Design of a PV-system with batteries for a grid connected building

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Abstract

Energy has always been a topic issue. Over the last years, many policies have been implanted in Europe as well as in an International World context like the Paris Agreement to decrease the dependence on fossil fuels and increase the energy provided by renewable energies. Also, the last reports about the growing on population will be a problem in the future to supply energy to all the inhabitants.

Based on this, this thesis come up with the idea of an alternative way to supply alternative energy to households because its consumption implies a 35% of the world total energy use. This energy will be provided by solar energy, promoting the figure of prosumers.

In this thesis, the case of a household placed in Sweden and in Spain is going to be evaluated. The latitude is a key factor to carry out this type of systems, however the policies about the implementation of PV systems plays also a main role in the study. First of all, the production of the PV system connected to the grid is going to be analysed. In this case, Spain is the country with higher production of electricity due to higher annual irradiation. In order to size the batteries, the days with large overproduction will determine the capacity of them.

Finally, the economic study it is only able to determine that the system in Spain represents a lower investment than the Swedish one due to is necessary to acquire less amount of energy from the grid as the solar production is higher.
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With this thesis a stage ends. The end of an enrichment stay as an Erasmus student in Sweden. Thanks to this wonderful country for giving me everything I needed to continue a new stage in Spain.

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Nomenclature

Mtoe  Million Tonnes of Oil Equivalent
IEA  International Energy Agency
EU  European Union
EC  European Commission
PV  Solar Photovoltaic
STC  Standard Test Conditions
DC  Direct Current
AC  Alternating Current
kWh  Kilowatt hour
DoD  Depth of Discharge
TES  Thermal Energy Storage
kWp  Kilowatt Peak
V  Voltage
A  Amperes
PR  Performance Ratio
SF  Solar Fraction
Design of a PV-system with batteries for a grid connected building
1. Introduction

1.1. Background

Fossil fuels (oil, coal and natural gas) have been throughout history, the backbone on which industrial activity has been developed and nowadays, they are the main energy resource of an industrialized society and also they have been the responsible of inequalities between countries with a limited access to this kind of resources, hindering their development.

![Figure 1. World Energy Production (Mtoe) [1]](image)

Figure 1 shows how fossil fuels supplied the highest amount of energy in 2014, however, this energy model has seen its days because the reserves of these fuels are declining, and in accordance with studies of the IEA (International Energy Agency), the demand of energy will continue growing due to the reliance on technology, enhanced living standards of developed countries and continuous increase of population in the developing countries [2].

In addition, a rising concern has appeared among the society and many world policies have been discussed from the parliament to different energy forums like the United Nations Framework Convention on Climate Change. This treaty, was joined in by international countries in order to cooperate and combat the climate change and in 1995 was launched the Kyoto protocol in order to reduce the emissions.

After it, a new strategy was settled in 2015 through the Paris Agreement (The Paris agreement limits the temperature increase due to greenhouse gases to 2 °C): 2020 Energy Strategy, which aimed to “Reduce the greenhouse gas emissions by at least 20%, increase the share of renewable energy to at least 20% of consumption, and achieve energy savings of 20% or more. All EU countries must also achieve a 10% share of renewable energy in their transport sector [3].”

Despite of that, some publications from the European Commission (EC) remark that the target of 20% savings is quite far from being reached in 2020 with the current state of policies. In accordance with the analyses carried out to explain this issue, the implementation of regulation and energy efficiency measures are proposed.
In Figure 2 is shown how in 2014 renewable energy supplied an estimated 19.2% of global final energy consumption. However, despite the use of renewable energy is raising rapidly, the share of renewables in total final energy consumption in not growing as quickly.

![Figure 2. Estimated Renewable Energy Share of Global Energy Consumption 2014 [4]](image)

In addition, according to a report from United Nations [5] it is estimated that by 2050 the population will continue growing, so the governments will have to implement new policies in order to ensure wellness of the inhabitants in an environmental and social sustainability way as it is the availability of energy to every one of them.

Finally, based on all of this background, a new model settled on renewable energies is needed and in order to propose a solution to these problems, the aim of this project is to present an alternative: A design of the batteries of a single family house in order to promote the self-consumption of solar electricity in a building with a PV system.

Using Photovoltaic solar energy to this purpose might solve problems like shortage, climate change, dependency, high prices fluctuation, pollution... Joined with some energy efficiency policies in buildings, energy supply could be reduced and decrease as well the amount of energy demand.

1.2. Aim of the thesis

The aim of this project is to design a PV system with batteries for a grid connected single family house. The size of the batteries needed to provide electricity to the house when the solar resource will not be available is determined. Also, the system is connected to the grid just in case the reserves of energy are zero. The size of the batteries are going to be enough to store energy from day to night, but no for more than a day, so seasonal storage is not going to be studied in this paper.

To do the sizing, self-consuming is going to be the master key since as less electricity we will be sold to the grid, as better will be for the family economy. The size of the system will be lower and easily to amortize. A comparison between the situation of Spain and Sweden will be carried out in order to see which kind of differences are there between both countries.
1.3. Limitations

The data achieved to do the simulations is related to the consumption of the family has been given and not measured in order to do this particular thesis so maybe the data doesn’t match perfectly with the building consumption. Anyway is only an approximation based on the behaviour of other similar families and it is supposed to be enough to this issue.

Achieving the meteorological data from another source different that the one PV SYST provide can give as some differences about the real measures. In this case, the data source is from PVgis and not from any meteorological station located in the surroundings.

Finally, the simulations carried out through PV SYST are quite different from the ones that we could obtain in the reality due to limitations of the program, and certain approximations within it.
2. Theoretical background

2.1. Energy

Energy is the measure of the ability of a body or system to do work or produce a change and it is expressed usually in joules or kilowatt hours. No activity is possible without energy and its total amount in the universe is fixed: It cannot be created or destroyed but can only be changed from one type to another. According to its origin we can divide it in two groups: Renewable and non-renewable energy.

Non-renewable energy is a limited resource. Fossil fuels, geothermal energy and nuclear energy are part of this group. Renewable energies are derived from natural processes that are replenished constantly.

2.2. Energy use in households

The Household sector includes those activities related to private dwellings, covers all energy-using activities in apartments and houses, including space and water heating, cooling, lighting and the use of appliances.

The building sector, which involves the residential and services sub-sectors, consumes 35% of global energy use [6] where electricity, natural gas and renewables (Biofuels) represent the main suppliers of energy. According to the European Union (Figure 3), the household sector accounts for almost 25% of the total European final energy consumption [1].

![Figure 3. Final energy consumption by sector and buildings energy mix, 2010 [6]](image)

There are several factors that can explain the upward trend in energy consumption such as an increase in the number of households, greater comfort demand and an increase in the electrical appliances in homes. In addition, several efficiency measures are carried out in the space heating in order to reduce the amount of energy required like improving the insulation of the buildings or create awareness about a more responsible consumption of energy.

In line with the IEA, figure 4 shows that the space heating accounts for over the half of the residential energy consumption in Europe [7].
Within the energy used in the residential sector, size and location are the main factors that determine the energy consumption: Small flats need less energy as there is less conditioned and transfer area, and also less occupation [8]. Also the weather and architectural design, energy system and economic level of the occupants determine the amount and type of energy used in the building.

Next figure shows the difference between the distribution of the energy consumption between Spain and Sweden, This is two countries with different location, weather and culture.

The building sector contributes to a large part of Sweden and Europe’s total end use of energy according to the Swedish Agency (Figures 5 and 6), the residential and service sector accounts for almost 40 per cent of Sweden’s total energy use [9]; This is a higher percentage than in Spain, where it is a third of the total energy use.
From figures 7 and 8, it is able to establish that the consumption of energy for heating is lower in Spain than in Sweden; because of the warmer climate. However, the energy use for water heating in Spain is higher than in Sweden.

2.3. Energy self-consumption

Self-consumption consists on consuming a part or the whole energy produced by an own energy power installation. When the total amount of energy is not needed in the system, the part of the energy that is not needed is sold to the grid. One of the most common ways of local energy production is solar systems.

During the last year a new term is suggested: Prosumers. “Prosumers” is a word based on the association of producer and consumer, and its used nowadays to refer to an electricity consumer who produces also electricity to support his/her own consumption (And possibly for injection into the grid).

The decrease of the solar photovoltaic (PV) panels price, as well as the increase on the number of the new regulations of PV-Systems and some subsidy schemes to promote the installation of panels has resulted in increased worldwide deployment of solar PV. The International Energy Agency’s Photovoltaic Power System Programme’s latest report [10] found that 75 GW of solar were installed globally in 2016, bringing the installed global photovoltaic capacity to at least 303 GW.

| TABLE 1. COST DATA FOR ELECTRICITY GENERATION TECHNOLOGIES [11] |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Technology      | Investment cost MEUR/ GW | Annual fixed O&M cost MEUR/ GW | Variable O&M cost kEUR/ GWh | Lifetime Years |
| Reservoir hydro | 1525 – 2563       | 15 – 25          |                     | 40             |
| ROR hydro       | 1635 – 3160       | 15 – 25          |                     | 40             |
| Wind power      | 1520 – 1611       | –                | 19                 | 20             |
| Biomass CHP     | 1500 – 1902       | 33 – 84          |                     | 25             |
| Natural gas     | 1188 – 1125       | 10 – 29          |                     | 25             |
| CHP             | 2638             | 29               |                     | 25             |
| Waste CHP       | 2638             | 29               |                     | 25             |
| PV in 2015      | 2250             | 3                |                     | 25             |
| PV in 2050      | 1500             | 3                |                     | 25             |

According to table 1, forecasts on PV Technology establish that its price will decrease over the next years to the half. In addition, the cost of batteries is falling at a higher rate than predicted. And due to their modular nature, both are well suited for distributed deployment and thereby could represent an alternative to supply energy for individual households [12].

In the European Union, several policies have been enacted in order to incorporate renewable energies to the electric power system in order to switch to a more sustainable energy system. Once an alternative source generates power at a levelized cost of electricity that is less than or equal to the price of purchasing power from the electricity grid in the wholesale market (Grid parity), new policies have come up to develop self-consumption installations in several countries.

Germany, a country with high PV power introduced a model based on feed-in tariff scheme for PV installations, where electricity produced to the grid is paid at a fixed or varied price over a guaranteed period [13]. Other examples are countries like USA and Australia where net metering is implemented, so
all the surplus energy is dumped to the grid with the possibility of getting the same amount from the grid when the installation needs it without any cost [14].

Self-consumption is missing an equal policy for the whole Europe, so that in each country this issue has been regulated in a different way, giving rise to several policies which each country should take care in a different way.

2.3.1. The case of Sweden
Self-consumption in Sweden has always been exempt from energy tax until 2016. The energy tax exemption was proposed to be limited and apply to homeowners and companies that install a maximum of 255 kWp of PV power [15]. This reduced the profitability of larger systems as the monetary saving of reducing purchased electricity decreased.

In 2016 the government initiated an investigation into the possibility of reducing the effect of the limited tax exemption, and in 2017 the government has announced its plan to cancel the tax for solar power systems with a capacity above 255 kWp. However, according to the Sweden's finance minister the tax could not be completely cancelled but it is going to be reduced from SEK 0.295 per kWh to SEK 0.005 per kWh. These rules are expected to come into force on July 1, 2017.

The total cost of electricity in Sweden is divided into two parts. These parts are the electricity price and the electricity grid cost. The electricity price consists of the electricity price itself, an electricity tax and a value added tax. The grid cost consists of the grid fee and value added tax. The energy cost is around 40% of the total cost.

Sweden has a unique position with a high penetration of heat pumps in single-family buildings which can be used to increase self-consumption of generated PV electricity.

2.3.2. The case of Spain
After almost 20 years without improving or modifying the Spanish electricity regulation and despite of the several researches and discoveries introduced in the society, industry and quite changes on the Spanish policies, the reform of the Power Sector Law (Ley del Sector Eléctrico 24/2013) was finally approved by the Spanish Parliament as December 26th, 2013 [16].

This new Power Sector Law introduced for the first time the regulation within the self-consumption scope: Self-consumption facilities, and in particular PV panels for own domestic consumption. The specific self-consumption regulation is developed in the Royal Decree 900/2015.

This new regulation, has retroactive nature, that means that all the installations which does not fit with any way of self-consumption contemplated by this Decree, must to be adapted making the pertinent changes in it. There are two kinds of self-consumption:

- Type 1 self-consumption. Residential, commercial sector.
- Type 2 self-consumption. Agricultural and industrial sector.
The maximum installation power size permitted for the type 1 self-consumption is 100 kWp.

Both types of self-consumption are allowed to dump energy to the grid but however producers of the first sector will not receive any financial remuneration for it. The energy selling price will be the market price obtained for each hour in the daily market by OMIE or a price agreed with the marketer. Also, there is a generation toll and a electricity tax that needs to be paid as a consequence of selling energy.

The scheme of the measurement equipment for this type of self-consumption is shown in figure 9.

In order to do the invoicing, the meter in the boundary point is the one that controls the power, the reactive power term and to register the hourly demand.

Also, there are taxes that self-consumers have to pay:

- **Variable charge (€/kWh).** Applied to the total energy consumed.
- **Fixed charge (€/kW/year).** According to the contracted power and the characteristics of the installation.

### 2.4. Renewable Energy

Renewable energy is defined by Sorensen as “Energy flows which are replenished at the same rate as they are used”. During the last years, they are becoming the forward-looking bet to be able to reach a sustainable energetic model.

Sun is the origin of almost all these kind of energies. Solar radiation is divided into visible light, infrared radiation and some ultraviolet [17]. However, in the atmosphere this energy that comes from the sun becomes a variety of effects and some of them have some importance as an energy resource:

- The irregular heating of different areas of the earth in addition to the Coriolis’ acceleration by the rotation movement of the Earth is what induces the air current which allows extracting energy from the wind through windmills.
- The heating of large masses of water causes its evaporation and consequently precipitations (Rain and snow) creating rivers and torrents which are going to let us extracting energy from hydraulics.
There are three types of solar energy technologies: Thermal, photovoltaic and thermo electric. Thanks to the waves produced by the force of the wind, it is possible to generate wave electricity. The rotation of the moon around the earth as well as the earth around the sun causes changes on the sea level. This change lets us use the difference of the sea level (Tides) to obtain energy.

Renewable power generation capacity saw its largest annual increase ever in 2015. Wind and solar both saw a record additions, making up together about 77% of all renewable capacity added in 2015 [2]. The world now adds more renewable power capacity annually than it ads (net) capacity from all fossil fuels combined. Renewable sources supplied by the end of 2015, about 23.7% of the total world energy demand [4]. This is shown in Figure 10.

![Figure 10. Estimated Renewable Energy Share of Global Electricity Production, End-2014 [4]](image)

2.5. Solar Energy

This form of energy relies on the nuclear fusion power from the core of the sun which produces high temperature of the sun and continuous emissions of large amount of energy. Solar energy is emitted to the universe by electromagnetic radiation which is distributed from the infrared to the ultraviolet.

Not all radiation reaches the surface of the Earth because shorter ultraviolet waves are absorbed by gases in the atmosphere primarily by ozone: Approximately one-third of the energy is reflected back (Figure 11). The magnitude that measures the solar radiation that arrives at the Earth is the irradiance (W/m²), which measures the energy that reaches Earth.
One of the major concerns about alternative energies is the economical investment and because of it, this type of energy is nowadays, not sufficient enough to independently power our modern society. In spite of being the most abundant renewable source, only a small percentage of basic power used comes directly from solar source. That is because using a photovoltaic (PV) panel still costs more than burning fossil fuels [18]. However, the total availability and access to this resource from all countries, makes solar energy represents the objective in this project to supply energy to a single family house.

This type of energy can be collected in two different ways: Solar electric or solar thermal systems.

2.6. Photovoltaic Energy
Photovoltaic solar energy is obtained directly from the sun and converted into electricity. This kind of technology uses solar cells (PV cells) to convert the sunlight into electricity. A solar cell is made by a semiconductor material wafer, usually highly pure silicon, consisting of two layers with different properties: One is of n-type and the other is p-type material making a p-n junction. So, when the light radiation from the sun reaches the solar cell, photons hit the semiconductor materials and cause a movement of electrons to the n-type side and holes to the p-type side of the junction (Figure 12) [19]. This generates a voltage difference between the front and the back of the cell and a dissipation of power in the load.
The voltage produced by a silicon PV cell is around 0.6V. The efficiency of crystalline solar cells is generally 15% under STC [20]. PV cells are connected in series or parallel creating a PV modules, panels or arrays which allows reaching voltage levels commonly used and produce the amount of electricity needed by the load (Figure 13).

2.7. PV Systems

A grid connected PV system consists of a PV array, a DC and an AC switch and an inverter. If the system is not connected to the grid it must be complemented with a battery storage system and a charge controller. A system schematic is presented in figure 14. Solar electricity systems are used lately more and more to reduce the need for purchased household electricity in residential buildings.

The electricity not used in the building can be fed into the electricity grid and sold at a substantial lower price than the purchased electricity or be stored in a battery system to provide energy when the solar resource is not available (Night).

A grid-connected PV system can feed the electricity surplus of the PV system to the electricity grid. This gives larger flexibility in terms of PV system size and grid-connected systems almost always have some overproduction. With an off-grid system, storage is needed when installing a system larger than the actual building electricity load. All PV electricity from an off-grid system must be self-consumed.
2.7.1. Net metering and self-consumption of electricity from PV systems

The net metering is a metering system where the electricity grid is acting as the battery [21].

When the PV system delivers more energy than is used in the building, the surplus is exported to the grid. The price of exported electricity is determined by market price for electric energy. So is much more favourable to save energy than to export energy. However, if a kWh is defined as saved or exported depends on the metering scheme [22].

The length of the net metering period affects the amount of PV-electricity regards as saved or exported. The saved electricity fraction is increasing with the length of the metering period, so a larger PV-system can be installed without the need to export and sell electricity to the grid. The electric meter configuration affects the amount of self-consumed and produced excess electricity from PV systems being responsible of wrong measures that can vary in a wide way [23].

There are three different types of metering schemes: instantaneous metering, daily net metering and monthly net metering.

With the instantaneous metering, the generated PV electricity has to be used a once in the building. If the PV electricity generation is greater than the building electricity demand, the surplus will be exported to the electricity grid and sold.

With daily net metering, the generated PV electricity for a whole day is settled against the building electricity demand for the same day, i.e. the consumer pays for the net. With this scheme, the PV-system surplus is exported to the grid but not sold. The surplus accumulated at daytime is settled against the electricity demand later the same day when no or little PV electricity is generated. If the PV-electricity generation is larger than the building electricity demand over the whole day, i.e. there is a positive daily net, the net surplus is sold to an electricity company.

The same principle as for daily metering also applies for monthly net metering but the PV electricity generation and the electricity demand are settled monthly.

2.8. Advantages and disadvantages

When implementing renewable energies, there are some pros and cons. In this section some of them will be discussed as well as its implementation to households, promoting in this way self-consumption.

2.8.1. Advantages

Solar energy is a reliable, accessible, free and inexhaustible source of energy, so most of planet has the ability to collect some amount of solar power. According to the European Energy Policies, solar energy is non-polluting, does not create greenhouse gases, such as oil based energy does, nor does it create waste that must be stored, such as nuclear energy, neither noise contamination because there are no noise contamination because there are not mechanical pieces in movement.

The cost of new photovoltaic power is dropping rapidly, and if the photovoltaic industry continues to grow and improve technologically, by 2020 the cost will be comparable to the cost of conventional power. Also the installation of photovoltaic systems is quite easy and simple and they have a long life, around 20
years. Solar panels require very little maintenance beyond regular cleaning. Without moving parts to break and replace, after the initial costs of installing the panels, maintenance and repair costs are very reasonable.

Residential size solar energy systems also have very little impact on the surrounding environment, in contrast with other renewable energy sources such as wind and hydroelectric power. Increased self-consumption and demand response open up the possibility of peak shaving and can lower the risk of overvoltage and reduce large quantities of surplus electricity in the low voltage part of the grid. This will in turn enable an even higher penetration of intermittent power sources.

2.8.2. Disadvantages
The main problem of using solar energy is the cost involved; it requires a high investment in photovoltaic systems although the costs are recovered over the years too. Despite with advances in technology, solar panels are still expensive. Even when the cost of the panels is ignored, the system required to store the energy for use can also be quite costly.

Although some solar energy can be collected during even the cloudiest of days, efficient solar energy collection is dependent on sunshine. Even a few cloudy days can have a large effect on an energy system, particularly once the fact that solar energy cannot be collected at night is taken into account.

A higher penetration of intermittent decentralized energy generation, might affect the electricity distribution network negatively with voltage problems [24].

2.9. Energy Storage Systems
Renewable energies are based on a variable resource, which is one of the main problems of this kind of energy.

The storage system allows reducing the dependence on the resource because of without them, we cannot be able to produce energy out of the hours when the sun source is not available (Night) could not use electricity whenever we want. For this reason, the investment in a battery system will allow a household to increase the self-consumption of its PV-generated electricity, and thus, independence from the grid [12].

In self-consumption household there are two main ways of save energy: Batteries and Hot water accumulators. Batteries are the area where this project will focus.

2.9.1. Batteries
Batteries stores energy in an electrochemical form and are the most widely used device for energy storage in a variety of applications. They are based on electrochemical oxidation-reduction reactions that take place in electrodes separated by an electrolyte and store energy in the form of direct voltage (DC). It has a one way conversion efficiency of 85 to 90% [25].
There are two basic types:

- **Primary battery.** Converts chemical energy into electric energy, and the process is non-reversible.
- **Secondary battery.** Also known as the rechargeable battery. The round-trip conversion efficiency is between 70 and 80%.

There are three factors that will limit the size up to which a household battery system can increase PV electricity self-consumption of PV-generated electricity: (1) the energy capacity of the battery; (2) the power capacity of the battery; and (3) the capacity of the PV panel. That one of these acts as the limiting parameter depends on the size configuration of the PV panel and battery and the shape of the household load curve [12]. Electrochemical batteries are the most commonly ones used in households self-consumption because of its characteristics of power, energy and price.

There are at least six major rechargeable batteries available: Lead acid, Nickel-cadmium, Nickel-metal hydride, Lithium-ion, Lithium-polymer and Zinc-air batteries although the most used ones in households self-consumption are Lead acid and Lithium-ion batteries.

- **The lead acid battery** is the oldest and most developed electrochemical battery systems. It has many advantages besides its low cost and low requirement of maintenance and also some disadvantages, for example a low cycle life.

- **The lithium ion battery** is a fairly new technology which presents the biggest advantages in energy and specific power, storage efficiency, discharge performance and absence of memory effect. After six months of resting, they can still retain 80% of its load. However its biggest disadvantage is the cost.

To enhance the battery life, a depth discharge (DoD) restriction of 50% is implemented in the simulated system giving a battery life of 1700 full cycles. The end of life is reached when the battery capacity has fallen below 80% of its specified capacity.
2.9.2. Hot water accumulators

Hot water accumulators are a technology for Thermal Energy Storage (TES). This technology collects all the surplus thermal energy generated for a later use and store electricity as heat.

The most common way to store this energy is through sensible heat, reached by changing the temperature of what is called the storage material (Water, air, oil, brick, concrete or sand). These systems are used to preheat the incoming water that is going to be used for domestic hot water generation.
3. Method

Once we know the background of the thesis, it is time to start with the method that it is going to be followed, in order to get the aim of the thesis and be able to obtain the pertinent results and conclusions.

3.1. Location

As previously said, two systems will be studied in this thesis, the case in Sweden and in Spain. The difference between the weather and location are going to play an important role in this analysis.

- The dwelling chosen in Sweden is located in Älvsjö, in the region of Gävleborg, in the East of Sweden (60° 34’ 07”N, 17° 26’ 56” W). It consists in a single family house, used as a family residence during the whole year.

- According to the dwelling located in Spain is situated in Zaragoza, in the region of Aragón, in the North-East (41° 39’ 22”N, 00° 52’ 38” W). It also consists in a single family house, used as a family residence during the whole year, with the same consumptions as the one in Sweden, to be capable to compare both systems.

![Figure 16. Location of the systems to study](image)

This work consists on evaluating the solar resource in order to study if a PV system is worth it to carry out, as well as the sizing of the batteries which are going to help to provide energy when the solar resource will not be available. In addition, the house is connected to the grid for the basic supply of energy.
3.2. Household load
To carry out the simulations and the pertinent analysis it is necessary to know the energy requirements of the building. It is necessary to know how much energy is needed during the year.

In this case, to do the sizing of the PV system, the energy load profile of the dwelling is really important in order to know the energy consumption of the system and how much energy we need to cover it. The household load belongs to the demand of a single family dwelling heated through a heat pump system. Each point represents the total electricity consumption during the measured hour. The household has been measured over a year period: January 1, 2016 to December 31, 2016. This household load is going to be used in both cases so that the comparison in solar energy received will be easier to show. The distribution of the energy load is shown in figure 17:

![Figure 17. Load curve of the household.](image)

The annual electricity demand for this household is about 10 MWh. The designed system will cover totally the energy consumption during the summer months. The peak power of those months is 5 kWp.
Figure 18 shows the monthly distribution of the load in the single family house, the energy consumption is bigger during the winter because of the heating required needs. Since the radiation is bigger during summer months, the PV-system curve production is higher then.

The system will be sized to cover the energy demand during summer months as they are the months were the PV production is the highest. The battery system should be big enough to cover the overproduction of one day and keep it to assure the energy demand during the night, so the autonomy will be taken into account for one day.

To do the study of the Swedish and Spanish system, the same load curve is going to be used. Although the winter in Spain is softer than in Sweden, buildings have a worse insulation and the consumption of the heating could not vary so much. Analysing the same data will help to compare in a better way both countries.

3.3. Estimation of PV and batteries

**PV system**

Before start using the PVSYST software to do the design of the installation, is necessary to have an idea of how is going to be the system. So, once the load profile of the household is known, the size of the PV system will be calculated to cover the consumption of summer months as follows:

\[
P_{PV} (kWp) = \frac{E_{Load}}{P_{Output}}
\]
Where:

- $E_{Load}$ is the monthly average load for summer months
- $P_{Output}$ is the power production from 1kWp of PV-modules during a summer months in kWh/month, kWp

The average load during the summer months (June, July, and August) is about 650 kWh/month. A 1kWp PV system will deliver around 150kWh per month during May-July.

**Batteries**

When sizing a battery it is necessary to follow some guidelines to do it in the best way. The load of the system is one of the terms that affect the size of the capacity, as well as the efficiency of the rest of components of the system. The depth of discharge is an important factor due to the battery will not be discharged until the end in every use. The battery capacity in Ampere hours is going to be calculated as follows:

$$C_{Bat} (Ah) = \frac{E_{Load}}{U_b} \cdot \frac{d}{DoD}$$

Where:

- $E_{Load}$ is the daily average load for summer months
- $U_b$ is the battery bus voltage
- $d$ are the number of days of autonomy
- $DoD$ is the depth of discharge

The autonomy will be only considered for one day and the voltage of the battery system 24V. Also, highest battery capacities per unit will be selected to reduce the number of battery strings in parallel for a better charging balance. Normally, the recommended maximum number of strings in parallel is 4 [27].

### 3.4. PVSYST

The software PVSYST is going to be used to model and simulate the system [28]. It is a tool used to design photovoltaic systems that allows us to perform the study, simulation and analysis of complete data of photovoltaic systems (grid-connected, stand-alone, pumping or DC-grid systems) [29]. It also allows performing an economic analysis using real component costs, additional costs and investment conditions, in any currency. This software is developed by the University of Geneva, Switzerland.

The evaluation of solar resource in a self-consumption household with batteries system requires the simulation of the PV system together with an optimization of the dispatch of the battery system. The simulation is done over one year with a temporal step of 1h. It aims at maximizing self-sufficiency for the household, minimizing the amount of electricity bought from the grid, which in turn maximizes PV electricity self-consumption. When maximizing this system, the sizes of the PV system and the battery need to be predefined and limited, as otherwise the maximization of self-sufficiency would always result in a PV-battery system with the largest allowed installation size. All of this will be study in the simulations.
3.5. Description of the simulation
The data introduced in the calculation software is going to be showed in the next steps.

3.5.1. Site and Meteo
Although PVSYST has a large meteorological database to which we can add data from other stations, the locations we are going to study (Zaragoza, Spain and Gävle, Sweden) are not available, so PVgis database is going to be checked. The data provided by this source will be imported into the software meteo database.

PVgis has been developed by the European Commission Joint Research Centre. The focus of this free tool is researching in solar resource assessment, photovoltaic (PV) performance studies, and the dissemination of knowledge and data about solar radiation and PV performance [30]. It gives access to irradiation and temperature monthly data, in this way the missing data will be provided and inserted into the simulation software.

Mean daily irradiation values on horizontal plane according to PVgis of the situation it is going to be study are shown in table 2.

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Irradiation Zaragoza</th>
<th>Irradiation Gävle</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1920</td>
<td>262</td>
</tr>
<tr>
<td>February</td>
<td>3070</td>
<td>868</td>
</tr>
<tr>
<td>March</td>
<td>4690</td>
<td>1930</td>
</tr>
<tr>
<td>April</td>
<td>5520</td>
<td>3600</td>
</tr>
<tr>
<td>May</td>
<td>6580</td>
<td>5230</td>
</tr>
<tr>
<td>June</td>
<td>7370</td>
<td>5540</td>
</tr>
<tr>
<td>July</td>
<td>7690</td>
<td>5190</td>
</tr>
<tr>
<td>August</td>
<td>6630</td>
<td>3810</td>
</tr>
<tr>
<td>September</td>
<td>5130</td>
<td>2380</td>
</tr>
<tr>
<td>October</td>
<td>3560</td>
<td>1060</td>
</tr>
<tr>
<td>November</td>
<td>2260</td>
<td>386</td>
</tr>
<tr>
<td>December</td>
<td>1700</td>
<td>150</td>
</tr>
</tbody>
</table>

Thanks to the option of “Import meteo data” both places are going to be included into the database list

3.5.2. Orientation
Several orientations are going to be analysed. The direction of the solar panels are facing south and the angles of inclination will be 20º, 37º, 45º and 70º tilted from the horizontal plane. The optimization of tilt angle of the solar panels surface at a certain site will provide the maximum output power over the year [31], so the optimisation will be calculated for a yearly irradiation yield for Spain and Sweden. The azimuth will be set at 0º and the modules are fixed so no tracking is used.
3.5.3. Horizon
This term simulates the horizon line letting to know how much useful radiation is available in the system. The red line that appears in the window corresponds to obstacles around the solar field meanwhile the blue line represents the auto-shading due to the modules. As bigger is the tilt, as bigger will be this line. In this project, no auto-shading will be considered.

3.5.4. Near shadings
This term considers the shadow generated over the panels due to close objects like buildings, trees, and fence. In this case, there is no shadowing effect assumed.

3.5.5. System
This part of the program let the user to import the load curve or select the peak power needed in the system. According to the type of solar panels selected, the number of them and the inverters as well as the way they will be connected (strings) change.

In this section, when we select the type of solar panels, several messages could appear in the screen:

- The Array MPP operating Voltage is lower than the Inverter Minimum Operating Voltage. That means the inverter doesn’t receive enough voltage, there are no enough panels in each string.
- The Inverter power is slightly oversized. The inverter is oversized according to the installation and it will never reach the optimal operating point.
- The Inverter power is strongly oversized. The inverter is strongly oversized according to the installation and it is needed to change it.
- The Inverter power is slightly undersized. The inverter is lower than the one needed. This is a good fact due to the calculation is made according to the peak power of the panels that is reached few times.
- The Inverter power is strongly undersized. The inverter is strongly undersized according to the installation and it is better to change it.
• *The Array MPP operating Voltage is greater than the Inverter Minimum Operating Voltage.* There are too many panels in each string.

Solar module
The solar module selected to simulate the system is a Topsun PV module, TS-S410 whose characteristics are shown in the table 3.

**TABLE 3. CHARACTERISTICS OF THE SOLAR MODULE**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Si-mono</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power</td>
<td>410 Wp</td>
</tr>
<tr>
<td>Vmpp</td>
<td>49.22 V</td>
</tr>
<tr>
<td>Impp</td>
<td>8.33 A</td>
</tr>
<tr>
<td>Length</td>
<td>1960 mm</td>
</tr>
<tr>
<td>Width</td>
<td>1308 mm</td>
</tr>
</tbody>
</table>

Inverter
The inverter change the electricity DC production into AC to supply this energy to the dwelling or to dump it to the grid. The inverter selected to simulate the system is a SMA inverter, Sunny Boy SWR 2500 U whose characteristics are shown in the table 4. It has been chosen to follow the Maximum Power Point each time.

**TABLE 4. CHARACTERISTICS OF THE INVERTER**

<table>
<thead>
<tr>
<th>Input voltage, MPP range</th>
<th>234-550 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max open circuit voltage</td>
<td>≤ 600 V DC</td>
</tr>
<tr>
<td>Max input current</td>
<td>13 A DC</td>
</tr>
<tr>
<td>Max DC power</td>
<td>2710 W DC</td>
</tr>
</tbody>
</table>

3.5.6. Simulation
The simulations which are going to be run in this work will represent several scenarios that will help us to understand in a better way the system and be able to write better conclusions about the results. As it has previously said, the case of Sweden and Spain will be represented and compared each other.

All these scenarios will be pursuing a common goal: Try to cover the energy demand of the dwelling from the PV system production. If the demand is lower than the produced by the PV system, the surplus energy will be stored and used to charge the batteries. If the production is even higher and the batteries are already full, the surplus energy will be dumped into the grid. On the other hand, in the case that the energy demand is higher than the production of the system, the energy stored in the batteries will be used and if the demand is even higher, the surplus will be provided from the grid.
System connected to the grid

First of all, the model is connected to the grid. This will let us know how many modules are needed to cover the demand during the months with high PV production. The scenarios stated are going to take place in Sweden (Gävle) and Spain (Zaragoza) with the following tilts:

- Tilt 20º
- Tilt 37º
- Tilt 45º
- Tilt 70º

![Figure 20. Scheme of the PV system connected to the grid](image)

The type and disposition of the solar modules is going to be the same in all scenarios. The generation of electricity will change with the tilt. The difference acquired between the PV production and the load consumption is called overproduction and this term is going to help us to find the suitable battery for the system.

Stand-alone system

As the PV system installed in the household is already calculated as well as the type of modules chosen, it is time to do the sizing of the batteries. The system will be connected to a diesel generator acting as a back-up system which is going to do the same function as the grid: It will Supply energy every time the PV system is not able to provide energy.
Although the battery size needed to cover the whole energy overproduced has been calculated, some simulations will be performed in order to obtain different results and obtain better conclusions of which type of batteries are more suitable in the system, so that we could store the maximum amount of energy without dumping it to the grid.

The scenarios that are going to be analysed are presented in table 5.

**Table 5. Scenarios of the different batteries simulations**

<table>
<thead>
<tr>
<th></th>
<th>Nserie</th>
<th>Nparallel</th>
<th>Voltage (V)</th>
<th>Capacity (Ah)</th>
<th>Total Capacity (Ah)</th>
<th>Total Capacity (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System 1</strong></td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>219</td>
<td>876</td>
<td>10.5</td>
</tr>
<tr>
<td><strong>System 2</strong></td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>65</td>
<td>260</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>System 3</strong></td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>729</td>
<td>1458</td>
<td>17.5</td>
</tr>
<tr>
<td><strong>System 4</strong></td>
<td>1</td>
<td>2</td>
<td>24</td>
<td>1710</td>
<td>3420</td>
<td>82</td>
</tr>
<tr>
<td><strong>System 5</strong></td>
<td>1</td>
<td>1</td>
<td>24</td>
<td>1710</td>
<td>1710</td>
<td>41</td>
</tr>
<tr>
<td><strong>System 6</strong></td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>296</td>
<td>592</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>System 7</strong></td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>100</td>
<td>400</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>System 8</strong></td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>169</td>
<td>676</td>
<td>8</td>
</tr>
<tr>
<td><strong>System 9</strong></td>
<td>12</td>
<td>4</td>
<td>2</td>
<td>908</td>
<td>3632</td>
<td>7.3</td>
</tr>
<tr>
<td><strong>System 10</strong></td>
<td>12</td>
<td>1</td>
<td>2</td>
<td>2025</td>
<td>2025</td>
<td>4.1</td>
</tr>
</tbody>
</table>

These systems have been chosen according different types of batteries that are available on the market nowadays. The configuration have been designed in order to simulate different alternatives and find out which one is more suitable so the difference between all the systems will be easier to analyse.

The investment analysis of it and the profitability of one or another type will be studied in the economic evaluation.
3.6. Economic evaluation

An important fact of the analysis of a system is usually the required economic investment. Sometimes an interesting project does not have any future because of the economical investment that implies is bigger than the incoming money, so it is important to know before developing it if it is economically viable or not.

The solar radiation absorbed by the solar panels is the master key in this type of systems. Figures 22 shows how PV-systems located in lower latitude areas have a higher irradiation and shorter energy pay-back time. The investments in the system has also a shorter pay-back time.

![Figure 22. Energy Pay-Back time of PV roof systems. Geographical comparison [32]](image)

Figure 22 shows the annual solar radiation on horizontal surfaces in Europe as well as the Energy Pay-Back (EPBT). EPBT means how long time it will take for the PV-module to produce as much energy as was used when the module was constructed. The lower is the latitude the lesser is this payback. If the pay-back is low, the project will be more likely to carry out than if it is bigger. Spain has a clear advantage according to the location however on the economic scenario; the lack of subsidies nowadays that the government was giving until 2012 has slowed down the expansion and development of this technology. On the other hand in the Swedish system, although the location makes this technology to invest more energy that went into the making system, the government has been introducing policies to increase the installation and energy production through this technology which can do this alternative more inviting.

To do the economic analysis, the calculation is going to be done considering the price of the battery system of the PV system as well as the price of buying electricity due to the PV system does not produce enough energy and subtracting the savings earned due to overproduction of energy generated thanks to the solar resource. The rest of the installation will be considered equal in both cases.
3.6.1. Analysis of the battery prices
As in each system, the amount and size of the batteries changes, a table will be elaborated in order to see the prices of the different battery system according to its capacity [33].

<table>
<thead>
<tr>
<th>System</th>
<th>Voltage (V)</th>
<th>Capacity (Ah)</th>
<th>Energy Storage (kWh)</th>
<th>Price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>219</td>
<td>10.5</td>
<td>485</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>65</td>
<td>3.1</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>729</td>
<td>17.5</td>
<td>3100</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>1710</td>
<td>82</td>
<td>11,500</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>1710</td>
<td>41</td>
<td>11,500</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>296</td>
<td>7.1</td>
<td>849</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>100</td>
<td>4.8</td>
<td>175</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>169</td>
<td>8</td>
<td>225</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>908</td>
<td>7.3</td>
<td>745</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>2025</td>
<td>4.1</td>
<td>1,594</td>
</tr>
</tbody>
</table>

3.6.2. The case of Sweden
The price for achieving electricity that a user has to pay in residential buildings in Sweden is around 0.40kr/kWh (1-1.1SEK/kWh including taxes). The price for selling is about 0.3SEK/kWh including taxes. However, this price changes according to the year. Table 6 shows the different variations that the price of the energy has undergone in the past years [34]:

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2015</th>
<th>2014</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>28.19</td>
<td>29.91</td>
<td>32.84</td>
<td>41.42</td>
</tr>
<tr>
<td>Feb</td>
<td>19.18</td>
<td>28.11</td>
<td>30.14</td>
<td>39.43</td>
</tr>
<tr>
<td>Mar</td>
<td>21.61</td>
<td>25.2</td>
<td>26.53</td>
<td>44.46</td>
</tr>
<tr>
<td>Apr</td>
<td>22.06</td>
<td>25.23</td>
<td>27.17</td>
<td>43.91</td>
</tr>
<tr>
<td>May</td>
<td>23.66</td>
<td>22.37</td>
<td>35.11</td>
<td>36.86</td>
</tr>
<tr>
<td>Jun</td>
<td>33.71</td>
<td>14.86</td>
<td>31.47</td>
<td>34.2</td>
</tr>
<tr>
<td>Jul</td>
<td>28.95</td>
<td>9.07</td>
<td>29.76</td>
<td>34.22</td>
</tr>
<tr>
<td>Aug</td>
<td>30.48</td>
<td>14.42</td>
<td>34.54</td>
<td>40.38</td>
</tr>
<tr>
<td>Sep</td>
<td>29.03</td>
<td>20.83</td>
<td>36.46</td>
<td>44.61</td>
</tr>
<tr>
<td>Oct</td>
<td>36.18</td>
<td>22.36</td>
<td>31.27</td>
<td>41.36</td>
</tr>
<tr>
<td>Nov</td>
<td>40.98</td>
<td>24.1</td>
<td>30.15</td>
<td>36.96</td>
</tr>
<tr>
<td>Dec</td>
<td>33.07</td>
<td>18.33</td>
<td>31.47</td>
<td>32.59</td>
</tr>
</tbody>
</table>
3.6.3. The case of Spain

In Spain, the price for achieving energy differs a bit. The electric tariff is divided in several periods and according to the one we are consuming energy in, the total price changes. As this thesis is not going to be a depth study in the economical fact, but only to have an idea of the difference between both systems, we will take an average price to get a rough idea. If not, it should have been taken into account the whole behaviour of the dwelling, the hours of consuming and separate them between different periods.

To obtain the average price, it has been consulted several marketing companies of low voltage tariffs for residential clients, and it will be used an average price of it.

| TABLE 8. PRICE OF DIFFERENT MARKETING COMPANIES IN SPAIN FOR TARIFFS OF TWO PERIODS (€/kWh) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| 2.0 A                           | P1              | 0.123           | 0.125           | 0.120           | 0.123           |
| 2.1 A                           | P1              | 0.139           | 0.128           | 0.145           | 0.137           |
| 2.0 DHA                         | P1              | 0.155           | 0.147           | 0.143           | 0.148           |
|                                 | P2              | 0.079           | 0.07            | 0.061           | 0.070           |
| 2.1 DHA                         | P1              | 0.167           | 0.159           | 0.174           | 0.167           |
|                                 | P2              | 0.089           | 0.08            | 0.075           | 0.081           |
|                                 |                 |                 |                 |                 | 0.121           |

In the case of selling energy, as acting as a generator of energy some taxes have to be paid. In table 8 is shown the evolution of the selling prices dependant on the pool prices [35]. The price for selling is going to be estimated in an average price of 57.77€/MWh including taxes.

| TABLE 9. FINAL PRICE OF THE ELECTRICITY IN THE FREE MARKET (€/MWh) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Jan                             | 2015            | 2014            | 2013            |
| Feb                             | 66.7            | 49.92           | 64.66           |
| Mar                             | 58.23           | 32.72           | 58.25           |
| Apr                             | 56.08           | 39.59           | 40.38           |
| May                             | 58.96           | 39.86           | 31.61           |
| Jun                             | 57.49           | 52.57           | 53.83           |
| Jul                             | 66.58           | 61.15           | 52.72           |
| Aug                             | 72.2            | 59.19           | 61.92           |
| Sep                             | 64.74           | 58.84           | 56.69           |
| Oct                             | 60.73           | 69.57           | 60.53           |
| Nov                             | 59.95           | 67.67           | 64.23           |
| Dec                             | 61.68           | 59.56           | 55.17           |
|                                 | 63.36           | 61.36           | 81.05           |
4. Results

In this chapter the simulations of several scenarios are made through the software PVSYST and some results are exposed. These results will determine the conclusions we will establish for this thesis.

4.1. System connected to grid

First of all is shown the amount of energy collected with a PV system of 5kWp (Enough to cover the demand of summer).

4.1.1. Tilt 20° South

<table>
<thead>
<tr>
<th>Design of the PV-System</th>
<th>Gävle</th>
<th>Zaragoza</th>
</tr>
</thead>
<tbody>
<tr>
<td>N modules</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>PV Installation</td>
<td>4920 Wp</td>
<td>4920 Wp</td>
</tr>
<tr>
<td>Produced Energy</td>
<td>4.46 MWh/year</td>
<td>7.76 MWh/year</td>
</tr>
</tbody>
</table>

4.1.2. Tilt 37° South

<table>
<thead>
<tr>
<th>Design of the PV-System</th>
<th>Gävle</th>
<th>Zaragoza</th>
</tr>
</thead>
<tbody>
<tr>
<td>N modules</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>PV Installation</td>
<td>4920 Wp</td>
<td>4920 Wp</td>
</tr>
<tr>
<td>Produced Energy</td>
<td>4.70 MWh/year</td>
<td>8.01 MWh/year</td>
</tr>
</tbody>
</table>

4.1.3. Tilt 45° South

<table>
<thead>
<tr>
<th>Design of the PV-System</th>
<th>Gävle</th>
<th>Zaragoza</th>
</tr>
</thead>
<tbody>
<tr>
<td>N modules</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>PV Installation</td>
<td>4920 Wp</td>
<td>4920 Wp</td>
</tr>
<tr>
<td>Produced Energy</td>
<td>4.72 MWh/year</td>
<td>7.93 MWh/year</td>
</tr>
</tbody>
</table>

4.1.4. Tilt 70° South

<table>
<thead>
<tr>
<th>Design of the PV-System</th>
<th>Gävle</th>
<th>Zaragoza</th>
</tr>
</thead>
<tbody>
<tr>
<td>N modules</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>PV Installation</td>
<td>4920 Wp</td>
<td>4920 Wp</td>
</tr>
<tr>
<td>Produced Energy</td>
<td>4.33 MWh/year</td>
<td>6.95 MWh/year</td>
</tr>
</tbody>
</table>

Tables 10-13, show the results obtained for the simulations of both systems and different tilts.

4.2. Stand alone

In this section, several simulations were run in order to get more information about the behaviour of the system and the conditions where are they going to be performance. The battery systems shown in next tables are described in the method part.
The optimum angle where the maximum amount of energy is reached has been chosen for each location. It has been obtained thanks to the PVsyst software.

4.2.1. Gävle. α=45°

The results for the batteries simulations with different characteristics are shown in Table 14.

<table>
<thead>
<tr>
<th>Energy available (kW/year)</th>
<th>Specific prod (kWh/kWp/year)</th>
<th>Capacity (kWh)</th>
<th>Used Energy (kW/year)</th>
<th>Unused Energy (kW/year)</th>
<th>PR (%)</th>
<th>SF (%)</th>
<th>Back-up (kW/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>4741</td>
<td>964</td>
<td>10.5</td>
<td>10265</td>
<td>251</td>
<td>74.27</td>
<td>40.38</td>
</tr>
<tr>
<td>S2</td>
<td>4793</td>
<td>974</td>
<td>3.1</td>
<td>10266</td>
<td>1007</td>
<td>61.12</td>
<td>33.23</td>
</tr>
<tr>
<td>S3</td>
<td>4735</td>
<td>962</td>
<td>17.5</td>
<td>10265</td>
<td>161</td>
<td>78.11</td>
<td>42.47</td>
</tr>
<tr>
<td>S4</td>
<td>4725</td>
<td>960</td>
<td>82</td>
<td>10263</td>
<td>4</td>
<td>80.86</td>
<td>43.97</td>
</tr>
<tr>
<td>S5</td>
<td>4732</td>
<td>962</td>
<td>41</td>
<td>10264</td>
<td>116</td>
<td>78.68</td>
<td>42.78</td>
</tr>
<tr>
<td>S6</td>
<td>4598</td>
<td>935</td>
<td>7.1</td>
<td>10272</td>
<td>634</td>
<td>63.06</td>
<td>32.88</td>
</tr>
<tr>
<td>S7</td>
<td>4609</td>
<td>937</td>
<td>4.8</td>
<td>10264</td>
<td>950</td>
<td>62.05</td>
<td>32.36</td>
</tr>
<tr>
<td>S8</td>
<td>4596</td>
<td>934</td>
<td>8</td>
<td>10271</td>
<td>606</td>
<td>65.82</td>
<td>34.32</td>
</tr>
<tr>
<td>S9</td>
<td>4573</td>
<td>929</td>
<td>7.3</td>
<td>10264</td>
<td>23</td>
<td>80.84</td>
<td>42.16</td>
</tr>
<tr>
<td>S10</td>
<td>4575</td>
<td>930</td>
<td>4.1</td>
<td>10264</td>
<td>57</td>
<td>79.84</td>
<td>41.43</td>
</tr>
</tbody>
</table>

Where:

- Energy available is the amount of energy that we are able to collect in each system.
- Specific production is the annual production of electric energy from a PV-system of 1kWp.
- Capacity shows the total size of the battery system.
- Used Energy is the amount of energy used along the year.
- Unused Energy is the amount of energy not possible to store.
- PR (Performance Ratio), is a relation between the real and the nominal efficiency of the system
- SF (Solar fraction), is the amount of energy provided by the solar technology divided by the total energy required
- Back-up is the extra energy (fuel) needed to supply energy to the system.

Next figure will help us to have a more visual acknowledgement of the results obtained for the case of Gävle.
4.2.2. Zaragoza, α=37°

The results for the batteries simulations with different characteristics are shown in Table 15.

<table>
<thead>
<tr>
<th>Case</th>
<th>Energy available (kW/year)</th>
<th>Specific prod (kWh/kWp/year)</th>
<th>Capacity (kWh)</th>
<th>Used Energy (kW/year)</th>
<th>Unused Energy (kW/year)</th>
<th>PR (%)</th>
<th>SF (%)</th>
<th>Back-up (kW/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>8006</td>
<td>1627</td>
<td>10.5</td>
<td>10264</td>
<td>724</td>
<td>46.36</td>
<td>44.89</td>
<td>5619</td>
</tr>
<tr>
<td>S2</td>
<td>8282</td>
<td>1683</td>
<td>3.1</td>
<td>10225</td>
<td>2701</td>
<td>33.06</td>
<td>48</td>
<td>5230</td>
</tr>
<tr>
<td>S3</td>
<td>7984</td>
<td>1623</td>
<td>17.5</td>
<td>10265</td>
<td>396</td>
<td>73.07</td>
<td>70.75</td>
<td>3004</td>
</tr>
<tr>
<td>S4</td>
<td>7977</td>
<td>1621</td>
<td>82</td>
<td>10263</td>
<td>293</td>
<td>74.58</td>
<td>72.20</td>
<td>2853</td>
</tr>
<tr>
<td>S5</td>
<td>7982</td>
<td>1622</td>
<td>41</td>
<td>10264</td>
<td>369</td>
<td>73.45</td>
<td>71.11</td>
<td>2966</td>
</tr>
<tr>
<td>S6</td>
<td>8247</td>
<td>1676</td>
<td>7.1</td>
<td>10270</td>
<td>1840</td>
<td>55.37</td>
<td>53.61</td>
<td>4769</td>
</tr>
<tr>
<td>S7</td>
<td>8279</td>
<td>1683</td>
<td>4.8</td>
<td>10247</td>
<td>2608</td>
<td>50.84</td>
<td>49.22</td>
<td>5195</td>
</tr>
<tr>
<td>S8</td>
<td>8242</td>
<td>1675</td>
<td>8</td>
<td>10269</td>
<td>1701</td>
<td>58.23</td>
<td>56.38</td>
<td>4483</td>
</tr>
<tr>
<td>S9</td>
<td>8194</td>
<td>1665</td>
<td>7.3</td>
<td>10263</td>
<td>353</td>
<td>75.83</td>
<td>73.41</td>
<td>2729</td>
</tr>
<tr>
<td>S10</td>
<td>8195</td>
<td>1666</td>
<td>4.1</td>
<td>10265</td>
<td>387</td>
<td>74.60</td>
<td>72.23</td>
<td>2852</td>
</tr>
</tbody>
</table>

Where:
- *Energy available* is the amount of energy that we are able to collect in each system.
- *Specific production* is a relation between an installation of 1000kWp and the nominal power.
- *Capacity* shows the total size of the battery system.
- *Used Energy* is the amount of energy used along the year.
- *Unused Energy* is the amount of energy not possible to store.
- **PR** (Performance Ratio), is a relation between the real and the nominal efficiency of the system
- **SF** (Solar fraction), is the amount of energy provided by the solar technology divided by the total energy required
- **Back-up** is the extra energy (fuel) needed to supply energy to the system.

Figure 24 will help us to have a more visual acknowledgement of the results obtained for the case of Zaragoza.

**Figure 24. Evolution of the unused energy according to the capacity of the system (kWh) Case of Spain**
4.3. Economical study

4.3.1. The case of Sweden

The results of the economical study in Gävle are shown in table 16.

<table>
<thead>
<tr>
<th>N batteries</th>
<th>Battery price (€)</th>
<th>Price batteries (€)</th>
<th>Excess Energy (kW/year)</th>
<th>Price sell Energy (€/kWh)</th>
<th>Grid Energy (kW/year)</th>
<th>Price buy Energy (€/kWh)</th>
<th>Total Electricity (€)</th>
<th>Total System (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>8</td>
<td>485</td>
<td>3880</td>
<td>251</td>
<td>0.03</td>
<td>6121</td>
<td>0.11</td>
<td>666</td>
</tr>
<tr>
<td>S2</td>
<td>8</td>
<td>120</td>
<td>960</td>
<td>1007</td>
<td>0.03</td>
<td>6855</td>
<td>0.11</td>
<td>724</td>
</tr>
<tr>
<td>S3</td>
<td>4</td>
<td>3100</td>
<td>12400</td>
<td>161</td>
<td>0.03</td>
<td>5906</td>
<td>0.11</td>
<td>645</td>
</tr>
<tr>
<td>S4</td>
<td>2</td>
<td>11500</td>
<td>23000</td>
<td>4</td>
<td>0.03</td>
<td>5751</td>
<td>0.11</td>
<td>633</td>
</tr>
<tr>
<td>S5</td>
<td>1</td>
<td>11500</td>
<td>11500</td>
<td>116</td>
<td>0.03</td>
<td>5874</td>
<td>0.11</td>
<td>643</td>
</tr>
<tr>
<td>S6</td>
<td>4</td>
<td>849</td>
<td>3396</td>
<td>634</td>
<td>0.03</td>
<td>6898</td>
<td>0.11</td>
<td>740</td>
</tr>
<tr>
<td>S7</td>
<td>8</td>
<td>175</td>
<td>1400</td>
<td>950</td>
<td>0.03</td>
<td>6943</td>
<td>0.11</td>
<td>735</td>
</tr>
<tr>
<td>S8</td>
<td>8</td>
<td>225</td>
<td>1800</td>
<td>606</td>
<td>0.03</td>
<td>6748</td>
<td>0.11</td>
<td>724</td>
</tr>
<tr>
<td>S9</td>
<td>48</td>
<td>745</td>
<td>35760</td>
<td>23</td>
<td>0.03</td>
<td>5878</td>
<td>0.11</td>
<td>646</td>
</tr>
<tr>
<td>S10</td>
<td>12</td>
<td>1594</td>
<td>19128</td>
<td>57</td>
<td>0.03</td>
<td>5992</td>
<td>0.11</td>
<td>657</td>
</tr>
</tbody>
</table>

Table 16 and 17 show according to each case simulated, the price of the battery system as well as the money earned for dumping energy to the grid and the one that it has to be paid for buying energy from the grid.
Price batteries refer only to the price of each battery multiplied by the number of batteries in each system. The price of the total PV Solar System has not been calculated since the purpose is only to do a comparison between each system where this investment to do the installation is supposed to be constant. Total electricity is the result of the earn money due to dump to the grid the surplus energy generated that is not possible to store within the battery system, less the amount of energy that we need to demand to cover the household load.
5. Discussion

Although sun is a worldwide available energy resource, the latitude affects in a really significant way the energy collected by the modules. As bigger is the latitude, as lower is the amount of solar energy collected.

As we can appreciate from table 10 to 13, the maximum energy provided by the Swedish PV-system is obtained for a tilt of 45° where the production reaches 960 kWh/kWp/year. For the case of Spain this result is even higher as we could expect, although, the maximum production is reached for a tilt of 37° achieving a production of 1627 kWh/kWp/year.

In the case of a tilt of 20° the production in both systems decreases compared with the optimum results, nevertheless this results are more profitable than the ones obtained in the last case (70°) were the tilt is quite high. This is because the season with more production of solar energy is the summer, where the solar irradiation is bigger. Changing the angle relation Sun and the tilt of the panel is one of the causes that make the energy production to be much lower because of as lower is it, as lower is the energy obtained.

However when sizing the batteries, the overproduction criteria was the one used to design it. In this case, the overproduction in the case of Sweden is bigger than the one in Zaragoza. This could happen because of overproduction depend on two factors: Load profile and solar radiation.

Both factors are inversely proportional to overproduction. So, based on the difference between the PV energy generated and the load consumption for the system, the size of the batteries has been calculated for the day with more overproduction. This day determines the size of the capacity because of being the day with more energy produced and also the autonomy criteria of the system is chosen to be one day. This day is not the same for neither of these systems, so it could happen that the day with more solar production and less load in Sweden, was one of the days with less solar production in Spain. From the results obtained thanks to the simulation it is possible to appreciate that the specific production in Spain in almost the double as in Sweden.

From Figures 23 and 24 where the relation between the capacity of the battery system and the unused energy are shown, there is a point where despite of increasing the size of the batteries, the energy unused does not decrease as fast. So this curve it is useful to decide that the range to choose a battery system could be between 10 and 20 kWh in both systems.

Regarding the amount of unused energy, it is possible to appreciate that is bigger in the case of Spain, due to the energy generated is bigger as well as the available energy. The energy required for the system as well as the size of the batteries are kept constant, so the amount of energy that needs to be dumped into the grid increases.

Finally, from the economic study is possible to determine that system 2 is the most profitable to implant in both cases. Thanks to it, it is possible to store 3.1 kWh although the capacity is one of the lowest one. This may be due to the lack of subsidies considered in this thesis that could help to the initial investment of the PV installation since the payback of this kind of technologies could be around 20 years and this study has been only based in one year. On the other hand, it is useful to remark that the Spanish system gives more benefits than the Swedish, and despite what we could expect at the beginning the range of prices for buy or selling energy are quite similar.
6. Conclusions

One of the objectives of the future policies mentioned before is to reach near zero energy buildings, where the energy supplied by conventional sources implied around a 32% of the total world energy produced. To begin with, reducing the supply of energy from conventional sources like fossil fuels could help to achieve these objectives. Thanks to this document we are able to say that is possible a future without a deep dependence on fossil fuels but it is also needed to increase the benefits for implant this alternatives technologies.

In this case, the simulations for the stand alone system, they have been carried out setting the number of solar modules, the type and characteristics of it, and from it compare the amount of energy obtained in each case. Another line of study could be setting the amount of energy it is wanted to obtain and from it, calculate the number of modules as well as the size of them needed to cover that demand.

As we could expected, the results from the stand alone system obtained, have corroborated that the theoretical optimum tilt 37° is the optimum tilt for Gävle, as it is 45° for the case of Zaragoza.

Figures 23 and 24 previously show that as bigger is the capacity of the battery, as lower is the energy produced by the system unused. It is important to choose a system of batteries placed in the middle, there is a time where increase the size of the battery does not compensate the investment of an extra capacity since during the months with less production, this capacity is not going to be covered at all.

However due to the lack of revenues taken in account and the profitability of the installation we only can say that with this study, the Spanish system represents more benefits than the Swedish one due to is necessary to acquire less amount of energy from the grid as the solar production is higher. Sweden has a lower solar radiation but nevertheless higher revenues in solar technology (It is needed higher batteries capacity) and Spain has a wider solar radiation but taxes to dump it into the grid are higher and there are no financial support to implement this type of technology.

System 3 would be the right option according to technical specifications although with a really high initial investment. To end up with, I would choose system number 1 (4.92 kWp) in both studies, where the sizing of the battery system is within the design parameters (10.5 kWh) and the total investment is around 4500 € where the rest of the installation costs have not been taking into account (It is only considered the battery system cost and the price of the electricity achieved needed to supply the household).
References


