UNIVERSITY
OF GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT

FEASIBILITY OF ALTERNATIVES TO PROVIDE ENERGY TO A COUNTRYSIDE SINGLE FAMILY HOUSE IN LULEA

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PREFACE

We want to use these lines to thank our supervisor Björn Karlsson not only for all the help and time he has dedicated to us during the project but also for being a devoted teacher in the course Sustainable Energy Systems. Subject that has motivated us, inter alia, with the topic of choice.

Thanks to the Nordic Outdoor Education program for providing us the opportunity to discover the great landscape in the Swedish Lapland where the topic of the project came as an idea. Thanks Hervor and Pekka.

We also want to thank Matthias Cehlin and Elisabet Linden who helped us in the previous steps to the project work.

At last but not least, we have to thank our Erasmus friends who have been supporting us during the project work.

ABSTRACT

After enjoying one week in the Swedish Lapland, the idea of providing energy to one of those isolated cabins in the far landscape caught our attention.

Nowadays, there still exist many dwellings, usually located in rural isolated sites, which have no easy access or even no possibility to get connected to the distribution and transport electricity grids. This situation may cause some inconvenience to the owners, therefore, the interest in finding new alternatives for supplying electricity.

Such a problem requires specific solutions, including the development of electrification programs in those countryside isolated spots. Thus, the present project intends to perform a study which would provide the proper electric system to a summerhouse in the North of Sweden.

Regarding the current European environmental politics and considering the rural location of the dwelling of study, the project will focus on various renewable alternatives to reach the above mentioned goal. In fact, Sweden has the greatest share of renewable energies in all European Union countries with a fixed goal of reaching 50% of its total energy production by renewable sources by the year 2020. For the present moment, Sweden already accounts for 9.4 GWh on solar energy production and 3.5 TWh on wind power production by the end of 2010. Therefore, the study will build on these alternatives as they represent two of the most extensively developed renewable possibilities in the country.

Thereby, the first objective of the project was to determine a concrete location considering both our initial idea and the possibility of obtaining the wind speed and solar radiation data. A plot located 20 km to the north of Lulea was finally chosen.

Then, once having the necessary baseline data comes the sizing of the different alternative: stand alone wind turbine system, stand alone PV system and a hybrid system combining wind power with the support of an electric generator. No option including grid connection is taken into consideration due to the lack of accessibility.

Finally, it is performed an economic study of each alternative that would lead to a clear conclusion of which is the most appropriate choice in the study case. Economic criteria will therefore be the most significant factor when choosing the optimum alternative. However, environmental issues would also be taken into account.

As no traditional electrification is studied, the economic analysis will not refer to the obtained monetary savings regarding to the grid connected option but will be performed by comparing initial investments.

After all, it is concluded that the studied dwelling will be electrified by a hybrid system combining wind power with an electric generator. The system includes a 20 kW wind turbine and a diesel fueled generator with 8 kW power service. The generator will provide the required energy to the house during those days when the wind resource is not capable to cover the demand. Therefore, the lack of electricity supply will be avoided.

Regarding investment costs of the chosen alternative, the hybrid system accounts for 20,729€ investment, which corresponds to about 40% the total price of both solar and wind stand alone systems. .

Considering environmental criteria, the hybrid system only requires 23 diesel liters to be burned during the six summer months. Therefore, emissions due to combustion are relatively low and not considered as damaging. So, the chosen alternative meets both economical and environmental requirements.

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Chapter 1

INTRODUCTION

1. INTRODUCTION

Being an Erasmus student in a country totally different from yours always provides a big chance to get to know and enjoy a new culture. In our case, it is so. Studying a master in energy systems in one of the countries that is performing a higher development over the issue is a great advantage. But we are not only increasing our knowledge in the different types of energy sources, always highlighting renewable energies, but also learning about the most intrinsic Swedish culture and relationship with nature by joining a Nordic Outdoor Education course.

It was during one of the journeys made with the Nordic course when the idea of the current project came up. We were practicing cross-country ski in the Kungsleden trail up in the Swedish Lapland. For one week, we slept in small isolated cabins with no electricity, no tap water or heating possibilities. The experience was genuine but, as engineers, we started thinking how could we make life easier in such remote areas. Hence comes the idea of studying the possibility to provide energy to a countryside single family house.

Nowadays, there are many isolated rural dwellings in which the impossibility to have access to the electricity grid involves some inconvenience to their owners. Therefore, researches looking for new electrification alternatives are currently carried out.

The main reason for this lack of service is the significant investment required for the conventional rural electrification of isolated dwellings. It is due to the large distance between the energy distribution network and the consumption spot. In the case of Lapland, it should be added the great dispersion of houses along the landscape and the reduced power required.

From the distribution companies' point of view, the high investment mentioned before, high operating and maintenance costs and the low energy demand make it difficult to turn the facility cost effective. Thereby, specific solutions are required to develop new electrification alternatives which include the use of the energy resources found at the location of study as well as good cost/service relation for the client. Either wind or solar available energy in the area could be exploited or a fuel generator could be installed in order to cover the demand.

Therefore, taking advantage of the current increased interest in the use of renewable energies all over the world and especially in those facilities with no concrete electric system; the current project will develop different renewable electrification alternatives for a single family summerhouse in the north of Sweden and discuss their viability regarding to both economic and environmental criteria.

It is a fact that more and more, society is becoming aware of the importance of taking care for the Earth. Developed countries energy consumption is greatly increasing over the years mostly based in non renewable energy sources which are the main reason for some environmental problems such as greenhouse effect, inter alia.

Because of that, governments are fixing renewable production targets to achieve in the coming years. Countries are mainly supposed to meet the targets nationally, but they can also do it in cooperation. Thus, countries with a good resource base can contribute to other countries facing difficult situations. In the case of Sweden, wind power is their most promising option to reach renewable power targets.

However, renewable technologies are usually not competitive according to the current power prices. Therefore, governments are promoting them by giving some subsidies such as power transmission tariffs or green certificates. Being the last option the one adopted by the Nordic governments over the last years.

To sum up, the present project takes into consideration the current electrical world situation and tries to efficiently adapt the summerhouse electrification to the new renewable trends. Thus, contributing to make a better use of the available energy sources and taking environmental awareness.

Chapter 2

THEORY

2. THEORY

2.1. TYPES OF ENERGIES

Energy sources can be divided into two big subgroups, renewable and non-renewable energy sources.

2.1.1. NON-RENEWABLE SOURCES

Non-renewable energy refers to those sources based in the usage of energy found in nature in a limited amount. These resources are often consumed much faster than nature can create them and since there is no production or extraction system available, they can not be replaced after being entirely consumed. Fossil fuels or uranium and plutonium deposits are some examples.

- Fossil fuels

Coal, oil and natural gas are the three fossil fuels. They come from buried remains of livings from millions of years ago, which have been changing under suitable conditions of pressure and temperature. These conditions make it impossible to synthesize these materials in a laboratory. It is a process in nature involving million of years to take place.

Fossil fuels can directly be burned in order to obtain heat, movement or electricity. In order to produce electricity, fossil fuels are used in thermal power plants. The water vapour obtained during combustion is guided, under pressure, to run an electric generator, usually operated buy a turbine. Those plants present not only efficiency problems due to the heat losses emitted to the atmosphere, but also high variable costs because of the fluctuations in the fuel's price and environmental problems due to greenhouse gasses emissions.

Internal combustion engines are another important application of this type of fuels. In this case, mechanic energy is obtained from the chemical energy developed in the burning room.

Therefore, in order to avoid the problems related to the use of fossil fuels, new research is done in terms of biofuels production.

- Biofuels

Biofuels are organically produced from biomass, which is the organic matter obtained from living organisms or their wastes, such as cow dung. Other agricultural wastes from corn or wheat can also be used as well as tree species like eucalyptus or pine.

The most developed biofuels so far are bioethanol and biodiesel. The first one is mainly produced from sugar cane or corn while the second one comes from different types of fat and oil, which can be either vegetable or animal oils.

- Nuclear fuels

The most common nuclear fuels are uranium and plutonium. However, all fissile elements that can be adapted to the reactor can be considered nuclear fuels. Those types of fuels are the most dense sources of energy available nowadays and require an enrichment process before used.

Nuclear fission is based in dividing nuclides in an exothermic reaction that delivers huge amounts of energy. Nuclear energy is capable of producing a lot of electricity from very low fuel. Variable costs are low and do not generate greenhouse gases. On the other hand, its biggest problem is the radioactive waste that can last for many years.

2.1.2. RENEWABLE SOURCES

Renewable energy is the energy obtained from unlimited natural sources such as sunlight, wind, rain, tides, and geothermal heat. Some are unlimited because of the high amount of energy contained, and some others because they can be regenerated by natural means.

Energy consumption is one important measure of progress and welfare in a society. During the last years, industrialized countries have experienced an economic development as well as an energy consumption increase. Taking into consideration that fossil fuel and nuclear power are finite sources, it is clear that at some point, the energy demand would not be supplied. Hence the interest in discovering and developing new methods to obtain energy. Renewable energies seem to be the perfect option among developed countries. Its main objective is getting to a more efficient energy system with renewable energies playing an important role, promoting a culture of sustainable development and energy saving in all sectors of society.

On the other hand, renewable energies also seem to be the perfect solution in the developing world. "60% of the energy growth in the next few decades will take place in the developing world where about two billion people are living without access to electricity." (*"Renewable energy – the future for the developing world"* article by *Professor Dieter Holms* and *Jennifer McIntosh*, *Renewable energy focus, January/February 2008)*. As is mentioned in the article, about 2.4 billion people in Africa and Asia depend on traditional biomass in the form of firewood for cooking and heating their homes. This biomass is usually burned with relatively low efficiencies and high levels of indoor pollution threatening people's health. Meanwhile, developing world has vast amount of undeveloped renewable resources which would provide the population with high energy possibilities. In addition, better access to clean modern energy in the developing countries would be a basic step to reduce poverty.

Regarding the developed world, the European Union has made significant efforts in developing this new energy sources in order to decrease fossil fuels consumption and its environmentally negative impact. Renewable energy promotion in the EU has been carried out through investment subsidies, tax advantages and special prices per kWh produced by these means. Such measures have lead to an uneven development of the renewable energies. Those which could mean a greater benefit for the equipment investors, like PV modules or wind mills, have been highly expanded.

Sweden has the greatest share of renewable energy in all European Union countries. Since 1970's, when the oil crisis started, Swedish energy and environmental policy has been focused on increasing the use of renewable energy sources. Nowadays, renewable energies represent about the same amount of energy supply than oil. As can be seen in Figure 1 below, most of that energy accounts for hydropower (12%) and biofuels (22%) out of the final supply, although some effort has also been put in solar and wind fields.

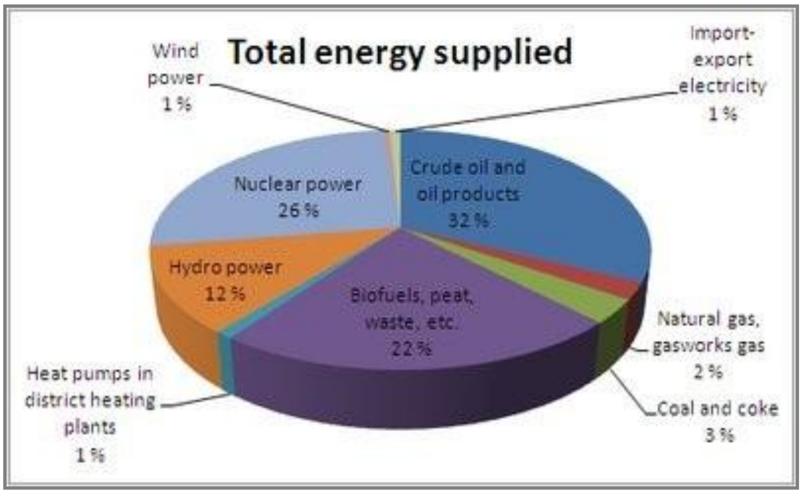

Figure 1: Distribution of the total energy supply in Sweden.

By 2020 renewable energy should account for 20% of the European's Union total energy consumption. I order to reach the target; each member state should increase its production and use of renewable energy in electricity, transport and heating and cooling demands. In the case of Sweden, the target is to reach 50% of renewable energy by 2020.

2.2. WIND POWER

2.2.1. INTRODUCTION

Along with thermal energy, wind power is one of the oldest energies used by humans. Actually, is has been used for more than 5000 years to propel sailboats and sailing ships. Windmills appeared around 7th century and were used for irrigation pumping and milling grain. But it wasn't until the early 1980's when wind energy started to be developed in a more efficient way and this development has continued up to now, when it has become a competitive energy source. Nowadays, wind energy is the most productive and most developed renewable energy field for electricity production.

According to a report released by *Cambridge, Mass.-based consulting firm Emerging Energy Research*, wind power capacity is predicted to rise to over 290 GW by the end of 2015.

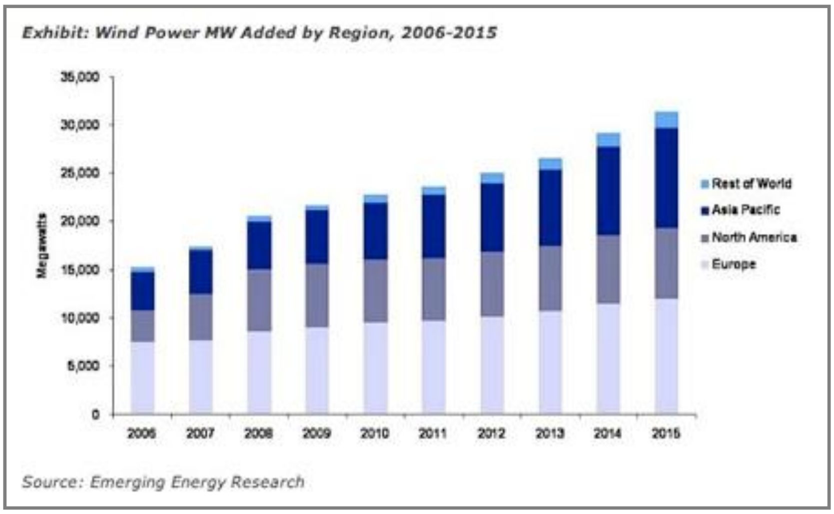

Figure 2: Wind power global predicted production in the world in MW.

As observed in Figure 2 above, both Asia and North America involve further development while Europe's growth remains constant over time accounting nowadays for 47'9% of the total capacity.

Germany, Spain, EEUU, India and Denmark are the five most involved countries with this type of energy. All together account for almost 73% of the global production. Meanwhile, although Sweden is considered an attractive market for wind power development mainly due to very good wind resources, to its long coastline and to the large size of the country and its relatively small population, the country presents a modest wind power capacity compared to other European countries.

In Figure 3 below it is observed how, despite not being a leading country in wind power, Sweden has increased its production in a considerable amount over the past 10 years. In fact it increased its production by 38.7% in 2010 starting 2011 with a total capacity of 2163MW.

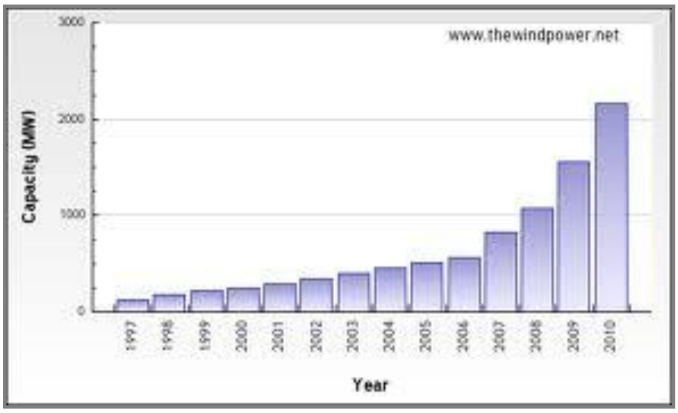

Figure 3: Yearly wind power capacity in Sweden (MW).

According to the *Swedish Wind Energy Association*, the technical wind energy potential in Sweden is estimated to be around 540 TWh/year. Therefore, Swedes plan to reach 14,000 installed megawatts for the year 2020, of which between 2,500 and 3,000 will be offshore. For the present future, Sweden has purchase orders for the installation of 319 wind turbines with a combined capacity of 676MW by the year 2011. It is thus clear the country's commitment to the promotion of renewable energy, and more specifically, wind energy.

At the present time, the main discussion about wind energy is focused on the possibility to build offshore wind farms. Costs and benefits of offshore wind relative to onshore power and conventional electricity production are discussed in the text "*Ecological and economic cost-benefit analysis of offshore wind energy"* by *Brien Snyder and Mark J. Kaiser, LSU Center for*

Energy Studies. Criticism on offshore wind power stand for the possibility of navigational problems for recreational boats and small fishing vessels attempting to navigate through a wind farm, no economical viability without federal subsides, more costly and risky environment regarding to maintenance and the most important, the impossibility to provide constant, predictable power to the grid which would imply the integration of backup systems (usually gas natural burning power plants) to quickly respond to the change of production. On the other hand, offshore turbines can operate at their maximum capacity for a larger percentage of time due to stronger and more constant winds blowing in the sea. Hence, providing a more constant source of power delivered to the electric grid.

Therefore, offshore farms mean higher investment costs and maintenance but may lead to a cheaper way to produce electricity in some cases. Thereby, the discussion is still open.

2.2.2. TECHNICAL BASE

Wind power is the energy obtained from the wind. It is the kinetic energy produced by the effect of air currents and transformed into other useful forms of human activities.

The existence of wind in the earth is a consequence of the sun. It appears due to the radiation of the sun along with some other circumstances such as Earth's tilt and shift or the distribution of continents and oceans. Due to the unevenly heated areas of the Earth's surface and the atmosphere, air masses circulation is activated all over the globe. When heated up, air molecules are agitated, its density decreases and therefore, become lighter. The warm air moves upwards while colder masses take its place, that phenomenon is known as wind.

On one hand, there are a number of wind currents circulating around the planet in layer of the stratosphere. These winds are ruled by global changes in temperature and atmospheric pressure but also by other factors like Coriolis forces. Such forces cause northern winds to rotate in the clockwise and southern in the opposite direction when approaching an area of low pressure.

On the other hand, other local and more specific winds appear close to the Earth's surface. Those winds are characterized by the terrain and other variables such as roughness or height. In the case of roughness, the woods or a building will decrease wind speed and cause turbulences while smooth surfaces like the sea or airport runways will promote air movement. In terms of height, as rougher is the surface, higher wind turbines are required. Therefore, an accurate analysis of emplacement characteristics has to be done before installing a wind farm.

As seen in Figure 4 below, windmill blades should be located over the region of high turbulence and where the wind speed is not decreased by obstacles. Thus, the sea could be the optimum location for wind turbines from the output perspective but not from the erection point of view.

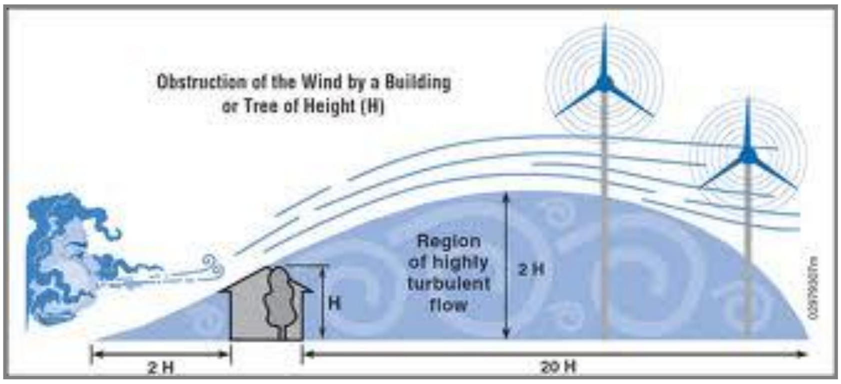

Figure 4: Air turbulence due to wind obstruction.

The two key values to analyze the wind are its speed (measured with an anemometer) and its direction (measured with a vane). It has to be taken into account that not every type of wind can be used to obtain electricity. Wind turbines require a minimum wind speed under which is not possible to produce energy due to friction and the blades weight. Furthermore, a maximum wind speed is determined in order to prevent from a structure break. Moderate profitable winds are usually between 4 and 25m/s.

Wind energy can be profitable for mechanical applications or for providing electricity to isolated houses. There are three main types of application:

- Mechanical applications, like water pumping and milling grain.
- Electric generation for isolated systems, productive uses and remote rural houses.
- Large-scale electric generation, construction of wind farms.

Being the second option the one developed in the current project.

The operating principle of this technology is based on a wind turbine, commonly known as windmill, which transforms the kinetic energy of the wind into electrical energy through a complex mechanism.

A mill is a machine that has blades or paddles attached to a common axis, which begins to rotate when the wind blows. The wind crashes into the turbine blades generating a torque (turning force) acting on the rotor blades. The rotor moves, as well, an electric generator (an alternator or a dynamo) which transforms the rotation mechanical energy in an electrical output that can be injected in the distribution network or intended for own consumption.

The amount of energy contained in the wind before going through a turbine depends on three parameters: incident wind speed, air density and the area swept by the rotor.

- **Incident wind speed:** kinetic energy in the wind increases proportional to its cubic speed. Therefore, air speed going through the blades is an important factor to take into account. The power-velocity relationship is:

$$P_{avaiable} = k \cdot v^3$$

- **Air density:** the energy contained in the wind is proportional to the air mass per unit of volume that, in normal conditions (sea level, 1013 mbar atmospheric pressure and 15ºC), is 1.225 kg/m^3. This means that when the air is cold and raises its weight, it also becomes denser and will transfer higher energy to the turbine. Otherwise, when the air is heated up or when placing at higher altitude, less kinetic energy will reach the turbine.

- **Swept area:** the larger is the area covered by the blades, the higher kinetic energy will be captured by the turbine. Currently used generators have three blades, an average power of 1.5 MW and an average blade's diameter of 60 meters.

Although the air contains a large amount of kinetic energy, not all can be captured by a wind mill. Therefore, it is necessary to make the difference between available power and profitable power of a particular location.

Available power is defined as the total amount of energy contained in the wind before going through the turbine. It is given by the following formula:

$$P_{available} = \frac{1}{2} \cdot \rho \cdot S \cdot v^3$$

where: $P_{available}$ = available power in [W] ρ = air density in [kg/m^3]

S = swept area by the blades in [m^2]

v = wind speed in [m/s]

In contrast, *profitable power* accounts for the real power that can be obtained from the wind by the chosen turbine. It is given by the following formula:

$$P_{profitable} = \frac{1}{2} \cdot \rho \cdot S \cdot v^3 \cdot C_p$$

where: $P_{profitable}$ = profitable power in [W]

ρ = air density in [kg/m^3]

S = swept area by the blades in [m^2]

v = wind speed in [m/s]

C_p = coefficient of power

The coefficient of power (or theoretical efficiency) is defined as the ratio between the maximum power obtained from the wind and the total power available in it. It is usually a data given by the wind turbine manufacturer. However, there is a maximum C_p value determined by the Betz's limit. Beth's law is a theory about the maximum possible energy to be delivered by a wind turbine out of a specific wind stream. The factor 0.593 is known as Betz's coefficient. Therefore:

$$C_{p_{max}} = \frac{16}{27}$$

Of course, the power output will also depend on many aspects regarding the shape and characteristics of the wind turbine itself.

There is a wide variety of wind turbines in the market attending to different classification criteria. The most common are: rated power, standalone systems or wind farms, rotor's diameter, number of blades (single, two, three, multi-blade...), position of the rotor shaft (horizontal or vertical axis), speed, etc.

- *Horizontal axis wind turbines* (HAWTs) are the most common form of turbines and researches have been focused on them over the last few years. They predominantly have two or three blades (low-solidity devices), or a large number of blades (high-solidity devices). With solidity accounting for the fraction of swept area that is solid.
  Its main feature is that the rotation shaft is parallel to the ground and to the wind direction. Due to its height (40 o 60 meters from the ground), it can make better use of air currents and therefore present higher efficiencies. Its disadvantage has to do with the transport, assembly and also with the impossibility to operate over 100 km/h wind speed in order to avoid structural damage.

- *Vertical axis wind turbines* (VAWTs), unlike their horizontal axis counterparts, can exploit winds from every direction without repositioning the rotor when the wind direction changes. They account for greater solidity (although the number of blades is usually smaller) which results in more expensive and heavier rotors.
  Its main feature is that the rotation shaft is perpendicular to the ground and to the wind direction. They can deal with high wind speeds but present a small capacity to provide energy.

Nowadays, the most common wind turbine configuration is the horizontal axis wind turbine with three-bladed windward rotor and constant rotation speed. There is also a wide range of power and blades diameter to choose. Its predominance is basically due to its capacity to achieve high energy efficiencies, thereby increasing the power production and reducing system expense per kW of power generated. However, VAWTs have the ability to fulfill certain requirements of energy generation not reached with HAWTs. As mentioned in the text "*Energy and exergy efficiency comparison of horizontal and vertical axis wind turbines* " by *K. Pope, I. Dincer, G.F. Naterer,* entropy in an isolated system always tend to increase and horizontal axis wind turbines can not deal with high wind turbulence, fluctuations and high directional variability while vertical ones can operate well. High entropy levels are associated with low useful levels of energy among horizontal axis turbines.

The basic schema of a windmill can be observed in Figure 5 and its main components are defined below.

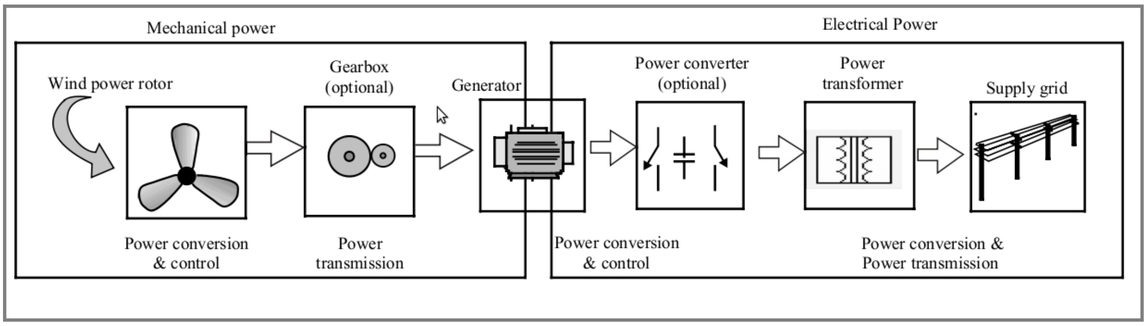

Figure 5: Basic schema and components of a wind power grid connected system.

- *Rotor*: rotor blades, mostly builded by composed material compounds, are designed to tranform wind's kinetic energy into a torque which will move the alternator shaft. Modern rortors can reach diameters from 42 up to 100 meters and produce from a couple of hundred kW to 5 MW. Rotation speed is usually limited by blades tip speed, which is determined by acustic criteria and allowable loads for materials.

- *Gearbox*: not all wind turbines have one. It transforms the low rotational speed of the rotor axis, which turns according to wind speed, into high rotational speed of the generator axis. The last mentioned has a fixed speed determined by the frequency of the electric network to which is connected.

- *Generator*: there are different types regarding to the wind turbine design. They can be synchronous, asynchronous, squirrel cage or doubly fed up, excited or with permanent magnets. It can be defined as the part converting energy into electricity.

- *Control system*: is responsible for the safe and efficient performance of the equipment. It controls the nacelle orientation, blades position and the total power delivered.

All those components are integrated into the nacelle. It sits atop the tower, at a specific height in order to capture the wind. Rotor blades are attached to the nacelle. On the other hand, the tower is the element in charge of sustaining the nacelle and outstaying all mechanical efforts of the entire assembly.

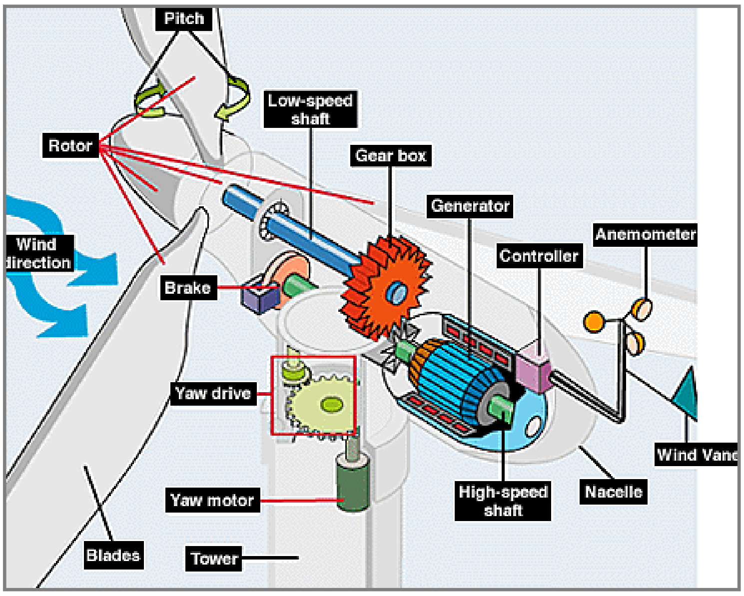

Figure 6: Components of a wind turbine.

In Figure 6 above, inside machinery of the nacelle is shown more specifically. Description of each component is included in Appendix A1.

2.2.3. ADVANTAGES AND DISADVANTAGES

As a renewable energy, wind technology raises a number of environmental advantages such as:

- Does not produce environmental pollution like other fossil fuel sources do. There is no emission of polluting gases, nor gaseous and liquid effluents or solid waste. Does not use water.

- There is a wide popular acceptation which facilitates its implementation.

- Simple and fast assembly and disassembly without environmental consequences (between 4 and 9 months).

- Can be installed in areas unsuitable for other purposes, such as deserted areas, near the coast, too arid and steep slopes to be cultivable.

- Possibility of building offshore parks (in the sea), where the wind is stronger and the social impact is reduced. However, installation and maintenance costs are increased.

- Wind farms are compatible with other land uses.

- It's inexhaustible. Saves fossil fuels and diversifies the energy supply.

- Combined with other energy sources, usually solar energy, it allows creating self efficient houses not connected to the electric grid. Up to 82 hours of autonomy can be achieved.

- It's an efficient and competitive energy source with high influence in the electricity market. However, it still requires incentives.

- After turbines 20 to 25 years lifecycle, 30% of fibre reinforced plastic (FRP) on the turbine blades can be reused to form new FRP. (See article "*Recycling wind turbine blades"* by *Kari Larsen, Renewable energy focus magazine, January/February 2009).*

The disadvantages that may result from the implementation of wind power are:

<u>Technical aspects</u>

- Wind generation does not adapt to demand. It's so unpredictable as the wind speed and direction.

- Power dips: motors are disconnected from the grid to avoid being damaged and, therefore, cause further disruptions in the network, lack of supply.

- Besides the obvious need for a minimum wind speed to move the blades, there is also a maximum limitation. Although a machine can be working full power, it has to be stopped if the wind increases just to exceed the specifications in order to prevent structure damages.

- Installation becomes less efficient as increasing the number of windmill because of the new less optimal locations.

- It is necessary to build high voltage lines that are capable of driving the peak electricity production although the average driving voltage is much lower. This means using cables 4 times thicker and often taller towers to accommodate correctly the wind peak.

Environmental aspects

- Visual impact. Wind farms are usually located in the top of the hill and can produce some impact on the landscape.

- Impact on wildlife, especially birds.

- Land occupation: wind farms require a considerable big area in order to avoid wind shadows or disturbances among the wind turbines.

- Noise pollution: the aerodynamic and mechanical noise produced by the blades may be annoying to nearby towns. Generates about 43dB (A) at 200 m.

2.3. SOLAR ENERGY

2.3.1. INTRODUCTION

Solar energy comes from a star which has illuminated the Earth for more than five billions years. Sun is the most important natural energy source that human being has used from its origins. Sun's light and heat can be turn into different types of energies.

The idea of using solar heat is very ancient; when human dried fur and leather from the animals or heated food on warm stones. The first advanced use of solar energy dates back to III century B.C, in the Ancient Greece, when is told that Archimedes used solar mirrors to burn down the enemy fleet that attacked his town and Sofocles suggested to orientate houses to the sun. It is on century XVIII and XIX when solar ovens, vapor generation and water purification began to be developed.

Since 1973, as a consequence of the high increase of fuel prices, there was a strong resurgence in the use of solar energy, both large-scale and domestic applications. Nowadays, almost 40 years after that crucial date, a moderated but sustained growth of the solar energy applications is taking place.

Energy, once is stored, can be used in thermal or photovoltaic processes. In thermal processes, solar energy is used to heat a gas or a liquid fluid. In photovoltaic processes, solar energy turns into electric energy without any mechanical device between. This project will focus in the solar photovoltaic, and how it can be used to generate electricity and provide it to a single family house.

Worldwide, China and Europe are the two leading solar cells producers accounting for 47.8% and 13.1% respectively, followed closely by Taiwan. (See Figure 7). As it can be seen, main photovoltaic installations in Europe are specifically placed in Germany. In Appendix B1 is possible to appreciate it in a graphic map.

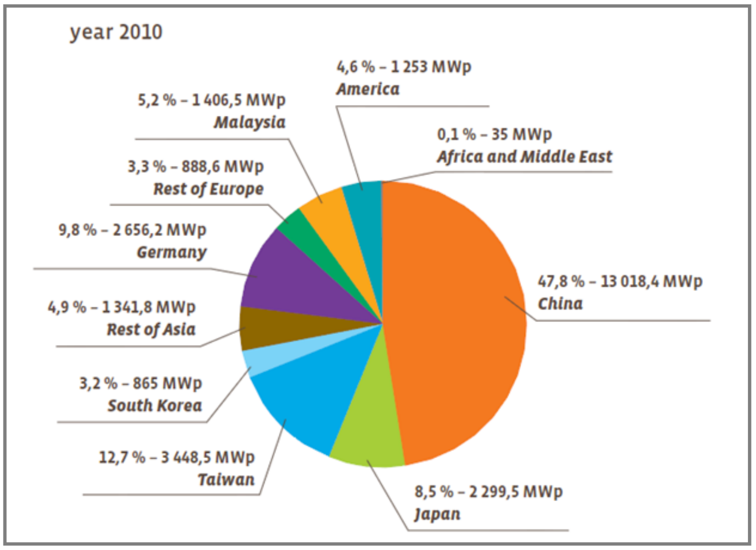

Figure 7: Distribution of photovoltaic cells world production (MW_{peak}).

The evolution of the world photovoltaic production is clearly appreciated in the following graph, reaching on the last year more than 27 GWp. (Source: *photon international*).

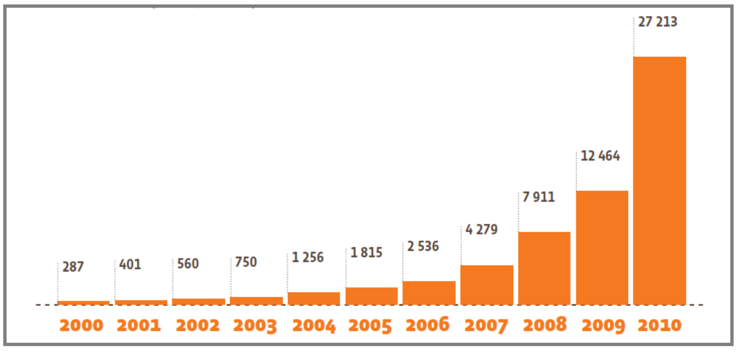

Figure 8: Yearly world solar cell production 2000 to 2010, (MW_{peak}).

According to *'Photovoltaic Barometer'*, (study carried out by *EurObserv'ER: Systèmes Solaires le journal du photovoltaique April, n° 5 – 2011.*) from 2009 to 2010, the modules connected to the grid in Europe were increased in 120% (5,918 MWp in 2009 to 13,023 MWp). In this year it was installed more new capacity of solar power production than any other renewable electricity source (Appendix B2). Within Europe, Germany is a model, both in government grant and awareness of the citizens. It is also the leading European producer of solar panels.

Sweden electricity production from solar photovoltaic energy reached 7.1 GWh in 2009 and 9.4 GWh in 2010. Going further, off-grid projects account for 60 % of this production, what suggests the amount of solar cells used just to provide energy in little projects as is studied in this project (international energy agency). More than 20,000 houses are estimated to obtain electricity using solar cells. As well as grid connected systems depend heavily on the distribution of the subsidy by the Government, the off-grid PV markets are quite stable with around 300 kWp installed each year. In the next graph Sweden accumulated photovoltaic capacity is compared with other European countries along 5, years since 2005.

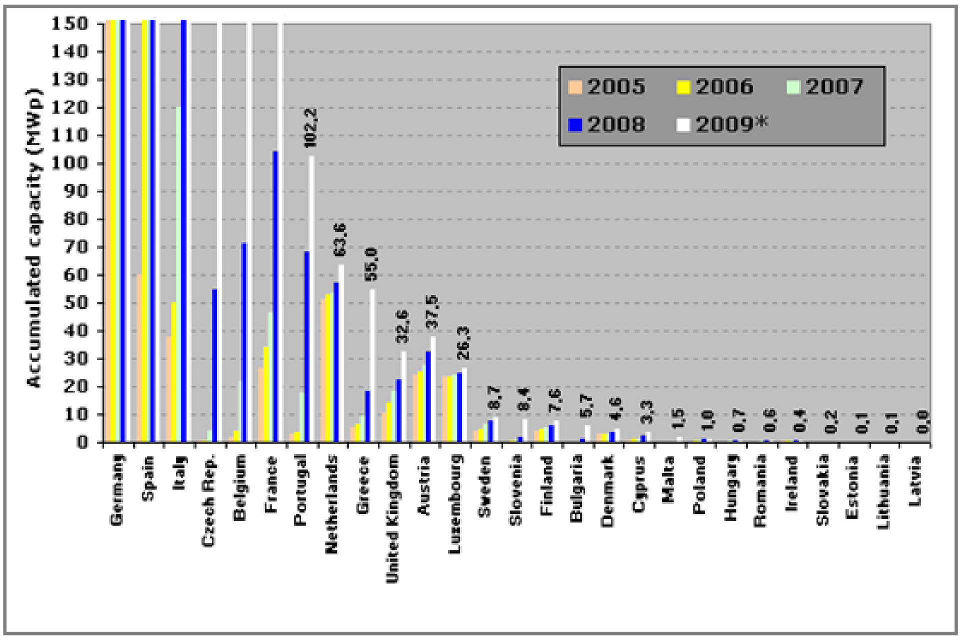

Figure 9: Accumulated yearly photovoltaic capacity in EU27 (MW_{peak}).

In Sweden, solar energy doesn´t have a great magnitude comparing to other renewable energy sources or other countries, but it is being developed in order to make it cheaper and more competitive in the near future.

2.1. TECHNICAL BASE

Solar energy is undoubtedly the source that has driven all life on planet Earth. The Sun is responsible for all nature cycles, climate, the movement of the wind, water and plants growth. Most of the energy sources used by humans indirectly derive from the Sun. Fossil fuels preserved solar energy from millions of years ago when it was captured through photosynthesis. As well, hydropower plant uses water potential and this water was evaporated by the sun, etc. Over the year, the Sun generates five thousand times more energy than world needs.

The magnitude that measures the solar radiation reaching the Earth is irradiance, which measures the energy per unit time and area that reaches the Earth. Its unit is W/m². In Figure 10 below, it can be observed both the yearly global irradiation (measured in kWh/m^2) and the yearly electricity generated by $1kW_{peak}$ system with performance ratio 0'75 (measured in kWh/kW_{peak})..

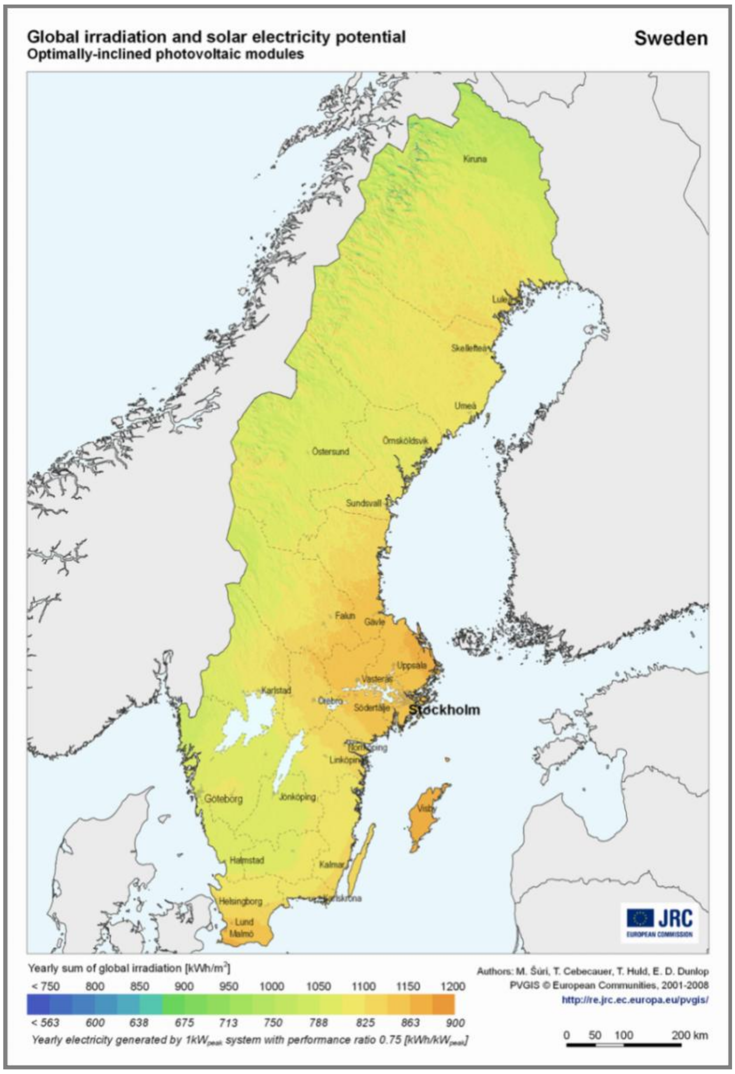

Figure 10: Solar resources in Sweden regarding optimally tilted photovoltaic modules (kWh/m^2).

Concerning to the operate principle of the photovoltaic modules, solar radiation is captured by the PV module generating electric power as direct current. There are basically two types of solar photovoltaic systems: the *off-grid* and the *grid connected*.

The energy generated in a *grid connected PV system* can be used for own consumption or can be sold to a power company. Those systems don't have any storage batteries, only the uptake and conversion facilities for the generated electricity (from DC to AC) and networking facility. They settle in urban areas of industrialized countries and rural areas close to power lines. Figure 11 below shows a schema of a grid connected PV system in a house.

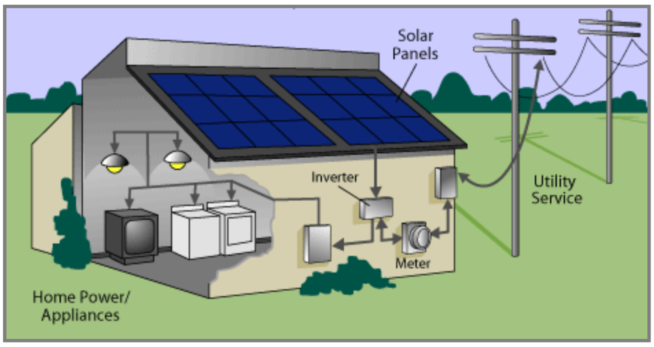

Figure 11: Residential Grid Connected PV system schema.

Off-grid systems provide electricity without drawing on supplemental power from the electrical utility. These systems consist of a solar panel array, the batteries to store the electricity generated in DC, usually an inverter and the control system and safety equipment to ensure the proper functioning of loading and unloading batteries. Stand-alone systems are basically used to supply electricity in places where the conventional electricity grid does not exist: rural areas, dwelling or water pumps are some examples. It can also have important applications in the developing countries.

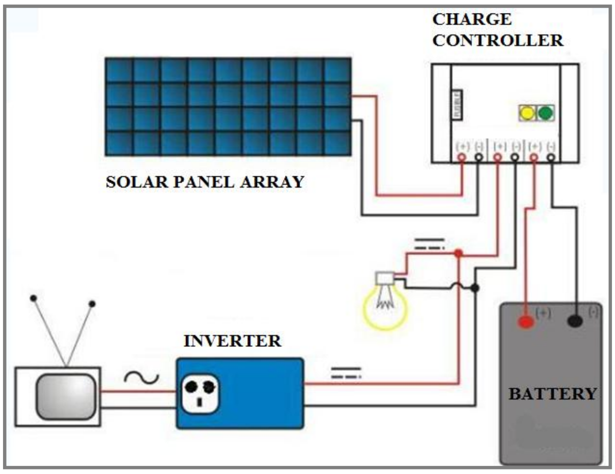

Figure 12: Off-grid PV system schema.

As it is shown on the figure above, stand-alone photovoltaic systems basically have the following components:

- *Solar Panels Array*: It turns solar radiation into electricity through the photovoltaic effect. The incidence of solar radiation on the solar cell creates a potential difference. They are usually made of silicon, phosphorus or boron. It is important to take into account the location, orientation and latitude of the solar panels to increase the use of solar radiation.

- *PV Cells*: A solar panel array is the union of many PV cells. From the text *"Energías Renovables para todos"*, written by *Pep Puig* and *Marta Jofra* and edited by *Haya Comunicación*, can be summarized that the photovoltaic effect of this PV cells is based on the ability of electrons from one material to arouse and promote a higher energy level. The difference between levels (called gap) can be saved in certain materials called semiconductors by the photons that compose the solar radiation (see Figure 13 below). Some materials used in these PV cells are monocrystalline silicon (energy efficiency 15% - 17%), polycrystalline silicon (efficiency around 10%), amorphous silicon (efficiency less than 10%), gallium arsenide, etc. Other innovate PV technologies are multi-junction PV cells, silicon spheres, photoelectrochemical cells or 'third generation' PV cells based on nanotechnology.

- *Charge controller*: Is the device that regulates the input current from the solar panel to the battery. It protects the system from overload or shock.

- *Battery*: The power required by the user may be not proportional to the solar radiation (and therefore to the electrical output of a PV system), so part of the energy produced by the photovoltaic field must be stored to be reused when it is needed. This is the purpose of a battery bank. Batteries can be connected in series or parallel to generate more current or voltage as appropriate.

- *Inverter*: The device which has as main purpose to change the direct current (DC) of PV modules and batteries to AC to power the house loads.

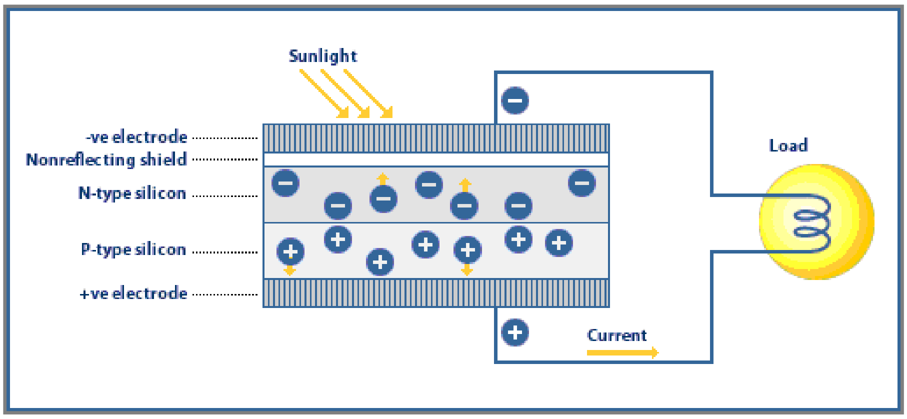

Figure 13: Principles of operation in a PV cell: electrons and protons position and movement on a silicon PV module.

The main characteristics of a PV Module are:

- *Peak power*: [Wp] Power supplied by the module in standard conditions STC (= 1000 W/m2 irradiance, Temperature = 25ºC, AirMass = 1.5).
- *Rated current*: current supplied by the module at the point of work.
- *Rated voltage*: working voltage of the module.

The PV system has to be dimensioned according to these characteristics and others such as latitude of the site, mean annual solar radiation, specific architectural features of the building, etc.

2.3.3. ADVANTAGES AND DISADVANTAGES

As a renewable energy, wind technology raises a number of environmental advantages such as:

- Photovoltaic modules are easily expandable. Also is possible to change the existing wiring for other which suit in the new electricity generation.

- PV modules do not pollute or produce noise at all, they do not consume fuel. Furthermore, although with less efficiency, they even work on cloudy days since they capture the light that is filtered through the clouds.

- The maintenance of the facilities is minimal.
- Does not diminish the quality of air and soil.
- It is clean and friendly environment: each kWh generated prevents the emission of one kilogram of CO2.
- A connection to the power grid is not required.

The possible disadvantages associated with this technology are:

- Solar radiation is lower in winter, which is precisely the time when most needed.
- The cost of the panels today is still very high, substantially more expensive initial investment.
- May cause esthetic problems with the environment.
- Sometimes, to produce the energy required, a large amount of panels are needed.
- Clouds and pollution can affect the energy produced.
- An extra device such as battery or generator is needed to store energy produced during the day because at night no energy is produced.
- It has to be placed in areas with lots of sunlight.
- PV module manufacturing requires the use of toxic elements, so that manufacturers must reduce the consumption of these compounds and avoid the uncontrolled disposal of waste components. As it is explained on the text of Kari Larsen *"End-of-life PV: then what?"* from the scientific publication *'Renewable energy focus' July/August 2009*, it is possible to recycle many substances from the PV modules such as glass, aluminum and semiconductor materials so they can be recovered and reused. Therefore, the environmental impact of the PV modules production is reduced.

2.4. GENERATOR

2.4.1. INTRODUCTION

Today's power units, or commonly named generators, consist of two basic parts, an electric generator and an engine.

Electrostatic generators were used before the connection between magnetism and electricity was discovered. Those generated very high voltages but low currents. Therefore, because of their inefficiency and the difficulty of insulating machines with such high voltages, they were never used for generating electricity with commercial aims.

It wasn't until 1832 when the first electrical generator capable of delivering power for the industry was built, the dynamo. It was a based on Faraday's law, which says that electromagnetic force is generated in an electrical conductor that encircles a varying magnetic flux. The dynamo has been widely used to supply electricity to low-intensity bulbs in bicycles. In the early twentieth century, dynamos were introduced in the vehicle field because they had higher power than the devices used so far. However, there is no vehicle using this system anymore, dynamos were gradually replaced by alternators since the 70's.

Regarding to the engine component, although various forms of internal combustion engines were developed before 19^{th} century, they weren't actively used until the petroleum boom in mid-1850. The most significant difference between modern internal combustion engines and old designs is the use of the compression stage.

Power units, are nowadays basically used when there is a deficit of power generation or when frequent power cuts take place. Today's most common utility is in CHP plants. Cogeneration is the process which simultaneously obtains electricity and useful thermal energy in one power cycle. Other applications would be providing electricity in those locations with no supply, often remote areas with little infrastructure and sparsely populated; or supporting public places such as hospitals and factories, where they can not run out of power due to their role in society. Those places require an alternative source of energy to satisfy the demand.

2.4.2. TECHNICAL BASE

As mentioned before, a power unit is the combination of an electricity deliver device and an internal combustion engine. Some fuel will operate the engine, which will release mechanical energy to the alternator and it will transform the energy into electricity by generating an alternating current through electromagnetic induction.

Therefore, the electricity source is the alternator. Those are based in the fact that an induced voltage is created by the magnetic variable field going through a conductor. An alternator has two basic components: the inductor, which creates the magnetic field; and the induced, which is the conductor through which the force lines of the magnetic field pass.

Self excited alternators with no brushes are usually used for relatively high power in order to avoid maintenance related to brushes and slip rings. However, they have a control system with an automatic voltage regulator, which is responsible for limiting the maximum power output of the alternator.

On the other hand, the driving force comes from the internal combustion engine. It is a type of machine which directly obtains mechanical energy from the chemical energy of a burning fuel. The fuel burns inside the combustion chamber, which is its basic element and consist on a cylinder, closed on one end, within which slides a piston. The chamber volume is modified by the movement of the piston along the cylinder. The outer face of the piston is attached to the crankshaft by a shaft. This is the device converting the piston's linear movement into the rotary motion of the engine's shaft.

Power units can be divided into two different groups regarding to their type of ignition, meaning how the combustion process in the chamber starts. Therefore, we can distinguish between spark ignition engines, which use petrol or gas as a fuel and follow Otto's cycle; or compression ignition engines, which are those using diesel or eventually natural gas, and behave according to Diesel cycle.

However, power units are usually classified regarding the fuel they use and their developed nominal power. Most common fuels used among the type of set that concerns the present project are natural gas and gasoil:

- *Natural gas* is an important renewable energy source formed from the mixture of light gases. It is found in oil or coal deposits. Although its composition varies depending on the site from where the gas is removed, methane is its main

component accounting for 90%-95% of the total. Natural gas often contains other gases such as nitrogen, CO_2, H_2S, helium or butane. Some of those gases have to be removed before being used because they have no energetic capacity or could damage the distribution pipes due to their high boiling point.
However, natural deposits are not the only natural gas suppliers; it can also be obtained from decomposition of organic waste processes taking place in waste treatment plants. The gas therefore obtained is called biogas.

- *Gasoil* or *diesel* is a whitish or greenish fluid accounting for 850 kg/m^3 density and mainly composed of paraffins. It is commonly obtained from petroleum distillation although nowadays, it is also found in vegetable oils. Thus called biodiesel.

In order to compare both fuels, a larger amount of natural gas is required to produce equivalent kVA of diesel fuel. Therefore, gasoil is most frequently used not only because of its higher efficiency but also because it has lower costs and is more durable in terms of engine consumption.

In addition, while natural gas requires an additional installation to provide the equipment with fuel, gasoil is usually manual refilled and doesn't need fuel pipelines.

When installing gas equipment, the contracted natural gas company would have to extend the service network to the generator room, which can be complicated on certain occasions. The pipes network would transport the gas at high pressure (60 bar in the transport network and 16 to 4 bar in the distribution one), from the place of origin to the point of consumption.

On the other hand, when installing gasoil equipment, a fuel deposit is usually coupled to assure the diesel supply in case of emergency. No additional installations are required.

2.5. HYBRID POWER SYSTEMS.

2.5.1. INTRODUCTION

The electricity provided by an installed renewable energy source (such as photovoltaic or wind power) is often lower than the energy required by the loads. Even if the facilities are correctly sized, there are consumption peaks due to cloudy weather or no wind blowing to move the windmill. Thus, each electrical system is defined with a safety range which should ensure the total electricity demand but it is not always satisfied.

Therefore, there are some cases where it is recommended to have an auxiliary generating system that can cope with the power demand. In those periods when the renewable resource is low or even zero, the hybrid systems will be used to guarantee the required power input.

As observed in Figure 14 below, hybrid systems are typically composed by one or more renewable energy sources (wind or sun), which are virtually inexhaustible, combined with conventional generators if needed. Usually, energy storage systems are used as well in order to save energy for the non-production hours.

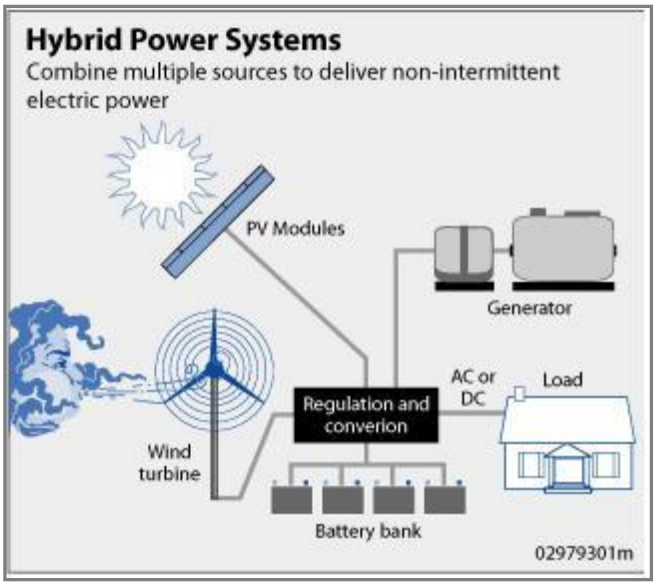

Figure 14: Schema and components of an hybrid power system.

Therefore, the typical configuration of a hybrid system is:

- One or more units of renewable sources: wind, photovoltaic or hydropower.
- One or more conventional generating units: natural gas or diesel.
- Storage system: mechanical, hydraulic or electrochemical.
- Conditioning power systems: inverter, rectifiers or charge controllers.
- Control and regulation system.

Hybrid systems represent today a concrete option compatible both in environmental and social terms. Current systems account for 80% to 90% of the energy need supplied by renewable sources and the storage. Therefore the generator is seldom used.

2.5.2. MOST COMMON HYBRID SYSTEMS.

Wind-Photovoltaic.

One of the generation systems consists of one or more wind turbines which, through the control system, are responsible for providing power to the batteries. In parallel with this, a PV system charges as well the batteries by the charge controller.

The driver required is more complex than in the isolated systems, as their total reliability is higher than the other two systems. Therefore, the charge controller that must be used will not be the same as if you hire a single installation system.

In some cases it is recommended to install in parallel a generator because in extreme cases it can charge the battery banks. This kind of power units can also directly supply power demand, without using batteries.

In the graph below it is seen the energy flow from wind power and solar energy along one day, as well as the load required. It is clearly appreciated in the battery evolution (diagram below) how is it charged when the wind or solar power level are over the load line, and how it offloads when the power level obtained from the sum of both the wind and solar sources doesn´t reach the total amount of power demand.

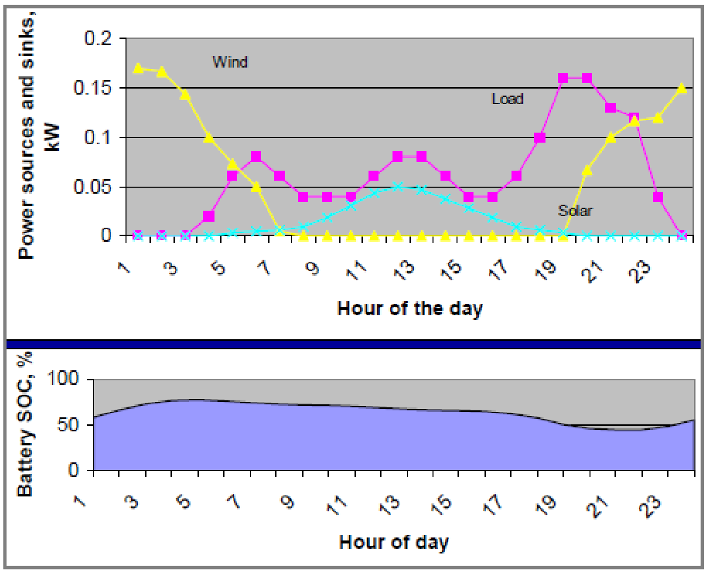

Figure 15: Hourly power curves regarding the required load and the wind and solar resources (kW). Second graph corresponds to the battery charge evolution (%).

On that figure it is possible to realize how sometimes, a single installation system (only wind power or solar energy) is not enough to assure the energy use. Therefore, hybrid systems seem to be a better solution.

Wind-Generator

In this case, the majority of the energy is released by the wind turbines while the remaining demand is covered with the production of the gas or diesel generator. This type of installation also needs an automatic load controller to check on every subsystem contained in the global hybrid plant.

Solar-Generator

In solar installations supported by a generator, the primary source of energy and the most abundant comes from the photovoltaic panels, while the rest is obtained from the gas or diesel generator.

As in the previous cases, an automatic load controller is required for the proper functioning of the equipment.

2.5.3. ADVANTAGES AND DISADVANTAGES

Main advantages of a hybrid system are:

- Possibility to optimize locally available renewable resources.
- High quality, reliability and performance efficiency.
- Cost reduction among installation and operation of the system.
- Environmentally and socially favourable.
- Possibility to supply energy to isolated unelectrified areas.

However being a good choice, hybrid systems also present some disadvantages such as:

- Including a generator in the equipment makes the system much more complex.

- Diesel generators present low efficiency and high maintenance costs.

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Chapter 3

PROCESS AND RESULTS

3. PROCESS AND RESULTS

3.1. SINGLE FAMILY HOUSE SPECIFICATIONS

The feasibility of different electrification alternatives of a single family house in a rural environment is to be studied. Therefore, the house specifications and the sites' various energy resources are to be examined in order to perform an accurate and detailed study.

3.1.1. LOCATION

The chosen dwelling is located in the North-West of Sweden in a small city called Lulea, capital of the Norrbotten County. It is located at 65.58 degrees latitude, just a few kilometres below the Arctic Circle and not far from the border with Finland (see Figure 16). Lulea does not belong to the Swedish Lapland (as was the original intention of the project) but is placed close to it. The reasons for the change of location have to do with the intention to obtain positive results and the difficulty to get the data from the Lapp territory.

Figure 16: Lulea location in Sweden regarding the Arctic Circle.

The town of Lulea is situated on a peninsula where Lulea Bay meets the Gulf of Bothnia in the Baltic Sea. It extends over the Lulea archipelago which contains more than 700 islands.

The dwelling chosen for the study is a summer single family house in the vicinity of Lulea. It is placed 20 km to the north in a plot next to the sea. The area has good circumstances regarding to sun and wind energies exploitation because there are no obstacles that limit the access of the sun and its proximity to the sea gives it a high wind possibility.

Due to its isolated location, the summer house has no chance to get connected to the electric power distribution network. Thus, a study of different technological alternatives for electrification is required. As mentioned in previous sections, renewable energies such as wind and solar power combined with electric generators will be analyzed as electrification alternatives for the house of study.

3.1.2. HOUSE SPECIFICATIONS

Before performing the analysis of power supply alternatives for the dwelling, it is necessary to know its usage conditions, that is to say, its consumption and energy demand. Both calculated as the total annual consumption of the house.

As mentioned before, the dwelling of study is a summer house located in a hardly accessible rural spot. As its name suggest, it is only used during the summer time when families move there on weekends or to spend their vacation. Therefore, only six months will be taken into consideration when making calculations, from April to September. In addition, only basic appliances are supposed to be there as it is not a permanent residence.

Moreover, performing a complete study of both electricity and heat demand for a single family house would be a very extensive study. Therefore the current project will only focus on the electrical demand. To specify, the electricity required to warm up water (no district heating reaches countryside houses) is not taken into consideration. Any other purpose for which electricity is needed will be regarded as energy demand.

Consumption data are mainly obtained from:

- Specification of the equipment electrical power.
- Estimated operational number of hours per day regarding to summer months.

In order to calculate the daily and total electrical consumption, it has been established that the house contains the following electrical appliances (see Table 1). The table specifies the amount of every type of devices, their rated power and their daily average operating hours.

Is to be considered that during summer time days are very long and nights are very short in such high latitudes. Thus, energy lamps and fluorescents are only required for very short periods of time.

	Number	Power [W]	Operational hours [h/day]	Daily energy use [W*h]	Total energy use [kW*h]
KITCHEN					
fluorescent	2	15	1	30	5,49
oven	1	900	*4h/week*	*3600 [W*h/week]*	93,6
electric stove	1	2500	1	2500	457,5
fridge	1	200	24	4800	878,4
freezer	1	100	24	2400	439,2
washing machine	1	1500	*3h/week*	*4500 [W*h/week]*	117
LIVING ROOM					
low energy lamp	2	20	3	120	21,96
high energy lamp	1	60	2	120	21,96
TV	1	70	1	70	12,81
video	1	90	*3h/week*	*180 [W*h/week]*	4,68
radio	1	15	1	15	2,75
ROOM					
low energy lamp	1	20	1	20	3,66
high energy lamp	1	60	1	60	10,98
laptop	1	150	2	300	54,9
BATHROOM					
high energy lamp	1	60	1	60	10,98
other electric apliances	3	300	1	900	164,7
		6695		12577,86	2300,57 kWh
		6,7 kW		12,6 kWh	

Table 1: Apportion of the energy consumption of the single family summerhouse.

Assuming that all expected loads are connected, it follows from the above table that the maximum possible power demanded is:

$$P_{max} = 6.7\ KW$$

3.2. ANALYSIS OF ALTERNATIVES

3.2.1. WIND TURBINE

DIMENSIONING OF THE ALTERNATIVE

The wind system purpose is to cover 100% of the house electric demand, 12.6 kWh/day. To do so, the installed system is dimensioned by calculating the total power amount and the number of turbines required to produce it, but also the number of batteries needed to ensure power supply when it is not possible to cover it with the turbines due to the lack of wind. Next figure shows the schema followed by the facility.

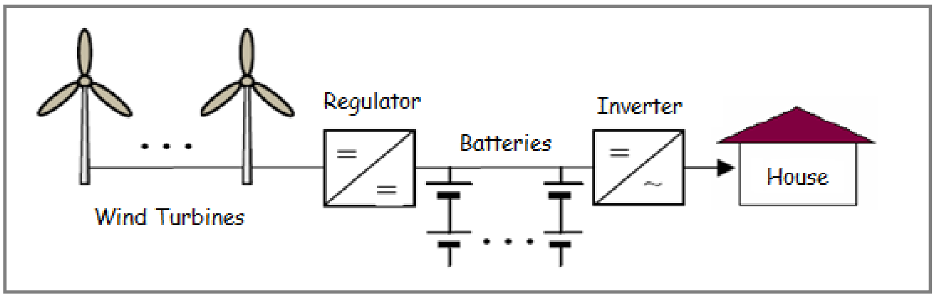

Figure 17: Wind system scheme.

The installation design will be based on the wind data obtained from the simulation program Meteonorm (see Appendix A2). Then, the required equipment will be selected by searching in different catalogs.

The following objectives must be fulfilled in order to determine the appropriate wind system:

- The wind system must be able to supply 100% of the daily energy demand. The energy supply is covered by the power produced by the wind turbines and/or the energy stored in the batteries, depending on the current electric production.

- Energy losses produced throughout the system have to be taken into account to fulfill the requirements.

- Accumulation system should never be discharged below the maximum discharged depth of the batteries (minimum 30% allowed).

- The choice of the number of wind turbines and batteries is based on reasonable cost of the wind system. The occupied land should also be taken into consideration.

The dwelling consumption is calculated in section 3.1.2 based on the average power and the approximate operating hours of each electric device. It is considered constant along the year with a value of 12.6 kWh/day.

Therefore: $E_{weekly\ demand} = 88\ kWh/week$

However, the required energy to be delivered by the energy system is not equal to $E_{weekly\ demand}$ due to losses associated to the installation. There are a number of factors that cause losses in every accumulation wind system. Some energy is lost in the way between the batteries and the house and other losses take place in the section between the batteries and the wind mill.

The first section of losses are determined by a series of coefficients (design parameters) such as the battery efficiency, discharge losses in the battery, losses in the inverter or Joule failures in the electric grid. Therefore, a total loss coefficient of 20% will be considered in the mentioned segment.

Being the energy consumption of the dwelling 88 Wh/week, the energy needed on battery terminals is:

$$E_{battery\ terminals\ 1} = \frac{E_{weekly\ demand}}{1-0.2} = 110\ kWh/week$$

Furthermore, losses caused by the wind turbine and the regulator have to be added to the above amount. Those losses take place in the segment between the wind turbine and the batteries accounting for another 30% loss coefficient.

Betz limit is used in the second segment to calculate the required power per m^2 demanded by the dwelling. Betz formula deduction can be followed in Appendix A2 (obtained from the course notes of the subject *Sustainable Energy Systems*, from the *Master Program in* Energy *Systems*).

$$P_{max} = \frac{1}{2} * \rho * v^3 * \frac{16}{27}\ \left[\frac{W}{m^2}\right]$$

Including the efficiency above:

$$P_{real} = \mathbf{0,7} * \frac{1}{2} * \rho * v^3 * \frac{16}{27}\ \left[\frac{W}{m^2}\right]$$

Where: ρ = air density (1.2 kg/m^2)

v = wind velocity (m/s)

Choice of the wind turbine

Considering the daily energy demand per hour and aiming to supply 100% of it, wind turbine model **TR 10.0-20 kW** has been chosen. Its technical characteristics are specified in the technical sheet included in Appendix A3. However, main parameters are listed below:

- Rated power: 20 kW.
- Rotor diameter: 10 m.
- Tower height: 18 m.
- Temperature range: -40ºC to +70ºC.
- Start wind speed: 2 m/s.

The choice of the most appropriate wind turbine is done not only taking into consideration power requirements but also the location specific characteristics. The property is located in Lulea, north of Sweden, where extreme temperatures can be reached, therefore the need for a turbine that can withstand low temperatures. Another important aspect is the starting wind speed as Lulea has quite constant and low average wind velocities all over the six months.

The wind turbine's power curve shows the relationship between the output power and the wind speed. The chosen wind turbine curve is shown below:

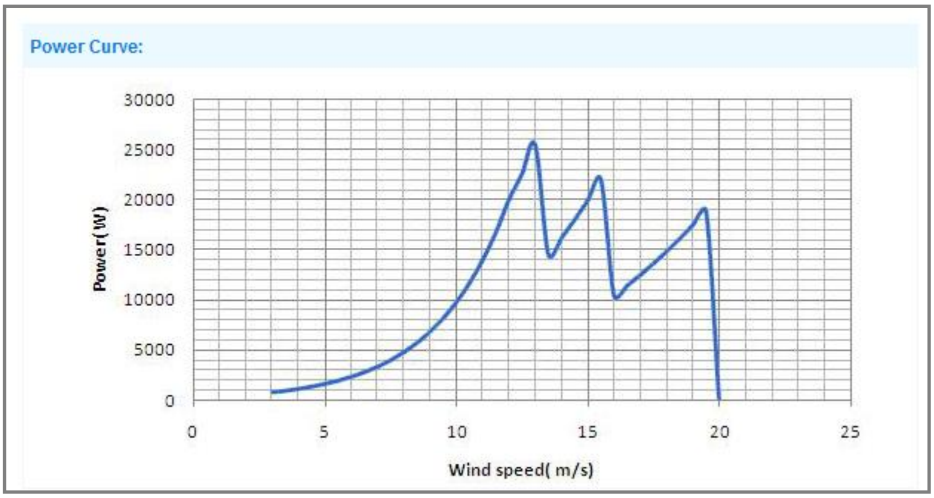

Figure 18: TR10.0-20 kW wind turbine power curve.

As relevant features of the chosen wind turbine, is to be noted:

- About the turbine: the rotor consists in three blades anchored to the hub, which is directly attached to the generator.
- About the regulator: as the supply and demand for the batteries can vary, the three-phase current supplied by the generator is rectified in the charge regulator. This element

controls the battery charge level, avoiding overloads and over discharges which may reduce its life.

It will be necessary one regulator in series with each installed 20 kW wind turbine.

- About the inverter: since wind generation is done in direct current and the house of study consumption is in alternate current, the inverter allows the proper conditioning of the system.

  Thus, it will be necessary to set an inverter for each installed 20 kW power wind turbine. It will be placed in parallel with the turbine and will be capable of transforming the direct current of the system (360V) into the alternate current of the dwelling (230V).

Having selected the appropriate wind turbine (model TR10.0-20kW) and considering its features, the weekly average power and energy are seen in Table 2 below. More detailed calculations are shown in Appendix A4. Weekly calculations are done corresponding week 1 to the first week of April. Therefore, 26 weeks are evaluated (April to September).

	Preal [W]	Energy [kWh/week]
Week 1	944,61	158,69
Week 2	2382,25	400,22
Week 3	2461,52	413,54
Week 4	1527,34	256,59
Week 5	385,57	64,78
Week 6	632,65	106,29
Week 7	3674,42	617,30
Week 8	2296,20	385,76
Week 9	922,27	154,94
Week 10	1790,57	300,82
Week 11	1643,60	276,12
Week 12	1121,37	188,39
Week 13	3265,26	548,56
Week 14	3278,57	550,80
Week 15	901,01	151,37
Week 16	424,61	71,33
Week 17	2450,08	411,61
Week 18	1568,68	263,54
Week 19	2557,87	429,72
Week 20	970,60	163,06
Week 21	505,16	84,87
Week 22	1553,54	260,99
Week 23	1582,96	265,94
Week 24	1757,43	295,25
Week 25	973,76	163,59
Week 26	2797,22	469,93

Table 2: Weekly average power and energy delivered by TR10.0-20kW turbine.

As observed, there are weeks when the electric generation is quite low, see week 5, 16 and 21. Such low values are obtained because of the weak wind conditions measured during those weeks. Thus, these values will be our precedent when studying the best number of wind mills and batteries combination in order to supply 100% of the energy demand.

Wind farm design

Once the average energy produced by a wind turbine model TR10.0-20kW has been calculated, it is necessary to determine the number of wind mills needed to cover the demand. The number of wind mills will determine as well the number of batteries required.

In order to make an unrestricted analysis, no space limitation will be considered. However, regarding noise discomfort, a maximum of two wind turbines is accepted.

Battery **B.MEIBAT VASO ABIERTO 4OPzS200** has been chosen to form the accumulation system. Characteristics are specified in Appendix A5. However electric parameters are shown in Table 3 below.

Battery parameters	
Nominal voltage [V]	12
Rated capacity [Ah]	300

Table 3: MEIBAT battery parameters.

Two different criteria have been considered when choosing the batteries:

- Batteries connected in series must comply with the system's voltage, 360V.

The number of batteries required is determined by both the battery nominal voltage (12V) and the system's (360V):

$$Number\ of\ batteries = \frac{System\ nominal\ voltage}{Battery\ nominal\ voltage} = \frac{360V}{12V} = 30\ batteries$$

- Intensity stored in the batteries regarding 5 days of autonomy must be lower than their rated capacity.

$$Intensity\ stored = \frac{Real\ daily\ demand * 5}{System\ voltage} = \frac{15{,}7\ kWh/day * 5\ days}{360V} = 218{,}41\ Ah$$

Where: $Real\ daily\ demand$ = dwelling demand divided by the efficiency of the section batteries-dwelling.

- $E_{batt} \cdot 0{,}7 \geq Autonomy\ energy\ needed\ for\ 5\ days$

Where: E_{batt}= current total amount of energy stored in the batteries has to be 30% of the total capacity over the weeks. Some assumptions are made:

- The batteries are already 100% charged before starting the first week of the simulation.
- If energy production is higher than energy demand:
  - Batteries already charged: excess of energy is lost.
  - Batteries not totally charged: excess of energy is used to charge the battery up to 100%.
- If energy production is lower than energy demand: stored energy will be used to cover the demand.

It is necessary to calculate the total energy that can be delivered by the battery bank. It must be taken into account that they can not discharge under 30% of their load. Therefore:

$$Single\ battery\ capacity = 300\ Ah \cdot 12V = 3.6\ kWh$$

As the system consists of 30 batteries, the total accumulated energy will be:

$$Battery\ bank\ capacity = 30 \cdot 3.6\ kWh = 108\ kWh$$

Batteries can only provide 70% of their capacity. Thus the available consumption will account for:

$$Available\ consumption = 108\ kWh \cdot 0.7 = 75.6\ kWh$$

Considering that 5 days of autonomy demand is:

$$Energy\ autonomy\ demand = 15.7 \frac{kWh}{day} \cdot 5day = 78.5\ kWh$$

The choice of battery is considered acceptable although the energy autonomy demand exceeds on 3 kWh. The next battery model in the catalog would imply both a significant oversize of the system and much higher economical expenses.

To summarize, the chosen system consist of one 20 kW wind turbine with an accumulation subsystem of 30 batteries of 300 Ah and 12V connected in series. The figure below shows the charge-discharge simulation of the batteries considering the criteria exposed before. As can be observed, energy stored in the batteries is used in those weeks when the energy demand can not be covered by the wind resource.

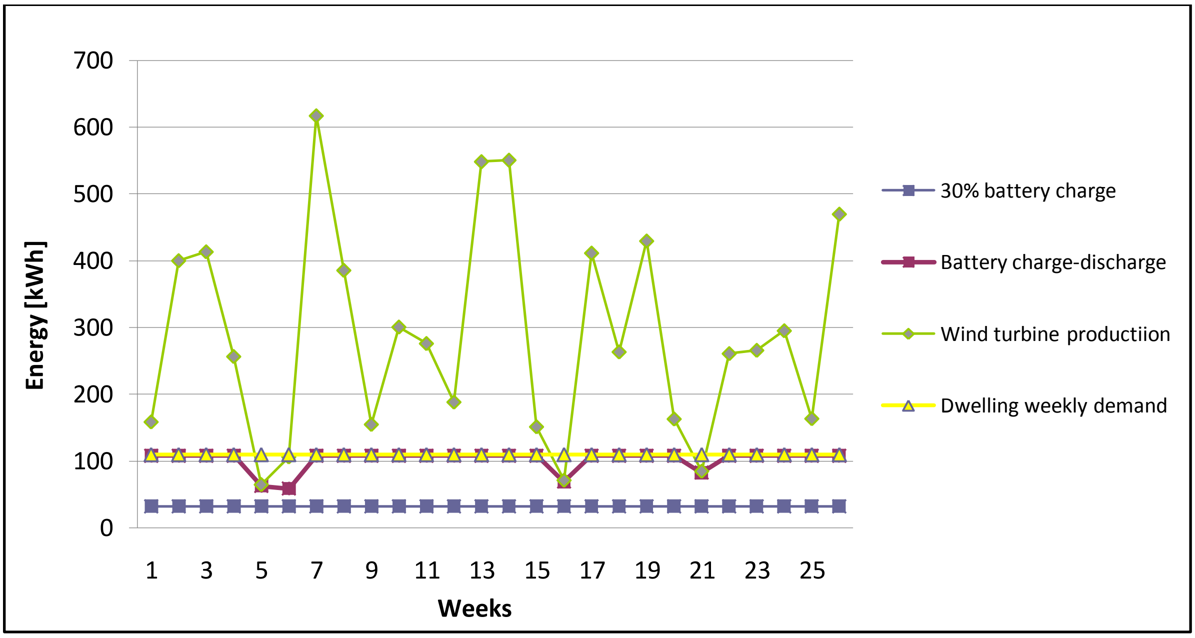

Figure 19: Batteries' simulation charge-discharge graph related to the wind turbine production, the dwelling demand and the limit 30% battery discharge.

As observed, capacity criteria (remaining at least 30% of the total capacity) is accomplish during every week of study. Calculations made to obtain the chart can be followed in Appendix A6.

ECONOMIC EVALUATION

Taking into consideration everything explained in the previous sections, the necessary economic investment is observed in Table 4 below. Economic calculations are done in Appendix A6.

	Number of units	Price/u [€]	Total [€]
Wind Turbine	1	17500	17500
Battery	30	779	23370
Total price [€]			**40870**

Table 4: Wind turbine + batteries installation economic results.

The price of the Wind Turbine takes into account the cost of the inverter and charge controller. Thereby, to the total price above, it has to be added other costs like structure and wiring costs, construction work costs, etc. The final investment cost of the Wind Turbine systems is **45070 €,** as it can be seen on Table 5.

	Percentage %	Cost [€]
Wind Turbine	32,3	17500
Battery	43,2	23370
Wiring	2,2	1200
Construction work	3,7	2000
Others	1,8	1000
Total price [€]		**45070**

Table 5: Wind turbine total investment costs apportion.

Considering the previous results, is possible to calculate the price for kW_{peak} installed by doing:

$$Price\ for\ kW\ installed = \frac{45070\ €}{20\ kW} = 2253.5\ €/kW_{peak}$$

3.2.2. STAND-ALONE PV SYSTEM

DIMENSIONING OF THE ALTERNATIVE

There are many criteria to choose the sizing of a stand-alone PV system. In this project, the choice is based on the energy balance between the energy needed and the power generated by photovoltaic panels.

The energy generated by solar panels is obtained directly from the computer program Winsun. Winsun already takes into account different coefficients to calculate solar cell output; therefore, no extra calculations are required. Input data introduced on the program can be appreciated in the figure below.

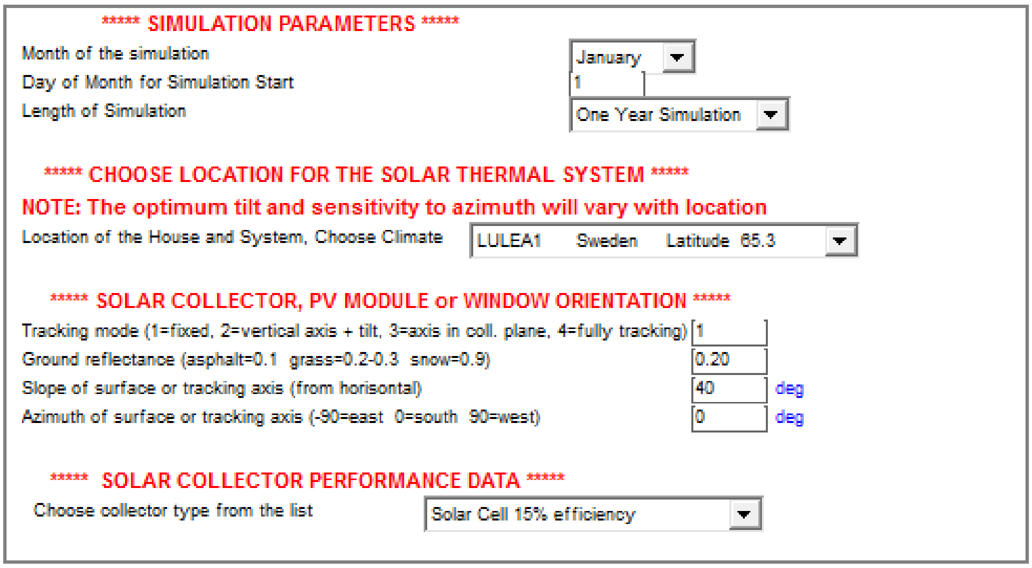

Figure 20: Parameters defined on Winsun Input.

In the next chart (Figure 21), yellow curve shows the intensity during each hour. The maximum value is around 1000 W/m^2. The operating temperature of the solar cell will be the same as the outdoor temperature (green line). The blue line indicates the solar cell output in W/m^2. The horizontal axis is divided in twelve parts (months in a year) and measured in hours.

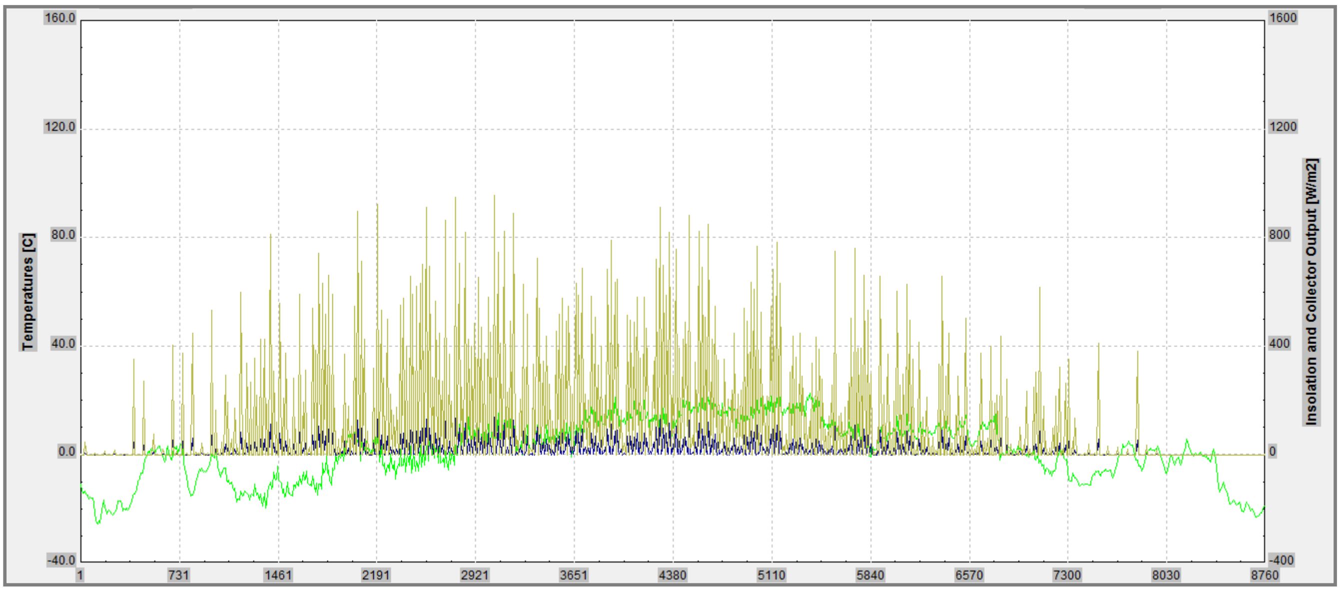

Figure 21: Insolation, ambient temperature and solar cell output from Winsun over the year

The power consumption of the summer house must be guaranteed throughout every month it is inhabited. The most unfavorable month should be chosen regarding the ratio of solar energy and energy consumption. Our system must cope with the situation when this ratio is the lowest.

The next table presents the monthly energy use in the summer house. Obtained from the Table 1 (house specifications):

$$Monthly\ energy\ use = \left(\frac{\text{Total energy use}}{\text{183 days}}\right) * \text{days/month}$$

	Days/month	Monthly energy use [kW*h]
april	30	377,14
may	31	389,71
june	30	377,14
july	31	389,71
august	31	389,71
sept	30	377,14

Table 6: Monthly energy use depending on 30 or 31 days per month.

It is also needed the output energy from the solar cell for each month (Table 7), obtained from Winsun outputs. Complete output data from Winsun can be seen on Appendix B3.

	TIME [hours]	Qcoll1 [kWh/m2]
January	744	1,67
February	1.416	6,21
March	2.160	14,08
April	2.880	20,92
May	3.624	22,02
June	4.344	23,40
July	5.088	20,39
August	5.832	16,13
September	6.552	11,10
October	7.296	5,75
November	8.016	1,89
December	8.760	-
SUM	8.760	143,60

Table 7: Monthly solar cell output from Winsun (kWh/m^2)

As mentioned earlier in this section, the criteria is based on the energy balance between the energy needed and the power generated:

$$Monthly\ energy\ balance = \left(\frac{\text{Energy use [kWh]}}{\text{Solar cell output [kWh/m2]}}\right)$$

As the consumption is almost equal for the different months, the most unfavorable month matches with the month with less solar cell output: September, 11.10 kWh/m^2.

In a stand-alone PV installation there are many factors causing losses in the overall efficiency. This means that the energy generated on the solar cells must be higher than the energy use on the house:

$$Energy_{solar\ cell} = \frac{\text{Energy}_{\text{house}}}{\text{Efficiency}}$$

Those losses take place in the batteries (losses and self discharge), inverter, network (Joule effect, etc), and charge controller. It is assumed 80% efficiency on the installation, therefore the energy that the solar cells must generate is:

$$Energy_{solar\ cell} = \frac{\text{Energy}_{\text{daily use}}}{0.8}$$

The energy use per day, as it can be seen on the Table 1 of house specifications, is 12.6 kWh/day. Thereby, the energy from the solar cells, according to the formula above, should be 15.7 kWh/day. Below is presented a schema of the installation.

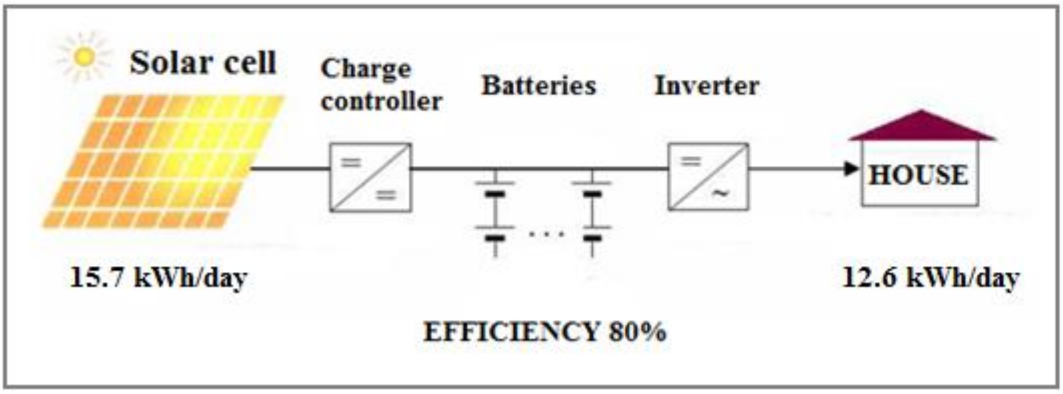

Figure 22: Stand alone PV system schema and components.

As it can be observed on the Figure 20, the simulation is done with a solar cell with 15% efficiency. This corresponds to 150 W_{peak} = 0.15 kW_{peak} which gives a total amount of 140 kWh/m^2 during the hole year and 11 kWh/m^2 in September. Therefore, 1 kW_{peak} will give around 74 kWh/m^2 in September (the most unfavorable month). In addition, 1 kWp corresponds to 6.7 m^2 with an efficiency of 15%. If 15,7 kWh/day is needed, that means 472 kWh/month (30 days in September).

Finally, the total amount of watt peak installed must be:

$$Power_{peak} = \frac{472}{74} \cong 6.4 \ \mathrm{kW_{peak}}$$

Or in square meters: 6.4*6.7 = 43 m^2

It is also possible to calculate it directily for square meters. In September, the average power demand is:

$$Load\ average\ power = \frac{377.14\ kWh}{30\ days * 24\ hours/day} = 530\ W$$

From Table 7, it is known that the output solar cell is 11.10 kWh/m^2, what means:

$$Average\ power\ PV = \frac{11.1\ kWh/m^2}{30\ days * 24\ hours/day} = 15\ W/m^2$$

Therefore, to calculate the total amount of m^2 needed:

$$PV\ modules\ m^2 = \frac{530\ W}{15\frac{W}{m^2}} = 35\ m^2$$

This result is similar to 43 m^2, which confirms that the PV system must meet these calculations.

Choice of the solar panel

The most practical solution is to choose a PV module with a determined peak power such that in a series-parallel combination, the total amount of peak power installed is close to 6,4 kWpeak.

The solar panel chosen in this installation is the **Solar Panel Monocrystalline 150 W**, from Juncoop (technical characteristics in appendix B4). The most important characteristics are shown in the next table:

Maximum Power, Pmax	150 Wp
Rated voltage, Vr	24 v
Open circuit voltage, Voc	43,5 v
Short circuit current, Isc	4,63 A

Table 8: Characteristic of the Solar Panel 150W monocrystalline. Juncoop

The number of PV modules that is necessary to connect on series, m_s, is calculated with the rated voltage of the system, V_{rs}, and the rated voltage of the chosen photovoltaic module, V_r.

V_{rs}= 48 V $\quad$ V_r = 24 V

$$m_s = \frac{V_{rs}}{V_r} = \frac{48}{24} = 2$$

m_s= 2 PV modules on series.

48 V are chosen in our system regarding the costs. A lower voltage leads to more expensive wiring and isolation (as higher current is needed).

The number of rows of PV modules that is necessary to connect on parallel, m_p, is calculated with the peak power needed on the solar cell system, P_p, the number of PV module on a row, m_s, and the power peak of the PV module, P_m.

m_s = 2 $\quad$ P_p = 6.4 k Wp $\quad$ P_m = 150 Wp

$$m_p = \frac{P_p}{m_s * P_m} = \frac{6400\ W}{2 * 150W} = 22$$

m_p= 22 PV modules on parallel

In this case, as the previous operation does not give an integer number, it has been selected the next higher integer value.

Instead of doing the calculations with the average power, the peak power is chosen in order to cover the energy demand in the worst possible situations.

Finally, our photovoltaic solar plant will have **44 PV modules of 150 Wp** each one. There will be **22 photovoltaic branches with 2 PV modules in each branch**. The total power peak installed is 6.6 kWpeak, which overcomes the 6.4 kWpeak that should be installed.

Battery system.

It is assumed that from the solar cell energy output to the batteries, there is a 7% losses. Therefore, the energy coming to the batteries is 14.6 kWh/day. Usually, not all the energy comes to the batteries, the charge controller divides the energy so only half the current goes through the batteries. However, as it is explained before, the worst situation is taken so it is suppose a case when the batteries need to be charged with all the energy available.

With the above information and the number of days of autonomy assumed (N = 5), it is possible to determinate the useful capacity of the battery system: C_u

$$C_u = E_b * N = 14.6 \frac{kWh}{day} \cdot 5\ days$$

$$C_u = 73.1\ \text{kWh}$$

The rated capacity of the battery, C, must be higher than the useful capacity. It must be taken into account two factors:

- The battery can only discharge till 70%

$$C' = \frac{C_u}{0.7} = 104{,}5\ kWh$$

- As there are some temperatures below the reference temperature of the battery, it is recommended to correct the rated capacity calculated with a factor $k_T = 0.85$

$$C = \frac{C'}{0.85} = 123\ kWh$$

As the capacity of a battery is expressed in Ah and not in Wh, the previous value must be divided by the rated voltage of the system, 48 V.

$$C = \frac{123}{48} = 2560\ Ah$$

Selected battery is the open cup battery **'B. MEIBAT VASO ABIERTO 8OPzS800, SUNLIGHT'.** The main characteristics can be seen on the next table, data sheet is attached on Appendix B5.

Rated voltage, Vb	12 V
Rated capacity, Cb	1295 Ah

Table 9: Main characteristics MEIBAT 8OPzS80.

The number of batteries that is necessary to connect on series, b_s, is calculated with the rated voltage of the system, V_{rs}, and the rated voltage of the battery, V_b.

V_{rs}= 48 V V_b = 12 V

$$b_s = \frac{V_{rs}}{V_b} = \frac{48}{12} = 4$$

b_s= 4 batteries on series.

The number of batteries that is necessary to connect on parallel, b_p, is calculated with C and the rated capacity of the battery, Cb

C = 2560 Ah C_b = 1295 Ah

$$b_p = \frac{C}{C_b} = \frac{2560}{1295} = 2$$

b_p= 2 batteries on parallel

Finally, our battery bank system will have **8 batteries of 12 V and 1295** Ah each one. There will **2 branches**, with **4 batteries in each branch**.

Charge controller.

Charge controller must adapt to the other electrical parameters of the installation. It must accomplish the function of protecting the battery from overload and over discharging. To determine the technical characteristics of the charge controller, it is necessary to know the peak current generated by the PV field, I_g, and the number of PV modules on parallel, m_p.

$$I_g = I_{sc} * m_p = 4.63*22 = 101.86 \text{ A}$$

With this peak current generated and knowing that our system rated voltage is 48 V, the choice has been the charge controller **R. SOLARIX POWER TAROM 4110**, from **STECA**. (data sheet on Appendix B6). Some electrical characteristics are shown in Table 10.

Rated input current	110 A
Output current	55 A
System voltage	48 V

Table 10: R. SOLARIX POWER TAROM 4110.

Inverter.

The inverter allows a proper power conditioning, since the energy generated by the solar cells is on DC and the house energy consumption is in AC.

As it can be seen on the house specifications, the total (Table 1), power demanded in AC is 6.7 kW, (it is considered 7 kW regarding the possible losses). The inverter has to convert 48 V DC into 230 V AC. With this information, the selected inverter is '**Inversor Senoidal Trifasico 380V + Monofásico 220V ISC 7000 48V', from SOLENER.** Some electrical characteristics are presented in the table below, the data sheet is on Appendix B7.

Rated input voltage	48 V
Output voltage	230V
Rated power	7 kW

Table 11: Main characteristics for Inversor Senoidal Trifásico.

ECONOMIC EVALUATION.

The investment required for the stand-alone PV system can be estimated with the cost of all devices of the installation. It can be clearly appreciated in the next table.

DEVICES	NUMBER	COST €/u	TOTAL €
Solar Panel Monocrystalline 150 W	44	455,2	20028,8
Batteries B. MEIBAT VASO ABIERTO 8OPzS800	8	2160	17280
Charge controller R.SOLARIX POWER TAROM 4110	1	1785	1785
Inverter SOLENER 'Inversor Senoidal Trifasico 380V + Monofásico 220V ISC 7000 48V'	1	4277	4277
			43370,8

Table 12: Devices costs in the PV system apportion.

To this total amount of money, it has to be added the cost of other necessary components (structure, wiring, etc) and the assembly costs. The finally investment cost of the PV stand-alone system is **53770 €**, as it can be seen on Table 13.

PV MODEL INSTALLATION	Percentage %	Cost €
Devices	80,7	43370
Wiring	5,0	2700
Structure	6,5	3500
Assembly	7,8	4200
Ohters	4,8	2600
		53770

Table 13: Stand-alone PV system total investment costs apportion

Considering the previous results, is possible to calculate the price for kW_{peak} installed by doing:

$$Price\ for\ kW\ installed = \frac{53770\ €}{6.6\ kW} = 8{,}147\ €/kW_{peak}$$

3.2.3. HYBRID SYSTEM: WIND-GENERATOR

DIMENSIONING OF THE ALTERNATIVE

It is intended to install a hybrid system combining wind power with an electric generator, so that the second one would supply the deficit of energy those weeks when the turbine do not generate enough energy to meet the dwelling demand.

The system will exploit the renewable source as long as possible while the power unit will balance the system. Thereby, days with little wind resource, demand will be covered by the generator which is going to be sized.

The hybrid system will consist on the wind turbine choose in section 3.2.1., turbine model **TR 10.0-20 kW** which characteristics are shown in Appendix A4, and a diesel generator. In this case, batteries are no longer required. Thus, the initial economic dispense will be reduced.

Choice of generator

The choice of the generator is based on the most critical supplying power situation, when the generator is not working due to the lack of an appropriate wind speed. In such a situation the engine power will be equal to the dwelling consumption increasing a 10% in order to oversize the system and prevent lack of supply problems. Thus, having a daily power demand of 6.7 kW (P_{max} obtained from the house specifications section), the chosen generator must have a rated power of:

$$P_{generator} = P_{max} * 1.1 = 7.37\ kW$$

Knowing the rated power of the engine, model **SP SSERIES-UK PERKINS 50Hz SP10**, from **SAONON** manufacturer has been chosen. Its characteristics are reflected in the technical sheet attached in Appendix C1. However, main parameters of the power unit are shown in Table 14 below.

Generator parameters	
Fuel	Diesel
Standby power [kW]	7,2
Power service [kW]	8
Deposit volum [l]	4,9
Fuel consumption [l/h]	2,4

Table 14: PERKINS generator parameters.

The fuel consumption will depend on the weekly energy demanded to the generator. Engine demand will vary every week because wind turbine production is not constant over the weeks due to the change in wind speed. It is calculated as seen below:

$$E_{generator} = E_{demand} - E_{produced}$$

Where: $E_{produced}$ = energy generated by the wind turbine including losses. It changes according to the wind resource.

E_{demand} = energy demand from the dwelling including losses. It has a constant value over the weeks, 88 kWh/week.

As in the previous alternatives, the initial energy produced by the turbine won't be the same amount of energy reaching the dwelling. Therefore an efficiency of 70% will be considered regarding interferences and Joule effect losses among the grid and performance losses of the devices included in the system.

Consequently, energy required over the weeks would be:

$$E_{generator} = 88\ kWh - 0.7 * E_{produced}$$

A schema of the hybrid system can be observed in Figure 23 below.

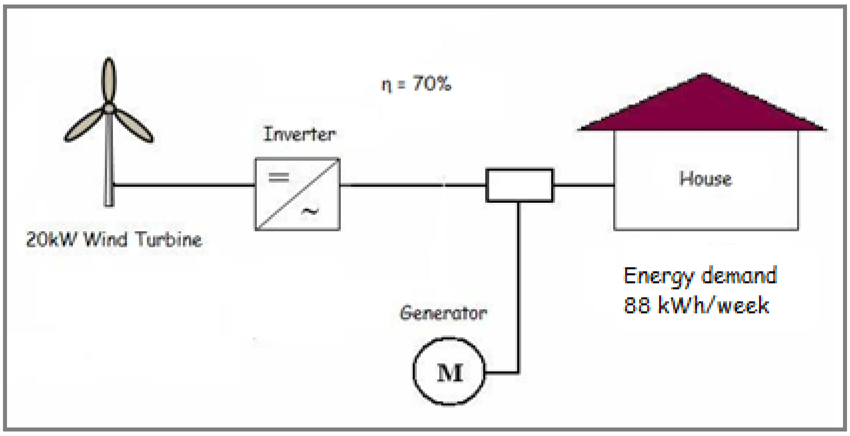

Figure 23: Hybrid system schema and components.

As can be observed in the figure above, there are no installed batteries in the dimensioned system. This fact implies that the generator should start working at the same moment that the wind turbine is not capable to provide the required energy demand.

This particularly schema leads to a significant problem as far as the system should switch instantly. It could be solved by installing a bank of batteries which would balance the system.

In the case of study, it is assumed that the inverter is capable of predicting and solving the mentioned critical situation in order to avoid the battery economical expenses.

A summary table including weekly energy production considering the mentioned efficiency, dwelling demand and the necessary energy to be delivered by the generator can be seen in next page.

	Energy [kWh/week]	Demand [kWh/week]	Generator production [kwh/week]
Week 1	158,69	88,06	0,00
Week 2	400,22		0,00
Week 3	413,54		0,00
Week 4	256,59		0,00
Week 5	64,78		23,28
Week 6	106,29		0,00
Week 7	617,30		0,00
Week 8	385,76		0,00
Week 9	154,94		0,00
Week 10	300,82		0,00
Week 11	276,12		0,00
Week 12	188,39		0,00
Week 13	548,56		0,00
Week 14	550,80		0,00
Week 15	151,37		0,00
Week 16	71,33		16,73
Week 17	411,61		0,00
Week 18	263,54		0,00
Week 19	429,72		0,00
Week 20	163,06		0,00
Week 21	84,87		3,19
Week 22	260,99		0,00
Week 23	265,94		0,00
Week 24	295,25		0,00
Week 25	163,59		0,00
Week 26	469,93		0,00

Table 15: Energy to be delivered by the generator over the weeks of study. Its calculated by comparing the wind turbine energy production and the dwelling demand.

As observed, the generator use is not required in most weeks because the wind resource is almost enough to cover the energy demand with the elected turbine. A total amount of 43.2 kWh will be produced by the generator over the 26 weeks. Therefore it is seldom used.

The generator's performance can be observed in Figure 24 below. It shows how the power unit complements wind turbine production in those weeks when the energy demand is higher than the energy obtained from the renewable resource.

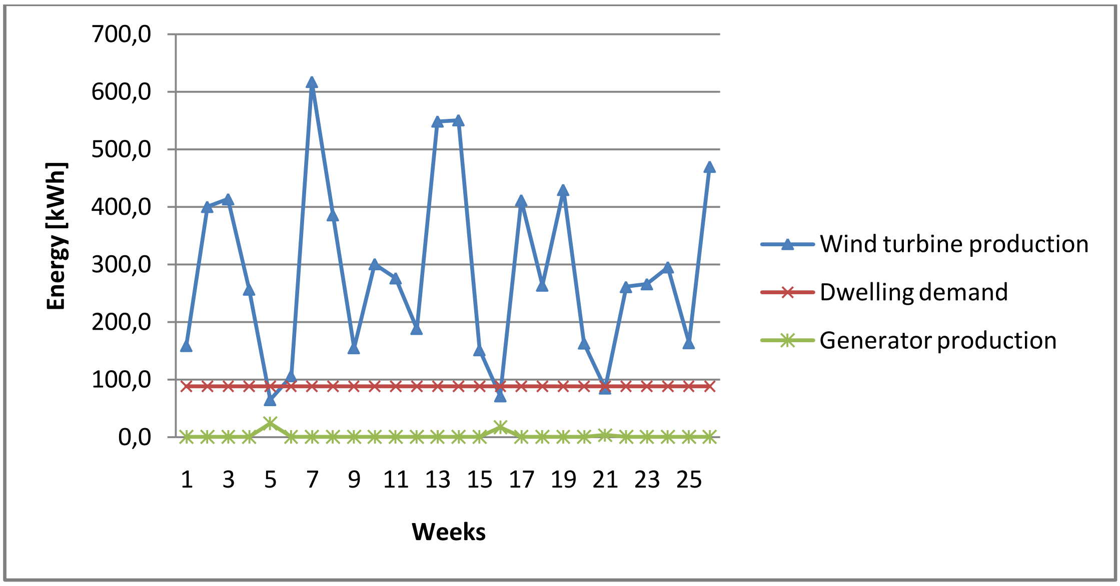

Figure 9: Generator's simulation performance graph related to the wind turbine production and the dwelling demand.

To conclude, the fuel consumed to produce the generator demand (43.2 kWh) is calculated assuming:

- The generator consumes 2.4 l/h of fuel.
- Efficiency decreases 11% because the generator is mostly working at part-load.
- Average power demand is assumed to be 5kWh (P).

$$Total\ fuel\ consumption = \frac{E_{demand}}{P} * 2.4\frac{l}{h} * 1.11 = 23.01\ l\ Diesel$$

Autonomy fuel consumption is calculated regarding week 5 because it accounts for the highest generator production. Generator's autonomy must cover the total demand for that week, even if all consumption takes place in one day.

So, $$Fuel\ consumption = \frac{E_{week\ 5}}{P} * 2.4 \frac{l}{h} * 1.11 = 12.4\ l\ Diesel$$

The generator fuel deposit capacity is 4.9 l. Thus, an extra deposit will be required to store the necessary amount of fuel to cover 5 days of autonomy.

ECONOMIC EVALUATION

In order to calculate the investment costs of the hybrid system wind-generator, it will be necessary to add the costs of both facilities: Wind Tower and Generator.

Now, as far as the accumulation system is replaced by the generator, no batteries neither charge controller are needed. The new cost for the Wind Tower is on Table 16 below.

	Percentage %	Cost [€]
Wind Turbine	82,1	16000
Wiring	4,1	800
Construction work	9,2	1800
Others	4,6	900
Total price [€]		19500

Table 16: Wind turbine total investment costs apportion.

Regarding the Generator, the model SSERIES-UK PERKINS 50Hz SP10 costs 1200 €.

As the average diesel price in Sweden is 1.27€/l, the cost of the diesel consumption is:

$$Fuel\ cost = Total\ fuel\ consumption * fuel\ price = 23.01\ l * 1.27 \frac{€}{l} = 29.22\ €$$

Finally, the total investment cost of the hybrid system is 20,729 €, divided as shown in the next Table 17.

	Percentage %	Cost [€]
Wind Turbine	94,1	19500
Generator PERKINS	0,1	29,22
Fuel consumption	5,8	1200
Total price [€]		20729,22

Table 17: Hybrid system total investment costs apportion.

Considering the previous results, is possible to calculate the price for kW_{peak} installed by doing:

$$Price\ for\ kW\ installed = \frac{20729.22\ €}{20+8\ kW} = 740\ €/kW_{peak}$$

Chapter 4

DISCUSSION

4. DISCUSSION

4.1. CHOICE CRITERIA

In previous sections, a deep study has been performed on two concrete fields of all the factors that affect an electrical installation. Dimensioning the different facilities (regarding the electricity demand required) must be done in order to be able to provide the total amount of money needed to install the facility. Both criteria define near completely each alternative, and allow creating a quite clear perspective.

Once both sizing and economic evaluation for each alternative are done, next step is choosing the most convenient one. There are many criteria to choose one alternative and no the others (environmental factors, easy assembly, maintenance, costs, etc). The chosen criteria determine which aspects must be taken into account.

In the current project, in order to choose the optimal alternative, the decision will be mostly based in economic and environmental issues, regarding the use of renewable energy.

Usually, economic criteria are based in a comparison with the cost of providing energy through traditional electrification. In this case all the alternatives are stand-alone systems, without grid connection, and there is no viable option to connect the house to the electrical network. Thereby, the considered economic criteria take into account the total costs of the installation without comparing it with the connected grid alternative and its costs.

In reference to environmental criteria, all the alternatives are based on renewable energy systems: wind power and solar energy. The first two options, stand alone windmill and PV modules, do not generate any CO_2 emissions or any other polluting agent, but both affect the rural environment: noise pollution (wind mill), visually pollution (both of them), they interfere with nature. On the hybrid system, apart from the already mentioned inconveniences, there also exist CO_2 emissions caused by the generator due to diesel combustion.

4.2. CHOICE OF THE OPTIMUM ALTERNATIVE

In order to compare the investment costs of the different alternatives, Table 18 below presents a clear summary.

	COSTS
WIND TURBINE	45.070 €
STAND-ALONE PV SYSTEM	53.770 €
HYBRID SYSTEM: WIND-GENERATOR	20.729 €

Table 18: Different electrification alternatives costs.

As it can be figured out from the text *"Energy in Sweden 2010"* published by the *Swedish Energy Agency*, there is no incentives for any off-grid installation, this is why they are not taken into account in the economic study.

Every alternative, as it is explained on the section 3, guarantee the energy demand and provide enough autonomy for the possible emerging needs.

As it is easily noticed in Table 18 above, the Hybrid system wind-generator is the optimal alternative regarding the economical criteria. Actually its investment costs are half the price of the other alternatives.

From an environmental view, as the CO_2 for a diesel is 2.6 kg CO_2/ liter, the Hybrid system generates:

$$CO_2\ emission = Total\ fuel\ consumption\ l * 2.6\frac{kg}{l} = 59.83\ kg\ CO_2$$

That amount of CO_2 emissions does not represent a large pollutant load. One person emits 1 kg CO_2/ day. If it is assumed there are 4 people on the house, the CO_2 emission of the generator is equal to what the family emits in 15 days breathing.

In the case that non fueled alternative could be chosen as the optimum alternative, the economic criteria would opt for the wind energy system as it saves 9,000€.

Furthermore, the cost-benefit study carried out in the table below confirms the decision.

	€/kW peak installed
WIND TURBINE	**2253**
STAND-ALONE PV SYSTEM	**8147**
HYBRID SYSTEM: WIND-GENERATOR	**740**

Table 19: €/kW_{peak} installed for each alternative.

However, other standards should be considered to achieve the proper solution.

As an example, other selection criteria could be the easiness of installing and transporting the different components, environmental impact, installation maintenance, etc. In this case it is also useful to look at sections 2.2.3 and 2.3.3, where advantages and disadvantages are shown.

Wind towers have a wider popular acceptation in Sweden than PV modules, as it has been described on the theory; technical wind energy potential in Sweden is estimated to be 3.5 TWh/year (*Swedish Energy Agency news, 17th May 2011, Anna Andersson & Charlotte Anners*) while Sweden electricity production from solar photovoltaic energy reached 9.4 GWh in 2010. On the other hand, more than 20,000 houses in Sweden are estimated to use solar cells in the present time.

Wind tower components imply an easier assembly and disassembly but have easier maintenance. In addition, it is more efficient to increase the number of PV modules rather than the wind towers if necessary. It is because increasing the number of windmills in the installation leads to a lower efficiency due to not as optimal locations for the turbines.

From a technical point of view, the main difference is the rated voltage. While wind power needs high voltage (360 v in our facility), which affects the whole installation and wiring; solar energy can operate with 48v.

Both solar and wind installations need big location areas in order to avoid wind shadows and disturbances on wind power and to have space to install 44 PV modules for the solar array.

Wind power is more harmful to the environmental wild (such as birds) than a solar array. As well as a solar array does not have other grave environmental damage, noise pollution from windmill could be annoying to the surround life, including the inhabitants of the house.

Chapter 5

CONCLUSSION

5. CONCLUSSION

The current project deals with the installation of an electrical alternative to provide energy to a self efficient house on the countryside. In this case, because of geographical emplacement, there is no possibility to connect the house to the electricity network. Besides, the location provides a good chance to generate the required energy different systems. However, this survey only includes renewable energies as suitable alternatives.

The first and maybe most important conclusion coming up is that the aim of this project can be satisfactorily achieved. As justified in the previous sections, it is possible to cover the house energy demand with alternatives based on renewable energy resources. Those resources though, do not adapt to instant demand; both wind speed and direction, and solar radiation affected by clouds and pollution vary unpredictably. For this reason, some backup devices are needed in every renewable facility in order to complement the production when natural resources are not enough.

As mentioned, there is almost no chance to install a renewable energy system without supporting it with accumulation devices or backup systems. Batteries or backup generators are needed to assure the electricity demand. These components which are alien to the production process, usually account for a significant monetary expense out of the total initial investment. Therefore, systems including accumulation facilities are especially expensive because of the batteries' high price. Consequently, reducing the number of batteries by using hybrid systems will always be a more profitable option.

The choice of an alternative or another depends on many factors. These include demand conditions, the size of the load to be installed but basically economic and environmental criteria.

Thus, it is important to mention that all equipment costs have a strong impact on both technical and economical feasibility of the alternatives. So, they will have an important role regarding to the economic criteria. In addition, natural resources existing in the location of study will be taken into consideration when sizing the system and choosing appliances. Thereby, they will also affect the system's economic feasibility.

In order to make the analysis easier, two different simulation programs have been used. Both WindSun, which provided the radiation data; and Meteonorm, which helped with the wind speed data, have been of great help to perform an accurate study.

However, some assumptions have been done to particularize the analysis. First of all, meteorological data used do not exactly correspond to the real emplacement. Collected data refer to Lulea while the dwelling is located 20 km to the north. In addition, only six month data are considered in the calculations because the study is focused on summer time. However, a yearly study will provide a more accurate analysis of the system. Furthermore, some appliances' efficiency has been approached.

Moreover, the most unfavorable situation has been considered when dimensioning the different alternatives. The reason for this is to ensure the hourly supply as there are no other electrification possibilities in case of emergency. As a consequence, the system might be a bit oversized.

In addition, it might seem that choosing a wind turbine providing 20kW rated power when the energy demand accounts for 6.7 kW is a waste of money and energy. However, the same study has been done with a smaller turbine, TR8.0-10 kW, and the total investment costs end up being similar (45,070 € for the 20kW turbine and 46,380€ for the 10kW turbine). This is because the wind turbine presents a lower rated output voltage which leads to a lower number of batteries connected in series. As the turbine presents a lower electricity production and only 20 batteries are needed, those will require a higher storage capacity which implies much higher prices per unit. Furthermore, batteries capacity should be extremely high (comparing to demand requirements) in order to satisfy the 30% limit discharge. To finish, lower energy delivered by the wind turbine will imply higher energy production by the generator in the hybrid system. Thus, higher fuel consumption and CO_2 emissions. All those reasons bring us to keep the 20kW wind turbine (Resumed calculations explained in Appendix A8).

To conclude, doing a study of such magnitude implies a deep analysis on renewable energies which leads to a better knowledge of the topic and provides us of a perfect end to our Master Program in Energy Systems. In addition, making some handmade calculations instead of using simulation programs (such as those used for battery calculations) allows us to achieve a greater understanding of the topic.

Chapter 6

REFERENCES

6. REFERENCES

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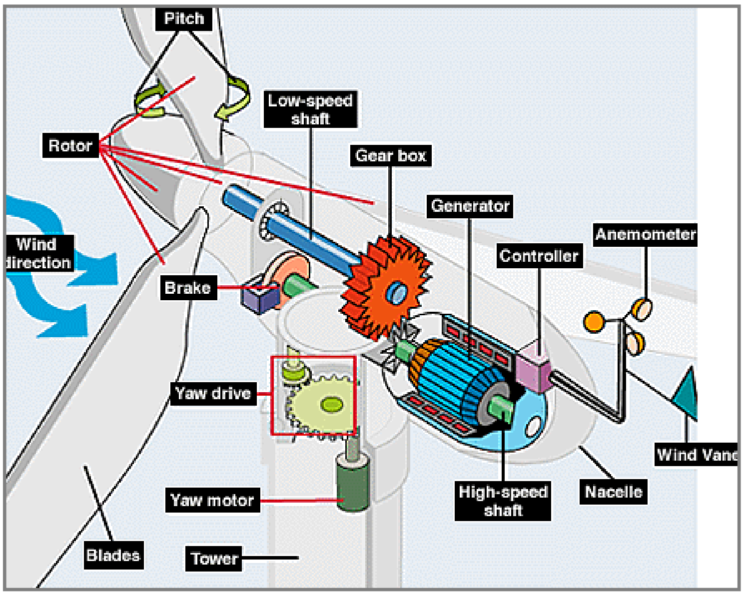
Chapter 7

APPENDICES

APPENDIX A

A1

Each component of a wind turbine is described below.



- *Anemometer*: measures the wind speed and transmits wind speed data to the controller.
- *Blades*: most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.
- *Brake*: a disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.
- *Controller*: the controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.
- *Gear box*: gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine.
- *Generator*: usually an off-the-shelf induction generator that produces 60-cycle AC electricity.
- *High-speed shaft*: drives the generator.

- *Low-speed shaft*: the rotor turns the low-speed shaft at about 30 to 60 rotations per minute.
- *Nacelle*: the nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.
- *Pitch*: blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.
- *Rotor*: the blades and the hub together are called the rotor.
- *Tower*: towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.
- *Wind direction*: this is an "upwind" turbine, so-called because it operates facing into the wind
- *Wind vane*: measures wind direction and communicate with the yaw drive to properly orientate the turbine regarding the wind direction.
- *Yaw drive*: the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.
- *Yaw motor*: powers the yaw drive.

A2

Wind data obtained from the program Meteonorm. For reasons of space, data from the first two days of April (week 1) are shown as an example.

As observed data are given hour per hour, therefore, a total amount of 4367 measurements are taken into consideration in the study.

	Hour	Wind speed [m/s]
	Week 1	
Day 1	0:00	2,4
	1:00	2,6
	2:00	3,9
	3:00	2,8
	4:00	2
	5:00	2,2
	6:00	2
	7:00	2,4
	8:00	1,3
	9:00	1,9
	10:00	2,2
	11:00	3,9
	12:00	6,6
	13:00	6,6
	14:00	4,8
	15:00	3,2
	16:00	4,2
	17:00	4,5
	18:00	3,7
	19:00	1,9
	20:00	2,8
	21:00	2,6
	22:00	3
	23:00	3,2
Day 2	0:00	2,8
	1:00	3,2
	2:00	4,5
	3:00	3,7
	4:00	3,4
	5:00	3,9
	6:00	6,6
	7:00	7,6
	8:00	7,3
	9:00	9,3
	10:00	5,5
	11:00	3,4
	12:00	4,5
	13:00	3,9
	14:00	4,2
	15:00	3,7
	16:00	2,8
	17:00	5,5
	18:00	5,5
	19:00	4,2
	20:00	5,9
	21:00	5,9
	22:00	4,5
	23:00	3,7

A3

Betz limit mathematical deduction can be seen below:

Energy in the wind: $W_o = \frac{1}{2} \cdot m \cdot v^2$ *Ec.1*

Flow after the wind mill: $= a \cdot v$

Delivered energy: $= \frac{1}{2} \cdot m \cdot v^2 - \frac{1}{2} \cdot m \cdot (a \cdot v)^2$ *Ec.2*

Mass flow: $q_m = \rho \cdot A \cdot \frac{v + a \cdot v}{2}$ *Ec.3*

Where: ρ= air density [kg/m^3]

A= area [m^2]

Now we introduce *Ec.3* in *Ec.2*:

$P = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot (1 - a^2) \cdot (\frac{1+a}{2})$ *Ec.4*

$$\frac{dP}{da} = 0$$

$$\frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot \left[\frac{1}{2} - (1 - a^2) - a \cdot (1 + a)\right] = 0$$

$$a = \frac{1}{3}$$

Therefore: $P_{max} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot \left(1 - \left(\frac{1}{3}\right)^2\right) \cdot \left(\frac{1+\frac{1}{3}}{2}\right)$

$$\boldsymbol{P_{max} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot \frac{16}{27}} \; [\boldsymbol{W}]$$

A4

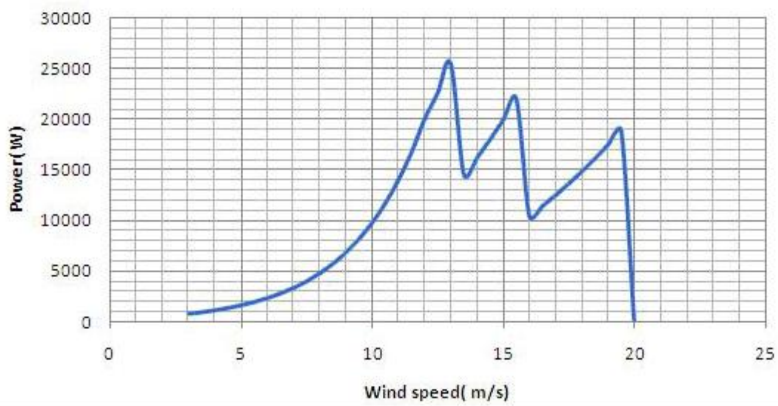
Technical specifications of the chosen wind turbine:

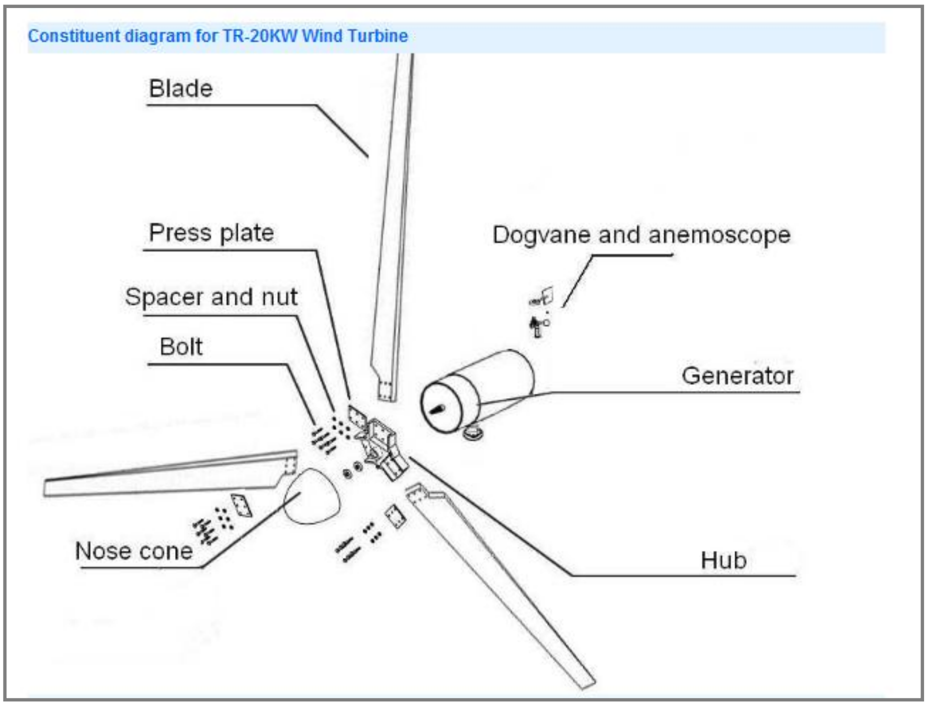
Tairui Windpower Co.,LTD
Renewable Energy For Future

Small wind turbine generator, model **TR10.0-20 kW**.

Main Parameter:			
Model:	TR10.0-20KW	Rated Power:	20KW
Max Power:	25KW	Generator:	Three Phase Permanent Magnet Alternator
Rated Output Voltage:	360V	Start Wind Speed:	2m/s
Rated Wind Speed:	12m/s	Maximum Wind Speed:	45m/s
Rotor Diameter:	10.0m	Rated Rotor Speed:	90r/m
Blade Number:	3	Blade Material:	Reinforced fiber glass
Blade Pitch Control:	None, Fixed Pitch	Overspend Protection:	Auto programmed control
Gearbox:	None, Direct Drive	Temperature Range:	-40 to +70 Deg. C
Tower Type:	Free Standing or Hydraulic Tower	Tower Height:	18m

Power Curve:




Constituent diagram for TR-20KW Wind Turbine
Blade
Press plate
Spacer and nut
Bolt
Dogvane and anemoscope
Generator
Nose cone
Hub

A5

The weekly average power delivered by the wind turbine is calculated from the wind speed data obtained from the Meteonorm interface introduced in the Betz Limit (see Appendix A2).

Weekly average cubic wind speeds are calculated out of the hour per hour data. Therefore, calculations will be weekly operated as well. Calculations are done for the 26 weeks corresponding to summer months, April to September (week 1 corresponds to the first week of April). In order to make calculations easier, we suppose that 1^{st} April is Monday.

Notice that the average wind speed is calculated over the cubic speed because the power is proportional to v^3 according to Betz limit.

	Average wind speed [m/s]^3	P [W/m2]	Preal [W/m2]	Preal [W]	Energy [kWh]
Week 1	48,32	17,18	12,03	944,61	158,69
Week 2	121,87	43,33	30,33	2382,25	400,22
Week 3	125,92	44,77	31,34	2461,52	413,54
Week 4	78,13	27,78	19,45	1527,34	256,59
Week 5	19,72	7,01	4,91	385,57	64,78
Week 6	32,36	11,51	8,06	632,65	106,29
Week 7	187,97	66,83	46,78	3674,42	617,30
Week 8	117,47	41,77	29,24	2296,20	385,76
Week 9	47,18	16,78	11,74	922,27	154,94
Week 10	91,60	32,57	22,80	1790,57	300,82
Week 11	84,08	29,90	20,93	1643,60	276,12
Week 12	57,37	20,40	14,28	1121,37	188,39
Week 13	167,04	59,39	41,57	3265,26	548,56
Week 14	167,72	59,63	41,74	3278,57	550,80
Week 15	46,09	16,39	11,47	901,01	151,37
Week 16	21,72	7,72	5,41	424,61	71,33
Week 17	125,34	44,56	31,20	2450,08	411,61
Week 18	80,25	28,53	19,97	1568,68	263,54
Week 19	130,85	46,53	32,57	2557,87	429,72
Week 20	49,65	17,65	12,36	970,60	163,06
Week 21	25,84	9,19	6,43	505,16	84,87
Week 22	79,47	28,26	19,78	1553,54	260,99
Week 23	80,98	28,79	20,15	1582,96	265,94
Week 24	89,90	31,97	22,38	1757,43	295,25
Week 25	49,81	17,71	12,40	973,76	163,59
Week 26	143,10	50,88	35,62	2797,22	469,93

The table below includes the necessary calculations to obtain the average power and energy delivered by the wind turbine. Power (P) is obtained by the use of the Betz limit.

Energy losses are taken into account to obtain the real power (P_{real}). 70% efficiency is considered.

To get P_{real} in watts, the area of the wind mill is been introduced considering its technical parameters, 10m diameter.

Energy is obtained by multiplying the P_{real} (W) by the total amount of hours in a week.

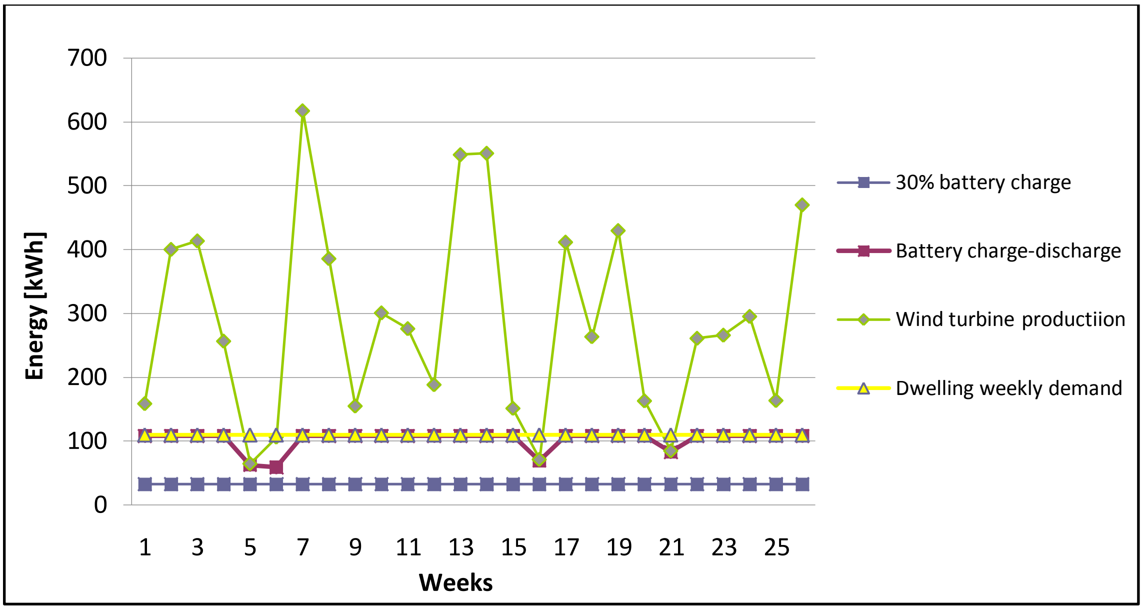
A6

Batteries' technical sheet. Model **B.MEIBAT VASO ABIERTO 4OPzS200, 12V 300Ah.**

5.1 Baterías Vaso Abierto OPzS SUNLIGHT		T. máxima	C100	alto-ancho-fondo (mm)	P.V.P.
2284100	B. MEIBAT VASO ABIERTO 2OPzS100	12V	185Ah	392x103x206	615,00
2284105	B. MEIBAT VASO ABIERTO 3OPzS150	12V	240Ah	392x103x206	701,00
2284110	B. MEIBAT VASO ABIERTO 4OPzS200	12V	300Ah	392x103x206	779,00
2284115	B. MEIBAT VASO ABIERTO 5OPzS250	12V	370Ah	392x124x206	895,00
2284120	B. MEIBAT VASO ABIERTO 6OPzS300	12V	440Ah	392x145x206	1.025,00
2284125	B. MEIBAT VASO ABIERTO 5OPzS350	12V	540Ah	508x124x206	1.081,00
2284130	B. MEIBAT VASO ABIERTO 6OPzS420	12V	645Ah	508x145x206	1.234,00
2284140	B. MEIBAT VASO ABIERTO 7OPzS490	12V	765Ah	508x166x206	1.374,00
2284145	B. MEIBAT VASO ABIERTO 6OPzS600	12V	970Ah	683x145x206	1.523,00
2284150	B. MEIBAT VASO ABIERTO 7OPzS700	12V	1055Ah	683x191x210	2.002,00
2284155	B. MEIBAT VASO ABIERTO 8OPzS800	12V	1295Ah	683x191x210	2.160,00
2284160	B. MEIBAT VASO ABIERTO 9OPzS900	12V	1380Ah	683x233x210	2.365,00
2284165	B. MEIBAT VASO ABIERTO 10OPzS1000	12V	1620Ah	683x233x210	2.560,00
2284170	B. MEIBAT VASO ABIERTO 12OPzS1200	12V	1950Ah	683x275x210	2.918,00
2284175	B. MEIBAT VASO ABIERTO 11OPzS1400	12V	2150Ah	833x275x210	3.363,00
2284180	B. MEIBAT VASO ABIERTO 12OPzS1500	12V	2300Ah	833x275x210	3.513,00
2284185	B. MEIBAT VASO ABIERTO 14OPzS1700	12V	2445Ah	809x397x212	4.381,00
2284190	B. MEIBAT VASO ABIERTO 15OPzS1875	12V	2850Ah	809x397x212	4.573,00
2284195	B. MEIBAT VASO ABIERTO 16OPzS2000	12V	3040Ah	809x397x212	4.771,00
2284200	B. MEIBAT VASO ABIERTO 20OPzS2500	12V	3765Ah	809x487x212	6.088,00
2284205	B. MEIBAT VASO ABIERTO 24OPzS3000	12V	4500Ah	809x576x212	7.113,00

A7

Charge and discharge simulation of the batteries can be observed in the chart below. Batteries are always remain charged over 30% of their capacity as required.



The table below shows the calculations made in order to size the system. Economic results of the wind power system are also obtained.

Real energy demand is obtained by applying an 80% efficiency.

Battery charge in kWh is calculated by comparing the wind turbine energy production and the dwelling real demand. When the demand>production, the battery is discharged. It will be charged again when demand< production.

Economic evaluation is also included in the table.

				Battery						Wind Turbine		
	Energy [kWh/week]	Demand [kWh/week]	Real demand [kWh/week]	Capacity [Ah]	Voltage [V]	Max charge [kWh]	Charge [kWh]	Number	Price [€]	Number	Price [€]	Total price [€]
Week 1	158,69	88,06	110,08	300,00	12	108	108,00	30,00	779,00	1,00	17500	40870
Week 2	400,22						108,00					
Week 3	413,54						108,00					
Week 4	256,59						108,00					
Week 5	64,78						62,70					
Week 6	106,29						58,91					
Week 7	617,30						108,00					
Week 8	385,76						108,00					
Week 9	154,94						108,00					
Week 10	300,82						108,00					
Week 11	276,12						108,00					
Week 12	188,39						108,00					
Week 13	548,56						108,00					
Week 14	550,80						108,00					
Week 15	151,37						108,00					
Week 16	71,33						69,26					
Week 17	411,61						108,00					
Week 18	263,54						108,00					
Week 19	429,72						108,00					
Week 20	163,06						108,00					
Week 21	84,87						82,79					
Week 22	260,99						108,00					
Week 23	265,94						108,00					
Week 24	295,25						108,00					
Week 25	163,59						108,00					
Week 26	469,93						108,00					

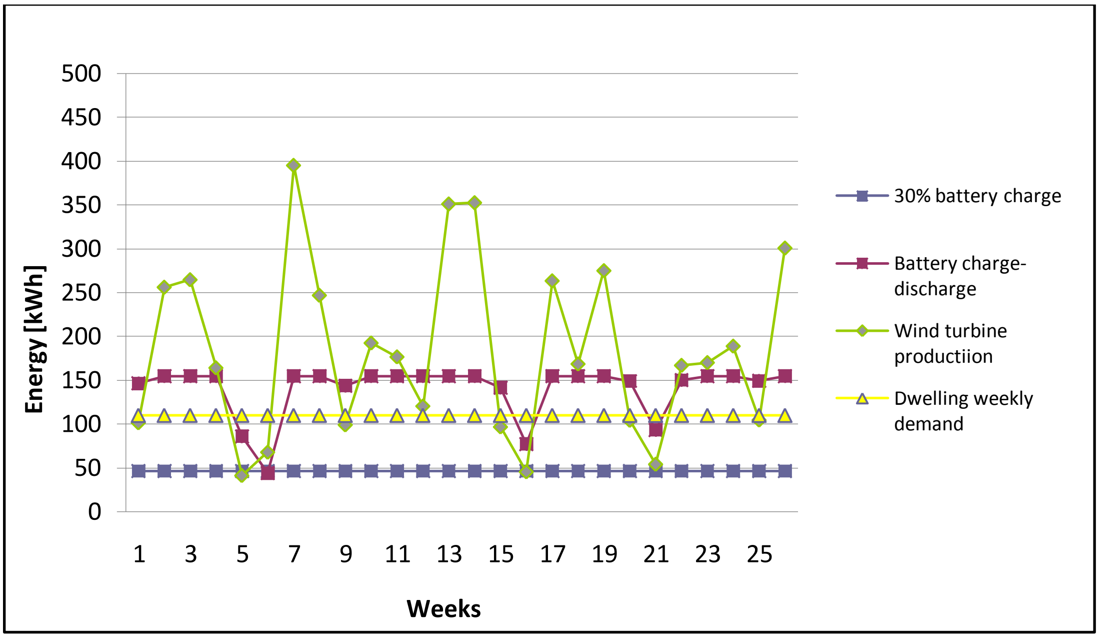
A8

Resumed calculations for the smaller wind turbine TR8.0-10 kW can be seen below. Process is equivalent to section 3.2.1.

$$Number\ of\ batteries = \frac{System\ nominal\ voltage}{Battery\ nominal\ voltage} = \frac{240V}{12V} = 20\ batteries$$

$$Intensity\ stored = \frac{Real\ daily\ demand * 5}{System\ voltage} = \frac{15{,}7\ kWh/day * 5\ days}{240V} = 327\ Ah$$

However, a battery accounting for 645Ah will be needed in order to reach the 30% limit discharge. Even in this case, the batteries will be discharged 5 kW below the limit during week 5 as can be observed in figure below. Therefore, even a higher battery capacity will be required.

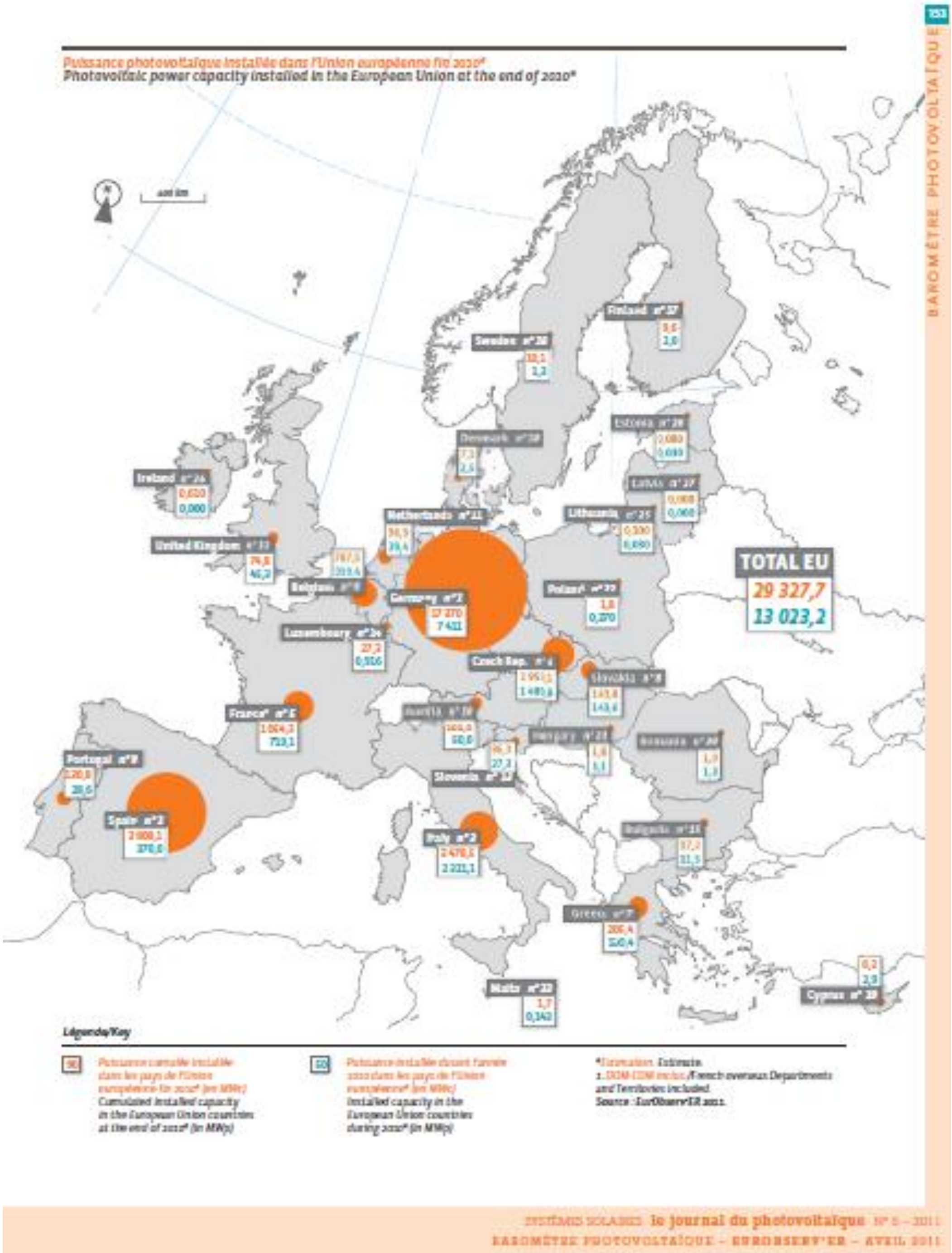


Batteries price will account for 1374€ while the ones used in the first study cost 779€. Therefore, the final investment cost ends up being almost the same.

APPENDIX B

B1

Below it can be observed for each country, how much power capacity they installed at the end of 2010.



B2

For on-grid and stand-alone photovoltaic, this table shows the supplementary capacity installed in European countries in 2009 and 2010, in MWp.

Additional photovoltaic capacity installed in the European Union in 2009 and 2010 (in MWp)*

	2009			2010		
	Réseau *On-grid*	Hors réseau *Off-grid*	Total	Réseau *On-grid*	Hors réseau *Off-grid*	Total
Germany	3 935,000	5,000	3940,000	7 406,000	5,000	7 411,000
Italy	698,700	0,100	698,800	2 321,000	0,100	2 321,100
Czech Rep.	408,626	0,020	408,646	1 489,780	0,000	1 489,780
France	215,200	6,000	221,200	719,000	0,146	719,146
Spain	15,765	1,245	17,010	369,000	1,000	370,000
Belgium	503,109	0,000	503,109	213,425	0,000	213,425
Greece	36,200	0,300	36,500	150,300	0,100	150,400
Slovakia	0,116	0,010	0,126	143,567	0,050	143,617
Austria	19,961	0,248	20,209	50,000	0,000	50,000
United Kingdom	6,922	0,155	7,077	45,000	0,255	45,255
Netherlands	10,578	0,091	10,669	29,393	0,000	29,393
Portugal	34,153	0,100	34,253	28,545	0,100	28,645
Slovenia	6,858	0,000	6,858	27,332	0,000	27,332
Bulgaria	4,285	0,008	4,293	11,540	0,000	11,540
Cyprus	1,109	0,033	1,142	2,869	0,049	2,918
Denmark	1,200	0,100	1,300	2,300	0,200	2,500
Finland	0,000	2,000	2,000	0,000	2,000	2,000
Romania	0,000	0,190	0,190	1,100	0,200	1,300
Sweden	0,516	0,338	0,854	1,000	0,300	1,300
Hungary	0,180	0,020	0,200	1,050	0,050	1,100
Luxembourg	1,795	0,000	1,795	0,916	0,000	0,916
Poland	0,121	0,248	0,369	0,150	0,220	0,370
Malta	1,289	0,000	1,289	0,143	0,000	0,143
Estonia	0,000	0,038	0,038	0,000	0,030	0,030
Lithuania	0,000	0,015	0,015	0,020	0,010	0,030
Ireland	0,000	0,210	0,210	0,000	0,000	0,000
Latvia	0,003	0,001	0,004	0,000	0,000	0,000
Total EU 27	**5 901,7**	**16,5**	**5 918,2**	**13 013,4**	**9,8**	**13 023,2**

*Estimation. Estimate. Les décimales sont séparées par une virgule. Decimals are written with a comma. Source : EurObserv'ER 2011.

B3

Next table shows the output from Winsun. All the columns except the time are measured in wh/m^2. The time shows the sum of hours through the year. The Htot is the total radiation coming to the earth surface, while Hbeam and Hdiff are beam radiation and diffuse radiation respectively. On the last column, Qcoll, it is shown how many wh/m^2 are produced for each 150 Wp installed (solar cell efficiency 15 %).

MONTH	TIME [HOURS]	Htot-tilt	Hbeam-tilt	Hdiff-tilt	Qcoll1
JAN	744.000	1,21E+04	6,50E+03	5,47E+03	1,67E+03
FEB	1.416.000	4,48E+04	2,74E+04	1,71E+04	6,21E+03
MAR	2.160.000	1,02E+05	6,37E+04	3,70E+04	1,41E+04
APR	2.880.000	1,53E+05	9,61E+04	5,39E+04	2,09E+04
MAY	3.624.000	1,62E+05	8,65E+04	7,19E+04	2,20E+04
JUN	4.344.000	1,72E+05	9,43E+04	7,36E+04	2,34E+04
JUL	5.088.000	1,51E+05	6,73E+04	8,03E+04	2,04E+04
AUG	5.832.000	1,19E+05	5,56E+04	6,08E+04	1,61E+04
SEP	6.552.000	8,09E+04	4,46E+04	3,50E+04	1,11E+04
OCT	7.296.000	4,17E+04	2,23E+04	1,89E+04	5,75E+03
NOV	8.016.000	1,36E+04	7,64E+03	5,88E+03	1,89E+03
DEC	8.760.000	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SUM	8.760.000	1,05E+06	5,72E+05	4,60E+05	1,44E+05

B4

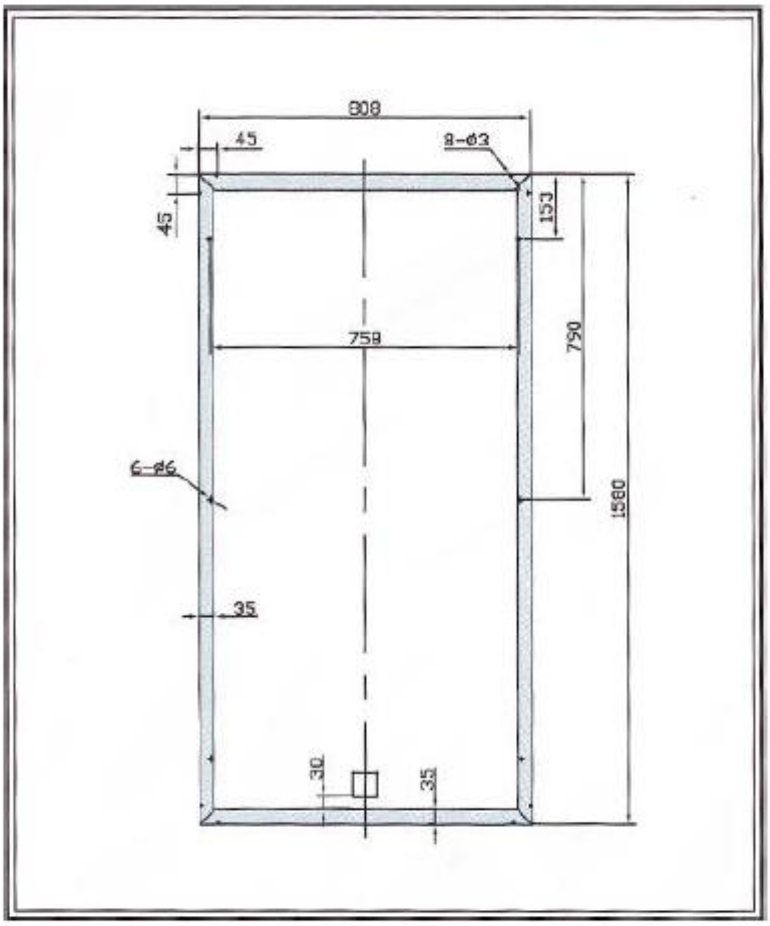
Data sheet of Solar Panel Monocrystalline 150 W from Juncoop

PS150M: Panel Solar 150W Monocristalino

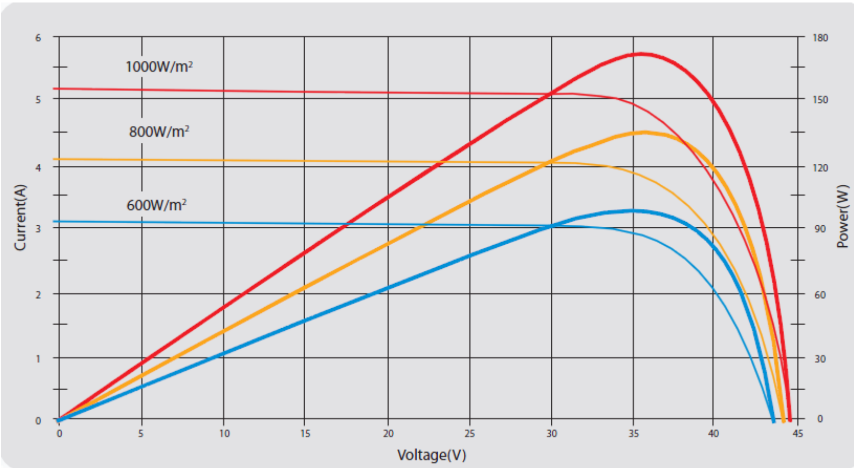
Potencia Max.	150W
Tolerancia	+/-3%
Corriente de Máxima Potencia (A)	4,26A
Tensión de Máxima Potencia (V)	35,25V
Corriente de Cortocircuito (A)	4,63A
Tensión de Circuito Abierto (V)	43,5V
TONC (ºC)	48ºC +/-2
Tensión Máxima del Sistema (V)	1000V
Tipo de célula	Monocristalino
Tamaño de célula	125x125mm
Número de células	6x12
Eficiencia células (%)	16-17%
Temperatura Trabajo	-40ºC a +85ºC
Certificados	CE, IEC61215, TUV Class II
Garantía	2 años sobre defectos de fabricación. 90% rendimiento hasta 12 años y 80% hasta 25 años.

Dimensiones (mm)	1580x808x35mm
Peso (Kg)	15kg
Marco	Alumnio anodizado
Cara frontal	Vidrio templado y microestructurado de alta transmisividad

PS150M: Panel Solar 150W Monocristalino

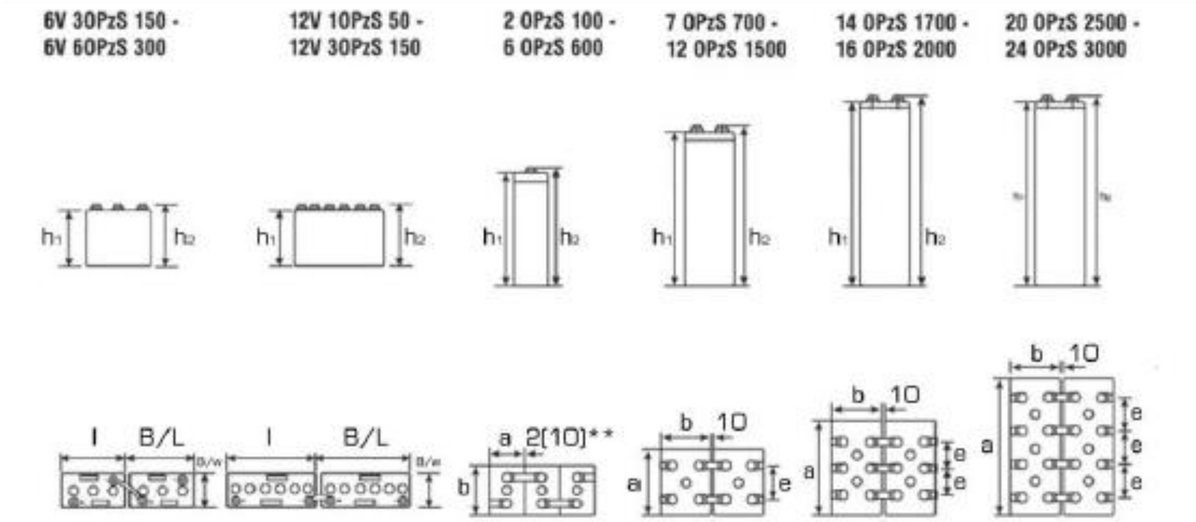


Power (W) and current (A) curve depending on voltage (V):



B5

Data sheet B. MEIBAT VASO ABIERTO 8OPzS800, SUNLIGHT.



** (para el OPzS 800)

Tipo de elemento		2 OPzS 100	3 OPzS 150	4 OPzS 200	5 OPzS 250	6 OPzS 300	5 OPzS 350	6 OPzS 420	7 OPzS 490	6 OPzS 600	8 OPzS 800	10 OPzS 1000	12 OPzS 1200
Tipo de placas				OPzS 50 (SPg250)**				OPzS 70 (SPg315)			OPzS 100 (SPg445)		
Capacidad en Ah en regimen de descarga	1h	52	78	104	130	156	180	216	252	324	432	540	648
	3h	75	113	150	189	225	264	315	369	450	600	750	900
	5h	85	126	170	215	255	300	360	425	510	690	865	1040
	10h	100	150	200	250	300	350	420	490	600	800	1000	1200
	100h	151	226	301	376	452	527	632	737	903	1204	1510	1810
Intensidad de descarga en Amp.	1h	52	78	104	130	156	180	216	252	324	432	540	648
	3h	25	37,6	50	63	65	88	105	123	150	200	250	300
	5h	17	25,2	34	43	51	60	72	85	102	138	173	208
	10h	10	15	20	25	30	35	42	49	60	80	100	120
	100h	1,51	2,26	3,01	3,76	4,52	5,27	6,32	7,37	9,03	12,04	15,1	18,1
Tensión final - en V/E regimen de descarga	1h			1,79				1,74			1,73		
	3h			1,82				1,79			1,79		
	5h			1,83				1,81			1,81		
	10h			1,85				1,83			1,83		
	100h*			1,85				1,85			1,85		
Dimensiones en mm	a	103	103	103	124	145	124	145	166	145	191	233	275
	b	206	206	206	206	206	206	206	206	206	210	210	210
	h_1	355	355	355	355	355	471	471	471	646	646	646	646
	h_2	375	375	375	375	375	491	491	491	666	666	666	666
	e	-	-	-	-	-	-	-	-	-	80	110	140
Numero de terminales		2	2	2	2	2	2	2	2	2	4	4	4
Peso en kg / Sin ácido / Con ácido		8,7 13,7	11 16	13 18	16 22	18 26	20 29	24 34	28 39	35 50	46 65	57 80	66 93

La densidad del electrolito de los elementos cargados es: **1,24±0,01 kg/l at 293°K (= +20°C)**

* alrededor 25 °C

** En el caso de las baterías enroscables, la altura h2 se incrementa en 30 mm.

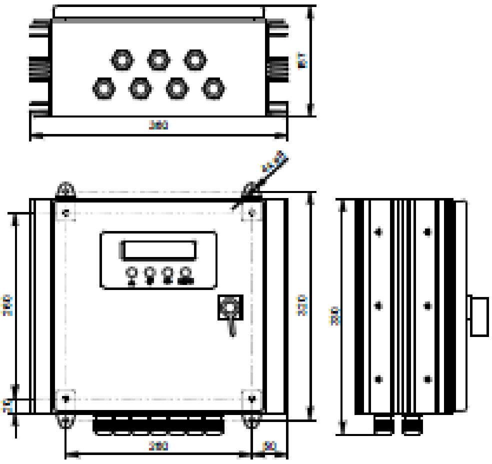
Data sheet with price included on the final column:

5. BATERÍAS

5.1 Baterías Vaso Abierto OPzS SUNLIGHT		T. máxima	C100	alto-ancho-fondo (mm)	P.V.P.
2284100	B. MEIBAT VASO ABIERTO 2OPzS100	12V	**185Ah**	392x103x206	**615,00**
2284105	B. MEIBAT VASO ABIERTO 3OPzS150	12V	**240Ah**	392x103x206	**701,00**
2284110	B. MEIBAT VASO ABIERTO 4OPzS200	12V	**300Ah**	392x103x206	**779,00**
2284115	B. MEIBAT VASO ABIERTO 5OPzS250	12V	**370Ah**	392x124x206	**895,00**
2284120	B. MEIBAT VASO ABIERTO 6OPzS300	12V	**440Ah**	392x145x206	**1.025,00**
2284125	B. MEIBAT VASO ABIERTO 5OPzS350	12V	**540Ah**	508x124x206	**1.081,00**
2284130	B. MEIBAT VASO ABIERTO 6OPzS420	12V	**645Ah**	508x145x206	**1.234,00**
2284140	B. MEIBAT VASO ABIERTO 7OPzS490	12V	**765Ah**	508x166x206	**1.374,00**
2284145	B. MEIBAT VASO ABIERTO 6OPzS600	12V	**970Ah**	683x145x206	**1.523,00**
2284150	B. MEIBAT VASO ABIERTO 7OPzS700	12V	**1055Ah**	683x191x210	**2.002,00**
2284155	B. MEIBAT VASO ABIERTO 8OPzS800	12V	**1295Ah**	683x191x210	**2.160,00**
2284160	B. MEIBAT VASO ABIERTO 9OPzS900	12V	**1380Ah**	683x233x210	**2.365,00**
2284165	B. MEIBAT VASO ABIERTO 10OPzS1000	12V	**1620Ah**	683x233x210	**2.560,00**
2284170	B. MEIBAT VASO ABIERTO 12OPzS1200	12V	**1950Ah**	683x275x210	**2.918,00**
2284175	B. MEIBAT VASO ABIERTO 11OPzS1400	12V	**2150Ah**	833x275x210	**3.363,00**
2284180	B. MEIBAT VASO ABIERTO 12OPzS1500	12V	**2300Ah**	833x275x210	**3.513,00**
2284185	B. MEIBAT VASO ABIERTO 14OPzS1700	12V	**2445Ah**	809x397x212	**4.381,00**

B6

Data sheet for R. SOLARIX POWER TAROM 4110, STECA.



Steca Power Tarom 2140, Power Tarom 4110, Power Tarom 4140

	2070	2140	4055	4110	4140
Funcionamiento					
Tensión del sistema	12 V (24 V)		48 V		
Consumo propio	14 mA				
Datos de entrada CC					
Tensión de circuito abierto del módulo solar	< 47 V		< 82 V		
Corriente del módulo	70 A	140 A	55 A	110 A	140 A
Datos de salida CC					
Corriente de consumo	70 A	70 A	55 A	55 A	70 A
Tensión final de carga	13,7 V (27,4 V)		54,8 V		
Tensión de carga reforzada	14,4 V (28,8 V)		57,6 V		
Carga de compensación	14,7 V (29,4 V)		58,8 V		
Tension de reconexión (SOC / LVR)	> 50 % / 12,6 V (25,2 V)		> 50 % / 50,4 V		
Protección contra descarga profunda (SOC / LVD)	< 30 % / 11,1 V (22,2 V)		< 30 % / 44,4 V		
Condiciones de uso					
Temperatura ambiente	-10 °C … +60 °C				
Equipamiento y dieseño					
Terminal (cable fino / único)	50 mm² / 70 mm² - AWG 1 / 00				
Grado de protección	IP 65				
Dimensiones (X x Y x Z)	330 x 330 x 157 mm	360 x 330 x 157 mm	330 x 330 x 157 mm	360 x 330 x 157 mm	
Peso	10 kg				

programable (Tensión final de carga – Protección contra descarga profunda)

Datos técnicos a 25 °C / 77 °F

B7

DATOS TÉCNICOS

Tensión de salida monofásica	230Vca
Tensión de salida trifásica	220/380Vca
Frecuencia de salida monofásica	50/60Hz
Frecuencia de salida trifásica	50Hz
Variación de frecuencia de salida	<0.1%
Variación de tensión de salida	<5%
Tensión mínima de entrada	5/6Vnom
Tensión máxima de entrada	4/3Vnom
Rendimiento	85-97%
Rendimiento con carga nominal	>85%
Autoconsumo (en búsqueda)	<120mA
Distorsión armónica	<5%

DATOS CONCRETOS DEL MODELO

Potencia nominal (W)	2000	2200	3300	4000	7000
Tensión nominal (V)	24/36/48	12	24/35/48	24/36/48	48
Tensión en monofásico			220		
Tensión en trifásico			220 ó 380		
Sobrecarga 3"(W)	4000	3600	6500	7000	12000
Sobrecarga 50"(W)	2700	3000	5400	6000	10500
Sobrecarga 6'(W)	2160	2400	4320	4320	8400
Longitud(mm)	460	535	535	535	647
Altura(mm)	457	178	178	178	210
Anchura(mm)	255	285	285	285	344
Peso neto(kg)	22	24	36	36	68

APPENDIX C

C1

Guangzhou Wanon Electric & Machine Co., Ltd.

Generator technical sheet is seen below. It's a **SAONON SP SSERIES-UK PERKINS 50Hz** model **SP10**, with engine model **403D-11G**.

Grupo electrógeno/Grupo generador de electricidad diesel Perkins

Grupo electrógeno/Grupo generador de electricidad diesel Perkins (Diesel Genset)

Descripción del grupo electrógeno/grupo generador de electricidad diesel Perkins:

1. Adopta un motor Perkins
2. Potencia: 4-2000kW (5-2600hp)
3. Voltaje de salida nominal: 380V, 400V, 220V, 480V etc.
4. Potencia nominal de frecuencia: 50Hz 60Hz
5. Adecuado para uso en el ferrocarril, en pequeñas naves industriales y fábricas etc.

SAONON SP SERIES-UK PERKINS 50HZ
10-2250KW (8-1800KVA)

Modelo de Generador	Energía en espera/ Primaria		Modelo de Motor	Cilindros	Desplazamiento	Consumo de Gasolina (L/H)	Capacidad almacenamiento de gasolina	Capacidad para líquido refrigerante	Tamaño del generador(mm)			Peso (kg)
	KVA	KW			(L)		(L)	(L)	L	A	A	
SP10	10 / 9	8 / 7.2	403D-11G	3	1.1	2.4	4.9	5.2	1320	552	1258	396
SP15	15 / 13.5	12 / 10.8	403D-15G	3	1.1	3.48	6	6	1320	552	1258	456
SP22	22 / 20	17.6 / 16	404D-22G	4	2.2	5.4	10.6	7	1320	552	1258	469
SP33	33 / 30	26.4 / 24	1103A-33G	3	3.3	7.1	7.9	10.2	1470	620	1280	520
SP38	38 / 35	30 / 27	1103A-33G1	3	3.3	8.1	7.9	10.2	1470	620	1280	580
SP50	50 / 45	40 / 36	1103A-33TG1	3	3.3	10.7	7.9	10.2	1470	620	1280	610
SP65	65 / 60	52 / 48	1103A-33TG2	3	3.3	14.1	7.9	10.2	1470	620	1280	650
SP73	73 / 65	58 / 52	1104A-44TG1	4	4.4	14.8	8	13	1590	710	1300	780
SP88	88 / 80	70 / 64	1104A-44TG2	4	4.4	18.7	8	13	1590	710	1300	830

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MASTER PROGRAM IN ENERGY SYSTEM

FEASIBILITY OF ALTERNATIVES TO PROVIDE ENERGY TO A COUNTRYSIDE SINGLE FAMILY HOUSE IN LULEA

Ana Surribas Comuñas
Fermín Ilundain Marina

13-June-2011

Examiner:
Mats Sandberg
Supervisor:
Björn Karlsson

- INTRODUCTION
- OBJECTIVE & LIMITATIONS
- METHODOLOGY
- ELECTRIFICATION ALTERNATIVES
  - *Wind power*
  - *Stand alone PV system*
  - *Hybrid system*
- RESULTS & DISCUSSION
- CONCLUSIONS

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Where do all begins?

Kebnekaise, Swedish Lapland

Master Program in Energy Systems

How can we provide electricity to those isolated cabins?

How much energy is required?

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MASTER PROGRAM IN ENERGY SYSTEM

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LOCATION

- *Norrboten county*
- *20 km north from Lulea*
- *rural area*
- *close to the sea*
- *no obstacles*
- *no grid connection possibility*

HOUSE SPECIFICATIONS

- *summerhouse*
- *basic appliances considered*
- *consumption data based on:*
  - equipment manufacturers specifications
  - estimated operational hours

Pmax = 6.7 kW

Consumption =12.6 kWh/day

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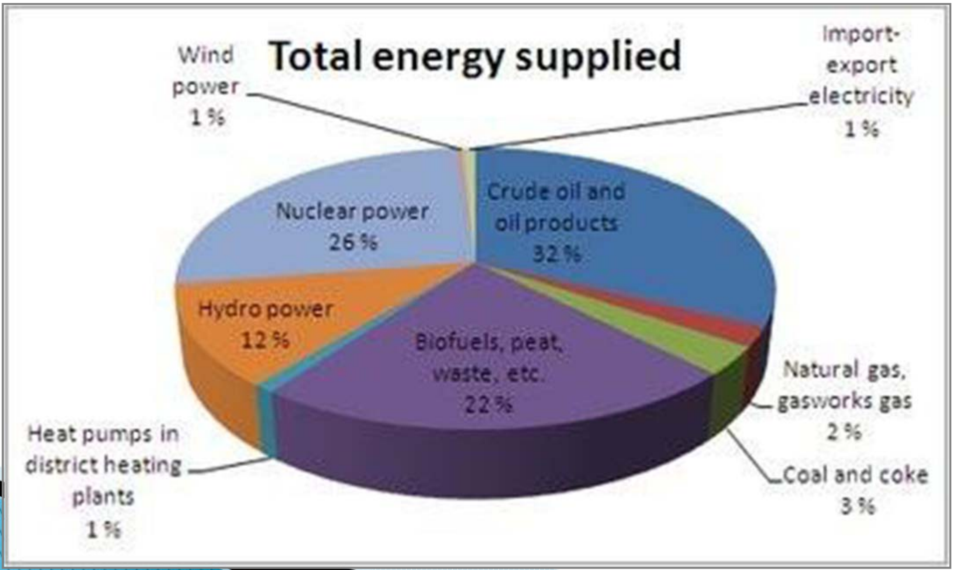
NON RENEWABLE

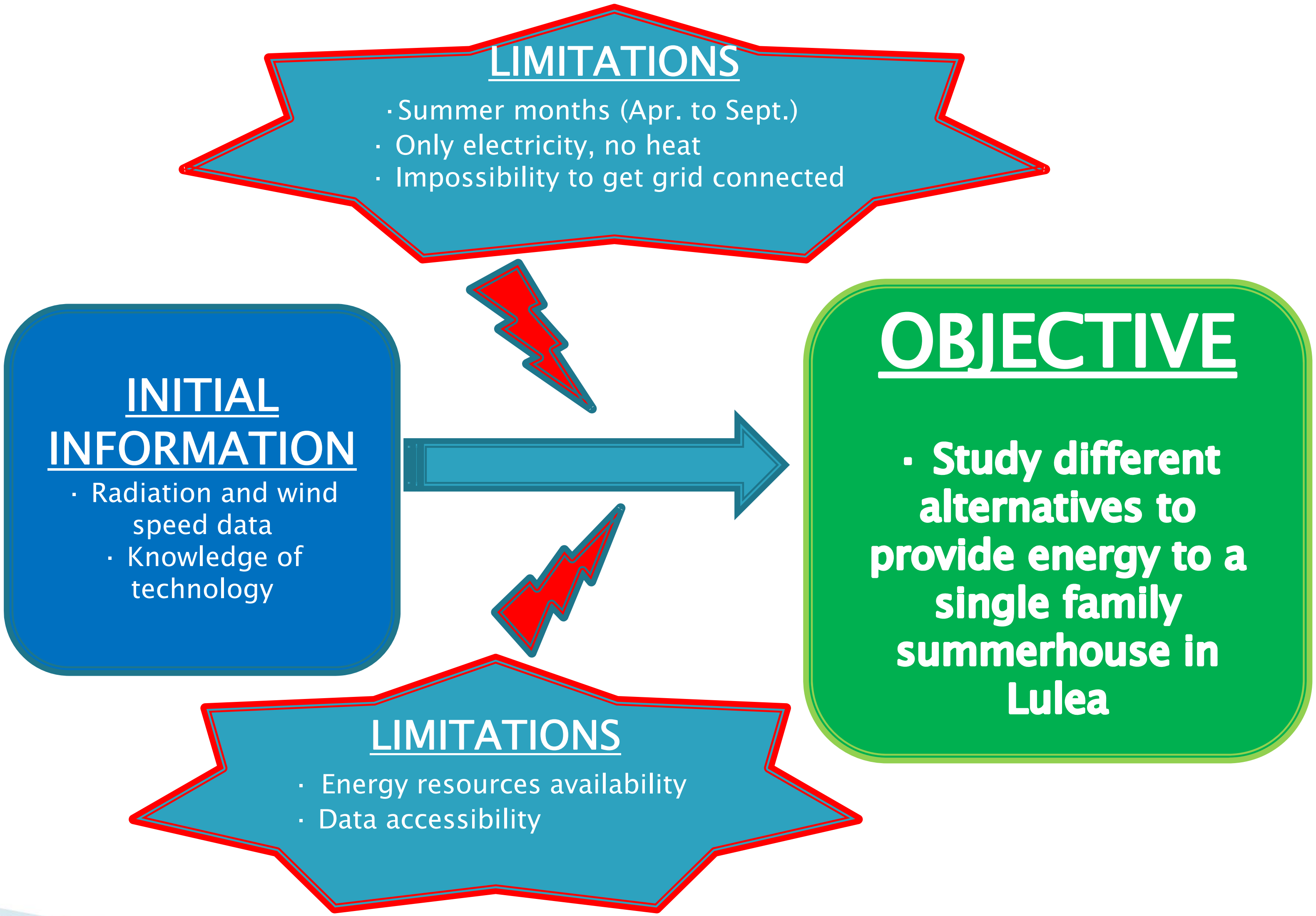
- Fossil fuels
- Biofuels
- Nuclear power

RENEWABLE

- Solar
- Wind
- Tides
- Geothermal
- Hydropower



Sweden has the greatest share of renewable energy in all European Union countries


LIMITATIONS
· Summer months (Apr. to Sept.)
· Only electricity, no heat
· Impossibility to get grid connected
INITIAL INFORMATION
· Radiation and wind speed data
· Knowledge of technology
OBJECTIVE
· Study different alternatives to provide energy to a single family summerhouse in Lulea
LIMITATIONS
· Energy resources availability
· Data accessibility

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1st. Data analysis

- Winsun
- Meteonorm

2nd. Study of each alternative

CONDITIONS:

- cover 100% energy demand
- losses in the system
- sizing regarding the "worst" case

3rd. Comparison and choice

CRITERIA:

- Economic
- Environmental

WIND TURBINE SYSTEM

CURRENT SITUATION
- Attractive market for wind power
- Starting 2011 with 2163MW capacity.
- Discussion onshore/offshore

DISADVANTAGES

- Does not adapt to demand.
- Max and min wind speed requirements.
- High voltage lines required.
- Visual and noise pollution.
- Impact on wildlife (birds).

ADVANTAGES

- Compatible with other land uses.
- Can be installed in areas non-suitable for other uses.
- 20 to 25 years lifecycle.
- Competitive, clean and inexhaustible source.
- Offshore possibility.

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WIND TURBINE SYSTEM

WIND DATA:
- Obtained from the Meteonorm software
- Average (m/s) per week.

→ BETZ LIMIT

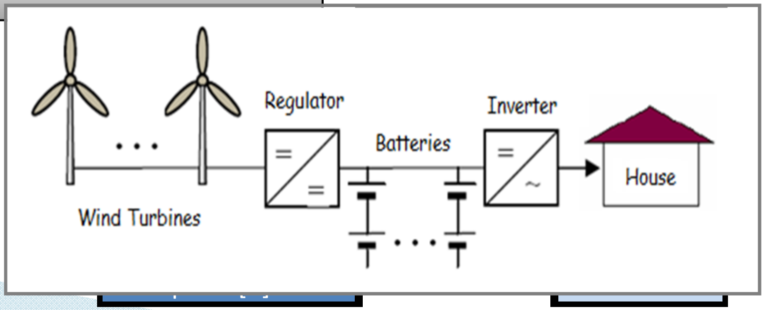
SELECTION OF WIND TURBINE
- Wind data
- Turbine cost
- Location characteristics
- Energy demand required

→ MODEL: **TR 10.0-20 kW**
- Rated power: 20 kW.
- Temperature range: -40ºC to +70ºC.
- Start wind speed: 2 m/s.

SELECTION OF BATTERIES
- System's voltage (360V)
- Autonomy
- Max depth discharge 30%

→ MODEL: **B.MEIBAT VASO ABIERTO 4OPzS200**
- Nominal voltage: 12 V
- Rated capacity: 300 Ah

ECONOMIC ANALYSIS



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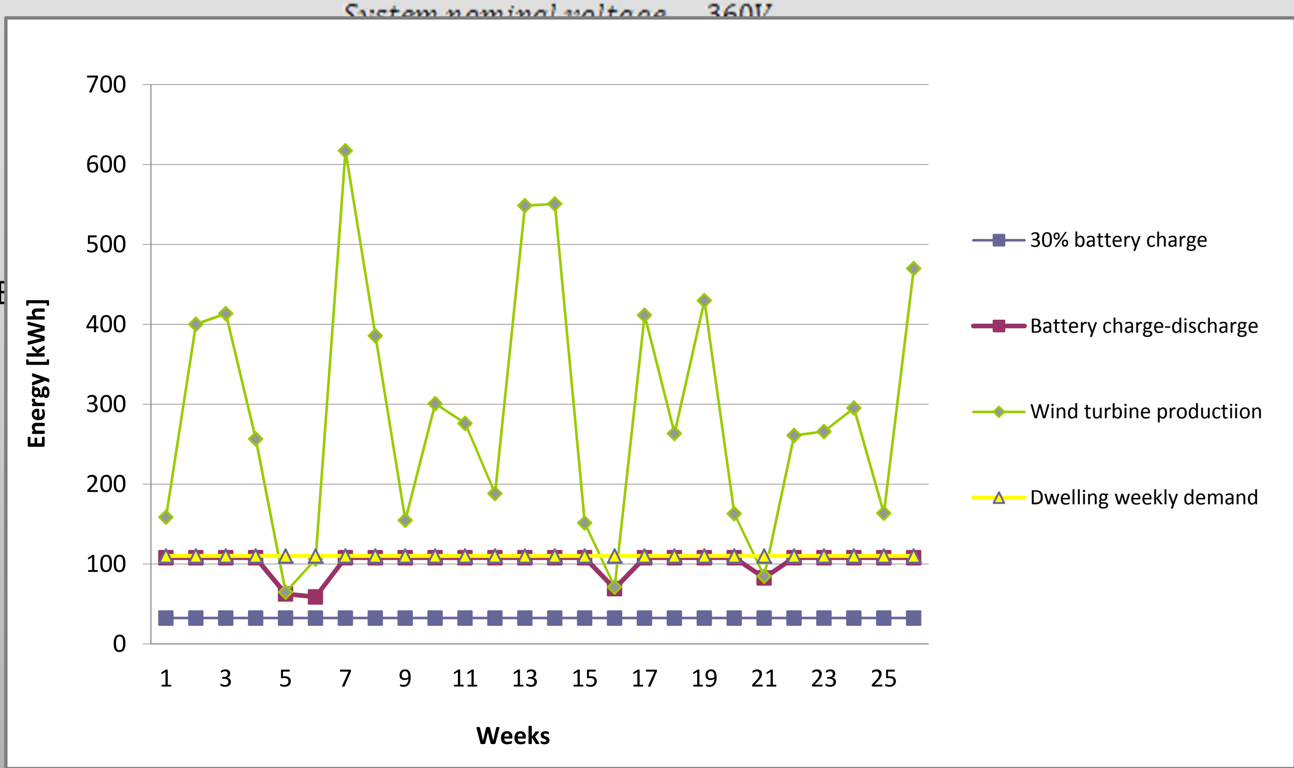
WIND TURBINE SYSTEM

BATTERY CALCULATIONS



30 batteries connected in series

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STAND ALONE PV SYSTEM

CURRENT SITUATION
- The Sun generates five thousend times more energy than world needs.
- Sweden electricity production from PV on 2010: 9,4 GW
- 340 kWpeak installed each year on off-grid PV markets

DISADVANTAGES

-Solar radiation is lower when most needed.

-Manufacturing involves toxic elements.

-Substantially high initial investment.

-Large amounts of panels are required.

-Aesthetic problems.

ADVANTAGES

-Competitive, clean and inexhaustible source.

-Minimal maintenance.

-No noise pollution.

-Easily expandable

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RADIATION DATA:
- Obtained from the Winsun software
- Solar cell output in kWh/m2 per month

Output provided for each 150 Wpeak installed

ECONOMIC ANALYSIS

PV MODEL INSTALLATION	Percentage %	Cost €
Devices	80,7	43370
Wiriling	5,0	2700
Structure	6,5	3500
Assembly	7,8	4200
Ohters	4,8	2600
		53770

SELECTION OF SOLAR PANEL
- Solar data
- PV module cost
- Location characteristics
- Energy demand required: Peak Power needed.
- System´s voltage

MODEL: **SP Monocrystalline 150 W**
- Maximum power: 150 Wpeak
- Rated voltage: 24 V
- Temperature range: -40° C to 85° C
- Short circuit current: 4,63 A

SELECTION OF BATTERIES
- System's voltage (48V)
- Autonomy
- Max depth discharge 30%

MODEL: **B.MEIBAT VASO ABIERTO 8OPzS800**
- Nominal voltage: 12 V
- Rated capacity: 1295Ah

SELECTION OF CHARGE CONTROLLER
- Peak current generated
- Number of modules on parallel
- System´s voltage (48 V)

MODEL: **R. SOLARIX POWER TAROM 4110**
- Nominal voltage: 48 V
- Rated input current: 110 A
- Rated output current: 55 A

SELECTION OF INVERTER
- volts in DC to volts in AC
- Power demand in AC

MODEL: **Inversor Senoidal Trifasico 380V + Monofásico 220V ISC 7000 48V**
- Input voltage: 48 V
- Output voltage: 230V
- Rated power: 7 kW

STAND ALONE PV SYSTEM

PV MODULES CALCULATIONS

Number of PV modules on series: $m_s = \frac{V_{rs}}{V_r} = \frac{48}{24} = 2$

Number of PV modules on paralell: $m_p = \frac{P_p}{m_s * P_m} = \frac{6400\ W}{2 * 150W} = 22$

44 PV modules;22 PV branches

Number of batteries on series: $b_s = \frac{V_{rs}}{V_b} = \frac{48}{12} = 4$

Number of batteries on parallel: $b_p = \frac{C}{C_b} = \frac{2560\ Ah}{1295\ Ah} = 2$

8 batteries, 2 branches

Peak current generated: $I_g = I_{sc} * m_p = 4.63 * 22 = 101.86\ A$

charge controller

HYBRID SYSTEM: WIND TURBINE-GENERATOR

GOAL
- Ensure the total electricity demand with a backup generator
- Reduce number of batteries

CURRENT SITUATION
Hybrid systems represent today a concrete option compatible both in environmental and social terms. Current systems account for 80% to 90% of the energy need supplied by renewable sources and the storage. Therefore the generator is seldom used.

DISADVANTAGES

-Including a generator makes the system more complex.

Diesel generators present:
-Low efficiencies

-High maintenance costs.

ADVANTAGES

-High performance efficiency.

-Cost reduction of the installation.

-Possibility to optimize locally available resources.

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- METHODOLOGY
- ELECTRIFICATION ALTERNATIVES
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  - Hybrid system
- RESULTS & DISCUSSION
- CONCLUSIONS

HYBRID SYSTEM: WIND TURBINE-GENERATOR

WIND DATA:
- Obtained from the Meteonorm software
- Average (m/s) per week.

→ BETZ LIMIT

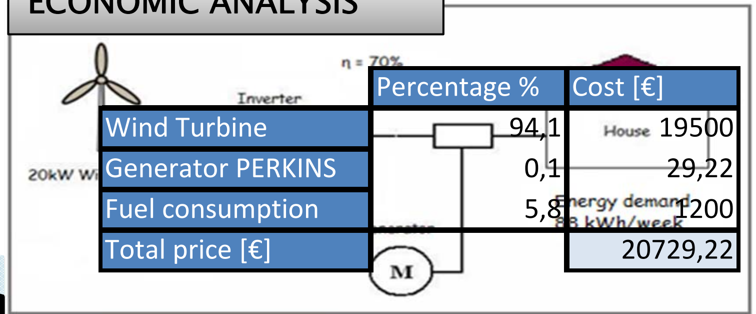
SELECTION OF WIND TURBINE
- Wind data
- Turbine cost
- Location characteristics
- Energy demand required

→ **MODEL: TR 10.0-20 kW**
- Rated power: 20 kW.
- Temperature range: -40°C to +70°C.
- Start wind speed: 2 m/s.

SELECTION OF GENERATOR
- Rated power
- Most critical supply situation

→ **MODEL: SP SSERIES-UK PERKINS 50Hz SP10 (DIESEL)**
- Standby/service power: 7.2/8 kW
- Deposit volume: 4.9 l
- Fuel consumption: 2.4 l/h

ECONOMIC ANALYSIS



	Percentage %	Cost [€]
Wind Turbine	94,1	19500
Generator PERKINS	0,1	29,22
Fuel consumption	5,8	1200
Total price [€]		20729,22

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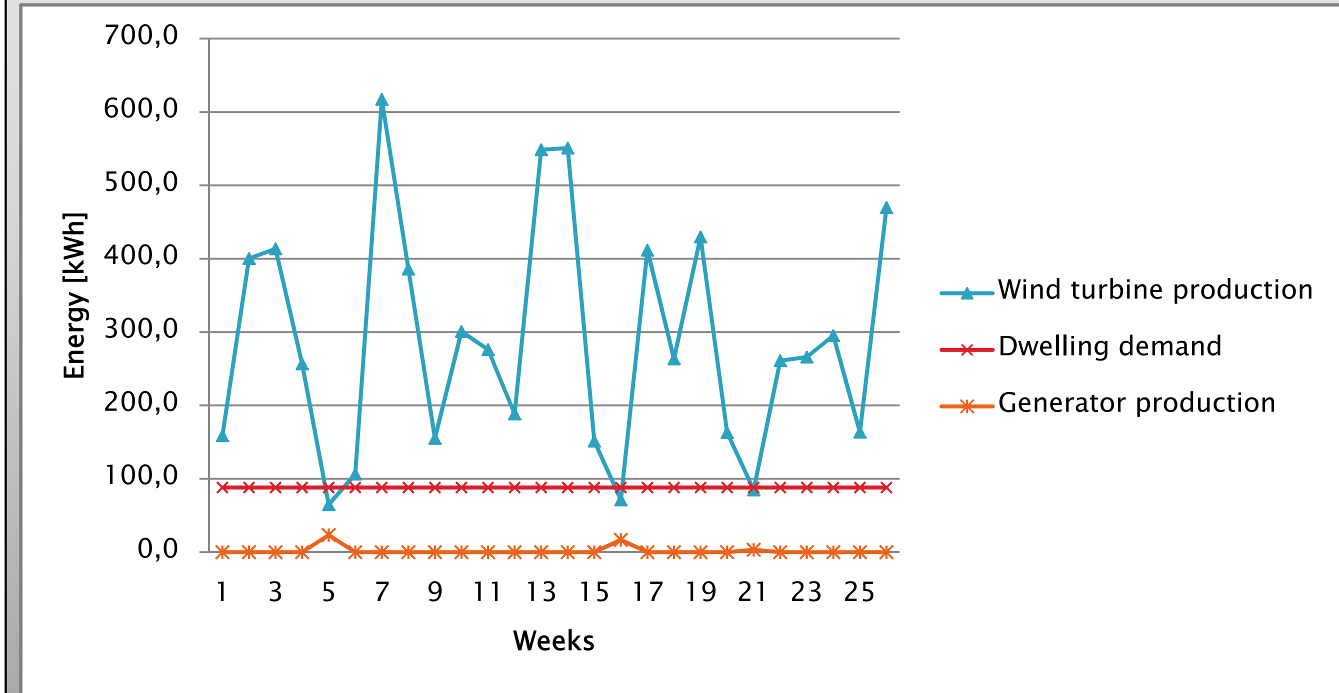
HYBRID SYSTEM: WIND TURBINE-GENERATOR

HYBRID SYSTEM CALCULATIONS



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CONCLUSIONS

RESULTS & DISCUSSION

ECONOMICAL

WIND TURBINE
STAND ALONE PV
HYBRID SYSTEM: W

installed

HYBRID SYSTEM

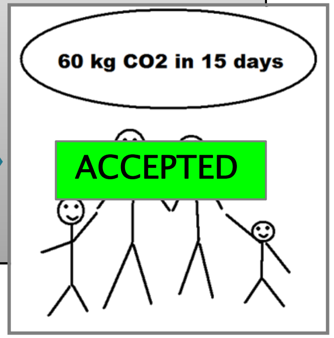
ENVIRONMENTAL

- Wind power system
- Stand alone PV system

No environmentally har ful

- Hybrid system

$$CO_2\ emission = Total\ fuel\ consumption\ l \times 2.6 \frac{kg}{l} = 59.83\ kg\ CO_2$$



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CONCLUSIONS

- Ensure total energy required demand by renewable sources is **POSSIBLE.**
- Renewable sources do not adapt to instant demand → **BACKUP FACILITIES NEEDED**
- Batteries are the most expensive component.
- **Software**'s used help with calculations, however do not allow as extensive knowledge of the process.
- Some **assumptions** are needed.
- Alternatives are **oversized**: tighter estimates would lead to lower investment costs.
- TR8.0-10kW vs TR10.0-20 kW windmill: 20kW windmill leads to less generator consumption in the hybrid system and does not mean a higher investment cost.

THANK YOU FOR YOUR ATTENTION

Any questions?