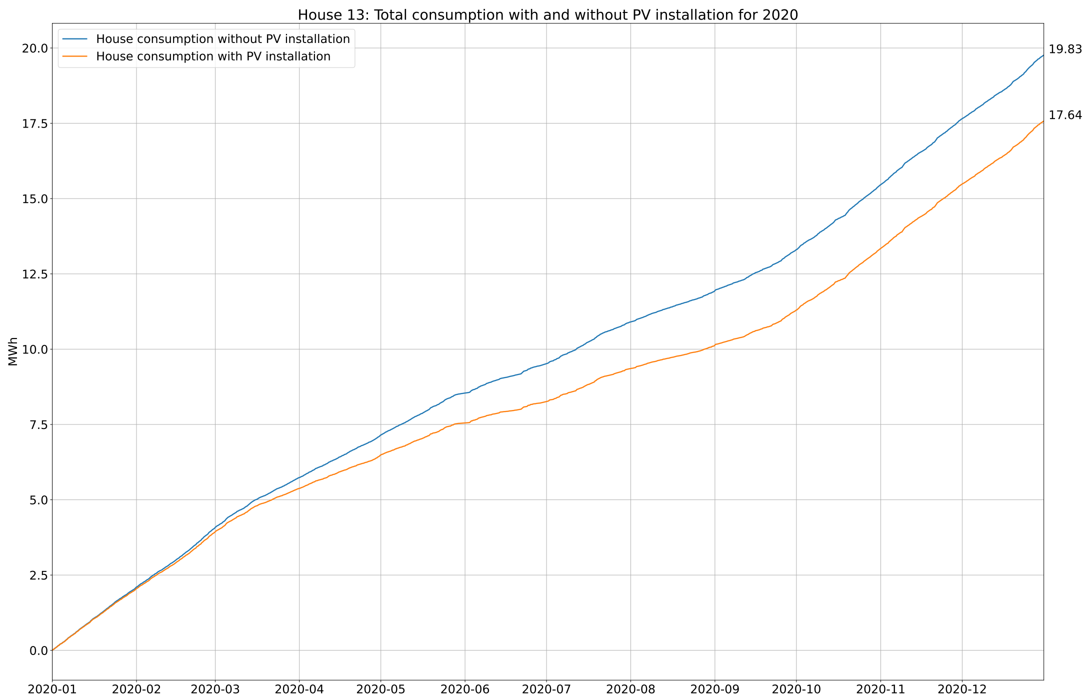
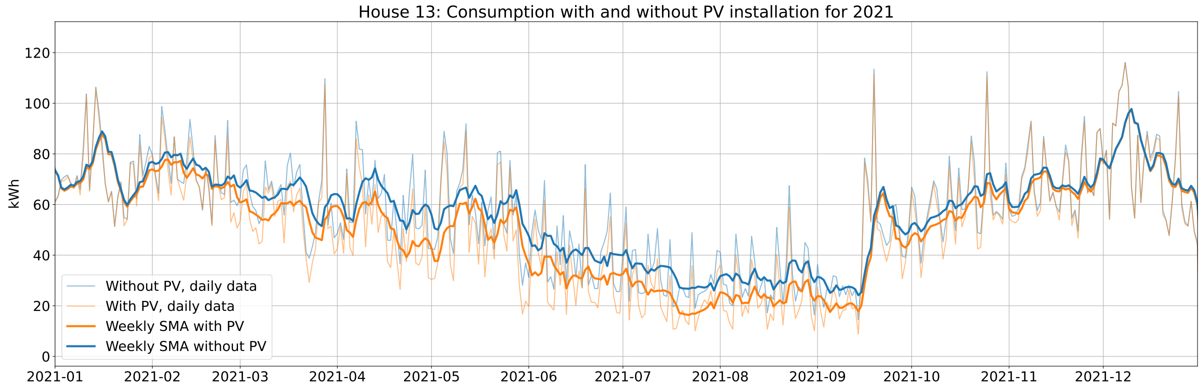



Figure A.267: Total house consumption for House 13 with and without a PV system accumulated over 2020

### 2021



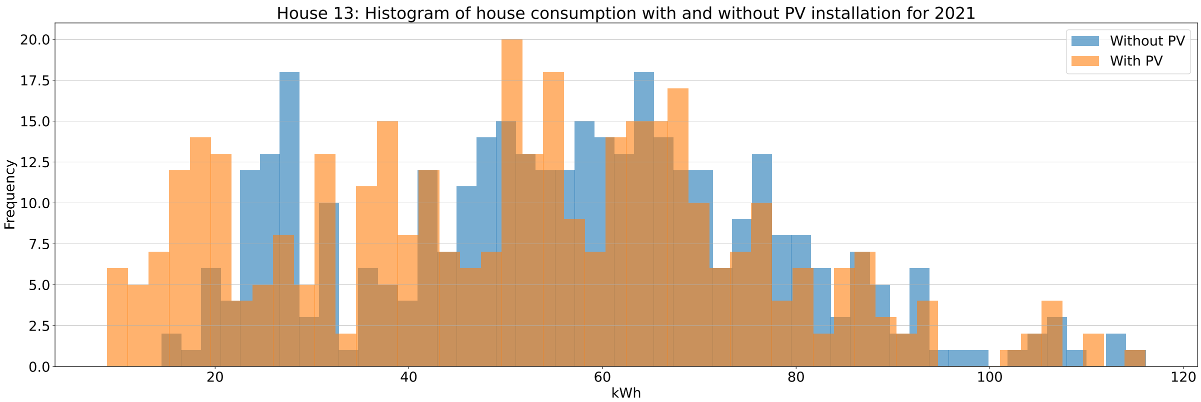




Figure A.268: Daily house consumption with and without a PV system for 2021 from House 13. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

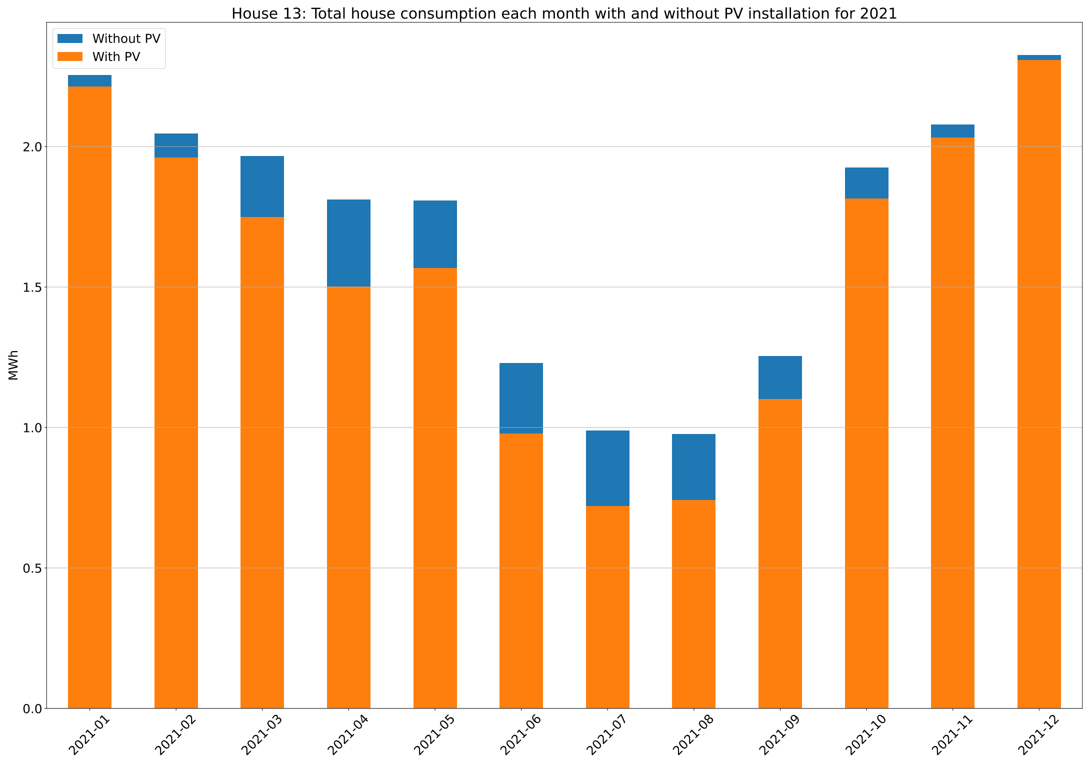



Figure A.269: Monthly house consumption for House 13 with and without a PV system for 2021.

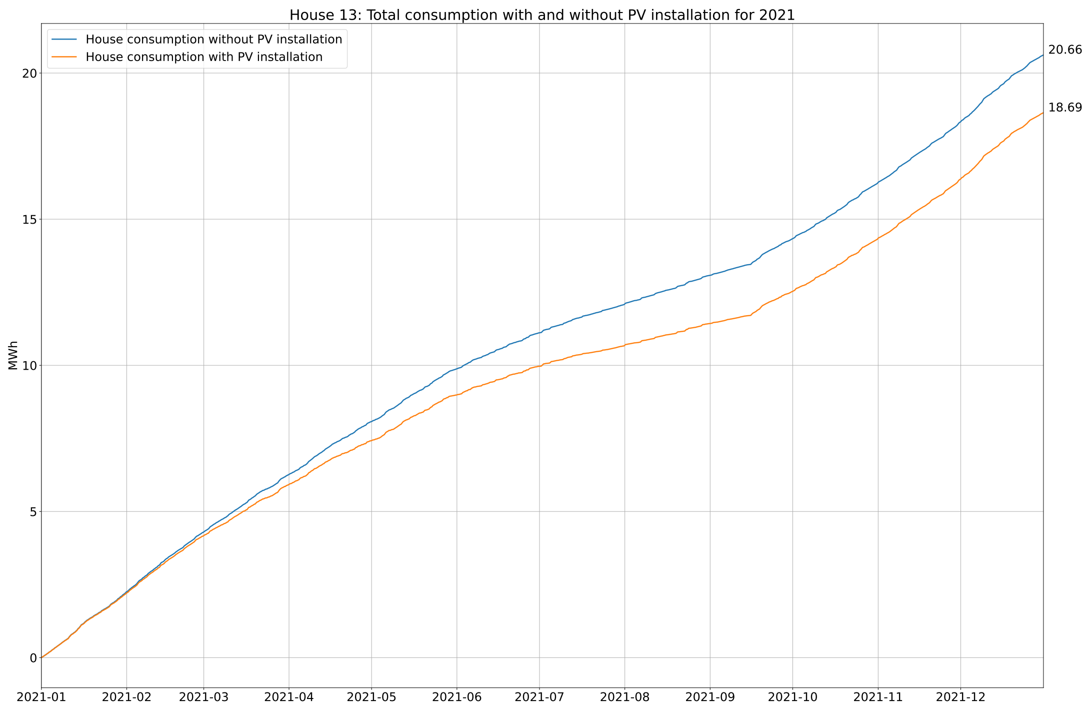



Figure A.270: Total house consumption for House 13 with and without a PV system accumulated over 2021

## A.13.2 Solar PV production

### 2020

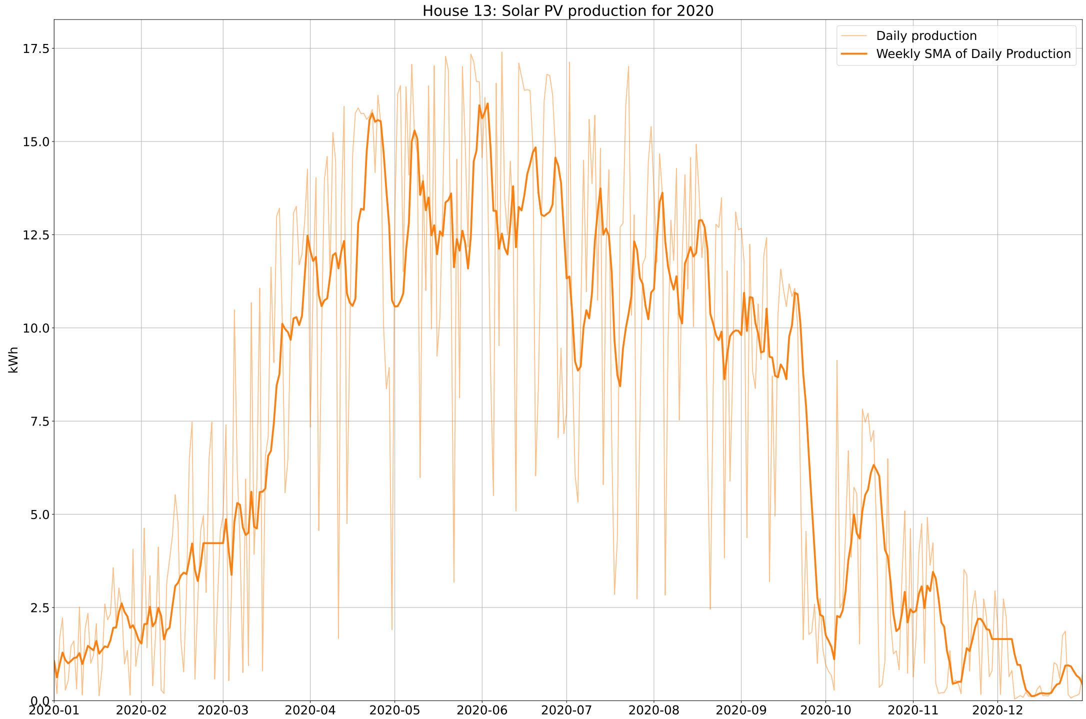



Figure A.271: Daily PV production and weekly SMA for House 13 in 2020.

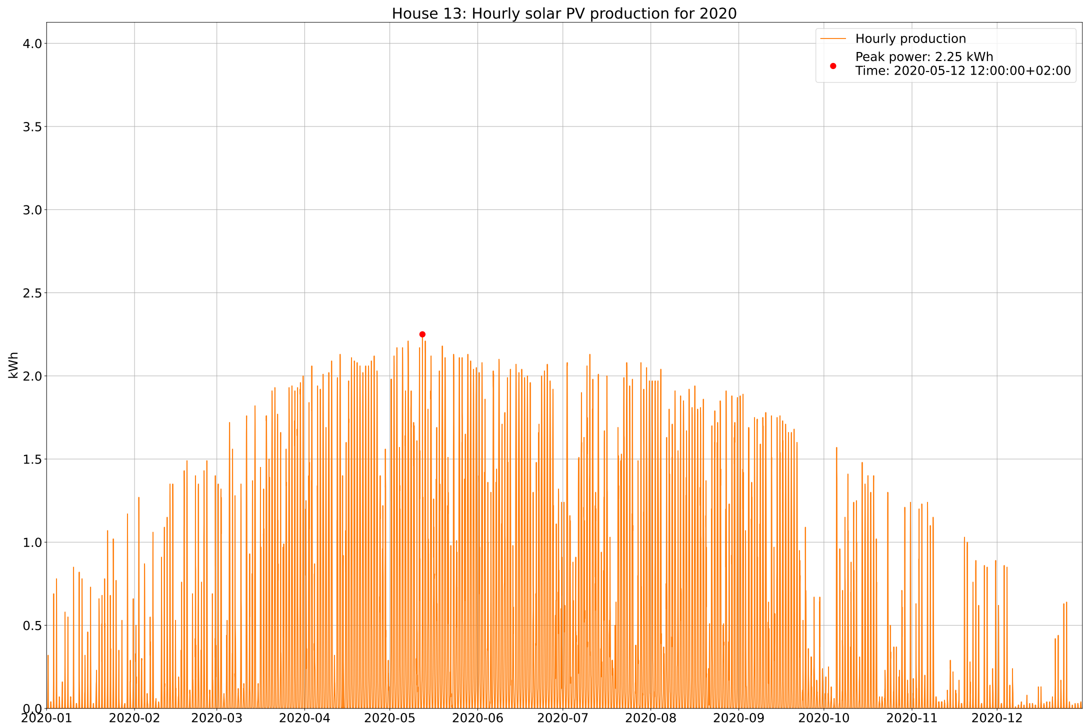



Figure A.272: Hourly PV production for House 13 in 2020.

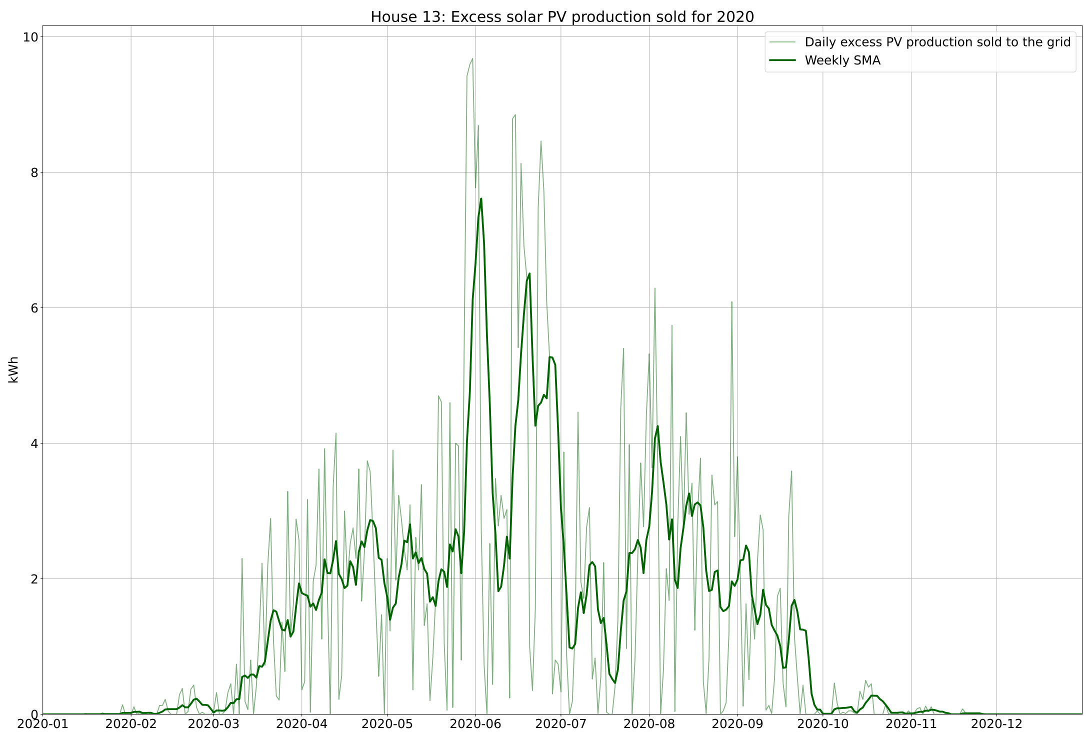



Figure A.273: Daily excess PV production sold to the grid and weekly SMA for House 13 in 2020

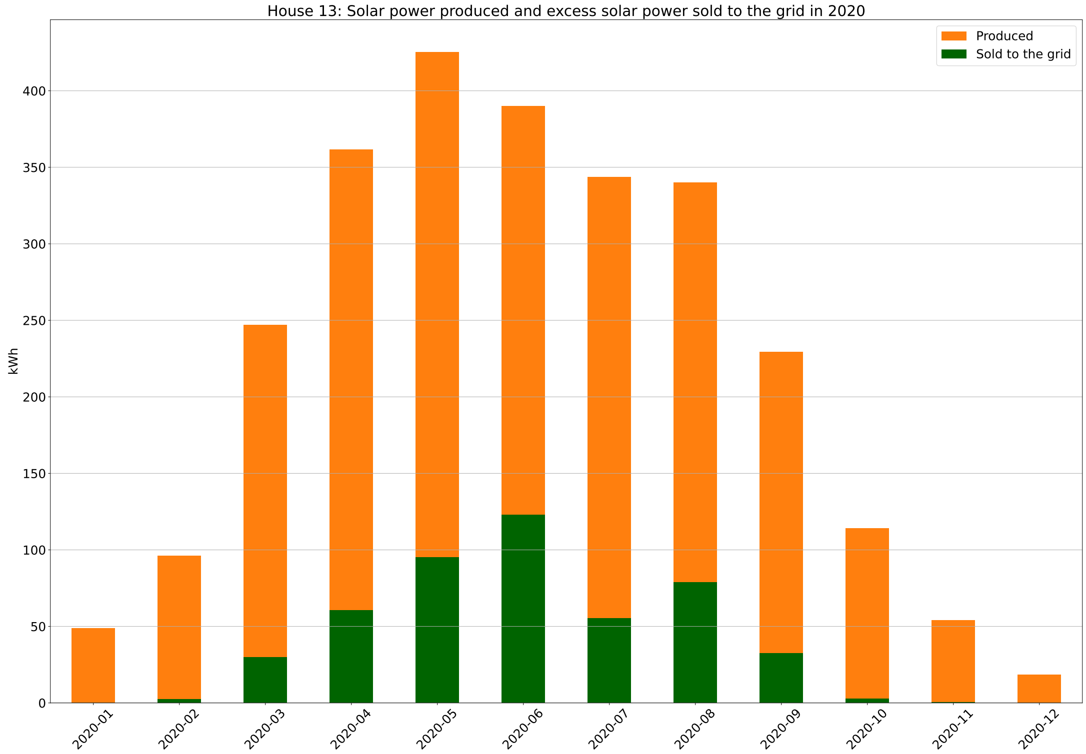



Figure A.274: Total solar PV production and excess production sold to the grid for each month in 2020 from House 13.

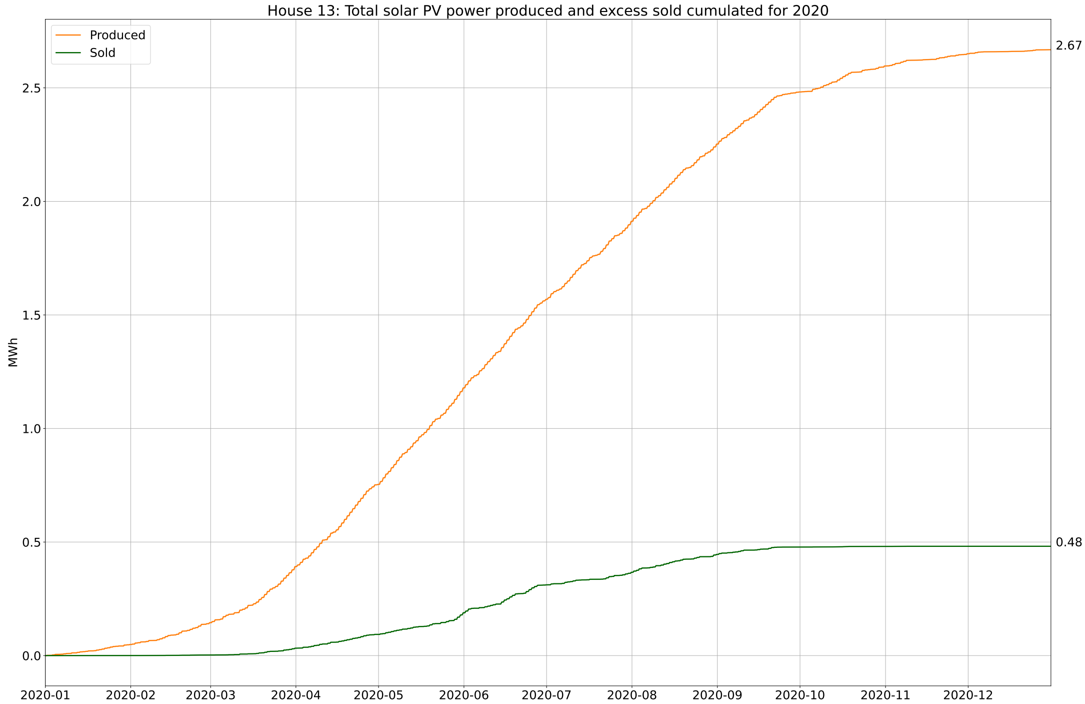



Figure A.275: Total solar PV production and excess production sold cumulated over 2020 from House 13

**2021**

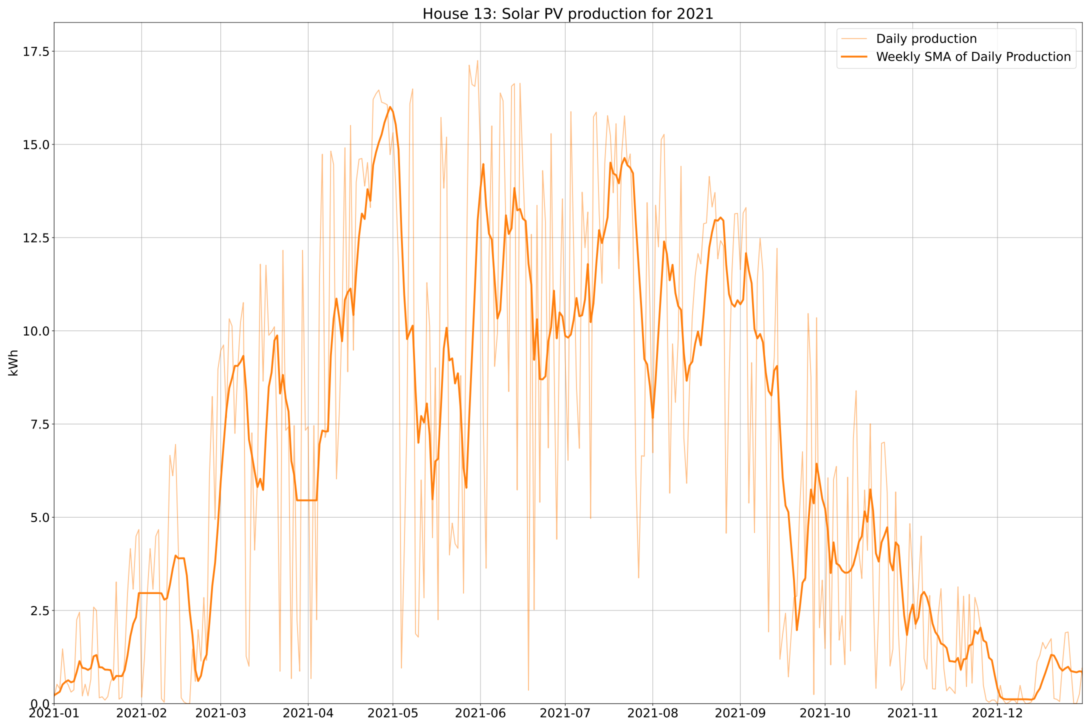



Figure A.276: Daily PV production and weekly SMA for House 13 in 2021.

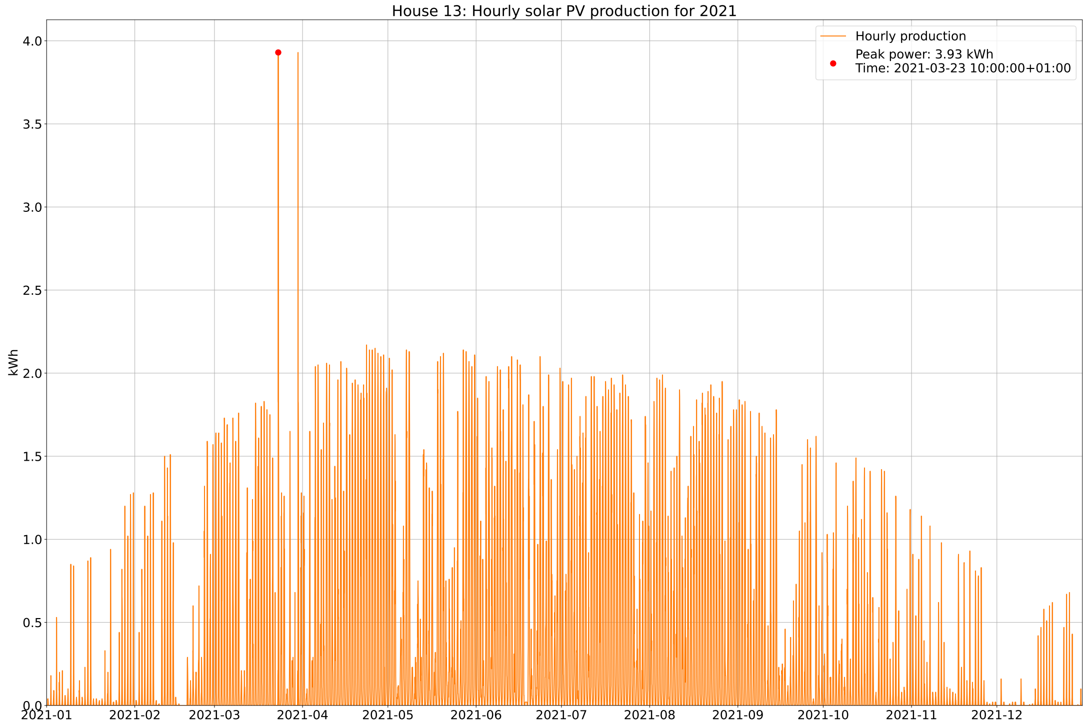



Figure A.277: Hourly PV production for House 13 in 2021.

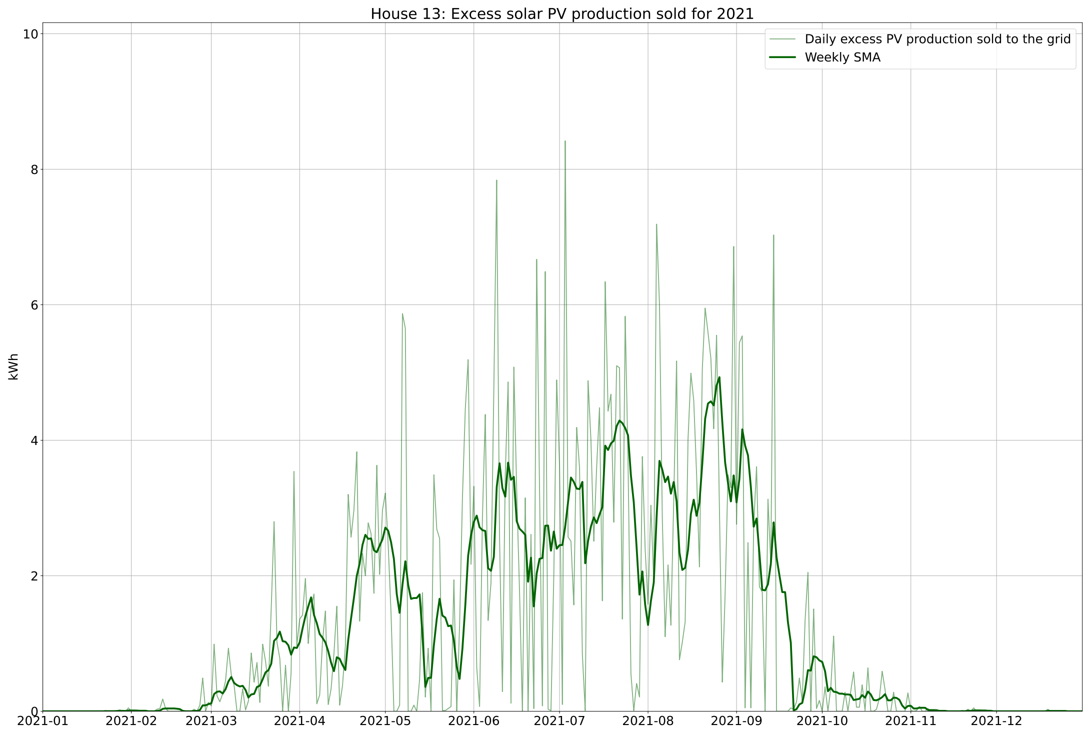



Figure A.278: Daily excess PV production sold to the grid and weekly SMA for House 13 in 2021

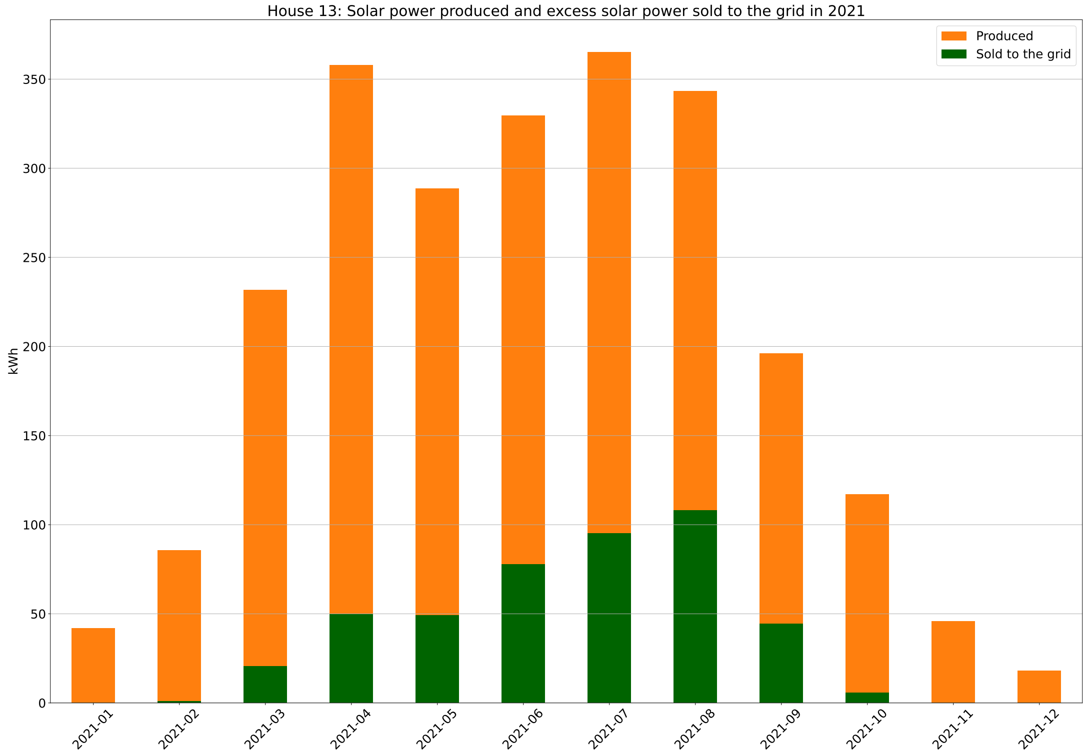



Figure A.279: Total solar PV production and excess production sold to the grid for each month in 2021 from House 13.

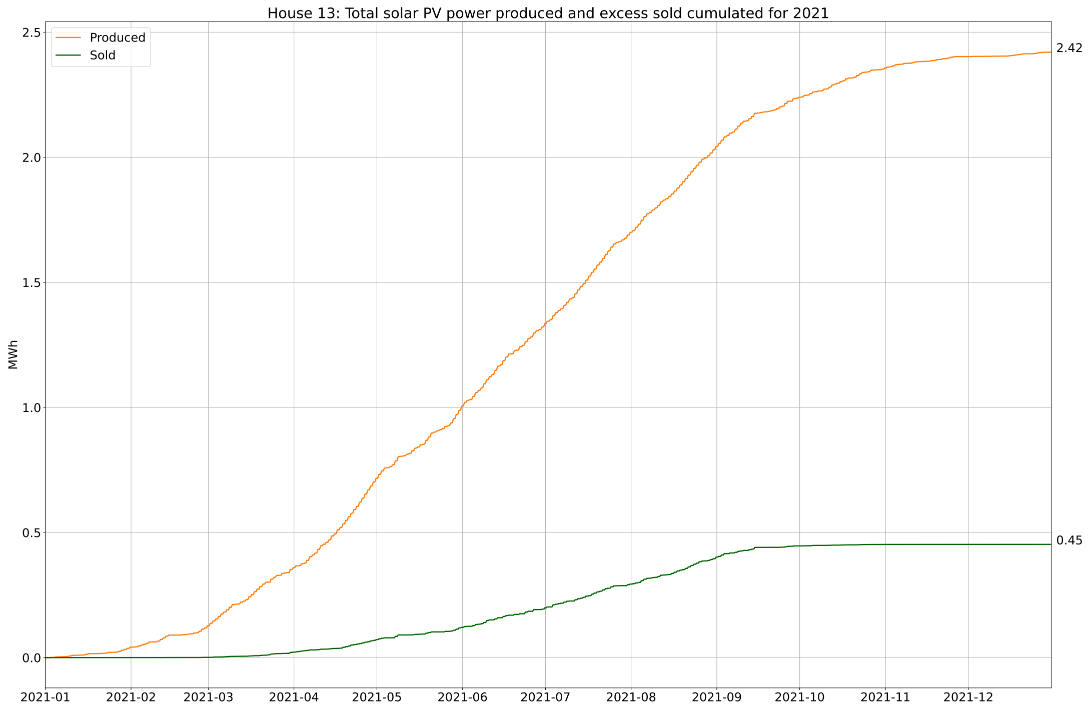
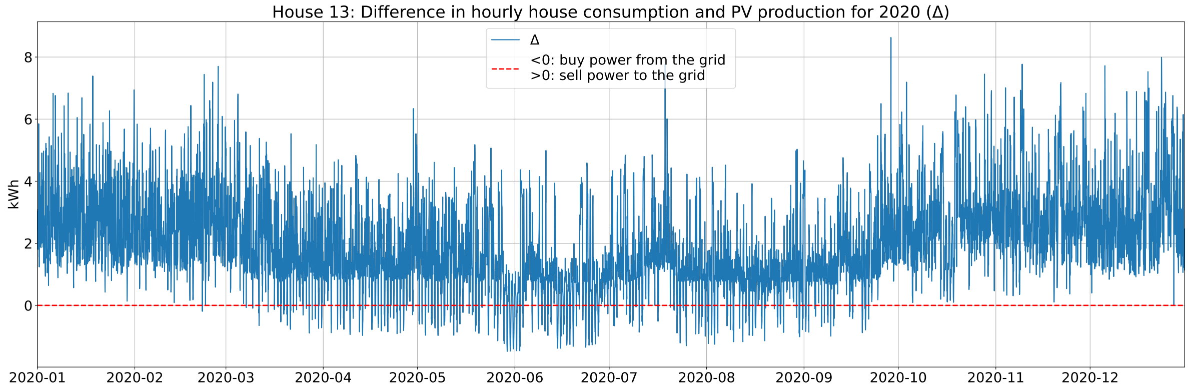



Figure A.280: Total solar PV production and excess production sold cumulated over 2021 from House 13

### A.13.3 Delta variable

#### 2020



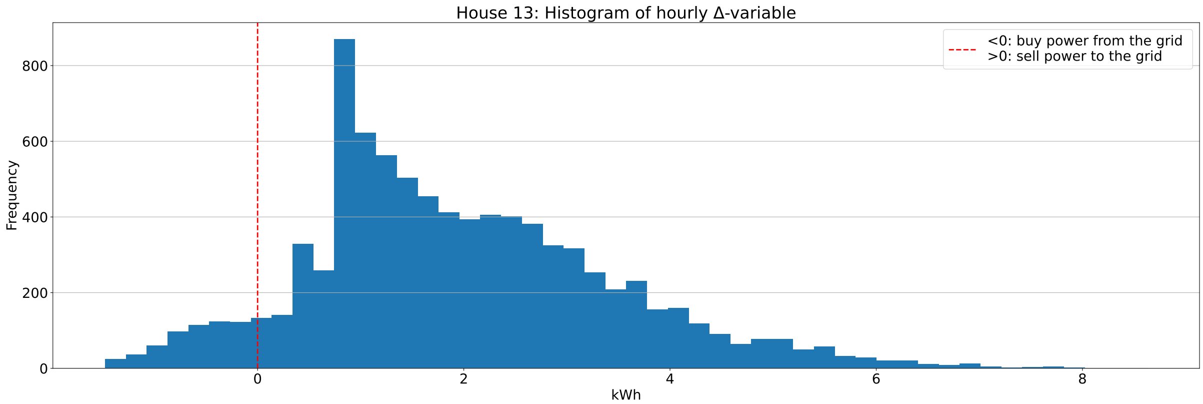
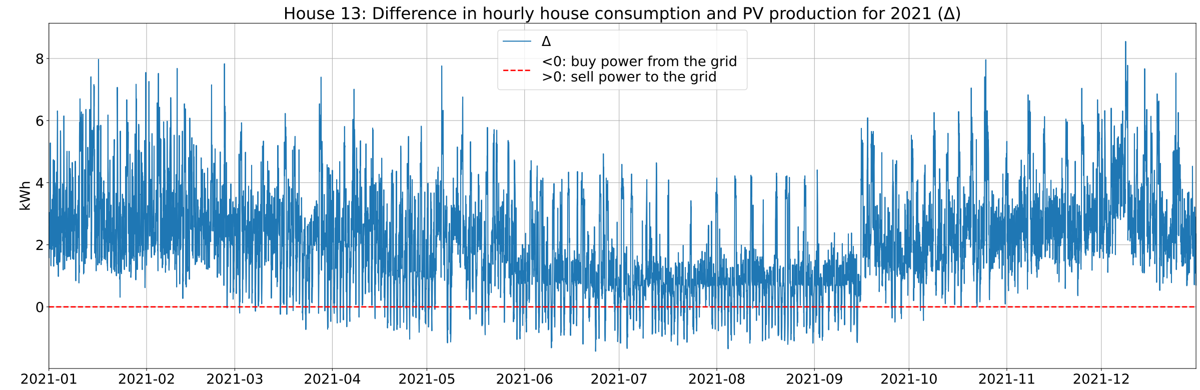




Figure A.281: The delta variable plotted for House 13. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**



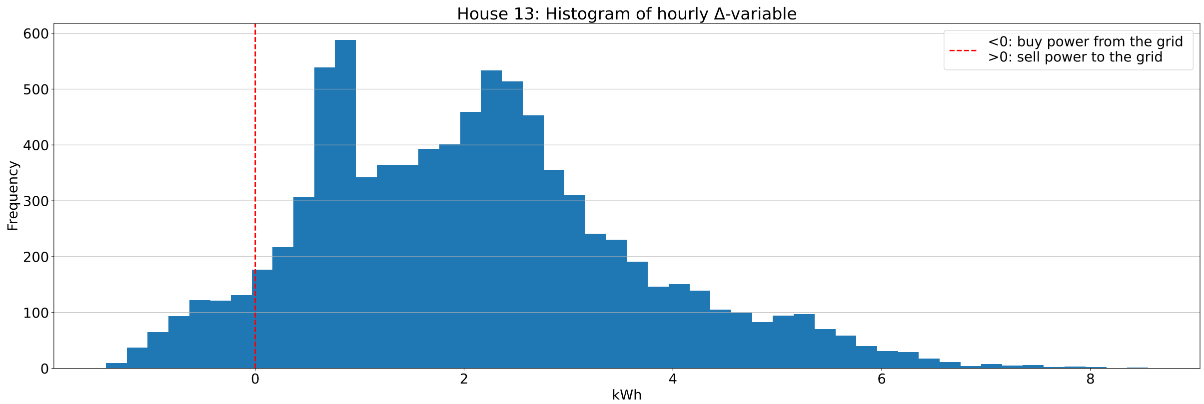




Figure A.282: The delta variable plotted for House 13. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.13.4 House consumption and PV production

#### 2020

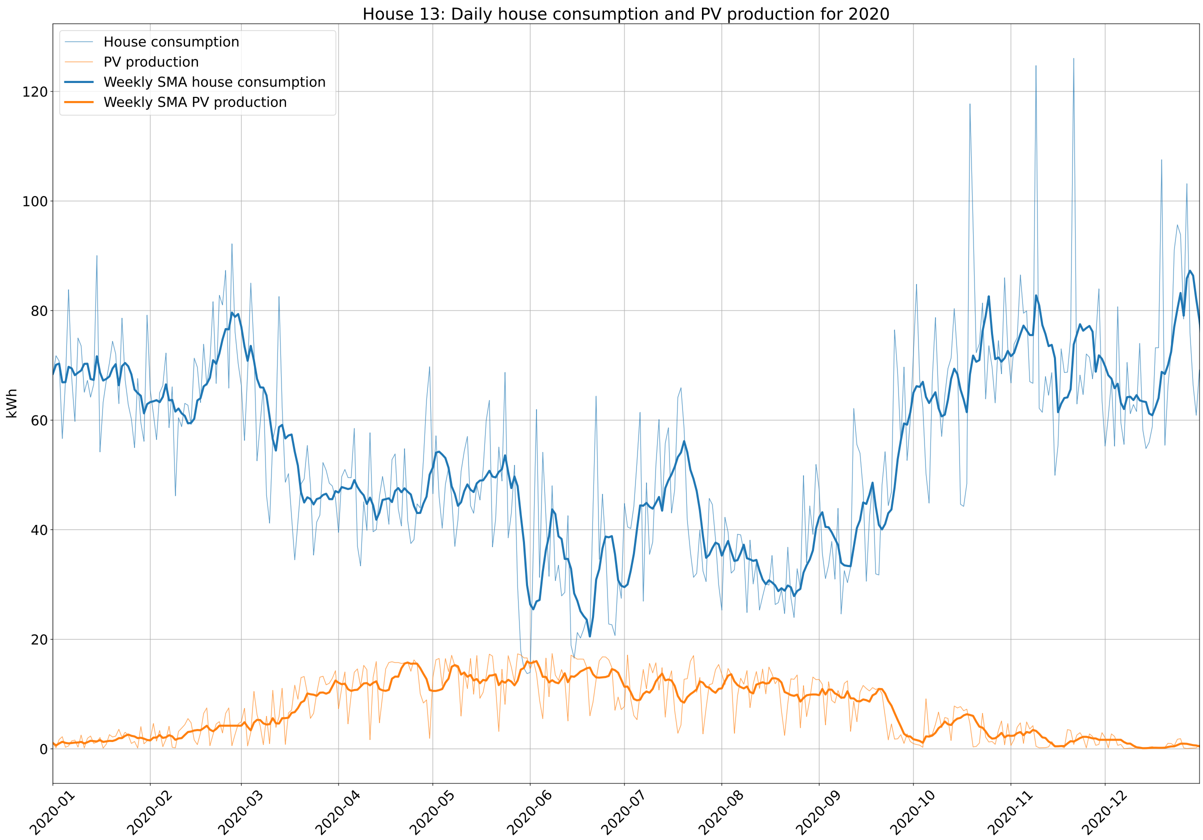



Figure A.283: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

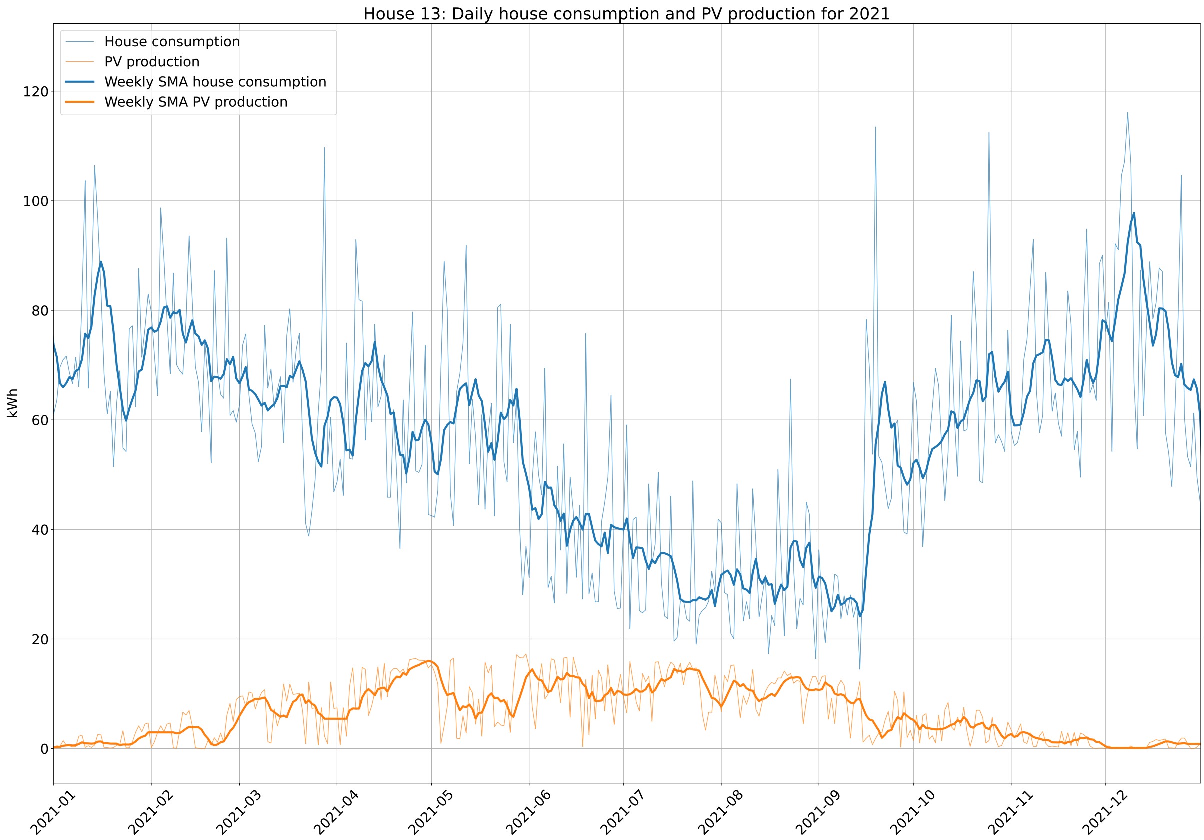



Figure A.284: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.13.5 Cost of energy

#### 2020

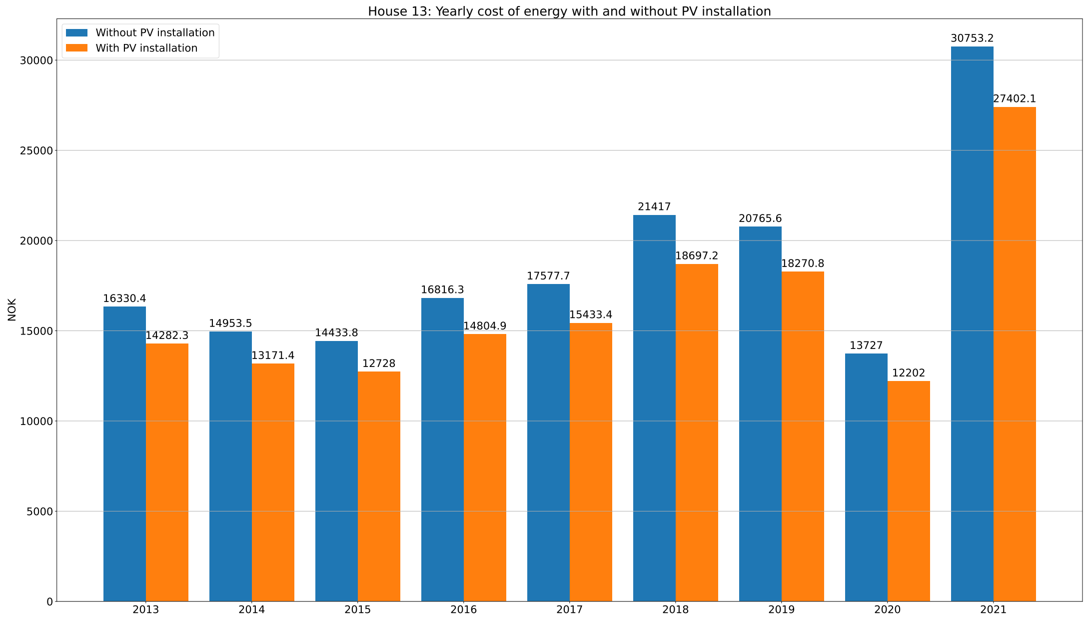



Figure A.285: Yearly cost of energy for House 13, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

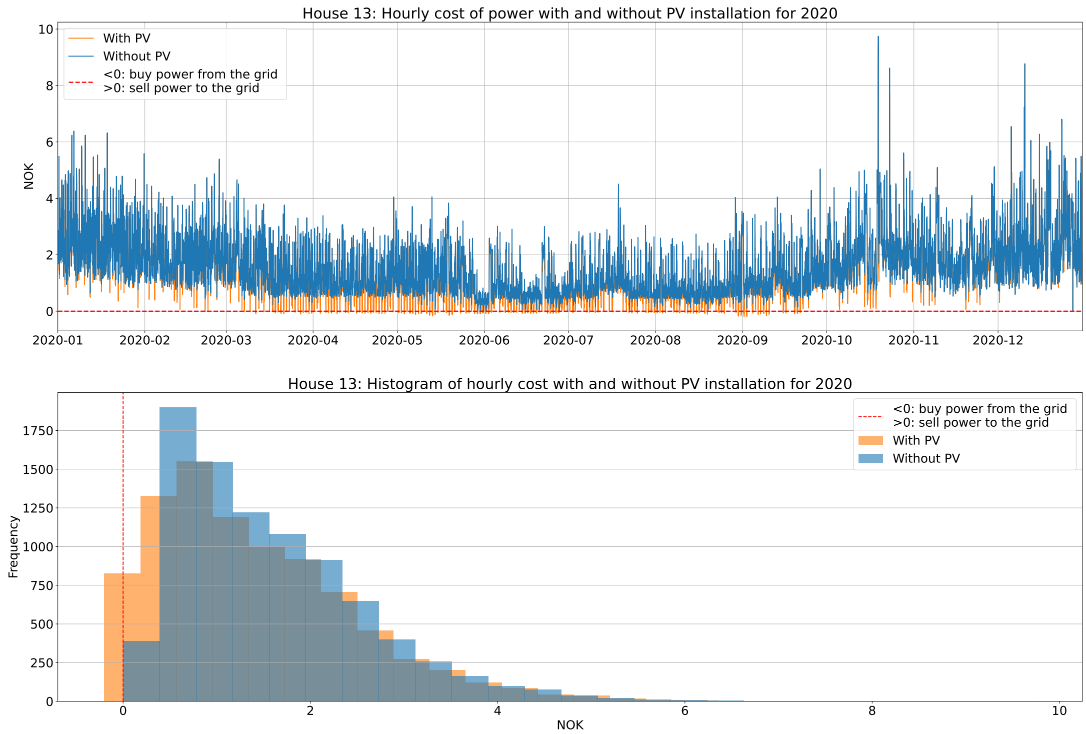



Figure A.286: Hourly cost of energy for House 13 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when > 0 and sell when < 0.

**2021**

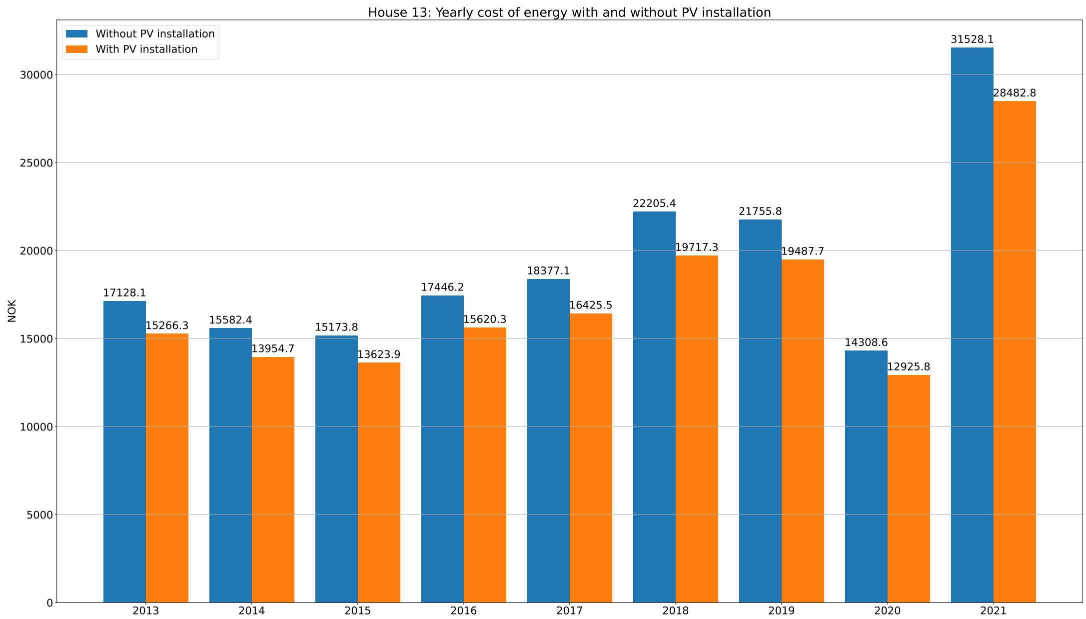



Figure A.287: Yearly cost of energy for House 13, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

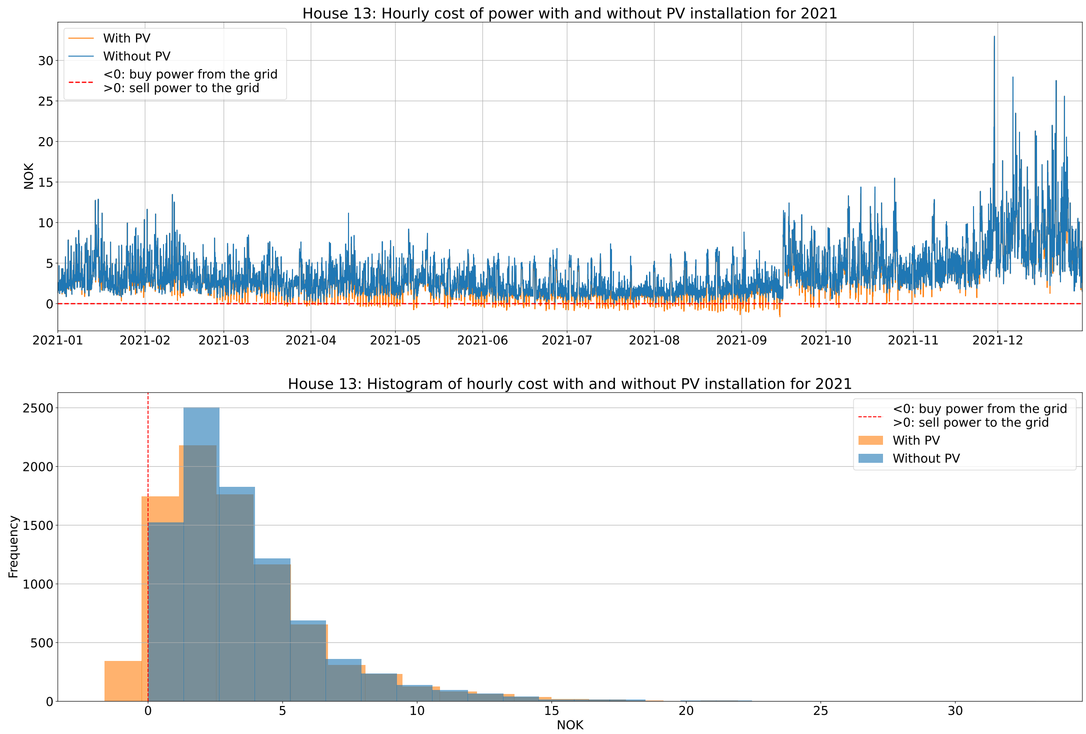
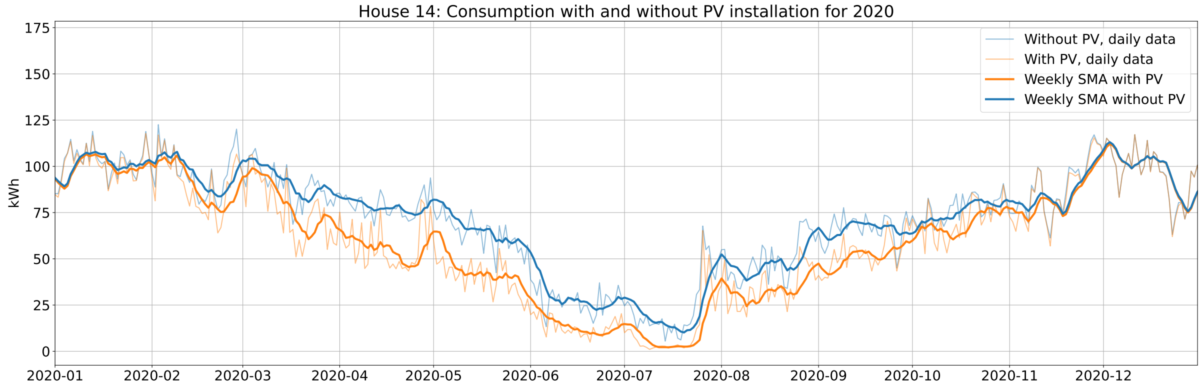



Figure A.288: Hourly cost of energy for House 13 with and without a PV system present for 2021. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when > 0 and sell when < 0.

## A.14 House 14

### A.14.1 House consumption

**2020**



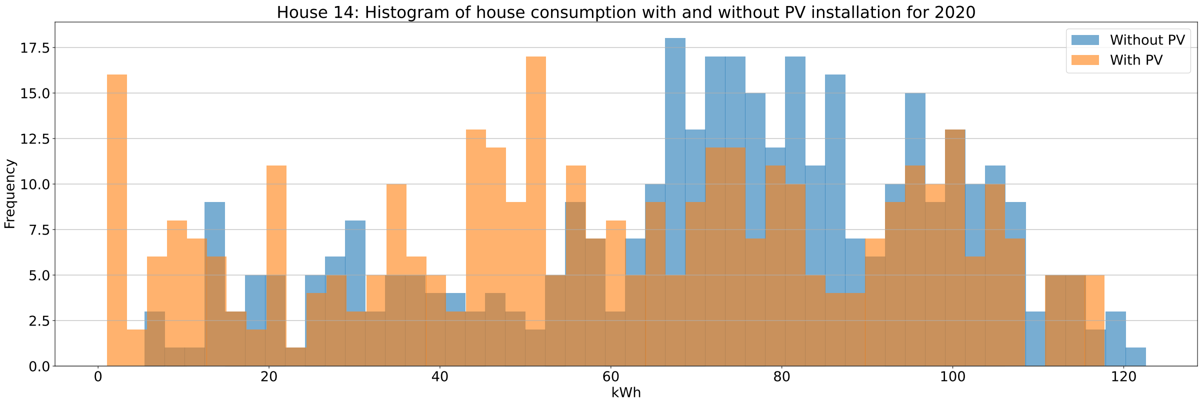




Figure A.289: Daily house consumption with and without a PV system for 2020 from House 14. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

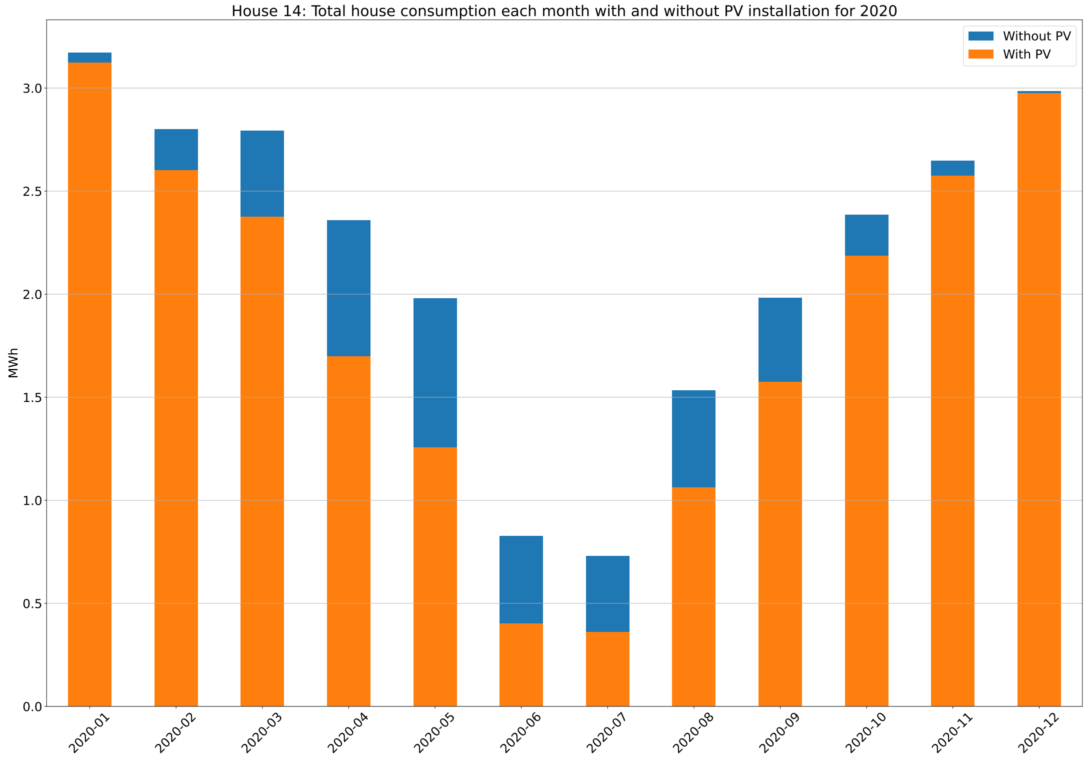



Figure A.290: Monthly house consumption for House 14 with and without a PV system for 2020.

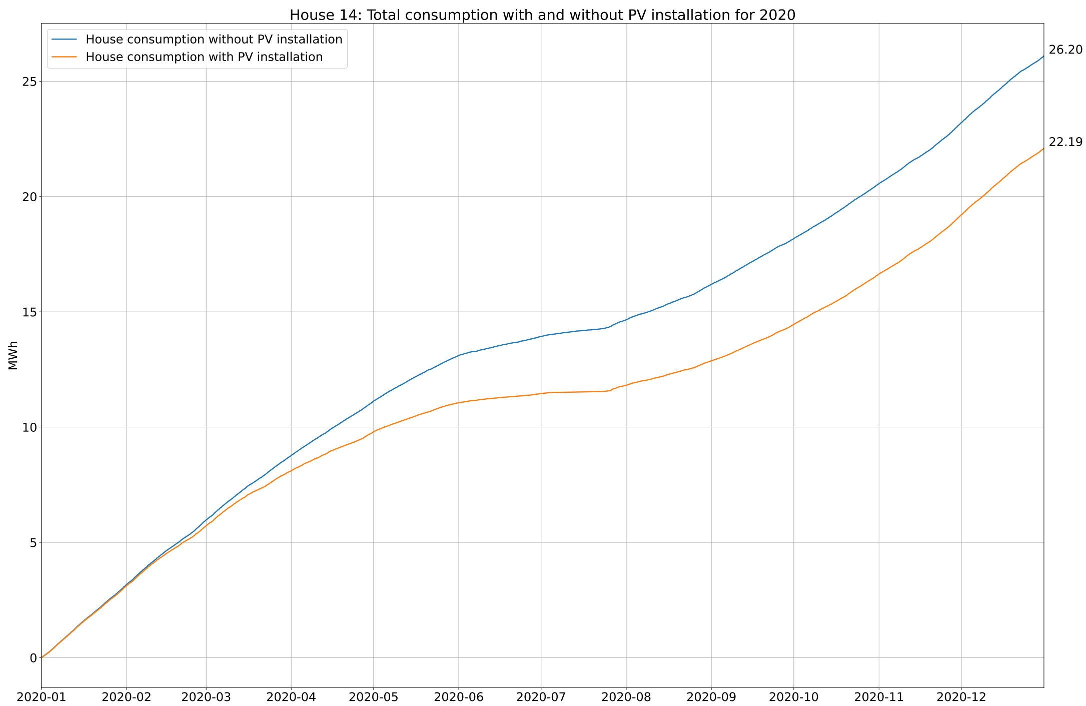



Figure A.291: Total house consumption for House 14 with and without a PV system accumulated over 2020

**2021**

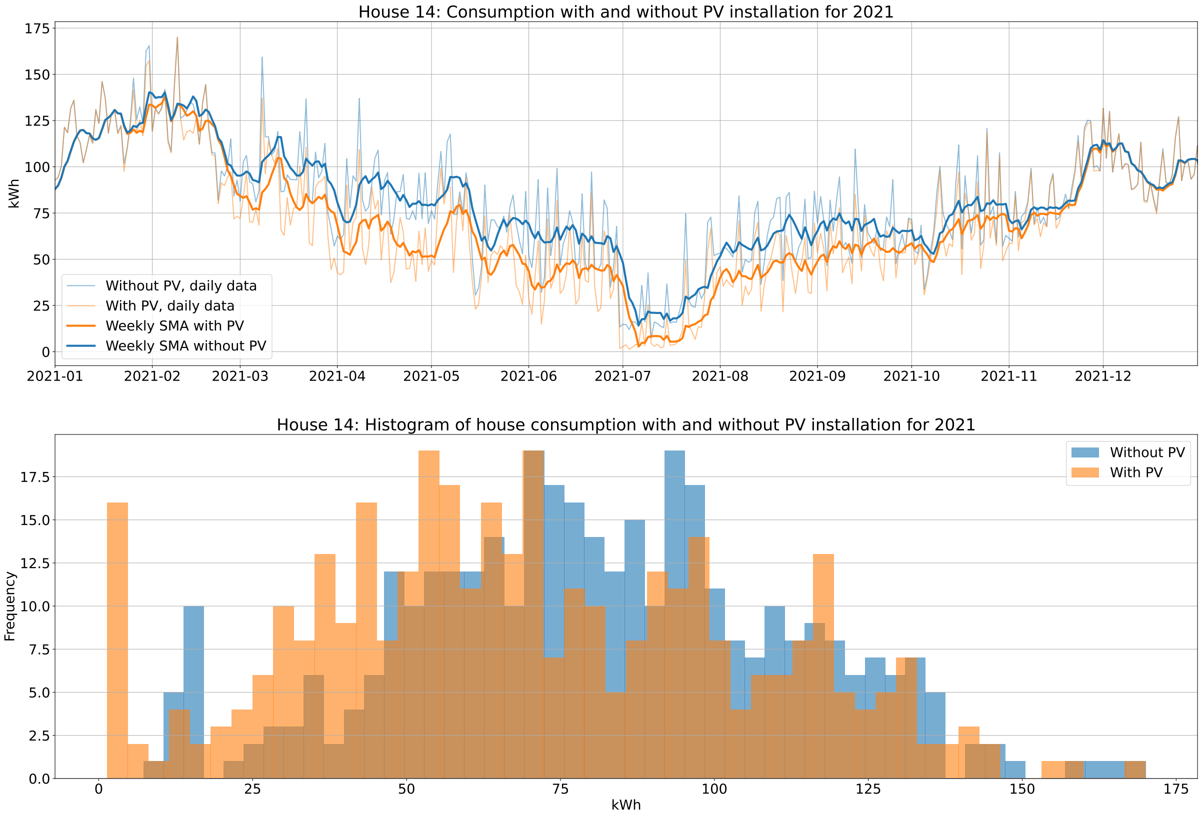



Figure A.292: Daily house consumption with and without a PV system for 2021 from House 14. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

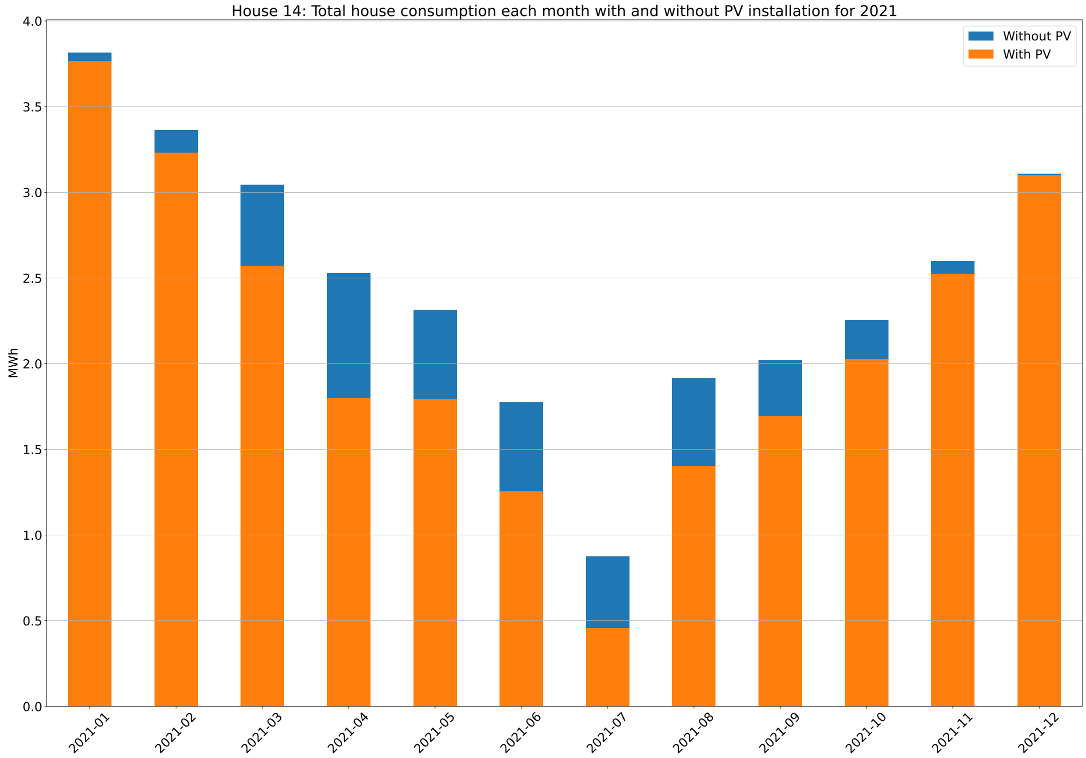



Figure A.293: Monthly house consumption for House 14 with and without a PV system for 2021.

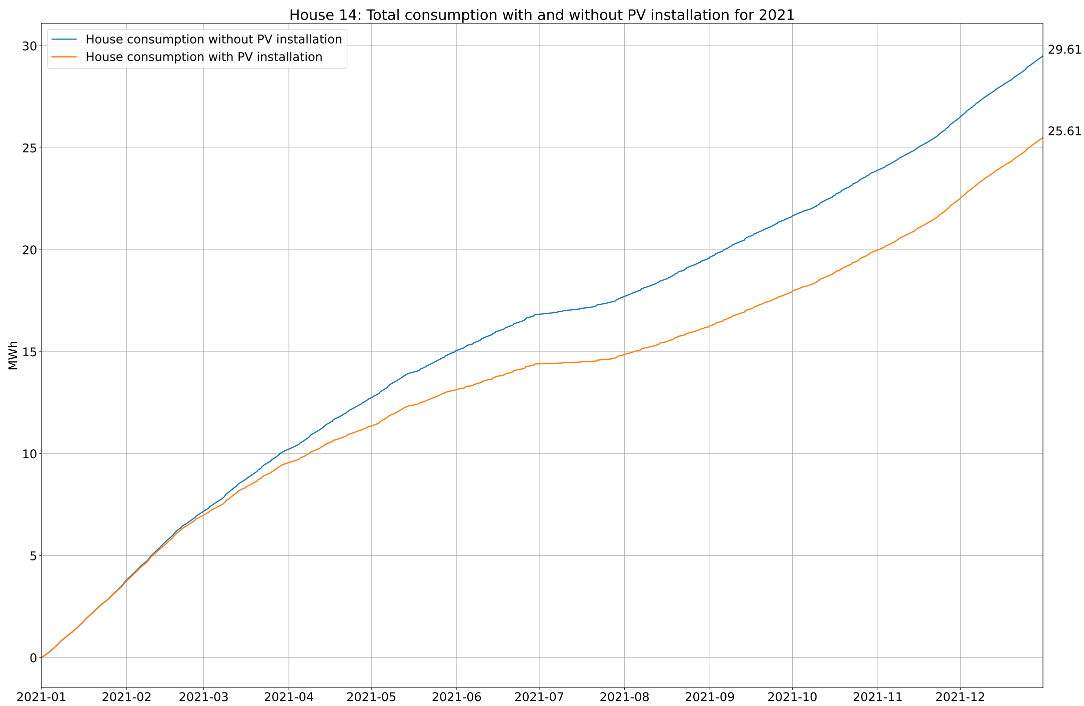



Figure A.294: Total house consumption for House 14 with and without a PV system accumulated over 2021

## A.14.2 Solar PV production

### 2020

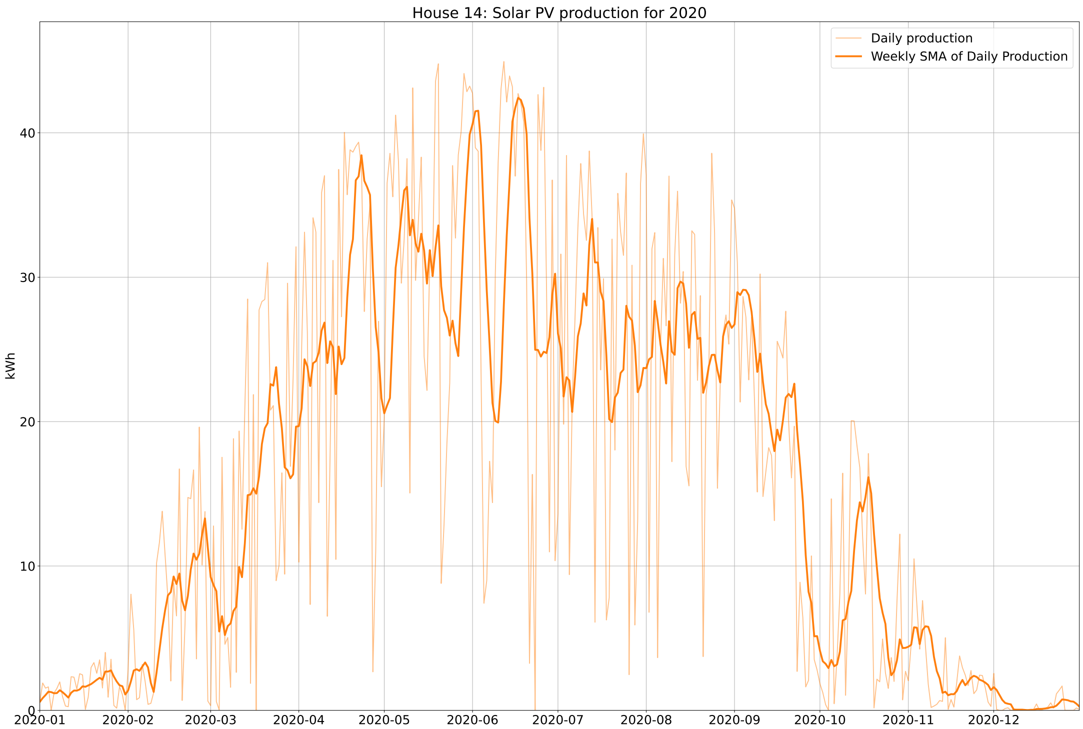



Figure A.295: Daily PV production and weekly SMA for House 14 in 2020.

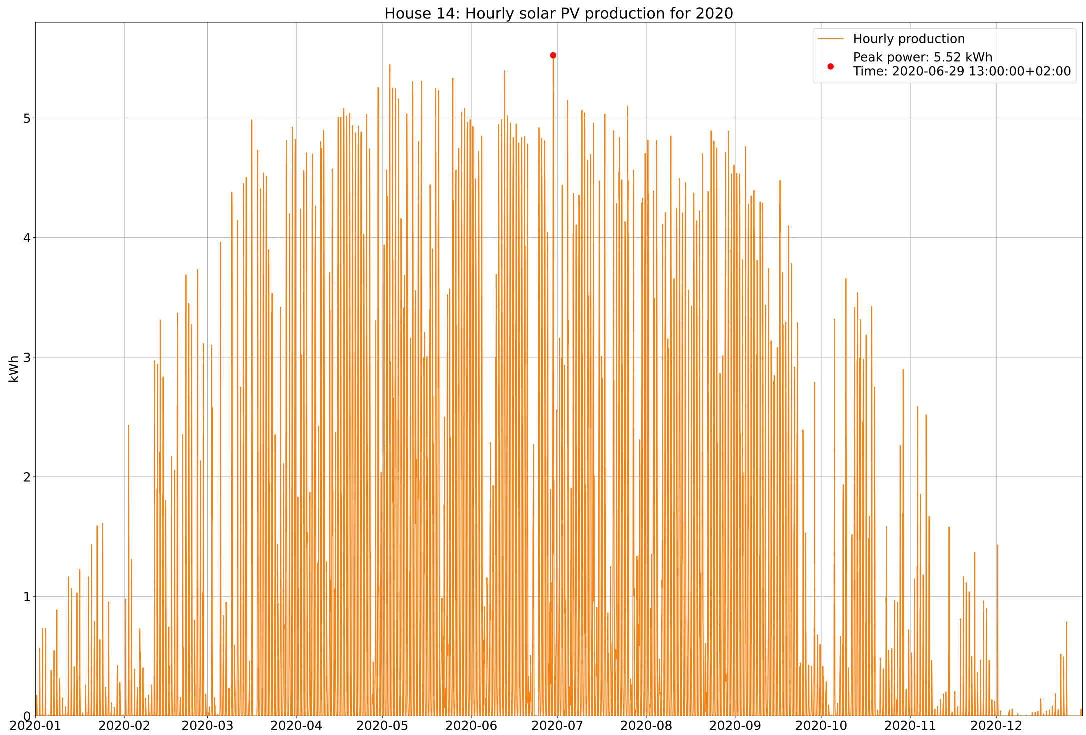



Figure A.296: Hourly PV production for House 14 in 2020.

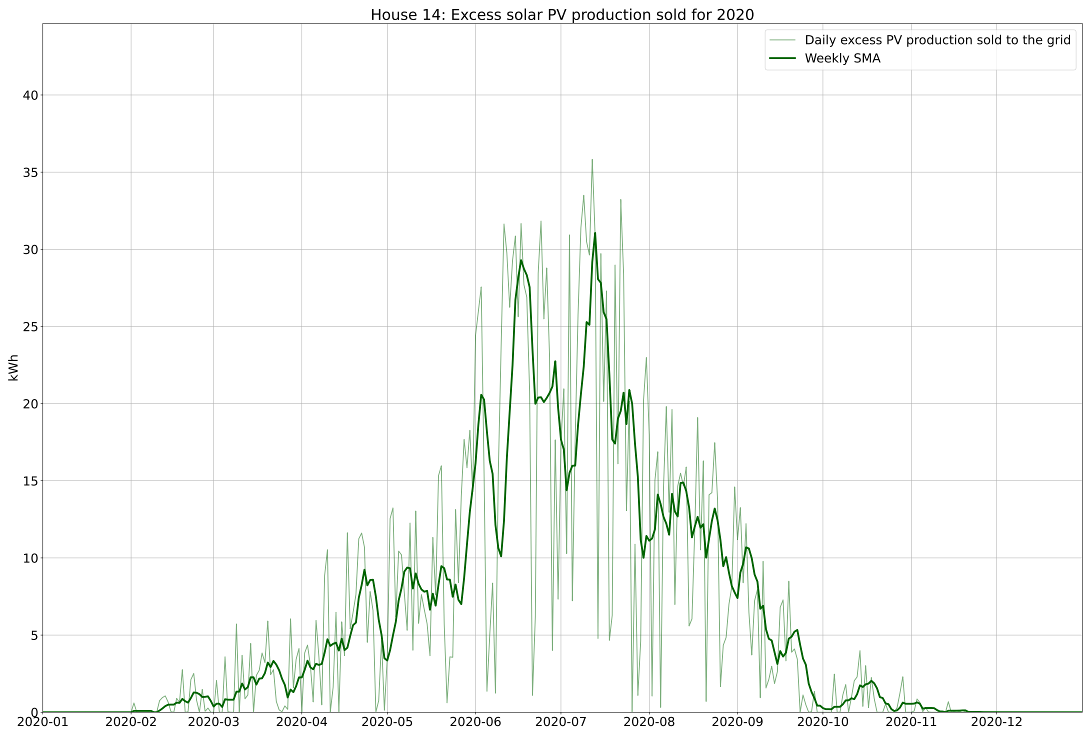



Figure A.297: Daily excess PV production sold to the grid and weekly SMA for House 14 in 2020

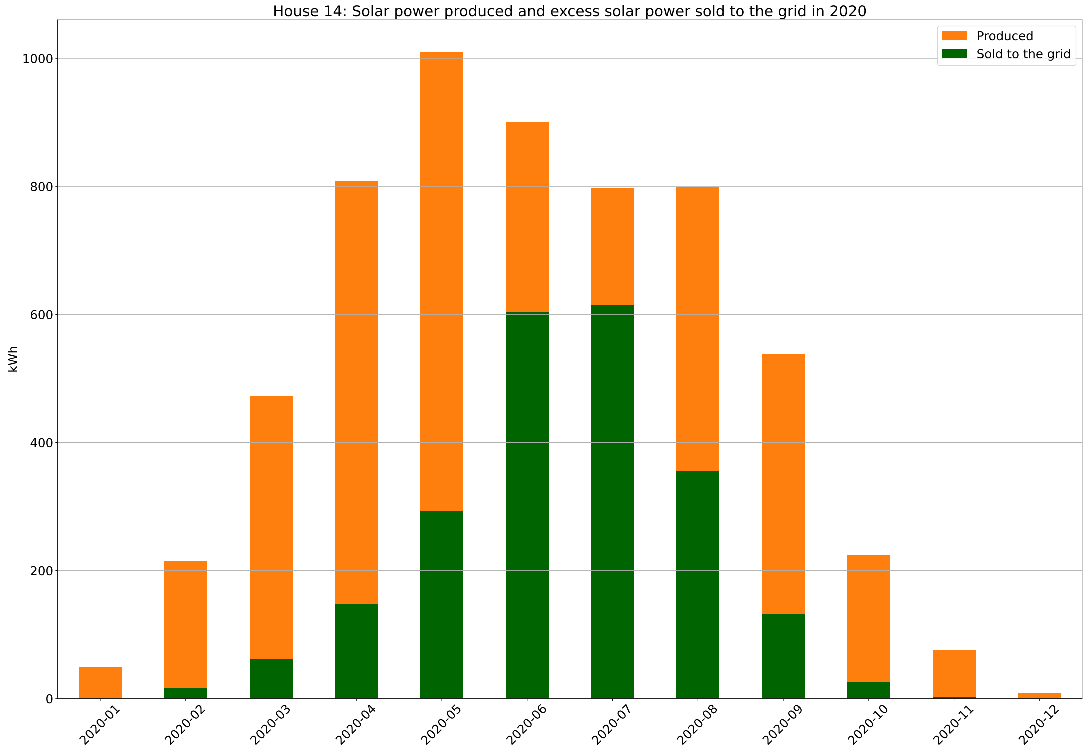



Figure A.298: Total solar PV production and excess production sold to the grid for each month in 2020 from House 14.

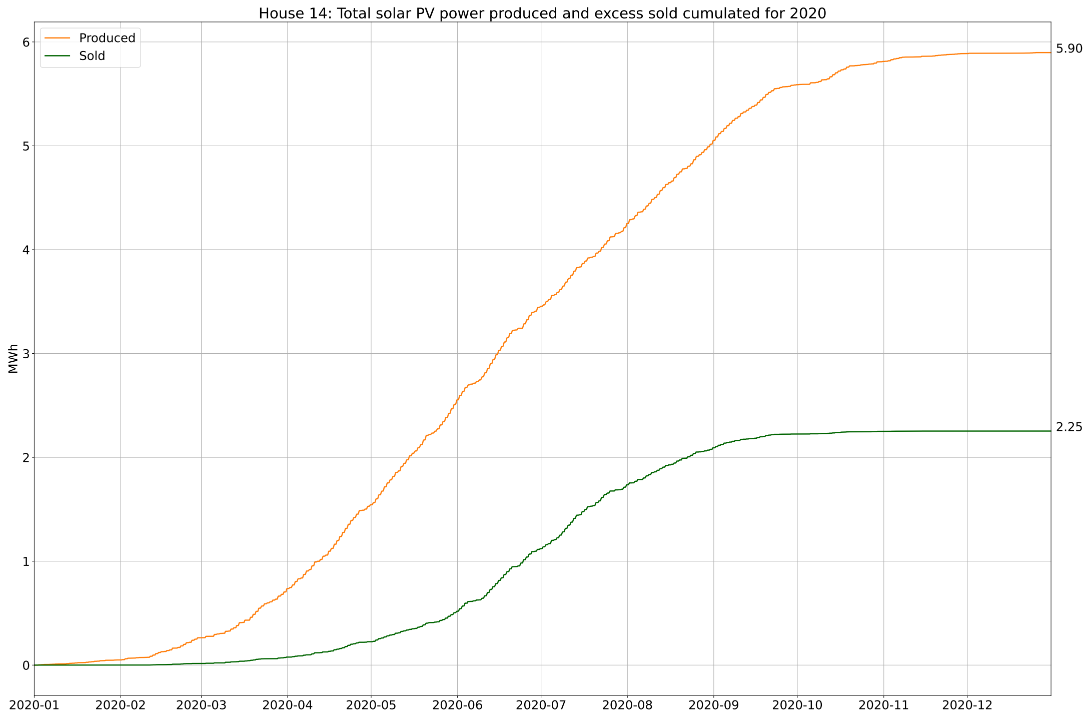



Figure A.299: Total solar PV production and excess production sold cumulated over 2020 from House 14

**2021**

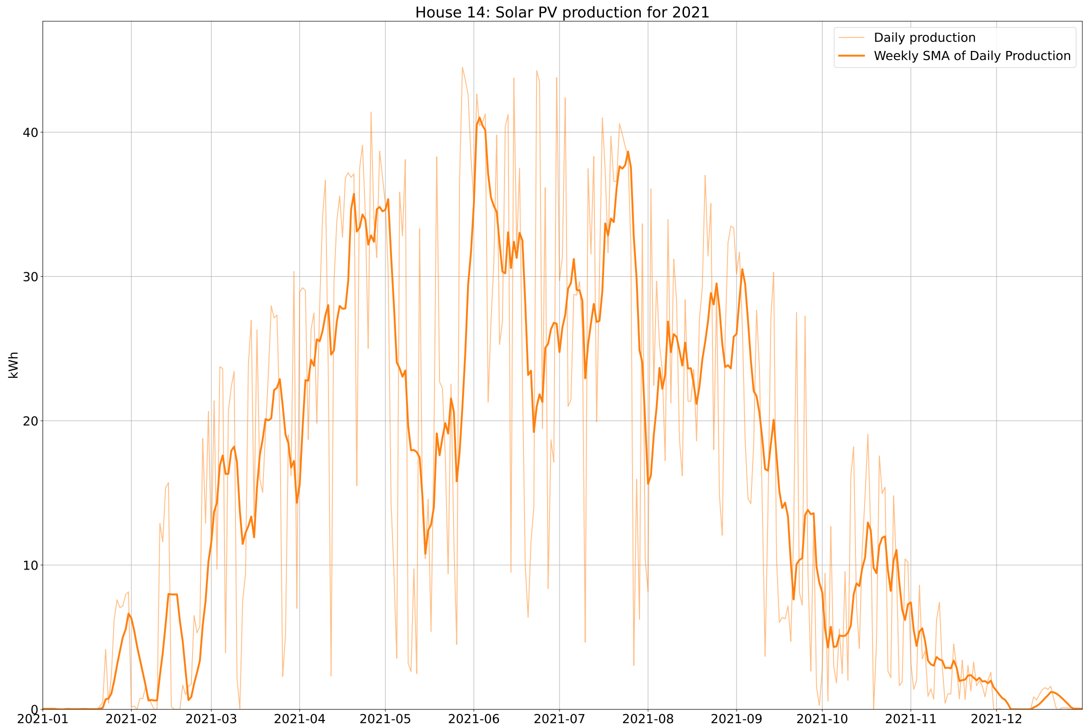



Figure A.300: Daily PV production and weekly SMA for House 14 in 2021.

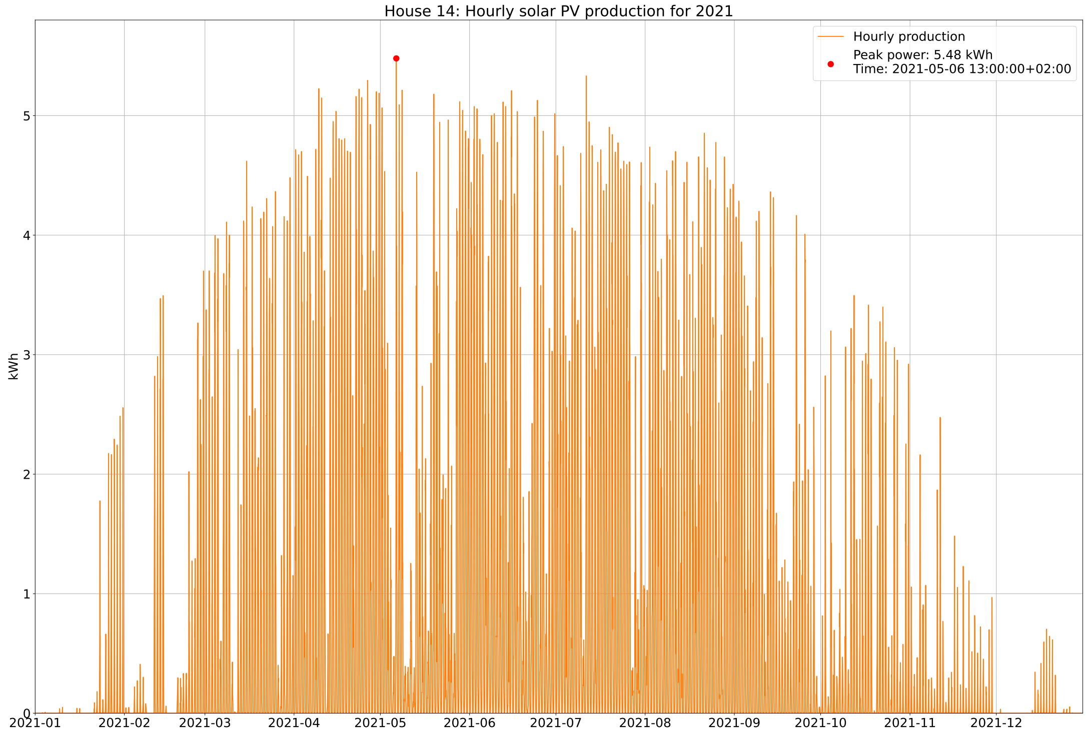



Figure A.301: Hourly PV production for House 14 in 2021.

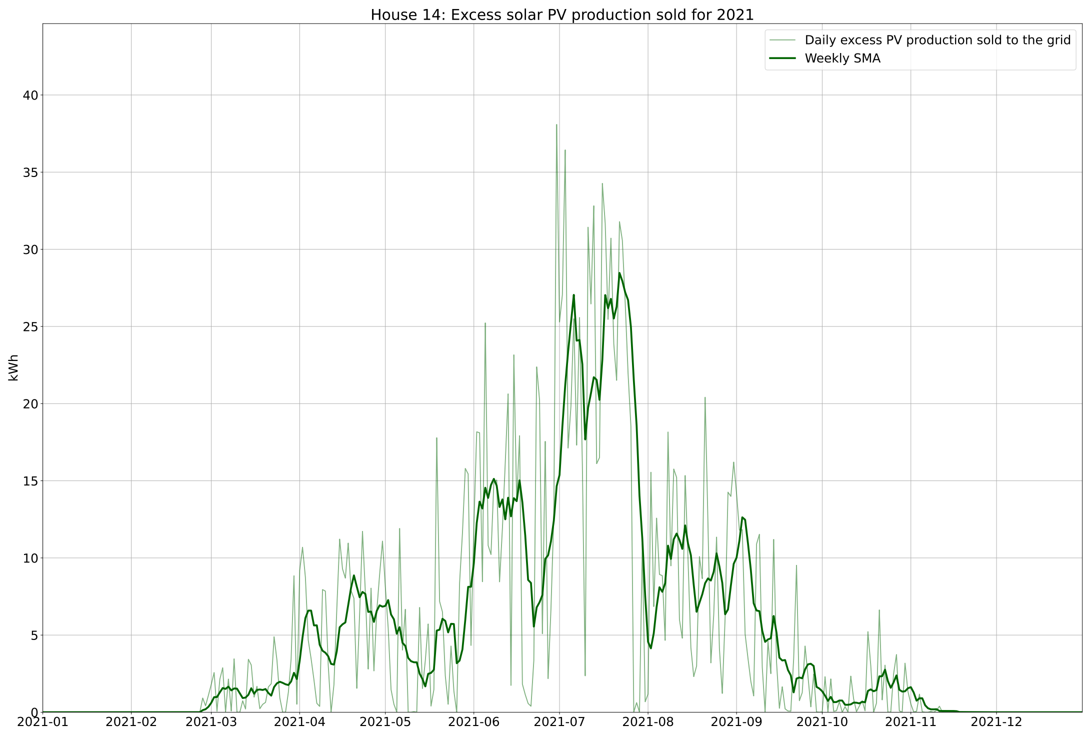



Figure A.302: Daily excess PV production sold to the grid and weekly SMA for House 14 in 2021

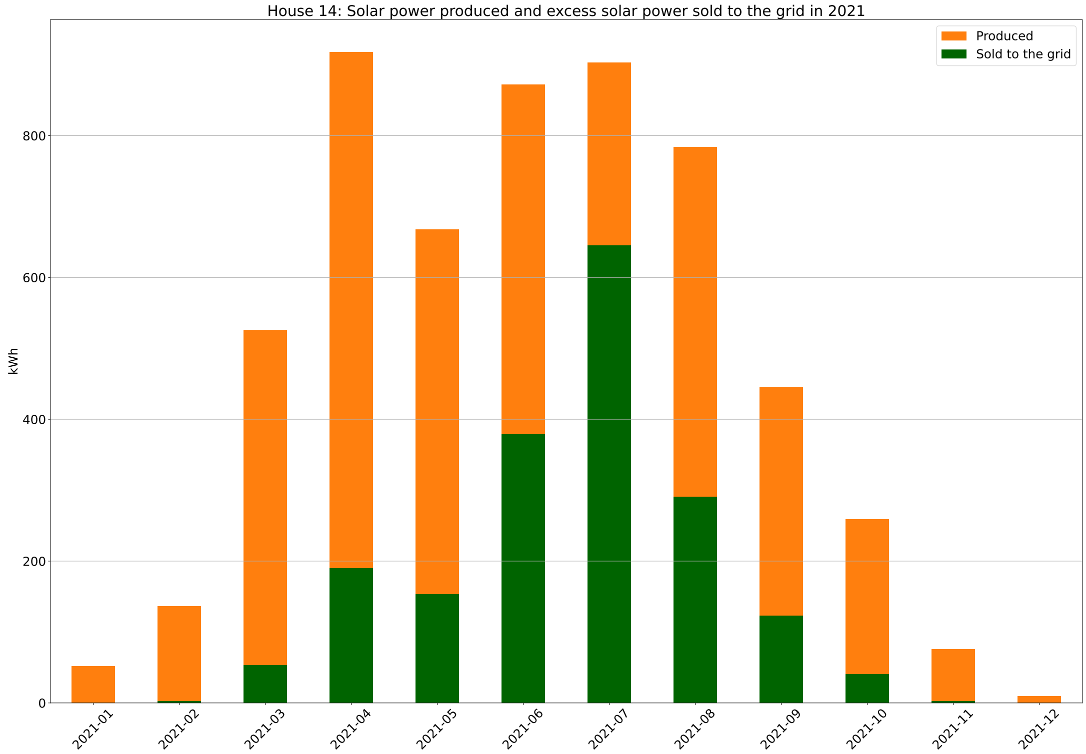



Figure A.303: Total solar PV production and excess production sold to the grid for each month in 2021 from House 14.

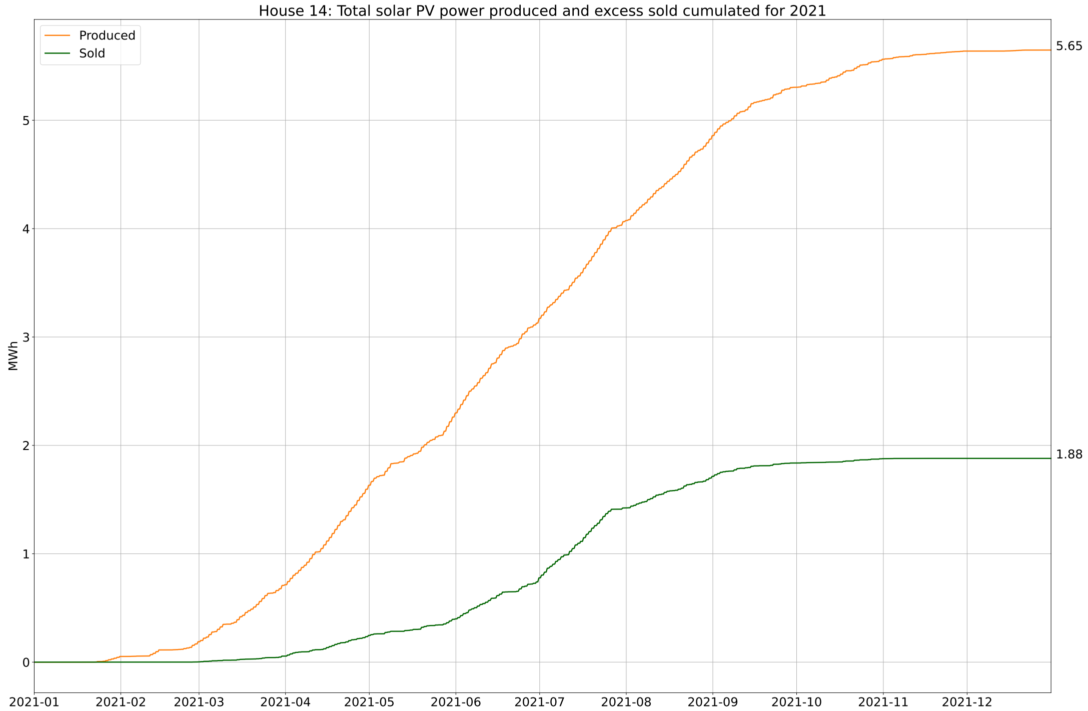



Figure A.304: Total solar PV production and excess production sold cumulated over 2021 from House 14

### A.14.3 Delta variable

#### 2020

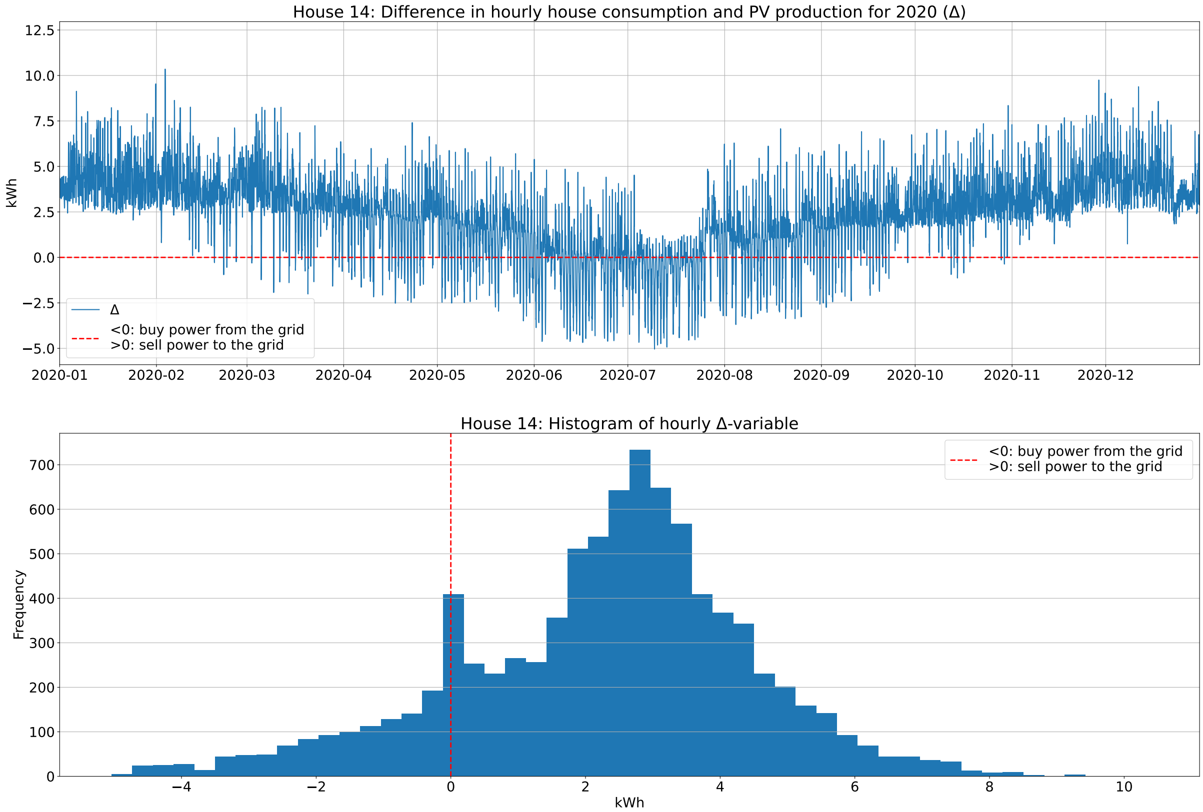
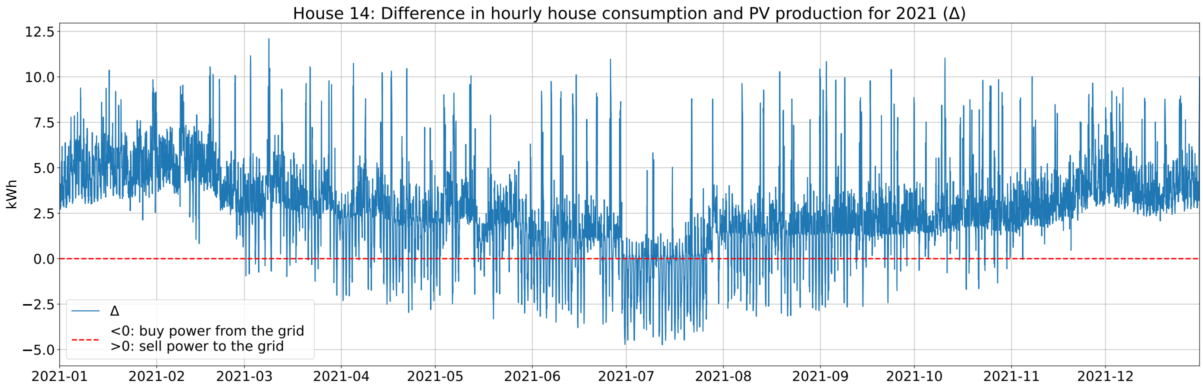



Figure A.305: The delta variable plotted for House 14. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $>0$ and sell when $<0$.

**2021**



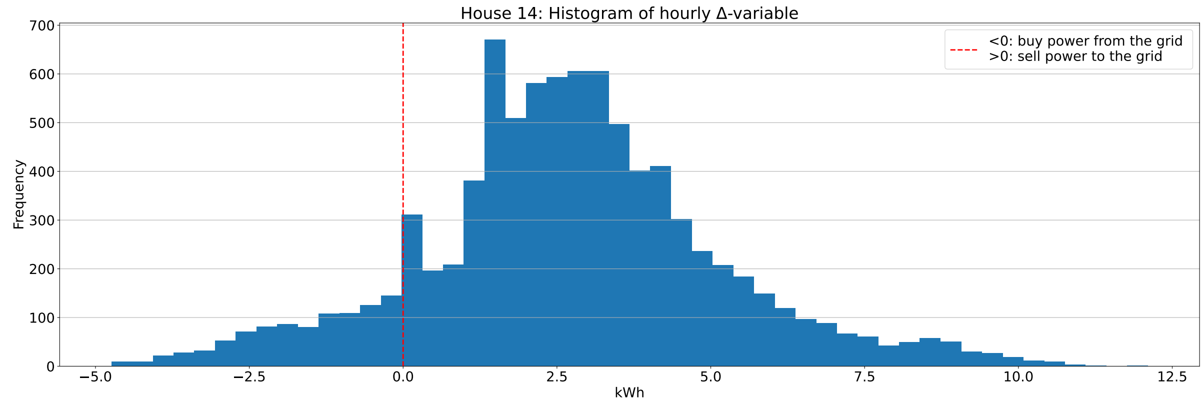




Figure A.306: The delta variable plotted for House 14. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.14.4 House consumption and PV production

#### 2020

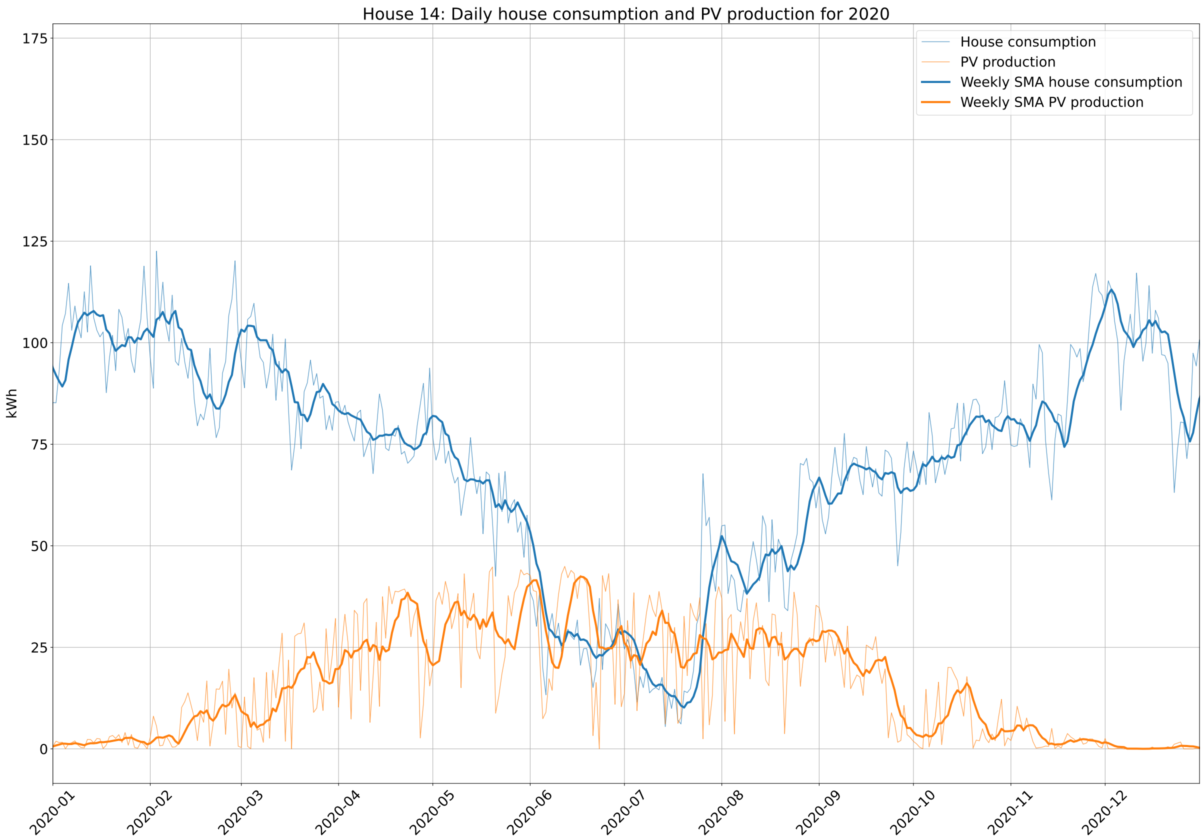



Figure A.307: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

### 2021

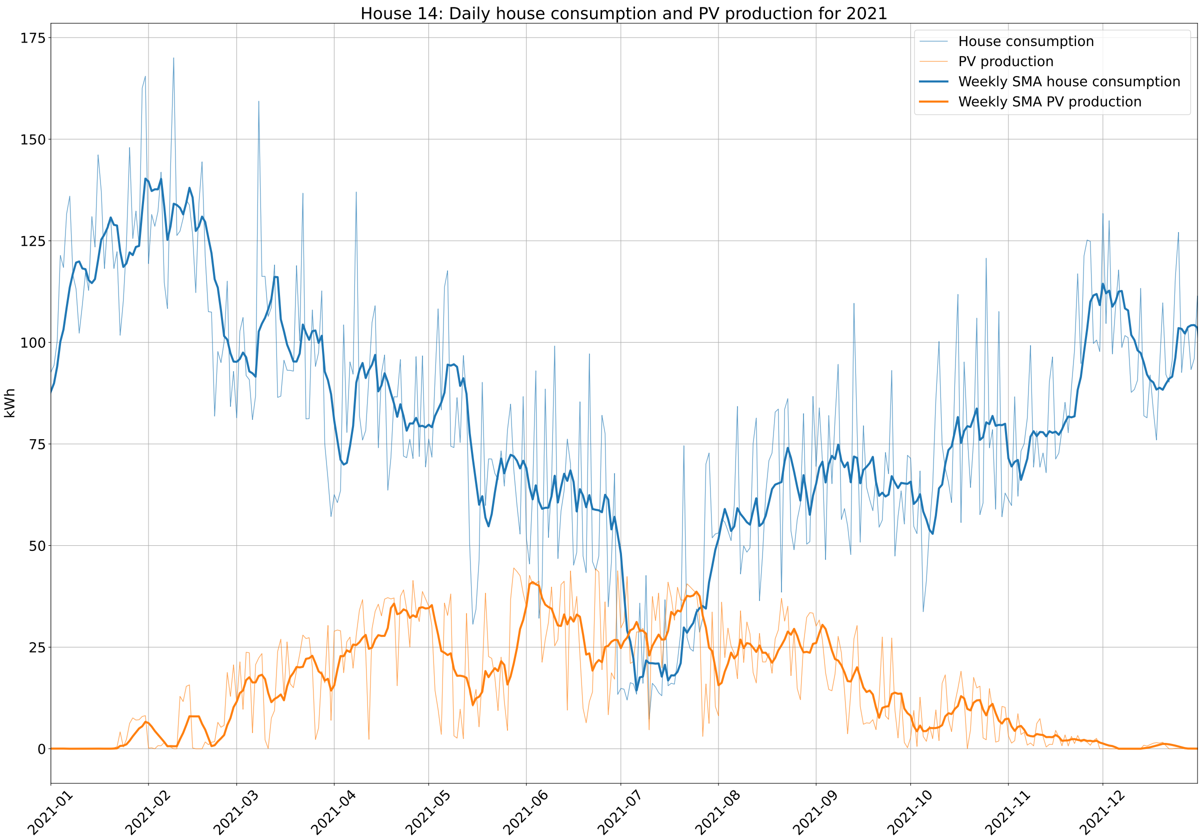



Figure A.308: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

## A.14.5 Cost of energy

### 2020

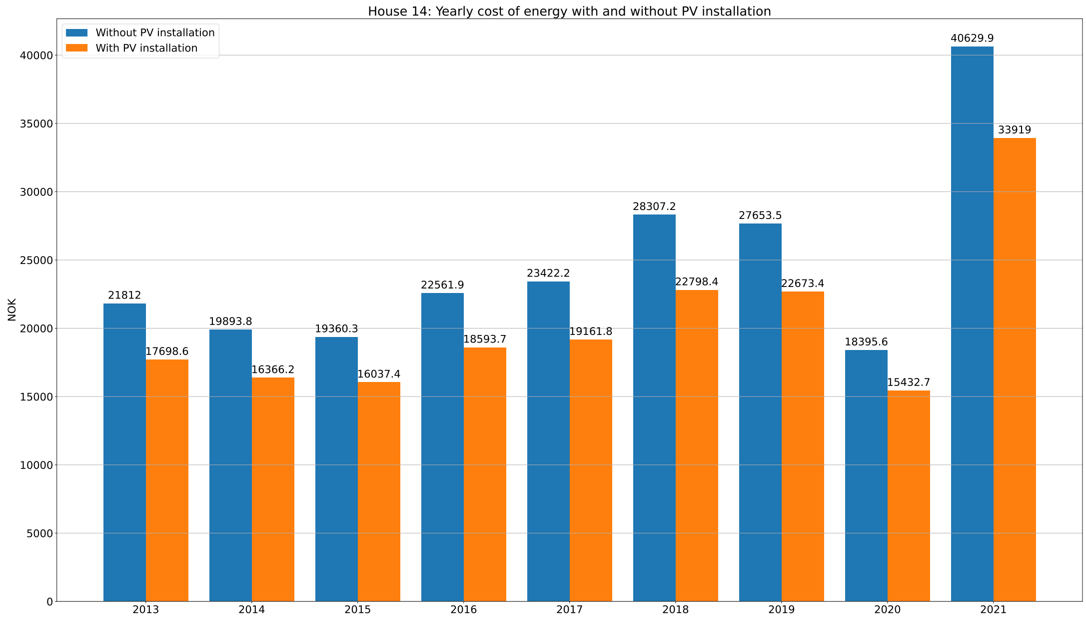



Figure A.309: Yearly cost of energy for House 14, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

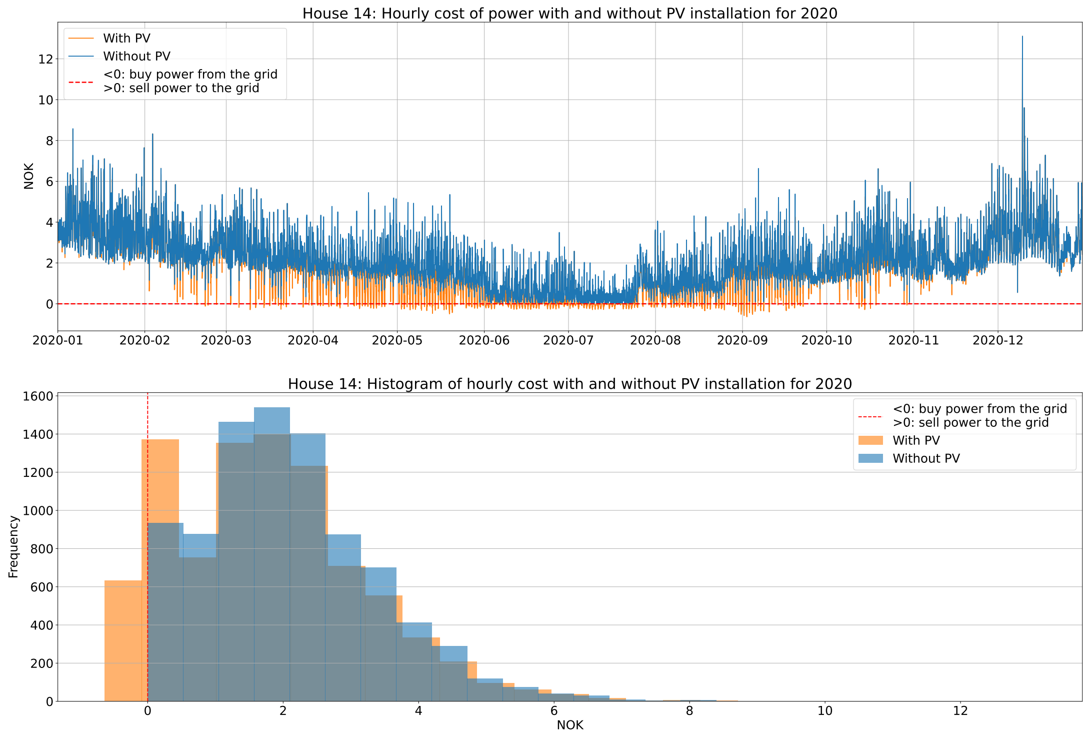



Figure A.310: Hourly cost of energy for House 14 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when > 0 and sell when < 0.

## 2021

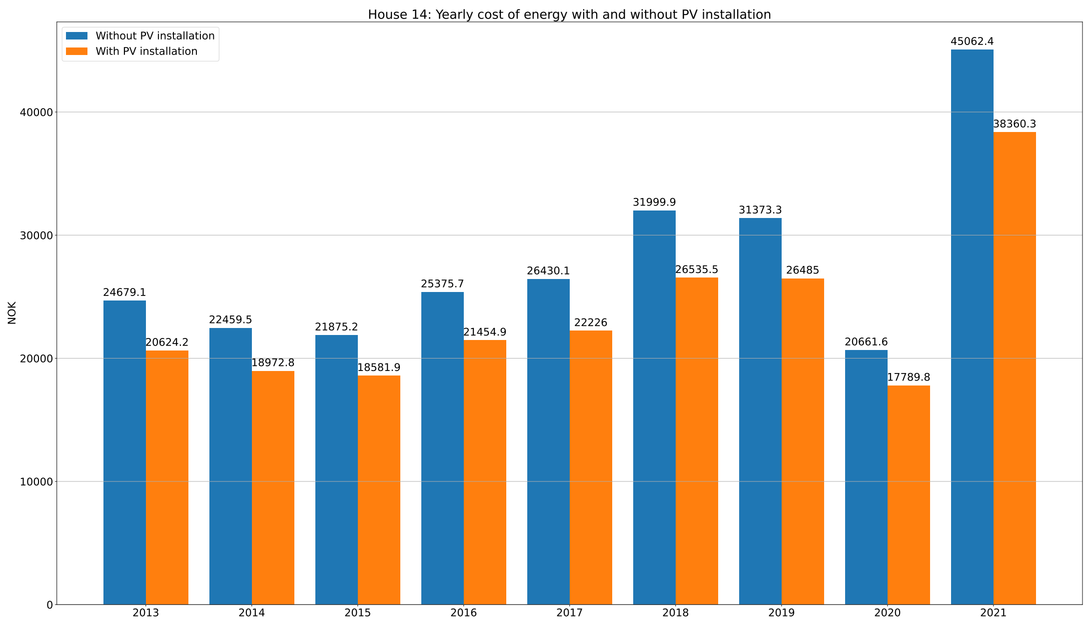



Figure A.311: Yearly cost of energy for House 14, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

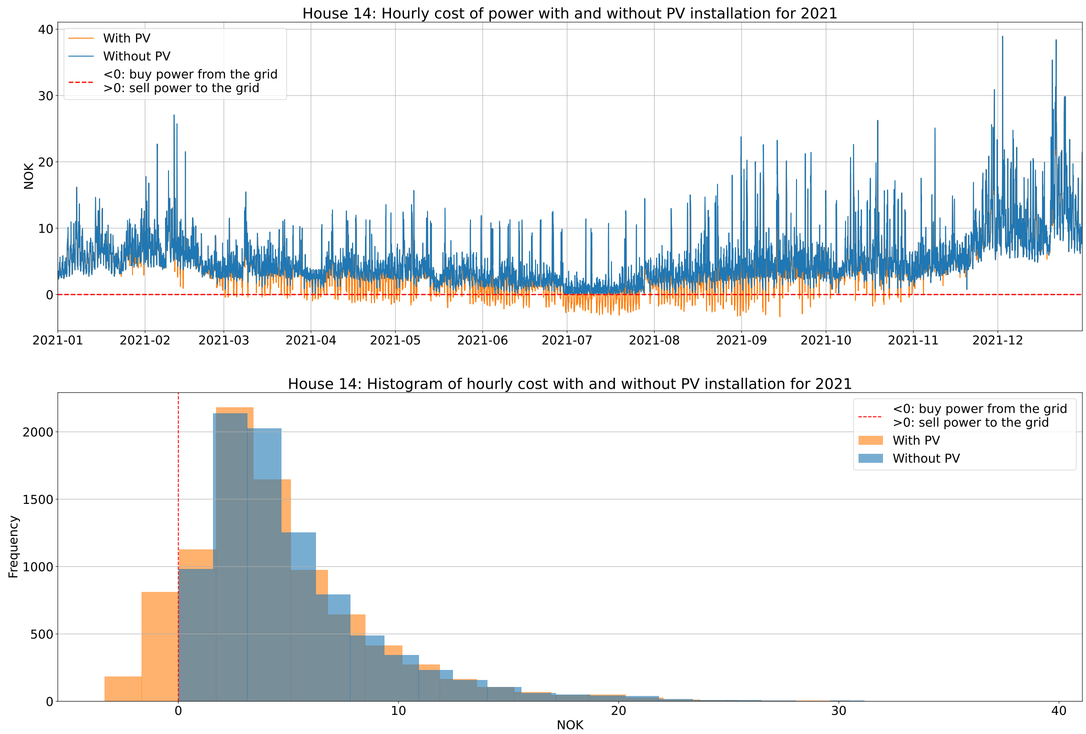
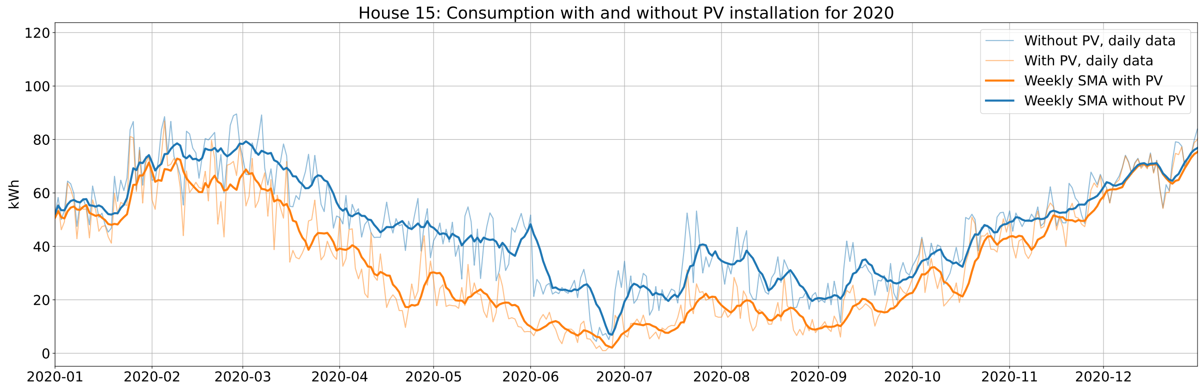



Figure A.312: Hourly cost of energy for House 14 with and without a PV system present for 2021. NB! Due to an small error the ”<” sign is reversed in both plots, it should say that you buy power when > 0 and sell when < 0.

# A.15 House 15

## A.15.1 House consumption

### 2020



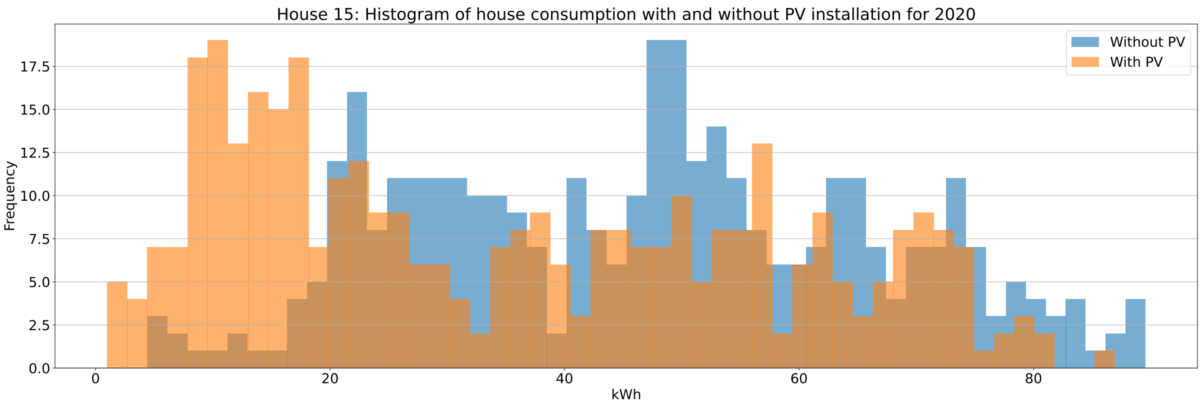




Figure A.313: Daily house consumption with and without a PV system for 2020 from House 15. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2020, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

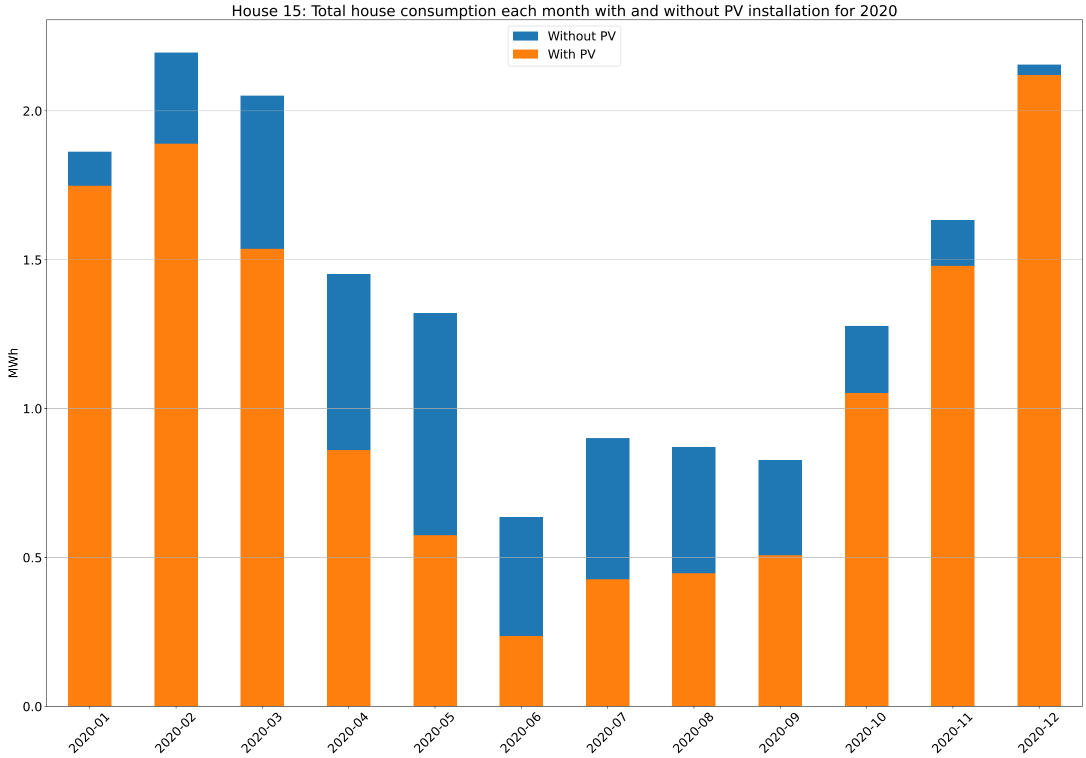



Figure A.314: Monthly house consumption for House 15 with and without a PV system for 2020.

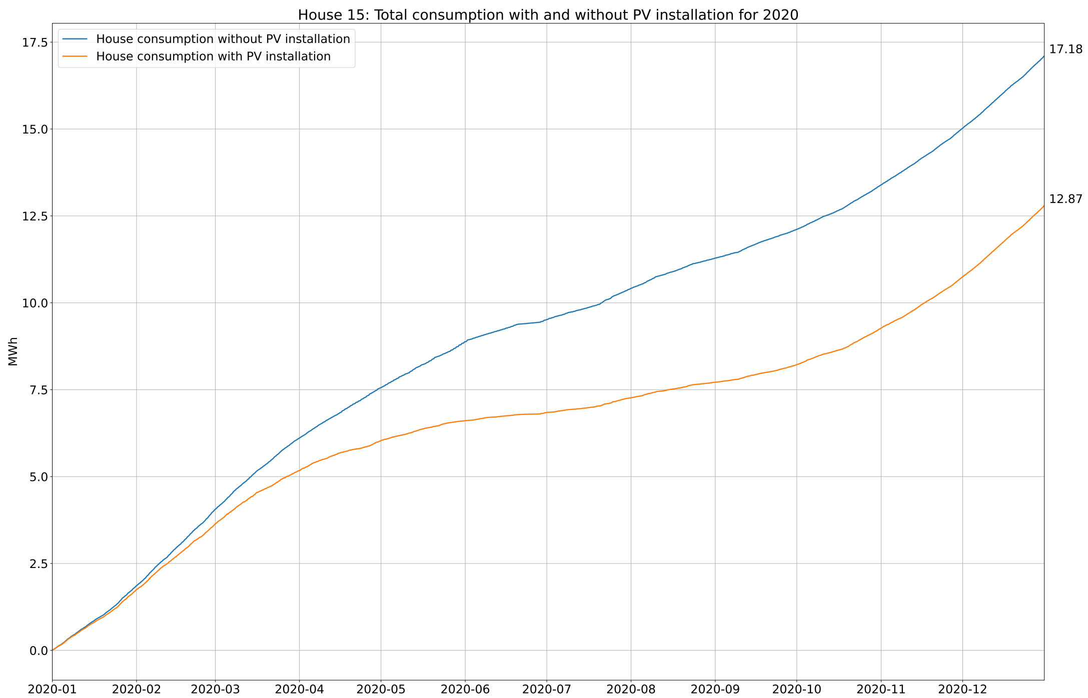



Figure A.315: Total house consumption for House 15 with and without a PV system accumulated over 2020

## 2021

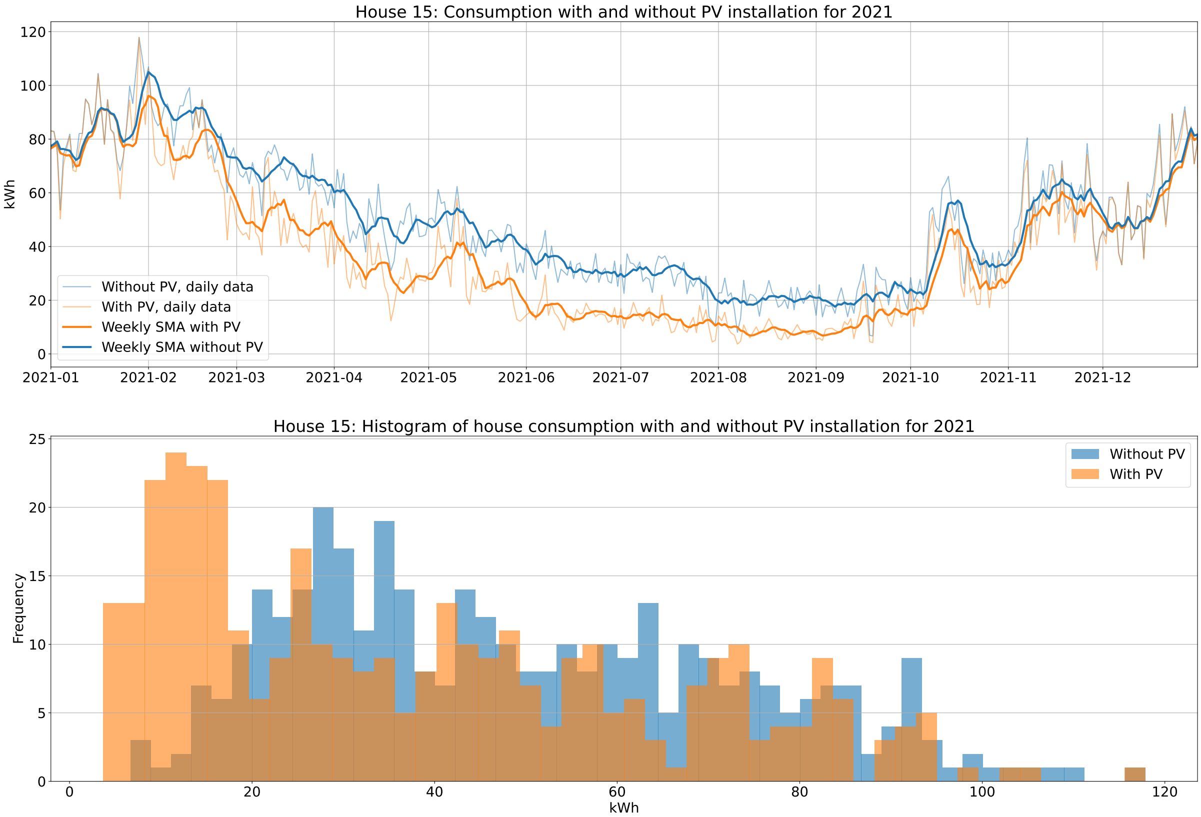



Figure A.316: Daily house consumption with and without a PV system for 2021 from House 15. The line graph (top graph) shows the daily house consumption and the weekly simple moving average of the house consumption with the PV system (in orange) and without the PV system (in blue). The histogram (bottom graph) shows the frequency of the different daily consumption values throughout 2021, where the orange bars represents the values with the PV system and the blue represents the values without the PV system.

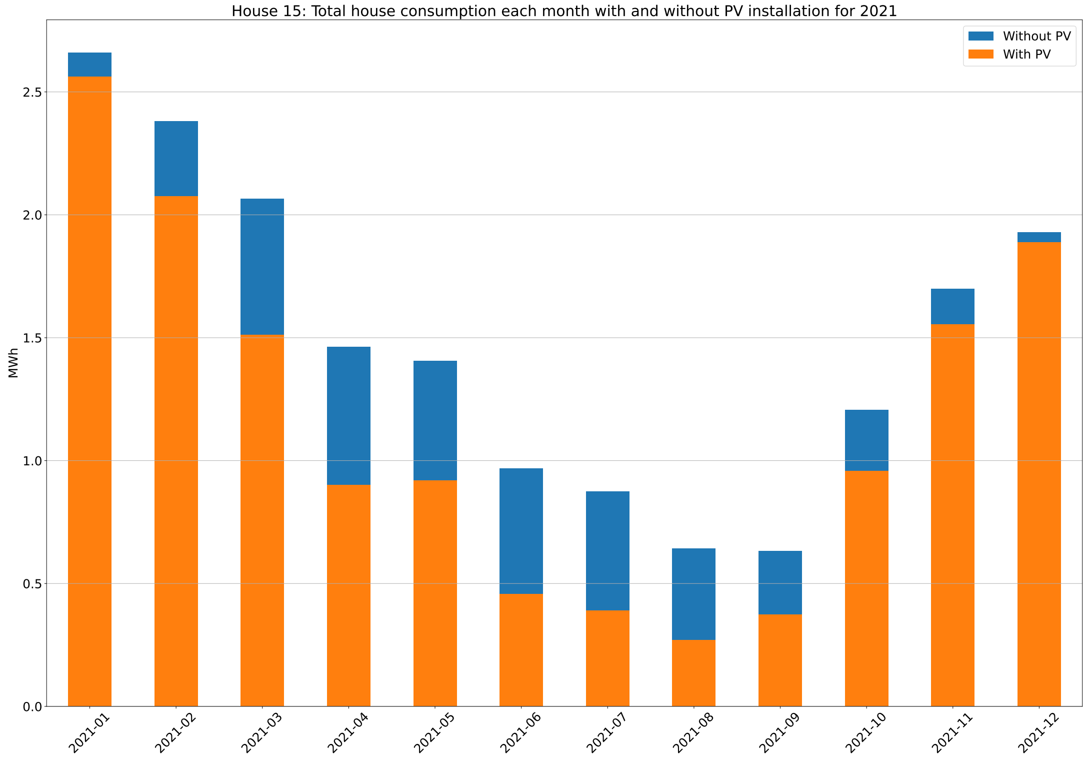



Figure A.317: Monthly house consumption for House 15 with and without a PV system for 2021.

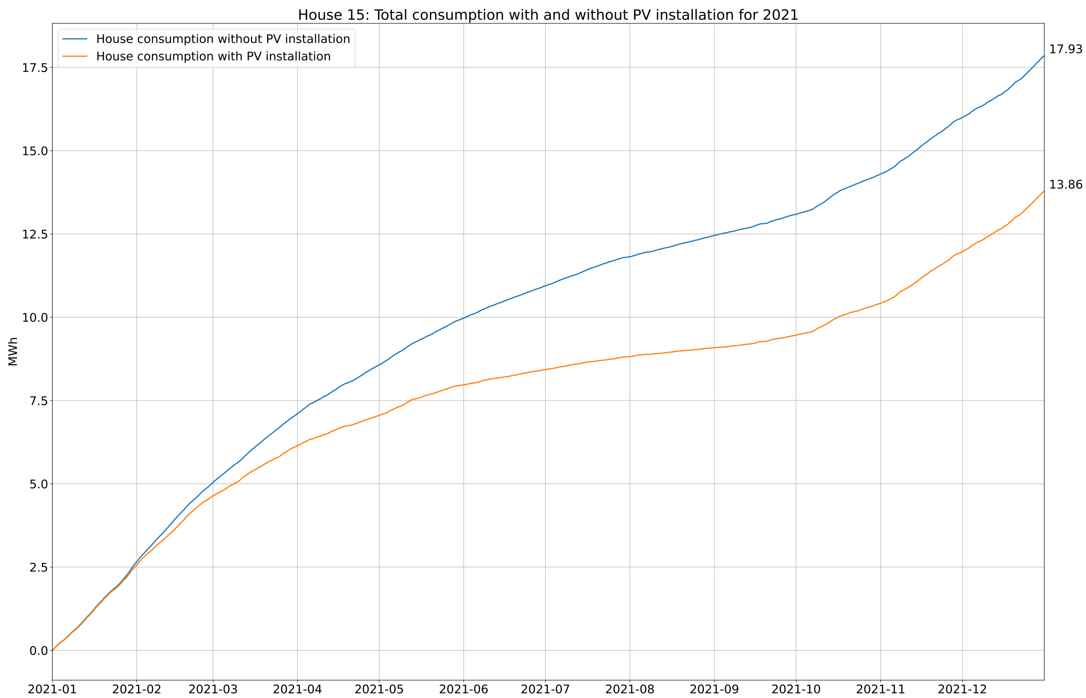



Figure A.318: Total house consumption for House 15 with and without a PV system accumulated over 2021

## A.15.2 Solar PV production

### 2020

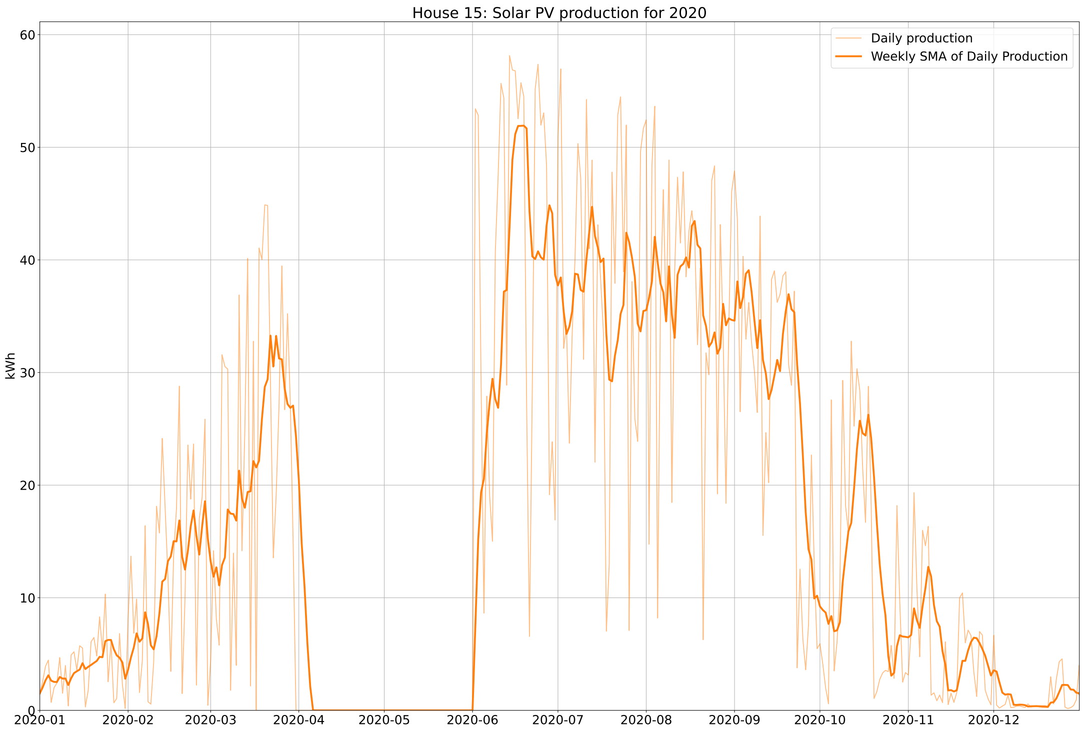



Figure A.319: Daily PV production and weekly SMA for House 15 in 2020.

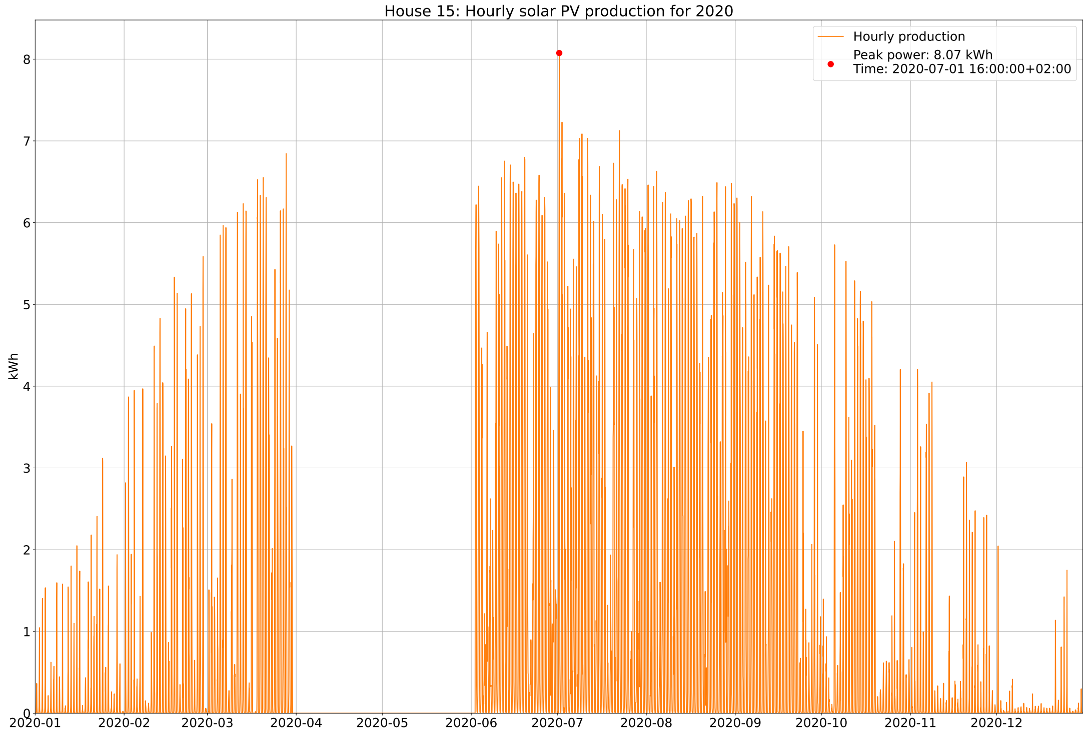



Figure A.320: Hourly PV production for House 15 in 2020.

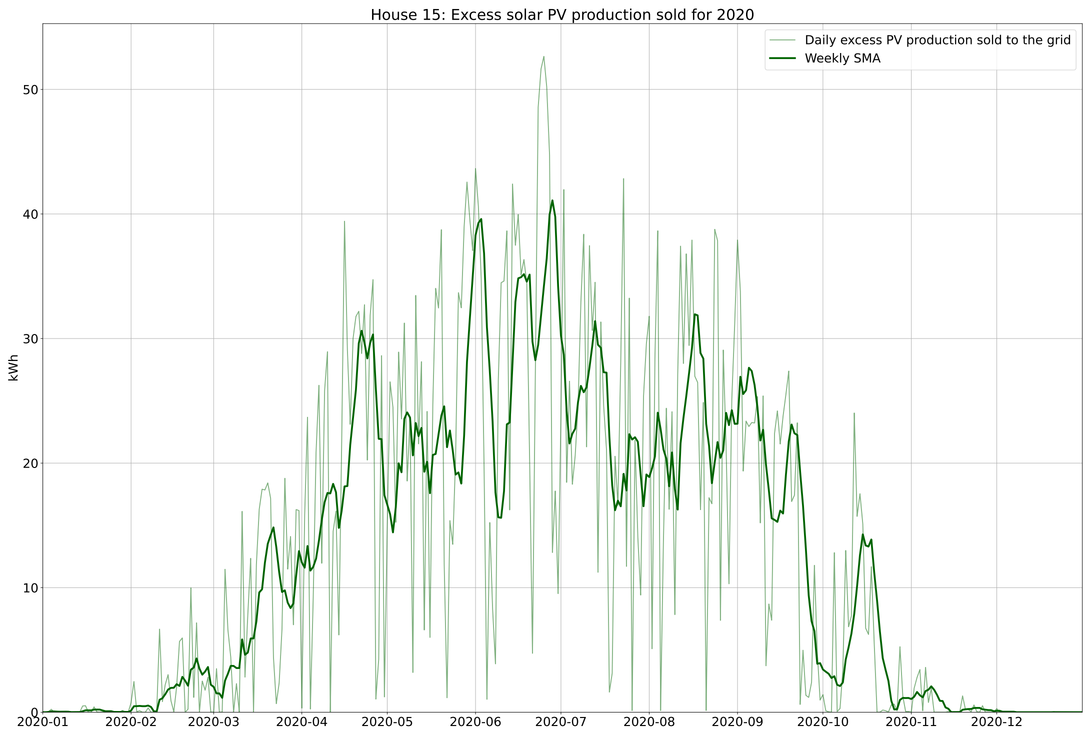



Figure A.321: Daily excess PV production sold to the grid and weekly SMA for House 15 in 2020

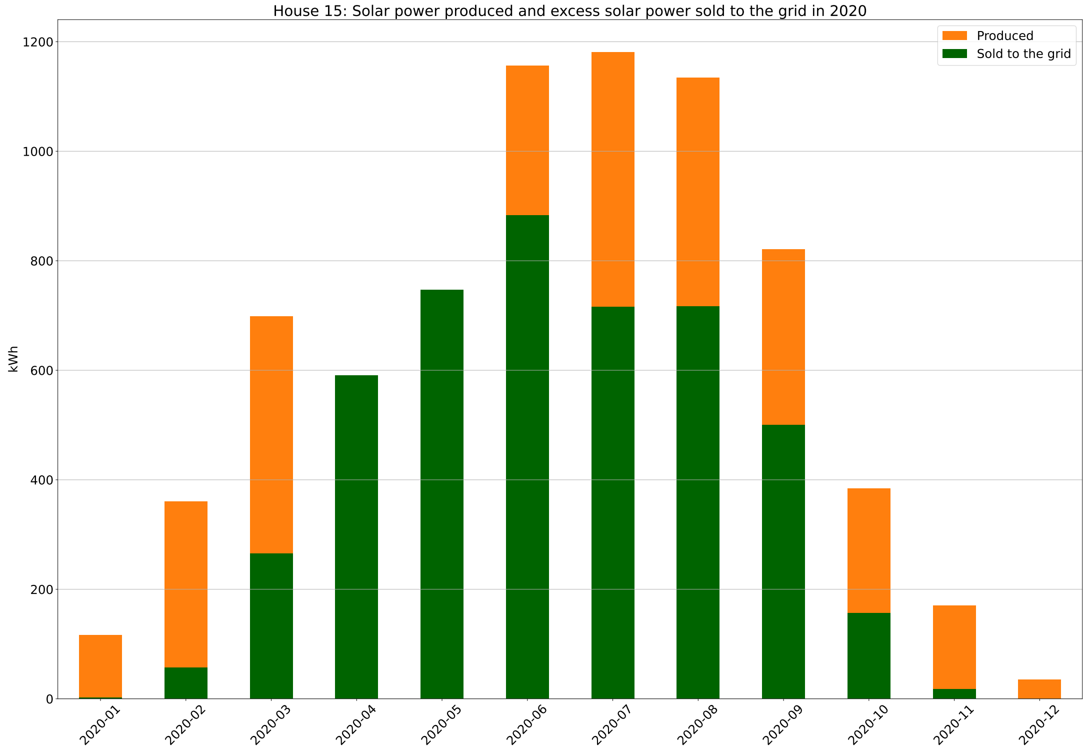



Figure A.322: Total solar PV production and excess production sold to the grid for each month in 2020 from House 15.

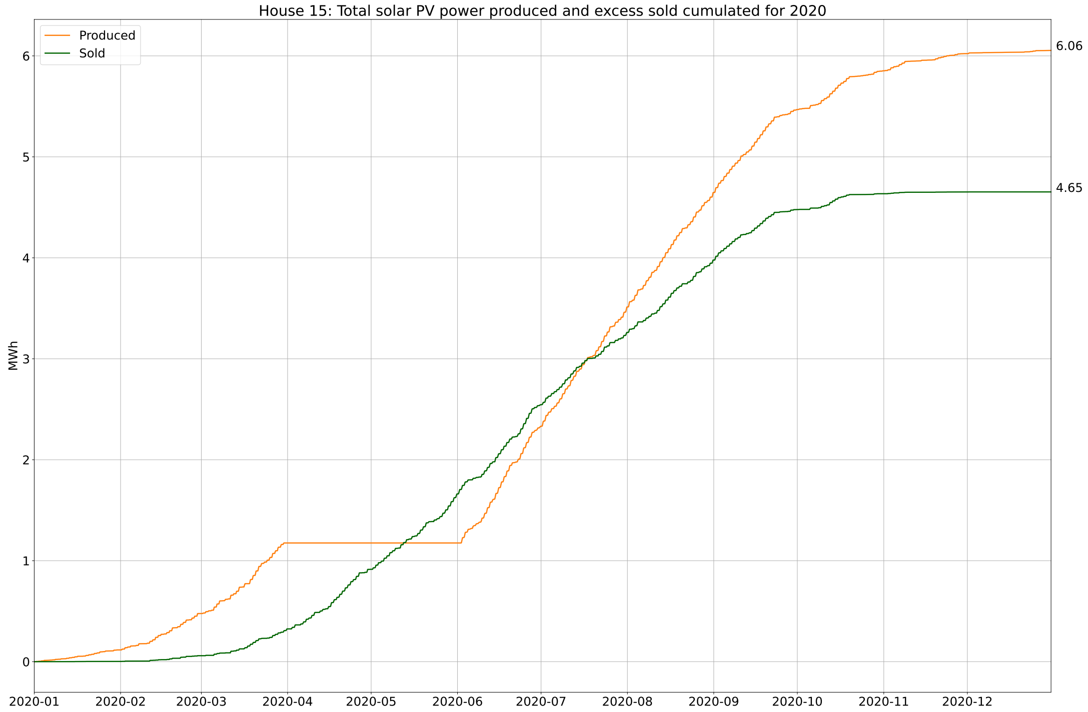



Figure A.323: Total solar PV production and excess production sold cumulated over 2020 from House 15

### 2021

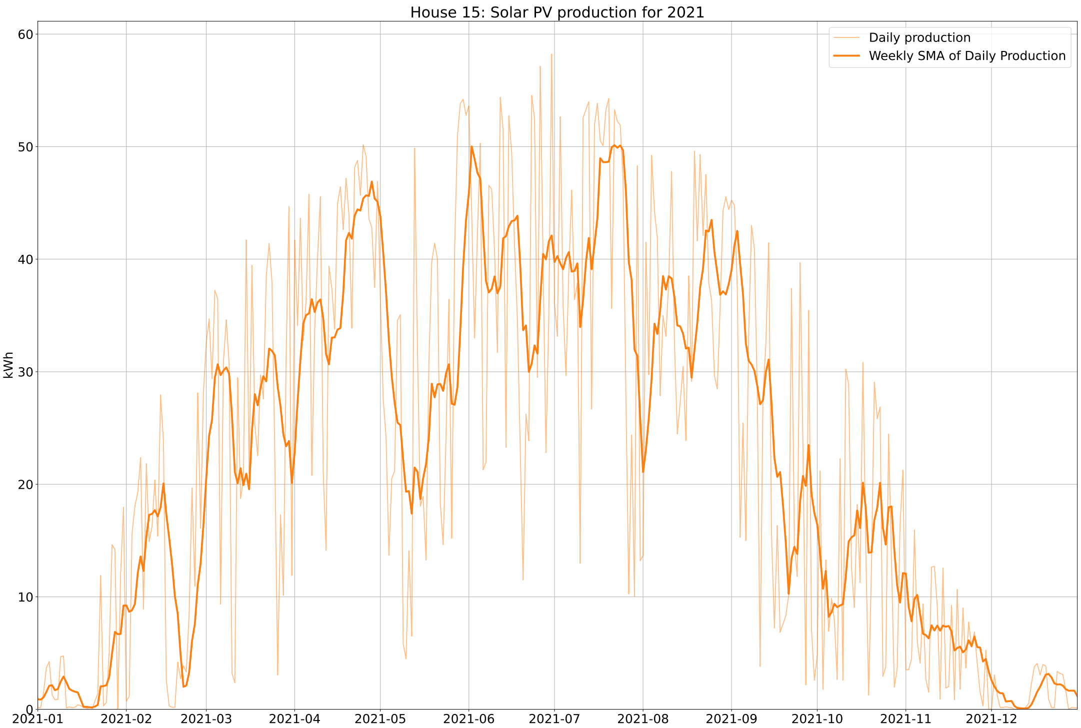



Figure A.324: Daily PV production and weekly SMA for House 15 in 2021.

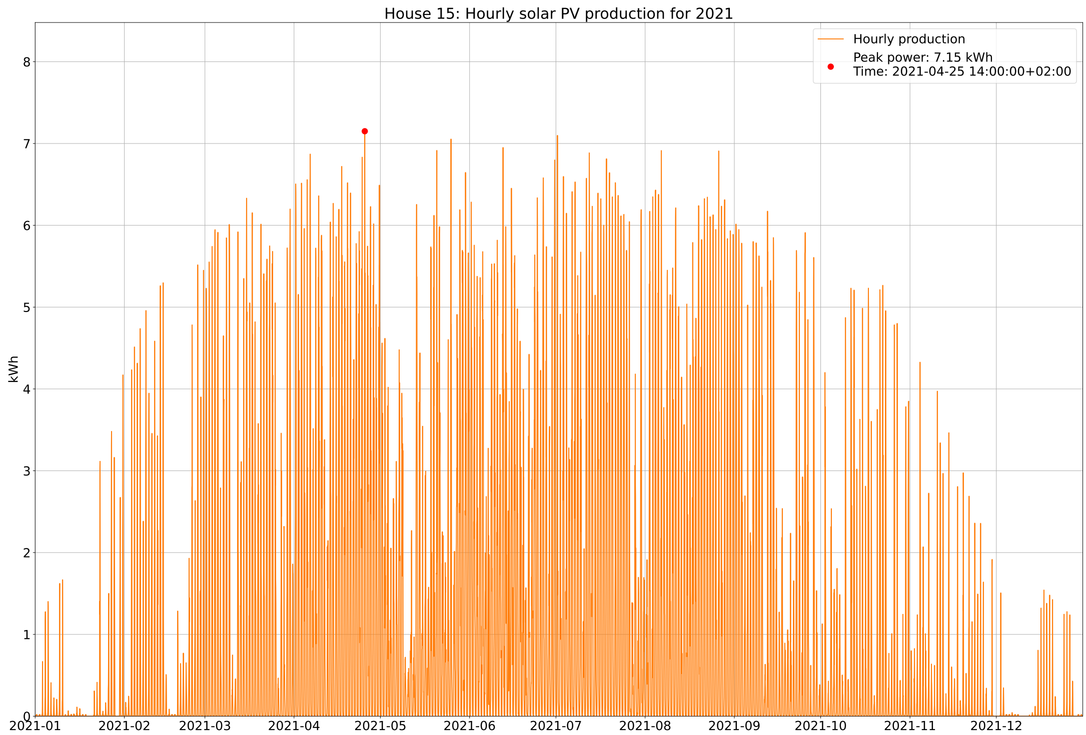



Figure A.325: Hourly PV production for House 15 in 2021.

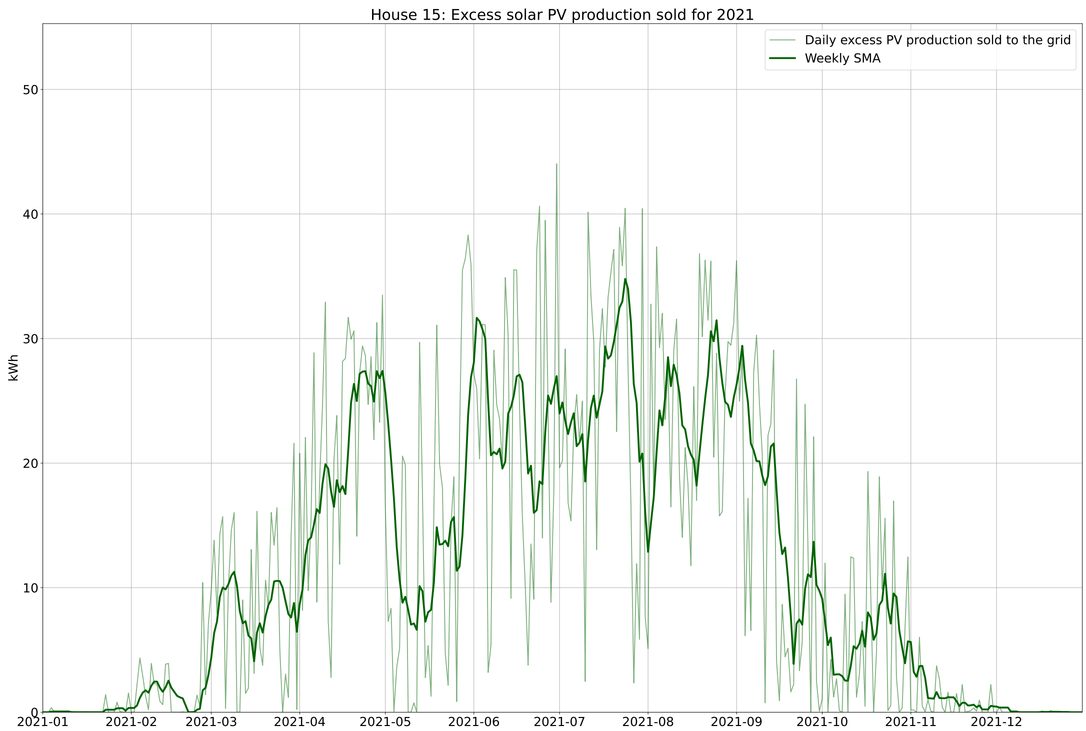



Figure A.326: Daily excess PV production sold to the grid and weekly SMA for House 15 in 2021

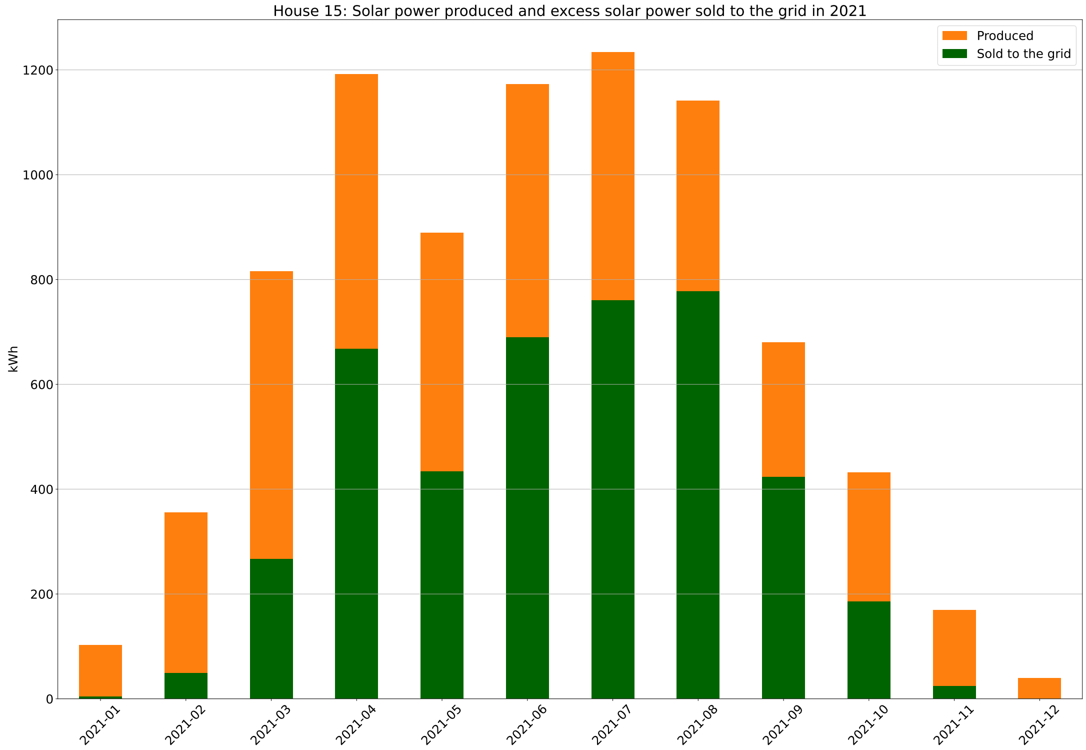



Figure A.327: Total solar PV production and excess production sold to the grid for each month in 2021 from House 15.

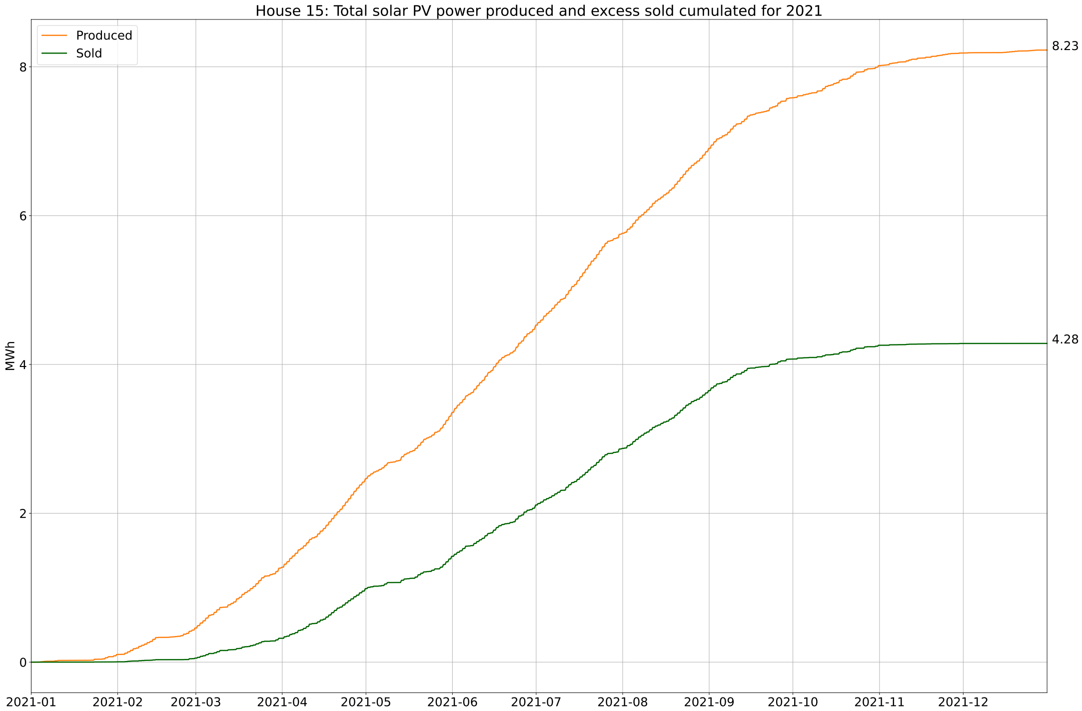



Figure A.328: Total solar PV production and excess production sold cumulated over 2021 from House 15

### A.15.3 Delta variable

#### 2020

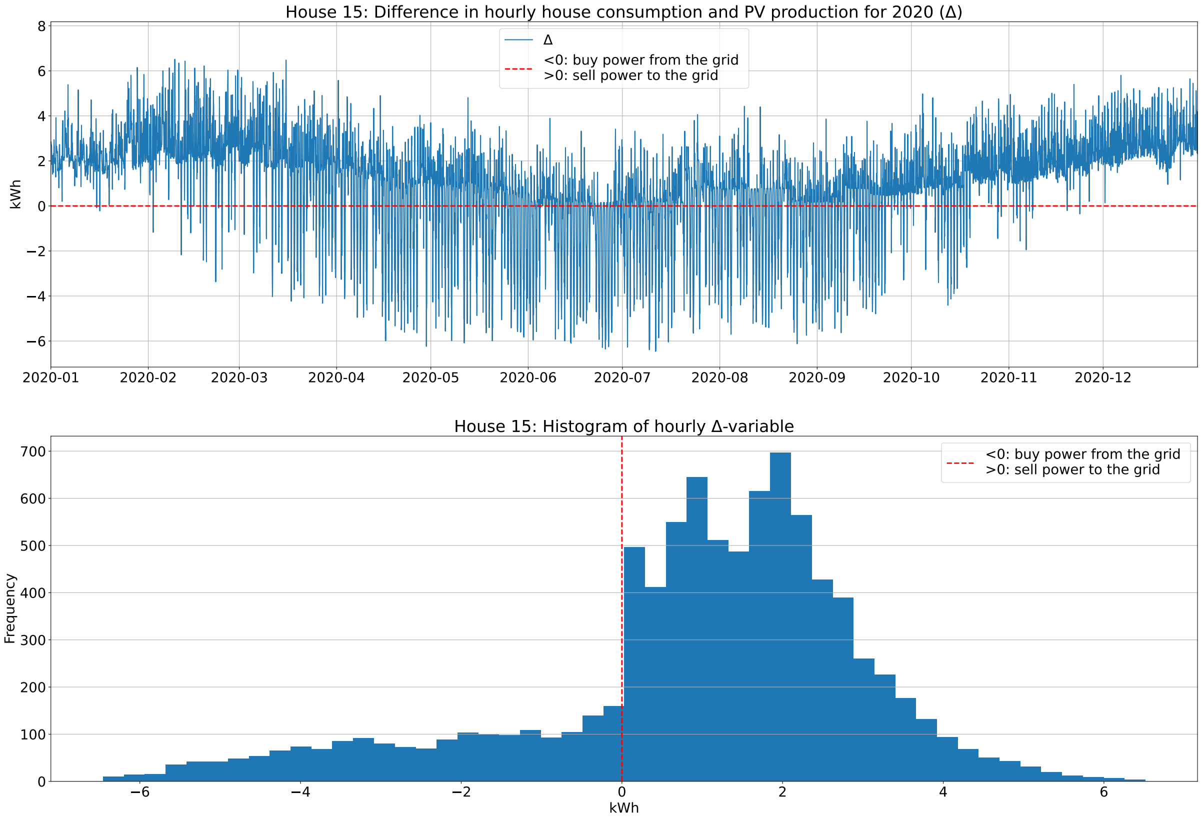
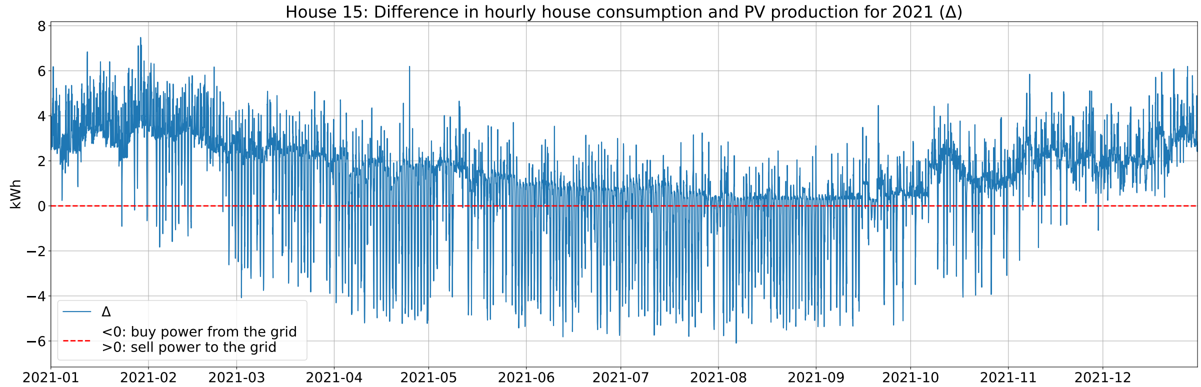



Figure A.329: The delta variable plotted for House 15. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**



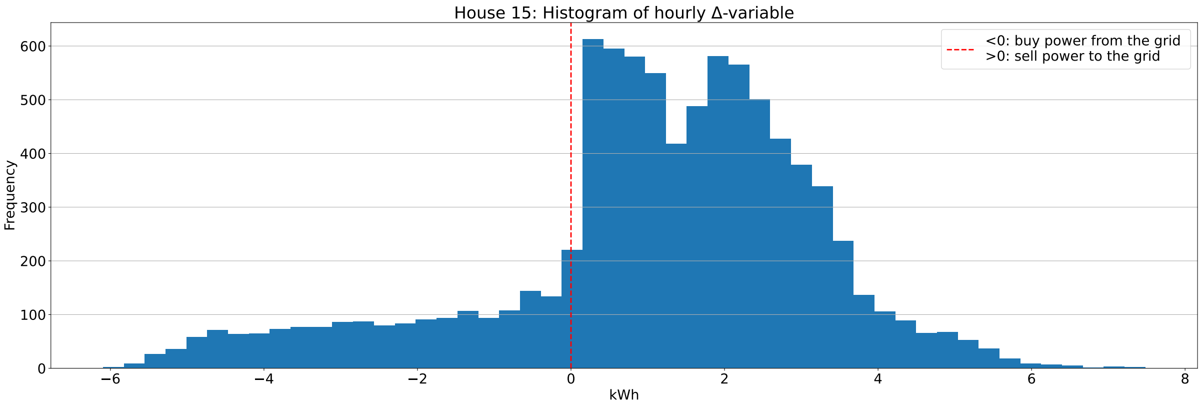




Figure A.330: The delta variable plotted for House 15. It shows the difference in house consumption and PV production at every hour, to give a better visualization of when the residence produce more power through their PV system than their house consumes. Where the red dotted line represents the energy equilibrium of the consumption in the residence. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

### A.15.4 House consumption and PV production

#### 2020

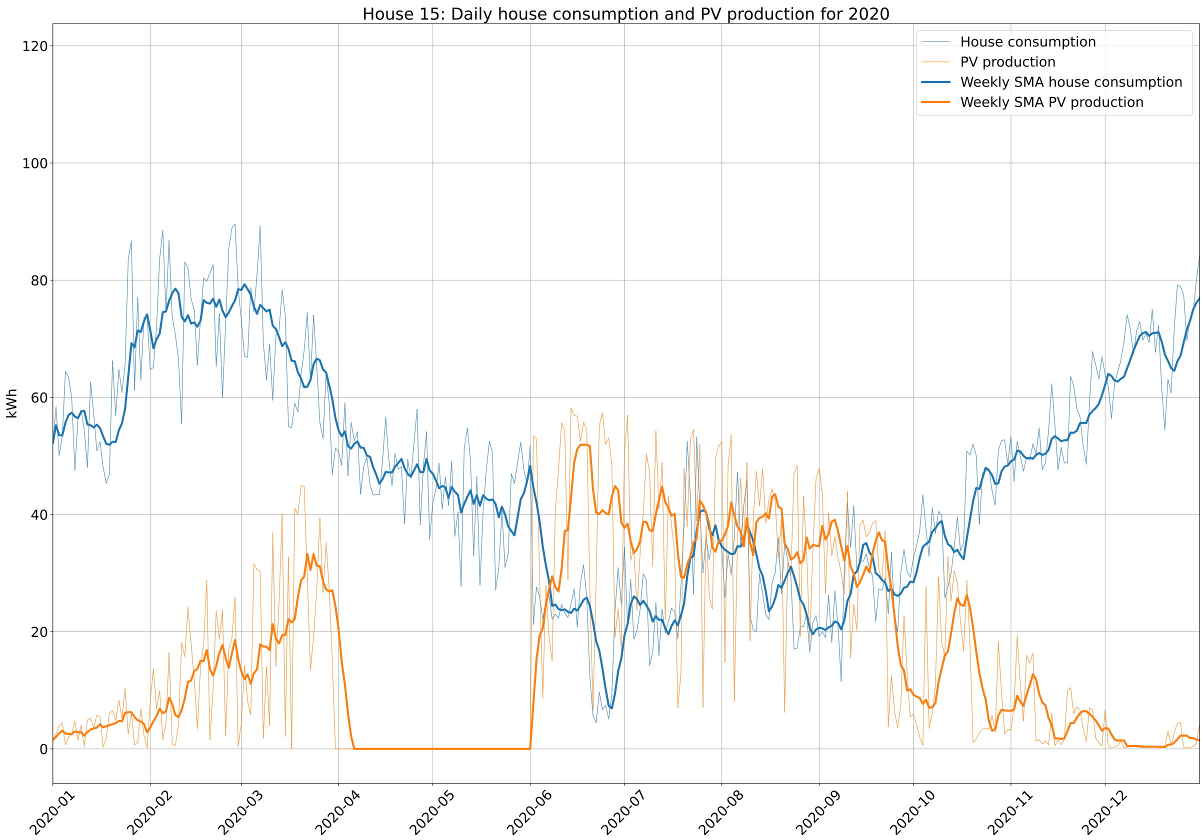



Figure A.331: House consumption simulated without PV system present and PV production for 2020 plotted against each other. Data in daily values and weekly SMA values.

**2021**

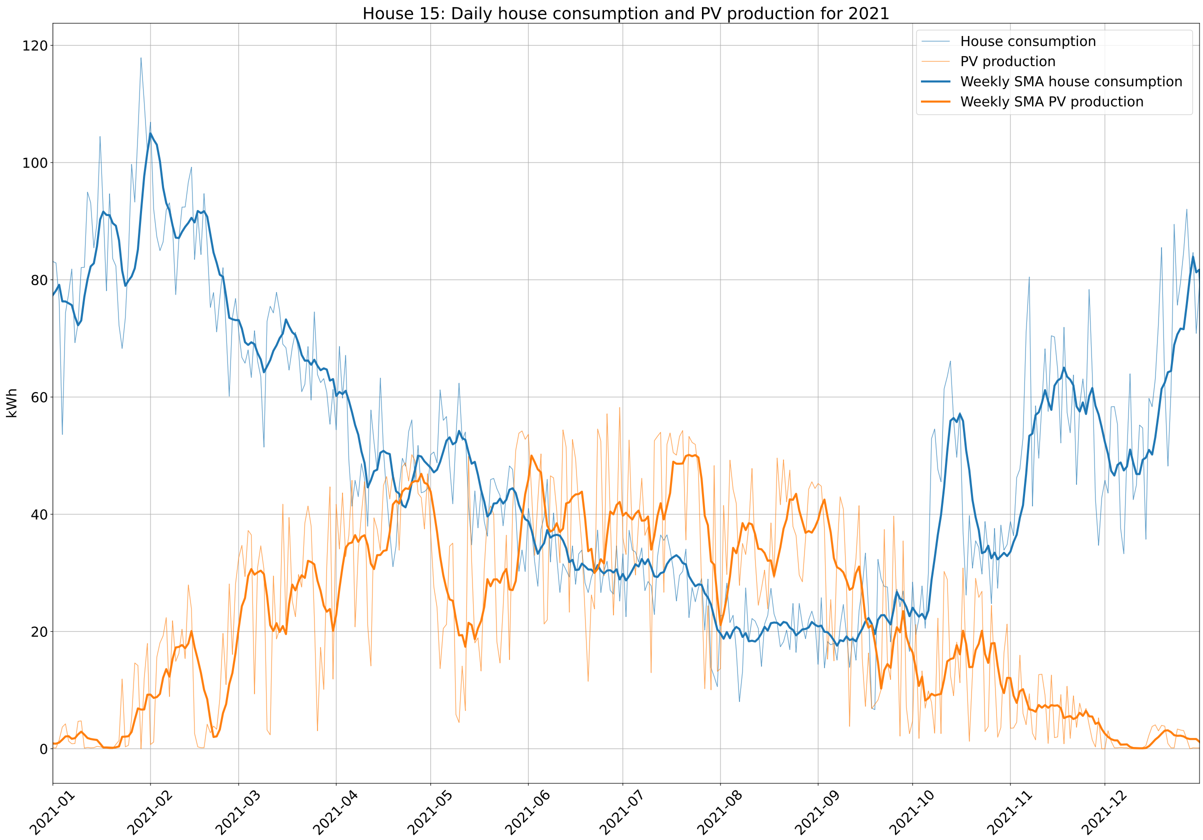



Figure A.332: House consumption simulated without PV system present and PV production for 2021 plotted against each other. Data in daily values and weekly SMA values.

### A.15.5 Cost of energy

#### 2020

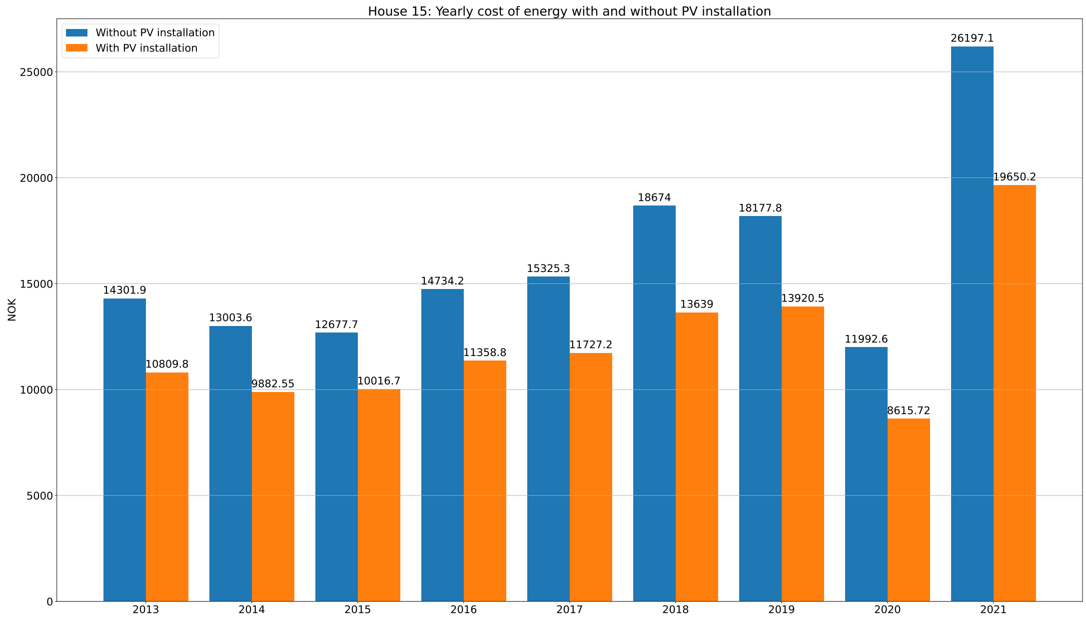



Figure A.333: Yearly cost of energy for House 15, based on the house consumption and PV production data from 2020, with and without a PV system present 2013-2021.

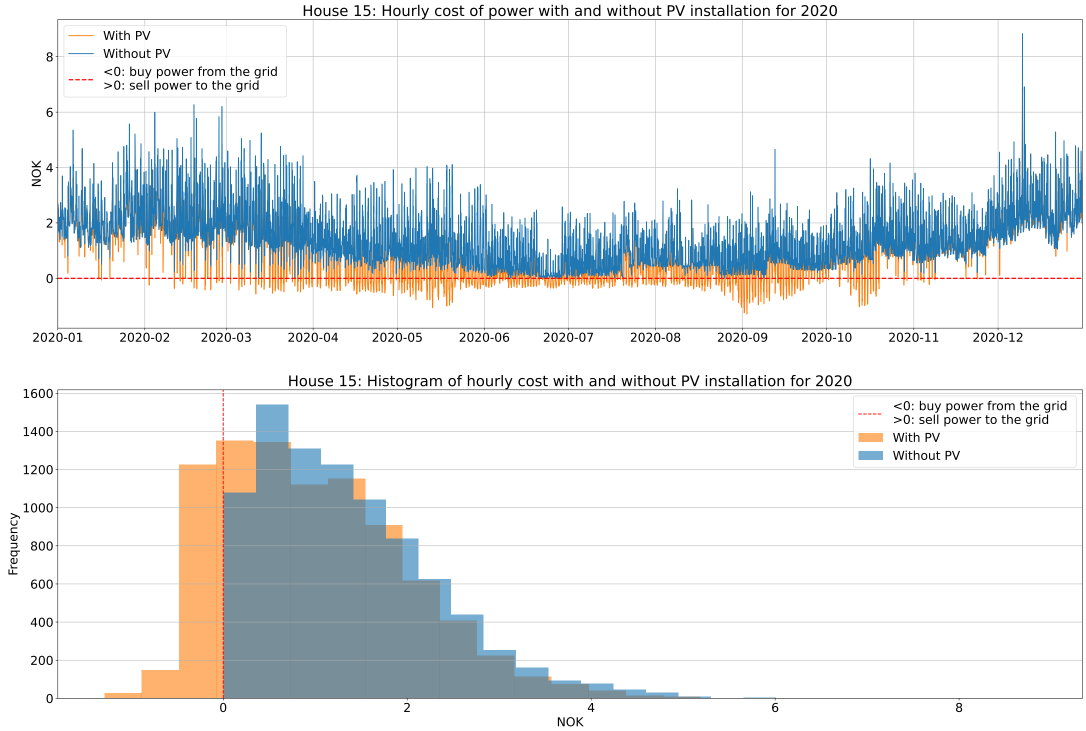



Figure A.334: Hourly cost of energy for House 15 with and without a PV system present for 2020. NB! Due to an small error the "<" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

**2021**

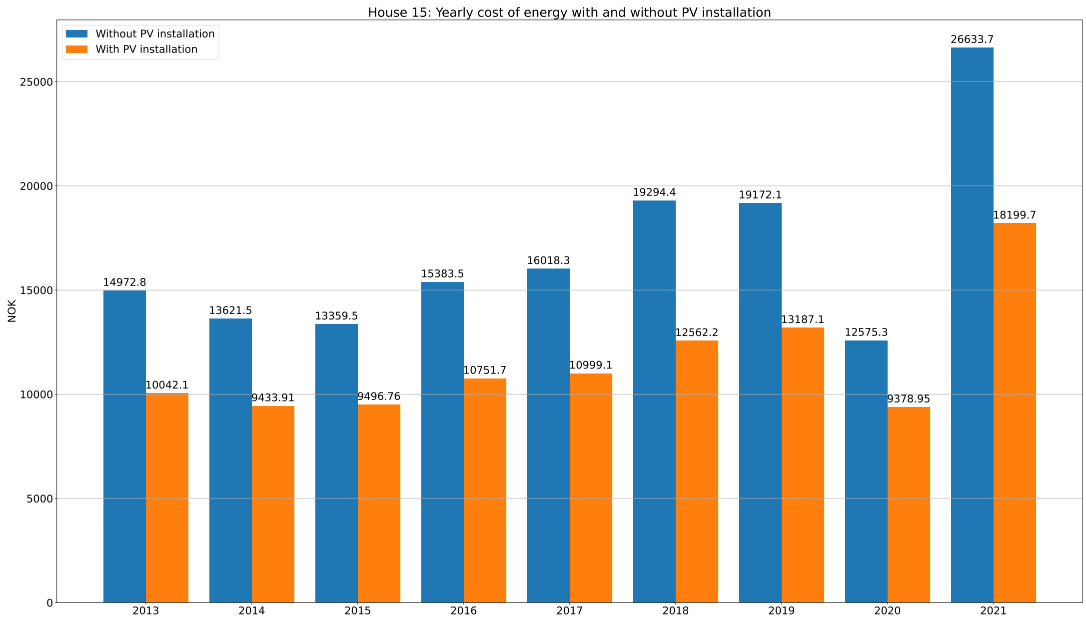



Figure A.335: Yearly cost of energy for House 15, based on the house consumption and PV production data from 2021, with and without a PV system present 2013-2021.

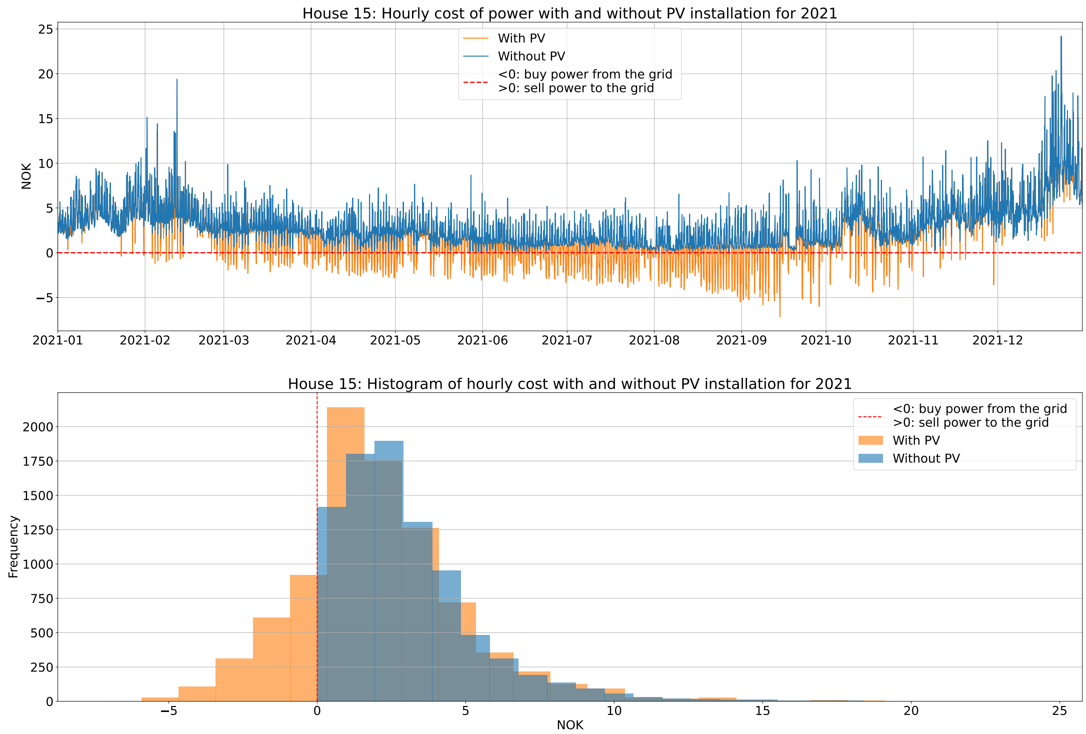



Figure A.336: Hourly cost of energy for House 15 with and without a PV system present for 2021. NB! Due to an small error the "$<$" sign is reversed in both plots, it should say that you buy power when $> 0$ and sell when $< 0$.

# Appendix B

# Tables

## B.1 House 1

### B.1.1 Yearly cost of power

Table B.1: Yearly cost of power for House 1, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 1 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 33 817 | 32 601 | 27 293 | 26 604 | 6524 | 5998 |
| **2014** | 30 686 | 29 676 | 25 126 | 24 559 | 5561 | 5117 |
| **2015** | 29 811 | 28 792 | 24 623 | 24 073 | 5188 | 4719 |
| **2016** | 34 876 | 33 588 | 28 598 | 27 847 | 6278 | 5742 |
| **2017** | 36 214 | 34 904 | 29 467 | 28 733 | 6747 | 6171 |
| **2018** | 44 008 | 42 356 | 35 174 | 34 116 | 8833 | 8239 |
| **2019** | 42 808 | 41 361 | 34 924 | 34 168 | 7885 | 7194 |
| **2020** | 28 276 | 27 226 | 23 808 | 23 204 | 4468 | 4022 |
| **2021** | 61 379 | 59 460 | 50 794 | 49 709 | 10 584 | 9751 |
| **Avg.** | **37 986** | **36 663** | **31 090** | **30 335** | **6896** | **6328** |

## B.2 House 2

### B.2.1 Yearly cost of power

Table B.2: Yearly cost of power for House 2, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 2 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 21858.77 | 17349.45 | 18105.03 | 13540.86 | 3753.74 | 3808.59 |
| **2014** | 19780.22 | 15807.64 | 16511.28 | 12506.14 | 3268.94 | 3301.5 |
| **2015** | 19129.3 | 15394.65 | 16031.47 | 12279.8 | 3097.83 | 3114.85 |
| **2016** | 22200.82 | 17508.45 | 18501.37 | 13833.04 | 3699.45 | 3675.41 |
| **2017** | 23388.88 | 18587.85 | 19448.89 | 14630.0 | 3939.99 | 3957.85 |
| **2018** | 28540.87 | 22394.09 | 23513.43 | 17315.43 | 5027.44 | 5078.66 |
| **2019** | 27525.43 | 22121.48 | 22966.05 | 17459.72 | 4559.38 | 4661.76 |
| **2020** | 15182.78 | 11881.79 | 17981.59 | 14592.64 | 2798.81 | 2710.85 |
| **2021** | 39187.34 | 31033.29 | 32994.52 | 24478.04 | 6192.82 | 6555.25 |
| **Avg.** | **24399.25** | **19421.06** | **20361.65** | **15324.98** | **4037.6** | **4096.08** |

## B.3 House 3

### B.3.1 Yearly cost of power

Table B.3: Yearly cost of power for House 3, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 3 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | N/A | 14781.45 | N/A | 10840.39 | N/A | 3941.06 |
| **2014** | N/A | 13536.36 | N/A | 10177.87 | N/A | 3358.49 |
| **2015** | N/A | 13284.28 | N/A | 10220.12 | N/A | 3064.16 |
| **2016** | N/A | 15157.4 | N/A | 11431.95 | N/A | 3725.45 |
| **2017** | N/A | 15849.5 | N/A | 11824.22 | N/A | 4025.28 |
| **2018** | N/A | 18868.09 | N/A | 13479.7 | N/A | 5388.39 |
| **2019** | N/A | 19129.01 | N/A | 14370.3 | N/A | 4758.71 |
| **2020** | N/A | 12628.18 | N/A | 10071.0 | N/A | 2557.18 |
| **2021** | N/A | 26255.27 | N/A | 18941.88 | N/A | 7313.39 |
| **Avg.** | **N/A** | **16609.95** | **N/A** | **12373.05** | **N/A** | **4236.9** |

# B.4 House 4

## B.4.1 Yearly cost of power

Table B.4: Yearly cost of power for House 4, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 4 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 18248.86 | 21538.62 | 16232.66 | 19676.15 | 2016.2 | 1862.47 |
| **2014** | 16690.73 | 19801.94 | 14952.26 | 18202.26 | 1738.47 | 1599.68 |
| **2015** | 16255.23 | 19338.4 | 14599.74 | 17824.1 | 1655.49 | 1514.3 |
| **2016** | 19076.85 | 22355.45 | 17107.43 | 20547.56 | 1969.42 | 1807.89 |
| **2017** | 19651.82 | 23202.51 | 17547.04 | 21268.01 | 2104.78 | 1934.5 |
| **2018** | 23850.53 | 27869.74 | 21157.81 | 25361.35 | 2692.72 | 2508.39 |
| **2019** | 23272.07 | 27691.59 | 20835.25 | 25449.26 | 2436.82 | 2242.33 |
| **2020** | 15621.12 | 18449.95 | 14082.32 | 17134.05 | 1538.8 | 1315.9 |
| **2021** | 34841.7 | 41189.31 | 31642.73 | 38045.85 | 3198.97 | 3143.46 |
| **Avg.** | **18684.14** | **24604.17** | **20834.32** | **22612.07** | **2150.19** | **1992.1** |

# B.5 House 5

## B.5.1 Yearly cost of power

Table B.5: Yearly cost of power for House 5, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 5 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | N/A | 35964.22 | N/A | 32269.13 | N/A | 3695.09 |
| **2014** | N/A | 32816.8 | N/A | 29605.77 | N/A | 3211.03 |
| **2015** | N/A | 31396.92 | N/A | 28353.02 | N/A | 3043.9 |
| **2016** | N/A | 37042.89 | N/A | 33394.28 | N/A | 3648.61 |
| **2017** | N/A | 38637.55 | N/A | 34763.6 | N/A | 3873.95 |
| **2018** | N/A | 47279.87 | N/A | 42278.29 | N/A | 5001.58 |
| **2019** | N/A | 45406.4 | N/A | 40952.87 | N/A | 4453.53 |
| **2020** | N/A | 29665.11 | N/A | 26959.69 | N/A | 2705.42 |
| **2021** | N/A | 64552.14 | N/A | 58712.99 | N/A | 5839.15 |
| **Avg.** | **N/A** | **40306.88** | **N/A** | **36365.52** | **N/A** | **3941.36** |

# B.6 House 6

## B.6.1 Yearly cost of power

Table B.6: Yearly cost of power for House 6, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 6 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 18605.33 | 17678.85 | 13065.71 | 12353.25 | 5539.62 | 5325.6 |
| **2014** | 16977.87 | 16120.39 | 12252.39 | 11596.28 | 4725.48 | 4524.11 |
| **2015** | 16451.5 | 15712.85 | 12073.92 | 11528.68 | 4377.58 | 4184.17 |
| **2016** | 19233.55 | 18120.96 | 13945.24 | 13072.75 | 5288.31 | 5048.21 |
| **2017** | 20048.8 | 18963.89 | 14357.76 | 13516.07 | 5691.04 | 5447.82 |
| **2018** | 24519.93 | 22910.2 | 17027.03 | 15647.8 | 7492.9 | 7262.4 |
| **2019** | 23515.57 | 22558.05 | 16772.17 | 16112.87 | 6743.4 | 6445.18 |
| **2020** | 15540.21 | 14842.27 | 11696.04 | 11333.31 | 3844.17 | 3508.96 |
| **2021** | 34935.59 | 31278.29 | 25669.49 | 21912.32 | 9266.1 | 9365.97 |
| **Avg.** | **21092.04** | | **15206.64** | | **5885.4** | |

# B.7 House 7

## B.7.1 Yearly cost of power

Table B.7: Yearly cost of power for House 7, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 7 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 18474.32 | 19641.87 | 12033.76 | 13486.62 | 6440.56 | 6155.25 |
| **2014** | 16806.71 | 17951.59 | 11353.01 | 12755.18 | 5453.7 | 5196.41 |
| **2015** | 16244.81 | 17351.02 | 11232.24 | 12599.4 | 5012.57 | 4751.62 |
| **2016** | 19152.9 | 20284.69 | 13050.88 | 14460.24 | 6102.02 | 5824.45 |
| **2017** | 19824.15 | 21075.77 | 13254.9 | 14799.15 | 6569.25 | 6276.62 |
| **2018** | 24215.76 | 25592.49 | 15482.73 | 17117.94 | 8733.03 | 8474.55 |
| **2019** | 23334.52 | 24976.43 | 15520.91 | 17580.57 | 7813.61 | 7395.86 |
| **2020** | 15440.36 | 16454.04 | 11130.21 | 12520.4 | 4310.15 | 3933.64 |
| **2021** | 34226.38 | 35803.81 | 23395.28 | 25002.05 | 10831.1 | 10801.76 |
| **Avg.** | **20857.77** | **22125.75** | **14050.44** | **15591.28** | **6807.33** | **6534.46** |

# B.8 House 8

## B.8.1 Yearly cost of power

Table B.8: Yearly cost of power for House 8, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| | | | **House 8** | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 15129.95 | 15224.53 | 7124.9 | 7382.0 | 8005.05 | 7842.53 |
| **2014** | 13698.39 | 13803.19 | 7013.9 | 7235.84 | 6684.49 | 6567.35 |
| **2015** | 13360.62 | 13298.57 | 7225.87 | 7307.79 | 6134.75 | 5990.78 |
| **2016** | 15585.9 | 15513.93 | 8136.16 | 8238.23 | 7449.74 | 7275.7 |
| **2017** | 16196.9 | 16243.08 | 8120.35 | 8325.24 | 8076.55 | 7917.84 |
| **2018** | 19733.05 | 19873.77 | 8884.42 | 9102.83 | 10848.63 | 10770.94 |
| **2019** | 19131.65 | 19243.99 | 9416.55 | 9747.16 | 9715.1 | 9496.83 |
| **2020** | 12568.87 | 12559.88 | 7115.41 | 7712.85 | 5453.46 | 4847.03 |
| **2021** | 27086.22 | 26766.89 | 13388.81 | 11596.73 | 13697.41 | 15170.16 |
| **Avg.** | **16943.51** | **16947.54** | **8491.82** | **8516.52** | **8451.69** | **8431.02** |

# B.9 House 9

## B.9.1 Yearly cost of power

Table B.9: Yearly cost of power for House 9, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| | | | **House** | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 22524.13 | 19886.26 | 18123.52 | 13557.88 | 4400.61 | 6328.38 |
| **2014** | 20360.92 | 17919.97 | 16455.05 | 12436.6 | 3905.87 | 5483.37 |
| **2015** | 19577.68 | 17417.79 | 15985.48 | 12249.52 | 3592.2 | 5168.27 |
| **2016** | 22757.65 | 19924.89 | 18435.63 | 13797.38 | 4322.02 | 6127.51 |
| **2017** | 24055.34 | 21191.73 | 19407.07 | 14570.77 | 4648.27 | 6620.96 |
| **2018** | 29372.58 | 25698.54 | 23417.33 | 17223.78 | 5955.25 | 8474.76 |
| **2019** | 28250.85 | 25117.68 | 22908.98 | 17416.7 | 5341.87 | 7700.98 |
| **2020** | 18429.86 | 16389.94 | 15161.26 | 11845.86 | 3268.6 | 4544.08 |
| **2021** | 40427.65 | 34868.71 | 32914.37 | 24529.8 | 7513.28 | 10338.91 |
| **Avg.** | **25084.07** | **22046.17** | **20312.08** | **15292.03** | **4772.0** | **6754.14** |

## B.10 House 10

### B.10.1 Yearly cost of power

Table B.10: Yearly cost of power for House 10, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 10 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 24849.28 | 29823.48 | 21253.4 | 25405.82 | 3595.88 | 4417.66 |
| **2014** | 22715.78 | 27124.58 | 19610.38 | 23359.47 | 3105.4 | 3765.11 |
| **2015** | 21918.13 | 26376.31 | 19083.98 | 22858.04 | 2834.15 | 3518.27 |
| **2016** | 25793.99 | 30877.68 | 22320.96 | 26639.14 | 3473.03 | 4238.54 |
| **2017** | 26742.79 | 32044.28 | 23011.55 | 27490.53 | 3731.24 | 4553.75 |
| **2018** | 32561.98 | 38758.8 | 27601.78 | 32748.53 | 4960.2 | 6010.27 |
| **2019** | 31406.16 | 37757.78 | 27065.22 | 32421.08 | 4340.94 | 5336.7 |
| **2020** | 20818.18 | 24806.11 | 17988.6 | 21798.66 | 2829.58 | 3007.45 |
| **2021** | 46092.3 | 53922.09 | 39960.73 | 46484.28 | 6131.57 | 7437.81 |
| **Avg.** | **28099.84** | **33499.01** | **24210.73** | **28800.62** | **3889.11** | **4698.4** |

## B.11 House 11

### B.11.1 Yearly cost of power

Table B.11: Yearly cost of power for House 11, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 11 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 26098.24 | 27071.89 | 20794.87 | 22139.16 | 5303.37 | 4932.73 |
| **2014** | 23805.52 | 24717.19 | 19266.86 | 20498.99 | 4538.66 | 4218.2 |
| **2015** | 22950.25 | 23966.28 | 18733.29 | 20050.48 | 4216.96 | 3915.8 |
| **2016** | 26921.9 | 27878.98 | 21833.0 | 23166.38 | 5088.9 | 4712.6 |
| **2017** | 28033.06 | 29105.22 | 22569.72 | 24031.92 | 5463.34 | 5073.3 |
| **2018** | 34123.63 | 35174.22 | 26959.12 | 28451.16 | 7164.51 | 6723.06 |
| **2019** | 33039.16 | 34443.46 | 26586.07 | 28480.11 | 6453.09 | 5963.35 |
| **2020** | 21871.74 | 22713.67 | 18101.79 | 19390.79 | 3769.95 | 3322.88 |
| **2021** | 47527.45 | 49333.77 | 38722.21 | 40367.32 | 8805.24 | 8966.45 |
| **Avg.** | **29374.55** | **30489.41** | **23729.66** | **25175.15** | **5644.89** | **5314.26** |

# B.12 House 12

## B.12.1 Yearly cost of power

Table B.12: Yearly cost of power for House 12, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 12 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 17558.63 | 15851.99 | 14641.39 | 12736.69 | 2917.24 | 3115.3 |
| **2014** | 15905.12 | 14446.68 | 13375.13 | 11749.11 | 2529.99 | 2697.57 |
| **2015** | 15533.5 | 14082.35 | 13187.53 | 11586.84 | 2345.97 | 2495.51 |
| **2016** | 17826.21 | 16002.69 | 14960.18 | 12980.88 | 2866.03 | 3021.81 |
| **2017** | 18782.23 | 16990.33 | 15724.34 | 13759.71 | 3057.89 | 3230.62 |
| **2018** | 22770.34 | 20487.77 | 18771.46 | 16241.05 | 3998.88 | 4246.72 |
| **2019** | 22248.11 | 20290.08 | 18673.3 | 16494.48 | 3574.81 | 3795.6 |
| **2020** | 14569.52 | 13276.48 | 12352.32 | 11114.36 | 2217.2 | 2162.12 |
| **2021** | 31051.49 | 28191.61 | 26139.29 | 22646.24 | 4912.2 | 5545.37 |
| **Avg.** | **19582.79** | **17735.55** | **16424.99** | **14367.71** | **3157.8** | **3367.85** |

# B.13 House 13

## B.13.1 Yearly cost of power

Table B.13: Yearly cost of power for House 13, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 13 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 16330.44 | 17128.11 | 14282.28 | 15266.31 | 2048.16 | 1861.8 |
| **2014** | 14953.49 | 15582.36 | 13171.43 | 13954.66 | 1782.06 | 1627.7 |
| **2015** | 14433.78 | 15173.76 | 12728.03 | 13623.91 | 1705.75 | 1549.85 |
| **2016** | 16816.29 | 17446.18 | 14804.86 | 15620.26 | 2011.43 | 1825.92 |
| **2017** | 17577.69 | 18377.13 | 15433.39 | 16425.48 | 2144.3 | 1951.65 |
| **2018** | 21417.02 | 22205.37 | 18697.19 | 19717.33 | 2719.83 | 2488.04 |
| **2019** | 20765.64 | 21755.83 | 18270.81 | 19487.69 | 2494.83 | 2268.14 |
| **2020** | 13726.99 | 14308.65 | 12201.97 | 12925.75 | 1525.02 | 1382.9 |
| **2021** | 30753.17 | 31528.06 | 27402.14 | 28482.82 | 3351.03 | 3045.24 |
| **Avg.** | **18530.5** | **19278.38** | **16332.46** | **17278.25** | **2198.05** | **2000.14** |

# B.14 House 14

## B.14.1 Yearly cost of power

Table B.14: Yearly cost of power for House 14, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 14 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 21812.05 | 24679.1 | 17698.57 | 20624.16 | 4113.48 | 4054.94 |
| **2014** | 19893.8 | 22459.51 | 16366.22 | 18972.85 | 3527.58 | 3486.66 |
| **2015** | 19360.28 | 21875.15 | 16037.37 | 18581.93 | 3322.91 | 3293.22 |
| **2016** | 22561.91 | 25375.71 | 18593.66 | 21454.94 | 3968.25 | 3920.77 |
| **2017** | 23422.15 | 26430.09 | 19161.83 | 22225.99 | 4260.32 | 4204.1 |
| **2018** | 28307.21 | 31999.86 | 22798.39 | 26535.46 | 5508.82 | 5464.4 |
| **2019** | 27653.45 | 31373.34 | 22673.43 | 26485.0 | 4980.02 | 4888.34 |
| **2020** | 18395.64 | 20661.58 | 15432.67 | 17789.75 | 2962.97 | 2871.83 |
| **2021** | 40629.87 | 45062.42 | 33919.02 | 38360.33 | 6710.85 | 6702.09 |
| **Avg.** | **24670.71** | **27768.53** | **20297.91** | **23447.82** | **4372.8** | **4320.71** |

# B.15 House 15

## B.15.1 Yearly cost of power

Table B.15: Yearly cost of power for House 15, with and without the presence of a PV system, based on the house consumption and PV production data from 2020 and 2021. Each year of collected data from the residence is used to calculate the simulated cost for the years 2013-2021 based on the energy spot price for the given year.

| House 15 | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Cost without PV (NOK)** | | **Cost with PV (NOK)** | | **Gain (NOK** | |
| | **2020** | **2021** | **2020** | **2021** | **2020** | **2021** |
| **2013** | 14301.9 | 14972.76 | 10809.84 | 10042.1 | 3492.06 | 4930.66 |
| **2014** | 13003.6 | 13621.53 | 9882.55 | 9433.91 | 3121.05 | 4187.62 |
| **2015** | 12677.73 | 13359.52 | 10016.71 | 9496.76 | 2661.02 | 3862.76 |
| **2016** | 14734.17 | 15383.53 | 11358.77 | 10751.74 | 3375.4 | 4631.79 |
| **2017** | 15325.34 | 16018.3 | 11727.18 | 10999.1 | 3598.16 | 5019.2 |
| **2018** | 18673.99 | 19294.39 | 13639.02 | 12562.18 | 5034.97 | 6732.21 |
| **2019** | 18177.81 | 19172.14 | 13920.55 | 13187.14 | 4257.26 | 5985.0 |
| **2020** | 11992.56 | 12575.27 | 8615.72 | 9378.95 | 3376.84 | 3196.32 |
| **2021** | 26197.12 | 26633.69 | 19650.18 | 18199.71 | 6546.94 | 8433.98 |
| **Avg.** | **16120.47** | **16781.24** | **12180.06** | **11561.29** | **3940.41** | **5219.95** |

# Appendix C

# Specialization project

# The value of having solar PV Modules in Norway: a case study

TTK4551 Engineering Cybernetics, Specialization Project


*Alexander Berglind*

supervised by
Prof. Sebastien Gros



Department of Engineering Cybernetics
Faculty of Information Technology and Electrical Engineering
Norwegian University of Science and Technology (NTNU)


December 14, 2021

# Preface

This report is the product of Alexander Berglind´s specialization project estimated to 7.5 credits. Submission and completion of the project is part of the mandatory tasks for completion of the master´s degree in Industrial Cybernetics at the Norwegian University of Science and Technology (NTNU).

The project assignment is provided by NTNU with the goal of serving as grounds for a master thesis.

The targeted audience is students with knowledge within cybernetics, electronics and specialists represented as supervisors and industry representatives.

A special thanks to Sebastien Gros for good guidance and availability for any discussion and to Geir V. Berglind for access to the data the laid the basis for the project.

.............................................................. ..............................

Alexander Berglind
(Student at NTNU)

Date

# Abstract

This project assesses the value of a current PV installation on a house in Norway for the purpose of validating the profitability by using energy spot-data from the last eight years on the actual house consumption and PV production.

Solar energy is important because of the increasing demand of renewable energy in the future as a result of the green shift. In line with this transition, comes the ramification of higher electricity prices, since renewable energy is costly compared to fossil fuels. By installing solar panels, one can start to produce own energy and even accumulate a profit by selling the surplus back to the grid.

Electricity in today´s market has a negative impact on the environment, since most of Europe´s energy comes from fossil fuels. Producing own energy will help get a decline in emissions. However, installing solar panels is expensive and will take years before you start accumulating a revenue on the investment made.

To address this, I have analyzed data from a house in Norway with solar panels installed. I have compared the house consumption and PV production for 2020 against the spot-market. I found that this data linked to the spot-market for the past eight years, shows how connected they are for solar panels to be economically viable. The cheapest year (2020) reflected that it would take 39 years for the solar panels to be profitable and the most expensive year (2018) reflected 19 years. This means that to assess the value, one must predict the development in the spot-market for the future.

Future research should continue this analysis for multiple residence in various locations that have solar panels to more accurately conclude the hypothesis. It should also include an investment model of the panels to optimize the production profit compared to the size of the modules.

# Contents

# List of Figures

# List of Tables

# Acronyms

**AC** Alternating current. 11

**AM** Air mass. 11

**API** Application Programming Interface. 12, 13

**CET** Central European Time. 6

**CSV** Comma-Separated value. 13

**DC** Direct current. 11

**NOK** Norwegian Kroner. 7, 8, 14

**NTNU** Norges Tekniske- og Naturvitenskapelige Universitet. I, 1

**NVE** Norges vassdrags- og energidirektorat. 2

**PPPP** Public-priavte-people partnership. 3

**PV** Photovoltaics. 1

**SDAC** Single Day-Ahead Coupling. 6

**SMA** Simple Moving Average. V, 18, 21, 23, 26

**VAT** Value added tax. 7, 8, 14

# Chapter 1

# Introduction

## 1.1 Problem description

The problem that shall be addressed is formulated as collaboration between the teaching supervisor representing NTNU, prof. Sebastien Gros and the student technician that is carrying out the specialization project, Alexander Berglind.

### 1.1.1 Objective

The objective of the project is to assess the value of a solar PV installation on private residences in Norway with an unbiased view which is not economically motivated by selling solar PV installation. The project has been done as a case study of a house in Asker, Norway.

### 1.1.2 Research questions

These research questions are to highlight and give insight in what this project in the end will answer.

- What type of economical and environmental effect does a solar PV installation have?
- What type of effect does the variations in the Nord Pool power market have on a solar PV installation in Norway?
- How does the yearly production from the solar PV modules correlate with the estimations from the solar PV retailer, and what sources of error affects this?

### 1.1.3 Sub-tasks

The following sub-tasks are suggested and performed during the project:

- Collect necessary data to perform the analysis of the PV installation. Which consist of:
  - House consumption for the house
  - Solar PV production of the house
  - Spot market data from the last 10 years
- Familiarize and understand the data collected.
- Calculate and evaluate the profitability of the PV installation in Python, based on the data gathered

## 1.2 Background and motivation

In this section the background and motivation on why this project is of importance in today's society is presented. It will include the solar power situation in Norway today and how the development in the power market towards 2040 will be.

### 1.2.1 Solar power in Norway

Solar power is currently a small part of power production in Norway, but it is the power generation technology that has the greatest increase. According to date from The Norwegian Resources and Energy Directorate (NVE) the total solar power capacity in Norway was 160 MW at the end of 2020. In Figure 1.1 the development of solar power in Norway can be seen, where one can see that there has been an huge increase in the past seven years, mainly solar power connected to the Norwegian power grid. [1]

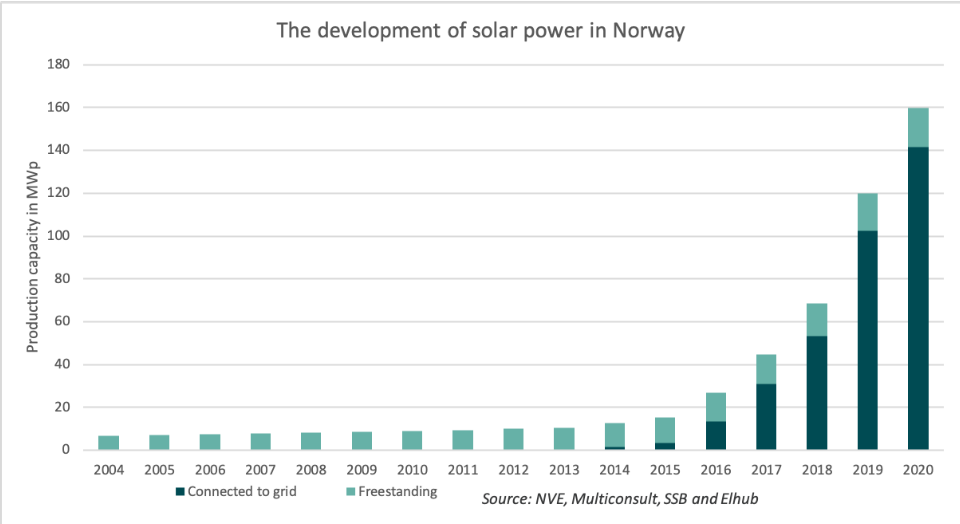



Figure 1.1: Development of solar power in Norway [1]

The potential for solar energy production rely on several different factors, with the most important being the amount of solar irradiance. In Figure 1.2 the potential for yearly production of solar power in different cities can be seen, given the amount of solar irradiance, air temperature and several other factors. While the solar irradiance is lower in Norway than it is in Central Europe, cooler air temperature help to reduce the loss in the PV system. This results in a potential for PV power production in Kristiansand and Oslo to be at the same level as cities in Germany, which is Europe´s largest market for PV power production.[2]

### 1.2.2 The power market

The development in the power market in Europe towards 2040 will in a large degree be driven by climate policy and technology advancement. A key part of the climate change involves replacing the production and use of fossil energy sources, with the production and use of renewable energy. A ramification of this is that conditions outside the power market will have a even greater impact on the power market, as many renewable energy sources are heavily dependent on weather conditions and the increasing price of $CO_2$ which is the result of the European Commission's decision to increase their emission targets [3]. The increase of the price of $CO_2$ causes a higher expense in the production of fossil energy. This contributes to higher energy prices in countries without fossil power production, through trade relations. [4]

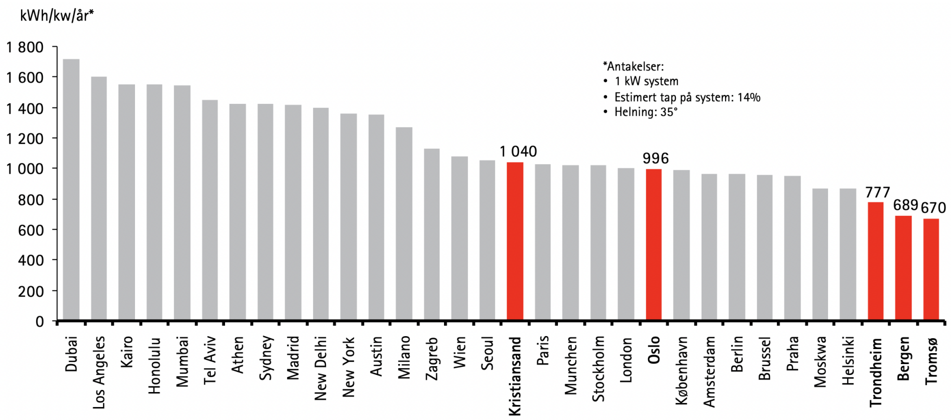



Figure 1.2: Potential for PV power production for chosen cities [2]

## 1.3 Review

Research and different case studies of solar energy in Norway has been done before, below are some examples and their main results.

- Xue et al. [5] proposed the reason for little use of solar power in Norway for private residence is the high initial costs of photovoltaics and the limited information and awareness of the possible benefits they have. They believe the main concern for the public sector is the low application of existing incentives, where they propose a model called Public-private-people partnership (PPPP) to overcome these barriers.
- Kjenstadbakk E. [6] does a case study of the effect of integrating a solar PV installation to a house cooperative in Trondheim, Risvollan. Where the main results show that with the current unit cost and grid electricity prices, the solar PV systems researched was not able to match the price of the grid electricity.
- Veie B. [7] thesis presents the results of a evaluation of real load data from industrial, commercial and residential sector and real solar power data from Trondheim to see if it is possible to reduce the strain on the grid in a cost effective manner. The key results show that there is a potential to both reduce peak load and to save money.

## 1.4 Scope and limitations

This project is done as a case study for a house in Asker, Norway, who had a solar PV installation installed in mid-2019. This results in the data for PV production used in the project to be limited for 2020 solely. The data for house consumption is also taken solely for 2020 to get a more stable and comparable result when comparing the dataset for the spot market from the last eight years.

This project is limited to a case study of one house because of the short time-frame of the project, the acute availability of resources and the limit of this project being 7.5 credits.

## 1.5 Structure of this report

This project report is divided into six chapters, excluding the introduction, followed by references. The second chapter will introduce the background for the project needed to comprehend the objectives and methodology of the project, which includes the set-up for the house in Asker, how the Nord Pool power market works, what and how Enova contributes to the solar power development and how the power consumption in Norway works. The third chapter will present relevant theory of solar PV power to give a in-depth understanding of the objectives of the project. The method used to gather the necessary data, the data processing and the calculations made are presented in chapter 4. Then the results of the project is presented in chapter 5 and thereafter a discussion of the results in chapter 6. The end of the report, chapter 7, concludes the report with a brief summary, conclusion and recommendations for further work.

# Chapter 2

# Background

In this chapter necessary background to understand where the different data used in the analyses originates from and how the data is presented. The house used in the case study is presented first, with what type of PV installation it has. Then the spot price is explained through presenting the Nord Pool power market. Then a section on the power consumption in Norway, where the power supplier and power company related to the case study is presented. Then different aid schemes for solar power in Norway and finally, the environmental impact energy has on society will be presented.

## 2.1 The house in Asker, Norway

This project is done as a case study that revolves around a house positioned in Asker, Norway which has solar panels installed on the roof of the house. The data from the house used in the study is the hourly house consumption and PV production for 2020.

### 2.1.1 The solar PV installation

The complete installation consist of 42 solar PV panels of the type Viridian Fusion PV16-300 300Wp Mono panel[8], 21 Solaredge P600 Optimizer[9] and one Solaredge SE17 10 kW three phase inverter[10], which are briefly explained in section 3.1. The solar PV installation in its whole can be seen in Figure 2.1. They cover a surface are of 78,3 m$^2$, having an azimuth of 163° (orientation South-East) and combined tilt of 38°. The installation was complete and working as of the summer of 2019.

Figure 2.1: The solar panel installation in Asker

## 2.2 Nord Pool

Nord Pool is a power market where the electricity prices for 16 European countries are decided. It is a market, called the day-ahead market, where customers trade in energy for the next 24 hours in a closed auction to decide the hourly spot-price for each zone. Figure 2.2 shows a map of the bidding zones for the Nord Pool power market [11], where Norway is normally divided into five bidding zones. This division is due to bottlenecks in the transmission systems, so the orders are matched to maximize the social welfare while network constraints provided by transmission system operators are taken into consideration.[12]

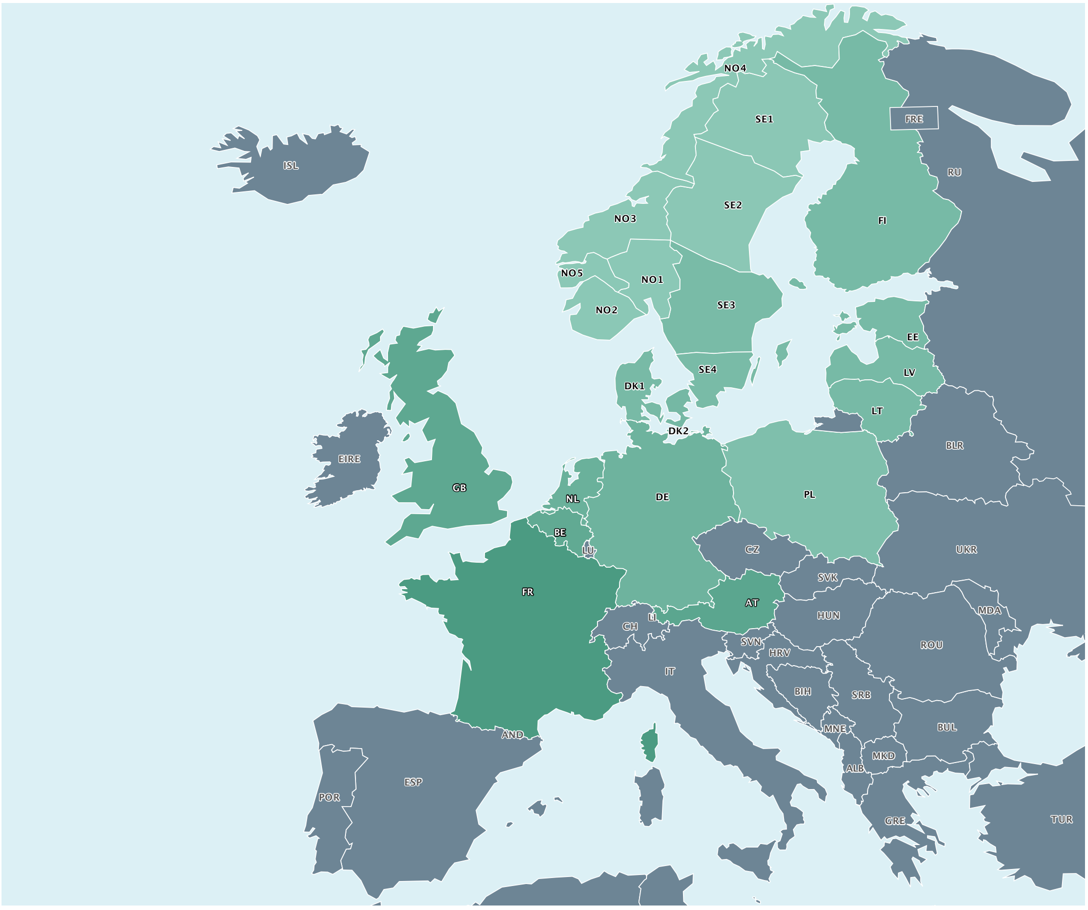



Figure 2.2: Map over Nord Pool power market bidding zones [11]

The way the day-ahead market works is that each day at 10:00 Central European Time (CET) the available capacities on the transmission lines between and within the bidding zones are published, where hourly prices for the next day are possible to bid on and the buyers and sellers have until 12:00 CET to finalize their bids. Then through a pan-European market coupling process called Single Day-Ahead Coupling (SDAC), each submitted order are then matched with other orders from the surrounding markets in Europe through an algorithm called Euphemia. The hourly prices are then typically announced to the market at 12:45 CET for the following day. [12]

### 2.2.1 Spot price

The spot-price from the power market depends mostly on supply and demand, where the main role of the market price is to establish an equilibrium between the two. But other factors may also have an impact on the price, such as weather or power plants having trouble producing to their full capacity. In Norway 2020 the average spot-price on the power market from Nord Pool was 116 Norwegian kroner (NOK) per megawatt hour (MWh). This is the lowest yearly price ever recorded on the power market. For the first six months of 2021 the average price was 429 NOK/MWh, while the average for the last ten years have been 278 NOK/MWh. The low prices was a result of good access to supply in combination with lower demand than usual. Heavy rain and snow in the mountains and good wind conditions gave record high power production. 2020 was in addition the warmest year ever recorded, meaning less heating. [13] So, by using Norway as an example, if the weather forecast predicts heavy rain for the following days, hydropower plants will expect a high power production leading to a high level of supply, this in return will often lead to low spot-prices. But, if it predicts low temperatures, consumers and suppliers will expect high demand, which in return often pushes the spot-price up. This model serves society well, where when the price of power goes up it also becomes clear where there are issues on the grid. Meaning it is easy to identify where production or capacity is lacking, since one can see where there is too high demand compared to production supply. [14]

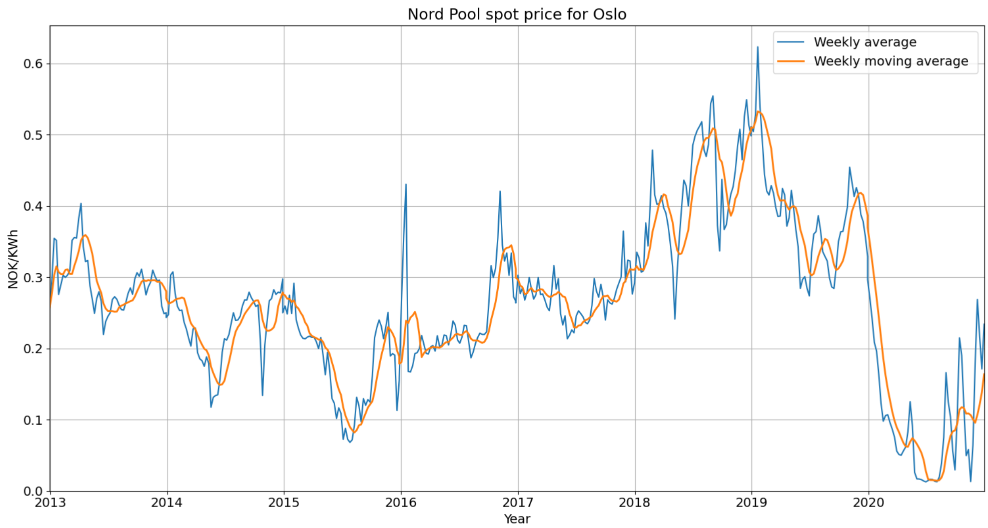



Figure 2.3: The Nord Pool spot market for Oslo 2013-2020

In Figure 2.3 the weekly average price from the Nord Pool spot market for Oslo can be seen. Here one can see that the spot price varies a great deal from year to year, where it is clear that 2020 had a substantially low price.

## 2.3 Power consumption in Norway

In Norway the electricity bill comprises of three different parts divided between the power company and power supplier. The first part is the power consumption, where the consumer pays for the electricity used during that time period. The second part is nettleie, where the consumer pays a fee based on the electricity consumption during that time period, which goes to operation and maintenance of the power grid the consumer is part of. The third part is government taxes, where the consumer pays for statutory fees that includes certificates. On top of both the power consumption and nettleie there is value added tax (VAT) from the Norwegian government. The first and third part comes from the power companies and the second part comes from the power supplier who owns the power grid. [15]

The choice of power company and power agreement is an unrestricted choice in Norway. Where consumers have a choice of having a fixed-, variable- or spot-based power agreement. The choice of power supplier is on the other hand a restricted choice, since power suppliers have monopoly on their respective areas. [15]

### 2.3.1 Elvia

Elvia is the power supplier for the Norwegian counties Viken, Innlandet and Oslo. It is a result of the merging of the two power suppliers Hafslund Nett and Eidsiva Nett. They are responsible for operation, maintenance and the development of the power grid for these counties. [16] Eliva is responsible for the nettleie part of the electricity bill, which also consists of three parts. The first part is a yearly fixed cost that pays for the consumers access to the power grid, it pays for the operation of the power grid. The second part is a variable cost linked to the consumers power consumption and is called ”energileddet”, where the consumer pays a small amount in rent of the power grid for each kWh used. The third part is statutory governmental fees, that consist of remittance to the energy fund Enova, electricity tax and VAT.[17]

### 2.3.2 Tibber

Tibber is a Norwegian power company offering only an hourly spot price agreement. This means that the spot price the consumer pays follows the market price from the Nord Pool power market, with a surcharge of maximum 1 øre/kWh to cover statutory fees, and (VAT). So, when the price of the power market decreases, the consumer pays less for power, and if it increases, the consumer pays more.[18]

Tibber is one of the power companies in Norway that helps consumers with solar panels on their home to sell the excess power produced back to the power grid. To do this, one must have solar panels on their house and an inverter to modify the data into usable data.[19]

## 2.4 Aid schemes for solar power in Norway

There are several different aid schemes in Norway to support investment in renewable energy sources. In this section, the schemes regarding solar panel installations are presented.

### 2.4.1 Enova

Enova is a state enterprise founded in 2001 to contribute to the reorganization of energy consumption and production, to help reduce greenhouse gas emissions and the development of energy and climate technology. Enova is meant to help businesses and private individuals to invest in the newest and most climate-friendly technologies, where Enova invest over NOK 3 Billion of public resources each year to these solutions.[20] Through the Enova Subsidy, support was given to 9115 projects in 2020, where electricity generation was the individual measure that received the most grants, with almost 18 percent of all the grants. The generation of electricity in households is mainly linked to installing solar PV modules to ones house.[21]

If a private individual decides to install solar PV modules on their house, through the Enova Subsidy, the installation itself will provide 7,500 NOK in support. The rest of the support will depend on how big of a capacity the installation have, where one will receive 1,250 NOK per kW installed effect, up to 15 kW. This results in a total maximum support of 26,250 NOK, as of today, for installing solar PV modules on ones house.[22]

### 2.4.2 Plusskunde at Elvia

When a consumer both uses and produces electricity, they can become something called "plusskunde". To become a plusskunde at Elvia, they demand that you cover part of your own energy consumption with self-produced power. The self-produced power can be sold back to the power company when one has en excess of power, as long as it does not exceed 100 kW at once. As a plusskunde the consumer does not pay nettleie for the power self-produced and sold back to the grid. As a plusskunde one also gets a subsidy for overproduction that affects the nettleie. The plusskunde gets 3,90 øre/kWh during the summer-period and 7 øre/kWh during the winter-period, as compensation for ease to the power grid.[23]

# Chapter 3

# Theory

## 3.1 The solar PV installation in Asker

In this section the theory of how the different components in the solar PV installation in Asker is presented. Only the theory relevant to the results will be presented here.

### 3.1.1 The solar panels: Viridian Fusion PV16-300 300Wp Mono panel

These solar panels are roof integrated, meaning they replace the tiles or slates on the roof so that the panels can sit lower down in the roofline to look more like an intended part of the house, see Figure 3.1. One of the benefits, compared to an on-roof system, include maintenance, since there are no tiles behind the panels that would need repairs. Another benefit is that if the house needs to replace the roof anyways, getting roof integrated panels eliminate the cost of the roof tiles or slates. [24]


Figure 3.1: Viridian Fusion PV16-300 300Wp Mono panel[8]

There are mechanical and electrical specifications that determine the effectiveness of the PV system, the most important ones to this project is now presented.

#### Dimensions

Each panel has an aperture area of 1.6 $m^2$, which is the area that receives the solar radiation, and is made up of 60 cells of the type mono-crystalline Silicon. [8]

#### Module Efficiency

The module efficiency of the panels are 19.2%, which expresses the percentage of the solar irradiation that the panel can transform into usable electricity at standard test conditions. The test conditions for this solar panel is solar irradiation of 1 kW/m$^2$, air mass (AM) coefficient of 1.5 and cell-temperature of 25°C. This shows that under these conditions this solar panel will produce a peak power of 300 W. [8]

### 3.1.2 Solaredge P600 Optimizer

The Solaredge P600 optimizer turn solar modules into smart modules. This means that it increase the energy output from the PV system by constantly track the maximum power point of each module individually. Which means that when the panels are in use the optimizer can directly tune the output of an individual panel to optimise the yield of the whole system. So, shading or manufacturing defects affecting one module will not bring down the output of the whole string, as it would with a string inverter.[25]

### 3.1.3 Solaredge SE17 10kW three phase inverter

The solar inverter converts the energy output from the solar panels into usable electricity. It takes in the variable direct current (DC) from the solar panels and transform it into usable alternating current (AC).[26]

# Chapter 4

# Method

In this chapter the methods used to achieve the results for this case study is presented. It includes what type of software was used, how the data was gathered and processed, and how the calculations was performed.

## 4.1 Software

The data gathering, calculations and illustrations made in this project are done with Python in Pycharm.

## 4.2 Data gathering

This section will present how and what type of data was gathered to achieve the results.

### 4.2.1 House consumption

The data for house consumption was gathered in two ways during the project, a python script which pulled historical data from Tibber and an excel-file from Elvia.

The reasons for retrieving the data in two ways was because of a technical issue in the beginning with the python script to pull data from Tibber. To communicate with Tibber a python3 library is needed, the issue arose because there are two versions of the library. The libraries are "Tibber" and "pyTibber", where the latter is the newest version of the two and with only that one installed the script would not run. So, to be able to run this script and retrieve the historical data, the library called "Tibber" version 0.16.0 was needed.

To use the script the application programming interface (API) key for the residence is needed to be able to communicate with the correct house. This API-key was easily redeemed by the resident of the house through the Tibber website. The historical data collected by the script was condensed into a pickle file, where the data contained the actual house consumption and cost.

Before the script was runnable a backup was needed to be able to obtain the data, this was done by contacting Elvia for the data. They sent over an excel-file containing the grid consumption for the house and the excess PV production sold back to the grid for 2020, both in kWh and with corresponding hourly timestamp, see Figure 4.1 for excerpt. The slight issue with the Elvia data was that it only contained the grid consumption data and not the actual house consumption data, which is explained further in section

4.3.2. This was an acceptable backup considering the goal for the case-study was limited to data solely for 2020, but for future work the script will be much more applicable eliminating the need to contact the power supplier to retrieve the data needed.

| | A | B | C |
|---|---|---|---|
| 1857 | 2020-03-18 07:00 | 4,42 | 0 |
| 1858 | 2020-03-18 08:00 | 1,29 | 0,84 |
| 1859 | 2020-03-18 09:00 | 0,89 | 1,08 |
| 1860 | 2020-03-18 10:00 | 0,35 | 1,12 |
| 1861 | 2020-03-18 11:00 | 3,05 | 0,01 |
| 1862 | 2020-03-18 12:00 | 1,4 | 0,24 |
| 1863 | 2020-03-18 13:00 | 0,68 | 0,72 |
| 1864 | 2020-03-18 14:00 | 0,2 | 0,98 |

Figure 4.1: Data from Elvia 2020. Column B is the grid consumption and column C is the excess PV production sold to the grid

### 4.2.2 Solar PV production

To get the solar PV production data the resident of the house set up a script that communicated with the Solaredge API and retrieved the hourly data comprised in a JSON-file which was then converted to a comma-separated value (CSV) file. The data contained an hourly timestamp and the solar energy in Wh produced during that hour, see Figure 4.2 for excerpt.

| | A | B | C | D |
|---|---|---|---|---|
| 1856 | 2020-03-18 07:00:00 | 278 | Wh | HOUR |
| 1857 | 2020-03-18 08:00:00 | 4179 | Wh | HOUR |
| 1858 | 2020-03-18 09:00:00 | 5726 | Wh | HOUR |
| 1859 | 2020-03-18 10:00:00 | 3235 | Wh | HOUR |
| 1860 | 2020-03-18 11:00:00 | 1302 | Wh | HOUR |
| 1861 | 2020-03-18 12:00:00 | 2289 | Wh | HOUR |
| 1862 | 2020-03-18 13:00:00 | 2548 | Wh | HOUR |
| 1863 | 2020-03-18 14:00:00 | 3487 | Wh | HOUR |

Figure 4.2: Data from Solaredge showing an excerpt of the hourly PV production from 2020

### 4.2.3 Spot market data and nettleie

The hourly spot price used in this project is retrieved from the Nord Pool power market, explained in section 2.2. The aim was to retrieve 10 years of hourly spot data to use in the calculations to get a larger time perspective over the results. A Python script was used to communicate with Nord Pool to retrieve the hourly data condensed into pickle files. Here an issue arose when the earliest hourly dataset the script was able to return was from 2019. The solution here was to download the historical market data directly from the Nord Pool website, where hourly data in excel-files was available back to 2013 at the earliest.[27] So, the hourly spot price data used in the project is the data from 2013 to 2020.

Since "nettleie" is a annual fixed fee, the data for 2013 to 2020 was retrieved from Elvia´s websites as constant variables in the script. [28] Where the data used in the calculations only consist of the variable cost linked to the consumption, called "energileddet" which is explained in section 2.3.1. NETTLEIE BONUSEN

## 4.3 Calculations and data processing

How the data gathered was used and how the calculations that achieved the end result was made will be presented here in chronological order, so that it can conveniently be replicated at a later time by anyone if needed.

### 4.3.1 Spot price

To process the spot market data there was made two different Python functions, one to handle the data from the pickle file and one to handle the excel file. Both functions returned dictionaries containing timestamps for the hourly data and the spot price for the associated timestamp both with and without VAT. The raw data from the files, both pickle file and excel file, had one observed missing value between 02:00-03:00 at a date at the end of march for each year, assumed to be some sort of maintenance gap. To counteract this a for-loop was implemented to iterate through the list finding any missing data and replacing them with the mean of the previous and following value.

Two modifications was needed to be applied to the raw data to return it in the desired form. All the values had to be divided by 1000 to turn them from NOK/MWh to NOK/kWh. For the spot price that included tax, each value had to also have 25% added, then another addition of 0.01 NOK, which is explained in section 2.3.2.

In Figure 4.3 and 4.4 a sample of the 2020 data is printed out as a DataFrame to illustrate what the functions returned. This process was done with all the data from 2013 to 2020.

```
                        Period  Price w/ tax [NOK/kWh]
0    2020-01-01 00:00:00+01:00                0.392335
1    2020-01-01 01:00:00+01:00                0.391710
2    2020-01-01 02:00:00+01:00                0.389247
3    2020-01-01 03:00:00+01:00                0.385672
4    2020-01-01 04:00:00+01:00                0.378772
...                        ...                     ...
8780 2020-12-31 19:00:00+01:00                0.338547
8781 2020-12-31 20:00:00+01:00                0.326972
8782 2020-12-31 21:00:00+01:00                0.326047
8783 2020-12-31 22:00:00+01:00                0.323935
8784 2020-12-31 23:00:00+01:00                0.316835

[8785 rows x 2 columns]
```

Figure 4.3: DataFrame of spot price with tax

```
                        Period  Price w/o tax [NOK/kWh]
0    2020-01-01 00:00:00+01:00                  0.31386
1    2020-01-01 01:00:00+01:00                  0.31336
2    2020-01-01 02:00:00+01:00                  0.31139
3    2020-01-01 03:00:00+01:00                  0.30853
4    2020-01-01 04:00:00+01:00                  0.30301
...                        ...                      ...
8780 2020-12-31 19:00:00+01:00                  0.27083
8781 2020-12-31 20:00:00+01:00                  0.26157
8782 2020-12-31 21:00:00+01:00                  0.26083
8783 2020-12-31 22:00:00+01:00                  0.25914
8784 2020-12-31 23:00:00+01:00                  0.25346

[8785 rows x 2 columns]
```

Figure 4.4: DataFrame of spot price without tax

### 4.3.2 House consumption and PV production

To process the house consumption data from Elvia and the PV production data from Solaredge, a Python function was created. The function returned the data as dictionaries containing timestamps for the hourly data and the corresponding house consumption and PV production at that time. As explained in section 4.2.1, the Elvia data contained the grid consumption of the house and the excess PV production sold to the grid. To get the house consumption data, the grid consumption had to be added to the total PV production then subtracted by the excess PV production sold to the grid. To make sure the correct values were added together with the corresponding timestamps, a Python function was made that correlated the indices to match. To get the correct result from the PV production data from Solaredge, each value had to be divided by 1000 to get the values from Wh to kWh.

In Figure 4.5 and 4.6 a illustration of the data is printed out as a DataFrame to show what is returned by the function.

```
                         Period  Consumption [kWh]
0    2020-01-01 00:00:00+01:00               6.65
1    2020-01-01 01:00:00+01:00               6.17
2    2020-01-01 02:00:00+01:00               7.36
3    2020-01-01 03:00:00+01:00               5.60
4    2020-01-01 04:00:00+01:00               5.85
...                        ...                ...
8779 2020-12-31 19:00:00+01:00               4.38
8780 2020-12-31 20:00:00+01:00               3.50
8781 2020-12-31 21:00:00+01:00               2.85
8782 2020-12-31 22:00:00+01:00               5.87
8783 2020-12-31 23:00:00+01:00               5.37

[8784 rows x 2 columns]
```

Figure 4.5: DataFrame of house consumption

```
                         Period  PV production [kWh]
0    2020-01-01 00:00:00+01:00                  0.0
1    2020-01-01 01:00:00+01:00                  0.0
2    2020-01-01 02:00:00+01:00                  0.0
3    2020-01-01 03:00:00+01:00                  0.0
4    2020-01-01 04:00:00+01:00                  0.0
...                        ...                  ...
8779 2020-12-31 19:00:00+01:00                  0.0
8780 2020-12-31 20:00:00+01:00                  0.0
8781 2020-12-31 21:00:00+01:00                  0.0
8782 2020-12-31 22:00:00+01:00                  0.0
8783 2020-12-31 23:00:00+01:00                  0.0

[8784 rows x 2 columns]
```

Figure 4.6: DataFrame of PV production

### 4.3.3 Delta variable

The delta ($\Delta$) variable is the difference between the house consumption and the PV production. When $\Delta > 0$, this means that the house consumption is greater than the PV production at that hour, which means the resident has to buy power from the grid. When $\Delta < 0$, this means that the house consumption is less than what the PV production is at that hour, which means the resident sells the excess power to the grid. When $\Delta = 0$, the house consumption matches the PV production perfectly, and the resident neither buys nor sells any power.

To obtain this variable a Python function was made that took the difference between the house consumption data and PV production data that was obtained by the previous function in section 4.3.2. The functions returns a dictionary containing the hourly timestamp and the delta variable at that time. In Figure 4.7 an illustration of the printout can be seen, which matches the printout in Figure 4.5 because in those time periods there was no PV production, which can be verified by Figure 4.6.

```
                         Period  Delta
0    2020-01-01 00:00:00+01:00   6.65
1    2020-01-01 01:00:00+01:00   6.17
2    2020-01-01 02:00:00+01:00   7.36
3    2020-01-01 03:00:00+01:00   5.60
4    2020-01-01 04:00:00+01:00   5.85
...                        ...    ...
8779 2020-12-31 19:00:00+01:00   4.38
8780 2020-12-31 20:00:00+01:00   3.50
8781 2020-12-31 21:00:00+01:00   2.85
8782 2020-12-31 22:00:00+01:00   5.87
8783 2020-12-31 23:00:00+01:00   5.37

[8784 rows x 2 columns]
```

Figure 4.7: DataFrame of delta variable

### 4.3.4 Hourly cost of electricity with and without PV installation

To get the hourly cost of electricity both with and without the PV installations, a Python function was created that took in nettleie, nettleie-bonus, house consumption, the delta variable and the spot price with and without tax as arguments. To make sure the calculations was accurate considering the timestamps, the Python function created to correlate the indices was applied. The calculations for the hourly cost of electricity without the solar PV installation was:

$$\text{Cost-w/o-PV} = (\text{spot-price-w/tax} + \text{nettleie}) \cdot \text{house-consumption}$$

And the cost of electricity with the solar PV installation was:

$$\begin{aligned}
&\text{if } \Delta > 0: \\
&\qquad \text{Cost-w/PV} = (\text{spot-price-w/tax} + \text{nettleie}) \cdot \Delta \\
&\text{if } \Delta < 0: \\
&\qquad \text{Cost-w/PV} = (\text{spot-price-w/o-tax} \cdot \Delta) + (\text{nettleie-bonus} \cdot \Delta)
\end{aligned}$$

These calculations were executed for each value corresponding to the timestamp. Then the function returned dictionaries containing the hourly timestamp and the cost for electricity with and without a solar PV installation. In Figure 4.8 an excerpt of what the function returns is shown.

```
                         Period  Cost w/ PVs [NOK/kWh]
1900 2020-03-20 04:00:00+01:00               3.454883
1901 2020-03-20 05:00:00+01:00               3.476762
1902 2020-03-20 06:00:00+01:00               4.445875
1903 2020-03-20 07:00:00+01:00               2.708999
1904 2020-03-20 08:00:00+01:00               0.380291
                         Period  Cost w/o PVs [NOK/kWh]
1900 2020-03-20 04:00:00+01:00                3.454883
1901 2020-03-20 05:00:00+01:00                3.476762
1902 2020-03-20 06:00:00+01:00                4.536979
1903 2020-03-20 07:00:00+01:00                3.496074
1904 2020-03-20 08:00:00+01:00                3.557560
```

Figure 4.8: Excerpt of DataFrame of cost of electricity with and without PV from 2020

Since the only available data for the house consumption and PV production was from 2020, these values were used for the calculations for all the different years.

# Chapter 5

# Results

In this chapter the results achieved in this project are presented. The results are based on the case study of the house in Asker which has a solar PV installation. The chapter is divided into two sections, where the first section presents the results of the data gathering of the house consumption and solar PV production, and the second section presents a cost analysis based on the past eight years.

## 5.1 House consumption and solar PV production

In this section the house consumption and the solar PV production for the house in Asker is presented based on the data retrieved from 2020. First the house consumption is presented, following is the solar PV production, then the difference between the two ($\Delta$-variable) and then finally the house consumption and solar PV production is shown together.

### 5.1.1 House consumption

The house consumption is based on real data from 2020. In Figure 5.1 the house consumption data for 2020 is shown with a representation of what the outcome would be if the solar PV installation was not present. The line plot shows both the daily data and the weekly simple moving average (SMA), to give more clear representation of the data, for the house consumption with and without the solar PV installation. The histogram shows the frequency of occurrence of different consumption's with and without the solar PV installation.

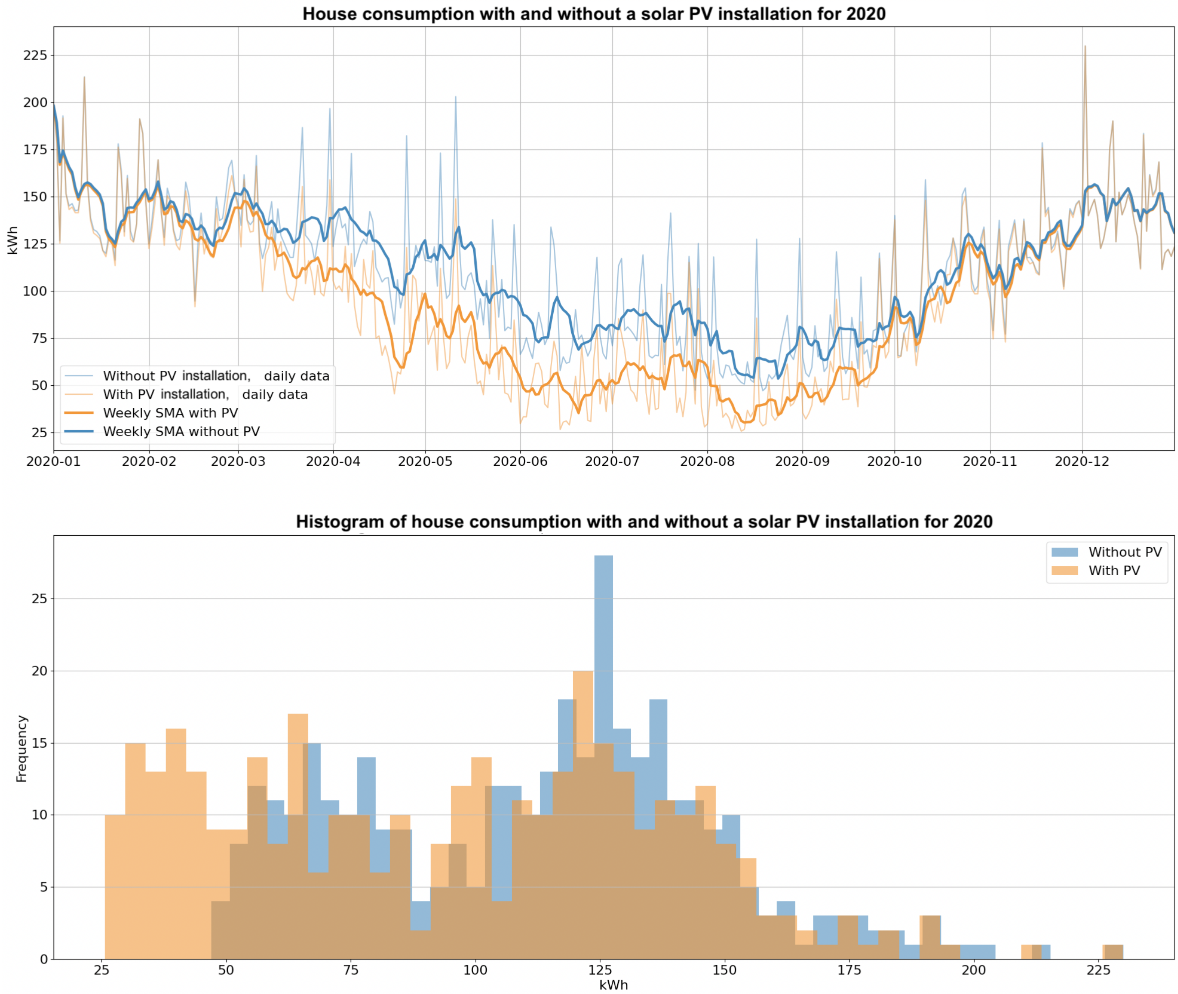



Figure 5.1: House consumption with and without a solar PV installation for 2020. Presented as line plot and histogram

In Figure 5.2 an excerpt of three different days throughout 2020 are shown, with hourly data for the house consumption with and without the PV installation. The dates are chosen as rough representatives of the different seasons. Where 1.February is representative of the winter, 1.June is representative of the summer and 1. October is representative of the fall, the dates are all separated by four months each to cover the entire year.

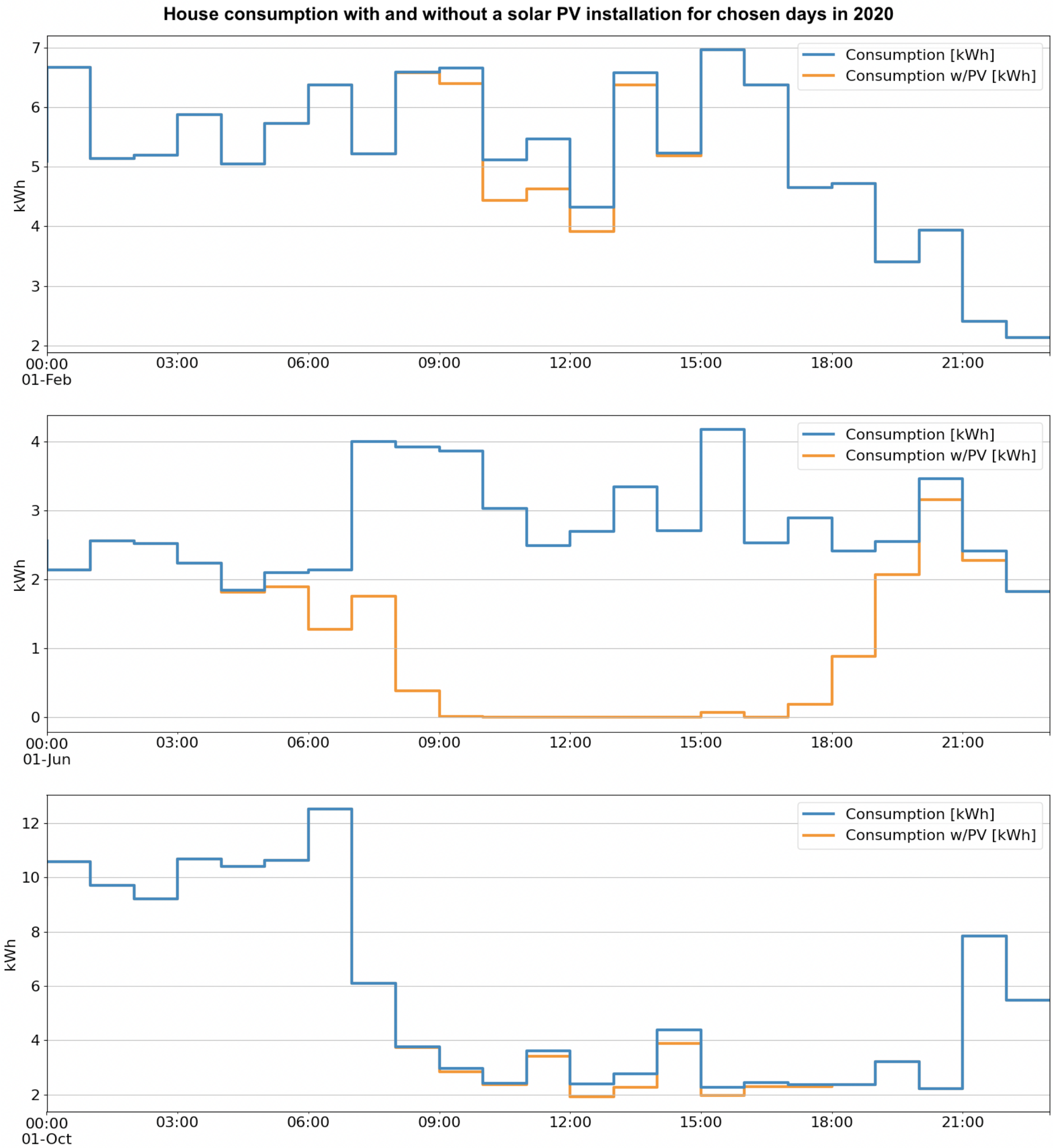



Figure 5.2: House consumption with and without a solar PV installation for chosen days in 2020

In Figure 5.3 the total house consumption for each month with and without solar PV installation is shown as a bar plot. In Figure 5.4 the sum over 2020 is shown with and without the solar PV installation. Which shows a total consumption saving over 2020 of:

$$\text{Consumption savings w/PV for 2020} = 40.82 \text{ MWh} - 34.67 \text{ MWh} = 6.15 \text{ MWh}$$

Which is a reduction of 18%.

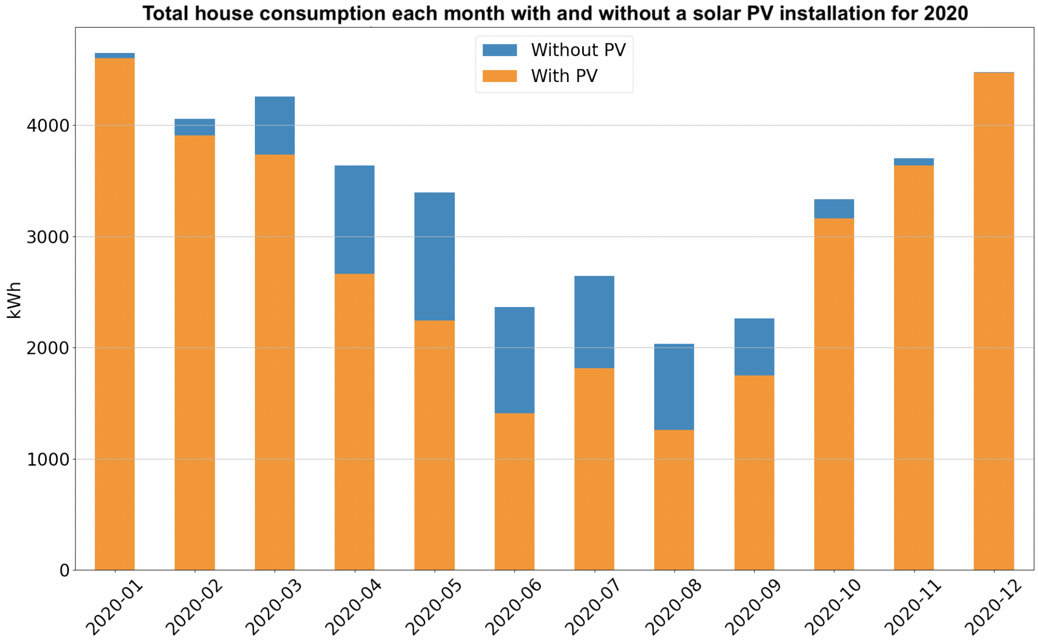



Figure 5.3: Total house consumption each month with and without PV installation for 2020

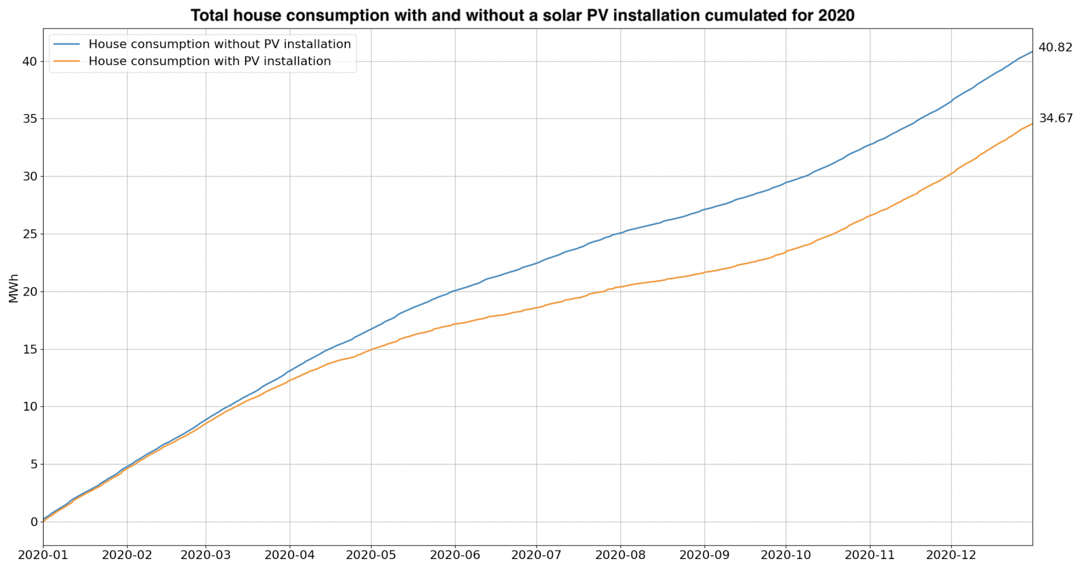



Figure 5.4: Total house consumption with and without PV installation cumulated over 2020

### 5.1.2 Solar PV production

The solar PV production is based on real data from 2020. In Figure 5.5 the solar PV production for 2020 is presented in daily data and weekly SMA data.

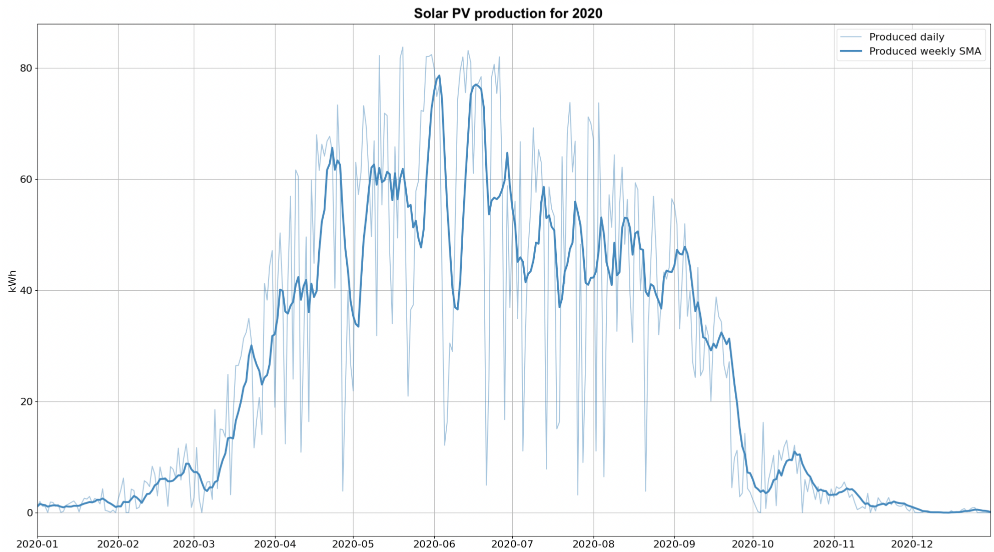



Figure 5.5: Solar PV production daily and weekly SMA data for 2020

In Figure 5.6 the hourly data for the solar PV production can be seen, where the peak power hour is marked at 10.083 kWh the 2020-05-27 14:00:00.

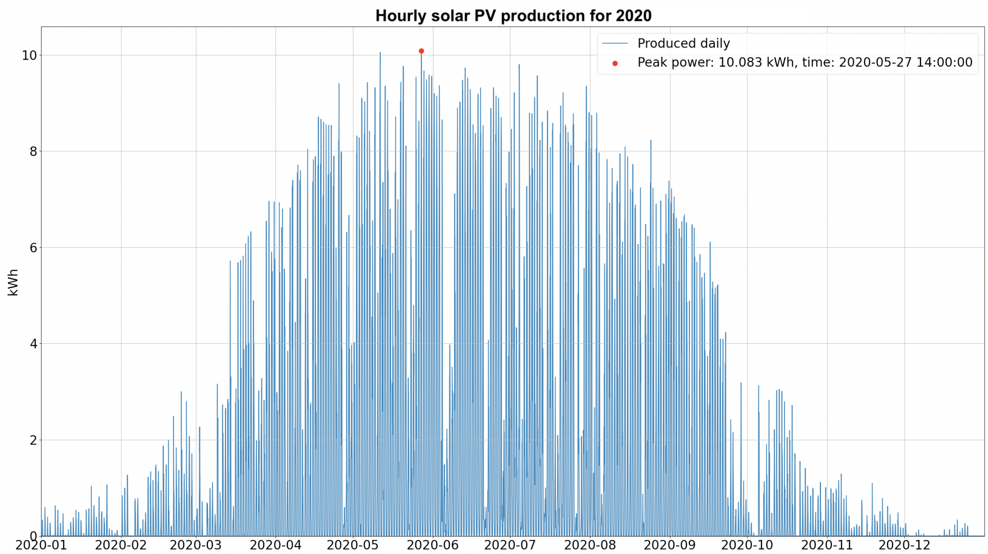



Figure 5.6: Hourly solar PV production and peak power for 2020

In Figure 5.7 the same three dates as in Figure 5.2 are plotted for the hourly solar PV production for those days.

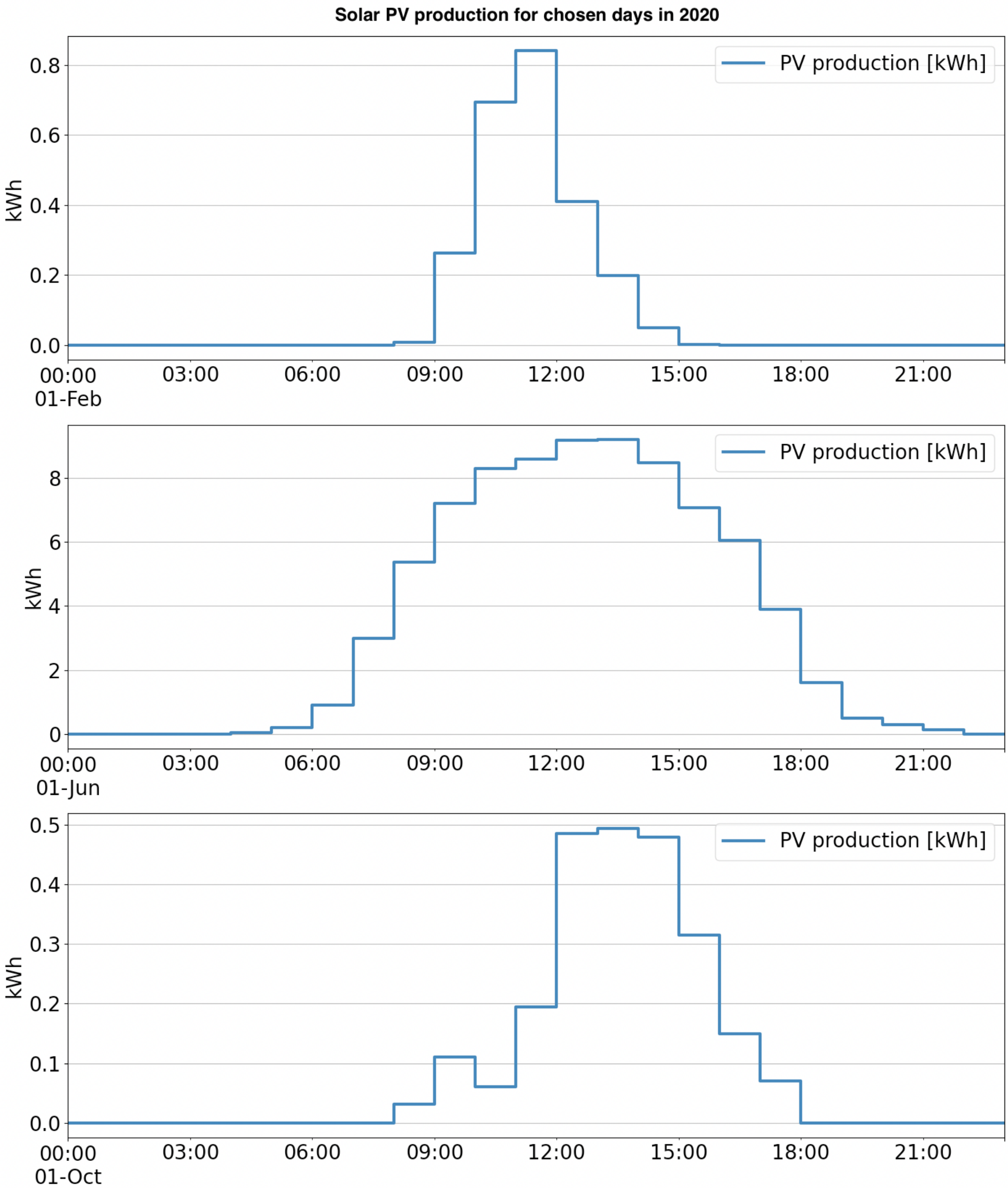



Figure 5.7: Solar PV production for chosen days in 2020

In Figure 5.8 the excess solar PV production sold back to the grid is presented in daily data and weekly SMA data. In Figure 5.9 the total solar PV produced and total excess solar PV production sold back to the grid is presented for each month of 2020.

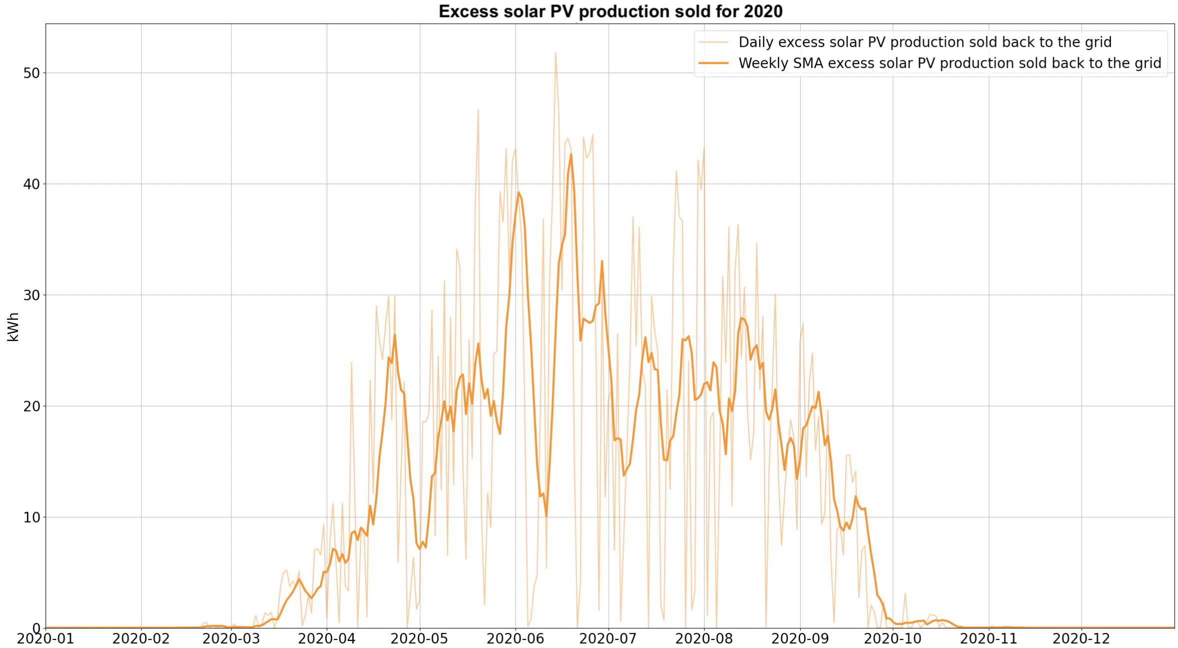



Figure 5.8: Excess solar PV production sold back to the grid in daily data and weekly SMA data.

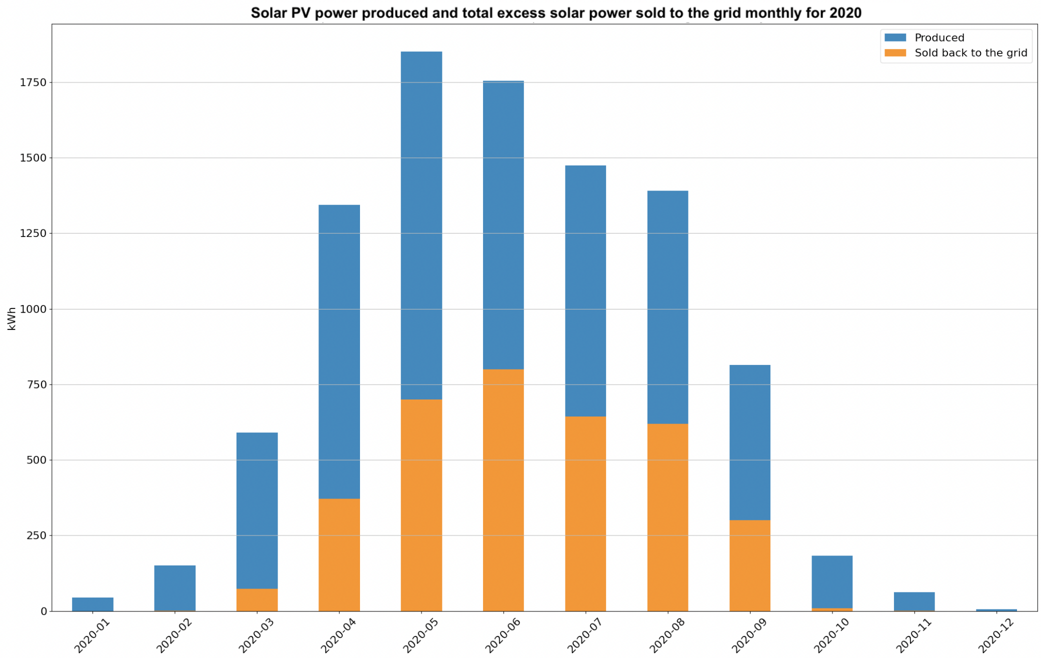



Figure 5.9: Total solar PV produced and total excess solar power sold back to the grid for 2020

The total solar PV production produced and the excess that was sold back to the grid is cumulated in Figure 5.10. Where the difference between what was produced and what was sold, shows the actual solar power consumption of the house, which resulted in:

$$\text{Solar power consumption} = 9.67\ \text{MWh} - 3.52\ \text{MWh} = 6.15\ \text{Mwh}$$

The retailer of the solar PV modules gave an estimate of a yearly production of 13.2 MWh (under the conditions discussed in section 3.1). The difference in the estimation and the actual production was:

$$\Delta_{PV} = 13.2\ \text{MWh} - 9.67\ \text{MWh} = 3.53\ \text{MWh}$$

which is a deficit of 26%.

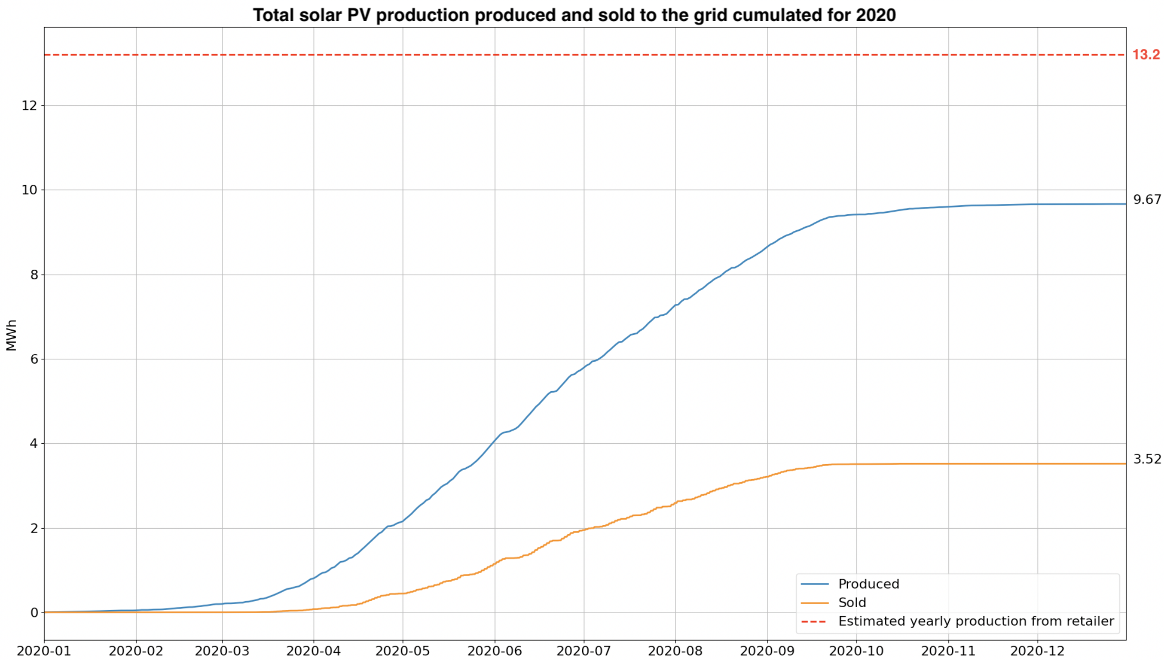



Figure 5.10: Total solar PV production produced an sold cumulated for 2020

### 5.1.3 Delta variable ($\Delta$)

The difference in the house consumption and the solar PV production at every hour is called $\Delta$-variable. In Figure 5.11 a line plot of the $\Delta$-variable is shown for every hour throughout 2020, where the red dotted line represents when $\Delta$ crosses the x-axis on 0. Whenever this happens the $\Delta$-variable becomes negative, which means that at that hour they are selling power to the grid. When the $\Delta$-variable is positive it means that they are buying power from the grid. In the bottom plot of Figure 5.11 a histogram shows the distribution and frequency of the $\Delta$-variable.

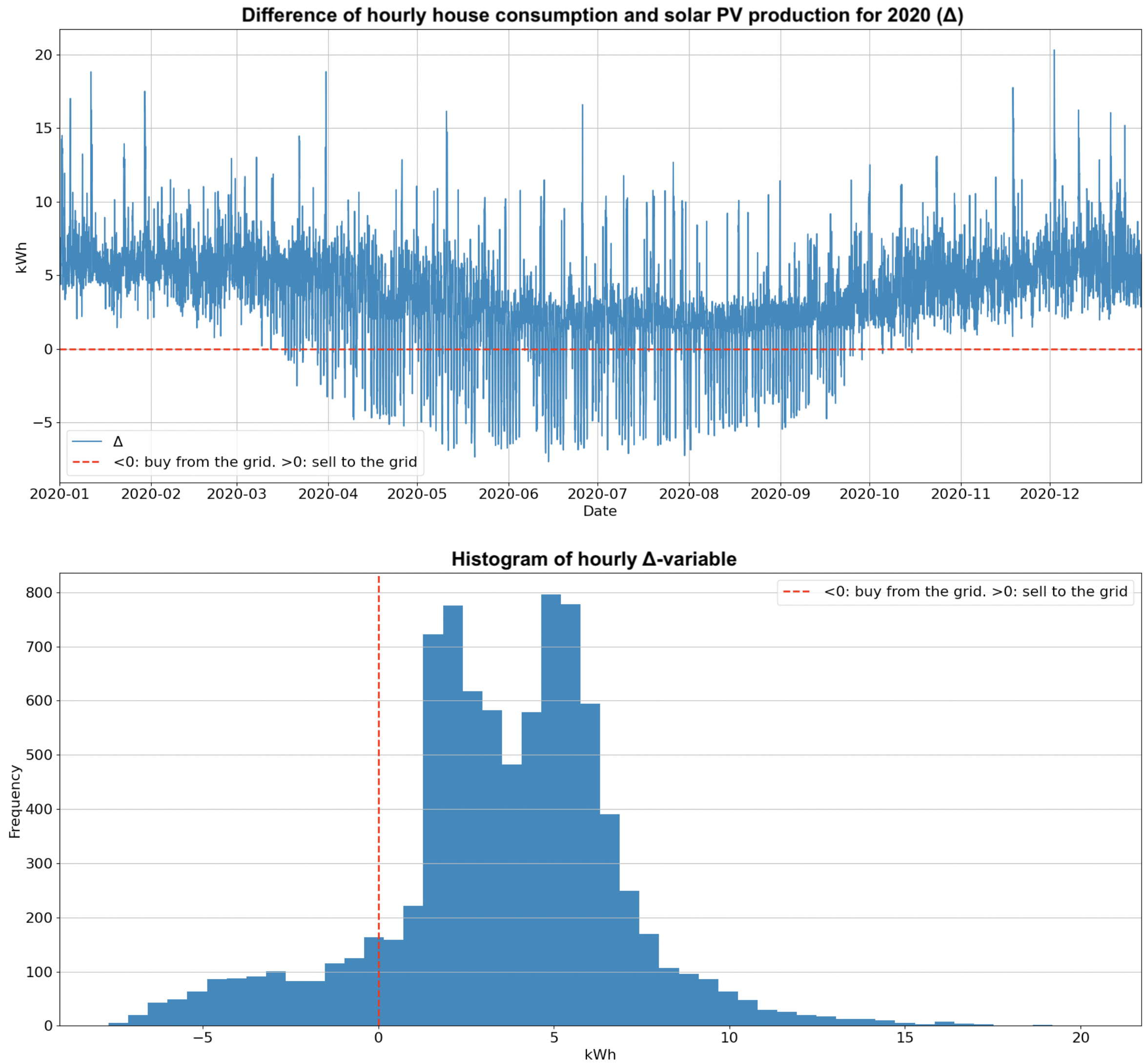



Figure 5.11: Difference of hourly house consumption and PV production for 2020 ($\Delta$)

### 5.1.4 House consumption and solar PV production

In Figure 5.12 the house consumption and solar PV production is plotted against each other, with daily data and weekly SMA data to give a holistic picture of the whole year.

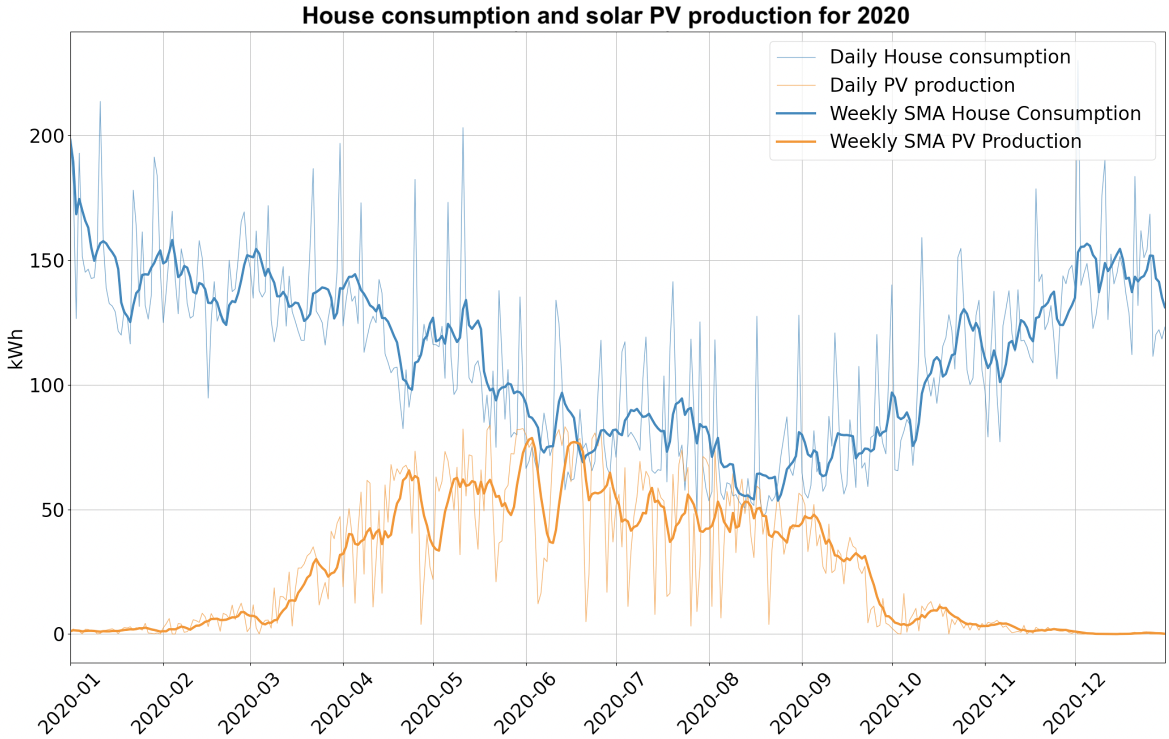



Figure 5.12: House consumption and solar PV production for 2020 plotted against each other. Plotted in daily data and weekly SMA data

In Figure 5.13 the same three dates as in Figure 5.2 and 5.7 are plotted with the hourly house consumption and solar PV production to show an excerpt of how some days will look.

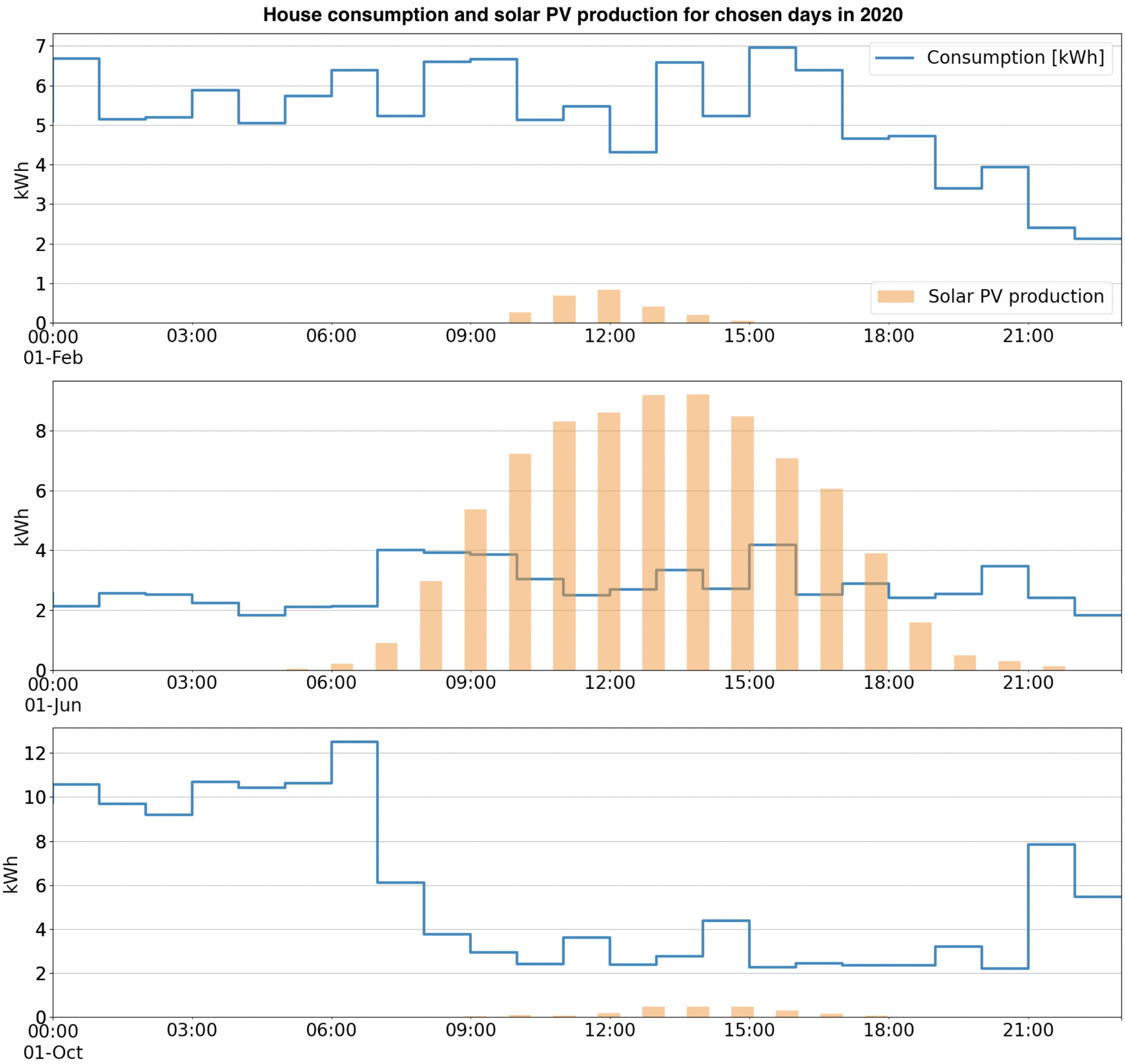



Figure 5.13: Hourly house consumption and solar PV production for chosen days in 2020

## 5.2 Cost of energy with and without a solar PV installation

In this section the house consumption data and solar PV production data from 2020 are used to calculate the cost of energy, with and without having a solar PV installation, by using spot data from the past eight years from the Nord Pool spot market. The variation in the spot market from 2013 to 2020 can be seen in Figure 2.3 in section 2.2. The total investment made in the solar PV installation for the house in Asker can be seen summarized in Table 5.1

Table 5.1: Total investment in the solar PV installation in Asker

| | Value [NOK] |
|---|---|
| Investment in solar PV modules | 184 000,- |
| Enova subsidy | -26 500,- |
| Total | 157 500,- |

### 5.2.1 Yearly cost

The yearly cost for each year between and including 2013 and 2020, with and without a solar PV installation, is presented in Figure 5.14. Then a summary, including yearly gain and payback period for each year, is presented in Table 5.2. Where the best year for the assumed solar PV installation would be 2018, if theoretically all years afterwards had the same spot price and solar PV production, it would take 19 years to payback the investment. For the worst year, 2020, it would take 39 years.

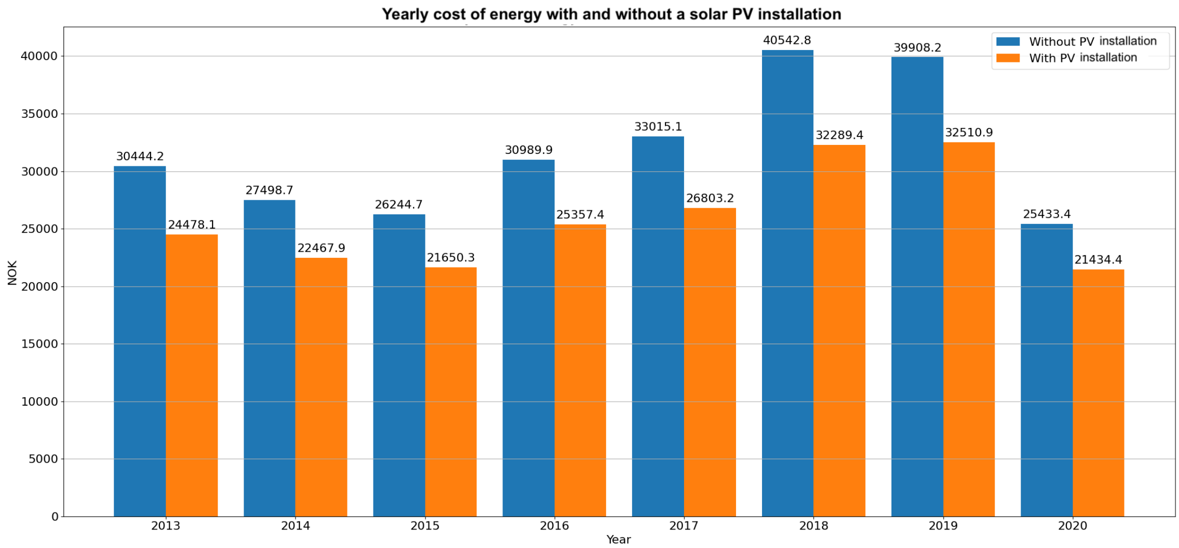



Figure 5.14: Yearly cost of energy for the house in Asker with and without a PV installation 2013-2020

By comparing the yearly gain for the best (2018) and the worst year (2020) we get a difference of:

$$\text{Percentage difference of yearly gain for 2018 and 2020} = \frac{8253}{3999} \cdot 100\% = 206\%$$

Table 5.2: Cost with and without solar PV installation 2013-2020

| Year | Cost without PV [NOK] | Cost with PV [NOK] | Yearly gain [NOK] | Payback period [Years] |
|---|---|---|---|---|
| 2013 | 30 444,- | 24 478,- | 5966,- | 26 |
| 2014 | 27 499,- | 22 468,- | 5031,- | 31 |
| 2015 | 26 245,- | 21 650,- | 4594,- | 34 |
| 2016 | 30 990,- | 25 357,- | 5633,- | 28 |
| 2017 | 33 015,- | 26 803,- | 6212,- | 25 |
| 2018 | 40 543,- | 32 289,- | 8253,- | 19 |
| 2019 | 39 908,- | 32 511,- | 7397,- | 21 |
| 2020 | 25 433,- | 21 434,- | 3999,- | 39 |
| Average | 31 760,- | 25 874,- | 5886,- | 27 |

### 5.2.2 Hourly cost

In Figure 5.15 the hourly cost for 2020 with and without the solar PV installation is presented, which is the worst of the eight years. The red dotted line represents when the excess solar PV power is sold to the grid. The histogram shows the frequency of occurrence of the different values. In Figure 5.16 the same dates as before are plotted to give a daily picture of the cost with and without a solar PV installation.

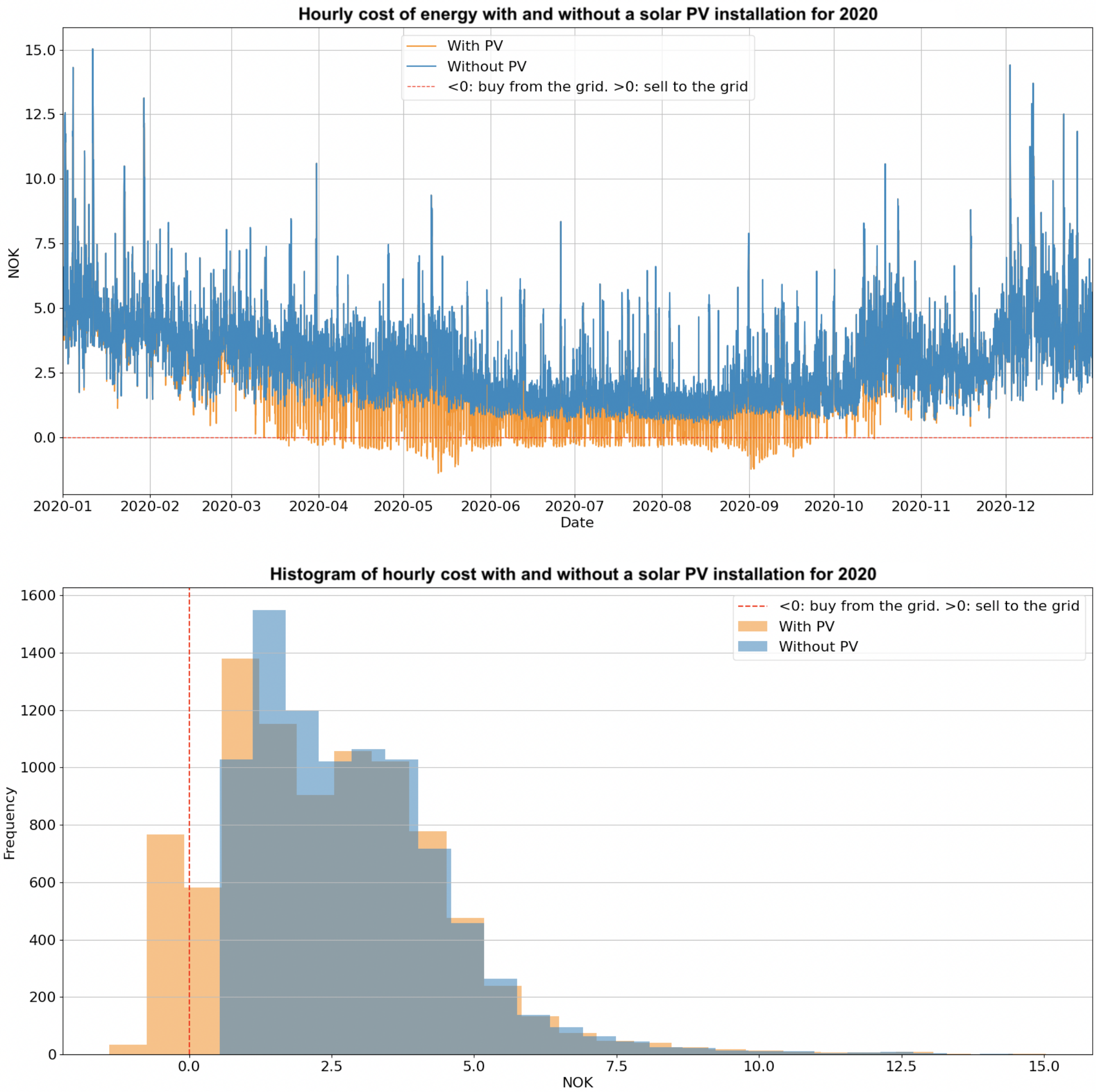



Figure 5.15: Hourly cost of energy with and without a solar PV installation for 2020

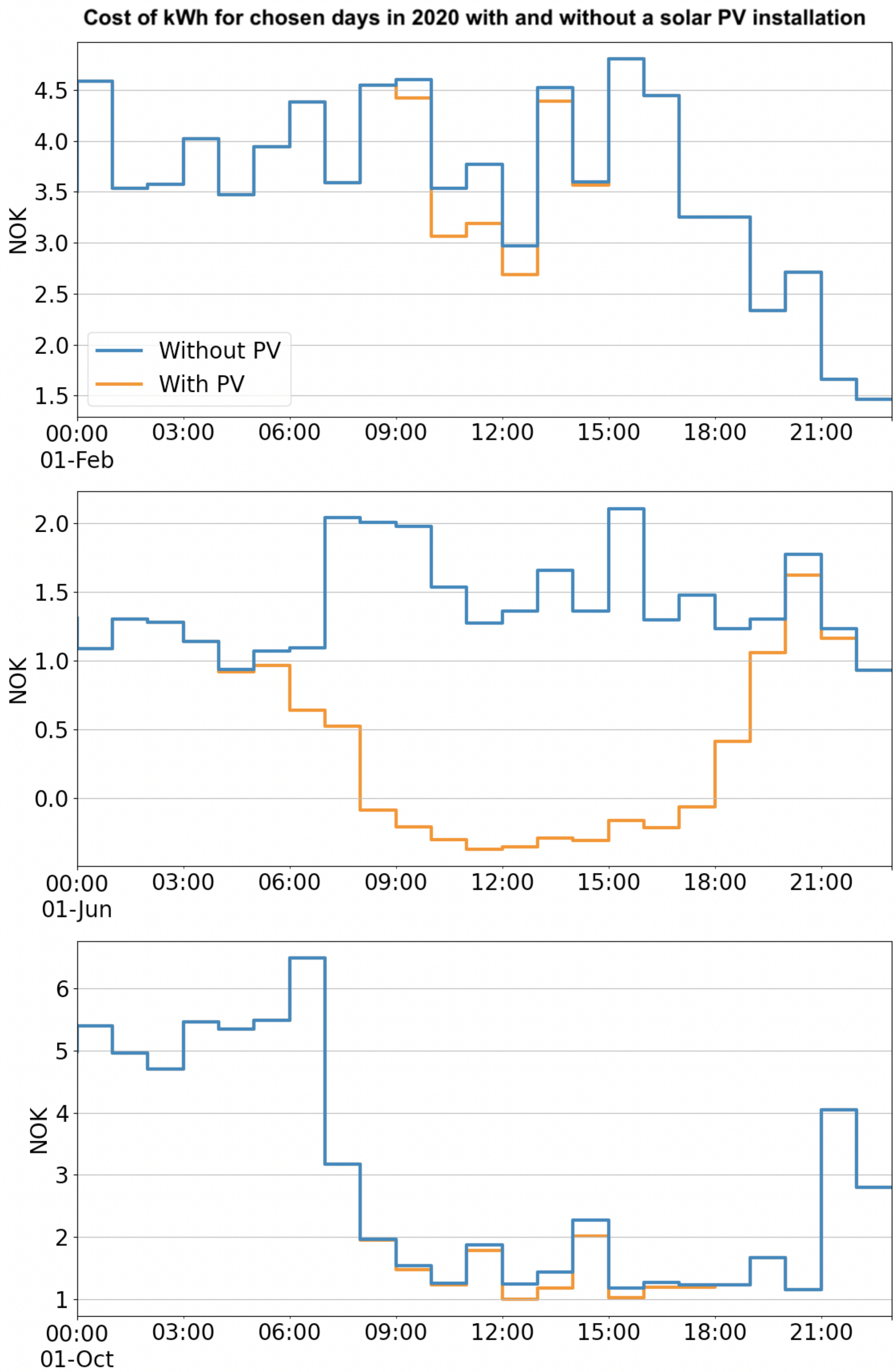



Figure 5.16: Cost of energy for chosen days in 2020 with and without a solar PV installation

In Figure 5.17 the hourly cost for 2018 with and without the solar PV installation is presented, which is the best of the eight years. In Figure 5.18 the same dates as before are plotted to give a daily picture of the cost with and without a solar PV installation.

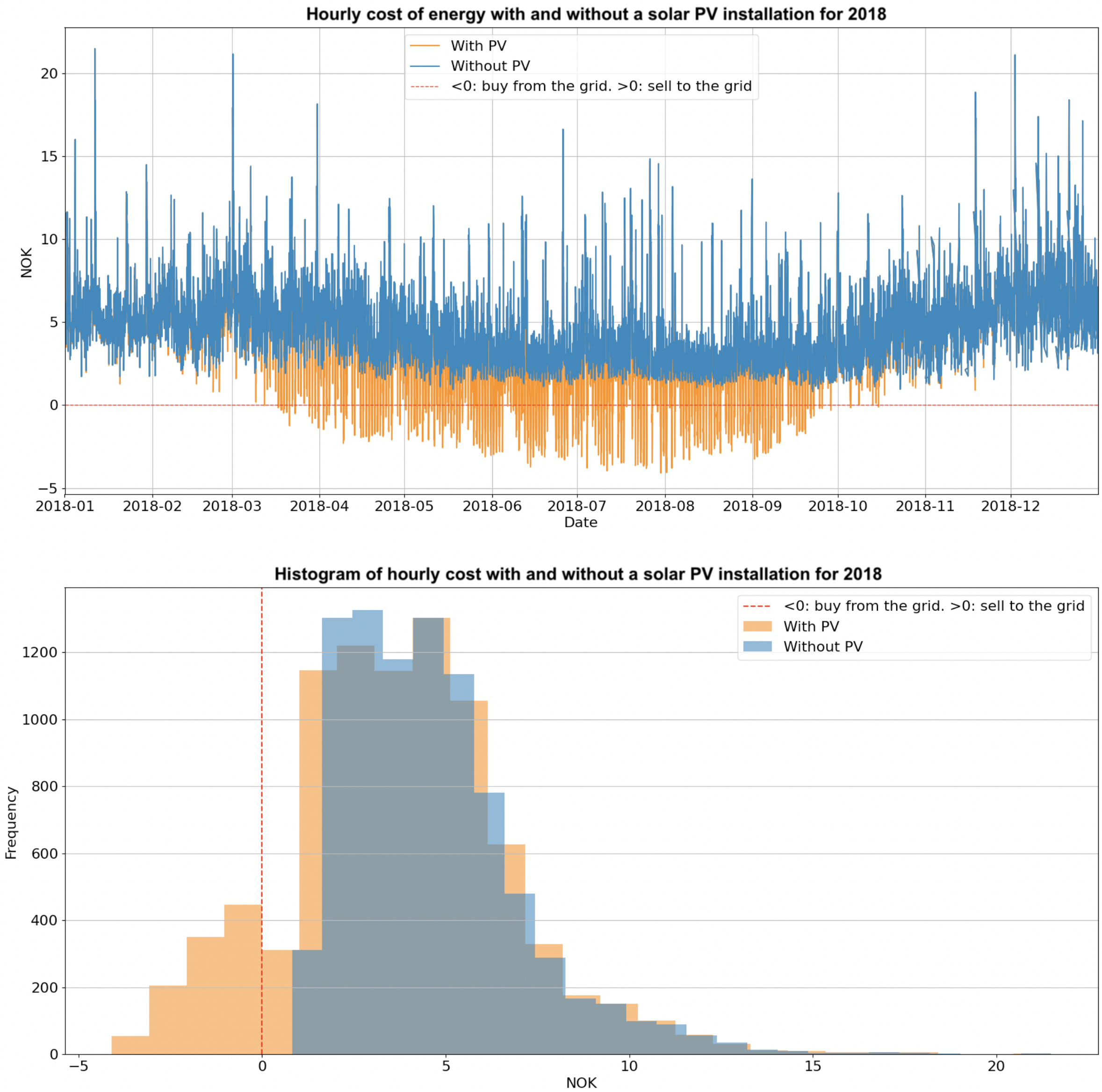



Figure 5.17: Hourly cost of energy with and without a solar PV installation for 2018

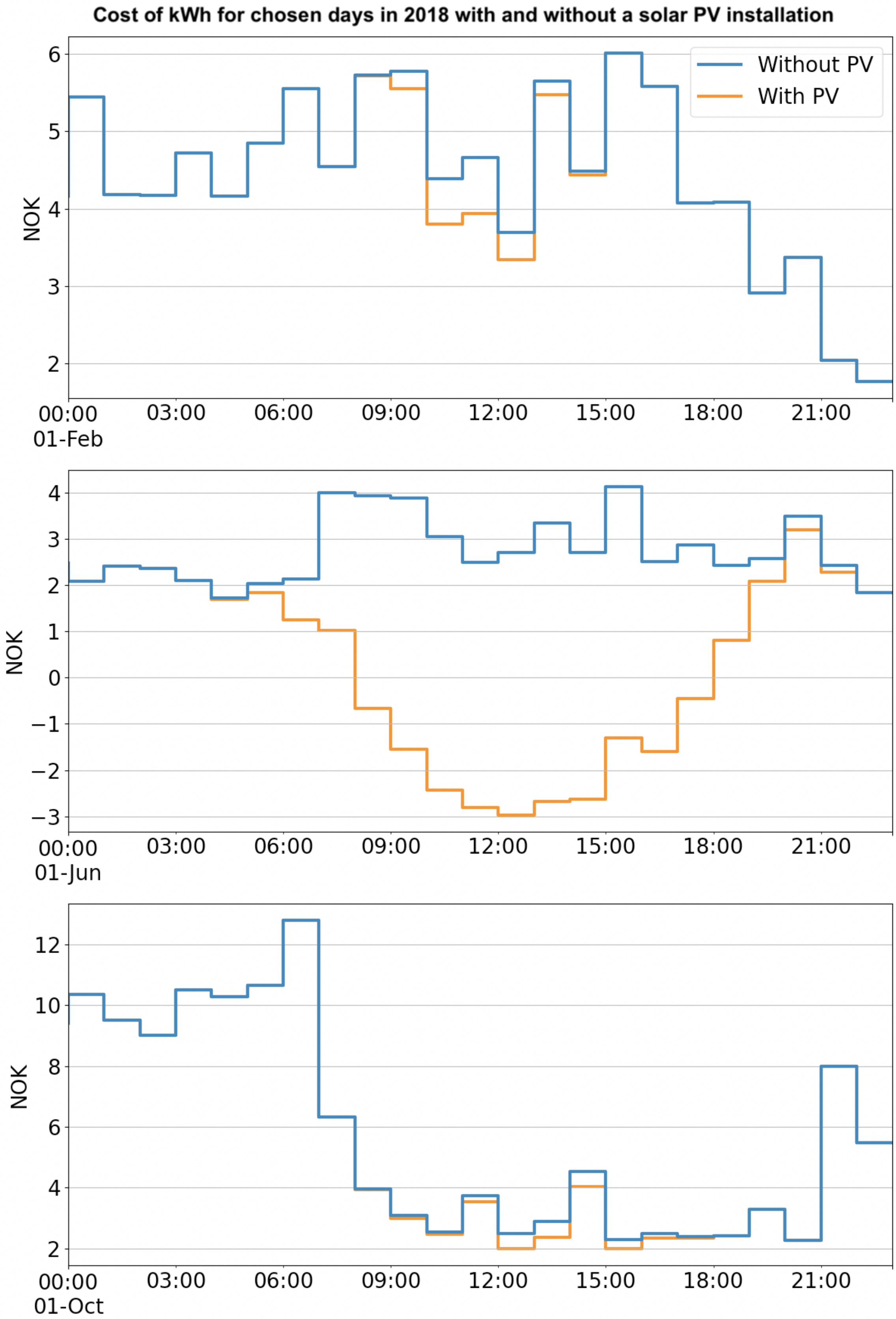



Figure 5.18: Cost of energy for chosen days in 2018 with and without a solar PV installation

# Chapter 6

# Discussion

This chapter presents a discussion of the results in terms of the research questions that were presented in chapter 1. There will be an overall discussion presenting the results, then limitations throughout the project and the effect this had will be presented.

## 6.1 The results

In this section the results will be discussed in chronological order in coherence with the previous two chapters.

### 6.1.1 House consumption and solar PV production

The data for the house consumption and solar PV production was all based on real time data from 2020 retrieved from Elvia, Tibber and Solaredge.

#### House consumption

The results for the house consumption with and without the solar PV installation coincide with my initial assumption that during the wintertime there would be little to no deviation and during the summertime there would be a great deal. In the summertime there were even days where the solar PV production accounted for all of the consumption during the daytime. This is as expected since the solar irradiation is much higher during the summer time in Norway, one of the drawbacks of this is that the summer time is also the period with the lowest house consumption.

#### Solar PV production

The solar PV production for 2020 coincided with my initial assumption as well, with low production during the wintertime and higher during the summertime. The highest peak power hour was 10.083 kWh in the end of may. The expected peak power from the retailer was 12.3 kWp, which is theoretically possible since the result found was for the peak power hour. From the daily data that was plotted, one can also see that compared the the house consumption plotted for the same days, during the summertime the production would exceed the consumption and the excess energy would be sold to the grid.

In total, almost a third of the solar PV production was sold to the grid and not utilized in the house itself. It would have been interesting too try and evaluate the value of buying a battery to store some of this excess production too see if this would have had a value.

The retailer estimated a yearly production of 13.2 MWh, whereas the installation only produced 9.67 MWh, which is a deficit of 26%. I did not find this very surprising, since their job is to sell this installation so they sell it with the best values possible. So under ideal conditions this value most likely would be true. If I had data for several years if would have been interesting to see if any year would have even come close to matching this.

**Delta variable $\Delta$**

My expectations for this variable was also met considering this is just the difference between the house consumption and solar PV production. It gives a good picture in showing the distribution in how much excessive solar PV production actually gets sold back the grid.

## 6.2 Cost of energy with and without a solar PV installation

In my initial thought about the savings one would have with a solar PV installation, I did not think about how big an impact the spot market would have on the results. Based on this case study the biggest difference of the cheapest and most expensive year for the yearly gain was 206%, which was way more than I would anticipate.

The house consumption data is only from 2020, which was a record low spot price year, which means that one would assume the residents of the house did not go overboard in trying to save energy and this might give a somewhat false image of the regular house consumption for this house. Since for more expensive years, one would assume that the residents would be more careful in how they used power and would try and cut back wherever possible. So with the time and resources, it would have been nice to get the full picture by having more than one year of house consumption data. The drawback for having just one year of solar PV production data might not be as big, since 2020 was a record hot year, it can be assumed that this was also a very good year for having a solar PV installation.

## 6.3 Limitations

The limitations with the assumed highest effect on the results are the missing data for house consumption and solar PV production for other years than just 2020. This limits the reliability of the results of cost for any other year than for 2020. Another limitation was the access to data and the short time frame of the project, the results would have been more solid if is was based on several different houses. With more time I could have extrapolated to other years by using local solar irradiance data and by the use of a solar PV model.

# Chapter 7

# Conclusion

This project was done as a case study and set out to assess the value of a solar PV installation on a residence in Norway. It consisted of a lot of research, data gathering and python programming to evaluate the installation. The main results show that the Nord Pool spot market has a huge impact on the profitability on the solar PV installation as it stands today. Originally, the project would also consist of a cost model based on different size solar PV installation to assess the optimal solution, but because of trouble getting answers and data from the suppliers, and considering the short time-frame of the project this was set aside.

The findings and knowledge achieved from this case study will lay a good foundation and serve as a laying ground for the continuation for the master thesis, as well as it has been a huge motivation for the continued work.

## 7.1 Recommendations for Further Work

The following list presents the recommendations I have for further work on the matter and some will serve as grounds for my continuation into the master thesis:

- Collect data for several residences that have solar PV installation to verify the findings in this case study. Ideally for several different locations.
- Create a cost model based on data from different retailers selling solar PV installation and include it in the analysis to optimize the optimal size of the installation in an economical perspective.
- Create different scenarios with different subsidies to see how if would effect the end result. I.e. increase the support from Enova, if the plusskunde-bonus from Elvia changed or if one were to get more than spot price for each kWh.
- Assess the value of including a battery in the system, to compare the value in storing the excess production instead of selling it to the grid.
- Develop a PV model and verify it against real time data on several different residences.
- Investigate the impact of having a smart management of the consumption to get the best value of out the solar PV system.

# References


[1] Norges vassdrags- og energidirektorat. *40 MW solkraft ble installert i 2020.* URL: https://www.nve.no/nytt-fra-nve/nyheter-energi/40-mw-solkraft-ble-installert-i-2020/. (accessed: 13.10.2021).

[2] D. Zaitsev et al. *Solkraft i Norge - Fremtidige muligheter for verdiskapning.* Accenture and World Wide Fund for Nature, 2020. URL: https://media.wwf.no/assets/attachments/solkraft_i_norge___fremtidige_muligheter_for_verdiskaping1.pdf. (accessed: 28.11.2021).

[3] European Commission. *2020 climate energy package.* URL: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2020-climate-energy-package_en#ecl-inpage-902. (accessed: 20.10.2021).

[4] H. Birkelund et al. *Langsiktig kraftmarkedsanalyse 2021-2040.* Norges vassdrags- og energidirektorat, Oct. 2021. URL: https://publikasjoner.nve.no/rapport/2021/rapport2021_29.pdf. (accessed: 28.11.2021).

[5] Yan Xue, Carmel Margaret Lindkvist, and Alenka Temeljotov-Salaj. "Barriers and potential solutions to the diffusion of solar photovoltaics from the public-private-people partnership perspective – Case study of Norway". eng. In: *Renewable sustainable energy reviews* 137 (2021). ISSN: 1364-0321.

[6] Emilie Kjenstadbakk. *A Study of How Integration of Solar Photovoltaic Impact a Housing Cooperative in Norway.* 2020. URL: https://hdl.handle.net/11250/2778256.

[7] Bjørnar Veie. *Balancing Solar Energy and Load Consumption given Different Load Consumption Profiles.* 2020. URL: https://hdl.handle.net/11250/2780913.

[8] Viridian Solar. *Clearline fusion Panel Options.* URL: https://www.viridiansolar.co.uk/solar-products-panels-for-roof-integration.html. (accessed: 25.11.2021).

[9] Solaredge. *Effekt Optimiser.* URL: https://www.solaredge.com/sites/default/files/se-p-series-commercial-add-on-power-optimizer-datasheet-nor.pdf. (accessed: 29.11.2021).

[10] Solaredge. *Three Phase Inverter.* URL: https://www.solaredge.com/sites/default/files/se-three-phase-inverter-extended-power-datasheet.pdf. (accessed: 29.11.2021).

[11] Nord Pool. *Nord Pool Day-ahead overview.* URL: https://www.nordpoolgroup.com/maps/#/nordic. (accessed: 25.11.2021).

[12] Nord Pool. *Nord Pool Day-ahead Market.* URL: https://www.nordpoolgroup.com/the-power-market/Day-ahead-market/. (accessed: 25.11.2021).

[13] Energi Norge. *Derfor er strømprisen uvanlig høy i år.* URL: https://www.energinorge.no/fagomrader/strommarked/derfor-er-stromprisen-hoyere-i-ar-enn-i-fjor/. (accessed: 25.11.2021).

[14] Nord Pool. *The power market.* URL: https://www.nordpoolgroup.com/the-power-market/. (accessed: 25.11.2021).

[15] Gjermund Stensrud. *Slik leser du strømregningen din.* URL: https://xn--strm-ira.no/str%C3%B8mregning. (accessed: 26.11.2021).

[16] Elvia. *Hva er Elvia?* URL: https://www.elvia.no/hva-er-elvia/. (accessed: 26.11.2021).

[17] Elvia. *Hva er nettleie?* URL: https://www.elvia.no/nettleie/alt-om-nettleie/hva-er-nettleie. (accessed: 29.11.2021).

[18] Tibber. *Synes du det er forvirrende med de ulike typene strømavtaler*. URL: https://tibber.com/no/magazine/power-hacks/typer-stroemavtaler. (accessed: 26.11.2021).

[19] Tibber. *Selg overskuddet fra solcellene*. URL: https://tibber.com/no/smart-styring/solceller. (accessed: 29.11.2021).

[20] Enova. *About Enova*. URL: https://www.enova.no/about-enova/. (accessed: 29.11.2021).

[21] Enova SF. *Enova Annual Report 2020*. Enova SF, 2020. URL: https://www.enova.no/download?objectPath=/upload_images/F00FA2198797415D9B8FBC7F46F68E2B.pdf. (accessed: 29.11.2021).

[22] Enova. *El-produksjon*. URL: https://www.enova.no/privat/alle-energitiltak/solenergi/el-produksjon-/. (accessed: 29.11.2021).

[23] Eliva. *Hva er plusskunde hos Eliva?* URL: https://www.elvia.no/proff/nettilknytning/plusskunde/hva-er-plusskunde-hos-elvia/. (accessed: 29.11.2021).

[24] Viridian Solar. *The Benefits of Roof Integrated Solar*. URL: https://www.viridiansolar.co.uk/solar-products-benefits-of-roof-integration.html. (accessed: 29.11.2021).

[25] Solaredge. *Power Optimizer Module Add-on*. URL: https://www.solaredge.com/products/power-optimizer#/. (accessed: 01.12.2021).

[26] Solaredge. *Three Phase Commercial Inverters*. URL: https://www.solaredge.com/us/products/pv-inverter/three-phase#/. (accessed: 01.12.2021).

[27] Nord Pool. *Historical Market Data*. URL: https://www.nordpoolgroup.com/historical-market-data/. (accessed: 27.11.2021).

[28] Elvia. *Historiske priser på nettleie i Oslo og Viken*. URL: https://www.elvia.no/nettleie/alt-om-nettleie/historiske-priser-pa-nettleie-i-oslo-og-viken/. (accessed: 26.11.2021).

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