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Sizing of Photovoltaic Systems and Simulation for Energy Production

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Abstract

Photovoltaic systems are one of the most promising renewable energies since it has a potential of reducing energy consumption and hence decrease pollution [1]. Application market and global photovoltaic manufacturing industries have experience in the 21st century remarkable growth[2]. The high cost of photovoltaic solar power makes it necessary, before undertaking any subsequent study, to dimension photovoltaic installations as accurately as possible to increase the efficiency of utilization.

Dimensioning the solar power generated by the system is crucial to decrease the excess in production and to lower the cost as much as possible [3]. The energy in the output from the photovoltaic systems should be analyzed since it directly influences the necessity of the battery.

The importance of zero-emission transportation is being recognized by a growing number of institutions and research facilities worldwide. However, the vehicle's zero-emissivity is a complicated topic that should be understood to not only aim to the absence of emissions while the vehicle is in operation but also while charging from a renewable source of energy[4]. Having an electric vehicle for a household that has a photovoltaic system makes the house energetically independent and with zero emissions. The sizing of the panels for the charging of the electric vehicle is possible through a simple calculation.

There are many tools online and software that can size a photovoltaic system *(refer to2.11)*, however the parameters required by the software are not very user friendly. The aim of the present thesis is to provide Midori S.r.l[5], the company with whom the thesis was prepared, the production curves of numerous houses to provide the users with the necessary information and details for the purpose of making an aware decision to become energy independent. Similarly, for electric vehicles, the calculation of the number of panels needed to charge the car is achieved. The design process and sizing of the photovoltaic system is a procedure that requires tackling many technical aspects *(refer to 2)*.

Since the data available is limited as it is obtained through an interview, the calculation was made after making some assumptions.

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1 Introduction

In 2009, photovoltaic reached the third place following wind and gas in Europe for installed capacity that year. By the end of 2010, there was more than 30 GW of PV installed. The world's expanding need for energy, the effects of climate change, the escalating environmental harm, and the dearth of fossil fuels have all contributed to the development of renewable energies. We have known for many years that the energy from the sun that reaches the surface of the earth each day could power the entire human race several times over. The time has come for solar photovoltaic (PV) energy to play a role in the fight against global warming and in the transition to a carbon-free economy. Additionally, it is a successful industry sector in and of itself[6].

Many startups are being created for the purpose of increasing the efficiency for renewable energy developments and their positive effect on the climate change [7]. The sizing of the photovoltaic systems accurately achieves this aim, and the production curves are very much needed. Their calculation requires parameters and specific data however, assumptions can be made for some of the input parameters and the production curves can be realized. The purpose of this thesis is to size photovoltaic systems of the houses profiles provided by Midori S.r.l [5] and deliver the hourly production curves for the consumption profiles of the houses available.

The datasets and data used in this research project come from Ned, the first smart intelligent meter developed and created in Italy by the Turin-based SME Midori, born in Italy of I3P, the Innovative Business Incubator of the Turin Polytechnic. Ned is considered one of the first smart home energy consumption monitoring systems, which allows you to constantly keep track of the waste of electricity. The fundamental mission of the Midori team, with their flagship project Ned, is proposed first to encourage a massive reduction in consumption in domestic homes with obvious beneficial effects also as regards the reduction of CO_2 emissions. The main customers of the company and users of the Ned service are above all those families who intend to reduce their waste of electricity and reduce spending on bills, but also the electricity grid operator.

One of the major problems for the massive applicability of electric vehicles (EVs) is the scarce capacity of conventional electrical energy storage systems. In a particular situation in solar power can become a solution for reducing transport costs[8]. Electric vehicles can work perfectly on a household solar system as it makes the perfect duo with it. Similarly, to the sizing of solar systems to a house, calculation to obtain the number of panels required to charge an electric car can be achieved *04.4)*. The vehicle to grid system is tackled as it makes the electric car a small provider of energy for any appliance in the house.

1.1. Preliminary Concepts

A photovoltaic (PV) system is made up of one or more solar panels, an inverter, and other mechanical and electrical parts that capture solar energy to produce electricity. PV systems come in a wide range of sizes, from compact rooftop or portable units to enormous utility-scale power plants[9].

The photovoltaic effect is the mechanism through which sunlight, which is composed of energy packets called photons *(refer to Figure 1),* strikes a solar panel, and generates an electric current. Each panel generates a relatively little quantity of electricity, but when connected to other panels, a solar array can generate much more energy.

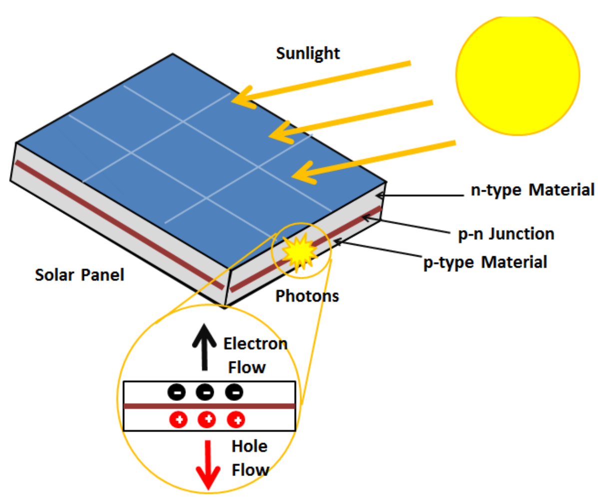

Figure 1: A diagram showing the photovoltaic effect [Source: einvestingforbeginners.com]

A solar panel (or array) generates direct current as its source of electricity (DC). Your phone and laptop are two examples of electronic gadgets that use DC electricity, but they are built to work with the electrical utility system, which uses (and supplies) alternating current (AC). As a result, before solar energy can be used, it must be transformed using an inverter from DC to AC [3].

1.2. System Components

Other significant parts of a photovoltaic system, also known as the "balance of system" or BOS, exist with solar panels. These parts, as shown in *Figure 2*, can include photovoltaic modules, mounting system, wiring, combiners, charge controller, and inverter and storage battery which often account for more than half of the system cost and most of the maintenance [10].

Figure 2: Components of PV System [source: cedengineering]

The battery is for use at night or during protracted periods of cloudy or overcast weather, when the PV array cannot generate enough electricity on its own, batteries store electricity. Days of "autonomy" in a standalone PV system refers to the number of days the battery storage capacity is available to operate the electrical loads straight from the battery, without any energy input from the PV array. Autonomy durations are commonly planned for between two and six days for normal, less important PV applications. Autonomy periods may be longer than ten days for crucial applications involving vital loads or public safety. Batteries such as lead-acid or lithium-ion are frequently utilized.

A charge controller connects batteries to the PV array. The charge controller guards against overcharging and over discharging of the battery. It can also allow for metering and payment for the electricity used, as well as information regarding the system's condition [11].

An inverter is a type of electrical appliance that absorbs direct current (DC) electrical current and converts it to alternating current (AC). This means that in solar energy systems, the DC current coming from the solar array is routed through an inverter to change it into AC. To use most electric gadgets or connect to the electrical grid, this conversion is required. Being The second most expensive component after the solar panels themselves, inverters are essential for practically all solar energy installations.

Most inverters have conversion efficiency of 90% or more and include crucial safety components like anti-islanding and ground fault circuit interruption. When the grid power fails, these turn off the PV system[12].

In a solar PV microgrid system, additional parts known as Balance of Systems (BoS) equipment are needed in addition to the PV modules, battery, inverter, and charge controller. The most frequent parts include mounting frameworks, tracking programs, electricity meters, cables, power optimizers, safety equipment, transformers, combiner boxes, switches, etc.

The mounting system that secures the solar array to the ground or rooftop is referred to as racking. These devices, which are typically made of steel or aluminum, precisely mechanically fix the solar panels in place. Systems for racking should be built to endure storms with hurricane- or tornado-force winds, as well as heavy snowfall. To prevent electrocution, electrical bonding and grounding the solar array is a crucial component of racking systems. The two main types of rooftop racking systems are pitched roof systems and flat roof systems. It is typical for the racking system to have weighted ballast for flat rooftops so that gravity can hold the array to the roof. The racking system needs to be mechanically secured to the roof structure on sloped rooftops. Some ground-mounted racking systems additionally include tracking mechanisms that follow the Sun's path through the sky using motors and sensors, boosting energy production at the expense of more expensive equipment and maintenance.

1.3. Solar Panel

One part of a photovoltaic system is a solar panel, also known as a solar module *Figure 3*. They are made up of a panel made of several solar cells. They are installed together to produce power and come in a variety of rectangular shapes. Sunlight energy is captured by solar panels, also known as photovoltaics, which then transform it into electricity that can be utilized to power buildings or residences. These panels can be used to extend a building's electrical supply or offer power in outlying areas.

Figure 3: Solar Module [Source: sunrun.com]

A solar cell is the fundamental element of every solar panel. A single solar panel is made up of many solar cells. The component of the apparatus that transforms sunlight into electricity is these cells. Crystalline silicon solar cells are used to create most solar panels [13]. Layers of silicon, phosphorus, and boron make up these cells. Once created, these cells are arranged in a grid arrangement. Due to the wide range of available panel sizes, the number of these cells is mostly dependent on the panel's size.

The panel itself is sealed to safeguard the cells once they are set out, and a non-reflective glass is placed on top. This non-reflective glass shields the solar cells from harm while still allowing sunlight to get through to the cells. This panel is sealed before being set into a sturdy metal frame. As an accumulation of water could decrease the effectiveness of the panel, this frame is made to avoid deformation and contains a drainage hole to do so. The panel's back is similarly sealed to guard against damage.

1.2.1 Solar Panels Function

When a photovoltaic cell is exposed to sunlight, a process known as the photovoltaic effect causes it to produce voltage or electric current. This phenomenon, which results from the solar panel's cells converting sunlight into electrical energy, is what makes solar panels valuable. The photovoltaic effect occurs in solar cells. These solar cells are made of a p-n junction, which is formed by joining two different types of semiconductors, a p-type, and an n-type. When these two varieties of semiconductors are combined, an electric field is created in the junction area as electrons and holes migrate from the negative n-side to the positive p-side. Positively charged particles flow in the opposite direction from negatively charged particles because of this field.

Photons, which are just tiny bundles of electromagnetic radiation or energy, are the building blocks of light. A photovoltaic cell, which makes up solar panels, can absorb these photons. An atom of the semiconducting material in the p-n junction receives energy from the photon when light with the right wavelength strikes these cells. The energy is specifically transmitted to the material's electrons. The result is a jump in the electrons' energy to a state known as the conduction band. The valence band where the electron jumped up from has a "hole" left behind as a result. An electron-hole pair is formed when the electron moves because of the extra energy[9].

Electrons in semiconducting materials are immobile when not energized because they establish connections with the atoms around them that keep the material together. These electrons can flow freely through the material because of their excited condition in the conduction band. As expected, electrons and holes travel in the opposite direction due to the electric field created by the p-n junction. The liberated electron tends to migrate to the n-side rather than being attracted to the p-side. An electric current is produced in the cell by this movement of the electron. The movement of the electron leaves a "hole" behind. This hole can likewise move, but it does so in the p-opposite side's direction. This mechanism causes a current to flow through the cell [9].

1.4. Types of PV Systems

1.3.1 ON-GRID SOLAR SYSTEM

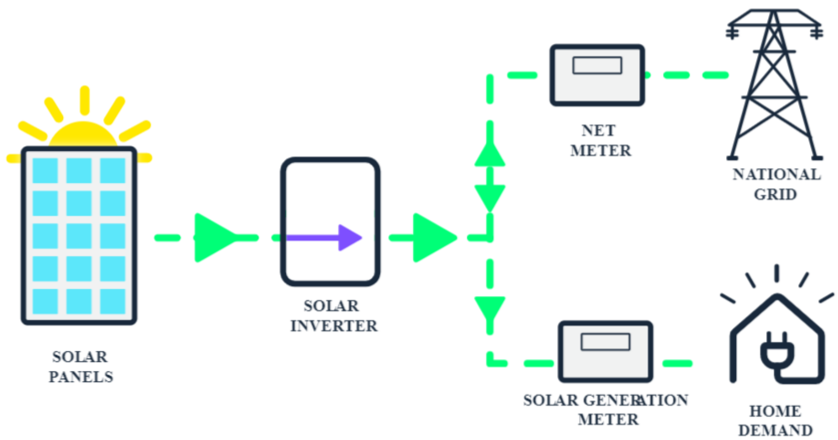

Figure 4: On-Grid system components [source: deegesolar.co.uk]

A solar PV system that is directly connected to the National Grid is referred to as being "on-grid" or "grid tied" as illustrated in *Figure 4*. The most popular Solar PV System among household and business owners is this one. For someone who is already connected to the grid but wants to lower their carbon footprint and energy costs, this kind of setup is ideal.

A solar or micro inverter is used to link an on-grid solar system directly to the National Grid without the need for a battery storage device [14]. The household uses this renewable energy source, which the solar panels transform into energy, to run appliances. Any solar energy that is produced in excess is exported back to the grid. The security of knowing that energy supply will always be supported by the National Grid is a major benefit of an on-grid system.

A battery can be added at any moment to transform an on-grid solar system into a hybrid system. Retrofitting is the process of installing the battery of your choosing combined with an AC linked control management system. A solar PV system can still supply power during these outages if battery storage is added. It is referred to as a hybrid system.

Installing a grid-connected system reduces the reliance on utilities, the cost is less since the storage battery is not included, since the household is connected to the grid which make the system more efficient due to the effective utilization of the power generated. However, if the area of the PV system experiences a grid power outage, the system would not provide power due to the lack of storage battery.

1.3.2 HYBRID SOLAR SYSTEM

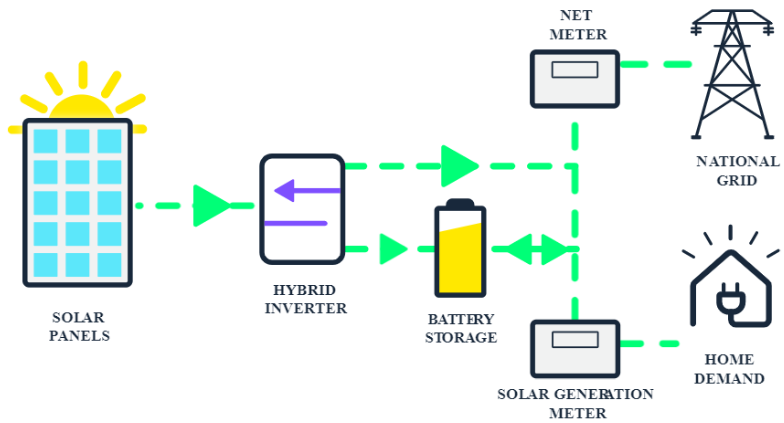

Figure 5: Hybrid system components [source: deegesolar.co.uk]

Hybrid solar systems combine solar battery and panel technology to produce a green energy solution that offers a backup energy supply. The National Grid is still connected to a hybrid PV system, but any solar energy produced is first stored in a residential battery system before being sent to the grid refer to *Figure 5*.

The main benefit of a hybrid solar system is utilizing solar energy to power a house at night and export less energy to the grid by storing the excess energy in a battery [15].

Hybrid solar panel systems give a lot of flexibility because the household can still take power from the grid once the battery is empty. A hybrid solar system is therefore the ideal compromise. This system serves as a bridge between the two options; it is less expensive than an off-grid system but more expensive than an on-grid system. The ability to increase the battery storage system at any time, as well as the ability to charge the batteries at low-cost off-peak rates, are two major benefits of a hybrid solar system. A hybrid solar system is less efficient than a grid-tied system since it has additional components.

1.3.3 OFF-GRID SOLAR SYSTEM

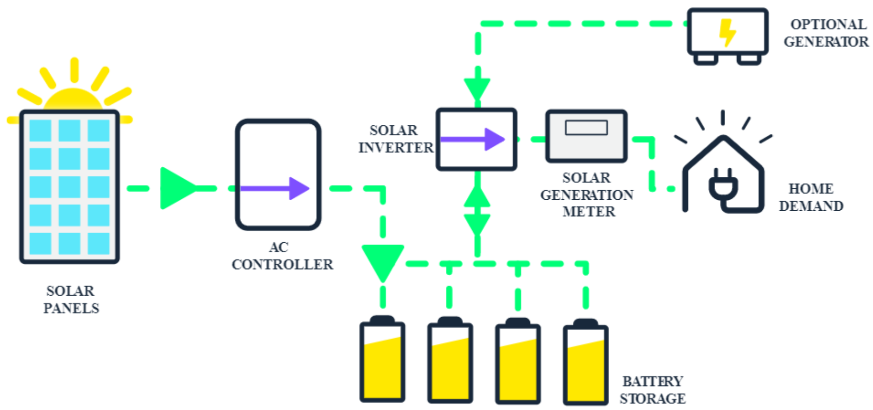

Figure 6: Off-Grid system components [source: deegesolar.co.uk]

An off-grid solar system has no connections to the national grid, in contrast to an on-grid solar system. Making it appealing to people who find it difficult to connect to the grid or who want to remain energy independent.

Electricity independence is more necessary than ever given the rising cost of energy. Everything needed to produce solar energy is included in an off-grid solar system. Off-grid systems, in contrast to hybrid systems, frequently include backup generators as shown in *Figure 6* and other renewable energy sources to make sure the battery is completely charged all year long. This is because the only source of electricity is the off-grid system. Even the most isolated regions can have electricity thanks to off-grid solar installations. With the help of this system, households may be energy independent and have access to power wherever the location is. An off-grid system has the advantages of having no energy bill and solely using ecologically beneficial resources. Off-grid solar systems are inherently more expensive than a typical grid-tied system since they require more components. Off-grid systems can be expanded at any moment to fulfill the energy needs because they are modular [16].

The Off-Grid system provides all the building's electrical needs, it is disconnected from the traditional power grid so in case of any outage the system can provide the required power and it can operate in remote areas. Nonetheless, it needs a much stronger system, it must generate more energy than it uses on average, and it is significantly more expensive for the cost of the storage.

1.5. FACTORS AFFECTING PV MODULE PERFORMANCE

The following parts that are explained below were studied from a course for this thesis. This online engineering PDH course provided by [17] presents the fundamental principles behind the workings of a solar PV system, use of different components in a system, methodology of sizing these components.

The amount of sunlight a PV module receives has a direct impact on how well it performs. A PV module's performance will suffer if it is even slightly shadowed. The output of a solar power system is influenced by several additional elements.

So that the consumer has reasonable expectations of the total system output and economic benefits under changing weather conditions throughout time, it is necessary to understand these elements.

The location is the beginning point for developing a PV system. For any PV system to be economically viable, the photovoltaic modules must receive enough sun access. Latitude is a crucial element, since it helps us identify the amount of sunlight received in that area from different sources available online and I will be discussed in the following chapters.

Solar irradiance is a measurement of how much sunshine a location is receiving in terms of Watts per square meter falling on a flat surface. It is possible to forecast the average monthly and annual energy production of a system using historical, standardized weather data because weather conditions tend to be reasonably consistent over time. Maps of solar resources are available, illustrating how much energy reaches the surface of panels. The information is displayed in standardized maps that demonstrate how many exact hours of standard sunshine can be calculated throughout a month or a year. It is expressed by the term “solar insolation”[18].

The amount of solar irradiance that ever reaches a PV surface is known as solar insolation. The unit of measurement for solar energy in a specific location is $kWh/m^2/day$. Typically, this is referred to as Peak Sun Hours (PSH). For instance, PSH for a location will be 5 hours if solar radiation for that location is 5 kWh/m^2/day. Without considering losses, a 1kW solar panel installed there will generate 1kW x 5h = 5kWh of electricity each day. Greater module output will be achieved with more intense sunlight. Lower solar irradiance means less current flow. Variations in sunshine intensity do not significantly affect voltage. The map below displays the daily solar energy available on an ideal inclined surface during the worst months of the year for power production (based on accumulated worldwide solar insolation data). This is helpful since it enables us to figure out how much electricity the solar system produces.

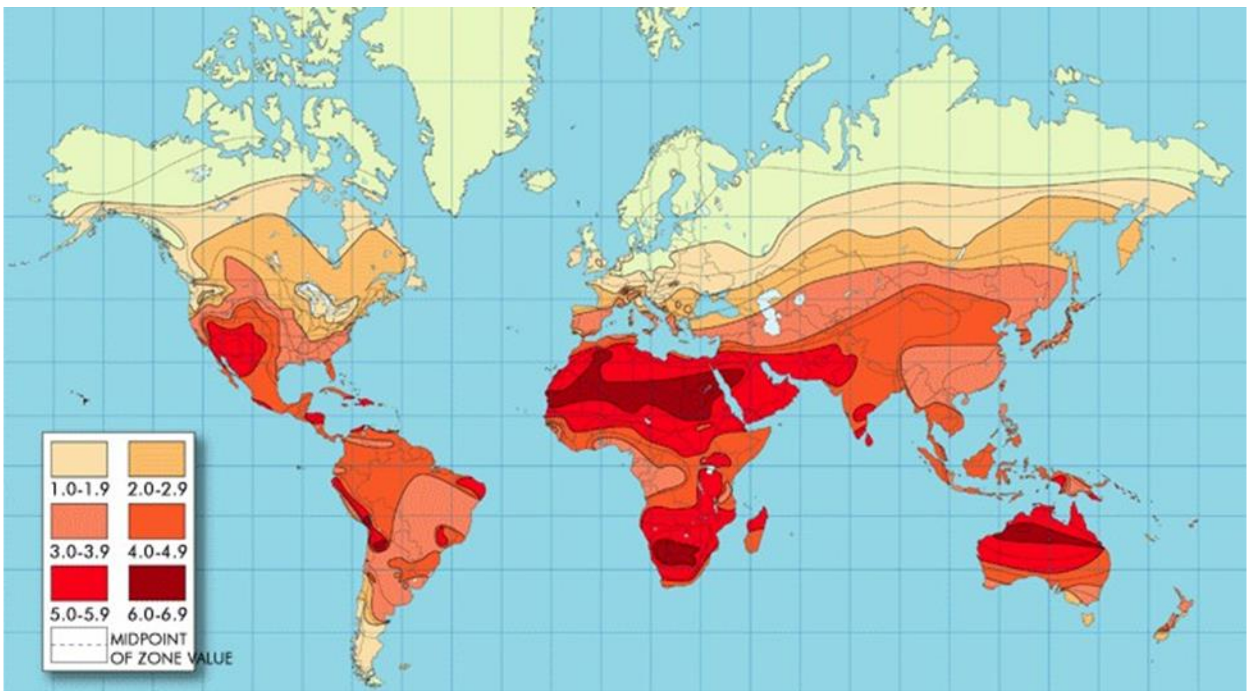

Figure 7:daily solar energy available [source: incentivifotovoltaico.org]

Statistical estimations of average daily insolation levels for specific locations as shown in *Figure 7* are commonly used in the PV design process and measured as kilowatt-hours per square meter per day (kWh/m^2/day). The amount of solar electricity to which the modules will be exposed depends on whether the plan is to use the system during the summer, winter, or all year long, the typical climate in the area, the position and angle of the PV array.

The orientation of a solar panel refers to the direction it faces. The solar array's direction has a significant impact on how much sunshine it receives and, consequently, how much power it will generate [19]. The tilt angle, or the angle between the solar panel's base and the horizontal, and the direction the solar module is facing (i.e., due south), respectively, make up the orientation. Because of how the sun moves across the sky during the day, the amount of sunlight that strikes the array fluctuates depending on the time of day *Figure 8*.

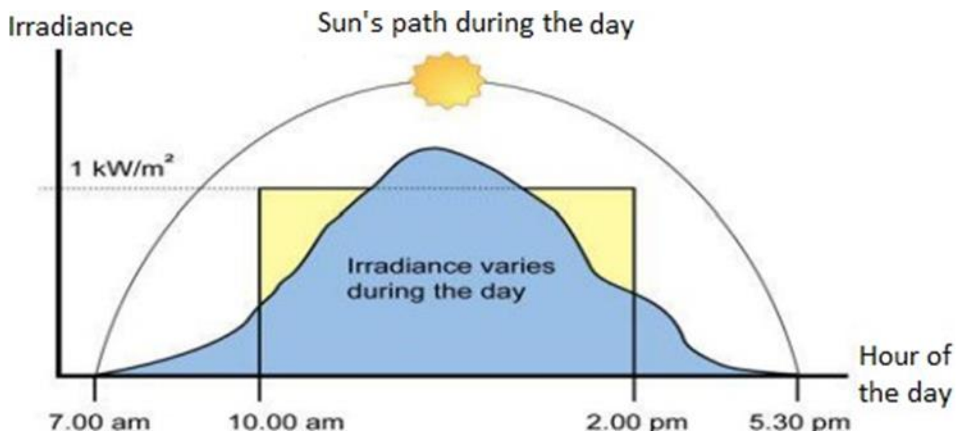

Figure 8: variation of irradiance as a function of hours of the day. [Source: repositorio.unal.edu.co]

The installation of solar panels should maximize the amount of radiation that is captured. The PV installations on the North of the equator should be tilted at an angle that is 15^o degrees higher than the site latitude and should be facing South for best performance. If the PV array is situated atop a structure that makes it impossible for the panels to face south, it can be oriented to the east or west but never to the north because doing so would severely impair its efficiency. When a PV module's surface is parallel to the sun's beams, it operates at peak efficiency or power. More energy is reflected by the modules than is absorbed as the rays' veer from their perpendicular path.

Since most PV systems are fixedly placed, they cannot move with the sun throughout the day. Installing PV modules on trackers that follow the sun from east to west during the day (single-axis trackers) and from north to south during seasonal shifts might increase the output (dual-axis trackers). For most PV applications, this is uncommon because it can be expensive.

One of the most crucial factors for energy loss in a PV array may be shading [20]. When one cell of a 36-cell module is partially shaded, the power output is drastically decreased. Trees and shrubs, nearby structures, and the several rows of module itself all have the potential to act as shading sources. The array should be placed at least twice as far away from the item as its height, according to the conventional rule of thumb. By doing this, the item will be protected from casting a shadow for four hours on either side of solar noon.

1.6. Electrical Characteristics

Direct current, or DC, is the solar energy generated by a photovoltaic solar cell, which is the same as a battery. No matter how strong the sun's light is, there is a physical limit to the maximum current that a single photovoltaic solar cell can produce [17]. The maximum current in Equation 1 sign stands for the maximum deliverable current. A single photovoltaic solar cell's maximum current value is influenced by its size or surface area, the quantity of direct sunlight it receives, how effectively it converts solar energy into current, and the type of semiconductor material used in its construction. Most commercially available photovoltaic solar cells have solar power ratings that show the maximum deliverable solar power, maximum power, that the cell can produce in watts. Maximum power is equal to the product of the cell voltage V multiplied by the maximum cell current I and is provided as

$$P_{MAX} = V_{MAX} * I_{MAX} \qquad \textit{Equation 1}$$

Where P is the power, V the voltage, and I the amperes

The maximum output power, peak power, rated power, maximum power point, and other designations used by different manufacturers to describe a PV cell's output power under full sun all mean the same thing.

Photovoltaic I-V Characteristics Curves

Manufacturers of the photovoltaic solar cells produce current-voltage (I-V) curves, which gives the current and voltage at which the photovoltaic cell generates the maximum power output and are based on the cell being under standard conditions of sunlight and temperature with no shading. Voltage (V) is plotted along the horizontal axis while Current (I) is plotted along the vertical axis. The available power (W) from the PV, at any point of the curve, is the product of current and voltage at that point.

Short Circuit Current (ISC)

A photovoltaic module will produce its maximum current when there is essentially no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is called the short circuit current (Isc). This value is higher than Imax which relates to the normal operating circuit current. Under this condition the resistance is zero and the voltage in the circuit is zero.

Open Circuit Voltage (VOC)

Open circuit voltage (Voc) means that the PV cell is not connected to any external load and is therefore not producing any current flow (an open circuit condition). This value depends upon the number of PV panels connected in series. Under this condition the resistance is infinitely high and there is no current.

Maximum Power (PMAX or MPP)

This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp). Imax and Vmax values occur at the "knee" of the I-V curve.

Fill Factor (FF)

The fill factor is the ratio of maximum power output (Pmax) to the product of the open-circuit voltage times the short-circuit current, (V_{OC} x I_{SC}).

The fill factor gives an idea of the quality of the array. The closer the fill factor to 1 (unity), the more power the array can provide. Typical values are between 0.7 and 0.8

1.7. PV Module Output

For a specific load, PV module output depends on two major factors, the irradiance or light intensity and the temperature. The PV cell's production is influenced by how much sunlight is shining on its surface. The cell generates more current the more sunlight it receives. The voltage will not change. *Figure 9* demonstrates how the power output from the PV module fluctuates proportionally depending on the test conditions, such as when day light is 1000 W/m2 vs. 600 W/m2.

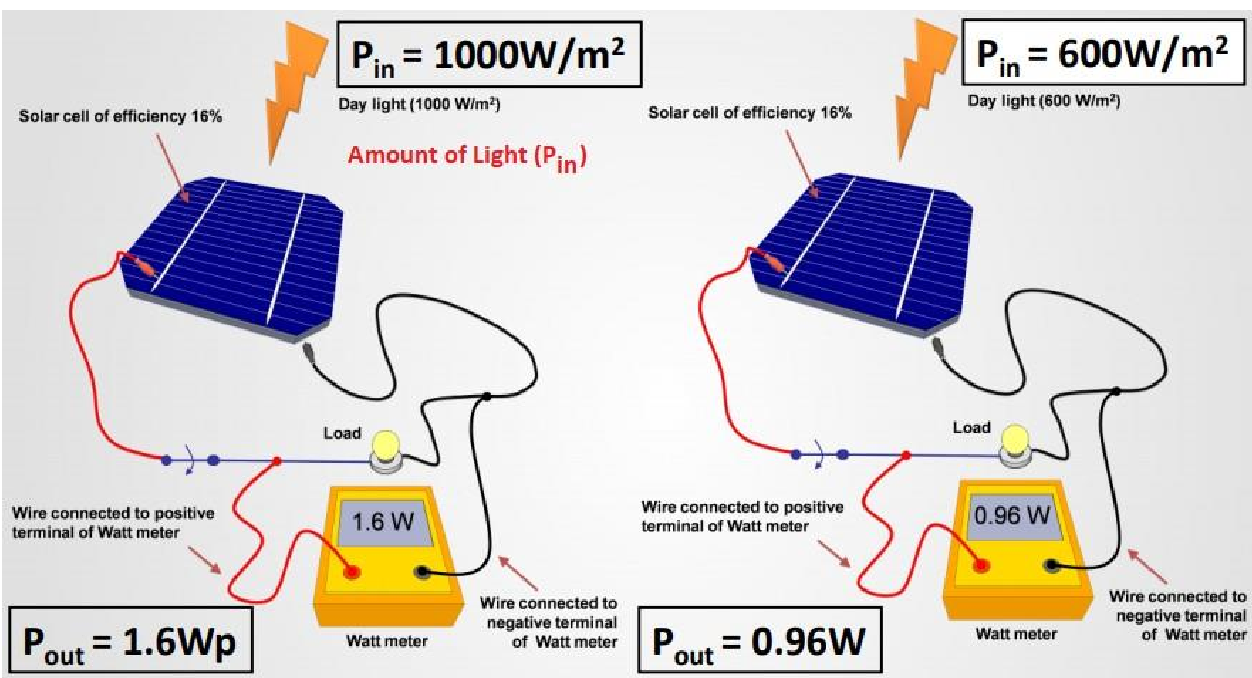

Figure 9 relation between amount of light and output Source: Cedengineering.com

At rising cell temperatures, the performance of PV cells decreases. With rising cell temperature, the operational voltage decreases. For every 25°C rise in cell temperature, the output voltage decreases by around 5% under direct sunlight. Then, to counteract power output losses brought on by high temperatures, photovoltaic panels with more solar cells are suggested for extremely hot areas than would be employed in colder ones[17].

In comparison to crystalline technologies, most thin film technologies have a smaller negative temperature coefficient. In other words, as the temperature rises, they tend to lose less of their rated capacity.

Chapter 2.

2 DESIGN & SIZING PRINCIPLES

Appropriate system design and component sizing is fundamental requirement for reliable operation, better performance, safety, and longevity of solar PV system.

A solar system can be designed by different methods, we can start from the demand of energy required and reach the system size suitable to cover that demand. Another way is to start from the output of the solar panels for a specific location and from there understand the system size suitable to cover the consumption. Moreover, there are different tools and software that are created to provide an accurate tool to realize a complete solar system project.

The sizing principles for grid connected and stand-alone PV systems are based on different design and functional requirements. Grid Connected Systems (without energy storage) provides supplemental power to facility loads and failure of PV system does not result in loss of loads. A Stand-Alone System (with energy storage) is designed to meet a specific electrical load requirement and failure of PV system results in loss of load. The sizing for grid connected systems without energy storage generally involves determining the maximum array power output, it is based on the available area, efficiency of PV modules used, array layout and budget. Selecting one or more inverters with a combined rated power output of 80% to 90% of the array maximum power rating at STC. In addition, the inverter string sizing as illustrated in *Figure 10* determines the specific number of series-connected modules permitted in each source circuit to meet voltage requirement and the power rating limits the total number of parallel source circuits. The estimation of system energy production is based on the local solar resource and weather data [21].

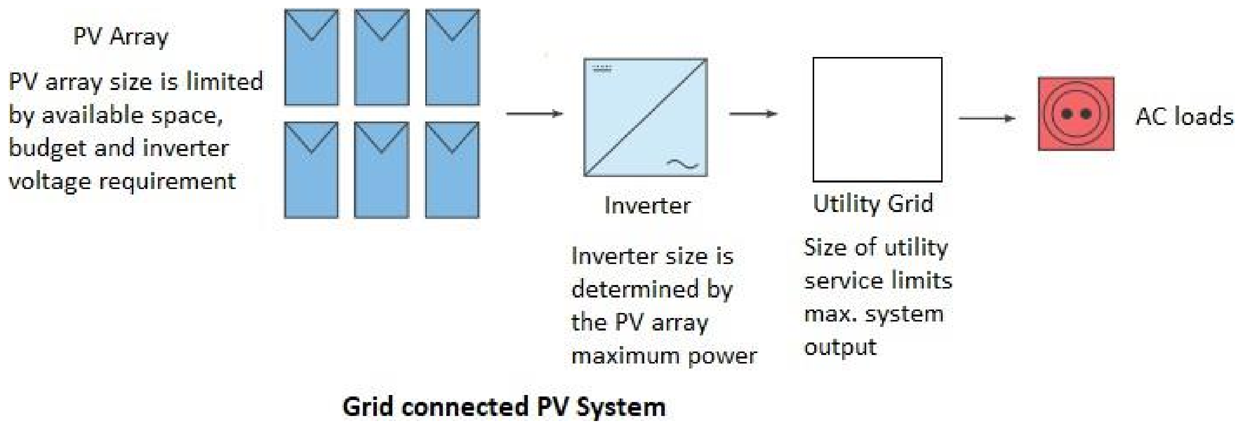

Figure 10 Grid connected PV system [source: cedengineeering.com]

2.1 Sizing for Grid Tie Solar System

The initial step is to find the monthly average electricity usage from the energy bill or any other method (a device can be installed to meter the consumption). In fact, Midori's device "Ned" is completely capable of providing energy consumption and update it every 15 minutes. This is the total kWh used for in a single month. Due to seasonal usage like air conditioning, space heating, it is recommended to look at bills from several months of the year. Using all the data available, determine the monthly average electricity usage. Secondly, daily average electricity usage needs to be determined to know the consumption that the system will cover and then divide monthly average kWh 30 days. Then we Find the daily average peak sun hours for the location [17] many sources online are available for the peak sun hours by location. The calculation of the solar system size (AC) to generate 100% of the electricity consumption is obtained by dividing the daily average energy usage by the average sun peak hours in the location. Only when all the parameters mentioned previously are provided, we can calculate the number of solar panels needed for this system.

Considering a well-designed solar system with 86% efficiency (14% loss), divide the solar system size (AC) by 0.86.

Let's say the system want to use a solar module with a nominal name plate power of 220 Watt. In that case: if the consumption is 8.78, 8.78 kW x 1000 / 220 W = 39.90 panels. Always round this number up. In this case, the system requires 40 solar modules at 220 Watt each to cover 100% of the energy needs.

2.2 Sizing a Standalone Systems

Standalone or off-grid PV systems are different from grid-connected. Stand-alone PV systems can be considered a type of banking system. The battery is the bank account. The PV array produces energy (income) and charges the battery (deposits), and the electrical loads consume energy (withdrawals). The components are represented in *Figure 11*.

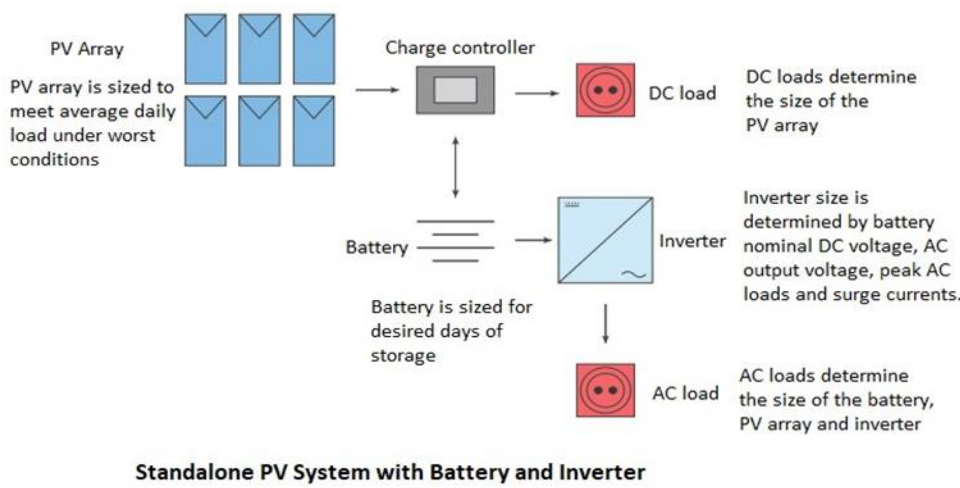

Figure 11: Standalone PV system [source: cedengineering.com]

The sizing objective for stand-alone PV system is a critical balance between energy supply and demand. It involves the following key steps:

a. Determine the average daily load requirements for each month.

b. Conduct a critical design analysis to determine the month with the highest load to solar insolation ratio.

c. Size battery bank for system voltage and required energy storage capacity.

d. Size PV array to meet average daily load requirements during period with lowest sunlight and highest load (usually winter).

e. Sizing stand-alone PV systems begins with determining the electrical load, and then sizing the battery and PV array to meet the average daily load during the critical design month.

The five-step procedure for sizing a photovoltaic system for a standalone photovoltaic power system will enable the designer or user to appropriately size a system based on the user's anticipated demands, goals, and budget. They are as follows:

a. Estimating the Electric Load

b. Sizing and Specifying an Inverter

c. Sizing and Specifying Batteries

d. Sizing and Specifying an Array

e. Specifying A Controller

2.3 Estimating the Electric Load

The first task for any PV system design is to determine the system load. The load determination is straightforward. Make a list of the electrical appliances and/or loads to be powered by the PV system. The power required by an appliance can be measured or obtained from the label on the back of appliance which lists the wattage. The power requirements are calculated by multiplying the number of hours per day that specific appliances will operate each day. For existing buildings, another alternative is to get consumption figures from the utility invoice; it shows actual usage over a 12-month period.

Three parameters should be known before starting with the calculation procedure (refer to *Figure 12*), these parameters are pre-defined since the adjustment factor is related to the efficiency of the inverter. The efficiency of the inverter is anywhere between 0.85 - 0.9, for DC loads operating straight from the battery bank an adjustment factor of 1.0 is used. The inverter AC voltage is available in 120V or 408V for the US, the output voltage of the inverter is designed for single-phase 120V or three phase 408V at 60Hz frequency. Battery bus corresponds to the required DC input voltage for the inverter.

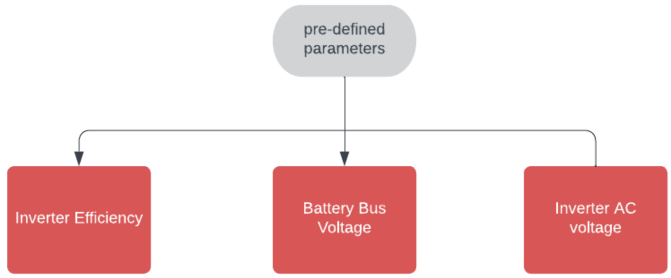

Figure 12: pre-defined parameters obtained from product label

The load is determined by listing all appliances with their power ratings and operation hours then summing it to obtain the total average energy demand in watt-hours or kilowatt-hours. The worksheet below gives ideas of how to estimate the load. It is good to list both the AC and DC loads separately because sizing of inverter is required for AC demands only. Apply inverter efficiency to determine the DC energy required for AC loads. Adjust for DC and AC loads by applying adjustment factor. This will give the 'Adjusted Watts'. The 'Average Daily Load' is then computed by multiplying the Adjusted Watts by the hours of use per day.

If the rated power is for DC, then the adjustment factor is 1, instead if it is for AC then the adjustment factor is equal to the inverter efficiency (refer to *Figure 12*). Adjusted wattage is calculated as Equation 2. Adjusts the wattage to compensate for the inverter inefficiency and gives the actual wattage consumed from the battery bank.

$$Adjusted\ Wattage = \frac{Rated\ Wattage}{Adjustment\ factor}$$ *Equation 2*

After the adjusted power is obtained, we need as an input the hours per day used in hours and then the energy per day is obtained as in Equation 3.

$$Energy\ per\ day = Adjusted\ Wattage * Hours\ per\ day$$ *Equation 3*

The sum of the energy per day used for all the appliances is equal to the total energy demand per day and is expressed in watt-hours, then total energy demand per day is obtained by Equation 4.

$$Total\ amp - hour\ deman\ per\ day = \frac{Total\ energy\ demand\ per\ day}{Battery\ Bus\ Voltage} \qquad \text{Equation 4}$$

The sum of the maximum AC power requirement is calculated as the sum of the rated wattage where the maximum DC power requirement is the sum of the Adjusted wattage.

2.4 Battery Sizing

Batteries for stand-alone systems are sized to store energy produced by the array for use by the system loads as required. The total amount of rated battery capacity required depends on the following:

a. Desired days of storage to meet system loads with no recharge from PV

b. Maximum allowable depth-of-discharge

c. Temperature and discharge rates

d. System losses and efficiencies

e. The system voltage defines the number of series-connected battery cells required.

f. The total capacity needed defines the number of parallel battery strings required.

Days of Storage or Autonomy

a. Autonomy is the number of days that a fully charged battery can meet the system loads without any recharge from the PV array.

b. Greater autonomy periods are used for more critical applications and increased system availability, but at higher cost due to the larger battery required.

Batteries should be capable of meeting both the power and energy requirements of the system. As a rule of thumb, the minimum autonomy should be kept as 3 days for regular loads. For critical loads autonomy should be more than 3 days based on weather conditions of the application area.

Sizing the battery bank for the worst case is not only important for ensuring that the PV system can cover the loads of the building under all conditions, but also because to increase the chances of minimizing the seasonal battery depth of discharge.

2.5 Calculation for Battery Sizing

For the battery sizing, the first parameter to be decided is the days of storage desired or more efficiently required (autonomy). Normally, the battery storage system is designed to provide the necessary electrical energy for a period equivalent to 5 days without any sunshine. The allowable depth of discharge limit is the maximum fraction of capacity that can be withdrawn from the battery, the battery selected must be capable of this limit or greater depth of discharge. Typical value is 0.8 for good new battery[17].

Required battery capacity is measured in amp-hour, it is determined by first multiplying the total amp-hours per day by the days of storage required. Then dividing the number obtained by the allowable depth of discharge limit gives the required battery capacity as shown in Equation 5.

$$Required\ battery\ capacity = \frac{Total\ amp\ hours\ per\ day * Days\ of\ storage\ required}{Allowable\ depth\ of\ discharge} \qquad \text{Equation 5}$$

The ampere hour capacity of the selected battery is selected from the manufacturers' information once the required number of amp hours has been determined (Refer to Equation 4). After calculating the steps above the number of batteries in parallel can be calculated dividing the required battery capacity by the ampere hour capacity of battery selected as shown in Equation 6, parallel connection attains higher capacity by adding up the total ampere hour.

$$Number\ of\ batteries\ in\ parallel = \frac{Required\ battery\ capacity}{Ampere\ hour\ capacity\ of\ selected\ battery} \qquad \text{Equation 6}$$

Batteries achieve the desired system voltage (operating voltage) by connecting several cells in series, each cell adds its voltage potential to derive the total terminal voltage. The number of batteries in series is calculated dividing the battery bus voltage by the selected battery voltage Equation 7.

$$Number\ of\ batteries\ in\ series = \frac{Battery\ Bus\ voltage}{selected\ battery\ capacity} \qquad \text{Equation 7}$$

Finally, the total number of batteries is calculated by multiplying the number of batteries in parallel by the number of battery cells in series. Where the total battery amp hour capacity is the total capacity of selected batteries and is determined by multiplying the number of batteries in parallel by the ampere hour capacity of the selected battery.

2.6 PV Array Sizing

Solar array size is determined by the following parameters:

a. The PV array for stand-alone systems is sized to meet the average daily load during the critical design month.

b. Solar insolation received in the site

c. System losses, soiling and higher operating temperatures are factored in estimating array output.

d. Characteristics of the PV modules

e. The system voltage determines the number of series-connected modules required per source circuit.

f. The system power and energy requirements determine the total number of parallel source circuits required.

The array is sized to meet the average daily load requirements for the month or season of the year with the lowest ratio daily insolation to the daily load. Using module power output and daily insolation (in peak sun hours), the energy (watt- hours or amp-hours) delivered by a photovoltaic module for an average day can be determined. Then, knowing the requirements of the load and the output of a single module, the array can be sized. Higher system availability can be achieved by increasing the size of the PV array and/or battery.

2.7 Calculation for PV Array Sizing

For the sizing of the PV array, the total demand per day is required. A factor between 0.7 and 0.85 is used to estimate battery round trip efficiency, if the battery selected is relatively efficient and if a significant percentage of the energy is used during daylight hours a value of 0.85 is used [6]. Dividing the total energy demand per day by the battery round trip efficiency determines the required array output per day Equation 8.

$$Required\ array\ output\ per\ day = \frac{total\ energy\ demand\ per\ day}{battery\ round\ trip\ efficiency} \qquad \text{Equation 8}$$

Selected PV module maximum power voltage is then obtained from the manufacturers' specifications for the selected photovoltaic module, and the quantity is multiplied by 0.85 to establish a design operating voltage for each module (not the array). The guaranteed power output at standard conditions is also obtained from manufacturers' database.

Peak sun hours at design tilt for design month is obtained from solar radiation data for the design location and array tilt for an average day during the wors month of the year. Then, after identifying the value, the energy output per module per day can be calculated by multiplying the selected photovoltaic power output at standard conditions by the peak sun hours at design tilt. Then the module energy output is multiplied by the de-rating factor to establish an average energy output from one module. For hot climates and critical applications, the de-factor is stabilized at 0.8, whereas for moderate climate and non-critical applications at 0.9. The number of modules required to meet energy requirements, the total energy demand per day, is determined by dividing the required output per day by the module energy output at operating temperature Equation 9.

$$Number\ of\ modules\ required\ per\ day = \frac{required\ array\ output\ per\ day}{Module\ energy\ output\ at\ operating\ T}$$ Equation 9

The number of modules required per string is determined by dividing the battery bus voltage by the module design operating voltage and then rounding this figure to the next higher integer determines the number of modules required per string Equation 10.

$$Number\ of\ modules\ required\ per\ string = \frac{Battery\ bus\ voltage}{Module\ design\ operating\ voltage}$$ Equation 10

The number of strings in parallel is determined by dividing the number of modules required to meet energy required by the number of modules required per string as represented in Equation11 and then rounding the number obtained to the next higher integer.

$$Number\ of\ string\ in\ paallel = \frac{Number\ of\ modules\ required\ to\ meet\ energy\ required}{Number\ of\ modules\ required\ per\ string}$$ Equation11

The modules to be purchased are then determined by multiplying the number of modules required per string by the number of strings in parallel. The nominal rated PV module output in watts is stated by the manufacturer and usually priced in terms of the rated module output. Finally, the nominal array rated array output is calculated by multiplying the number of modules to be purchased by the nominal rated module output.

2.8 Selecting an Inverter

Inverter is required to convert direct current to alternating current. Stand-alone inverters are typically voltage-specific, i.e., the inverter must have the same nominal voltage as your battery. The inverter is rated in Watts [20]. The input rating of the inverter should never be lower than the total watt of the appliances, the inverter capacity should always be greater than the maximum power DC required.

The size of an inverter for a standalone system is measured by its maximum continuous output in watts and this rating must be larger than the total wattage of all the connected AC loads. Also, electrical appliances such as washing machines, dryers, refrigerators, etc. use electric motors, which require more power to start. This high starting power consumption can be more than twice the normal power consumption so the input rating of the inverter should be ideally 25-30% bigger than the rated wattage of your appliances.

2.9 Sizing the Controller

The function of a charge controller is to regulate the charge going into the batteries bank from the solar panel array and prevent overcharging and reverse current flow at night. Most used charge controllers are Pulse width modulation (PWM) or Maximum power point tracking (MPPT) [20].

The voltage at which PV module can produce maximum power is called maximum power point (or peak power voltage). Maximum power varies with solar radiation, ambient temperature, and solar cell temperature. When an MPPT solar charge controller notices variations in current-voltage characteristics of solar cell, it will automatically and efficiently correct the voltage. It forces PV module to operate at voltage close to maximum power point to draw maximum available power.

MPPT solar charge controller allows users to use PV module with a higher voltage output than operating voltage of battery system. For example, if PV module must be placed far away from charge controller and battery, its wire size must be very large to reduce voltage drop. With an MPPT solar charge controller, users can wire PV module for 24 or 48 V (depending on charge controller and PV modules) and bring power into 12 or 24 V battery system. This means it reduces the wire size needed while retaining full output of PV module.

The charge controller current input represented in Equation 12 rating is equal to the product of the short circuit current ofthe PV module, number of PV modules in parallel, and safety factor, where safety factor 1.25.

$$I_{rated} = N_{PV-parallel} * I_{sc} * 1.25 \quad \text{Equation 12}$$

2.10 Cable Sizing

The purpose of this step is to estimate the size and the type of wire in the following loops:

a. Cable between PV modules and Batteries
b. Cable between the Battery Bank and the Inverter
c. Cable between the Inverter and Load

The cross section of copper wire is determined by Equation 13

$$A = \frac{p \ x \ L \ x \ I \ x \ 2}{Vd} \quad \text{Equation 13}$$

Where:

- p=resistivity of wire------[For copper p=1.724 x 10^{-8} Ω ·m]
- L = length of wire (in m)
- A = cross sectional area of cable in mm^2
- I =the rated current of regulator, amps
- V_d =Voltage drop, volts

In both AC and DC wiring, the voltage drop is taken not to exceed 4 % value.

2.11 Software Tools

Different software is available specifically for designing a photovoltaic system. The flowcharts shown in *Figure* 13, Figure 14, *Figure* 15 and *Figure* 16 illustrate the different inputs required by the software to realize the layout of the project.

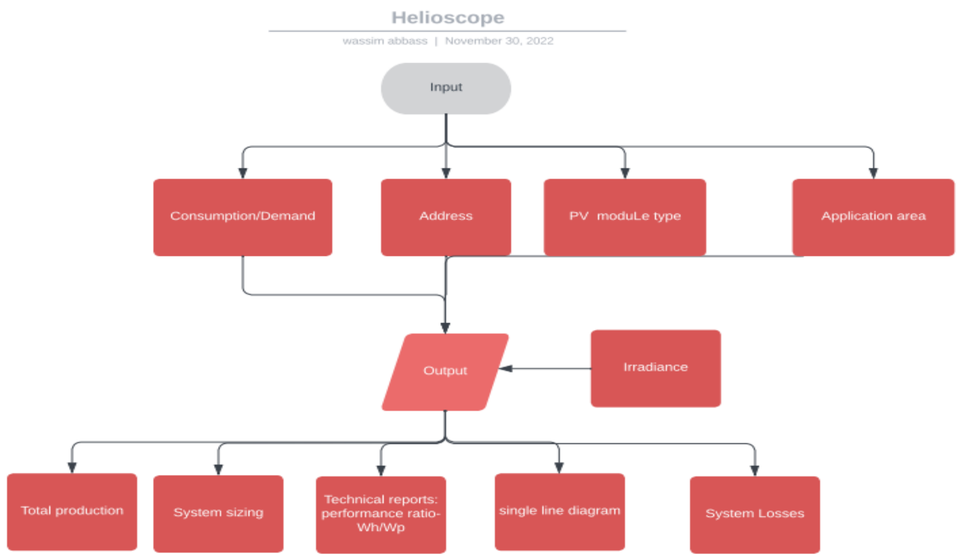

Figure 13 Helioscope flowchart

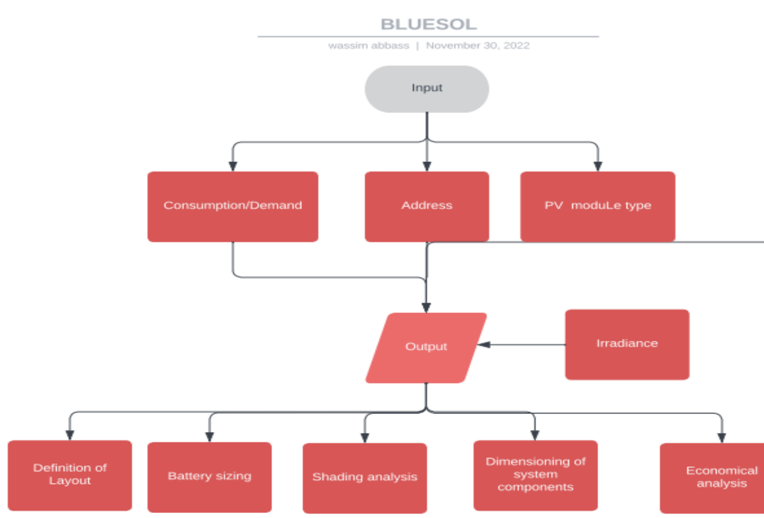

Figure 14 Bluesol Flowchart

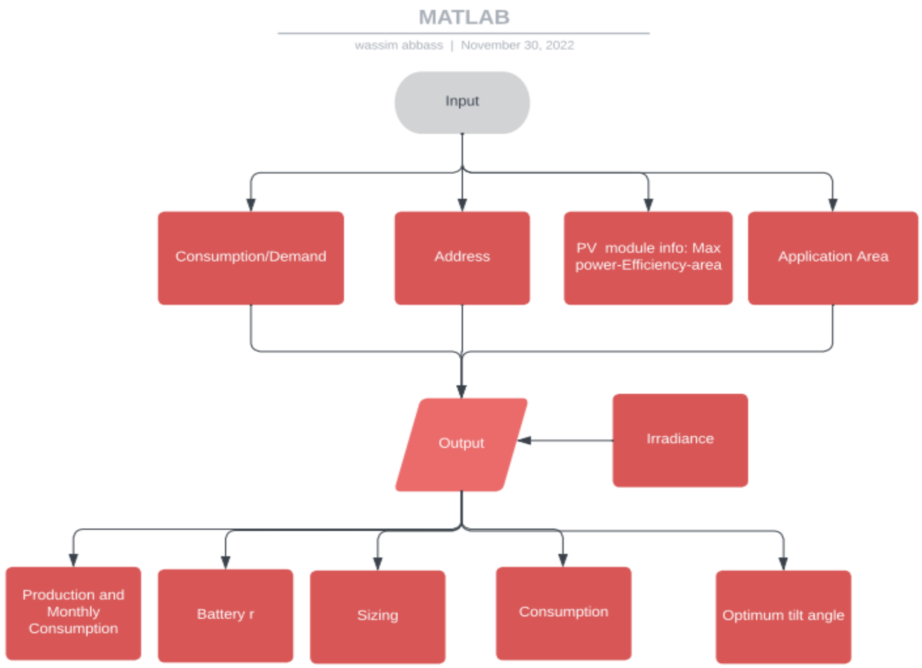

Figure 15 Matlab Flowchart

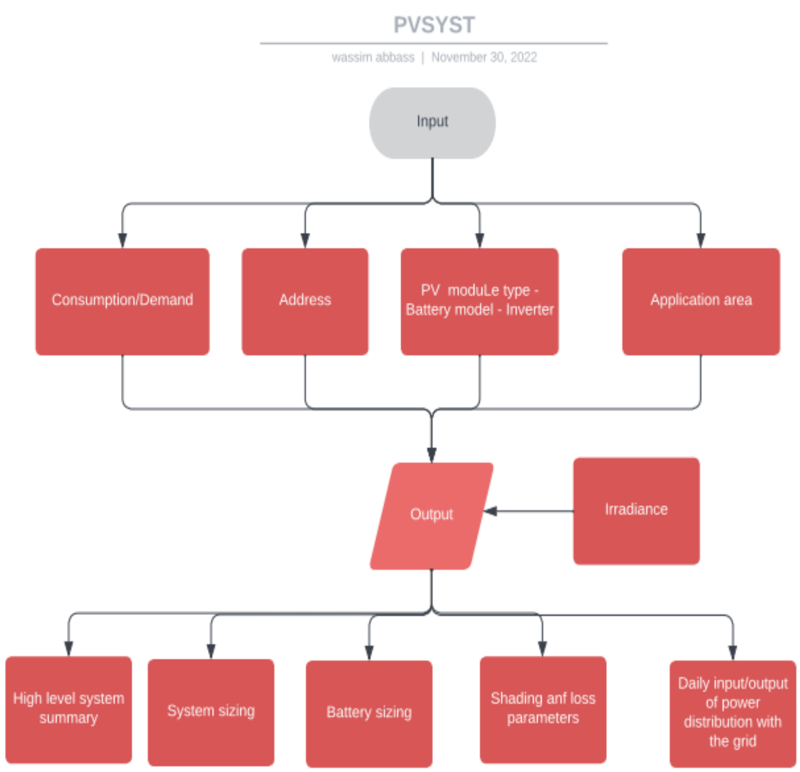

Figure 16 PVSYST Flowchart

As we can see, the software mentioned above provides an easy method to design a photovoltaic system, providing the software with necessary parameters. All software require the consumption data, address, PV module type and application area. Helioscope and Bluesol represented in *Figure 13* and *Figure 14* do not require other details about the projects, however Matlab represented in *Figure 15* asks for the efficiency and the areas of the module. PVsyst instead, requires details about the battery and inverter in addition to the basic parameters. Simulations are made with this software to provide detailed reports that help the user build the most accurate solar system. The software presented in 2.11 used by the companies that provide as a service the estimation and the installation of the PV. For this thesis, in the following chapter, the calculation is based on the global formula used to size the PV.

Chapter 3.

3 Energy of Solar Panel in Output

This chapter provides the steps followed to estimate the energy production of thirty-nine houses provided by Midori S.r.l. The households examined located in Italy in different regions, which is fundamental to use the correct data of solar irradiance in the application area. For each household, with respect to the consumption of a day in the worst month of irradiance [17], the energy required is calculated. Considering the energy needed per day, the area of solar panels needed is calculated for three technologies with three different efficiencies.

3.1 Photovoltaic Systems Output Calculation

There are various methods to calculate the energy in output of PV, Equation 14 is used to calculate the energy in output for a singular panel that considers the solar panel area, hourly solar radiation, specific for the installation area since the latter is in different regions, the solar panel yield or efficiency which is provided by the label of the product and the performance ratio, coefficient for losses [25].

After calculating the output of a singular solar panel, we can size the solar system to reach the output that would cover the consumption.

$$\boldsymbol{E = A * r * H * PR} \qquad \textit{Equation 14}$$

Where:

E = Energy (kWh)

A = Total solar panel area (m2)

r = solar panel yield or efficiency (%)

H = Hourly solar radiation kwh

PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75) r is the yield of the solar panel given by the ratio: electrical power (in kWp) of one solar panel divided by the area of one panel.

The performance ratio is one of the most important variables for evaluating the efficiency of a PV plant. Specifically, the performance ratio is the ratio of the actual and theoretically possible energy outputs. It is largely independent of the orientation of a PV plant and the incident solar irradiation on the PV plant. The performance ratio is affected by the temperature of the PV module, solar irradiation, shading and efficiency of the rest of the components of the system [22].

3.1.1 Peak sun hours

If the direction of the solar panels will face is known, we can enter an azimuth angle (in degrees clockwise from north). If the panels are being installed on a house, the azimuth angle is limited to whichever direction the roof faces. To get to the peak sun hours we need to know the tilt angle and the azimuth. Many tools online are available to know the PSH of a specific region[23].

3.1.2 Tilt Angle

Calculating the tilt angle is an improvement of the general method that gives better results. In this method, the optimum tilt angle for solar panels during winter is calculated by multiplying the latitude by 0.9 and then adding 29°.For summer, the tilt angle is calculated by multiplying the latitude by 0.9 and subtracting 23.5°. Also, there are tools online that require as an input only the latitude of the application area, and it provides the tilt angle. Once the tilt angle and azimuth are known, peak sun hours can be derived [17].

The rule of thumb states that the tilt angle should be set equal to the latitude of the household or the application site and can be adjusted during the summer by subtracting 15° and instead in the winter adding 15° [24].

We can also get the tilt angle and peak son hours from Global Solar Atlas by locating “Global Horizontal Irradiation” (GHI) in the Site Info section[23]. Then, choose per day in the settings and Atlas provides avg peak sun hours per day it also with the tilt angle. After obtaining the daily peak sun hours per month we can calculate, using the formula above, the output of the solar system.

3.2 Solar Output Calculation Simulation

Starting from the consumption of actual households from database provided by Midori s.r.l, a simulation on excel was prepared to calculate the production of a solar system to cover the consumption of these households. Equation 4 is used to obtain the hourly production of the panel output power.

By obtaining how much a singular solar panel produces energy, we can estimate the area required to produce electricity that would cover the consumption. Three different solar panels were considered in this simulation, considering naturally the efficiency of the chosen panel.

3.3 Battery

For the battery, in case the production in the peak hours is higher than the consumption, there is no need to add panels to charge the battery. Instead, when the production is lower than the consumption, solar panels are installed to charge the battery. By considering the following parameters we can estimate how many panels are needed with respect to the output of the solar panel. The parameters are represented in Table 1.

Table 1: Parameter for the calculation of the number of panels needed to charge the battery

Battery Voltage (V)	12, 24 or 48
Battery Amp Hours (Ah)	Capacity of Chosen Battery
Battery Type	Lithium or Lead Acid
Battery Depth of Discharge (DoD)	level of discharge
Solar Charge Controller Type	MPPT or PWM
Desired Charge Time (in peak sun hours)	user's choice

Divide the total Watt-hours per day used (known) by 0.85 for battery loss, then divide by 0.6 for depth of discharge and by the nominal battery voltage. Then, multiply the answer with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) following Equation 15 to get the required Ampere-hour capacity of deep-cycle battery.

$$\text{Battery Capacity (Ah)} = \frac{Total\ Watt{-}hours\ per\ day\ used\ by}{(0.85\ x\ 0.6\ x\ nominal\ battery\ voltage)} * Days\ of\ autonomy \qquad \text{Equation 15}$$

Once the parameters reported in the table above are obtained and hence the battery type, we can estimate how many panels are needed to charge the battery. For example, from Table 2 obtained from footprinthero.com for 12V battery, we can derive the solar panel size needed.

Table 2 Battery capacity and estimated solar panel size

Battery Amp Hours (Ah)	Battery Type	Estimated Solar Panel Size	DoD percentage
50	Lithium (LiFePO4)	160 watts	100%
60	Lithium (LiFePO4)	190 watts	100%
80	Lithium (LiFePO4)	250 watts	100%
50	Lead acid	120 watts	50%
60	Lead acid	140 watts	50%
80	Lead acid	180 watts	50%

3.4 Simulation and Results

Midori S.r.l provided 50 households hourly consumption for the year of 2022 for this simulation, including the province of where the household is based. By identifying the hourly sun irradiance for each region, choosing three different technologies of solar panels with different efficiencies, we can estimate the area requested to produce energy that covers the consumption at 100%. In addition, by knowing the parameters mentioned before, we can produce a curve that shows the hourly production of the photovoltaic system during the whole year.

The three panels that were chosen have efficiencies of 25%, 21.2% and 19.7% as shown in Figure 17. The calculation was made to have the output of the best-case scenario, so we start from the month with the lowest number of peak sun hours. By starting from the worst month, we have the certainty that the solar panels installed will be able to produce energy that can cover consumption all year long.

SunPower A Series Efficiency 1	Q. CELLS PEAK Duo Efficiency 3	Panasonic N330 Efficiency 2	losses coeff %
0.25	0.212	0.197	0.75

Figure 17 Solar panels efficiencies used for the excel simulation

The month with the lowest amount of peak sun hours is December for all the regions in Italy since the households are in different regions in Italy. Identifying the consumption of a day in December and the sun irradiance that reaches the surface in the day we can get the number of panels needed to cover the consumption by dividing the consumption by the output of a singular panel for the three different technologies. The calculation made with excel is shown in *Figure 18*.

Province	VA	CASA 2	consumo del 15/12 WH	irraggiamento del 15/12 W/M2	produzione di un singolo pannello del 15/12 1	produzione di un singolo pannello di 15/12 2
Size	200	G(i) W/m2	28302	3397.81	1834.8174	967.0507041
Load.2022-01-14T00:00:00	924	0				
Load.2022-01-14T01:00:00	873	0				
Load.2022-01-14T02:00:00	863	0				
Load.2022-01-14T03:00:00	943	0				
Load.2022-01-14T04:00:00	976	0				
Load.2022-01-14T05:00:00	960	0				
Load.2022-01-14T06:00:00	890	0				
Load.2022-01-14T07:00:00	1181	0				
Load.2022-01-14T08:00:00	772	451.68				
Load.2022-01-14T09:00:00	61	638.49				
Load.2022-01-14T10:00:00	0	754.67				
Load.2022-01-14T11:00:00	0	741.83				
Load.2022-01-14T12:00:00	0	362.54				
Load.2022-01-14T13:00:00	0	408.21				
Load.2022-01-14T14:00:00	0	530.7				
Load.2022-01-14T15:00:00	41	245.21				
Load.2022-01-14T16:00:00	955	0				
Load.2022-01-14T17:00:00	1291	0				
Load.2022-01-14T18:00:00	1762	0				
Load.2022-01-14T19:00:00	2221	0				
Load.2022-01-14T20:00:00	1586	0				

Figure 18 Consumption and production in the lowest month of solar irradiance

Then by applying the same formula to get the output of the solar system, we can obtain the hourly output of the system as shown in *Figure 19*. The system will have an excess in the production in the months where the panels receive higher amount of sun irradiance. The user can choose to use the solar system all year long and use the excess in the month with higher amount of sun irradiance for different applications, storage them in a battery or sell them to the grid though the "Net-metering" procedure to compensate when the grid electricity is used. The other option is to use the solar system only during the sun hours, in this case a battery is not needed, and the cost is less.

Hourly output 1	Hourly output 2	Hourly output 3
Module 1	Module 2	Module 3
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
3762.260797	3762.260797	3762.260797
5318.291482	5318.291482	5318.291482
6286.010795	6286.010795	6286.010795
6179.060236	6179.060236	6179.060236
3019.770699	3019.770699	3019.770699
3400.178179	3400.178179	3400.178179
4420.456529	4420.456529	4420.456529
2042.472481	2042.472481	2042.472481
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0

Figure 19 Hourly output of the simulation

Then we draw the curve of consumption and production, since the simulation is based on the month with the least amount of sun irradiance the production is higher than the consumption during the sun hours as shown in Figure 20. It is high since the goal is to cover the consumption also when the solar system is not producing, and the battery is used to store the excess in production during the day to be used at night.

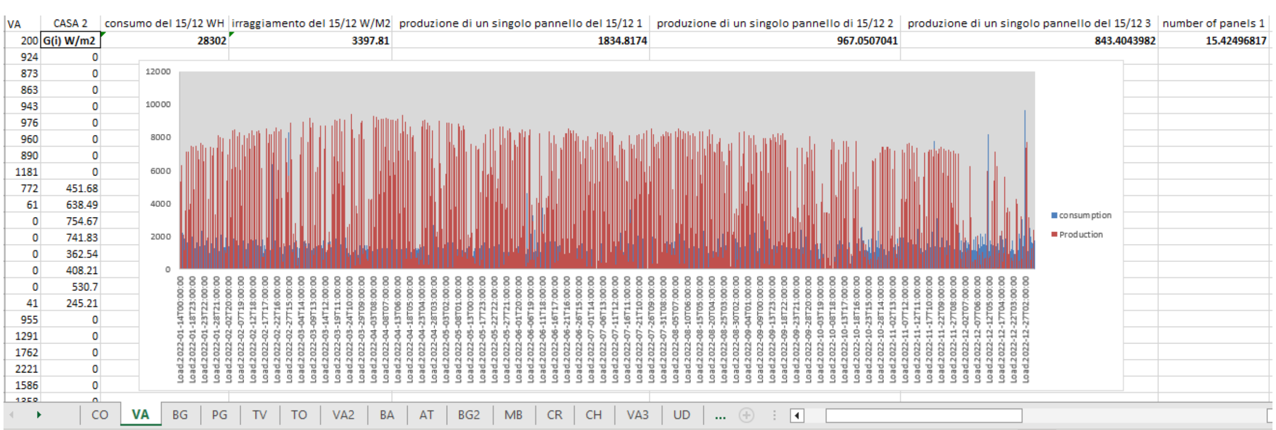

Figure 20 Example of the output of the simulation

The same result is obtained for all the 39 houses provided by Midori s.r.l. The model can provide the consumption and production curves simply by changing the consumption depending on the house under application. In addition, if the client wants to use the solar system only when the system is producing then that calculation would be made with respect to a month with higher sun irradiance.

Figure 21, Figure 22, Figure 23, Figure 24, Figure 25, and Figure 26 are some of the curves for some of the houses that were simulated for Midori [5].

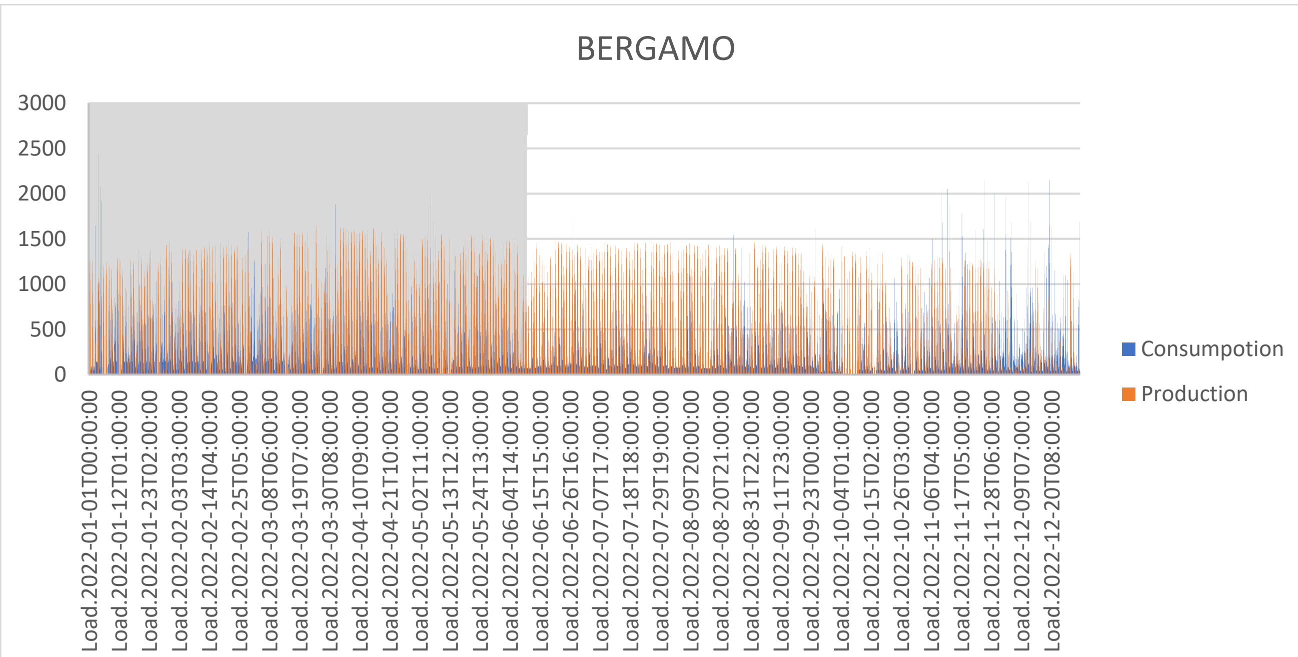

Figure 21 Hourly Consumption and Production of a house in Bergamo

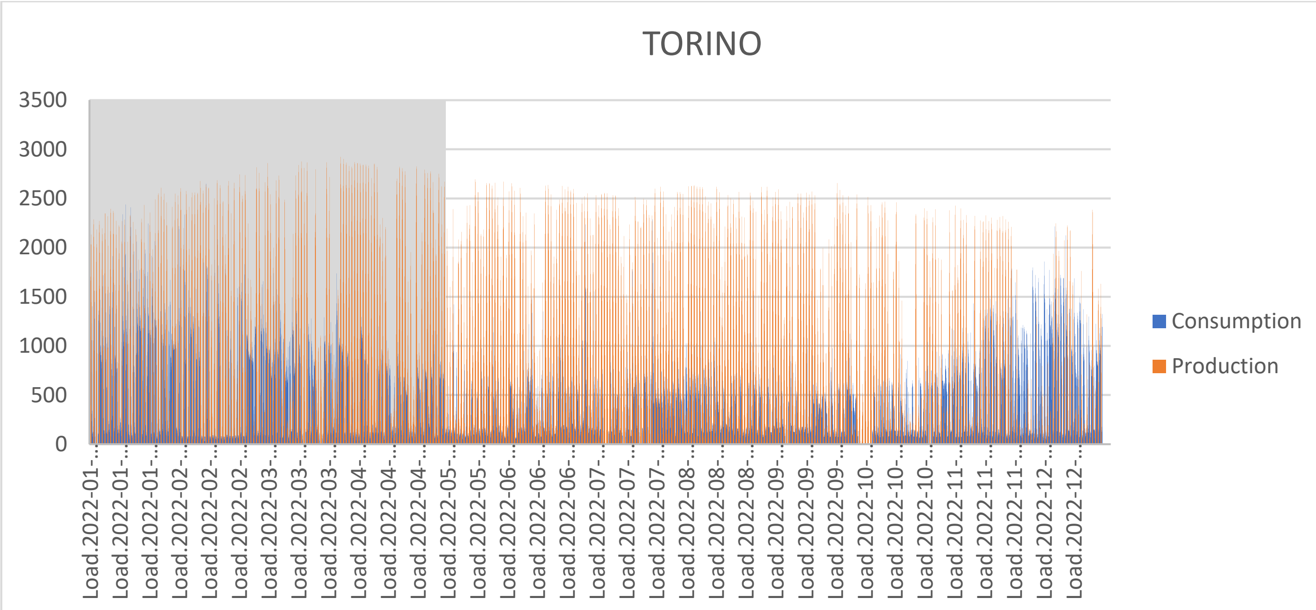

Figure 22 Hourly Consumption and Production of a house in Torino

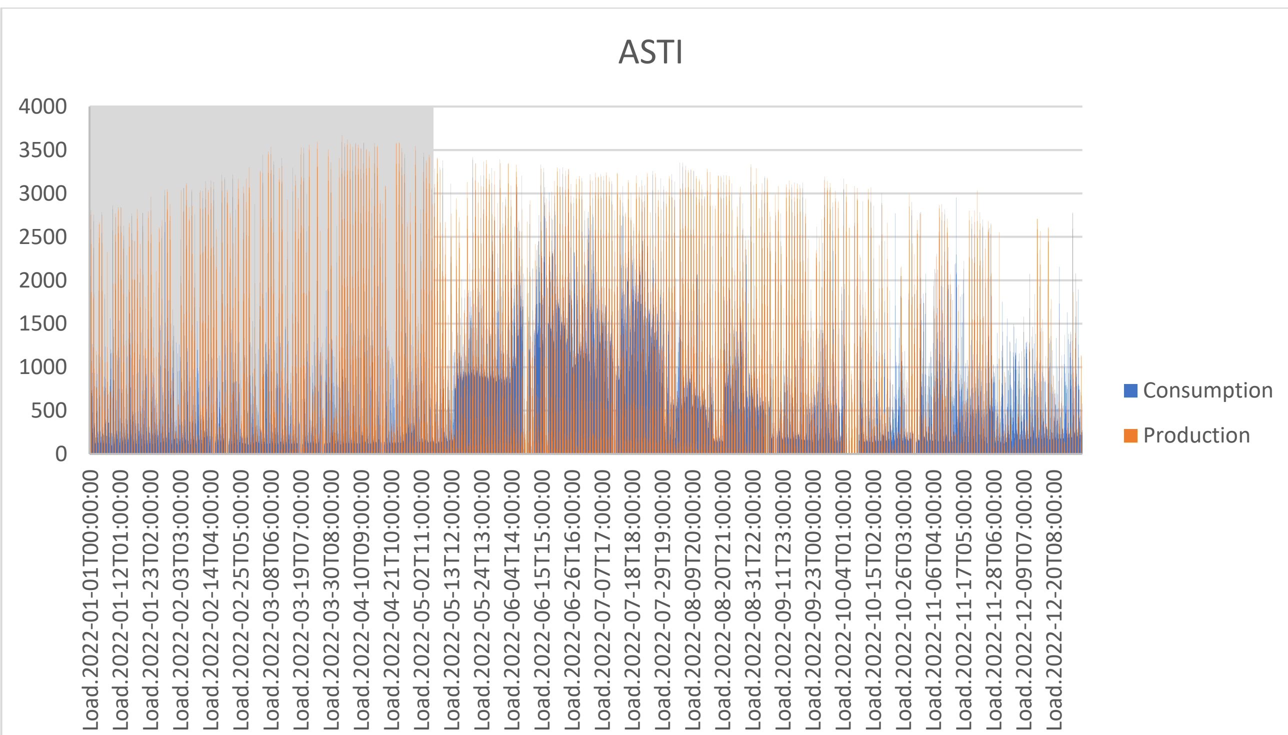

Figure 23 Hourly Consumption and Production of a house in Asti

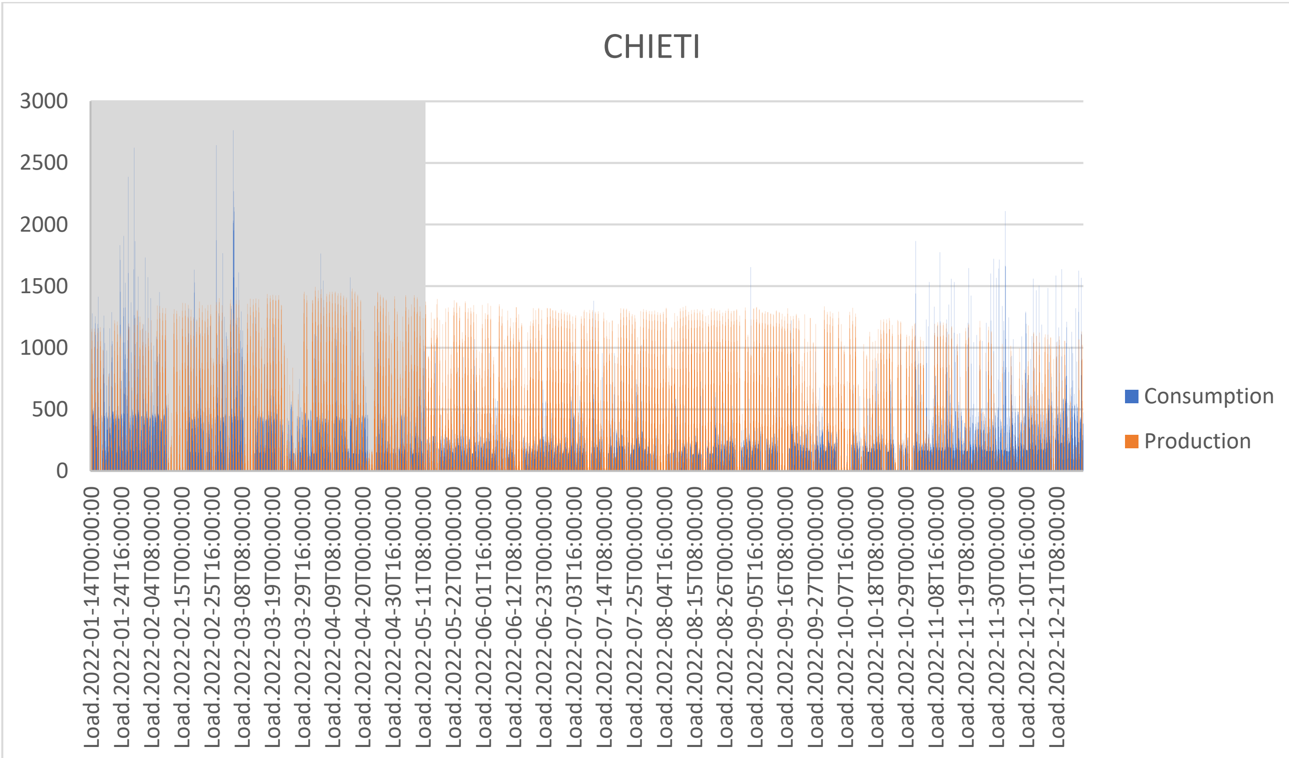

Figure 24 Hourly Consumption and Production of a house in Chieti

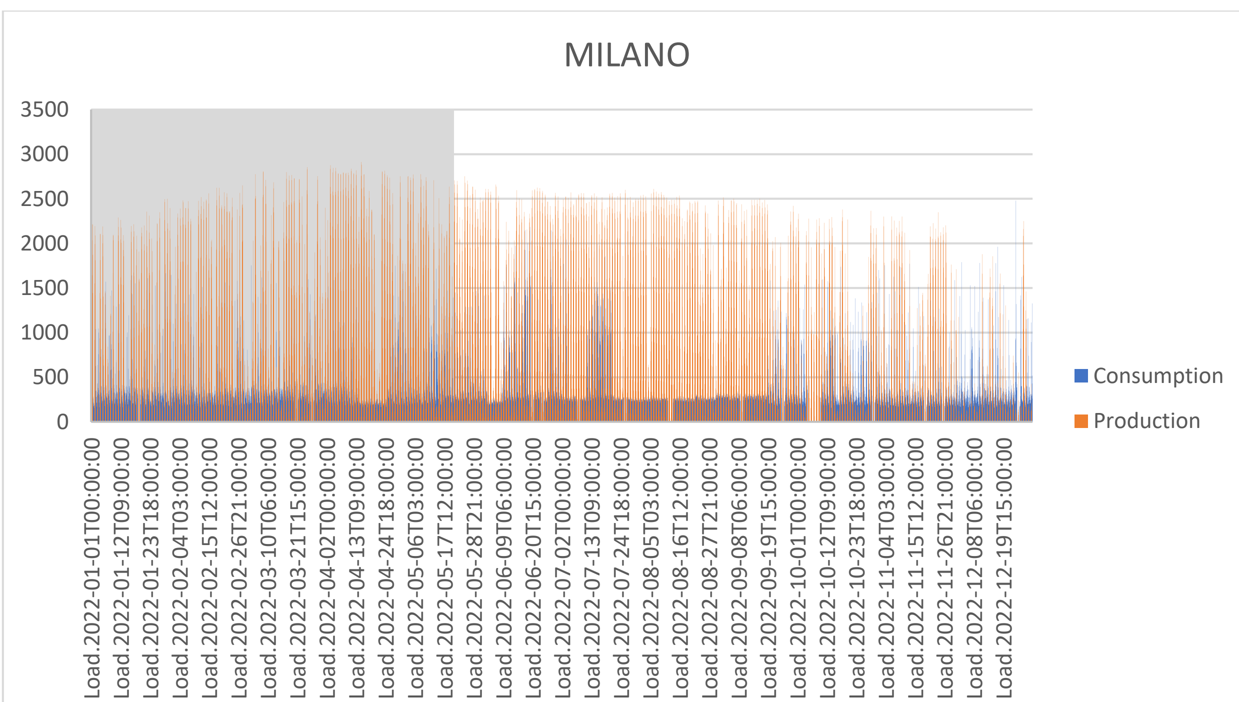

Figure 25 Hourly Consumption and Production of a house in Milano

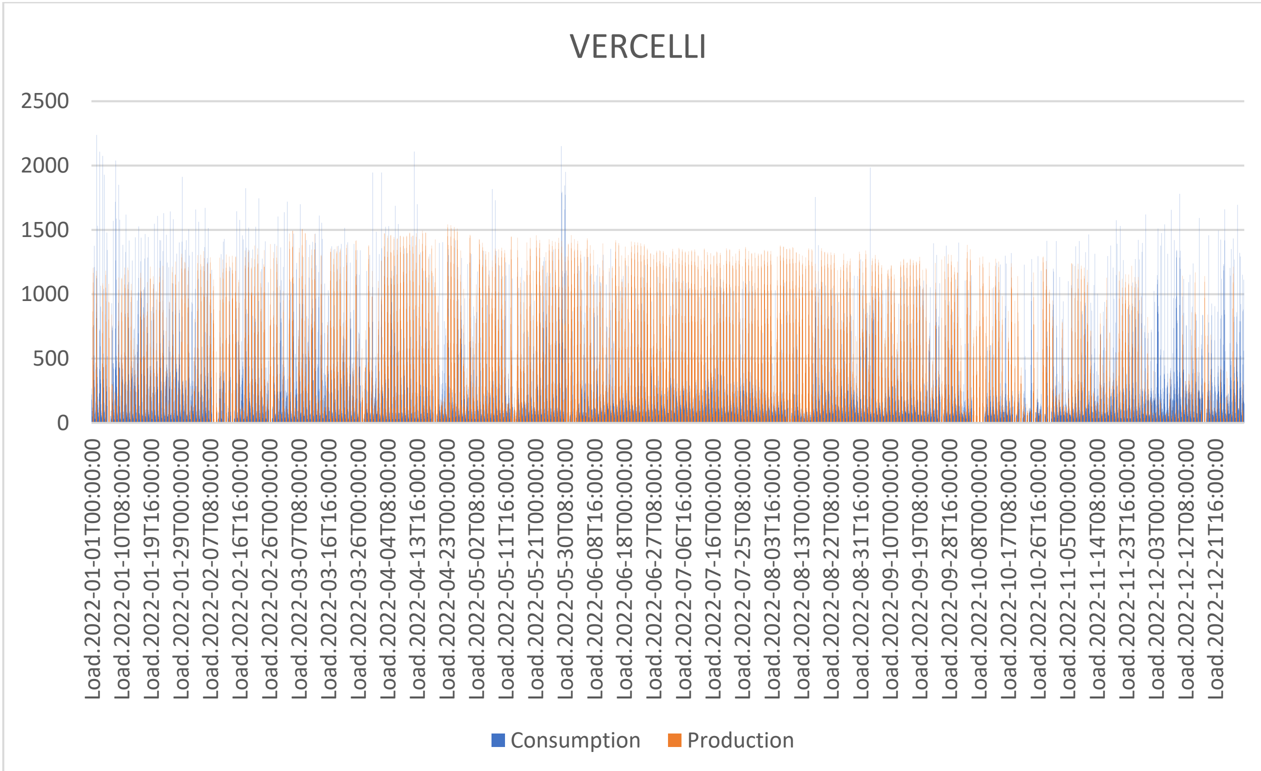

Figure 26 Hourly Consumption and Production of a house in Vercelli

With the production and consumptions curves from the simulation, the objective is obtained, and the hourly production is achieved. There is an excess in production since the simulation was based on the worst month of irradiance and for the use of all year long. By analyzing the production curves, the user can be furnished with all the necessary information to make the suitable decision. With excess production the client can utilize the net metering procedure and use electricity from the grid when the system is not producing.

Net-Metering (scambio sul posto)

As explained by the RES LEGAL EUROPE "Scambio sul Posto" is a form of auto-consumption that allows prosumers to offset the electricity produced and fed into the network at a certain moment with the energy taken from the grid and used. Therefore, the electricity system is used as a tool for the virtual storage of electricity produced but not self-consumed in the moment in which it is produced. The "scambio sul Posto" can be combined with tax deductions but cannot be combined with the "Ritiro Dedicato".

In Italy, RES-E producers can make use of the Scambio sul Posto if their plant’s capacity does not exceed 500 kW (Art. 2bis,2 e 612/2014/R/eel) The principle of Scambio sul Posto is based on the balance of the energy fed in and consumed (Art. 1, 2 570/2012/R/efr). Under scambio sul Posto, the plant operator pays the supplier for the electricity consumed, while GSE gives credit for the electricity fed in. This method can lead to a surplus on behalf of the plant operator (Art. 1 par. 1 a 570/2012/R/efr). The balance is calculated once a year (Art. 8 par. 2 570/2012/R/efr). More specifically, the owner of such plants will receive a compensation equal to the difference between the value of electricity exported to the grid (e.g., for PV installations the energy fed in during daytime) and the value of the electricity consumed in a different period. If more energy is fed in than consumed, plant operators are entitled to have economic compensation, (Art. 6 570/2012/R/efr). If they feed in less than they consume, the difference is subject to a payment. Plant operators receive credit for the produced electricity. This credit will be available for an unlimited period (Art. 6 par. 7 570/2012/R/efr).

A given plant operator is contractually entitled to net-metering against the grid operator.

Plant operators shall apply to the GSE as defined by the GSE and positively verified by the directorate of the Regulatory Authority for Energy, Grids and Environment (ARERA). Following reception of the application, the GSE verifies that all the requirements to be eligible for the net metering are met. Then, the GSE reaches an agreement with the plant operator comprising the connection and the respective time frames (Art. 3 par. 2 and 3 of Annex A, 570/2012/R/efr). GSE assesses the information and data submitted by the producers as the competent authority (Art. 9 570/2012/R/efr).

Since 1 January 2015, RES plant operators that present, for at least one day during the year, a valid Net-Metering Convention - except for facilities with a capacity up to 3 kW - must pay to GSE a fee to cover the costs of management, verification, and control.

Tariffs are applied annually. There is a fixed fee of € 30 per Net-Metering Convention and a variable fee depending on the RES plant capacity. The variable fee is about € 1 /kW and only applies for RES units with a capacity between 20 kW and 500 kW.

For cases in which net metering is used under several offtake and injection points, an additional contribution of € 4/year for each connection point applies (DM 24/12/2014)[26].

Chapter 4

4. Data Analysis

Electric cars are complementary for a house that has a photovoltaic system installed, since they can use the energy produced by the photovoltaic system to recharge the battery in the electric vehicle. In addition, the electric vehicle battery can supply the household with the energy stored with the "vehicle to grid" or "vehicle to home" system.

Starting with collecting data of 1600 cars with different types of combustion fuel, a summary excel file was created to identify the level of improvement an individual can achieve by passing to an electric vehicle. The summary excel file where the average is calculated from the consumption and emissions values presented for the cars is represented in *Figure 27*.

	Categoria della macchina\Carburante	Benzina	Diesel	Ibrido Benzina	Ibrido Diesel	Ibrido plug-in Benzina l/100km	kWh	Elettrico in kWh/100km
Consumo Energetico l/100km	Mini	5.59	N/D	5.85	N/D	N/D	N/D	15.7
Emissioni di CO2 g/km		28.2	N/D	29.5	N/D	N/D	N/D	3.69
Consumo Energetico l/100km	Piccole	6.09	4.9	5.13	N/D	N/D	N/D	18.45
Emissioni di CO2 g/km		30.7	23.5	25.9	N/D	N/D	N/D	4.54
Consumo Energetico l/100km	Medie inferiore	6.89	5.25	5.78	4.75	1.27	15.16	17.89
Emissioni di CO2 g/km		34.68	25.48	29.14	23	10.28		4.45
Consumo Energetico l/100km	Medie	8.07	5.8	9.03	5.92	1.28	18.19	18.59
Emissioni di CO2 g/km		40.85	28	45.88	28.72	11.1		4.8
Consumo Energetico l/100km	medie superiori	11.01	7.05	7.24	6.38	1.53	18.13	22.63
Emissioni di CO2 g/km		55.87	34.13	36.47	30.76	12.13		5.67
Consumo Energetico l/100km	Lusso	11.33	8	6.31	6.54	1.65	22.27	22.43
Emissioni di CO2 g/km		57.5	38.67	30.42	31.67	13.83		5.75
Consumo Energetico l/100km	Coupe	10.59	6.74	10.21	5.73	2.4	14.3	24.74
Emissioni di CO2 g/km		52.81	32.6	51.87	27.71	16		6
Consumo Energetico l/100km	Roadster	9.56	5.61	8.38	5.5	4.4	14.5	15.35
Emissioni di CO2 g/km		48.32	27.29	42.42	26.67	26		3.5
Consumo Energetico l/100km	SUV S	6.89	5.24	5.88	N/D	1.73	16.63	15.74
Emissioni di CO2 g/km		34.71	25.45	29.72	N/D	12.67		3.93

Figure 27 Summary for cars consumption and CO2 emissions

The consumption and emissions values were exported from the website of "Bundesamt für Energie – BFE / L'UFE" which is the federal statistical office for energy in Switzerland.

It is evident that electric cars have the lowest values of CO2 emissions, and the consumption is also lower with respect to other Internal combustion engine vehicle (ICEV). Moreover, by passing to an electric vehicle, especially if the house is equipped with a photovoltaic system, the footprint of the household with the electric car will have a zero footprint on the environment for the energy consumed.

The most important component of the electric vehicle is the battery. To use the electric car in the most efficient way, the parameters that affect the battery charging and discharging are to be considered and considered when purchasing an electric car. In addition, the EV has an elevated value if the battery is going to be charged using solar panels, which also requires knowing some important values to estimate the energy necessary for the electric car.

4.1 The Battery: Function and Performance

The battery stores the energy necessary to move an electric car, but it is way more than that. Even if the motor stimulates the movement of the car, the motor is directly influenced by the battery and its efficiency to give energy. Hence, it can be said that the battery is the real motor of an electric car.

Capacity is the parameter used to measure the performance of the battery, it is measured in kWh, that corresponds to the quantity of kW (unit of measure of the power) that the battery can give or store in an hour. So, a battery with a capacity of 50 kWh can make a motor of 50 kW at maximum power for an hour or a motor of 100 kW for a half hour. Following the same logic, a charging system of 50 kW will serve for one hour to charge the battery and half an hour if the charging system is of 100 kW.

The second parameter is the quantity of energy that can be transmitted in one second, expressed in ampere. The voltage is the third measure, which corresponds to the velocity for one ampere to be transmitted. It is easy to understand that the increase in volt and ampere will result in a battery with high capacity also for charging.

Since the charging at high power or "fast", and the discharging are processes that with time wear out the components and reduce the performance of the battery, the effective capacity used will never be the maximum capacity but limited electronically to a lower level.

Normally, a margin of 5% to 15% of capacity is left not used and it's a parameter that the suppliers declare with the manufacturing. For example, in an Audi e-tron, the battery has a nominal capacity of 95 kWh while the effective one is 83.5 kWh and later was increased to 86.5 kWh with the latest update of the software.

4.2 Battery Decay and Wear

The decay of the battery depends on the coat wear of anode and cathode that with time reduce the capacity of storing. This does not compromise the performance like the power output, that remains constant over time, but the capacity is lower.

Battery wear is related to the number of cycles for charging and discharging that the battery must face. The suppliers give an estimate that is based on the average milage that a battery can assure at full charge, in this way they calculate the distance that a battery can cover before its performance gets reduced significantly.

The threshold usually is fixed, with respect to the manufacturer of the battery between 70% and 80% of the initial effective capacity. Below this level the battery is no longer considered usable to power a vehicle, although it can be reused as a static accumulator for ups and similar systems.

Many batteries on the market are nowadays guaranteed for 8 years or 160.000 km, even if some manufacturers give more milage coverage up to 200.000 or 240.000 km always in the 8-year range, while some give a guarantee of 10 years or 160.000 km.

In words, each manufacturer guarantees that in the arc of the specified period or distance the capacity of the battery will not be decreased below the threshold indicated. New technologies as shown in *Figure 28* improve the range of the battery.

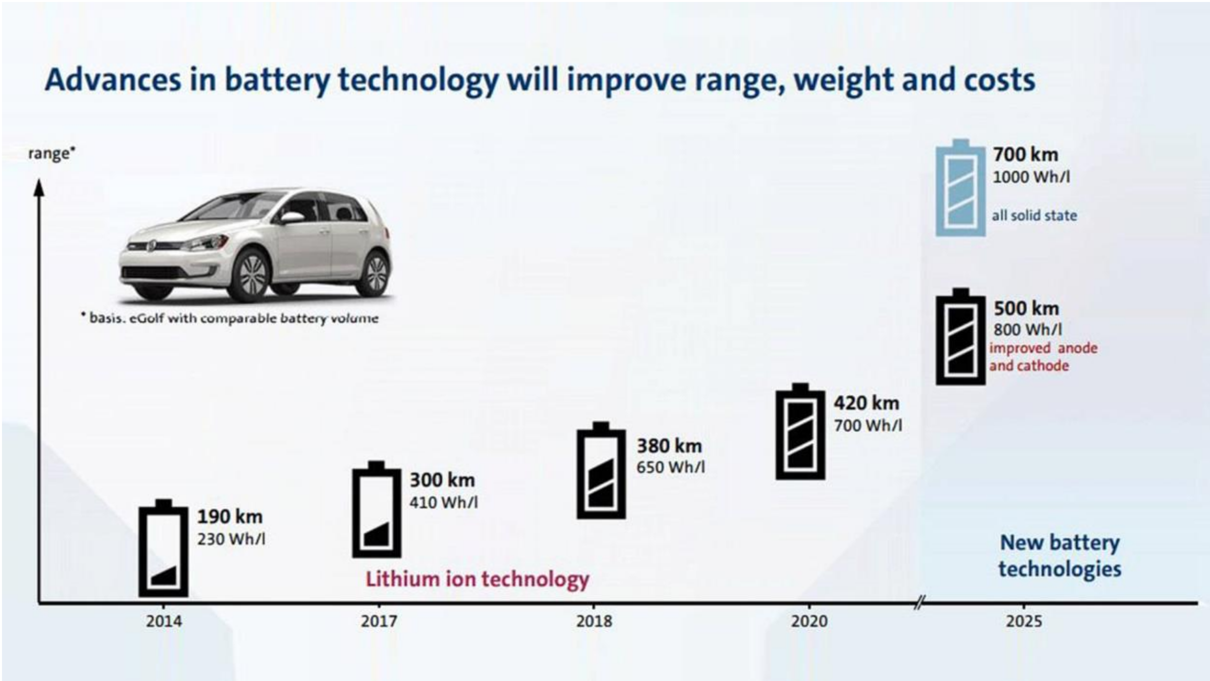

Figure 28 Battery Technology with Range [Source: autoclubgroup.it]

4.3 Battery Charging

The energy per unit time that the charging station or outlet can transfer into the battery of the car is the power of the charging outlet. It is measured in kW; this number is dependent on the availability of power and the type to which the car is connected. Usually, the maximum charging power limit of the machine is lower than the power of the charging outlet. The charging cable has a maximum current, if the cable supports higher currents, it can charge faster, but the cost of the cable will be higher as well.

If the EV charging points are connected to the grid, then it has limited energy to avoid blackout. In this case a load balancing system or power management gives a great advantage since it allows the user to use all the power available in the network by self-regulating the charging according to the home consumption. Equation 16 is used to calculate charging time [27].

$$Charging\ time = \frac{Battery\ capacity\ (kWh)}{Charging\ power\ (kW)}$$

Equation 16

The result of this calculation is the hours required to charge the car battery from totally discharged to fully charged. As shown in *Figure 29*, the higher the power outlet, the lower is the charging time.

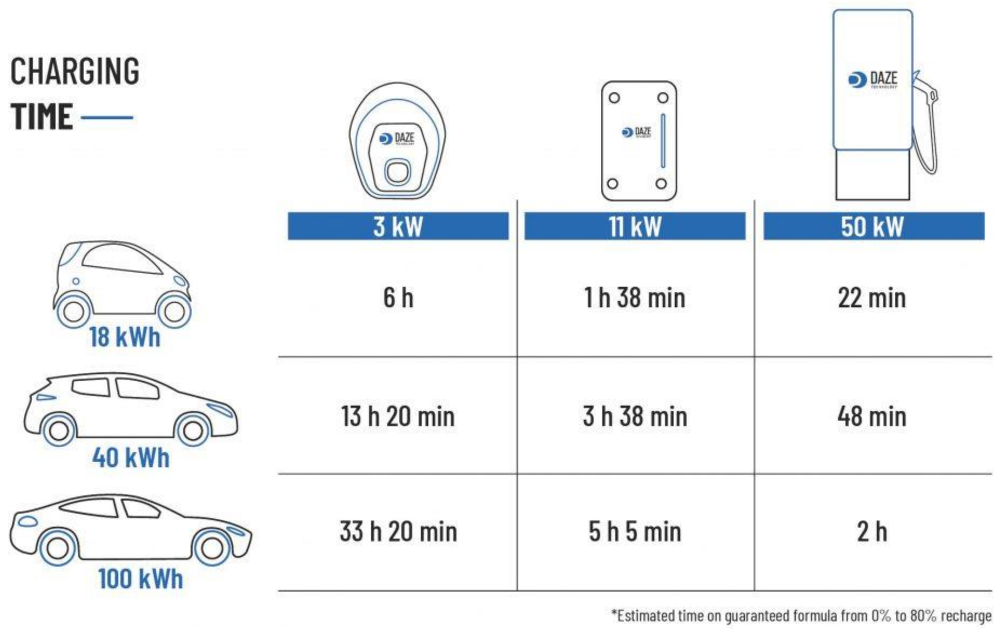

Figure 29 Charging time for different power outlet [source: dazetechnology.com]

A table on Excel was elaborated to estimate the charging time for different battery capacities of numerous cars, about 300 electric vehicles.

The calculation of charging time was made for three types of chargers:

- Plug-in (socket) EV charger 2 kW
- Single-phase Wallbox EV charger 7 kW
- Three-phase Wallbox EV charger 12 kw

By applying the Equation 16, we obtain the results shown in Table 3.

Table 3: Exported from excel, some of charging time calculation results

Electric Vehicle	Battery capacity kWh	Plug-in (socket) EV charger kw	Single-phase Wallbox EV charger kw	Three-phase Wallbox EV charger kw
		2	7	12
		charging time h	charging time h	charging time h
VinFast VF 9 Extended Range	123	61.5	17.57	10.25
Lucid Air Dream Edition R	118	59	16.86	9.83
Lucid Air Grand Touring	112	56	16	9.33
Fisker Ocean Ultra	100	50	14.28	8.33
Mercedes EQS SUV 450+	108.4	54.2	15.48	9.03
Tesla Model S Plaid	95	47.5	13.57	7.92
Mercedes EQS SUV 58	108.4	54.2	15.48	9
Mercedes EQE SUV	90.6	45.3	12.94	7.55
Mercedes EQS 450	107.8	53.9	15.4	8.98
NIO ET7 100 kWh	90	45	12.86	7.5

4.4 Solar panels Needed Calculation

To calculate the number of solar panels needed to charge an electrical vehicle, the following steps should be followed:

1. The first parameter to identify is the electricity an EV will use per day. Number of km travelled per day and the fuel efficiency rating of the EV. Fuel efficiency rating can be expressed in mi/kWh (km/kWh) for the purpose of this calculation, if it can't be found simply divide the MPGe (which the Environmental Protection Agency provides for all EVs) and divide it by 33.705 to get mi/kWh.
2. Divide the km (miles) traveled per day by the number of km the EV can travel per kWh and get the kWh per day. This figure is the average amount of energy the EV uses per day and how much solar capacity the driver needs to keep the EV charged.
3. Find how much a single panel can produce per day in Wh per day by multiplying the wattage with the sun hours per day and then multiply by 1000 to get kWh per day.
4. Divide the kWh of electricity needed by the daily kWh of a singular panel to get the number of panels.

To understand better the calculation process, the number of panels was estimated for different types of electric vehicles with different battery capacities. As shown in Table 4, first the fuel efficiency for each EV was converted to km/kWh. Then a parameter of ana average distance travelled per day was selected, for an optimal result this parameter can be asked to the client threw an interview. Lastly for this part, we get the kWh/day needed by dividing the kilometers travelled per day by the fuel efficiency in km/kWh.

Table 4: Exported from excel, some kWh per day needed calculation results

Electric vehicle	Fuel efficiency rating Wh/km	fuel efficiency km/kWh	Km traveled per day	kWh/day needed
Hyundai IONIQ 6 Standard Range	150	6.67	12.9	1.93
Tesla Model 3	151	6.62		1.95
Dacia Spring Electric 45	152	6.58		1.96
Tesla Model 3 Long Range Dual Motor	155	6.45		1.99
Hyundai IONIQ 6 Long Range 2WD	156	6.41		2.01
Renault Megane E-Tech EV40 130hp	160	6.25		2.06
Mini Cooper SE	161	6.21		2.08
Lucid Air Pure	157	6.37		2.02
Volkswagen e-Up!	158	6.33		2.4
Renault Twingo Electric	164	6.09		2.11
BMW i4 eDrive35	168	5.95		2.17

Then three technologies of solar panels were chosen with different wattage 330, 380 and 425 W. Multiplying then the wattage with the sun hours available per day, we get the kWh a singular solar panel can produce. Sun hours parameter for this calculation was chosen as an average, for a better result the sun hours considered should be those available in the area where the panels will be installed. Then dividing the kWh needed per day by the output for a singular solar panel we get the number of panels needed as shown in Table 5.

Table 5: Exported from excel some of number of panels calculated for different wattage

	Sun hours per day	kWh per day SunPower wattage	kWh per day Q. CELLS PEAK Duo wattage	kWh per day Panasonic N330 wattage	number of Sunpower panels	number of Q.CELL panels	number of Panasonic panels
	4	425W	380W	330W			
		1.7	1.52	1.32			
Tesla Model Long Range Dual					2	2	2
Peugeot e-Rifter Long 50 kWh					2	2	3
Volkswagen ID. Buzz					2	2	3
Volvo EX90 Twin					2	2	3
VinFast VF Extended					2	2	3

Factors that affect the number of panels it takes to charge an EV extracted from Table 5 are:

- Number of km traveled per day
- Wattage of the solar panels
- Average hours of sun per day

4.5 Vehicle To Grid

In a Conventional EV Charger electricity goes from the electric grid into the electric car in unidirectional (one-way). However, in a bi-directional EV charger as represented in Figure 30, electricity flows both from electric grid to vehicle and from vehicle back to grid (bi-directional) [28].

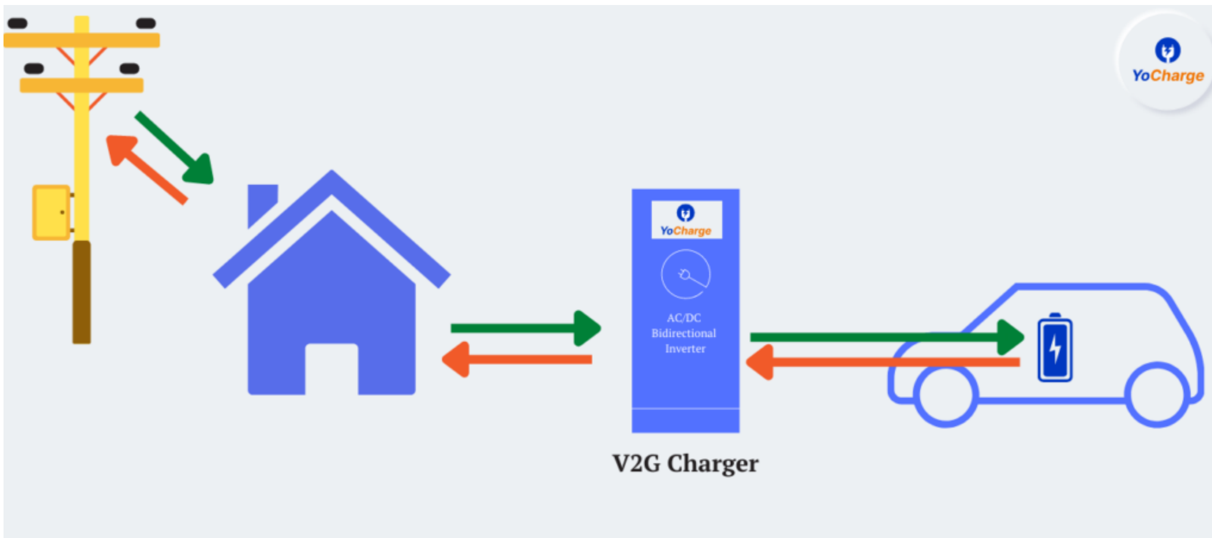

Figure 30 Vehicle to Grid illustration [Source: yocharge.com]

Vehicle to Grid is a technology that allows the transformation of electric vehicles increasingly present on the roads, from simple means of transport to a real energy provider capable of exchanging electricity with the grid. From this point of view, and once the system is established, each owner of an electric car will be able to become a small energy supplier and thus contribute to the rationalization and efficiency of the electricity system. In fact, thanks to the vehicle recharging phases, the car batteries can also be used as energy storage systems serving the grid.

The services provided by these vehicles, with respect to the D.M. of 30th January 2020, can be divided into tertiary reserve and balancing services. The vehicle to grid technology has as its primary objectives both to increase the diffusion of electric vehicles that will participate in the operation of the public network and exploit the batteries of these electric cars in terms of greater safety and flexibility of the electrical system.

Conclusion

Having a house that is independent energetically, with an electric vehicle as well, makes the footprint negligible if not zero energetically. The decision to live in an energetically independent house, however, should be based on technical information and assessment of the investment before applying it.

The purpose of this thesis work can be declined in two key points, the calculation of the production of photovoltaic systems from the database of consumption of houses provided by Midori S.r.l. and the integration of electric vehicles with the photovoltaic system of the household.

There are numerous sources available to size and design a photovoltaic system, however they require a high level of understanding, which for a user that is not in the science field might be difficult to use. The method used in the simulation for this thesis is using a simple formula that can calculate the number of panels needed for a house and the respective hourly energy output, making it more accessible to the user. Some parameters should be defined or known before starting with the calculation method. It is important to know the consumption that the solar system should cover, the type of panel that is going to be used, the address of the installation site, the number of days of autonomy of the battery and the use period of the PV (seasonal or all year long). The main goal of estimating the production of the estimated size of a photovoltaic system is necessary for providing the client with the important details to make the investment the most beneficial possible.

In addition, having an electric vehicle at a house that is energetically independent through a photovoltaic system would make it very convenient to add panels to cover the km travelled per day by the electric vehicle. The charging time formula is dependent on the output power and the size of the battery inside the electric car, as the charging power increases the charging time decreases and as the battery capacity increases the charging time increases.

To calculate the number of panels required to cover the daily consumption of an electric vehicle, several parameters need to be known: number of kms travelled per day, the sun hours available, the fuel efficiency rating of the electric vehicle and the outage power of the panels used. The calculation was made for 300 cars, and it shows that to travel 12.9 km distance by the cars examined, two or three panels are enough (refer to Table 5).

As a final remark, the accuracy of the calculation can be optimized by getting some parameters directly from the clients. A good method to be used is explained throughout the thesis (refer to2.6). On the other hand, sometimes measuring all the parameters necessary might not be available and it is important to have a method to estimate any project.

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