University of Strathclyde

Mechanical Engineering Department

Renewable Hydrogen Energy System

For Household Applications

Thesis Submitted for the MSc degree

Energy Systems & The Environment

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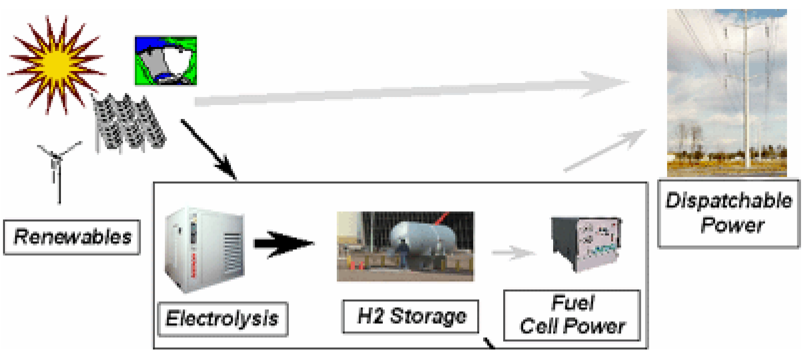
Abstract

The purpose of the paper is to define and analyze a renewable hydrogen energy supply system for household use. The energy system combines solar energy, wind energy, hydrogen production, and fuel cell for household energy supply. The components of the system are available, but have not yet to be integrated in this way.

The main advantages and problems of this system are discussed from technical and environmental aspects. Mainly the environmental aspect of the system is being evaluated by using the Life Cycle Assessment method to assess the environmental impact of the system compared to the house.

The possibility of applying this system into UK is discussed and evaluated. Calculations of components size are made based on a house in UK. Cardiff is recommended as suitable region for application of this system.

Keywords: Solar energy, Wind energy, Storage, Electrolysis, Fuel cells, Life Cycle Assessment



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CHAPTER 1

INTRODUCTION

At present, the large scale use of fossil fuels is a dominant feature of industrial societies. It is regarded as essential for the growing, distribution and preparation of foods, for construction, manufacturing, communication and organisation, and many other activities.

As we have seen, modern societies, and particularly industrial societies, are now totally dependent upon the use of large quantities of energy, most of it in the form of fossil fuels, for virtually all aspects of life. In 1992, the estimated total world consumption of primary energy, in all forms, was approximately 400 EJ per year, equivalent to some 9500 million tones of oil per year.

Assuming a world population of about 5300 million in that year, this gives an annual average fuel use for energy man, woman and child in the world equivalent to about 1.8 tones of oil. A breakdown of world primary energy consumption by source in 1992 is shown in ***Figure 1.1***.

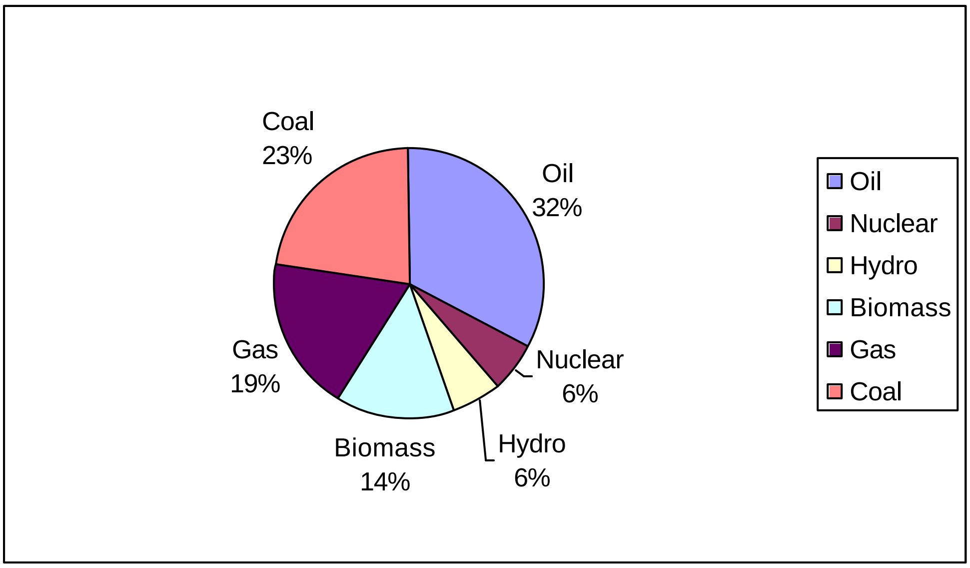

Figure 1.1: World Primary Energy Breakdown

Oil is the dominant fuel, contributing some 32%, followed by coal at 23%. Coal was once the dominant world fuel, but is now losing ground rapidly to oil and gas, which has a 19% share. Hydroelectricity and nuclear are used much less, at around 6% each. The estimated share of traditional non-commercial fuels such as biomass is around 14%.

To understand how best to make use of renewable sources, and also to understand fully the problems caused by the present use of fuels, we must take a closer look at the way energy is currently used in industrial societies.

To make some sense of the great variety of energy use, it is necessary to categorise it. In most official statistics human activity is divided into four main sectors:

- The *transport* sector (which includes road, rail, air and water transport, both public and private, and both goods and passengers)
- The *domestic* sector (private households)
- The *commercial* and *institutional* sector (which includes government buildings, commercial offices, education, health, shops, restaurants, commercial warehouses, plus pubs, clubs, entertainment, religious buildings, and miscellaneous other energy users)
- The *industrial* sector (which includes manufacturing, iron and steel, food and drink, chemicals, buildings, agriculture)

The first question to consider is how much energy is used by each sector. The domestic sector comprises the second most important energy consumer as we can see from the ***Figure 1.2***.

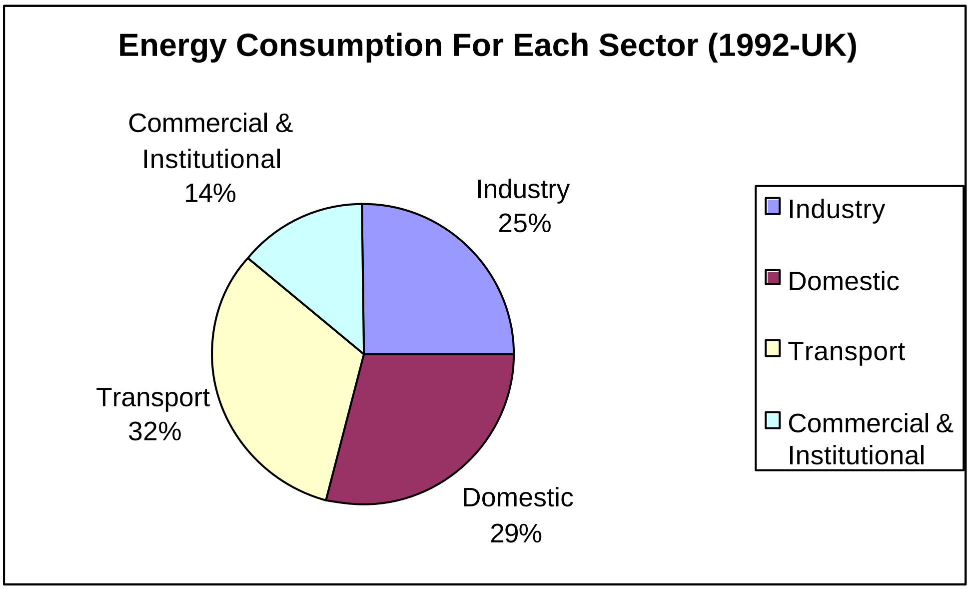

Figure 1.2: Energy Consumption by Sector

The principal uses of energy in the domestic sector, which is our area of concern, are for space heating, water heating, cooking, lighting and electrical appliances. Most of the energy used, around 70%, is for low-grade heat for space and water heating.

This is generally provided directly by high grade sources such as the electricity from thermal power plants. ***Figure 1.3*** gives an overall picture of energy use in the domestic sector.

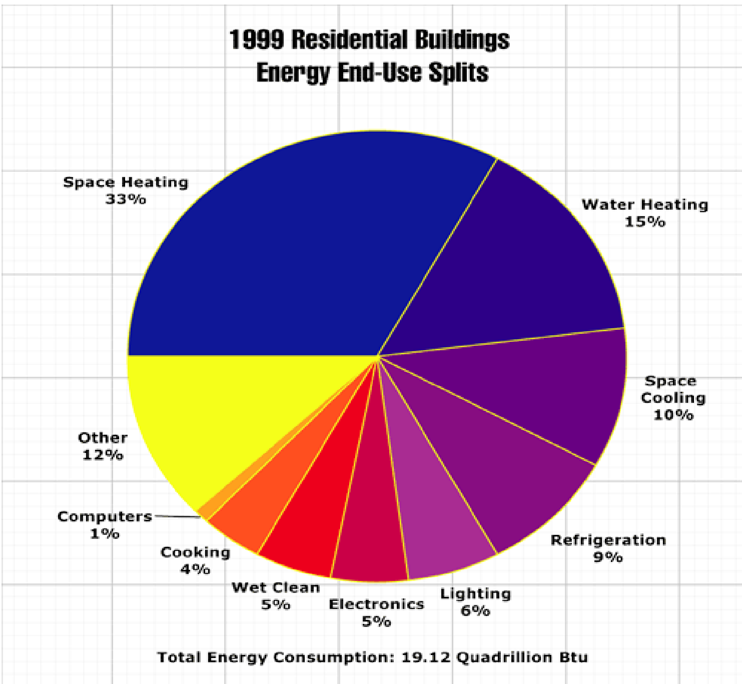

Figure 1.3: Energy Breakdown in Houses

Today the energy related problems that hit the headlines most often are environmental ones. Various environmental problems look large in the public consciousness at present. Many of these are largely a result of large scale fuel use.

One of the most significant problems appears to be that of global warming, a gradual increase in the global average air temperature at the earth's surface. The majority of scientists believe that global warming is probably taking place, at a rate of around 0.3 C per decade, and that it is caused by increases in the concentration of so called 'greenhouse gases' in the atmosphere.

The most significant single component of these greenhouse gas emissions is carbon dioxide (CO_2) released by the burning of fossil fuels. Another side effect of the burning fuels is acid rain. Some of the gases which are given off when fuels are burned, in particular sulphur dioxide and nitrogen oxides, combine with water in the atmosphere to form sulphuric acid and nitric acid respectively. The result is that any rain which follows is slightly acidic. This acid rain can cause damage to plant life, in some cases seriously affecting the growth of forests, and can erode buildings and corrode metal oxides.

After considered the ways in which energy is used and the scale of its use and have looked at the various problems associated with the current use of fossil and nuclear fuels such as the environmental impact we are now in a position to look more closely at renewable sources, to see whether and to what extent they offer solutions to these problems.

The term 'renewable energy' can be defined in several ways: for example Twidell and Weir (1986) define renewable energy as *'energy obtained from the continuous or* *repetitive currents of energy recurring in the natural environment.'* Sorensen (1979) defines renewable energy as *'energy flows which are replenished at the same rate as they are "used"'*, adding that the term renewable energy may be taken to include 'the usage of any energy storage reservoir which is being "refilled" at rates comparable to that of extraction'.

Most renewable energy sources are derived from solar radiation, including the direct use of solar energy for heating or electricity generation, and indirect forms such as energy from the wind, waves and running water, and from plants and animals. Tidal sources of energy result from the gravitational pull of the moon and sun, and geothermal energy comes from the heat generated within the earth. Energy from wastes of all kinds is also often included under the heading of renewable.

The use of renewable on a more significant scale than at present would at the very least replace a further significant proportion of fossil and nuclear fuel use, thereby reducing the associated environmental impacts. Most of the renewable sources enable the forms to be avoided, but all have some form of local environmental impact of their own, ranging from very minor to major in the case of the larger tidal and hydroelectric schemes.

As clearly shown on the following ***Figure 1.4***, renewable sources are likely to make up more than 50% of the total energy supply after 2050. While, the use of oil will start to decline after the year 2020, the message someone can get from the diagram is quite simple. The power plant for the domestic sector will need to use a fuel that can be derived from a variety of sources. This means that major structural changes are needed in the infrastructure of fuel supply and the domestic sector itself.

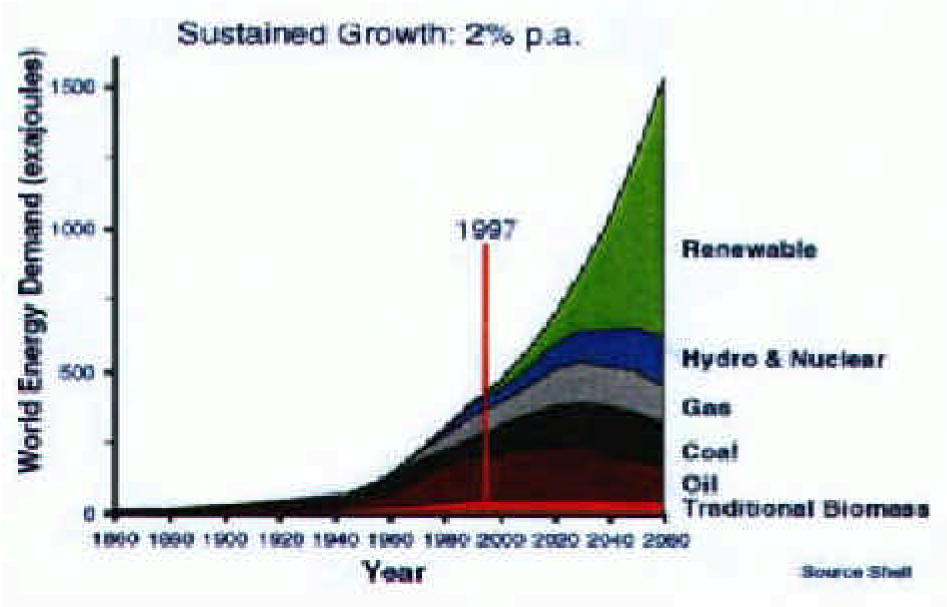

Figure 1.4: World Energy Generation

Summarizing all of the above it can be said that renewable energy sources seem to be a promising new way of producing energy, better and cleaner from the energy produced from the burnt of oil. With the passage of time, and as the fossil fuel reserves are getting smaller, renewable source of energy will eventually bring changes worldwide in the energy sector as they may offer a solution to the matter above.

Project Aims

The aim of the project is to investigate the use of renewable energy in the domestic sector and more specifically for an isolated house by providing the 100% of the needed energy from renewable. The technology that is gone to be used is by wind energy, photovoltaic, hydrogen production and fuel cell.

Although the first uses of renewable sources such as the wind and photovoltaic are likely to involve the direct production and use of electricity, the potential for utilizing renewable for electricity is limited by the intermittent character of solar radiation and wind energy by the difficulty of using electricity when the extraction of energy from such technologies is limited. The role of renewable in the global economy could be greatly extended if they could be converted to energy carriers that are easily stored.

Even if nowadays this problem has been overcome with the use of batteries still some environmental concerns prevent the acceptance of the system. But since this new technology of producing hydrogen and use it in the fuel cell is in a very early stage of development it is very difficult to be able to replace the existing batteries with a hydrogen-fuel cell system at the moment. Further developments have first to be accomplished before the above application to be feasible.

On the other hand, many electrical applications could be powered by this coming technology without using power from the grid or from the batteries as it is being done at the moment. Thus, replacing the batteries of a system like the wind – photovoltaic with a fuel cell system the author investigates how this could work and if can improve the efficiency of it. Hence, a better view of the fuel cell technology can be obtained for the use in the domestic sector.

As we mentioned before batteries cause a significant environmental impact from the time of production until the elimination phase. To assess which system, batteries or fuel cell, is the most environmental friendly and which causes the largest impact we compared them by using the Life Cycle Assessment method.

“The life cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impacts of those energy and material uses and releases to the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extracting and processing raw materials; manufacturing transportation and distribution; use / re-use / maintenance; recycling, and final disposal.” (Guidelines for Life-Cycle Assessment: A 'Code of Practice', SETAC, Brussels, 1993)

By using the LCA method not only in the batteries and the fuel cell but also in the entire house and the remaining system of wind turbine and photovoltaic we could evaluate the whole system once with the batteries and once with the fuel cell. With this way we could compare which technology is most environmental friendly. Also we compared the entire system with the house to evaluate the degree of the impact the system has against the house.

CHAPTER 2

Solar Photovoltaic Power

Solar energy runs the engines of the earth. It heats its atmosphere and its lands, generates its winds, drives the water cycle, warms its oceans, grows its plants, feeds its animals, and even (over the long haul) produces its fossil fuels. This energy can be converted into heat and cold, driving force and electricity.

Solar power is one of the first things that come to most people's minds when the subject of alternative energy comes up. Solar power first gained wide public awareness during the 1970's energy crisis, and while it may not be such a hot topic these days, solar technology has made great advances since then.

Solar Thermal Panels

The first widespread residential use of solar energy came in the form of solar thermal heating panels. By covering a system of copper pipes with a black heat-collecting surface beneath a greenhouse-style pane of glass, fluid inside the copper pipes can be heated with solar radiation and pumped through a baseboard heating system, used for household water heating or for heating swimming pools.

However solar thermal panels aren't very efficient for applications requiring very high heat fluid. While these systems may be ideal for keeping a small swimming pool at a comfortable temperature, baseboard heating or household hot water would likely require a gas or electric secondary heater. In Alaska, during much of the year solar radiation would not be sufficient to counteract the extreme cold, so these systems are probably best left for summer cabins and more southern homes.

Solar Electric Panels

Photovoltaic (PV) panels, which use sunlight to produce electricity, are much more efficient for their purpose than their solar thermal cousins. They are also much more useful in northern climates. While the manufacturing process and the mechanism by which they work is more technical than solar thermal, they are much simpler to install and maintain in actual use. Following is an overview of the function and purpose of photovoltaic panels, as well as the many benefits they have in alternative energy systems.

How Photovoltaic Panels are Used

Solar electric panels are probably one of the simplest alternative energy sources to use. They can be mounted on a rooftop or a freestanding solar array rack. Once mounted, a wire needs to be run from the solar panel to a solar charge controller, and a wire needs to be run from the charge controller to a deep cycle battery bank. If the building's electrical system runs on DC power, the battery bank can be wired directly into the system.

Multiple solar panels increase the wiring complexity a bit, and of course, most homes will use 120 volt AC power or a combination of AC and DC power. AC power systems will require the use of an inverter to convert the DC battery power into useable 120VAC power, and other details can be added, expanded and customized from there.

However, the fundamentals of using solar power remain simple. The solar panels turn sunlight into electricity, and that power is stored in a battery bank for household use. The household power needs are drawn out of the stored battery power, and the solar panels recharge the batteries when their charge drops below a certain level.

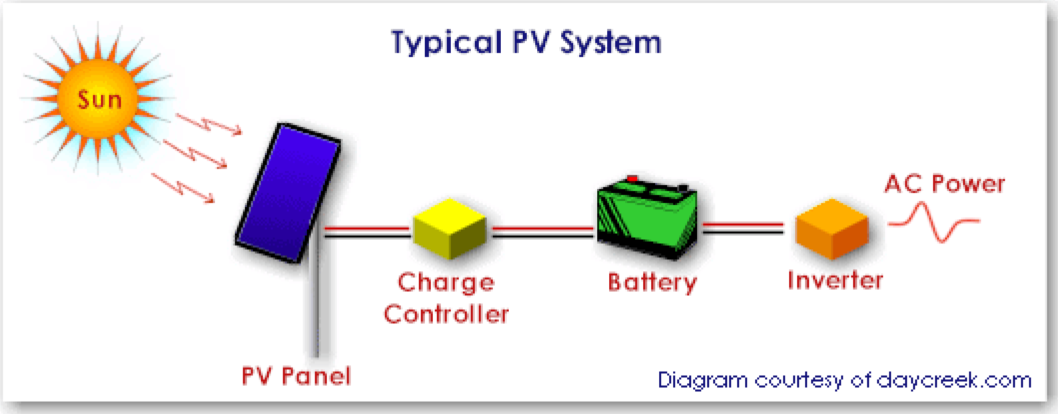

Figure 2.1: Typical PV System

Types of PV Cell

Monocrystalline Silicon Cells:

Made using cells saw-cut from a single cylindrical crystal of silicon, this is the most efficient of the photovoltaic (PV) technologies. The principle advantage of monocrystalline cells are their high efficiencies, typically around 15%, although the manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

Multicrystalline Silicon Cells:

Made from cells cut from an ingot of melted and recrystallised silicon. In the manufacturing process, molten silicon is cast into ingots of polycrystalline silicon, these ingots are then saw-cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones, due to the simpler manufacturing process. However, they tend to be slightly less efficient, with average efficiencies of around 12%., creating a granular texture.

Thick-film Silicon:

Another multicrystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, this is encapsulated in a transparent insulating polymer with a tempered glass cover and usually bound into a strong aluminium frame.

Amorphous Silicon:

Amorphous silicon cells are composed of silicon atoms in a thin homogenous layer rather than a crystal structure. Amorphous silicon absorbs light more effectively than crystalline silicon, so the cells can be thinner. For this reason, amorphous silicon is also known as a "thin film" PV technology. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces and "fold-away" modules. Amorphous cells are, however, less efficient than crystalline based cells, with typical efficiencies of around 6%, but they are easier and therefore cheaper to produce. Their low cost makes them ideally suited for many applications where high efficiency is not required and low cost is important.

Other Thin Films:

A number of other promising materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules. The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiencies than amorphous silicon. New technologies based on the photosynthesis process are not yet on the market.

Types of PV System

Grid Connected

The most popular type of solar PV system for homes and businesses. The solar system is connected to the local electricity network allowing any excess solar electricity produced to be sold to the utility. Electricity is taken back from the network outside daylight hours. An inverter is used to convert the DC power produced by the solar system to AC power needed to run normal electrical equipment.

Grid Support

The solar system is connected to the local electricity network and a back-up battery. Any excess solar electricity produced after the battery has been charged is then sold to the network. Ideal for use in areas of unreliable power supply.

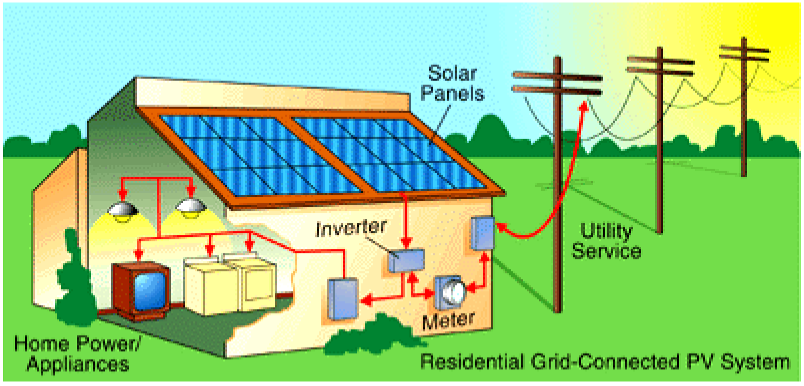

Figure 2.2: Residential Grid – Connected PV System

Off-Grid

Completely independent of the grid, the solar system is directly connected to a battery which stores the electricity generated and acts as the main power supply. An inverter can be used to provide AC power, enabling the use of normal appliances without mains power.

Hybrid System

A solar system can be combined with another source of power - a biomass generator, a wind turbine or diesel generator - to ensure a consistent supply of electricity. A hybrid system can be grid connect, stand alone or grid support.

Figure 2.3: A Hybrid Wind – PV System

Types of Panels and Their Uses

Solar panels are available in types and sizes for everything from recharging AA batteries to powering large household electrical systems. You can buy small, flexible panels designed for maintaining a fully charged battery (ideal for vehicles that go into storage for months at a time). You can get household power panels ranging up to 120 watt models, and you can add multiple panels to expand the system to any size you need. Of course, the most durable, efficient and highest output panels will be more expensive than the lower-end models, but for large, long-term applications the greater initial outlay is worthwhile in the long run.

Flexible panels are limited to smaller output sizes. They tend to be more expensive per watt of rated output, and less durable in long-term applications. However, they're extremely convenient for intermittent use where the panel may need to be stored and moved around regularly.

Unframed rigid panels also tend to be available primarily in smaller sizes. They're much lighter weight than the more common framed panels, and convenient for portable applications. What these panels lose in convenience as compared to flexible panels, they make up in cost per watt and durability.

Framed rigid panels are the most common type of solar panel for full solar power systems. They are the most durable type of panel, and are generally used in permanent or long term installations for household, RV or marine power systems. Large framed panels can get quite expensive, but with 20-25 year warranties, high durability and low maintenance, they're worth it.

Solar roofing is one of the newer styles of photovoltaic unit. For a large household system, solar roofing can be found that mimics the appearance of regular roofing shingles or regular metal channel roofing. Probably the most cosmetically pleasing option for a full-house solar system, these products are now becoming available on a widespread basis.

Benefits of Solar Energy

Photovoltaic power is one of the most benign forms of electrical power available. It produces no emissions, uses no fuel, and other than the power storage batteries, PV system components are all solid-state, with no hazardous materials involved.

Most rigid photovoltaic panels come with 20-25 year warranties on their rated power output, and they require virtually no maintenance during that time. Cleaning the surface of the panels and maintaining a proper fluid level in the storage batteries are the two primary maintenance duties.

For villages and individuals outside the reach of the grid power system, solar panels can be a highly reliable and relatively economical source of power. In northern climates, photovoltaic are perfectly suited for powering remote summer vacation cabins, or providing a seasonal power source for year-round homes.

For commercial and industrial use, PV panels can be put to use powering monitoring stations, signal lights, telecommunications towers, and other remote sites where there are no full-time employees stationed. Solar power is also useful for small power loads even in grid-powered areas where running grid power to the load would be inconvenient or expensive (such as signal lights on an airstrip or parking lot lighting).

How Photovoltaic Panels Work

Solar electric panels are composed mainly of silicon. Silicon is used because it naturally releases electrons (electrical energy) when hit with a photon (light source). The trick for photovoltaic manufacturers was to find a way to "catch" the displaced electrons and use their energy.

Most solar panels consist of a clear protective top layer, two layers of specially treated silicon with collecting circuitry attached to the top layer, and a tough polymer backing layer. From there, the panel can be framed (adds durability) or unframed (reduces weight), and in some cases the layers are even comprised of flexible materials. The vast majority of PV panels work in the same way:

The top layer of silicon is treated to give it an electrically negative character. The back layer is treated to make it electrically positive. Due to these treatments and added elements, the top layer is rich in electrons, and the back layer is relatively electron poor. These two layers are separated by an electrically charged junction, which allows electrons to flow from back to front, but not the other way around.

When light strikes the PV panel, some of the photons are absorbed by the silicon layers. The photons cause electrons to be released from the silicon crystal, and those electrons "wander around" looking for somewhere to attach themselves. Some of the electrons are freed from the bottom layer, and they find their way through the junction into the top (electron rich) layer. Some of the electrons are freed from the top layer, and since they cannot travel to the bottom (electron poor) layer, and are being "crowded" by new electrons from the bottom layer, they are left free to be collected by electrical contacts on the surface of the top layer.

Those collected electrons are routed through an external circuit, providing power to the electrical system attached to the panels. The circuit is completed when the electrons return to the bottom layer of the PV panel, find "resting spots" in the electron poor bottom layer, and wait for the next photon to shake them loose.
There are no moving parts in the PV panel, so maintenance is limited to keeping the junction boxes and wiring free from moisture and corrosion, and keeping the surface of the panel clean enough to allow light through to the silicon layers.

PV SYSTEMS WITH BATTERIES

The simplest solutions have certain drawbacks - the most obvious one being that in case of PV powered pump or fan could only be used during the daytime, when the sun is shining. To compensate for these limitations, a battery is added to the system.

The battery is charged by the solar generator, stores the energy and makes it available at the times and in the amounts needed. In the most remote and hostile environments, PV-generated electrical energy stored in batteries can power a wide variety of equipment. Storing electrical energy makes PV systems a reliable source of electric power day and night, rain or shine. PV systems with battery storage are being used all over the world to power lights, sensors, recording equipment, switches, appliances, telephones, televisions, and even power tools.

A solar module generates a direct current (DC), generally at a voltage of 12 V. Many appliances, such as lights, TV's, refrigerators, fans, tools etc., are now available for 12V DC operation. Nevertheless the majority of common electrical household appliances are designed to operate on 110 V or 220 V alternating current (AC). PV systems with batteries can be designed to power DC or AC equipment. People who want to run conventional AC equipment add a power conditioning device called an inverter between the batteries and the load. Although a small amount of energy is lost in converting DC to AC, an inverter makes PV-generated electricity behave like utility power to operate everyday AC appliances, lights, or computers.

PV systems with batteries operate by connecting the PV modules to a battery, and the battery, in turn, to the load. During daylight hours, the PV modules charge the battery. The battery supplies power to the load whenever needed. A simple electrical device called a charge controller keeps the batteries charged properly and helps prolong their life by protecting them from overcharging or from being completely drained. Batteries make PV systems useful in more situations, but also require some maintenance.

The batteries used in PV systems are often similar to car batteries, but are built somewhat differently to allow more of their stored energy to be used each day. They are said to be deep cycling. Batteries designed for PV projects pose the same risks and demand the same caution in handling and storage as automotive batteries. The fluid in unsealed batteries should be checked periodically, and batteries should be protected from extremely cold weather.

A solar generating system with batteries supplies electricity when it is needed. How much electricity can be used after sunset or on cloudy days is determined by the output of the PV modules and the nature of the battery bank. Including more modules and batteries increases system cost, so energy usage must be carefully studied to determine optimum system size. A well-designed system balances cost and convenience to meet the user’s needs, and can be expanded if those needs change.

PV ADVANTAGES

High Reliability

PV cells were originally developed for use in space, where repair is extremely expensive, if not impossible. PV still powers nearly every satellite circling the earth because it operates reliably for long periods of time with virtually no maintenance.

Low Operating Costs

PV cells use the energy from sunlight to produce electricity - the fuel is free. With no moving parts, the cells require low-maintenance. Cost-effective PV systems are ideal for supplying power to communication stations on mountain tops, navigational buoys at sea, or homes far from utility power lines.

Non-polluting

Because they burn no fuel and have no moving parts, PV systems are clean and silent. This is especially important where the main alternatives for obtaining power and light are from diesel generators and kerosene lanterns.

Modular

A PV system can be constructed to any size. Furthermore, the owner of a PV system can enlarge or move it if his or her energy needs change. For instance, homeowners can add modules every few years as their energy usage and financial resources grow. Ranchers can use mobile trailer-mounted pumping systems to water cattle as they are rotated between fields.

Low Construction Costs

PV systems are usually placed close to where the electricity is used, meaning much shorter wire runs than if power is brought in from the utility grid. In addition, using PV eliminates the need for a step-down transformer from the utility line. Fewer wires mean lower costs and shorter construction time.

Wind Turbines for Home Power

Wind energy is a form of solar energy produced by uneven heating of the Earth's surface. The sun radiates 100,000,000,000,000 kilowatt hours of energy to the earth per hour. In other words, the earth receives 10 to the 17th power of watts of power. About 1 to 2 per cent of the energy coming from the sun is converted into wind energy. That is about 50 to 100 times more than the energy converted into biomass by all plants on earth.

With good, consistent wind flow, wind energy is one of the most economical forms of alternative energy available today. If your wind flow fluctuates, wind turbines can still be an excellent addition to a solar system, providing more consistent year-round power.

Advances in wind turbine technology have focused on improving the efficiency of the components and reducing the number of moving parts, resulting in very reliable and effective turbine designs. Today, wind turbines are an essential part of a reliable renewable energy system.

Wind Turbine Basics

Essentially, a wind turbine (or: wind generator) is an alternator attached to a propeller. When the wind blows, the propeller turns and the alternator begin producing electricity. The design details that determine which turbines are best suited for various wind speeds get more involved, but all wind turbines operate in the same manner.

How Wind Turbines are Used

Installing a wind turbine is a bit more involved than installing solar panels, but they are still relatively easy to incorporate into alternative energy system. The turbine needs to be mounted in an area free from obstructions to wind flow (nearby buildings, trees, etc.).

Some smaller turbines can be mounted to the rooftop of houses, but vibrations from the turbine may be transferred to the frame of the building. Rooftop turbine mounts often come with rubber vibration dampers to minimize this problem. As a general rule however, the higher in the air you can get wind turbine the more effective it will be, so independent, guyed towers are the recommended mounting system.

When installing the controls and wiring of a wind generator, it is important to understand two fundamental differences between wind turbines and solar panels:

Current Rectifiers: Solar panels produce direct current (DC) electricity required by power storage batteries, and can be connected directly to the battery bank without causing harm. Wind generators do not produce DC electricity, so a device called a "rectifier" is used to convert the turbine's output current to DC.

Some turbines have a rectifier built in. In most cases though, the rectifier is supplied as a separate component that must be installed between the wind turbine and the battery. Often, the rectifier is combined with a charge controller into one complete wind turbine control unit.

Load Diversion: Solar panels are "passive" electricity producers. Even though the sun is shining, they only produce electricity when a charge is needed by the battery. Wind generators are "active" electricity producers. If the wind is blowing, they will produce current whether the battery bank needs the charge or not. In order to prevent damage to the wind turbine, all of the electricity it produces must be "used" in some way.

When the system batteries need charging current, they provide an electrical load to use the wind turbine's electricity. If the batteries are fully charged, the turbine's output must be "diverted" to another electrical load.

A load diverting charge controller regulates wind generator output so batteries receive charging current when they need it, and any excess electricity generated by the wind turbine is diverted to an alternate load when the batteries are fully charged.

Some wind turbines have charge control features built-in, diverting their own excess current and allowing it to dissipate as heat through the wind turbine housing. In most turbine systems however, the charge controller is an external unit, and while DC rectifiers are always included as part of a basic wind turbine package, the load diverting controller may not be.

Some load-diverting charge controllers come with a heat-sink resistor to attach as the diversion load. When the batteries reach full charge, the load-diverting controller will simply send electricity to this resistor, where the energy will be released as heat. Some wind turbines have diversion features built into the turbine body itself, and the turbines outer shell acts as a heat sink for the excess power. Many charge controllers allow to use the diverted current for other uses, such as running a water heating coil, a ventilating fan or a space heating system, making the wind generator an even more useful and efficient source of power.

Once a load-diverting charge controller is attached between the wind turbine and the storage batteries, the electrical system can be connected to the batteries, either directly for a matching-voltage DC system, or through an inverter for an AC or mixed AC/DC system.

Types of Wind Generators

Wind turbines come in a range of output voltages, to match the overall voltage of the electrical system. While 12 volt is common for small to mid-sized systems, large systems can be designed in 24 or 48 volt configurations.

The primary consideration in a wind generator is the average wind speed at the installation site. A different turbine will give optimum performance at a site with average wind speeds below 15mph than one at a site with speeds in the low 20mph range. Generally, low speed generators will either have longer rotor blades or a larger number of short, wide blades to maximize power drawn from minimal wind.

High speed generators may be built of more durable material, and will have narrow, relatively short blades to minimize potential rotor damage in extremely high winds.

Before choosing which type of turbine is best for a particular site, some sort of wind speed measurement should be taken for a few consecutive months (or ideally, a full year). With long term wind measurements an accurate average wind speed can be calculated, as well as determining likely maximum wind speeds. Armed with this information, a turbine can be chosen that will maximize performance at the average wind speed, as well as one that will withstand the likely maximum forces.

SMALL WIND TURBINES

Small wind energy systems can be used in connection with an electricity transmission and distribution system (called grid-connected systems), or in stand-alone applications that are not connected to the utility grid. A grid-connected wind turbine can reduce consumption of utility-supplied electricity for lighting, appliances, and electric heat. When the wind system produces more electricity than the household requires, the excess can be sold to the utility. With the inter-connections available today, switching takes place automatically.

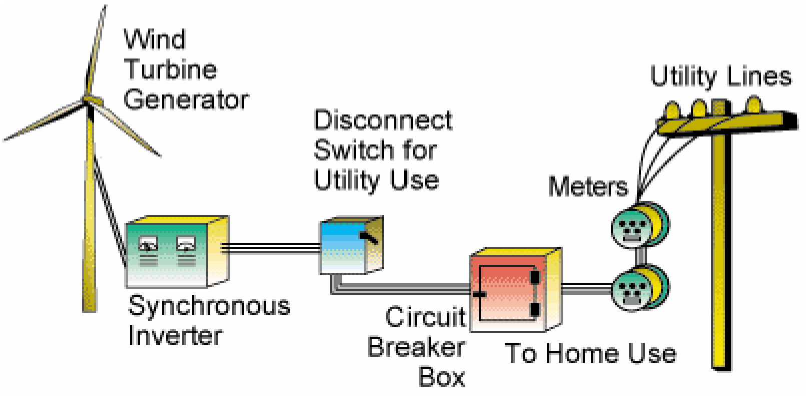

Figure 2.4: A Grid – Connected Wind Turbine

Stand-alone wind energy systems can be appropriate for homes, farms, or even entire communities (a co-housing project, for example) that are far from the nearest utility lines. Either type of system can be practical if the following conditions exist.

Small wind generator sets for household electricity supply or water pumping represent the most interesting wind-energy applications in remote areas. Such generators can be very promising for the Third world countries as well where millions of rural households will be without grid connections for many years to come and will thus continue to depend on candles and kerosene lamps for lighting as well as batteries to operate radios or other appliances.

Wind turbines for domestic or rural applications range in size from a few watts to thousands of watts and can be applied economically for a variety of power demands. In areas with adequate wind regimes (more than five meters per second annual average), simple wind generators with an output range of 100 to 500 W can be used to charge batteries and thus supply enough power to meet basic electricity needs.

In the past reliability of small wind turbines was a problem. Small turbines designed in the late 1970’s had a well deserved reputation for not being very reliable. Today’s products, however, are technically advanced over these earlier units and they are substantially more reliable. Small turbines are now available that can operate 5 years or more, even at harsh sites, without need for maintenance or inspections. The reliability and cost of operation of these units is equal to that of photovoltaic systems.

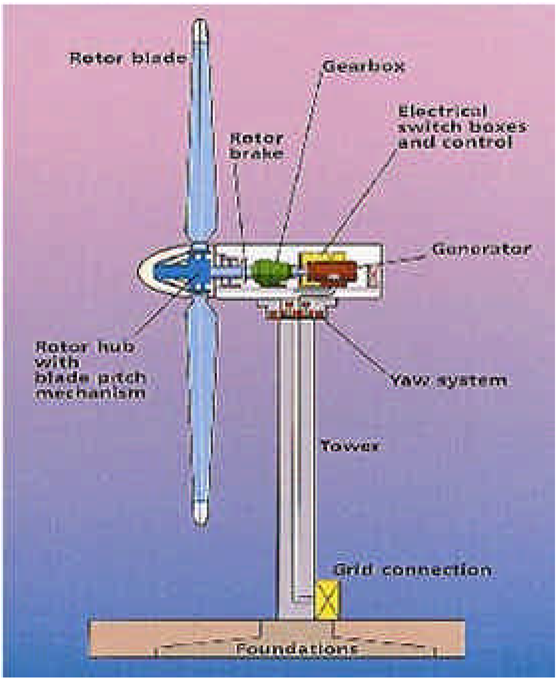

Figure 2.5: Wind Turbine Components

Benefits of Wind Energy

Like solar power, a wind energy system is an entirely clean source of power. The only potentially hazardous materials involved are the storage batteries. Wind turbines produce no emissions, use no traditional fuel, and can provide reliable year-round power given the right location.

Wind generators require relatively little maintenance, but it is recommended that the generator receives annual visual check-ups to ensure the propeller blades haven't been damaged. If the turbine is located in a good spot it's very unlikely to be damaged by any flying debris, but a chipped or cracked blade can be a hazard should it break completely, and a chipped or damaged blade will also negatively affect the turbine's performance.

Wind turbines are very useful in almost any marine or household electrical system. In marine use, the movement of the boat will raise enough breeze to get the generator turning even when actual winds are fairly low, making them an extremely reliable source of on-board power. For residential systems, wind power can be a wonderful source of power during low-light winter months and even year-round, depending on the site. They can also be configured to power dedicated water pumping systems, which may be of particular interest to individuals currently without running water.

For commercial and industrial use, wind turbines are particularly useful in rugged remote locations such as mountaintop repeater stations or offshore oil platforms. High elevation and offshore or seaside remote sites often have fairly high year-round wind current that will make the most of wind generation systems. Industrial grade wind generators are available to withstand the worst storm winds present at such sites.

Hydrogen Production - Storage

Hydrogen has been widely regarded as a possible ultimate fuel and energy storage medium for the next century and beyond. This view is mainly based upon scenarios in which fossil fuel are no longer available, while other primary energy sources such as nuclear and solar are employed to generate hydrogen.

The potential of hydrogen for the storage and cheap transmission of energy over long distances has led to the concept of the so-called "hydrogen economy".

The interest in hydrogen as an ideal secondary fuel stemmed initially from concern over the growing pollution associated with fossil fuel combustion. The use of hydrogen is essentially non-polluting. It can be derived from water if a source of high quality energy is available and combusted back to water in a closed chemical cycle involving no release of pollutants except possibly those connected with the source of high quality energy.

However there are major technical and economic problems associated with both production and storage of hydrogen.

Hydrogen Production

Fossil Fuel Based Hydrogen Production

A closer look at the chemical formula for any fossil fuel reveals that hydrogen is present in all of the formulas. The trick is to remove the hydrogen safely, efficiently and without any of the other elements present in the original compound.

Hydrogen has been produced from coal, gasoline, methanol, natural gas and any other fossil fuel currently available. Some fossil fuels have high hydrogen to oxygen ratio making them better candidates for the reforming process. The more hydrogen present and the fewer extraneous compounds make the reforming process simpler and more efficient. The fossil fuel that has the best hydrogen to carbon ratio is natural gas or methane (CH_4).

Steam Reforming of Natural Gas

Hydrogen production from natural gas commonly employs a process known as steam reforming. Steam reforming of natural gas involves two steps.

The initial phase involves rendering the natural gas into hydrogen, carbon dioxide and carbon monoxide. This breakdown of the natural gas is accomplished by exposing the natural gas to high temperature steam. The second phase of steam reforming consists of creating additional hydrogen and carbon dioxide by utilizing the carbon monoxide created in the first phase. The carbon monoxide is treated with high temperature steam and the resulting hydrogen and carbon dioxide is sequestered and stored in tanks.

Most of the hydrogen utilized by the chemical and petroleum industries is generated with steam reforming. Steam reforming reaches efficiencies of 70% - 90%. The reformer component on a complete fuel cell system is usually a smaller variation of the process described above. Component reformers operate under varying operating conditions and the chemical path that the hydrogen generation follows will vary from manufacturer to manufacturer, but the resulting hydrogen reformate is essentially the same.

Water Based Hydrogen Production

Electrolysis

Electrolysis is the technical name for using electricity to split water into its constituent elements, hydrogen and oxygen. The splitting of water is accomplished by passing an electric current through water. The electricity enters the water at the cathode, a negatively charged terminal, passes through the water and exists via the anode, the positively charged terminal. The hydrogen is collected at the cathode and the oxygen is collected at the anode. Electrolysis produces very pure hydrogen for use in the electronics, pharmaceutical and food industries.

Relative to steam reforming, electrolysis is very expensive. The electrical inputs required to split the water into hydrogen and oxygen account for about 80% of the cost of hydrogen generation. Potentially, electrolysis, when coupled with a renewable energy source, can provide a completely clean and renewable source of energy. In other circumstances, electrolysis can couple with hydroelectric or off-peak electricity to reduce the cost of electrolysis.

Photo electrolysis

Photo electrolysis, known as the hydrogen holy grail in some circles, is the direct conversion of sunlight into electricity. Photovoltaic, semiconductors and an electrolyser are combined to create a device that generates hydrogen. The photoelectrolyzer is placed in water and when exposed to sunlight begins to generate hydrogen. The photovoltaic and the semiconductor combine to generate enough electricity from the sunlight to power the electrolyser. The hydrogen is then collected and stored. Much of the research in this field takes place in Golden, Colorado at the National Renewable Energy Laboratory.

Photo biological

Photo biological production of hydrogen involves using sunlight, a biological component, catalysts and an engineered system. Specific organisms, algae and bacteria, produce hydrogen as a by-product of their metabolic processes. These organisms generally live in water and therefore are biologically splitting the water into its component elements. Currently, this technology is still in the research and development stage and the theoretical sunlight conversion efficiencies have been estimated up to 24%. Over 400 strains of primitive plants capable of producing hydrogen have been identified, with 25 impressively achieving carbon monoxide to hydrogen conversion efficiencies of 100%.

In one example, researchers have discovered that the alga, Chlamydomonas reinhardtii, possesses an enzyme called hydrogenase that is capable of splitting water into its component parts of hydrogen and oxygen. The researchers have determined the mechanism for starting and stopping this process, which could lead to an almost limitless method for producing clean, renewable hydrogen. The algae need sulphur to grow and photosynthesize. Scientists found that when they starved the algae of sulphur, in an oxygen-free environment, the algae reverted to a hydrogenase-utilizing mode. This mechanism was developed over millions of years of evolution for survival in oxygen-rich and oxygen-free environments. Once in this cycle, the algae released hydrogen, not oxygen. Further research is necessary to improve the efficiencies of the engineered plant systems, collection methods and the costs of hydrogen generation.

Where does the hydrogen come from?

Hydrogen made from renewable energy resources provides a clean and abundant energy source, capable of meeting most of the future's high energy needs. When hydrogen is used as an energy source in a fuel cell, the only emission that is created is water, which can then be electrolyzed to make more hydrogen – the waste product supplies more fuel. This continuous cycle of energy production has potential to replace traditional energy sources in every capacity – no more dead batteries piling up in landfills or pollution-causing, gas-guzzling combustion engines.

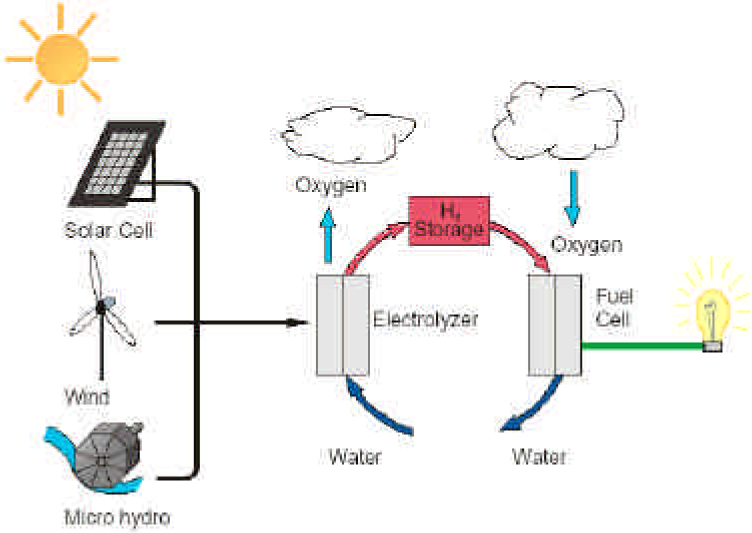

Figure 2.6: Renewable Hydrogen Energy System

The only drawback is that hydrogen is still more expensive than other energy sources such as coal, oil and natural gas. Researchers are helping to develop technologies to tap into this natural resource and generate hydrogen in mass quantities and cheaper prices in order to compete with the traditional energy sources. There are three main methods that scientists are researching for inexpensive hydrogen generation. All three separate the hydrogen from a 'feedstock', such as fossil fuel or water - but by very different means.

Reformers - Fuel cells generally run on hydrogen, but any hydrogen-rich material can serve as a possible fuel source. This includes fossil fuels – methanol, ethanol, natural gas, petroleum distillates, liquid propane and gasified coal. The hydrogen is produced from these materials by a process known as reforming. This is extremely useful where stored hydrogen is not available but must be used for power, for example, on a fuel cell powered vehicle. One method is endothermic steam reforming. This type of reforming combines the fuels with steam by vaporizing them together at high temperatures. Hydrogen is then separated out using membranes. One drawback of steam reforming is that is an endothermic process – meaning energy is consumed. Another type of reformer is the partial oxidation (POX) reformer. CO_2 is emitted in the reforming process, which makes it not emission-free, but the emissions of NO_X, SO_X, Particulates, and other smog producing agents are probably more distasteful than the CO_2. And fuel cells cut them to zero.

Enzymes - Another method to generate hydrogen is with bacteria and algae. The cyanobacteria, an abundant single-celled organism, produces hydrogen through its normal metabolic function. Cyanobacteria can grow in the air or water, and contain enzymes that absorb sunlight for energy and split the molecules of water, thus producing hydrogen. Since cyanobacteria take water and synthesize it to hydrogen, the waste emitted is more water, which becomes food for the next metabolism.

Solar- and Wind- powered generation - By harnessing the renewable energy of the sun and wind, researchers are able to generate hydrogen by using power from photovoltaic (PVs), solar cells, or wind turbines to electrolyze water into hydrogen and oxygen. In this manner, hydrogen becomes an energy carrier – able to transport the power from the generation site to another location for use in a fuel cell. This would be a truly zero-emissions way of producing hydrogen for a fuel cell.

Hydrogen Storage

If new sources of energy are to be fully exploited then an efficient energy storage system must be developed to meet variable demand. This is so because, in most cases, energy demands are periodic in nature whereas energy supply operates most efficiently on a constant output basis.

The supply and demand patterns of the electric utility industry illustrate the point well. Generating capacity must be sized for maximum demand, which can be more than twice minimum demand, since no economic storage method is currently available on a large-scale basis. The result is that fixed charges contribute significantly to electricity costs and consumers must pay heavily for a guaranteed supply.

At present, the relative ease with which fossil-fuels are stored is taken for granted. The energy associated with such fuels is in the form of latent chemical energy which can be released on combustion. On the other hand, in the case of new energy sources the actual form of energy is different. It is usually kinetic (wind, tidal) or heat (nuclear, geothermal, solar) energy. Also it is not available uniformly, but rather on a cyclic basis.

In order to enable effective storage, these new energy sources need to be converted into a secondary energy form. Electricity and hydrogen are the two most promising candidates to fulfil this role. However, electricity suffers from the disadvantage that it is almost impossible to store efficiently. Storage of electricity by means of batteries is not practical.

In contrast to electricity, hydrogen closely resembles our present fuels, especially natural gas. It can be made fluid and hence can be moved and stored in the same manner as today’s fuels.

Hydrogen can be stored in three forms: as a gas, as liquid, or as a solid combined chemically with a metal. The first two methods are applicable to natural gas storage but the third is unique to hydrogen.

Which of the above forms will serve best as a form to store hydrogen will depend upon the gas's end use? In addition the economic criteria, safety aspects must also be carefully considered.

CHOICE OF STORAGE

The choice of which method of hydrogen storage is best depends on:

- The application (Is liquid hydrogen required? What pressure is required?)
- The required energy density (What form of hydrogen delivery will be used? Is space an issue?)
- The quantity of hydrogen to be stored (Is the storage used as a buffer, or primary storage for a large amount of hydrogen?)
- The storage period (Will the storage be used to keep hydrogen for a few hours, or is it seasonal storage?)
- What forms of energy are readily available (Is there waste heat available? Is there high-pressure steam available for a turbine?)
- What is the geology of the area (Are there abandoned natural gas well available?)
- Any future expansion needs (Are there reasons to believe additional storage will be needed in the future?)
- Maintenance requirements (Is high reliability required? How often can the storage system be shut down for maintenance?)
- Capital costs (Are high capital costs prohibitive?)

Application

If hydrogen is required for a cryogenic application, the only choice is liquid hydrogen. If on the other hand, hydrogen can be used as a gas, this would allow all forms of storage and delivery to be considered.

Energy Density

The energy density of the hydrogen may be an important consideration. For example, if the hydrogen must be delivered to a site far away, liquid hydrogen would probably be the best option. The higher density of liquid hydrogen means one truck can carry as much liquid hydrogen as 20 trucks carrying compressed gas.

Energy density can be expressed in terms of the volumetric energy density or the weight density. If hydrogen is being delivered continuously by pipeline, little if any hydrogen storage may be required, and it would not make sense to liquefy the hydrogen, then deliver it to a pipeline as a gas. In pipelines with large variation in flow, hydrogen may need to be stored to meet peak demand. The method of storage in that case would depend on the quantity to be stored and the storage time.

Quantity

The quantity of hydrogen to be stored is a major consideration because the capital cost per pound of hydrogen is generally lower for larger capacity storage units. In the case of liquid hydrogen, boil-off rates are also inversely proportional to the vessel size, so larger storage units will have lower boil-off rates. Compressed gas storage can be used for small quantities of hydrogen when cryogenic temperatures are not required. Because of the high capital cost of a liquefaction plant, liquid hydrogen would be cost-prohibitive for small quantities of hydrogen, and the high boil-off rates associated with the smaller vessel size would raise this cost even more. A metal hydride might be a cost-effective option if the hydrogen is produced at a low pressure and a high- pressure gas is required. A metal hydride could also be used if the hydrogen must be purified. With very small quantities of hydrogen, the cost difference between compressed gas and metal hydride storage is not great because both require a pressure vessel and the metal hydride alloy cost is small compared to the vessel cost for small units. As the storage requirements increase, the metal hydride alloy becomes a larger percentage of the unit cost and becomes the driving cost factor. At the same time, the cost of compressed gas storage decreases per unit volume with larger vessels, making compressed gas storage more economical. Metal hydride storage may still be economical if high pressure hydrogen is needed and a source of waste heat is available. For even greater quantities of hydrogen, liquid hydrogen starts to become competitive because of the lower storage unit cost per pound of hydrogen. For small quantities of hydrogen, the pressure vessel cost for the compressed gas is lower than the combined costs of the insulated dewar, liquefier, high boil off, and high energy use. However, as the quantity of hydrogen to be stored increases, the cost of the pressure vessel increases faster than the liquefaction costs.

Underground storage is a special case of compressed gas storage where the vessel cost is very low. In most cases, underground storage in a natural geological formation will cost less than any other storage technique. The only case it wouldn't be cheaper is with small quantities of gas in large caverns where the amount of working capital invested in the cushion gas is large compared to the amount of hydrogen stored.

Compressed gas storage is generally limited to 1,300 kg (2,800 lb) of hydrogen or less because of high capital costs. Over this, liquid hydrogen storage or underground storage should be considered.

Storage Period

The longer hydrogen is to be stored, the more favourable underground or liquid hydrogen storage becomes because of lower capital costs. If hydrogen is stored for a long time, the operating cost can be a small factor compared to the capital costs of storage. Underground storage is the cheapest for short-term storage, followed by above-ground compressed gas storage, which should be considered for storage times of several hours to several days. Liquid storage and underground storage should be considered for seasonal or long-term storage of hydrogen for periods longer than a couple of days or 5% annual turnover rates of gas. Metal hydride storage is not economical for large quantities of gas because of the high capital cost of the metal hydride.

Energy Availability

The available energy may be another consideration when choosing methods of storage. For compressed gas storage and hydrogen liquefaction, compressor power consumption can be quite high. If inexpensive electricity, gas turbine, or steam turbine power is available, the compression costs will be lower. A cheap source of thermal energy or waste heat would benefit metal hydride storage by reducing the energy costs for releasing the hydrogen from the hydride.

Maintenance and Reliability

Maintenance and reliability will depend on how simple the storage method is to operate and maintain. A liquefaction plant will be much more complicated and more costly to maintain than a metal hydride storage unit that has no rotating assemblies. Liquefaction will have the highest maintenance requirements, followed by compressed gas storage, and then metal hydrides.

Safety

Safety is a concern with any option. When the main options for storage are examined, metal hydrides appear to be the safest storage option because the storage unit is at low pressure. If there is a leak in the container, very little hydrogen will leak out because a source of continuous heat is required to release the bond between the metal and the hydrogen. For compressed gas, there are two dangers. First, a high-pressure vessel always presents some level of risk, whether it is an inert gas or a reactive gas such as hydrogen. Second, if a compressed gas tank develops a leak, it will result in the release of a large amount of hydrogen very quickly. Liquid hydrogen has the potential to release even more hydrogen than compressed gas if a storage container leaks because the liquid hydrogen will quickly vaporize. In open areas there is, however, little chance of detonation, because hydrogen diffuses into air quickly.

Summary

Based on current hydrogen storage technology, the following generalizations can be made:

- Underground Storage - For large quantities of gas or long-term storage.
- Liquid Hydrogen - For large quantities of gas, long-term storage, low electricity costs or applications requiring liquid hydrogen.
- Compressed Gas - For small quantities of gas, high cycle times or short storage times.
- Metal Hydrides - For small quantities of gas.

ENVIRONMENTAL CONSIDERATIONS

Emissions Of Greenhouse Gases And Air Pollutants

Hydrogen can be used with zero or near zero emissions at the point of use. When hydrogen is burned in air, the main combustion product is H_2O, with traces of NO_x, which can be controlled to very low levels. No particulates, CO, unburned hydrocarbons or sulphur oxides are emitted. With hydrogen fuel cells, water vapour is the only emission. Moreover, the total fuel cycle emissions of pollutants and greenhouse gases, (such as CO_2, which could contribute to global climate change) can be much reduced compared to conventional energy systems.

Fuel cycle emissions are all the emissions involved in producing, transmitting, and using an alternative fuel. For example, for hydrogen made from natural gas, there would be emissions of CO_2 and NO_x at the hydrogen production plant, emissions associated with producing electricity to run hydrogen pipeline compressors (the nature of these emissions would depend on the source of electricity), and zero local emissions if the hydrogen is used in a fuel cell. The more efficient the end-use device (e.g. a fuel cell vehicle), the lower the fuel cycle emissions per unit of energy service (e.g. emissions per mile travelled).

Various primary resources are considered for hydrogen production (natural gas, biomass, coal, solar, wind and nuclear) and methanol production (natural gas, biomass, coal). The effect of sequestration of carbon is shown for hydrogen production from natural gas, biomass and coal.

If hydrogen is made from renewable energy sources such as biomass, solar or wind, the fuel cycle greenhouse gas emissions are virtually eliminated. Emissions from electrolytic hydrogen production depend on the source of the low cost electricity.

In cases such as Brazil, where the source is hydropower, greenhouse gas emissions should be essentially zero. With biomass hydrogen and carbon sequestration, it would be possible to have a net negative carbon balance: carbon would be removed from the atmosphere. It would be possible to envision a future energy system based on hydrogen and fuel cells with little or no emissions of pollutants or greenhouse gases in fuel production, distribution or use.

Resource, Land and Water Use for Hydrogen Production

As mentioned above, there are a variety of primary sources which can be used to make hydrogen. Over the next few decades and probably well into the next century, fossil sources such as natural gas or coal may offer the lowest costs in many locations, with small contributions from electrolysis powered by low cost hydropower. In the longer term (or where locally preferred) renewable resources such as wastes, biomass, solar or wind might be brought into use.

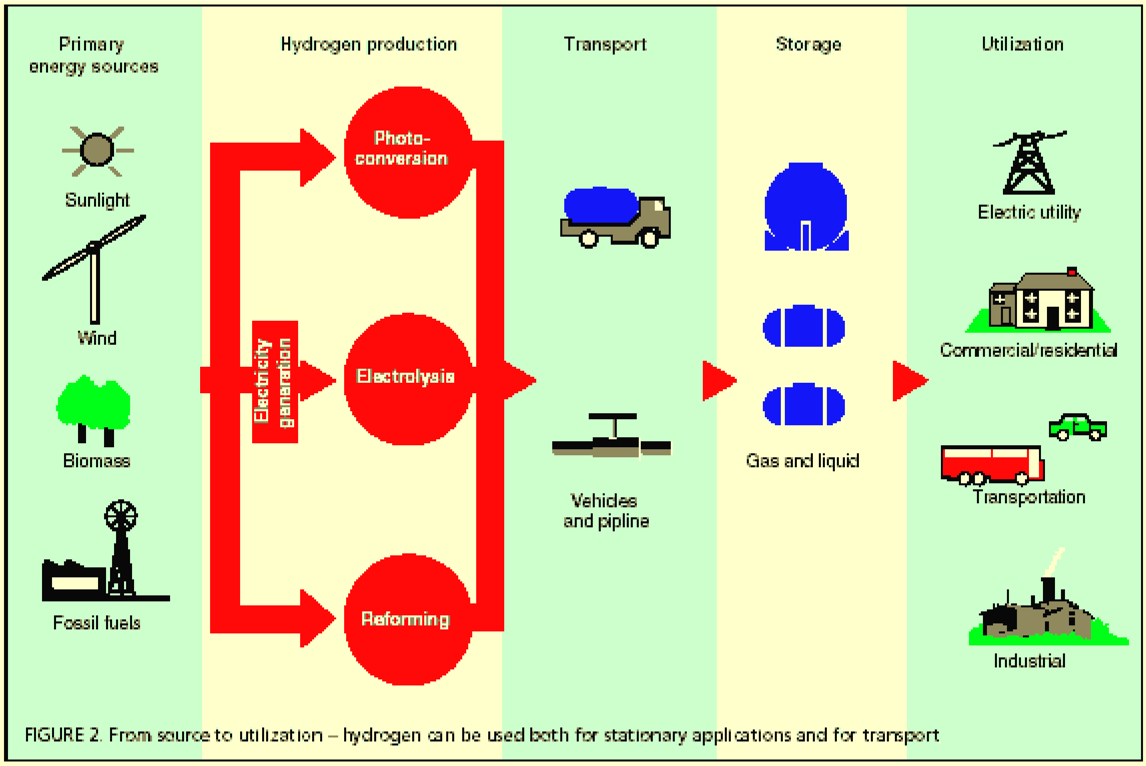

FIGURE 2. From source to utilization – hydrogen can be used both for stationary applications and for transport

Figure 2.7: Hydrogen Production, Transport, Storage and Utilization

Home Power Hydrogen Fuel Cells

Hydrogen fuel cells are one of the most promising up-and-coming clean power sources today. Fuel cells have been used for decades on NASA spacecraft, and other types of fuel cells are currently in use for power generation at a variety of commercial and industrial sites. Use of fuel cells in small system / home power applications has so far been limited by cost considerations, but prices are falling and fuel cells should emerge as a viable home power source within the next year or two.

What Is A Fuel Cell

In principle, a fuel cell operates like a battery. Unlike a battery, a fuel cell does not run down or require recharging. It will produce energy in the form of electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat.

Hydrogen fuel is fed into the "anode" of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron, which take different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they return to the cathode, to be reunited with the hydrogen and oxygen in a molecule of water.

A fuel cell system which includes a "fuel reformer" can utilize the hydrogen from any hydrocarbon fuel - from natural gas to methanol, and even gasoline. Since the fuel cell relies on chemistry and not combustion, emissions from this type of a system would still be much smaller than emissions from the cleanest fuel combustion processes.

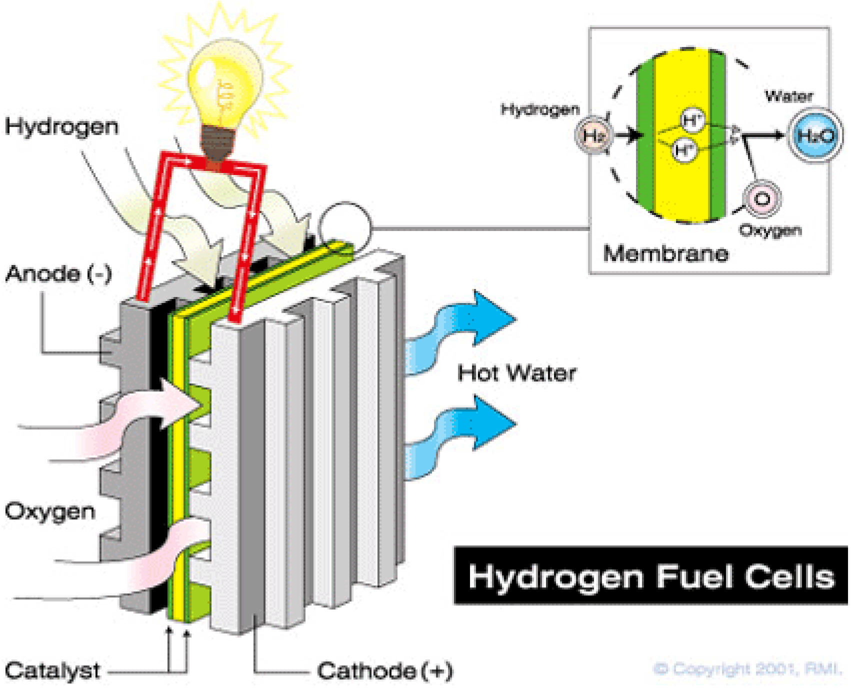

Figure 2.8: A Hydrogen Fuel Cell System

How Fuel Cells Work

A fuel cell consists of a central electrolyte layer, sandwiched between two catalyst layers. Various materials for these layers are used, but the basic process is the same. When a hydrogen atom contacts the negative anode catalyst layer, it splits into a proton and an electron. The proton passes straight through the central electrolyte layer, while the electron produces electricity as it passes through an external circuit. The circuit returns the electrons to the positive side of the electrolyte layer, where they bond again with the protons and join with an oxygen molecule, creating water in the positive cathode catalyst layer.

The fuel cell itself can be roughly correlated to the alternator in a wind, hydro or engine generator. The fuel cell itself is the mechanism that actually produces the electricity. However, in order for a wind, water or engine generator to produce electricity, a propeller or engine must turn the alternator. In order for a fuel cell to produce power, something must supply it with hydrogen and oxygen.

Various methods are used to supply the fuel cell with the necessary hydrogen and oxygen. Some systems use a "fuel reformer" to extract hydrogen from another fuel source such as propane, and can extract oxygen from the surrounding air. Some systems (in laboratory or industrial settings) are designed to be attached to tanks of pure hydrogen and oxygen.

The most interesting method of obtaining hydrogen, from a renewable energy standpoint, is to use an "electrolyser" to separate water into hydrogen and oxygen, which is then stored in tanks and fed into either end of the fuel cell. The "waste" water produced at the end of the fuel cell process is then fed back into the initial water source. A fuel cell generator set up to electrolyze and re-use water is known as a regenerative fuel cell. Any type of fuel cell could be used in a regenerative system, and the water electrolyser could be powered with wind, solar or hydro energy, resulting in a truly clean power system.

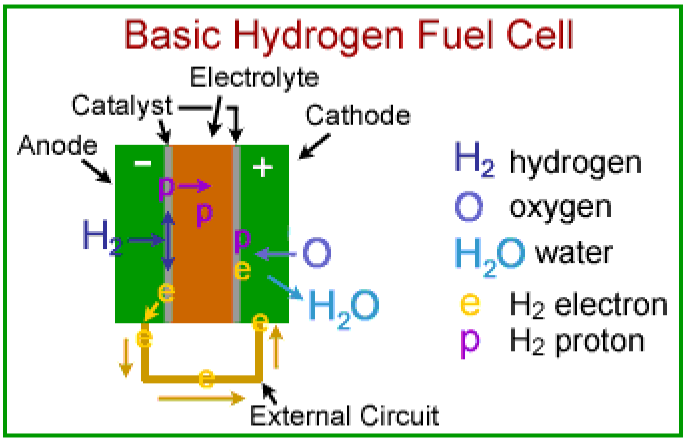

Figure 2.9: Basic Hydrogen Fuel Cell System

Types of Fuel Cells

Proton Exchange Membrane (PEM) fuel cells are currently being considered for development of fuel cell powered cars, home power generators, and other small applications. Instead of using a liquid electrolyte, they use a thin polymer membrane. They operate in the range of 200º Fahrenheit, and can quickly vary power output depending on current demand. Many companies are currently working to develop commercially available, mass-produced PEM fuel cells.

Alkaline fuel cells have been used by NASA to provide power to spacecraft since the 1960s. They use alkaline potassium chloride as their electrolyte. Alkaline fuel cells can reach power generating efficiency of 70%, although their production costs have long rendered them out of range for mass production. A few companies are currently working on mass production techniques for these cells that would reduce their price within range of commercial use.

Phosphoric Acid fuel cells are by far the most widely used type of fuel cell today. They are primarily used for large back-up and remote power applications in hospitals, schools and other locations where an engine generator would traditionally be used. They operate in the 400º F range, and can reach 40% power generation efficiency (much higher if by-product heat and steam are used for other purposes). Phosphoric acid cells can also be used in large vehicles, such as buses and train engines.

Solid Oxide fuel cells are currently being refined for optimum operation in high-power industrial and utility applications. Operating efficiency could reach 60%, and the use of a hard ceramic electrolyte allows operating temperatures to run as high as 1800º F.

Molten Carbonate fuel cells operate in the range of 1200º F, and show promise for high power generation efficiency. They have the ability to use coal-based fuels, making them easy to integrate into the existing fuel supply system.

Direct Methanol fuel cells are a newer sub-type of the PEM cells. Rather than using a fuel reformer to extract hydrogen from an external fuel source or a electrolyser to break down water molecules, the anode catalyst extracts hydrogen directly from liquid methanol. These cells are expected to reach operating efficiencies around 40%.

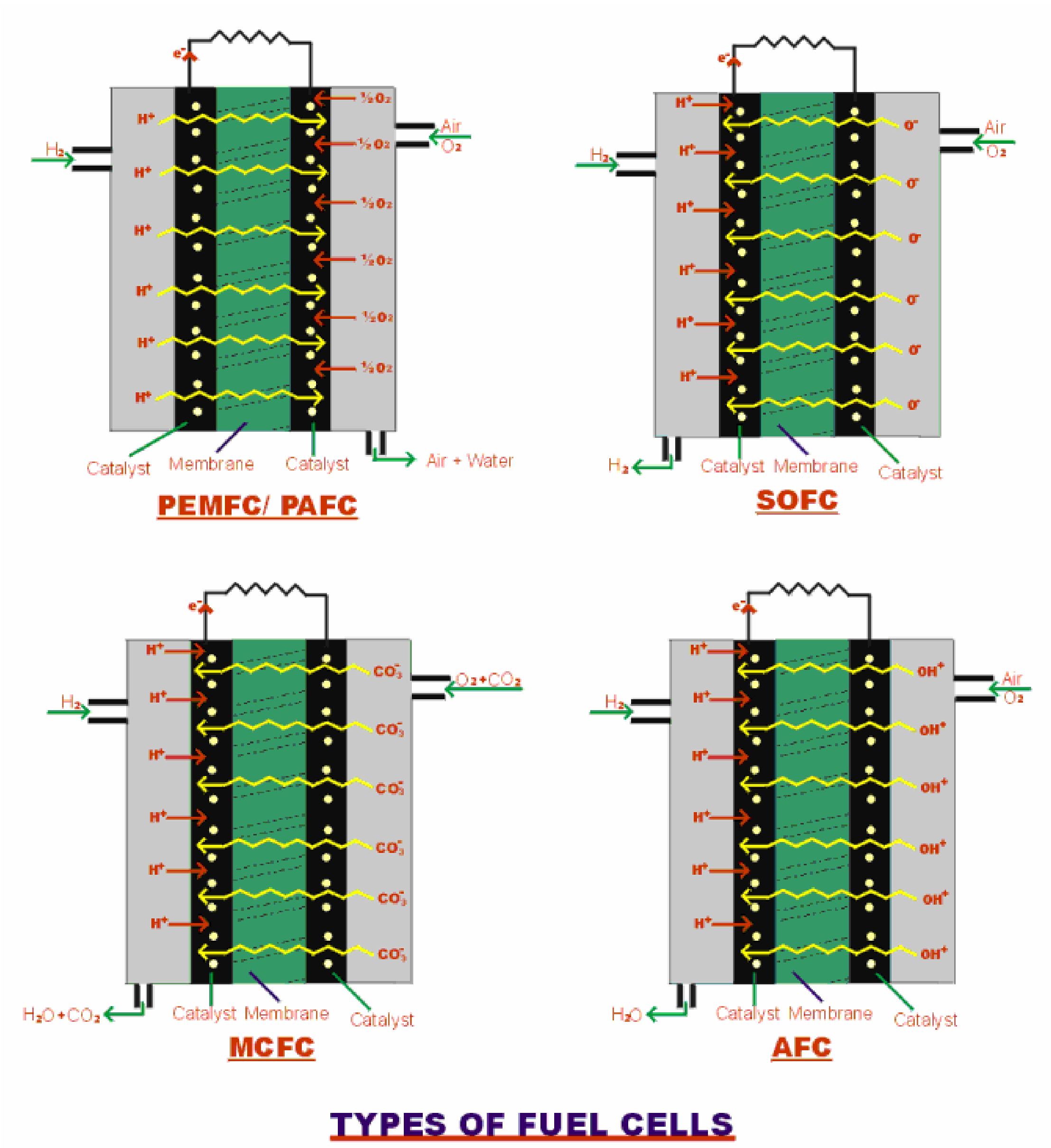

Figure 2.10: Types of Fuel Cells

Applications for Fuel Cells

There are many uses for fuel cells — right now, all of the major automakers are working to commercialize a fuel cell car. Fuel cells are powering buses, boats, trains, planes, scooters, even bicycles. There are fuel cell-powered vending machines, vacuum cleaners and highway road signs. Miniature fuel cells for cellular phones, laptop computers and portable electronics are on their way to market. Hospitals, credit card centres, police stations, and banks are all using fuel cells to provide power to their facilities. Wastewater treatment plants and landfills are using fuel cells to convert the methane gas they produce into electricity. The possibilities are endless.

Stationary. More than 200 fuel cell systems have been installed all over the world — in hospitals, nursing homes, hotels, office buildings, schools, utility power plants, and an airport terminal, providing primary power or backup. In large-scale building systems, fuel cells can reduce facility energy service costs by 20% to 40% over conventional energy service.

Residential. Fuel cells are ideal for power generation, either connected to the electric grid to provide supplemental power and backup assurance for critical areas, or installed as a grid-independent generator for on-site service in areas that are inaccessible by power lines. Since fuel cells operate silently, they reduce noise pollution as well as air pollution and the waste heat from a fuel cell can be used to provide hot water or space heating for a home. Many of the prototypes being tested and demonstrated for residential use extract hydrogen from propane or natural gas.

Transportation. All the major automotive manufacturers have a fuel cell vehicle either in development or in testing right now — Honda, Toyota, DaimlerChrysler, GM, Ford, Hyundai, Volkswagen — you name it. They speculate that the fuel cell vehicle will not be commercialized until at least 2004.

Portable Power. Miniature fuel cells, once available to the commercial market, will help consumers talk for up to a month on a cellular phone without recharging. Fuel cells will change the telecommuting world, powering laptops and palm pilots hours longer than batteries. Other applications for micro fuel cells include pagers, video recorders, portable power tools, and low power remote devices such as hearing aids, smoke detectors, burglar alarms, hotel locks and meter readers. These miniature fuel cells generally run on methanol, an inexpensive wood alcohol also used in windshield wiper fluid.

Landfill/Wastewater Treatment. Fuel cells currently operate at landfills and wastewater treatment plants across the country, proving themselves as a valid technology for reducing emissions and generating power from the methane gas they produce.

Diagram of a fuel cell power plant.

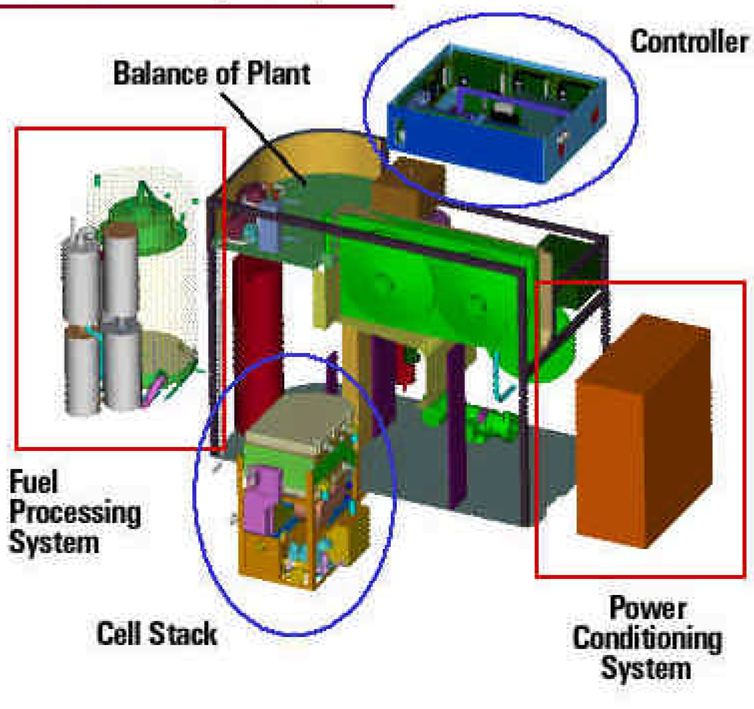

Figure 2.11: A Fuel Cell Power Plant

Fuel Cell Engineering Benefits

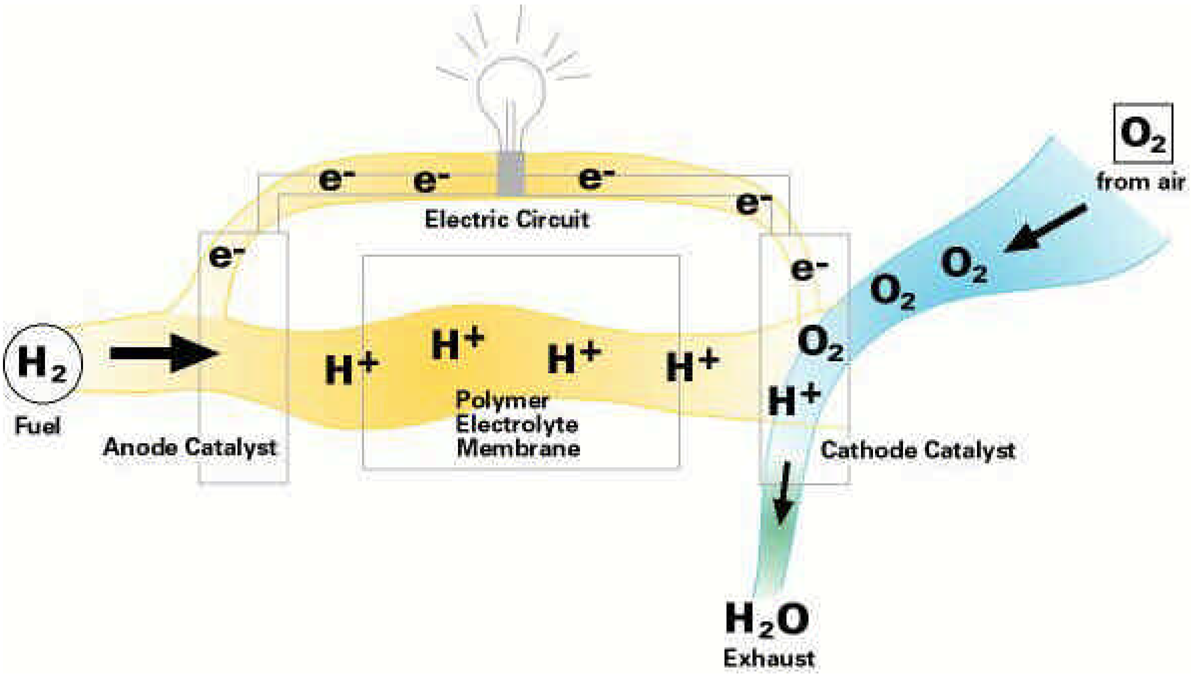

Figure 2.12: How a Fuel Cell Works

Fuel Flexibility

Fuel cells are capable of operating on hydrogen, or hydrogen reformed from any of the common fossil fuels available today.

High Power Densities

The amount of power a fuel cell can generate within a given volume is usually given in kWh/liter. These numbers continue to rise as manufacturers continue research and development on their respective products.

Low Operating Temperatures and Pressures

Fuel cells operate at 80° C to over 1,000° C, depending on the type of fuel cell. These numbers might seem high, but the temperature inside your vehicle's internal combustion engine can reach over 2,300° C.

Site Flexibility

Fuel cells, with their inherently quiet operation, zero to minimal emissions and reduced permitting requirements, can be located in a variety of areas, both residential and commercial, inside and outside.

Cogeneration Capability

When the waste heat from the fuel cell's electrochemical reaction is captured, it can be utilized for water, space heating and cooling. With cogeneration capabilities the efficiencies achieved by a fuel cell system approach 90%.

Quick Response to Load Variations

To receive additional energy from a fuel cell, more fuel is introduced into the system. Fuel cell load response is analogous to depressing the gas pedal in your vehicle, more fuel more power.

Engineering Simplicity

Fuel cells do not contain any moving parts. The lack of movement allows for a simpler design, higher reliability's, quite operation and a system that is less likely to fail.

Independence from the Power Grid

A residential fuel cell system allows people to become independent of the brown outs, power failures and voltage irregularities that are commonplace when connected to the utility grid. Any one of these common power disruptions can damage sensitive computer systems, electronic equipment and the quality of life people desire to have. Reliable energy in areas that are subjected to weather related power outages.

Advantages and Uses of Fuel Cells

A fuel cell would be of most use in one of two ways. For individuals with an existing solar, wind or hydro power system, the fuel cell could be used for backup power in place of an engine generator. Given that an engine generator operates at approximately 30% efficiency and the least efficient fuel cell currently offers 40% efficiency (up to 80-90% if by-product heat and/or steam are used for other heating needs), the advantage is clear. When you also consider that the fuel cell will operate silently, with no waste products in regenerative systems and minimal waste in others, the fuel cell comes out a clear winner.

For individuals without an existing alternative energy system, a larger capacity fuel cell could comprise their primary power system. Since a fuel cell can produce power on demand, as long as hydrogen is available, there is no need for storage batteries if the fuel cell generator is large enough to support the electrical system in question. A wind turbine and/or solar panels could be added to power the water electrolyser or fuel reformer, and the entire power system would be virtually self-contained.

Fuel Cells vs. Traditional Batteries

Fuel cells offer a reduction in weight and come in a compact package for the same amount of available energy when compared to batteries.

To increase the power in a fuel cell, more fuel is introduced into the system. To increase the power of a battery, more batteries have to be added increasing the cost, weight and complexity of the system.

A fuel cell never "runs down", it continues to produce electricity as long as fuel is present. When a battery "runs down" it has to undergo a lengthy, inconvenient recharge time to replace the spent electricity. Depending on where the electricity originates, pollution, costs and efficiency problems are transferred from the batteries location to the central generating plant.

Table 2.1: Advantages of Fuel Cells Vs. Batteries

Energy Source Comparison		
	Fuel Cell	**Battery**
Efficiency	40 - 60%	35 - 85%
Emissions	Water	None
Fuel	H_2 or Hydrocarbons	Electricity
Energy Output Duration	Unlimited based on Fuel Availability	Limited based on Size of Battery
Hazardous Disposables	None	Acids and Corrosives
Noise	Low	Low
Life Expectancy	5 - 10 Years	3 - 4 Years
Maintenance Requirements	Low	Moderate

Basic Battery Information

Batteries are devices that translate chemical energy into electricity. But that simple definition greatly understates the pervasive role of batteries in our life. Batteries are an efficient way to make electricity portable. In addition, batteries provide power to replace electricity from the utility electrical grid for a variety of critical functions. As the world becomes increasingly addicted to electricity and mobility batteries play an ever greater role in all aspects of our life.

Batteries are an integral part of any automotive, RV, marine or home power electrical system. Since most people are fairly familiar with automotive batteries, we will concentrate on deep-cycle power storage batteries used in home power, RV and marine applications, with brief comparisons between deep-cycle and automotive batteries.

Battery Capacity

Battery capacity is a primary concern in home power systems. The storage battery bank must have enough storage capacity to meet power needs between charging cycles. Making sure the battery storage capacity is about double the power that would be used in a normal use day is a good minimum.

Home power (deep cycle) batteries are generally measured in "amp-hour" capacity. One amp-hour is equal to one amp of power drawn for one hour of time. Amp-hour capacity is generally given as the "20 hour rate" of the battery. Therefore, the number given as the amp-hour capacity for a deep cycle battery will be the number of amp-hours the battery can deliver over a 20 hour period at a constant draw. A 105 amp-hour battery can deliver 5.25 amps constantly over a 20 hour period before its voltage drops below 10.5 volts, at which point the battery is discharged.

Types of Batteries

Lead Acid Automotive Batteries

Automotive batteries are designed to deliver a relatively high amount of current in a short period of time, but should never be heavily discharged. An automotive battery plate is very porous (like a slice of Swiss cheese), to maximize surface area and enable the sudden high current output. Because home power systems require repeated deep discharges of stored power, automotive batteries are largely useless for these applications.

Lead Acid Deep Cycle Batteries

Deep cycle batteries are designed to have a large amount of their stored current discharged between charging sessions, with very heavy non-porous battery plates to withstand repeated major discharging and charging cycles (deep cycles). They are generally useless for delivering the sudden surges of power needed from automotive batteries.

1. **RV/Marine Batteries** are usually 12 volt, and available in a variety of capacities up to 100 amp-hours. They can be found in "sealed" or standard serviceable types, and are commonly used in small home power or portable power applications. RV / Marine batteries are generally small, compact and easy to handle and install. They are relatively inexpensive, and the sealed type batteries are non-spillable and safer for indoor applications.

   However these batteries are not designed for very heavy cycling (as is found in a home power system), so their life-spans are often shorter than other types of deep cycle batteries. Sealed batteries are also very sensitive to overcharging, which may further shorten their useful lifespan. Also, in order to obtain more than 100 amp-hours of storage capacity, multiple batteries must be attached in parallel, which is less efficient than using a single, higher capacity battery

2. **Golf Cart Batteries** have capacities in the 220-300 amp-hour range, and are generally 6 volt. They are well suited to small to medium home power systems. They are designed for deep discharge cycles, so they will tend to have longer lifespan and better performance in a residential alternative energy system. They are still relatively light weight, but are generally cheaper per amp-hour than RV type batteries. They are also less sensitive to mild overcharging.

   However since most home power systems are 12 volt, two 6 volt batteries must be connected in series, which is a bit more complicated than connecting a single battery. Since golf cart batteries are unsealed, they need to be stored in a well ventilated area and will require periodic water replacement. Their amp-hour capacity is also too limited to be of use in a large power system.

3. **Industrial/Stationary Batteries** are normally manufactured as individual 2 volt units, which are then combined to create the necessary voltage for the power system. (Six for 12 volt systems, twelve for 24 volt systems) They're available in a wide variety of capacities, up to 3000 amp-hours. A very high amp hour capacity can be obtained with a single six cell set, so charging characteristics are very stable. Industrial batteries will have the longest

average lifespan under deep cycling home power conditions.

However due to their extremely high amp-hour capacities, industrial battery sets will have a significantly higher initial cost. These batteries can also weigh up to 350 lbs. per two volt cell, so they will need to be stored in a well supported area, contained in a rigid external box, and will likely require special transporting assistance.

Nickel Alloy Batteries

Nickel Cadmium (NiCad) and Nickel Iron batteries, rather than consisting of lead plates submerged in a sulphuric acid solution, feature nickel alloy plates in an alkaline solution. They are also well suited for home power use, but are much less common and much more expensive than lead acid types.

A nickel alloy battery can have up to 50 years of useful life, compared to 20 years with a well-maintained lead acid battery. They can also sit for extended periods of time partially or fully discharged without suffering damage, unlike lead acid types. They are lower maintenance, and can be completely discharged repeatedly without suffering damage. A lead acid battery should never be completely discharged, meaning they need to be more closely monitored. Nickel alloy batteries operate better at lower temperatures, and can discharge more of their total amp-hour capacity as useful current.

Despite all these advantages, the higher initial cost of the batteries is prohibitive. Also, nickel alloy batteries are harder to dispose of when they finally become unchangeable. Their unique charging voltage range can also create compatibility problems with battery management and charging equipment.

How Batteries are used in Home Power

A storage battery bank is what enables a home power system to deliver a constant level of power to the electrical system. Without storage batteries, the entire electrical system would be limited by the immediate output of the alternative energy generators. At night, a solar-run house would have no electrical power available to turn on interior lights. A wind-powered system would be subject to constant power fluctuations as the wind speed increased, dropped or disappeared entirely.

By running the output of renewable power generators through charge controllers and into a battery bank, power can be available 24 hours a day, regardless of weather. Solar panels or wind generators can deliver power to the battery bank regardless of current power usage, so excess power can be stored during low use times (generally the middle of the day and middle of the night) and be available during high use times (usually morning and evening).

Batteries supply DC power, so if power is needed for an AC power system or a mixed AC/DC system, the battery power will need to be run through an inverter to change 12VDC or 24VDC power into 120VAC household current.

Basic Lead Acid Battery Function

Lead acid batteries are by far the most common type of power storage battery in use today. A fully charged lead acid battery undergoes a chemical reaction when attached to an electrical load, which releases stored energy from the battery. All lead acid batteries consist of the following components:

- A positive plate, composed of lead dioxide (PbO_2)
- A negative plate, composed of "sponge" lead (Pb)
- An electrolyte solution of sulphuric acid (H_2SO_4) and distilled water (H_2O)

When the battery discharges current, the sulphate (SO_4) in the electrolyte combines with lead from the plates to form lead sulphate deposits ($PbSO_4$). After repeated or extended discharge, the sulphate content of the electrolyte becomes increasingly "bound" in the lead sulphate deposits and can no longer be used to create electric current. The battery becomes discharged when too much of the electrolyte sulphate is depleted.

Over time, in a non-sealed battery, the water content of the electrolyte solution will drop due to evaporation during discharge. This leads to excessive acid concentration, which raises the resistance of the battery. Periodic checking and refilling of the fluid level in an unsealed battery is essential to its proper functioning.

When a discharged battery is recharged, the majority of the lead sulphate is broken down and the sulphate returns to the electrolyte where it is once again available to create electricity. However, over time a sulphate residue builds up on the battery plates and begins to crystallize. As more of the sulphate becomes locked in the crystallized residue, the battery capacity and ability to be recharged declines until the battery finally "dies."

With deep cycle batteries, the sulphate crystals simply "insulate" the battery plates from the remaining weakened electrolyte, preventing the chemical reactions needed to produce current. In automotive batteries, with their thin, porous plates, crystallization will actually cause the plates to break apart, permanently destroying the battery.

Battery Charging & Maintenance

In an alternative energy system, battery charging is usually accomplished through charge controllers attached to the various power generators. A good quality charge controller will use a three stage, pulse width modulated charging system. This allows the battery to receive the highest charging current during the bulk stage of charging, with a second lower absorption level to bring the charge to maximum voltage, and a third "float" charging current to maintain the battery charge. A good quality charge controller will maximize charging efficiency and minimize lead sulphate build up, increasing the battery's useable lifespan.

Lead acid batteries will lose their charge if they are left unused for an extended period of time. If an automotive or deep cycle battery goes unused for a month or longer, it should be outfitted with a charge maintainer or "trickle charger" (if the deep-cycle battery is not attached to a three-stage charge controller). Solar panels are available for this purpose, and will deliver a low level of current to the battery while exposed to sunlight. For batteries or vehicles stored indoors, plug-in charge maintainers are also available.

Sulphate crystallization in batteries can be slowed or reversed by the use of battery pulse conditioners. Lead sulphate can be more effectively removed, and negative battery plates better maintained if battery voltage periodically reaches 2.5 volts per cell. (15v for a 12v battery, 30v for a 24v, etc.) A pulse conditioner will deliver periodic brief pulses of higher current to the battery, causing the sulphate residue to be released back into the electrolyte and maximizing the lifespan and performance of the battery.

CHAPTER 3

House Energy Consumption

Before we start calculating the heat losses and the energy consumption of the house we had first to decide the site that the house will be placed. By using NASAs surface meteorology and solar energy data we wanted to find a place in UK that it will have the highest solar insolation per month, the highest average monthly temperature and the highest wind velocity per month. After careful consideration for the desired parameters we conclude that the best site in UK that fulfils all the criteria that we have settled was in the area of Cornwall. Cornwall is England's south-westernmost county.

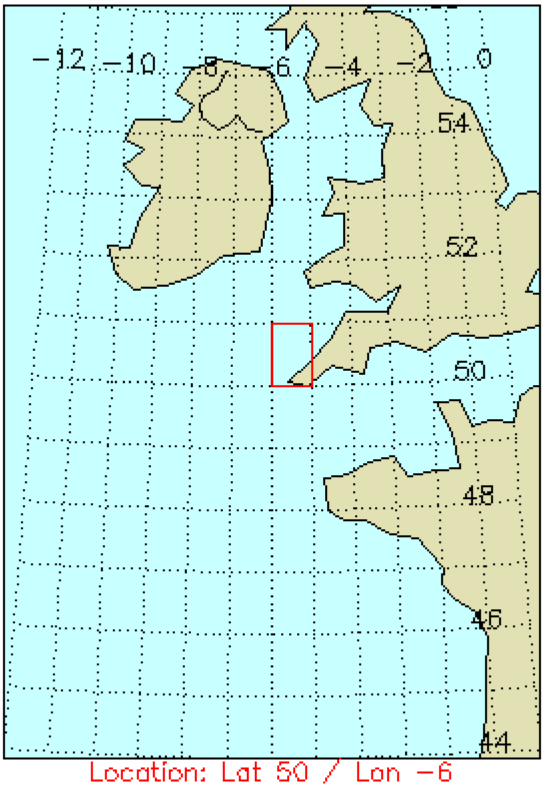

Figure 3.1: Chosen Place for Calculations

House Analysis

Because the house is assumed to be placed in an isolated area it was decided that it will be quite large. With this in mind we decided to analyse a house of 220 m^2 that is above the average of a normal UK house in the countryside.

ROOM	AREA (m^2)
Kitchen Room	**24.55**
Living Room	**77.47**
Dining Room	**31.08**
East Bedroom	**35.21**
West Bedroom	**35.43**
Toilet	**15.62**
TOTAL	***219.36***

Table 3.1: House Breakdown

In every procedure, the initial and most necessary step is to gather the conditions that are required and the data of the building. In the case of the house that is investigated in the project, the standards are the following:

Conditions:

a) Internal spaces 20°C

b) Toilet 20°C

c) Under the roof: Average Monthly Temperature - 3°C

d) Outdoors temperature (minimum possible): Average Monthly Temperature

e) Ground temperature: Average Monthly Temperature + 2°C

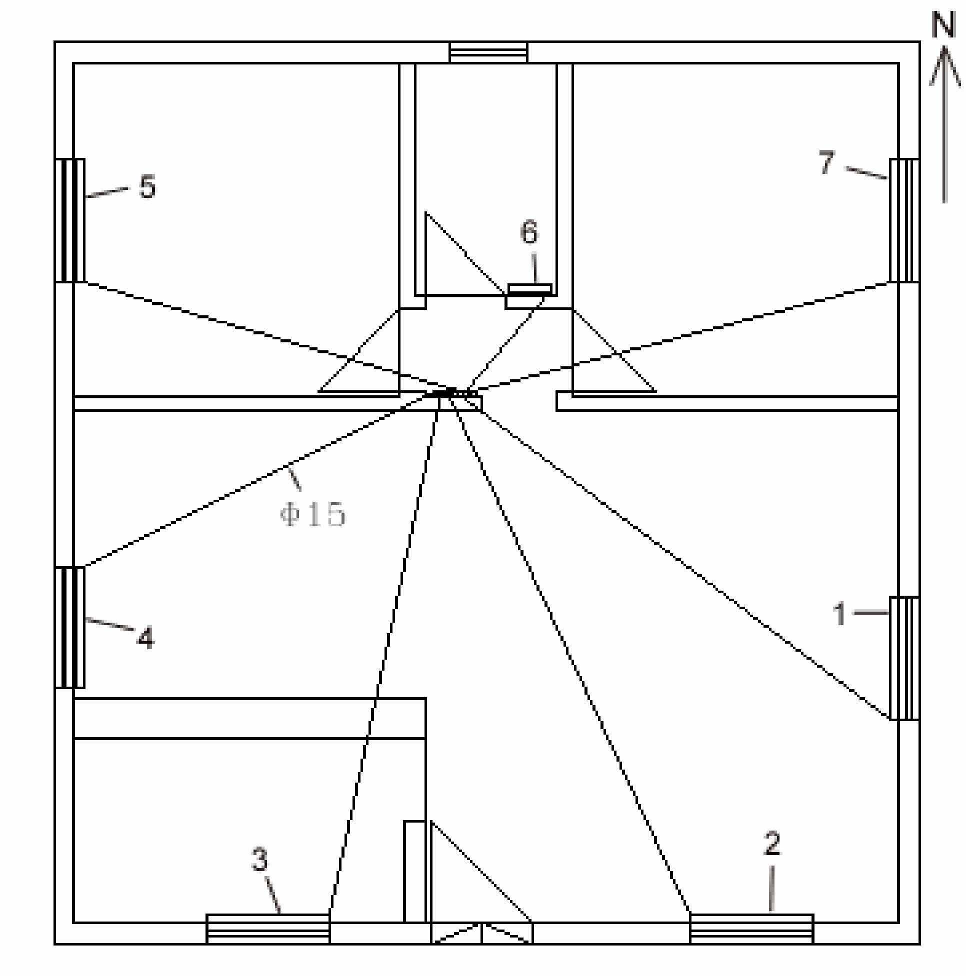

Figure 3.2: Diagram of the House

Building elements

The main entrance is preferably made of wood material and its size is larger than the internal doors (1m x 2.1m). There are a total of seven windows, six of the same size and a smaller one (toilet), which is double-glassed with wooden frame (3.38m x 1.2m and 2.05m x 0.73m for the toilet).

The external surfaces of the house are extremely well thermo insulated, in order to minimise the heat losses. These surfaces are the ceiling, the floor and the external walls, which consist of more than one material. The final dimensions and the material used for each of those cases are plotted in the table 1 of the appendix.

Heat Losses

Heat loss from a building occurs by a number of mechanisms. Some important factors which affect the rate at which this heat is lost are listed here and summarised below:

- Insulation of building
- Area of the external shell
- Temperature difference
- Air change rate
- Exposure to climate
- Efficiency of services
- Use of building

Insulation of shell

The heat loss from a building decrease as the insulation of the external fabric of the building is increased. The external parts of the structure surrounding occupied areas need most consideration but all buildings which are heated, for whatever purpose, should be well insulated in order to save energy. The thermal transmittance coefficient, the U-value, of a construction is a commonly used measure of insulation.

Area of the shell

The greater the area of external surfaces the greater is the rate of heat loss from the building. A terraced house loses less heat than a detached house of similar size. The basic plan shape of a building is one of the first design decisions to be made, although choices may be restricted by the nature of the site and by local regulations.

Temperature difference

A large difference between the temperature inside and outside the building increases the rate of heat lost by conduction and ventilation. This loss is affected by the design temperature of the inside air, which depends upon the purpose of the building.

Air change rate

Warm air leaving a building carries heat and is replaced by colder air. The air flow occurs through windows, doors, gaps in construction, ventilators and flues. The rate of air change is also affected by effects of wind upon the building.

Exposure to climate

When a wind blows across a wall or roof surface, the rate of heat transfer through that element increases. This effect is included in the standard value of external surface resistance used in calculating a U-value. Standard surface resistances are available for three types of exposure listed below:

- *Sheltered:* buildings up to three storeys in city centres
- *Normal:* most suburban and country buildings
- *Severe:* buildings on exposed hills or coastal sites

Efficiency of services

There is usually some wastage of heat energy used for water heating and space heating, and the design of the services can minimise or make use of this waste heat.

Use of building

The numbers of hours per day and the days per year that a building is used have a large effect on the energy consumption of a building. Many buildings which are unoccupied at times, such as nights, need to be pre-heated before occupancy each morning.

These patterns of building use and occupancy vary greatly, even for similar buildings. When a building has separate areas with different patterns of occupancy, each part needs to be considered as a separate building for heating calculations.

Calculation of heat loss

Various methods are available for calculating the rate at which heat flows out of a building and the quantity of heat loss in a given time. It is relatively difficult to calculate heat losses for unsteady or cyclic conditions where temperatures fluctuate with time. However, certain simplified calculations can be used for predicting heating requirements and the amount of energy required. The results obtained by these calculations are found to give adequate agreement with the conditions that actually exist.

With steady state conditions the temperatures inside and outside the building do not change with time and the various flows of heat from the building occur at constant rates. Assuming steady state conditions the heat losses from a building can be classes as either a 'fabric loss' or a 'ventilation loss' and then calculated by the methods described below.

Fabric heat loss

Fabric heat loss from a building is caused by the transmission of heat through the materials of walls, roofs and floors. Assuming steady state conditions, the heat loss for each element can be calculated by the following formula:

$P_f = U*A*DT*(1 + Z_D + Z_\Pi)$

Where P_f = rate of fabric heat loss = heat energy lost / time (W)

U = U-value of the element considered (W / m^2K)

A = area of that element (m^2)

DT = difference between the temperatures assumed for the inside and outside environments (^oC)

Z_D = Interrupting operation coefficient

Z_Π = Orientating coefficient

The heat loss per second is a form of power and therefore measured in watts. The notation P is used here to represent this rate of heat energy. Some CIBSE documents use the less-correct notation Q for rate of heat loss.

To calculate daily heat losses, appropriate temperatures would be the internal environmental temperature and outside environmental temperature, both averaged over 24 hours.

To have a better idea of the procedure that we used to calculate the heat losses of the house an example will be shown for the month of January. The example concerns the west external wall of the kitchen.

Example of West External Wall (Kitchen-January):

$P_f = U*A*DT*(1 + Z_D + Z_\Pi)$

P_f = 0,616 (W / m^2K)*18,36(m^2)*12,5(K)*(1+0,05-0,07)

P_f = 141,3 W

Kitchen	Heat Loss (W)
External Wall W	141,3

Window S	**164,8**
External Wall S	**204**
Floor	**128,9**
Ceiling	**123,7**
TOTAL	**777,9**

Table 3.2: Heat Losses from Kitchen

ROOM	Heat Loss (W)
Kitchen	**777,9**
Living Room	**1983,1**
Dining Room	**693,3**
West Bedroom	**1057,5**
Toilet	**289,9**
East Bedroom	**1033,6**
TOTAL	**5835,3**

Table 3.3: Heat Losses from the House

Ventilation loss

Ventilation heat loss from a building is caused by the loss of warm air and its replacement by air that is colder and has to be heated. The rate of heat loss by such ventilation or infiltration is given by the following formula:

$P_v = (c_v*N*V*DT) / 3600$

Where P_v = rate of ventilation heat loss = heat energy / time (W)

C_v = volumetric specific heat capacity of air = specific heat capacity X density (J / m^3K)

N = air infiltration rate for the room (the number of complete air changes per hour)

V = volume of the room (m^3)

DT = difference between the inside and outside air temperatures (^oC)

The values for the specific heat capacity and seconds in an hour are sometimes combined into a factor of 0.33, to give the following alternative formula:

$P_v = 0.33*N*V*DT$

As an example the same room will be used as in the fabric heat loss.

Example of West External Wall (Kitchen-January):

$P_v = 0.33*N*V*DT$

$P_v = 0{,}33*1{,}5*73{,}65*12{,}5$

$P_v = 455{,}7$ W

ROOM	Heat Loss (W)
Kitchen	**455,7**
Living Room	**1437,9**
Dining Room	**577,3**
West Bedroom	**657,6**
Toilet	**289,9**
East Bedroom	**653,6**
TOTAL	**4072**

Table 3.4: Heat Losses from the House

Total Heat Loss from Fabric + Ventilation (January)

House	Heat Loss (W)
Fabric Loss	**5835,3**
Ventilation Loss	**4072,0**
TOTAL	**9977,4**

Table 3.5: Total Losses from the House

As we can see the total energy that we have to supply to the house is 9,97 kW for keeping it in a comfortable state. If we assume that we want to keep this state for specific hours per day (assume 10h) then the total daily energy consumption should be 99,77 kWh for the January. With the same way we have analysed the energy consumption of the house for the whole year.

MONTHS	Average Daily Energy Consumption (kWh)	Monthly Energy Consumption (kWh)
January	**99,77**	**2993,1**
February	**99,77**	**2993,1**
March	**91,69**	**2750,7**
April	**83,71**	**2511,3**
May	**63,76**	**1912,8**
June	**47,95**	**1438,5**
July	**35,82**	**1074,6**
August	**35,82**	**1074,6**
September	**47,95**	**1438,5**
October	**63,76**	**1912,8**

November	**83,71**	**2511,3**
December	**91,69**	**2750,7**
	Household Total kWh	**25362,0**
	Total Cost per year (£)	**1724,6**
	Total CO2 per year (kg)	**11070,5**

Table 3.6: Daily and Monthly Energy Consumption from the House

Appliances consumption

Electrical Load Calculation

Before we start evaluating the components for a home power system, we need to know how much power we use. By taking an inventory of all the electrical loads in the house, and doing a basic electrical load evaluation, we can get a good idea how much power the system needs to produce. If we are designing our power system before building the home, we will need to carefully plan what appliances and electrical systems will be using.

List All Electrical Appliances

First, we will need to make a list of everything in the home that uses electricity (or every appliance we plan to have in your home). For the purposes of this evaluation, all these items will be called appliances. Besides the obvious items like televisions, refrigerators and microwaves, appliances we may not immediately think must also be included.

Appliances that are only used occasionally, such as power tools, must be included to correctly assess necessary system surge capacity (unless such items will be powered directly off a generator).

Determine Power Draw for Each Item

For each appliance listed, the wattage should be noted, as well as whether it runs on AC or DC current. If wattage information cannot be found on the product labelling or in the manual, amperage and voltage should be noted instead. Most household appliances will run on 115 volt AC power, but some major appliances require 220 VAC instead. The voltage requirements of AC appliances should be easily determined. For DC appliances, the voltage should match whatever DC system voltage is (or will be), whether 12V, 24V, or more rarely, 32 or 48V. For the final load calculation, we should obtain specific information from appliance labels and/or manuals wherever possible.

Estimate Appliance Usage Time

For each appliance, we should estimate how many hours per day the appliance is used. A refrigerator may be used seven days a week, but on average the refrigerator motor only runs up to 1/2 of the time, depending on the temperature settings and how warm the house is kept. That would be 12 hours/day. For a clock radio, it would be 24 hrs. A microwave may have a very large wattage rating, but may only be used for 1/2 hour or less per day.

For appliances we only use occasionally (1/2 hour or less per week, total), use 0.1 as your hours per day. This may lead to a slightly high estimation, but when in doubt, always estimate high. It's far better to have a slightly larger system than you need, than to have a system that regularly shuts down due to overloads.

In the following table we can see the total energy consumption that each room consumes in a period of one year. By taking into consideration that a kWh costs 0,068 pounds the total cost of energy will be 735,59 pounds per year.

Total Household Consumption	
Room	**Total kWh per year (from other tables)**
Living Room	**1057,07**
Kitchen	**5865,55**
Main Bedroom or Office	**975,40**
Number of other bedrooms	**2,00**

Other bedroom	**975,40**
Bathroom	**837,68**
Rest of House	**1106,47**
Household Total kWh	**10817,6**
Total Cost per year (£) =	**735,59**
Total CO2 per year (kg) =	**4721,87**

Table 3.7: Total Household Consumption

Total Energy Consumption (Heating + Appliances)

By adding the energy consumption for heating and for appliances we can see the total energy consumed from a house in a period of a year. Also the total cost in the same period it can be seen together with the total carbon dioxide emissions caused by the energy that a house of 220 m^2 consumes.

	Heating	Appliances	TOTAL
Household Total kWh	**25362**	**10817,6**	**36179,6**
Total Cost per year (£)	**1724,6**	**735,59**	**2460,2**
Total CO2 per year (kg)	**11070,5**	**4721,87**	**15792,4**

Table 3.8: Heating and Appliance Consumption in a Year

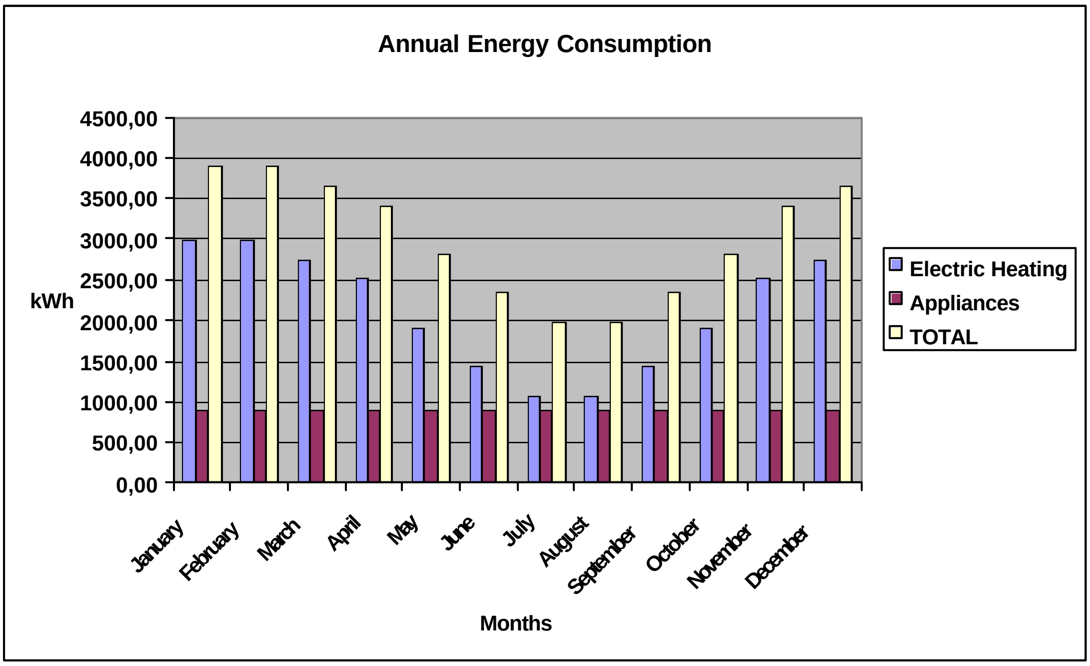

Figure 3.3: Annual Energy Consumption

CHAPTER 4

Site Analysis

Site analysis can come before or after our electrical load evaluation, but we'll need both analyses done before we start sizing and designing our renewable energy system.

Solar Site Analysis - *Find Our Average Insolation*

For a solar power system, the first question to ask is, "Do we have a place to install our solar panels?" This isn't quite as obvious as it may seem. A solar panel's output can be seriously reduced by even a single shadow from a single tree branch, and the direction the panels face also affects their output. Ideally, we need to find an area to install our solar panels where they can all face towards the equator ('solar south' for the northern hemisphere, 'solar north' in the southern hemisphere), and be completely unshaded at least from 9am to 3pm, if not for the entire day.

If we're lucky enough that our roof peak runs east-west, we can install the panels directly on the equatorial side of our roof, with perhaps some compensating framing to tilt them at the proper angle. If our roof won't cooperate, see if there's an area in our yard that remains shade-free through the middle of the day. If not, are we able to clear trees or obstructions to create a shade free mounting area? If we live in a snowy region, and need to have power from our panels all year-round, we should also make sure our panels will be located where we can easily clear snow from their surface when needed.

After we find a good location for our solar panels, we'll need to determine how much solar energy our location will gather on an average day, the "insolation" for our location.

If we're using our solar array to power a seasonal vacation home, we can concentrate on the figures given for the season we spend at the home. If we plan on using a solar-only power system all year-round, use the lowest insolation figures for our location. If our system can support our needs during the least-sunny months, we should be doing great the rest of the year, with a little power left over for house fans during the sunniest months!

Wind Site Analysis - *Average Wind Speed for Our Site*

For a wind power installation, the basic considerations are the same as solar: resource availability (wind speed instead of insolation of course) and the availability of a good installation location. A wind turbine must be installed far enough from any obstructions that it will a) not damage anything with its rotor blades, and b) receive an unobstructed wind stream. This generally means we must be able to install a very high tower on our property, or attach a tower to our house. If we don't have the room on our property, or don't own our own home, it may be best to wait until we can relocate to install a wind turbine system.

One major manufacturer recommends mounting our wind turbine at least 25' (8m) taller than any obstacles (telephone poles, trees, buildings, etc.) within 500' (150m) of the tower. The more clearance the turbine has, the less wind turbulence will interfere with its power output. Depending on the type of tower we're installing our turbine on, we may also need to determine clearance for tower support wires. Generally speaking, the taller our turbine mounts the more wind our turbine will get. The height of our tower is really only restricted by our available installation area.

Once we find a good location on our site, we'll need to find out how much wind we can expect throughout the year. Whether we have frequent gusting winds or relatively constant but slow wind throughout the year will decide what style of turbine you purchase. Many residential turbines are specifically designed to maximize output in low-wind-speed conditions, while others are designed for maximum durability in high speed conditions. The best way to find out average wind speeds for your specific location is to purchase an anemometer, install it approximately where our turbine would be, and keep a record of wind-speed measurements for a year prior to installing our turbine.

If our area is rated a 1 or 2 for average wind speeds, we'll probably want to look at low start-up speed turbines, which can start producing measurable power in winds below 10mph. For those in regions ranking 3 or higher, a turbine designed for high speed durability might be preferable.

Of course everyone, regardless of location, should use basic common sense when predicting wind speed for their system. If our region is rated a "4" by NREL (or an equivalent local authority), but our property is located on the sheltered side of a hill, our specific location may call for a different turbine than our neighbors on the other side of the hill.

What to do With the Data?

Once we have all the relevant site analysis figures for our location, and we've completed our *load evaluation* to determine how much power we need, we can proceed to the actual system sizing and design stage of the process. Using the figures gathered in the first two steps, we can figure out how many solar panels, wind turbines will supply our power needs, and what other system components will ensure the most reliable, highest quality power for our installation.

For our site analysis the data from NASA was used in order to evaluate how many solar panels and wind turbines will be needed. To calculate the size of solar panels that is needed we took the average monthly insolation of a ten year period in order to have more accurate results. To calculate the size of turbines that is gone to be used we took the average monthly speed of the wind and also the frequency of the wind speed for each month.

Wind + PV + Batteries Size Analysis

Solar size analysis

Because the insolation in a country such as UK isn't so high we decided to use the panels for producing the energy that is gone to be used for the consumption of the appliances.

As we know the monthly average consumption of energy from the appliances is 901,4 kWh. So this amount of energy should be extracted each month from the solar panels. Because the efficiency of the panels was assumed to be 15% and because the insolation in UK is very low this would cause a great demand in solar panels. So it was decided to calculate each month separately and to find an average value of solar panels that would give as the best supply for all the year.

The electricity supplied each month can be estimated as:

$Electricity\ per\ month = I*A*E_m*30$ kWh

Where I = average annual irradiation in kWh / m^2-day

A = array area in m^2

E_m = module efficiency (15%)

30 = number of days in a month

Example (January):

901.4 kWh = 0.75*A*0.15*30

$A = 267.08\ m^2$

Electricity per month = 0.75*120*0.15*30 = 405.0 kWh / month

MONTHS	Insolation	Panel m^2	kWh/month with 120 m^2
January	**0,75**	**267,08**	**405,00**
February	**1,32**	**151,75**	**712,80**
March	**2,52**	**79,49**	**1360,80**
April	**4,12**	**48,62**	**2224,80**
May	**5,29**	**37,87**	**2856,60**
June	**5,21**	**38,45**	**2813,40**
July	**5,35**	**37,44**	**2889,00**
August	**4,48**	**44,71**	**2419,20**
September	**3,29**	**60,88**	**1776,60**
October	**1,79**	**111,91**	**966,60**
November	**1,00**	**200,31**	**540,00**
December	**0,57**	**351,42**	**307,80**
AVERAGE	**2,97**	**119,16**	**1606,00**

Table 4.1: Monthly Energy Generation from PV

The number that was come out was 120 panels (of 1 m^2 each and of 150 W power) or 120 square meters of panel. Because the project is concerned with the use of batteries or fuel cells as a back up power system we decided to remain the number of the panels to 120. The number 120 was come out because was giving the yearly desired production of energy for the appliances. Also as we will mention in the part of the batteries and the fuel cell size calculation this number of panel is enough to provide as with energy that is gone to be stored for one day inventory. So for the production of energy from the solar panels an 18 kW power system will be required.

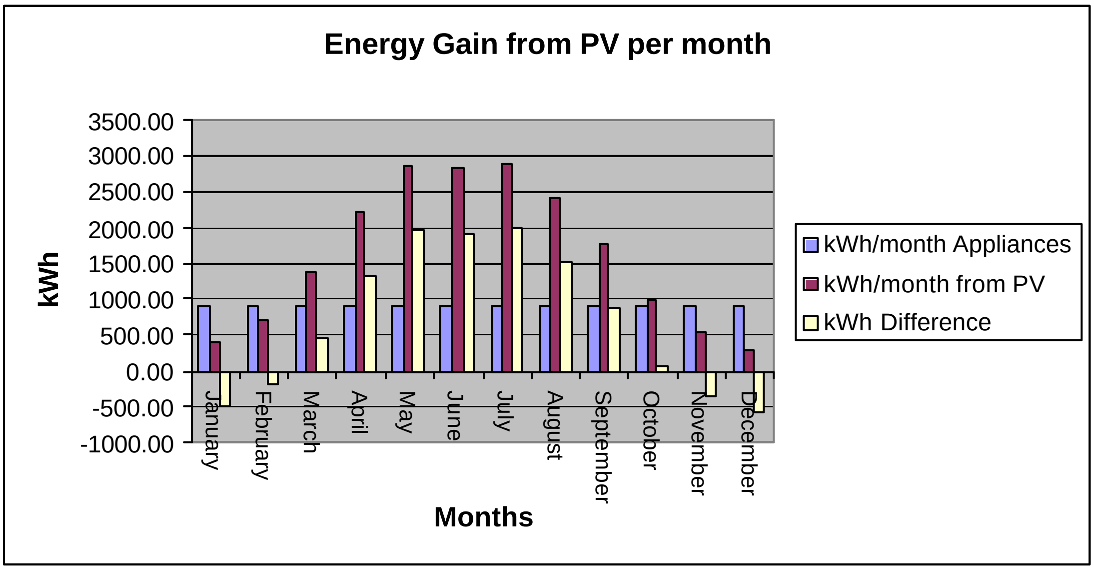

Figure 4.1: Energy Gain from PV per month

Wind size analysis

Because the wind speed in a country such as UK is quite high we decided to use the turbines for producing the energy that is gone to be used for the consumption of the heating in the house.

As we know the monthly maximum consumption of energy from the heating is 2993,1 kWh. So this amount of energy should be extracted each month from the wind turbines.

The first we had to calculate was the total amount of energy captured by the turbine in a typical year of operation and the capacity coefficient. From the monthly frequency of the wind speed we estimated the energy for the specific month and for all the year 15.306 kW.

A graph is created showing the number of days for which wind blows at different wind speeds, during a given period of time.

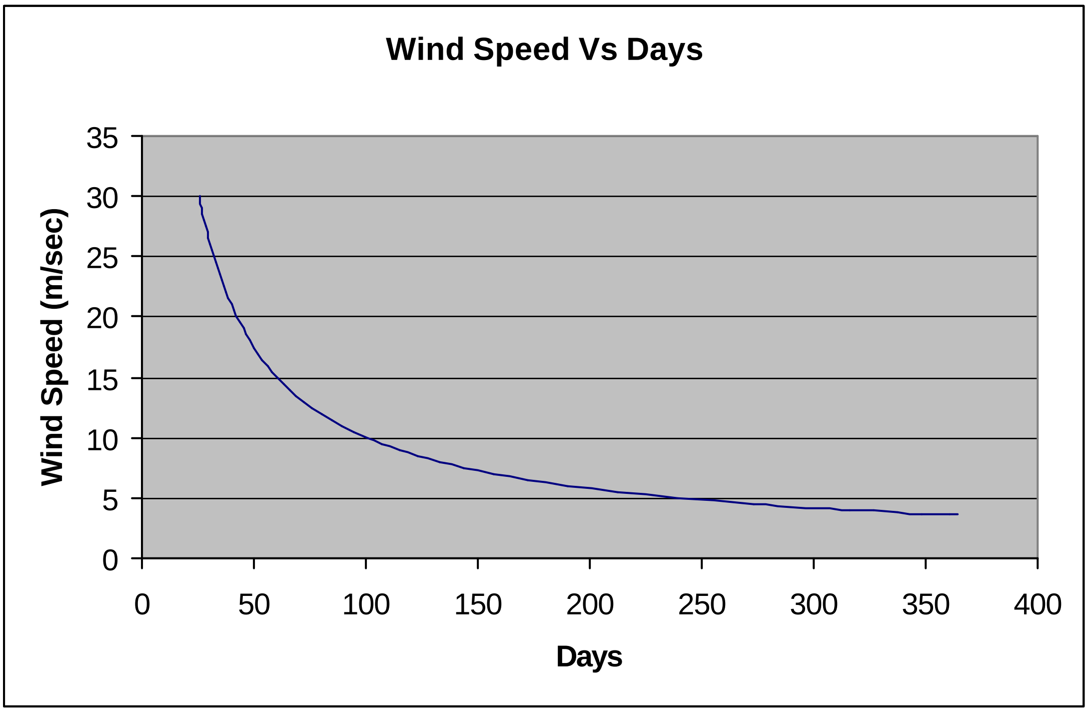

Figure 4.2: Wind Speed Vs Days

The best way to determine the wind speed distribution at a site is to carry out wind speed measurements with equipment that records the number of hours for which the wind speed lies within a speed range. For most applications of wind power, it is more important to know about the continuity of supply than the total amount of energy available in a year. In practise when the wind blows strongly more than 12 m / sec, there is no shortage of power and often generated power has to be dumped. Difficulties appear if there are extended periods of light or zero wind. A rule of thumb for electricity generation is that sites with average wind speed less than 5 m / sec will have unacceptably long periods without generation, and that sites of average 8 m / sec (ours average speed is 7.88 m / sec) or above can be considered very good. The longer the period over which measurements are taken, the more accurate is the estimate of the wind speed distribution.

$$P_{rated} = Cp \times \frac{1}{2} \times A \times r \times V^3 \Rightarrow P_{rated} = 0.4 \times \frac{1}{2} \times \frac{p \times 7.65^2}{4} \times 1.25 \times 11^3 \times \Rightarrow$$

$$P_{rated} = 15.306 kW$$

The power output of a wind turbine varies with wind speed and every turbine has a characteristic wind speed-power curve. The power curve will primarily determine how much energy can be produced by a particular turbine on a given site under given wind conditions. The energy that a wind turbine will produce depends on both its wind speed-power curve and the wind speed frequency distribution at the site.

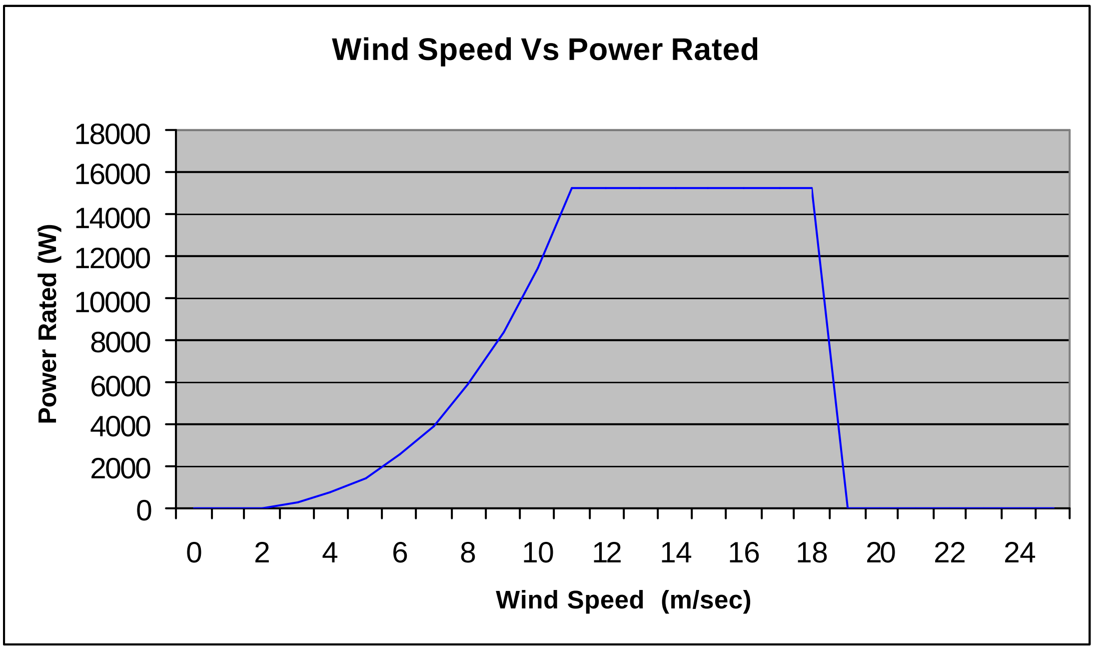

Figure 4.3: Wind Speed Vs Power Rated

For each wind speed within the operating range of the turbine that is between the cut-in wind speed and cut-out wind speed, the energy produced at that wind speed can be obtained by multiplying the number of days and the hours of a day by the corresponding turbine power at this wind speed. The total energy produced is then calculated by summing the energy produced at all the wind speeds within the operating range of the turbine.

The total annual energy is 52,536 kWh

In order to calculate the mean power we using the formula below:

$$P_{mean} = \frac{E_{Total}}{days \times hours} = \frac{52536}{365 \times 24} \Rightarrow P_{mean} = 5.99kW$$

and the coefficient capacity:

$$C_c = \frac{P_{mean}}{P_{rated}} = \frac{5.99}{15.306} \Rightarrow C_c = 0.392$$

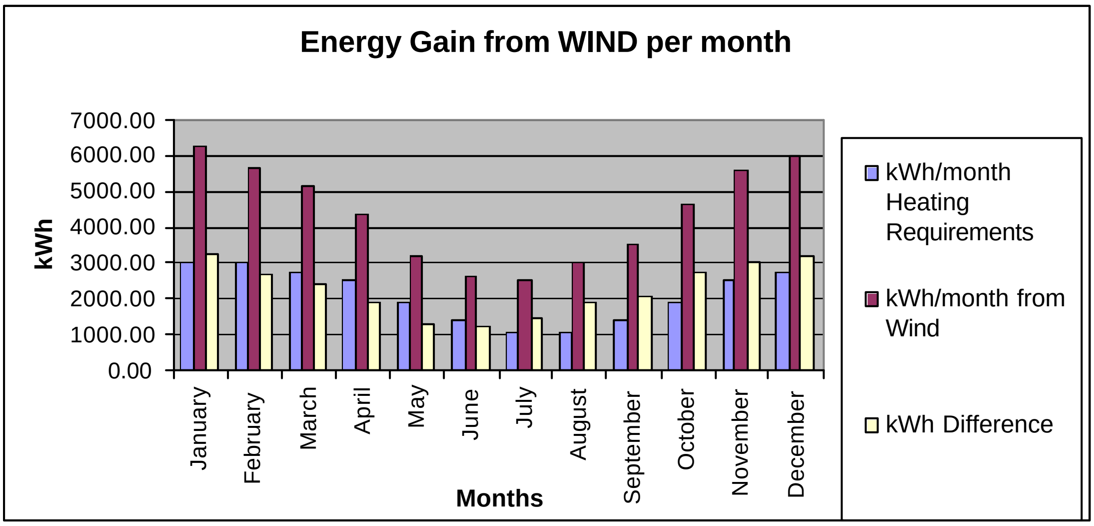

Figure 4.4: Energy Gain from Wind per month

Wind & PV

By combining the two technologies together the amount of energy that is being extracted in the period of one year is 71,808.60 kWh. This amount of energy is going to be used in order to cover the energy consumption of the house without problems and without extracting any new energy from the grid.

Batteries size analysis

To calculate the batteries size and number that we must use to cover our daily energy consumption we should first find the type of the battery that we going to use. As we mentioned in the theory that concerns the batteries, the type that matches for a power storage device is the stationary batteries. The capacity of the chosen system is 1500 Ah and the voltage is 24 V.

The maximum energy is consumed in the period of January with an amount of 129.81 kWh per day. So this amount must be covered from the renewable sources. The energy that is gained from the wind and photovoltaic per day in the same month is 222 kWh. Because the efficiency of a battery is around 60% then the energy that is remained from the renewable sources is 133 kWh.

From the chosen system a battery can handle 36 kWh per day. To find the number of batteries that is gone to be used we divide the daily input of energy in the batteries with the storage capacity of the battery. The maximum number of batteries needed per day is 5. Because the battery is separated in different parts of 2 V each we need 60 such components in order to have the 24 V batteries.

We chose this number of batteries because in months where we have an excess in energy we could store it and use it in months that the energy extraction is less. This can be seen from the figure below comparing the blue and the red bar.

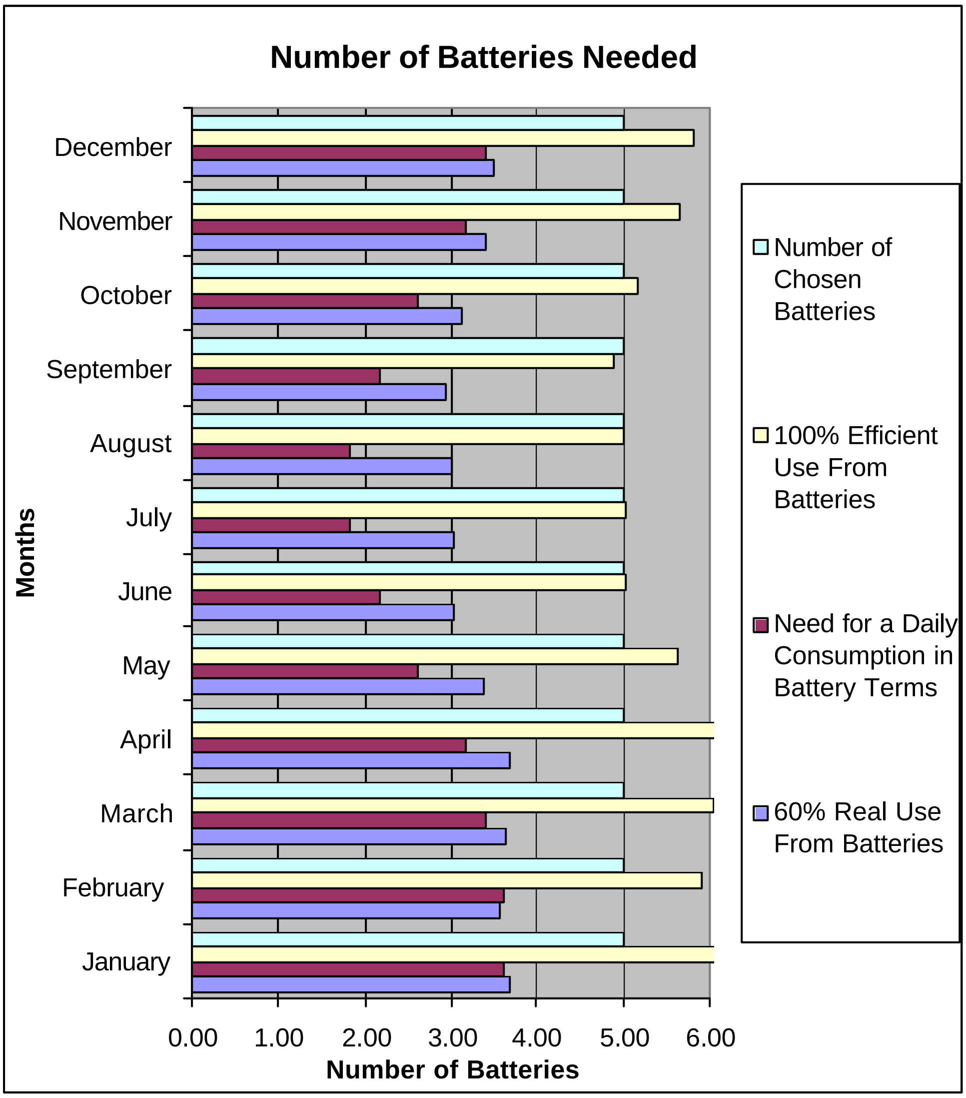

Figure 4.5: Number of Batteries Needed

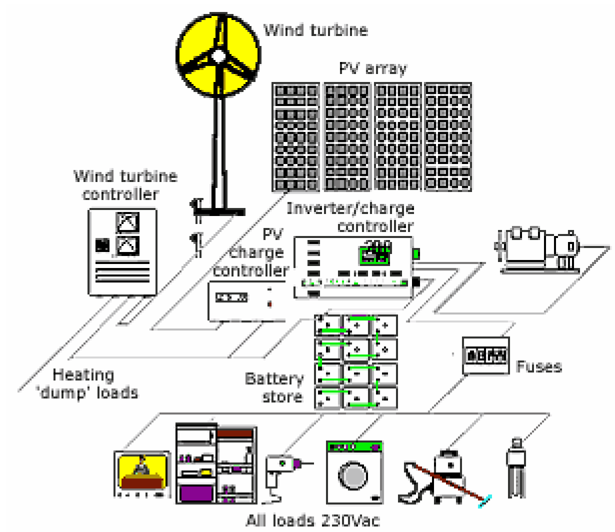

Figure 4.6: A Typical Wind, PV, Battery System

Matching Demand and Supply

Because the previous calculations was made to find the monthly energy that is required from renewable in order to cover the energy in a month now we will try to show what happens in a period of two days in a common summer and winter days.

Winter Period

As we said before in a typical winter day in the month of January the home needs 130 kWh. This amount is being distributed during the day as shown from the figure below.

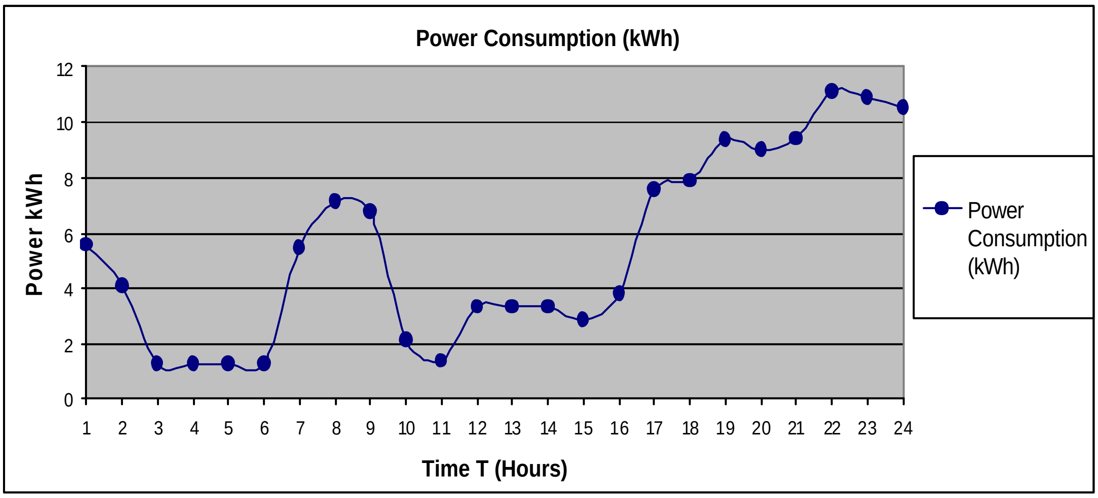

Figure 4.7: Power Consumption for a Day

For two days in the same month we have the same distribution.

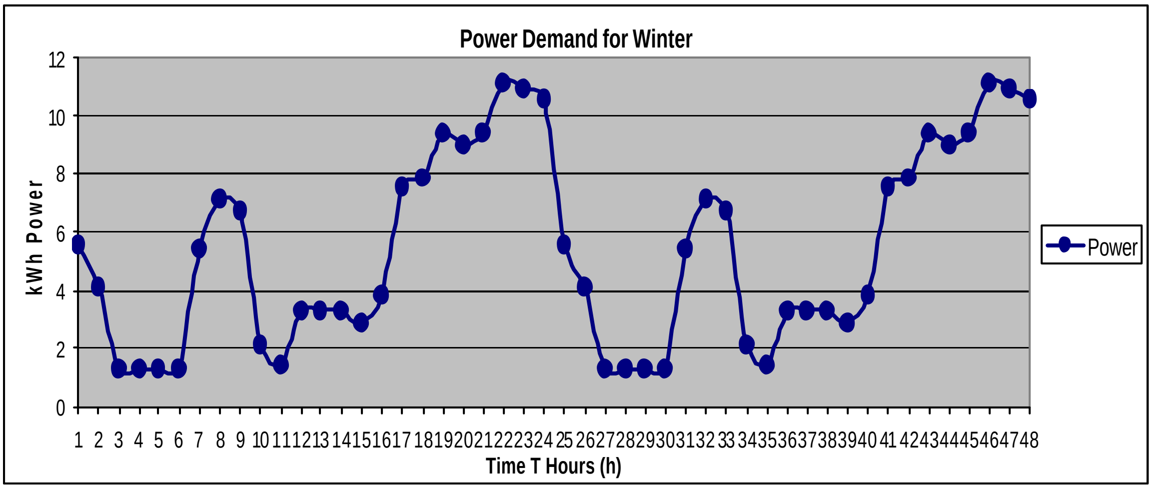

Figure 4.8: Power Demand for 2 Days in Winter

With the same way we found how the energy from renewable is being distributed in the period of two days.

First from the wind turbine.

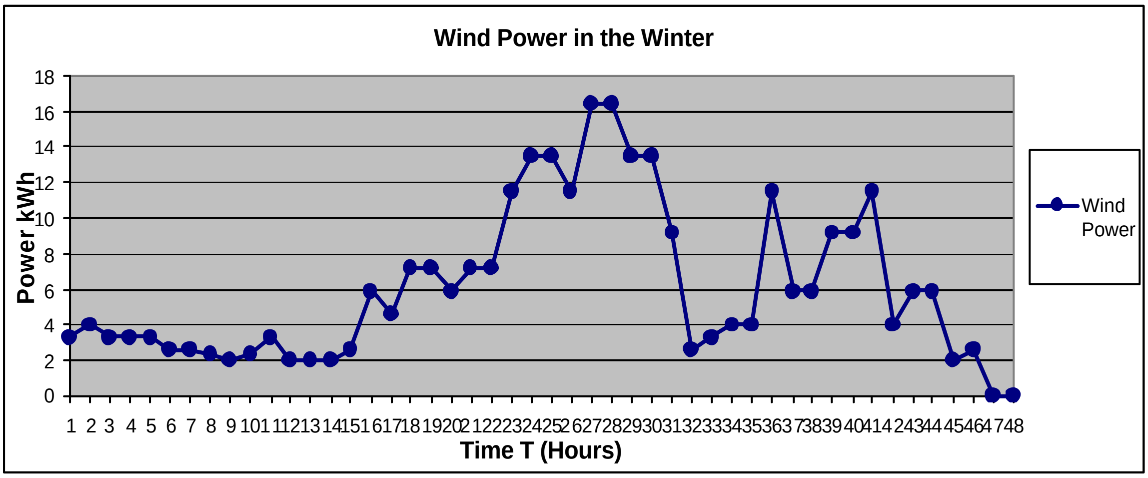

Figure 4.9: Wind Power in 2 Winter Days

And latter from the photovoltaic.

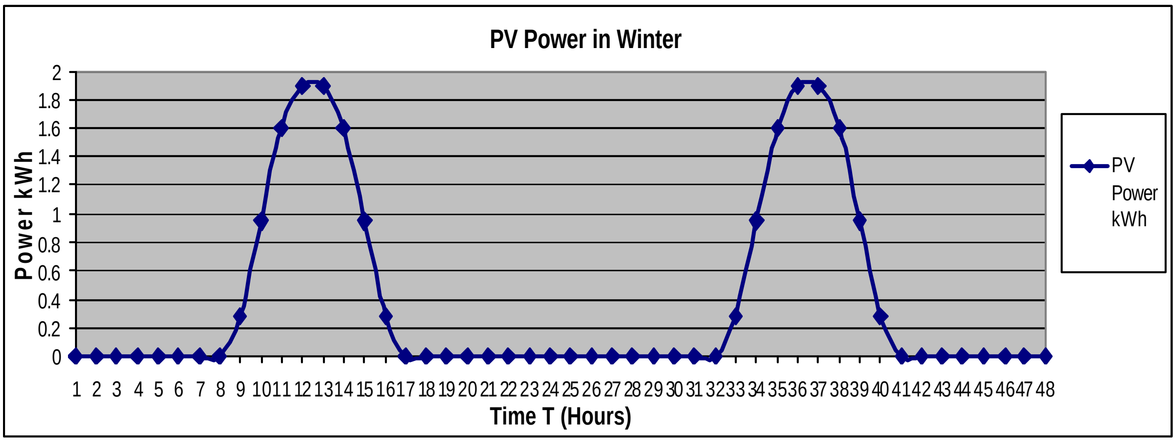

Figure 4.10: PV Power in 2 Winter Days

To see how the daily need for energy is being matched with the renewable production we can see the next figure that shows the three previous graphs in one.

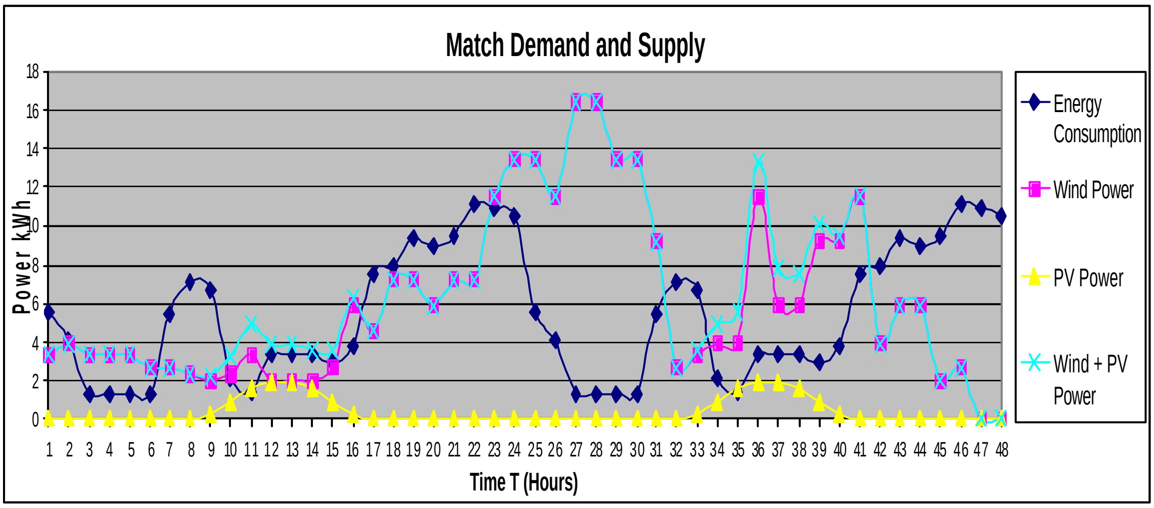

Figure 4.11: Match Demand and Supply in 2 Winter Days

Here we can see how the wind and photovoltaic power (green line) is being distributed in relation with the daily energy consumption of the house (blue line).

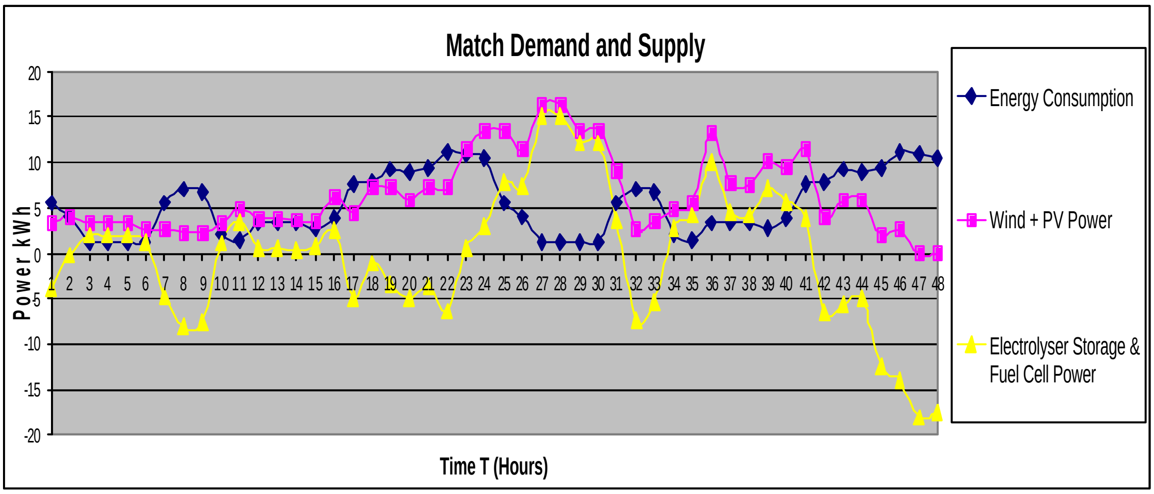

Figure 4.12: Match Demand and Supply in 2 Winter Days

In the figure above with the help of the yellow line we can see when the battery is charged and discharged during the period of two days.

Summer Period

In a day during the summer like in July the daily need for energy is 66 kWh and is being distributed like in the figure below.

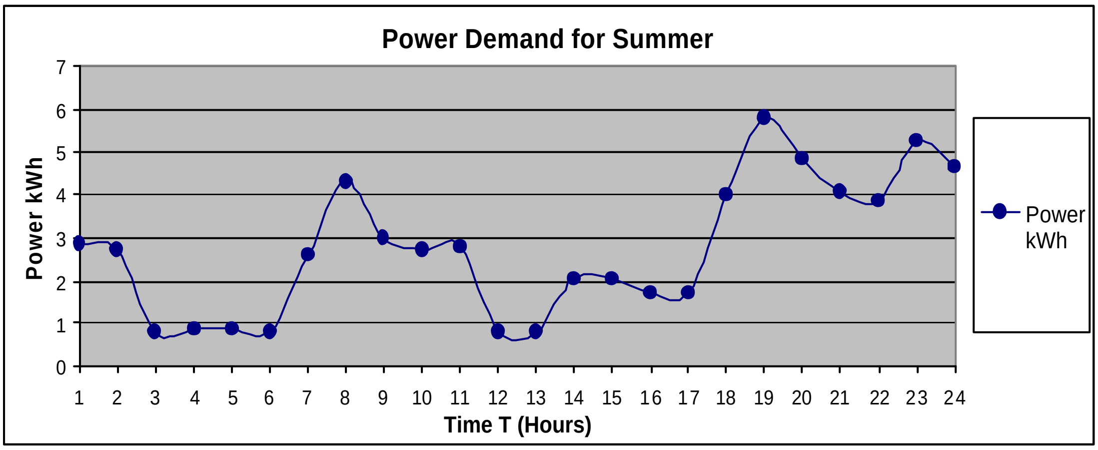

Figure 4.13: Power Demand for Summer

For two days the graph is becoming like in the figure below.

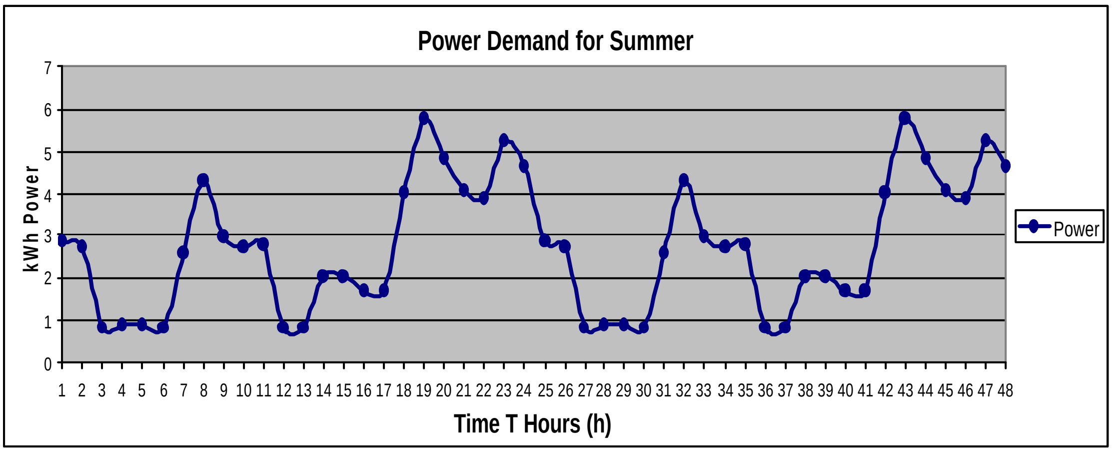

Figure 4.14: Power Demand for 2 Summer Days

The wind and photovoltaic power in the same time have a distribution that seems like in the next two figures below.

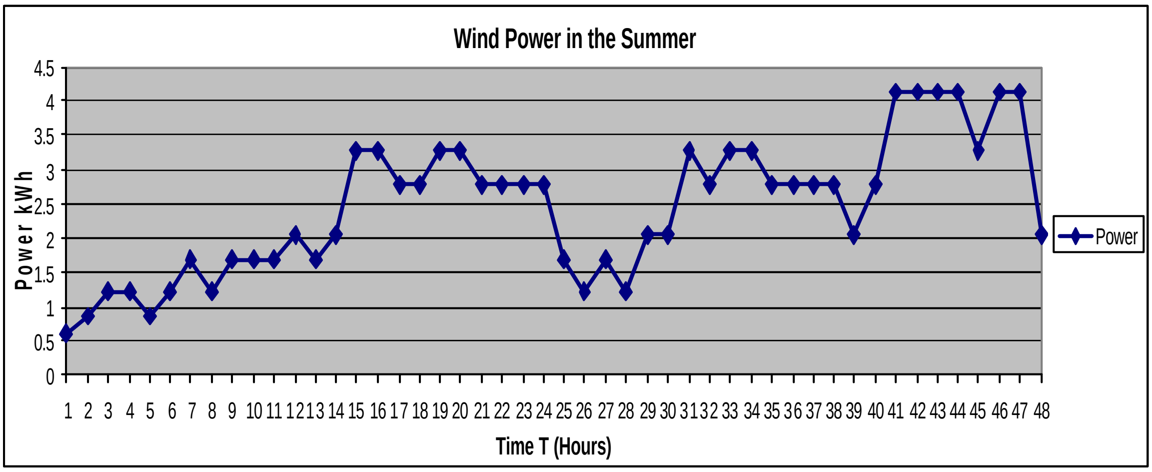

Figure 4.15: Wind Power for 2 Summer Days

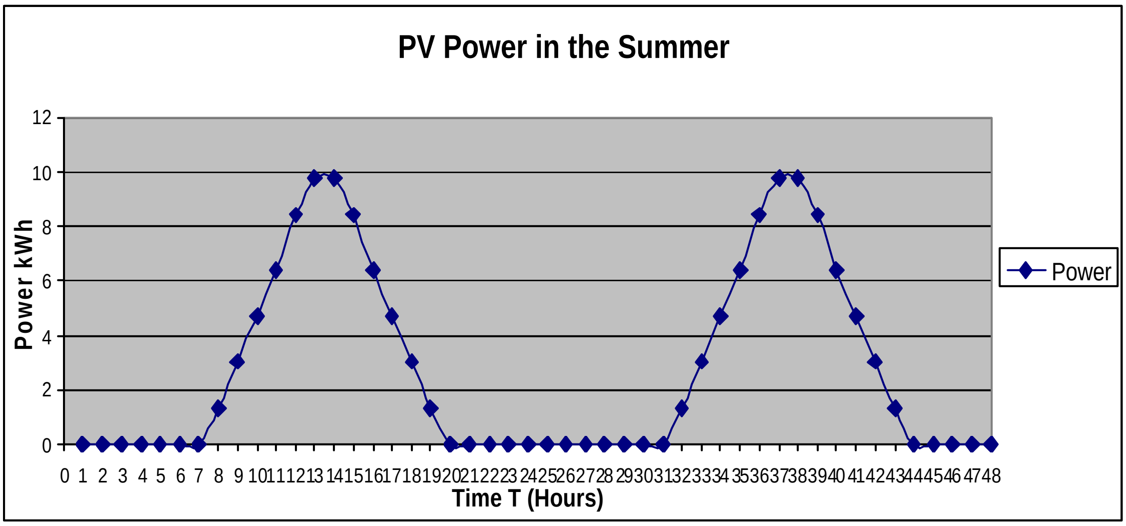

Figure 4.16: PV Power for 2 Summer Days

To match the demand and the supply we will use the figure below. In the different lines we can see how the desired energy (blue line) is being distributed during the day and how the wind and PV (red and yellow lines) produce their energy in the same time.

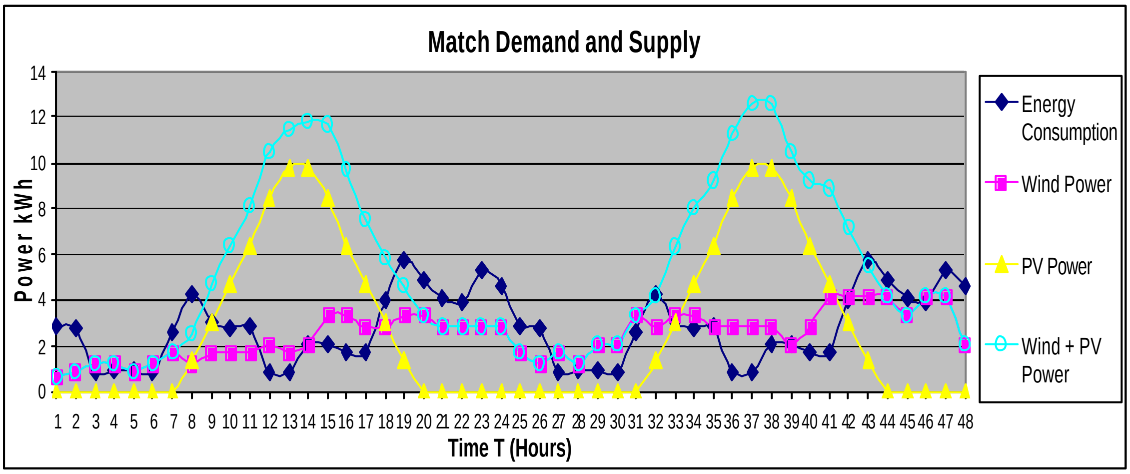

Figure 4.17: Match Demand and Supply for 2 Summer Days

When the energy from renewable cover the specific consumption then the excess amount is being stored in the battery and when there is a lack of supply then the battery covers the remaining. This can be seen in the yellow line where when it is in the positive direction then stores energy and when is negative supply the required energy.

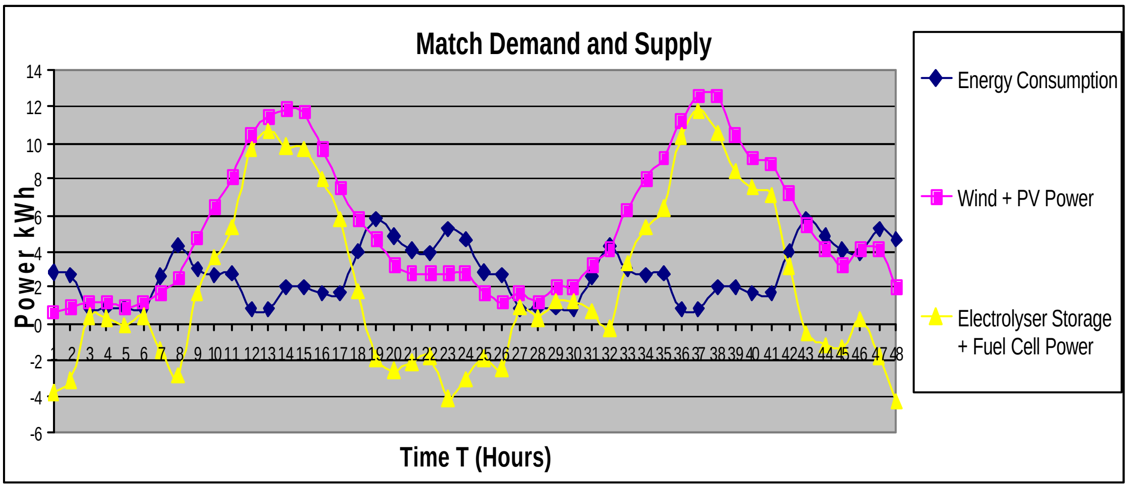

Figure 4.18: Match Demand and Supply for 2 Summer Days

The whole system functions with a final efficiency of 65%.

Wind + PV + Fuel Cell / Electrolyser Size Analysis

Solar size analysis

As we know the monthly average consumption of energy from the appliances is 901.4 kWh. So this amount of energy should be extracted each month from the solar panels. Because the efficiency of the panels was assumed to be 15% and because the insolation in UK is very low this would cause a great demand in solar panels.

The electricity supplied each month can be estimated as:

Elecricity per month = $I*A*E_m*30$ kWh

Where I = average annual irradiation in kWh / m^2-day

A = array area in m^2

E_m = module efficiency (15%)

30 = number of days in a month

Example (January):

901.4 kWh = 0.75*A*0.15*30

A = 267.08 m^2

Electricity per month = 0.75*120*0.15*30 = 405.0 kWh / month

MONTHS	Insolation	Panel m^2	kWh/month with 120 m^2
January	0,75	267,08	405,00
February	1,32	151,75	712,80
March	2,52	79,49	1360,80
April	4,12	48,62	2224,80
May	5,29	37,87	2856,60
June	5,21	38,45	2813,40

July	**5,35**	**37,44**	**2889,00**
August	**4,48**	**44,71**	**2419,20**
September	**3,29**	**60,88**	**1776,60**
October	**1,79**	**111,91**	**966,60**
November	**1,00**	**200,31**	**540,00**
December	**0,57**	**351,42**	**307,80**
AVERAGE	**2,97**	**119,16**	**1606,00**

Table 4.2: Monthly Energy Generation from PV

The number that was come out was 120 panels (of 1 m^2 each and of 150 W power) or 120 square meters of panel. So for the production of energy from the solar panels a 18 kW power system will be required.

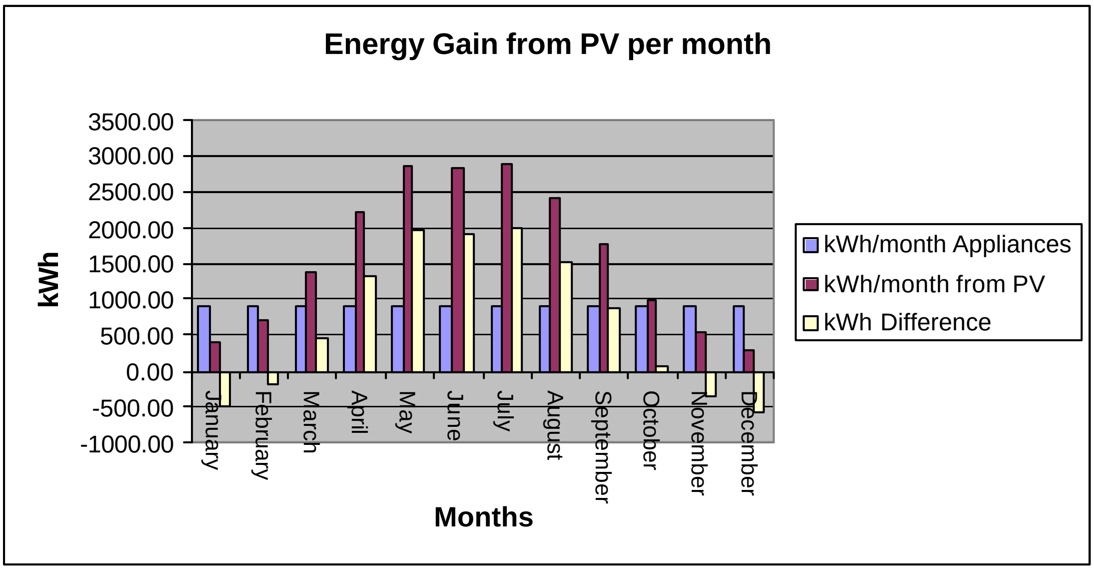

Figure 4.19: Energy Gain from PV per month

Wind size analysis

The first we had to calculate was the total amount of energy captured by the turbine in a typical year of operation and the capacity coefficient. From the monthly frequency of the wind speed we estimated the energy for the specific month and for all the year 24.956 kW.

A graph is created showing the number of days for which wind blows at different wind speeds, during a given period of time.

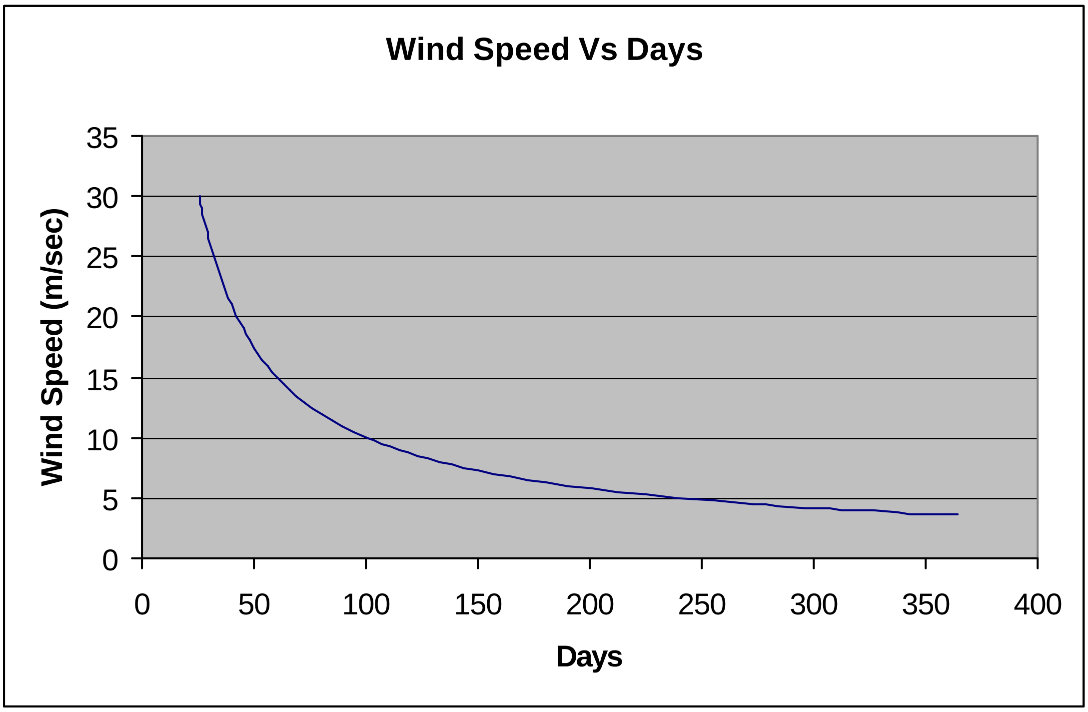

Figure 4.20: Wind Speed Vs Days

$$P_{rated} = Cp \times \frac{1}{2} \times A \times r \times V^3 \Rightarrow P_{rated} = 0.4 \times \frac{1}{2} \times \frac{p \times 9.8^2}{4} \times 1.25 \times 11^3 \times \Rightarrow$$

$$P_{rated} = 24.956kW$$

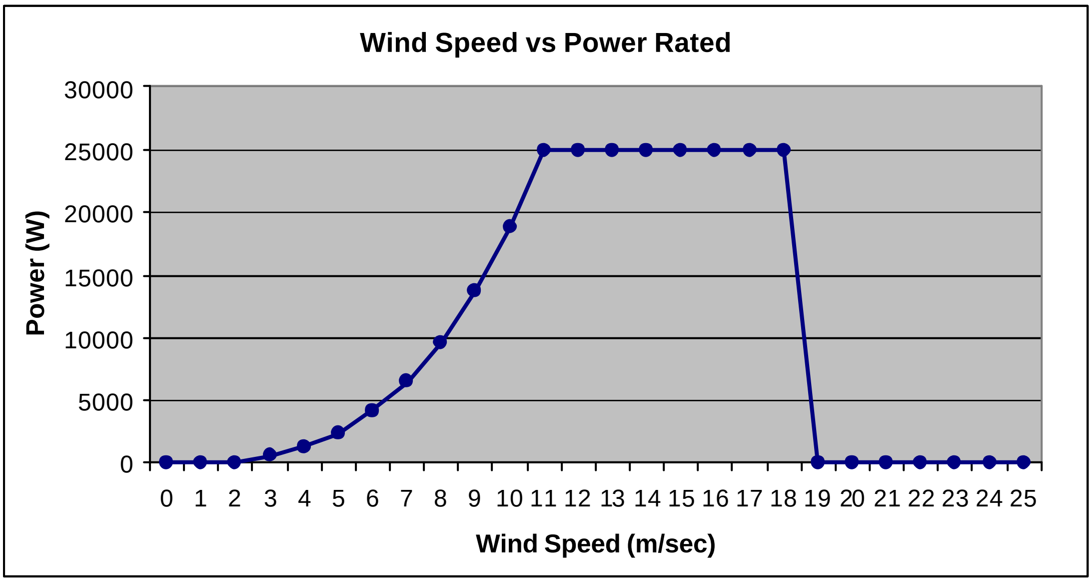

Figure 4.21: Wind Speed Vs Power Rated

The total annual energy is 85,657 kWh

In order to calculate the mean power we using the formula below:

$$P_{mean} = \frac{E_{Total}}{days \times hours} = \frac{85657}{365 \times 24} \Rightarrow P_{mean} = 9.78kW$$

and the coefficient capacity:

$$C_c = \frac{P_{mean}}{P_{rated}} = \frac{9.78}{24.956} \Rightarrow C_c = 0.392$$

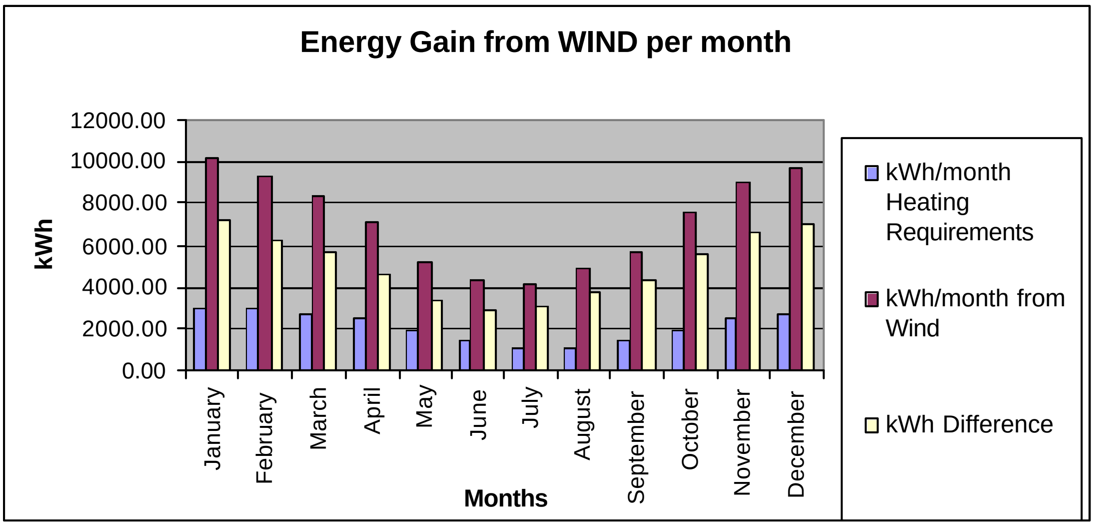

Figure 4.22: Energy Gain from Wind per month

Wind & PV

By combining the two technologies together the amount of energy that is being extracted in the period of one year is 104,929 kWh. This amount of energy is going to be used in order to cover the energy consumption of the house without problems and without extracting any new energy from the grid.

Hydrogen Production and Storage size analysis

Nowadays the efficiency of an electrolyser is in the range of 65% - 80%. We assume that our electrolyser has an efficiency of 70%.

To extract 1Nm3 of hydrogen we need 2.995 kWh with 100% efficiency. As we mentioned before our device is 70% efficient. So the energy needed to produce 1Nm3 of hydrogen is 4.27 kWh.

If we use all the energy that we get from renewable in the production of hydrogen then for the month January we will have 2356.32 Nm3 of hydrogen.

In the figure below we can see the production and use of the H2 every month.

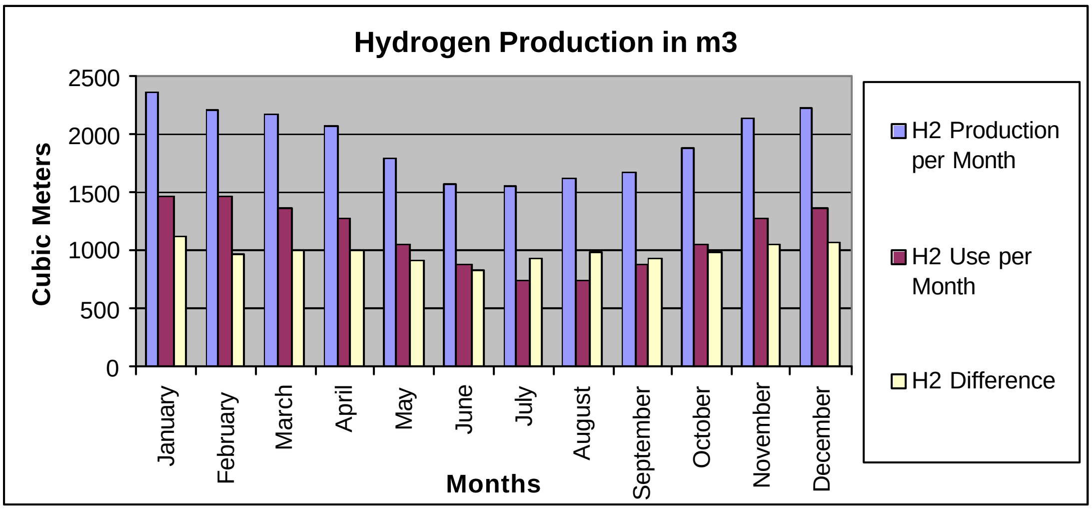

Figure 4.23: Hydrogen Production per month in m3

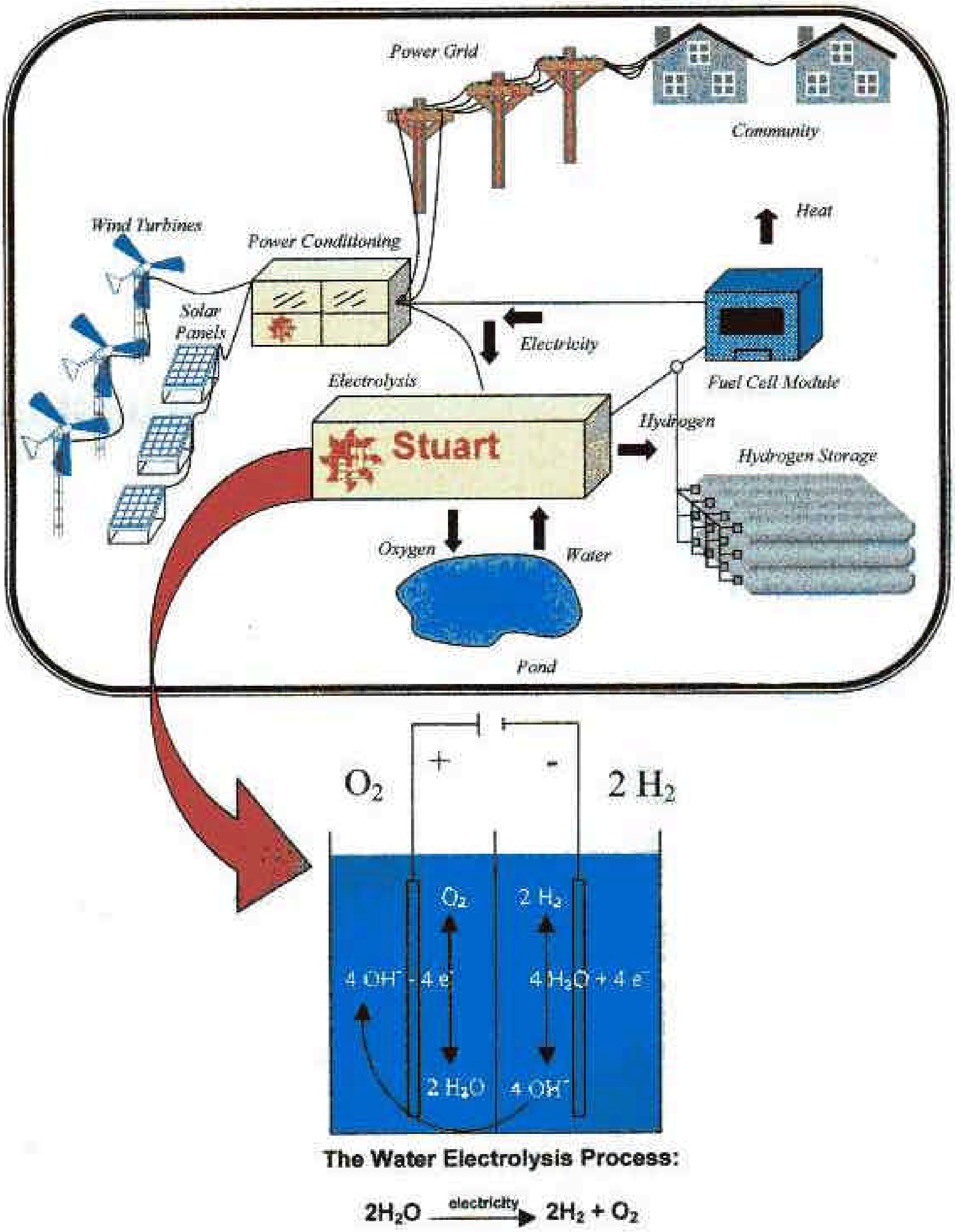

Figure 4.24: A Renewable Hydrogen Energy System

Fuel Cell size analysis

By assuming that the efficiency of a fuel cell is 55% we are going to estimate how much energy is being produced from the use of hydrogen that was stored. Again we are going to size the maximum production of energy that can be extracted from the fuel cell from using all the stored H2 for a month.

For the month January the energy production was 3879.725 kWh and the desired energy consumption was 3894.50 kWh. This means that we have a shortage of 14.77 kWh energy the specific month.

Fortunately this shortage is being covered from the excess amount of hydrogen that is being gathered in months with less consumption of energy.

This can be seen in the figure below.

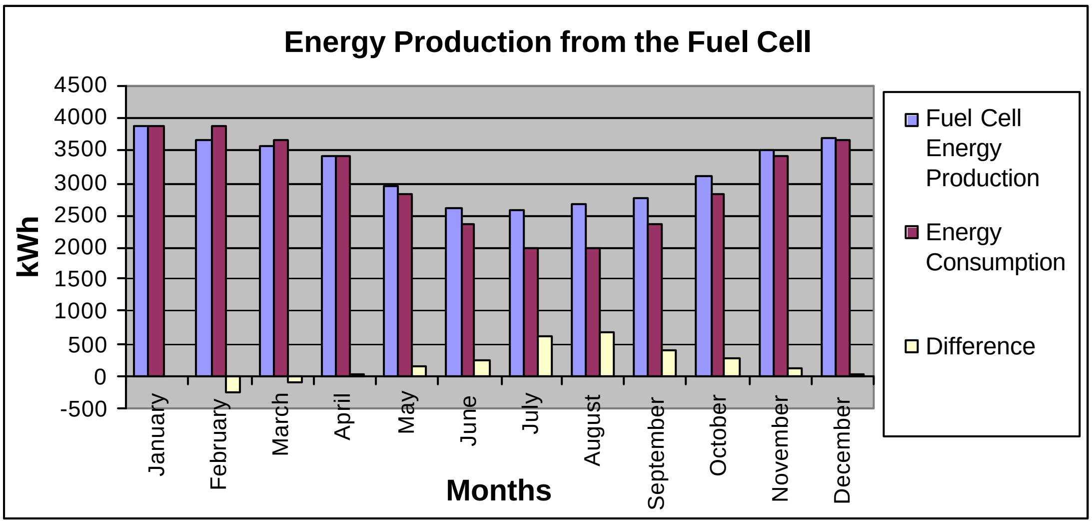

Figure 4.25: Energy Production from Fuel Cell

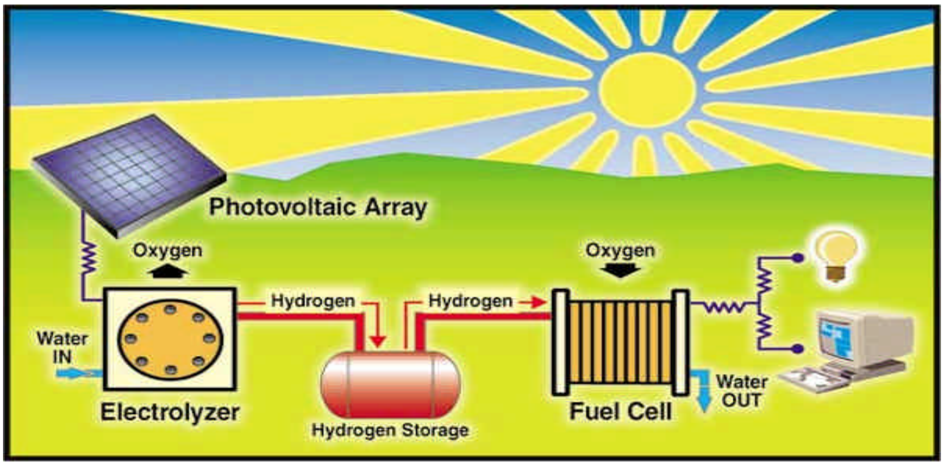

Figure 4.26: How a Renewable System Works with a Electrolyser / Fuel Cell

Matching Demand and Supply

The same we will try to show with the Fuel Cell in the system in a period of two days in the summer and winter.

Winter Period

As we said before in a typical winter day in the month of January the home needs 130 kWh. This amount is being distributed during the day as shown from the figure below.

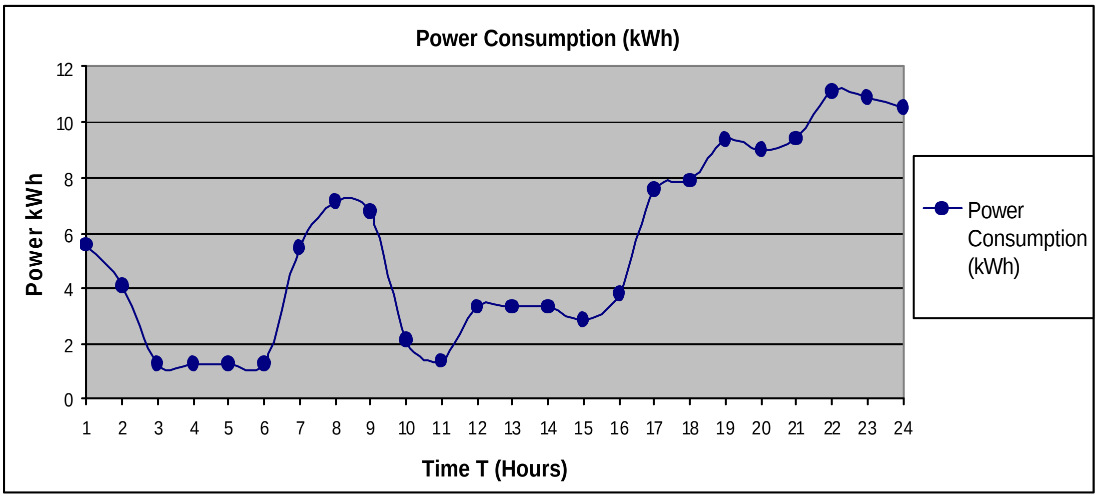

Figure 4.27: Power Consumption for 1 Day

For two days in the same month we have the same distribution.

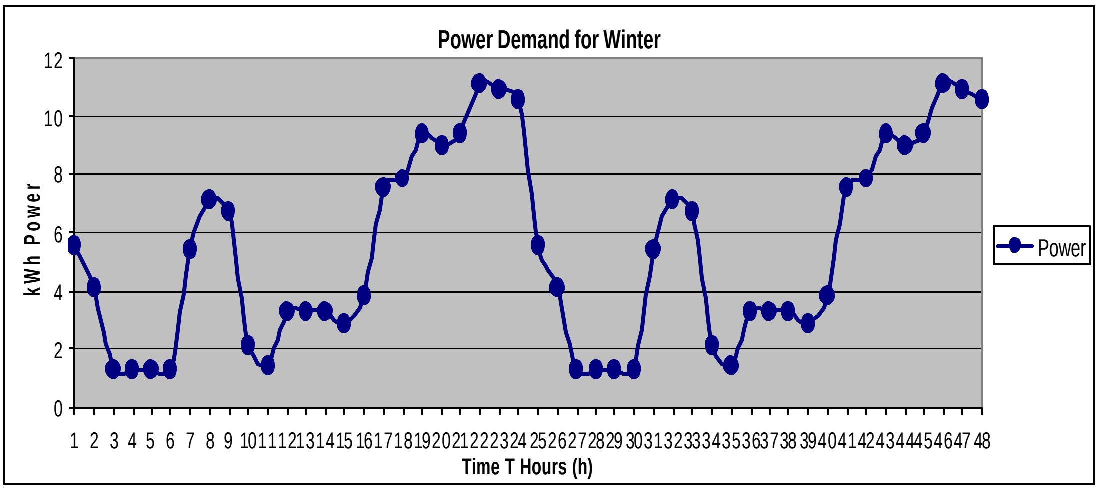

Figure 4.28: Power Demand for 2 Winter Days

With the same way we found how the energy from renewable is being distributed in the period of two days.

First from the wind turbine.

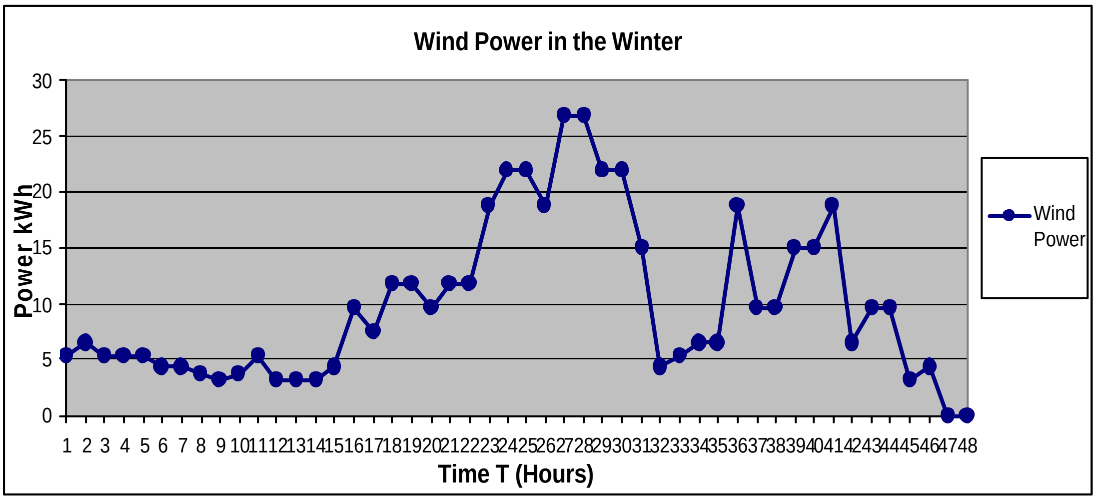

Figure 4.29: Wind Power in 2 Winter Days

And latter from the photovoltaic.

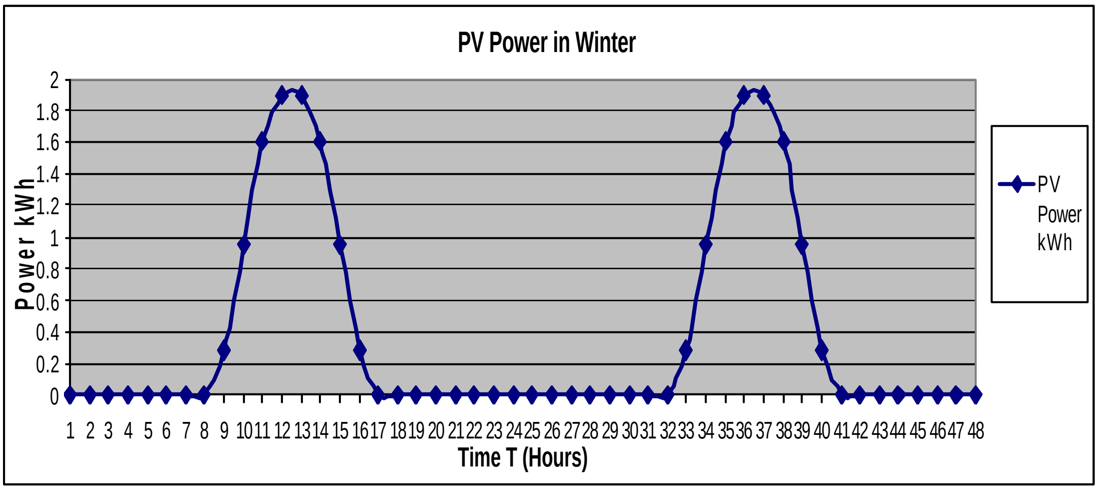

Figure 4.30: PV Power in 2 Winter Days

To see how the daily need for energy is being matched with the renewable production we can see the next figure that shows the three previous graphs in one.

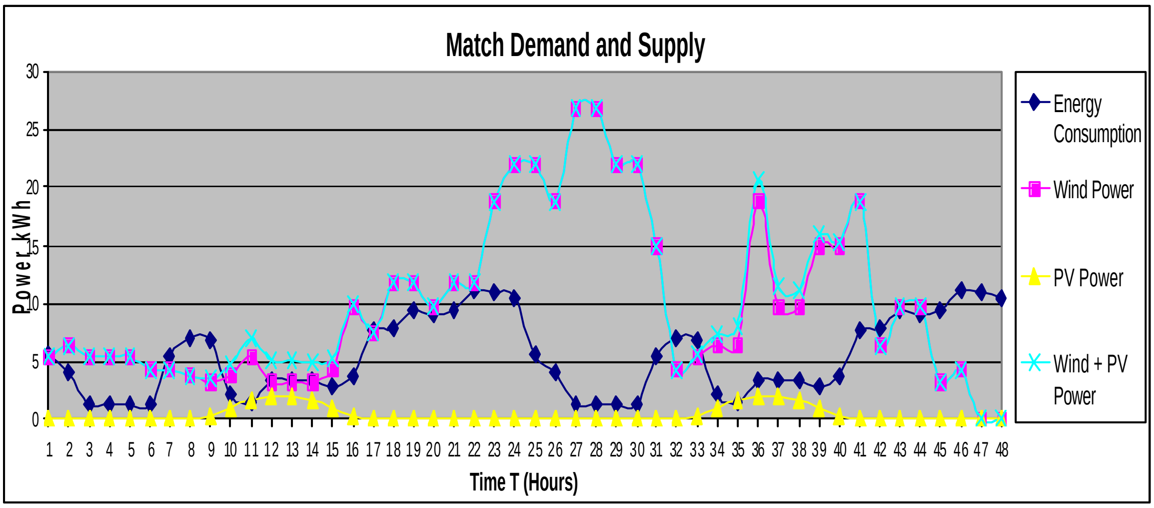

Figure 4.31: Match Demand and Supply for 2 Winter Days

Here we can see how the wind and photovoltaic power (green line) is being distributed in relation with the daily energy consumption of the house (blue line).

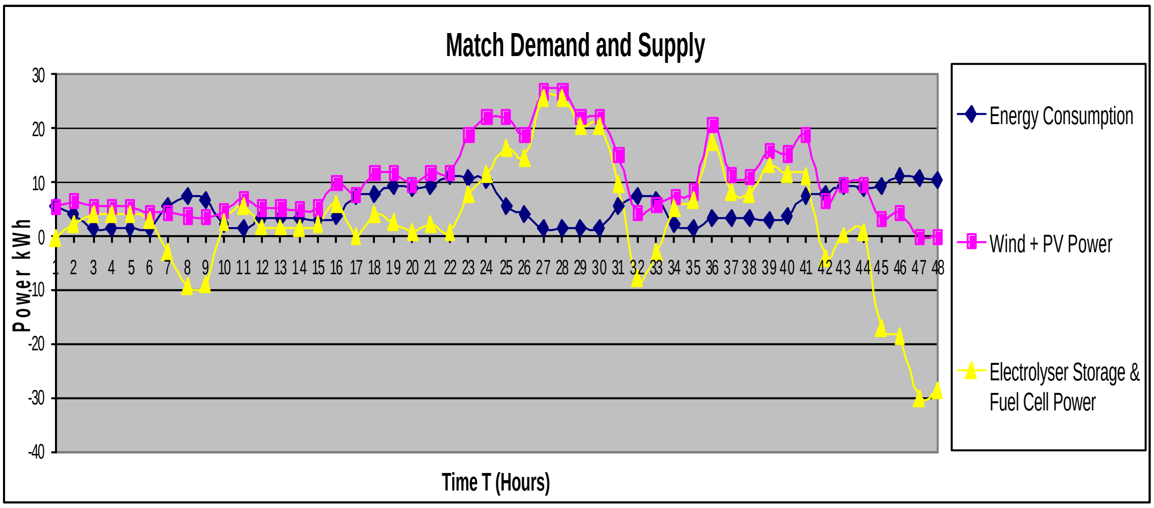

Figure 4.32: Match Demand and Supply for 2 Winter Days

In the figure above with the help of the yellow line we can see when the battery is charged and discharged during the period of two days.

Summer Period

In a day during the summer like in July the daily need for energy is 66 kWh and is being distributed like in the figure below.

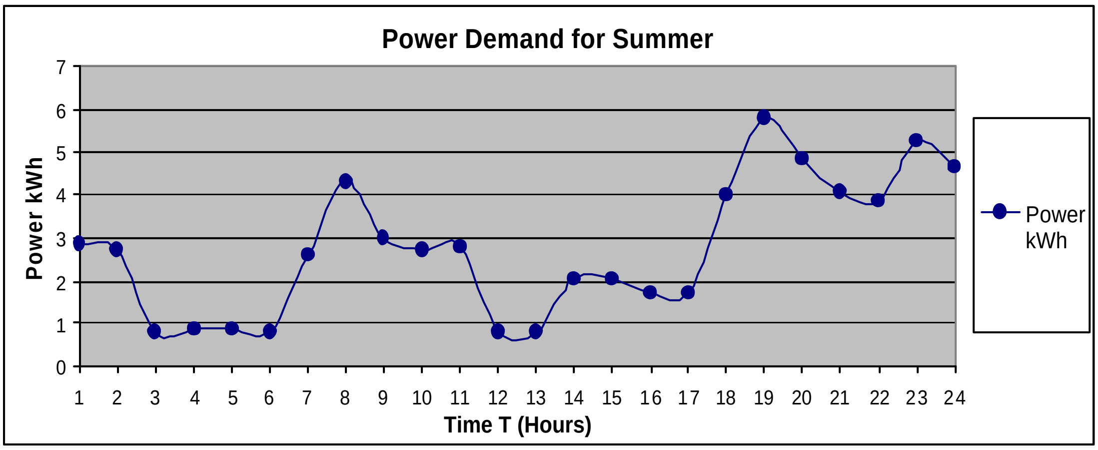

Figure 4.33: Power Demand for 1 Summer Day

For two days the graph is becoming like in the figure below.

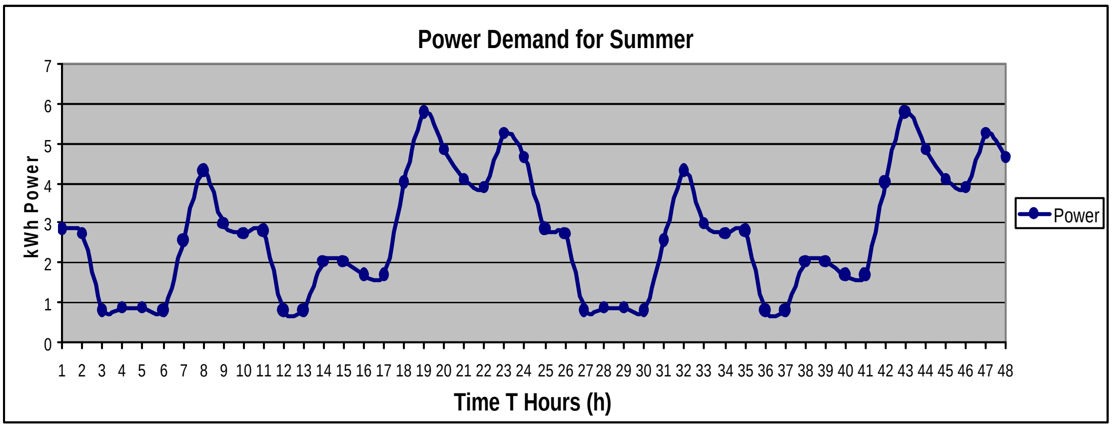

Figure 4.34: Power Demand for 2 Summer Days

The wind and photovoltaic power in the same time have a distribution that seems like in the next two figures below.

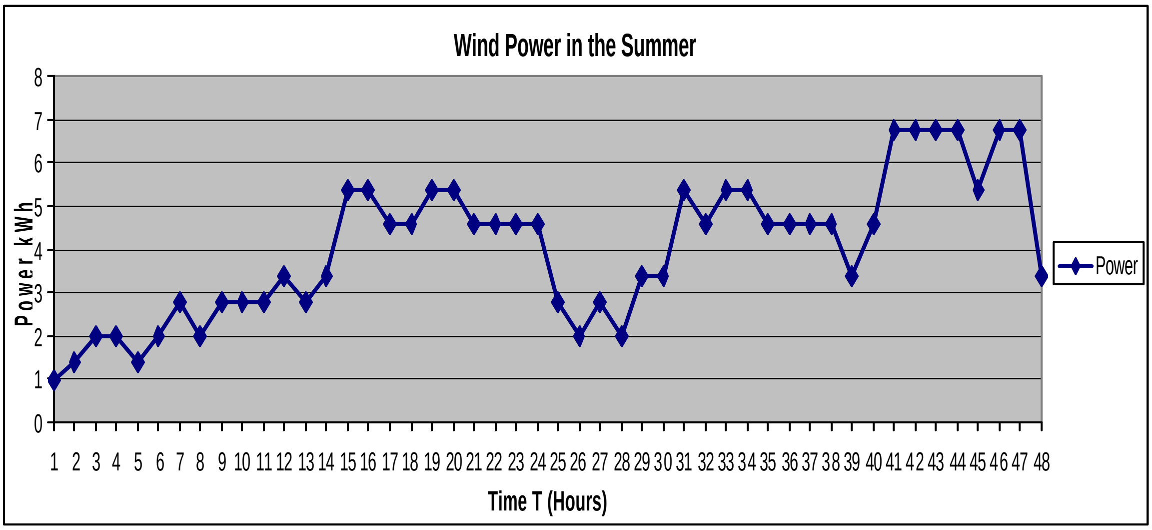

Figure 4.35: Wind Power in 2 Summer Days

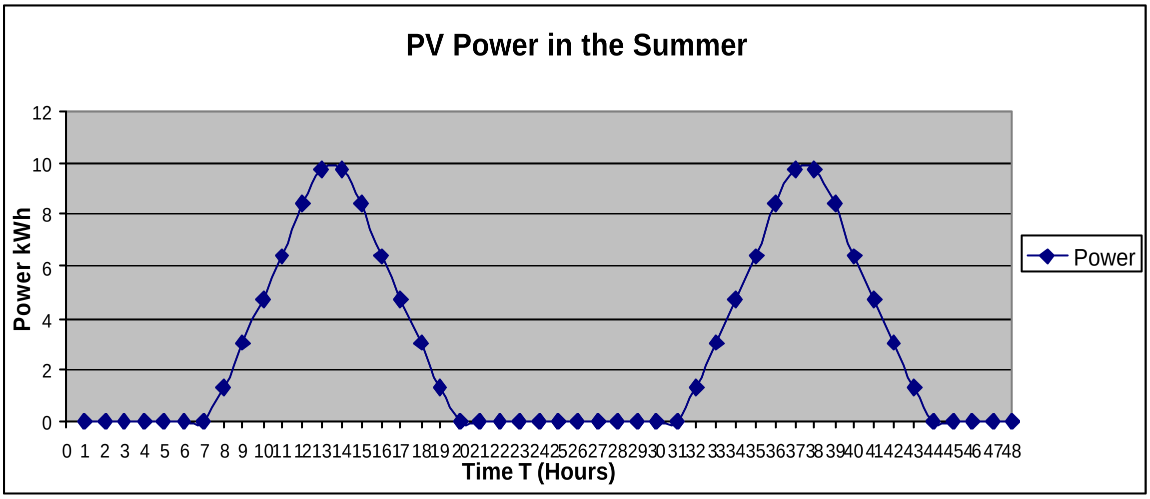

Figure 4.36: PV Power in 2 Summer Days

To match the demand and the supply we will use the figure below. In the different lines we can see how the desired energy (blue line) is being distributed during the day and how the wind and PV (red and yellow lines) produce their energy in the same time.

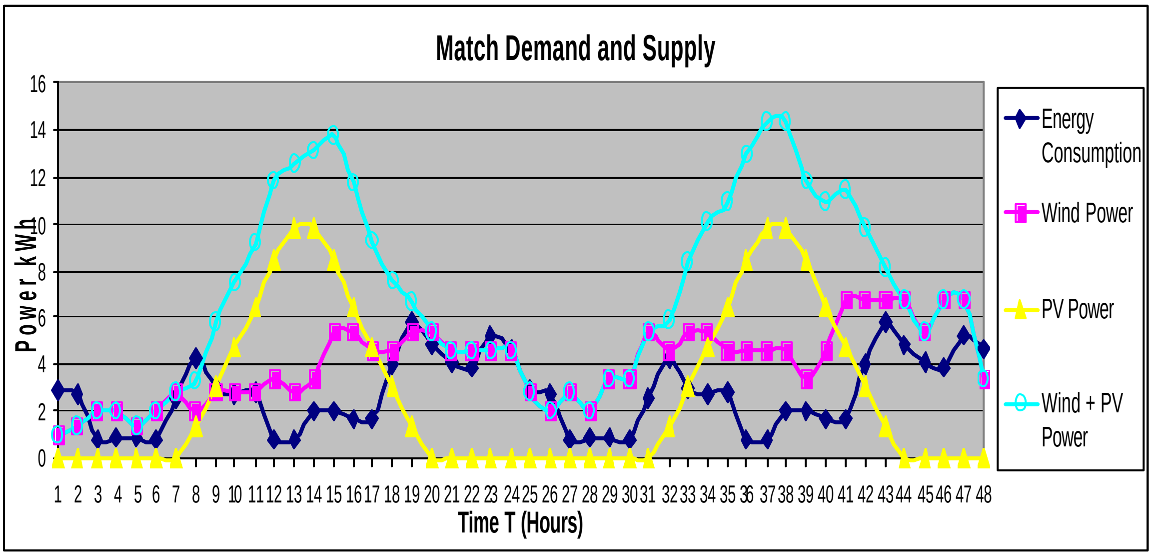

Figure 4.37: Match Demand and Supply for 2 Summer Days

When the energy from renewable cover the specific consumption then the excess amount is being passed in the electrolyser, where there produces the hydrogen and then is being stored and when there is a lack of supply then the fuel cell uses hydrogen and covers the remaining. This can be seen in the yellow line where when it is in the positive direction then stores energy and when is negative supply the required energy.

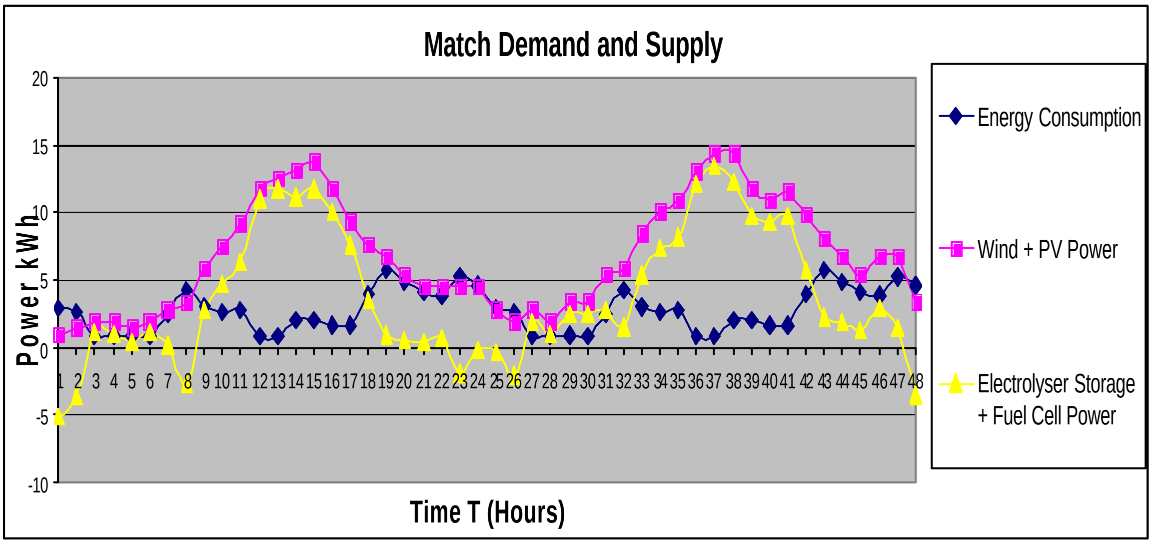

Figure 4.38: Match Demand and Supply for 2 Summer Days

The whole system functions with a final efficiency of 53.28%.

How the Renewable System Works with Batteries and Fuel Cell

To see more clearly how such a system works we will try to present it in a diagrammatic form in the next two figures.

With Batteries

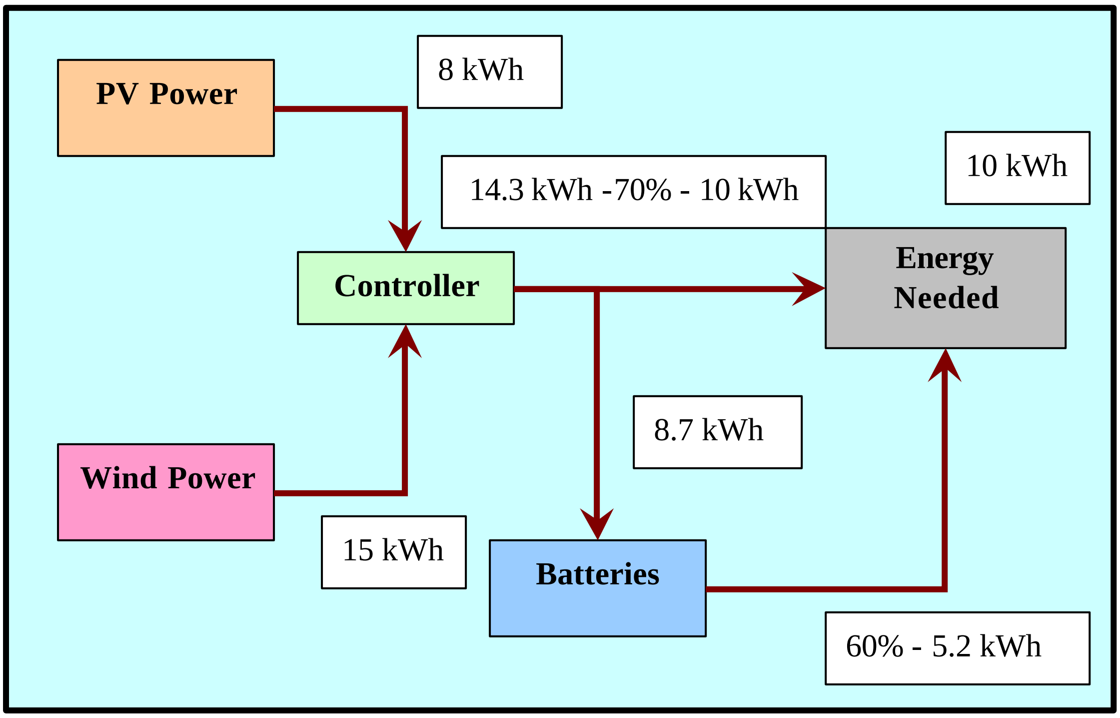

Figure 4.39: A Wind, PV, Battery System

In this example we can see that in a specific time during the day how the home needs are covered with this system.

When we need 10 kWh of energy in a specific time during the day and in the same time we extract from renewable 23 kWh this is being distributed like in the figure above.

The 10 kWh is being given directly for our needs but because this procedure has 70% efficiency we provide the system with 14.28 kWh. The remaining 8.7 kWh is being stored in the batteries. When an excess amount is required for the house and the renewable can't afford to give it then the batteries provide the additional amount.

In this case the 8.7 kWh previously stored will give as in some time in the future the amount of 5.2 kWh cause of the 60% efficiency of the batteries.

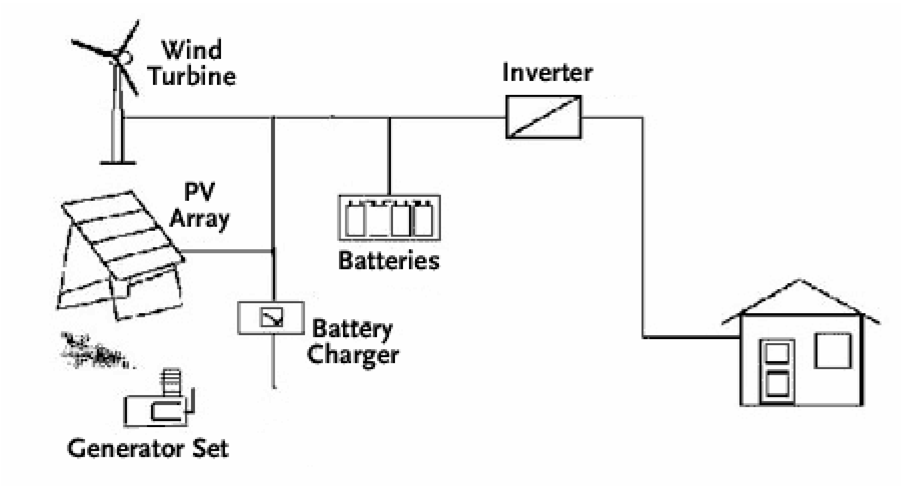

Figure 4.40: A Wind, PV, Battery System

With Electrolyser and Fuel Cell

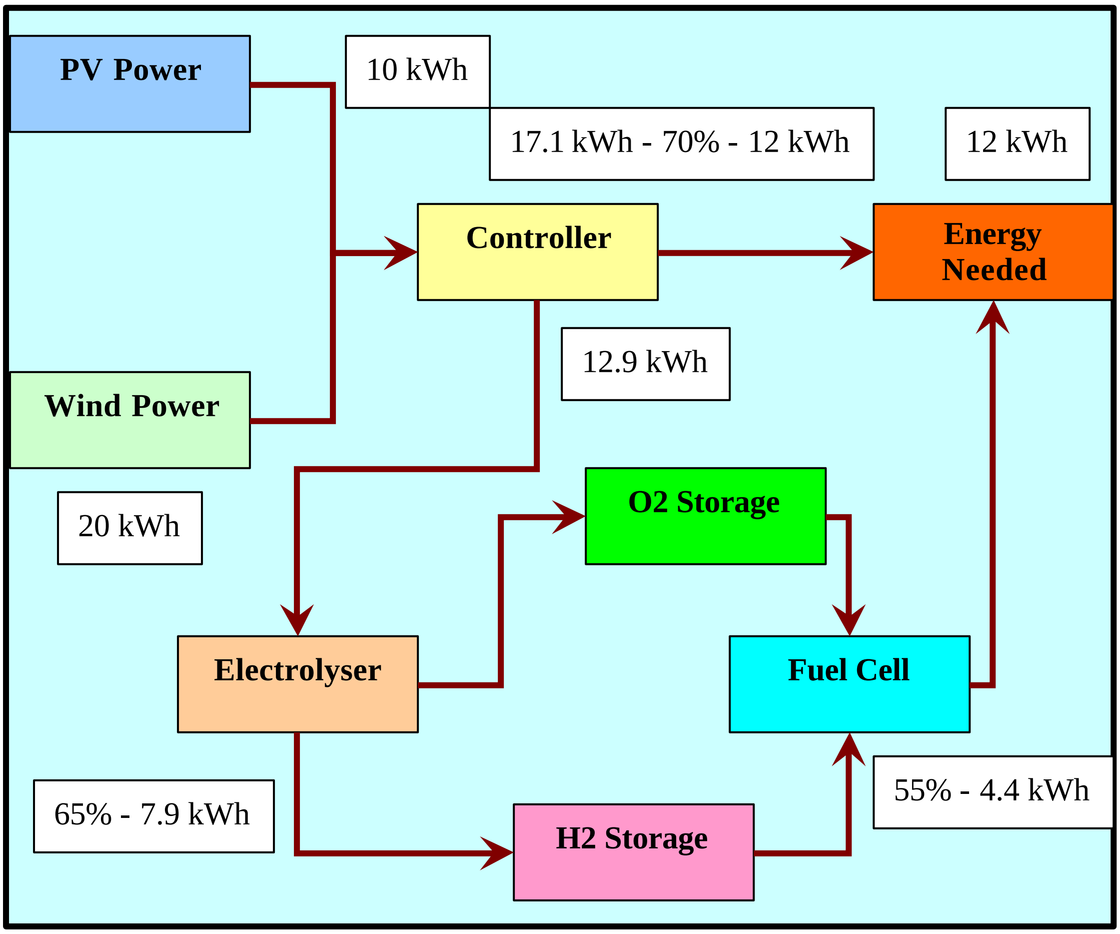

Figure 4.41: A Wind, PV, Fuel Cell System

The system with the fuel cell works almost with the same way but the efficiency is lower than the previous one.

When the house needs 12 kWh and the renewable produces 30 kWh the system works as in the figure above.

The 12 kWh is being given directly for our needs but because this procedure has 70% efficiency we provide the system with 17.1 kWh. The remaining 12.9 kWh is being headed to the electrolyser where it produces hydrogen with an efficiency of 65% equals with 7.9 kWh of energy and stores it in a vessel. When an excess amount is required for the house and the renewable can't afford to give it then the fuel cell uses the stored hydrogen and provides the additional amount. In this case the 7.9

kWh previously stored will give as in some time in the future the amount of 4.4 kWh cause of the 55% efficiency of the fuel cell.

CHAPTER 5

Unlike conventional fossil fuel technologies, renewable energy technologies (apart from biomass) generally produce no greenhouse gases or other atmospheric pollutants during their generation stage. However, emissions do arise from other stages in their life cycle (i.e. during the chain of processes required to manufacture, transport, construct and install the renewable energy plant and transmission equipment). Emissions from these stages need to be evaluated if a fair comparison of emissions is to be made.

LIFE CYCLE STAGES FOR RENEWABLE ENERGY TECHNOLOGIES

For each of the renewable energy technologies considered, life cycle emissions have been calculated.

For non-biomass technologies, the typical stages of the life cycle are:

- · Resource extraction;
- · Resource transportation;
- · Materials processing;
- · Component manufacture;
- · Component transportation;
- · Plant construction;
- · Plant operation;
- · Decommissioning;
- · Product disposal.

Ideally, each of the life cycle stages listed above should be considered, in order to evaluate the total emissions from the life cycle of the technology. However, an exact analysis of every stage is neither possible nor necessary. The emissions of most of the major air pollutants (particularly carbon dioxide, sulphur dioxide, oxides of nitrogen and particulates) are expected to be broadly proportional to energy use. Therefore, the most important life cycle stages for atmospheric emissions are those with the highest energy use.

This has shown that, for most renewable:

- The emissions released during the manufacture of the materials are the most important;
- Energy use in all of the transportation stages is likely to be negligible;
- Energy use in the extraction of the primary materials used in construction (e.g. limestone and aggregates) or in components (e.g. iron ore and copper ore) is typically an order of magnitude lower than energy use in their primary processing;
- Energy use in the construction, decommissioning and disposal processes is also likely to be at least an order of magnitude lower than for material manufacturing.

In assessing the energy use and emissions from the various technologies, data relating to realistic sites and technologies have been used, in recognition of the fact that these factors are important in determining the magnitude of some emissions.

Emissions associated with the manufacture of materials and components are dependent (to some extent) on industrial practices, the generation mix and pollution control regime in the country of manufacture. In most cases studied there was an indigenous industry, so manufacture in the country of location has been assumed; in other cases, manufacture in an appropriate exporting country was assumed.

INTRODUCTION-Wind

Wind power has been used as a source of mechanical energy for many centuries but it is now becoming a competitive electricity generation technology, with widespread use in North America, Europe and the Indian sub-continent. Wind has a very large potential global resource, yet generates few environmental impacts. Indeed, wind turbine schemes are a clean source of energy in that they produce no atmospheric emissions from electricity generation, because they harness a natural resource and convert it into electrical power.

Although the technology does not produce any long-term damage, some potential environmental impacts can arise from wind energy developments. These are usually easily reversible and tend to affect human amenity. Therefore, they are dominated by the conditions at each individual site and it is necessary for potential sites to be sensitively selected.

This module describes the possible environmental impacts which can arise from onshore wind power schemes and describes the common practices which are used to ameliorate them.

ENVIRONMENTAL IMPACTS OF WIND POWER

In many part of the world, there is such a dearth of electricity generation that the public welcomes wind turbines with open arms. Where there are alternative choices, however, environmental impact is of major significance for development. Note that impacts may be judged as either beneficial or harmful. The impacts of wind turbines and the factors influencing these are:

ACOUSTICS

Noise is mostly generated from blade tips (high frequencies), from blades passing towers and perturbing the wind (low frequencies) and from machinery, especially gearboxes. Since noise is essentially a sign of inefficiency and because of complaints, manufacturers have reduced noise-generation intensities greatly over the last five years.

The critical noise intensity is usually considered to be 40 dBA, or less, as judged necessary for sleeping. This level of acceptance is usually attained at distances of about 250 m or less. However, attitudes to noise are strongly psychological; the owner of a machine probably welcomes the noise as a sign of prosperity; whilst neighbours may be irritated by intrusion into “their space”.

LAND AREA AND USE

Turbines should be separated by at least five to ten tower heights; this allows the wind strength to reform and the air turbulence created by one rotor not to harm another turbine downwind. Consequently, only about 1 % of land area is taken out of use by the towers and the access tracks. The taller and larger the turbines, the greater the separation. Megawatt machines should be spaced between half and one kilometre apart. Neither buildings nor commercial forestry can be established between, so the land is thereafter safeguarded against such development and can be used for agriculture, leisure or natural ecology.

VISUAL IMPACT

Wind turbines are always visible from places in clear line of sight. The larger the machines, the greater the distance between them. The need for a long fetch of undisturbed wind, and the economic bias to large machines, means that machines will potentially be visible from distances of tens of kilometres. However, at such distances, the majority of the public will have their view obscured by hills, trees, buildings etc. The most likely people to notice the machines on land are walkers and pilots. For the former, beauty is in the eye of the beholder, and for the latter there is danger for exceptionally low flying. For offshore machines, visual impact is largely, as yet, unassessed.

BIRD STRIKE

Birds often collide with high voltage overhead lines, masts, poles, and windows of buildings. They are also killed by cars in the traffic. Birds are seldom bothered by wind turbines. Radar studies from Tjaereborg in the western part of Denmark, where a 2 megawatt wind turbine with 60 metre rotor diameter is installed, show that birds - by day or night - tend to change their flight route some 100-200 metres before the turbine and pass above the turbine at a safe distance. In Denmark there are several examples of birds (falcons) nesting in cages mounted on wind turbine towers. The only known site with major bird collision problems is located in the Altamont Pass in California. A "wind wall" of turbines on lattice towers is literally closing off the pass. There, a few bird kills from collisions have been reported. A study from the Danish Ministry of the Environment says that power lines, including power lines leading to wind farms, are a much greater danger to birds than the wind turbines themselves. Some birds get accustomed to wind turbines very quickly, others take a somewhat longer time. The possibilities of erecting wind farms next to bird sanctuaries therefore depend on the species in question. Migratory routes of birds will usually be taken into account when sitting wind farms. Offshore wind turbines have no significant effect on water birds. That is the overall conclusion of a three year offshore bird life study made at the Danish offshore wind farm Tunø Knob.

There have been many independent studies of birds killed by rotating blades. This undoubtedly happens, but perhaps to a similar or lower frequency than strikes by a car, against the windows of a building or: against grid transmission cables. Every death is regretted. The counter argument, again attested by experts, is that land around wind turbines may provide excellent breeding conditions. The exception to this argument is the possibility of strikes by large migratory birds flying in the dark and by raptors intent on their prey.

ELECTROMAGNETIC INTERFERENCE

TV, FM and radar waves are perturbed in line of sight by electrically conducting materials. Therefore, the metallic parts of rotating blades can produce dynamic interference in signals. It is easy, but not necessarily cheap; to install TV and FM repeater stations to provide another direction of signal for receivers. Radar interference is, as yet, a largely undocumented effect, of most concern to the military. However, wind turbines are a fact of life that has to be accepted by the military on an international scale. There are many sites of wind turbines close to airfields, and no significant difficulties occur.

INTRODUCTION- PV

The underlying principle of generating an electric current directly from light has been known for over a century. However, the development of practical applications is much more recent, so photovoltaic (PV) technology is still at a relatively early stage of development. It has been identified as a technology with considerable potential and the technology has undergone rapid development over the past decade, resulting in efficiency improvements, development of thin film PV and production of new PV materials.

At present, PV cells are used mainly in stand-alone systems to provide an electricity supply in either remote rural locations or remote industrial applications such as communications stations. Recently, modules have been integrated into building facades to provide power for the building itself. Large-scale applications such as the provision of power to the grid are still at the pilot stage. Worldwide the potential solar resource is huge and, as developments in PV technology lead to reductions in the cost of systems, the uses of PV are likely to expand to include the provision of power for the grid.

PV systems generate few environmental impacts; indeed, they are a clean source of energy in that they produce no atmospheric emissions from electricity generation, because they harness a natural resource and convert it into electrical power.

Nonetheless, some potential environmental impacts can arise from PV systems. These are confined mainly to large multi-megawatt systems and are due principally to the large land area such systems require, which can cause visual intrusion and have potential impacts on ecosystems. There are also a number of potential impacts associated with the manufacture of PV cells, which is energy intensive and uses some potentially toxic and hazardous materials.

Introduction – Fuel Cells

Fuel cells, when powered by pure clean hydrogen not acquired through the reformation of fossil fuels, are totally emissions free. The only products of the cell, besides electric current, are heat and pure potable H_2O. Through cogeneration of the heat into steam and regeneration of the water using the process of electrolysation, even these by-products are utilized. In the case that they are not utilized, there is still no harm done to the surrounding environment.

The reality, however, is that pure hydrogen is rarely used except for in laboratory studies. Steam reformers are often used to isolate the hydrogen out of hydrocarbon fuels. Steam reformation is the process of combining steam with a hydrocarbon to isolate the hydrogen. The resulting CO_2 emissions are lower than those from a combustion engine. Steam reformation emits zero to very small amounts of NO_x and SO_2.

Even though the use of fossil fuels such as natural gas and propane is not totally emissions free and not renewable, the use of these fuels to power fuel cells is cleaner than the use of combustion engines and will allow for the continued improvement of fuel cells. Fuel cells are more environmentally sound than conventional energy technologies. Below is a comparison of the amount of pollution produced by fuel cells versus conventional energy technologies.

	Acid Pollutant (e.g.SO2, Nox)	CO2 Global Warming	CH4 Global Warming	Human Health & Safety	Particulates	Heavy Metals	Catastrophes	Waste Disposal	Visual Intrusion	Noise	Land Requirement		Overall
Passive Solar Energy	1	1	1	1	1	1	1	1	2	1	1		1
Photovoltaics	1	1	1	1	2	2	1	2	2	1	2		1
Wind Power	1	1	1	1	1	1	1	1	4	2	2		1
Biomass	2	1	4	2	2	2	1	2	2	2	4		2
Geothermal Energy	2	2	2	2	1	2	1	3	2	2	1		2
Hydroelectricity	1	1	1	1	1	1	3	1	4	1	4		2
Tidal Energy	1	1	1	1	1	1	2	1	4	1	2		1
Wave Power	1	1	1	1	1	1	2	1	2	1	1		1
Fuel Cell	1	1	1	1	1	1	1	2	1	1	1		1
Coal	5	5	3	2	3	3	2	3	3	2	4		3
Oil	4	5	2	2	3	2	3	2	2	1	2		3
Natural Gas	2	5	4	2	1	1	3	1	2	1	2		2
Nuclear Power	2	2	1	2	1	1	4	4	3	1	2		2

Negligible=1
Negligible/Significant=2
Significant=3
Significant/Large=4
Large=5

Introduction to Life Cycle Assessment

Before we start calculating and analysing the emissions of the house together with the renewable energy system emissions we must first know what is LCA, how is being used, what results can give us, what steps to take for implementing such a tool.

As environmental awareness increases, industries and businesses have started to assess how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. Many businesses have responded to this awareness by providing "greener" products and using "greener" processes. The environmental performance of products and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving *beyond* compliance using pollution prevention strategies and environmental management systems to improve their environmental performance. One such tool is called life cycle assessment (LCA). This concept considers the entire life cycle of a product.

What is Life Cycle Assessment (LCA)?

Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection.

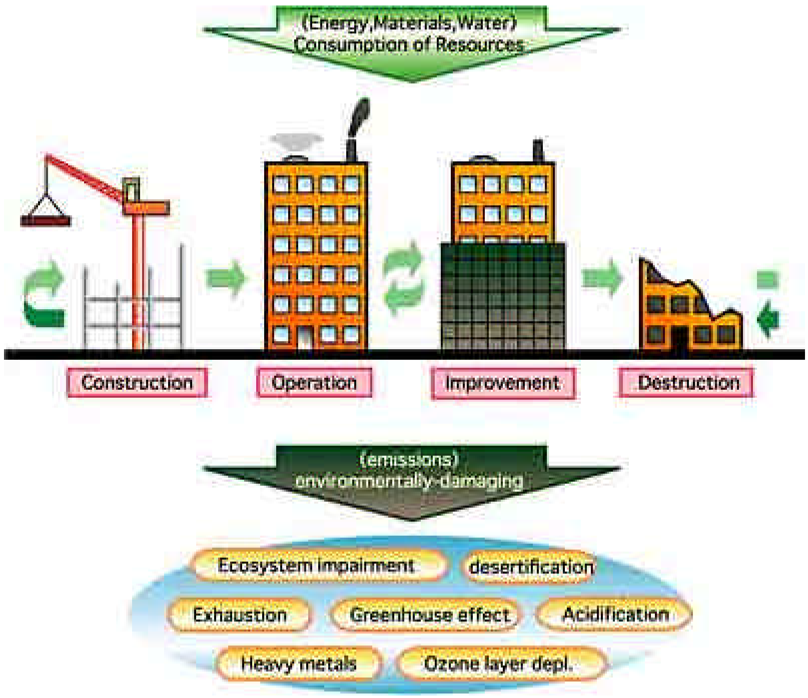

Figure 5.2: Life Cycle Stages

Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- compiling an inventory of relevant energy and material inputs and environmental releases;
- evaluating the potential environmental impacts associated with identified inputs and releases;
- interpreting the results to help you make a more informed decision.

LCA is a technique for assessing all the inputs and outputs of a product, process, or service (Life Cycle Inventory); assessing the associated wastes, human health and ecological burdens (Impact Assessment); and interpreting and communicating the results of the assessment (Life Cycle Interpretation) throughout the life cycle of the products or processes under review. The term "life cycle" refers to the major activities in the course of the product's life-span from its manufacture, use, maintenance, and final disposal; including the raw material acquisition required to manufacture the product. Figure 5.3 illustrates the possible life cycle stages that can be considered in an LCA and the typical inputs/outputs measured.

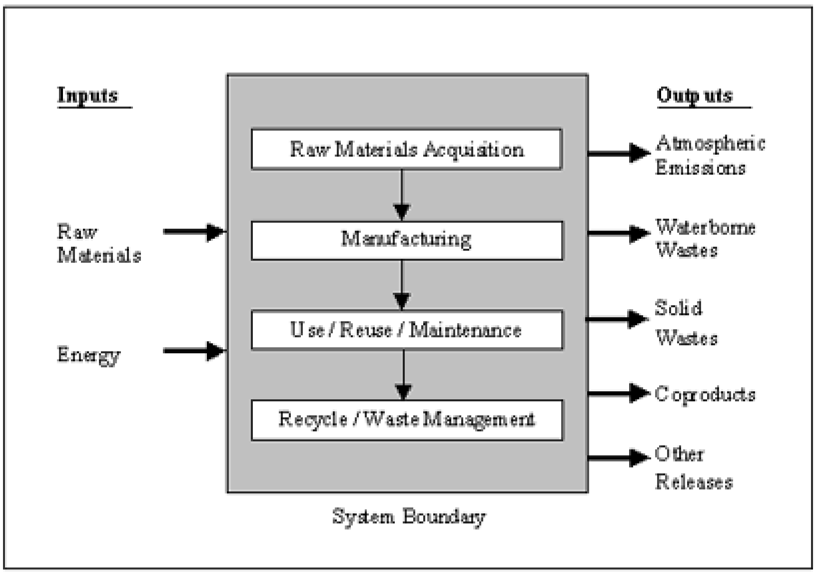

Exhibit 1-1. Life Cycle Stages (Source: EPA, 1993)

Figure 5.3: Life Cycle Stages

The LCA process is a systematic, phased approach and consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation as illustrated in Figure 5.4:

- *Goal Definition and Scoping* - Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.

- *Inventory Analysis* - Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, and wastewater discharge).
- *Impact Assessment* - Assess the human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.
- *Interpretation* - Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

Life cycle assessment is unique because it encompasses all processes and environmental releases beginning with the extraction of raw materials and the production of energy used to create the product through the use and final disposition of the product. When deciding between two alternatives, LCA can help decision-makers compare all major environmental impacts caused by products, processes, or services.

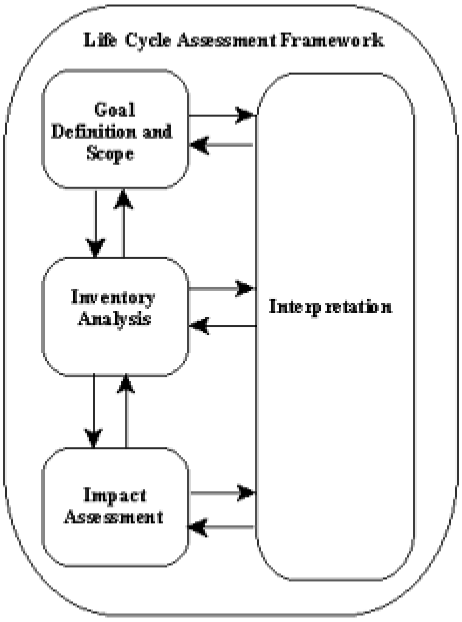

Exhibit 1-2. Phases of an LCA (Source: ISO, 1997)

Figure 5.4: Phases of an LCA

Impact Factors

In order to assess the LCIA, we required some impact factors on which to base our analysis. The ISO standards for LCA do not provide impact factors on which to judge the LCIA, however from the literature review it was decided that the most appropriate impact factors were contained in the CML methodology. These were:

- Global Warming Potential – this is the effectiveness of a compound in contributing to global warming on a molecule-by-molecule basis measured relative to CO2.
- Acidification Potential - The acidification potential is calculated for each material relative to 1kg of SOx.
- Photochemical Ozone Creation Potential or (POCP) – Photochemical ozone creation measures the potential of emissions to air to form harmful ground level ozone, a precursor to smog.

- Non renewable energy – This is the amount of energy required that comes from a non-renewable source. Non Renewable Energy is different to embodied energy, as embodied energy takes account of the energy that comes from both renewable and non-renewable sources.

LCA in the House

The "product" that we are going to analyse in order to identify the emissions that extract during its life time is the house. The general characteristics of the house can be seen from the table below.

House – 220 sq.m. with 6 Rooms	***Materials Used for the Rooms***
Kitchen, Living Room, Dining Room, West and East Bedroom, Bathroom	***Varnish, Brick, Polystyrene, Plate Glass, Marble Plates, Cement, Concrete, Rock Layer, Roof Tile***

Table 5.1: House Characteristics

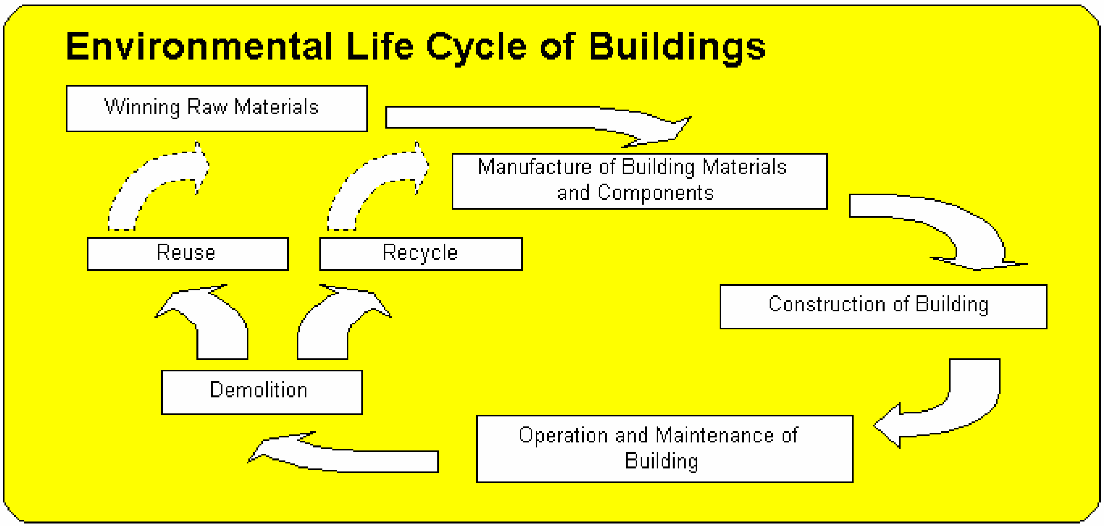

Figure 5.5: Environmental Life Cycle of the Building

After the materials have been selected the next step was to calculate the weight of each material used separately.

In the table below we can see how we calculated the mass of Brick that needed for the wall of the kitchen room.

Description	*Thickness (m)*	*Surface Area (m2)*	*Volume (m3)*	*Density Mass (kg/m3)*	*Mass (kg)*	*Assembly Loss (%)*	*Total Mass (kg)*
Brick	**0.09**	**18.36**	**1.6524**	**1200**	**1983**	**5**	**2082**

Table 5.2: Calculation of Bricks Mass

The total estimated weight from all the materials was 407.1 tonnes.

The life expectancy of the house is estimated to be 45 years. The analysis of the environmental impact of the house will start from the manufacture of the products, the construction of the house, the use of the house for a period of 20 years and last the elimination phase. In the analysis we also have included the transportation of the products to the place of construction and the transportation to a landfill. This representation it can be seen in the figure below.

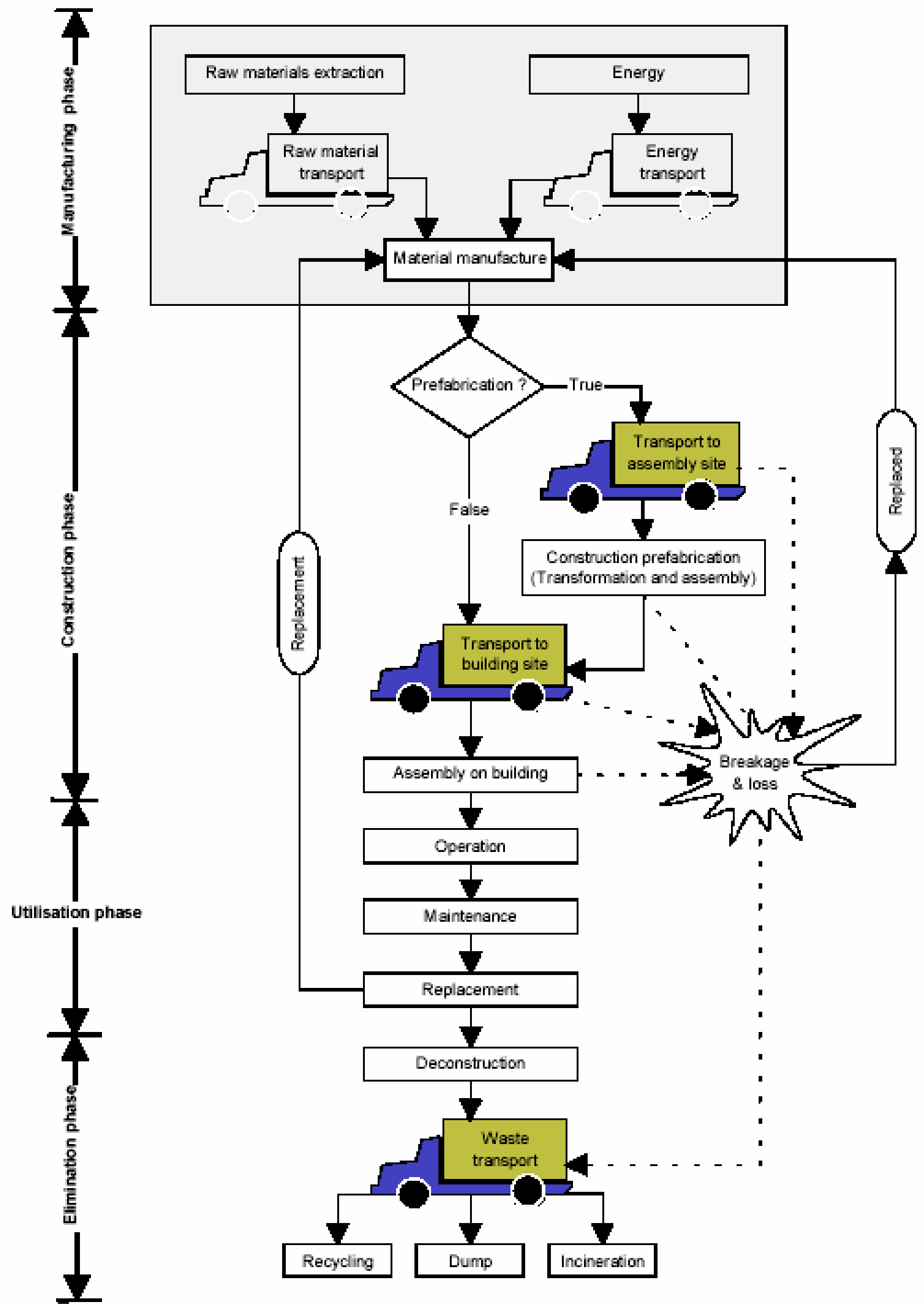

Figure 5.1 System boundaries for the building LCIA. (boundaries very little.flo)

Figure 5.6: System Boundaries for the Building

Material Manufacture

In order to calculate the environmental impact of the produced material we need to know the mass of the materials and the impact that each kg of material causes in the environment. This will be found from the chosen impact factors of GWP, AP, POCP and NRE.

In the table below we can see the procedure that was followed in order to calculate the impact for the Brick.

Description	*NRE (MJ/kg)*	*GWP (kg CO2/kg)*	*AP (kg SOx/kg)*	*POCP (kg Nox/kg)*
Brick	**1.93E+00**	**1.94E-01**	**1.22E-03**	**7.00E-05**

Table 5.3: Impact of producing 1kg of Brick

Description	*Total Mass (kg)*	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Brick	**2082**	**4.02E+03**	**4.04E+02**	**2.54E+00**	**1.46E-01**

Table 5.4: Impact of producing 2082 kg of Brick

For the whole house to manufacture the materials used the total impact is shown in the table below.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg Nox)*
House	**6.44E+05**	**6.13E+04**	**2.64E+02**	**1.63E+02**

Table 5.5: Impact of the House

Transport to construction point

To find the transportation impact we need to know the mean that carried the materials, the distance until to reach the construction point and the mass of the materials.

Again in the table below we can see the procedure.

Description	*Distance (km)*	*Transport Mean*	*Total Mass (kg)*	*NRE (MJ/tkm)*	*GWP (kg CO2/tkm)*	*AP (kg SOx/tkm)*	*POCP (kg NOx/tkm)*
Brick	**150**	**Lorry 16t**	**2082**	**5.10E+00**	**3.30E-01**	**3.80E-03**	**7.60E-04**

Table 5.6: Impact of transport 1 tkm of Brick

Description	*Total Mass (kg)*	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg Nox)*
Brick	**2082**	**1.59E+03**	**1.03E+02**	**1.19E+00**	**2.37E-01**

Table 5.7: Impact of transport 312.3 tkm kg of Brick

For the whole house the impact is.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
House	**2.73E+05**	**1.79E+04**	**1.99E+02**	**3.91E+01**

Table 5.8: Impact of transport the materials of the House

Utilisation Phase

In the utilisation phase we have the daily energy consumption of the house. In a year the house consumes 36,178.8 kWh of energy for space heating and electricity. With this amount we are going to estimate the environmental impact from the consumption of the house in the period of 20 years. For 20 years the consumption of the house is 723,576 kWh.

We know that 1 kWh equals to 3.6 MJ, so in MJ is 2.6E+06.

In the table below we can see the impact from the electricity usage for 1 MJ.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg Nox)*
Electricity	**3.555E+00**	**1.681E-01**	**1.201E-03**	**2.441E-04**

Usage	

Table 5.9: Impact from Electricity Usage of 1MJ

For the amount we calculated the impact is.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg Sox)	POCP (kg NOx)
Electricity Usage	**9.25E+06**	**4.38E+05**	**3.13E+03**	**6.35E+02**

Table 5.10: Impact from 20 years Electricity Usage

Transportation to the landfill

Again to find the transportation impact we needed the distance to the landfill and the mean of transport.

Description	Distance (km)	Transport Mean	Total Mass (kg)	NRE (MJ/tkm)	GWP (kg CO2/tkm)	AP (kg Sox/tkm)	POCP (kg NOx/tkm)
Brick	**200**	**Lorry 16t**	**2082**	**5.10E+00**	**3.30E-01**	**3.80E-03**	**7.60E-04**

Table 5.11: Impact of transport 1 tkm of Brick

Description	Total Mass (kg)	NRE (MJ)	GWP (kg CO2)	AP (kg Sox)	POCP (kg NOx)
Brick	**2082**	**2.12E+03**	**1.37E+02**	**1.58E+00**	**3.16E-01**

Table 5.12: Impact of transport 312.3 tkm of Brick

For the whole house is.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg Sox)	POCP (kg NOx)
House	**4.15E+05**	**2.69E+04**	**3.09E+02**	**6.19E+01**

Table 5.13: Impact of transport the materials of the House

Elimination to landfill

In this phase the impact that the materials have on the ground is estimated.

Description	NRE (MJ/kg)	GWP (kg CO2/kg)	AP (kg Sox/kg)	POCP (kg NOx/kg)
Brick	8.23E-03	5.57E-04	5.29E-06	5.75E-06

Table 5.14: Impact of 1 kg of Brick in the landfill

Description	Total Mass (kg)	NRE (MJ)	GWP (kg CO2)	AP (kg Sox)	POCP (kg NOx)
Brick	2082	1.71E+01	1.16E+00	1.10E-02	1.20E-02

Table 5.15: Impact of 2082 kg of Brick in the landfill

For the whole house the impact is.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg Sox)	POCP (kg NOx)
House	3.35E+03	2.27E+02	2.15E+00	2.34E+00

Table 5.16: Impact of the House in the landfill

Total Emissions from the House

If we combine all the previous phases together we will have the total emissions that the house causes from the beginning of the material production until the disposal of it in the landfill.

In the table below we can see all the five phases together.

Life Cycle Phases	Total NRE (MJ)	Total GWP (kg CO2)	Total AP (kg Sox)	Total POCP (kg Nox)
Manufacture	6.44E+05	6.13E+04	2.64E+02	1.63E+02
Transport	2.73E+05	1.79E+04	1.99E+02	3.91E+01

Utilisation	**9.25E+06**	**4.38E+05**	**3.13E+03**	**6.35E+02**
Transport	**4.15E+05**	**2.69E+04**	**3.09E+02**	**6.19E+01**
Landfill	**3.35E+03**	**2.27E+02**	**2.15E+00**	**2.34E+00**

Table 5.17: Impact from all Life Cycle Stages for the House

For more convenience we are going to use only three phases that we are going to mention them, pre-use phase, use phase and elimination phase. That's why the transport impacts are going to be added in the manufacture and landfill phase respectively.

The final table then is.

Life Cycle Phases	Total NRE (MJ)	Total GWP (kg CO2)	Total AP (kg Sox)	Total POCP (kg Nox)
Pre-Use Phase	**9.17E+05**	**7.91E+04**	**4.63E+02**	**2.02E+01**
Use Phase	**9.25E+06**	**4.38E+05**	**3.13E+03**	**6.35E+02**
Elimination Phase	**4.19E+05**	**2.71E+04**	**3.12E+02**	**6.42E+01**

Table 5.18: Impact from the three phases for the House

We will see now in a graphical representation, the distribution of the environmental impact from the house in the three main phases.

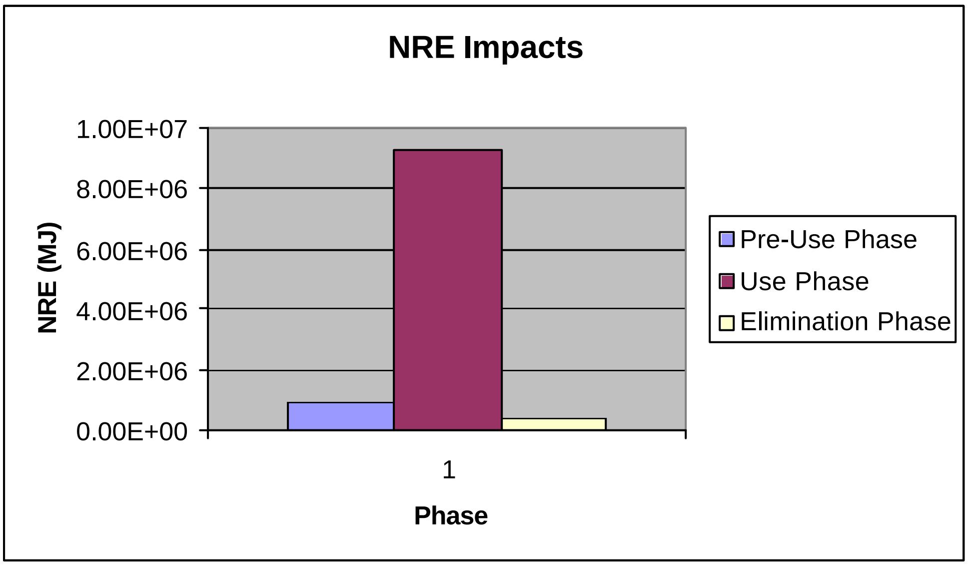

Figure 5.7: NRE Impact for each phase

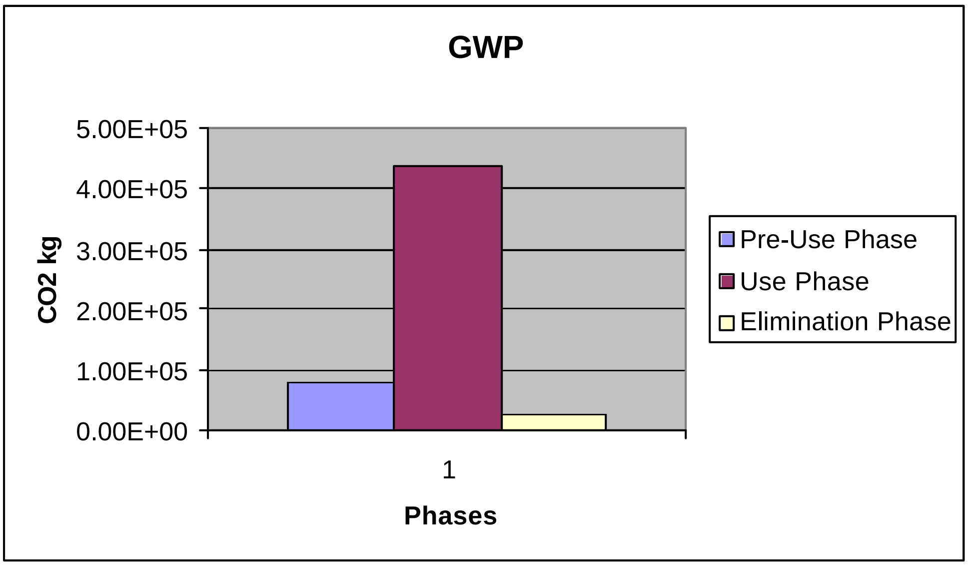

Figure 5.8: GWP Impact for each phase

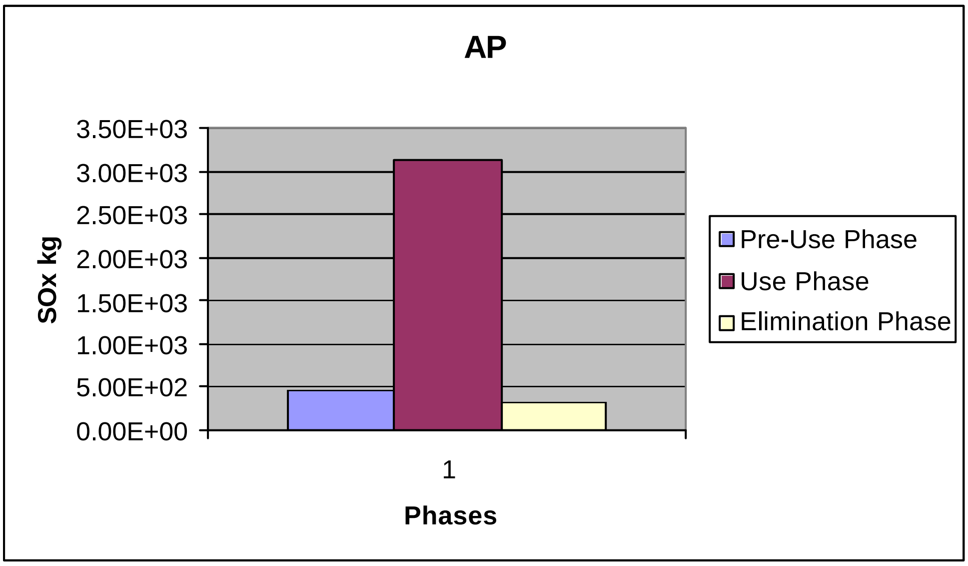

Figure 5.9: AP Impact for each phase

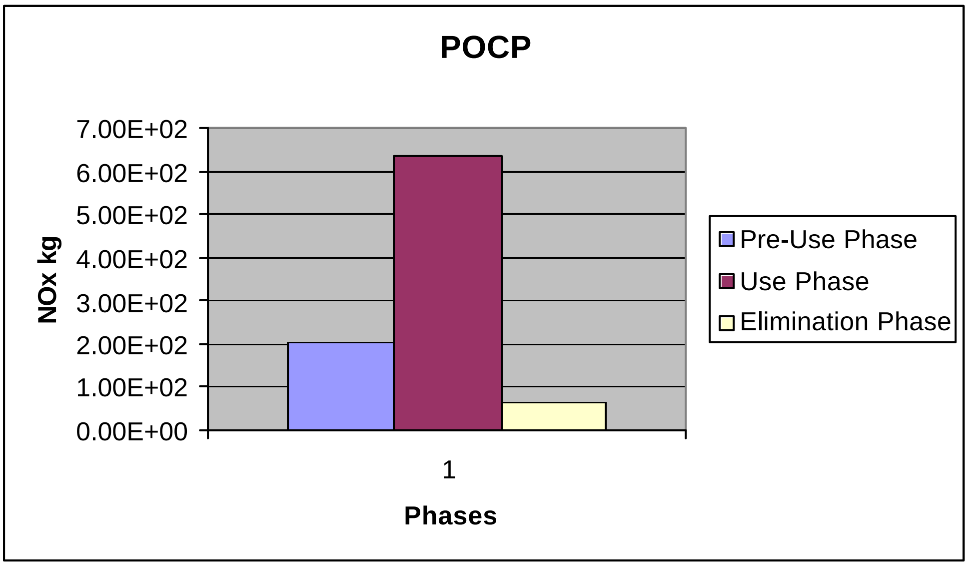

Figure 5.10: POCP Impact for each phase

From the figures above we can see that the main environmental impact comes from the use phase. This means that if there was a way to disappear these emissions then it would be better for the environment.

This can be also seen from the figure below where the use phase counts almost the 80% of the total emissions.

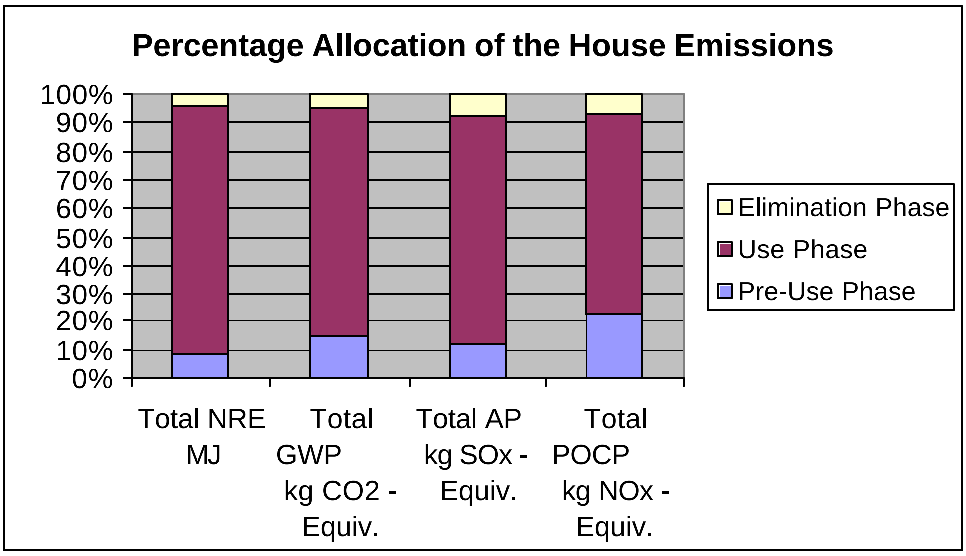

Figure 5.11: Percentage Allocation of the House Emissions from each phase

That's why we tried in the previous chapter to replace the energy that was coming from conventional plants with renewable energy that would come from PV and Wind turbines.

In chapter 4 we managed to succeed this replacement and now will try to measure the affect that the renewable equipment has in the environment and if this amount causes greater impact than the amount of the electricity that was used before.

In our next topics in this chapter will try to analyse with what material these equipment operate and to evaluate the environmental impact of the whole renewable system in comparison with the house.

LCA in PV

Before we start analysing the emissions of PV lets first see the general characteristics of the system.

PV of 120 sq.m	***Materials Used for the PV***
Each PV is of 150 W and of 1 sq.m	***Silicon, Polyester, Aluminium,***

The mass for 1 sq.m of PV is 15 kg	***HPDE, Glass***

Table 5.19: General Characteristics of the PV

The same procedure is going to be followed here as in the house.

Material Manufacture

To find the impact that the manufacture of these materials into PV we need to know the mass of each component and the emissions that one kg of material causes to the environment.

Description	*Mass for 1m2*	*Mass for 120 m2*	*Assembly Losses (%)*	*Total Mass (kg)*
Silicon	**3**	**360**	**10**	**396**

Table 5.20: Total Mass of the Silicon in the PV

For 1 kg the emissions are.

Description	*NRE (MJ/kg)*	*GWP (kg CO2/kg)*	*AP (kg Sox/kg)*	*POCP (kg NOx/kg)*
Silicon	**8.68E+01**	**2.54E+00**	**2.050E-02**	**2.67E-02**

Table 5.21: Impact from 1 kg of Silicon

For 396 kg of the total Silicon the emissions are.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
Silicon	**3.44E+04**	**1.01E+03**	**8.12E+00**	**1.06E+01**

Table 5.22: Impact from 396 kg of Silicon

The total emissions for the PV are.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*

PV	**1.15E+04**	**4.48E+03**	**6.29E+01**	**2.53E+01**

Table 5.23: Impact from all the PV

Transport to the installation point

To find the transportation emissions we need to know the distance from the factory to the house and the mean of transport.

Description	*Distance (km)*	*Mean*	*NRE (MJ/tkm*	*GWP (kg CO2/tkm*	*AP (kg Sox/tkm*	*POCP (kg NOx/tkm*
Silicon	**1000**	**Delivery van, < 3.5 tonnes**	**1.10E+01**	**7.00E-01**	**5.80E-03**	**1.80E-03**

Table 5.24: Impact of transport 1 tkm of Silicon

For 396 tkm (396 kg = 0.396 t * 1000 km = 396 tkm) the factors are changing to.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
Silicon	**4.36E+03**	**2.77E+02**	**2.30E+00**	**7.13E-01**

Table 5.25: Impact of transport 396 tkm of Silicon

The total emissions for the PV are.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
PV	**2.18E+04**	**1.39E+03**	**1.15E+01**	**3.56E+01**

Table 5.26: Impact of transport for all the PV

Utilisation Phase

In the use phase we assume that the maintenance of a system like PV cause negligible emissions compared with the other two phases.

An important advantage of PV systems is that they require little maintenance. The arrays themselves are durable and reliable and need little attention.

Unless you live in an extremely dusty area or have severe problems with ice storms, you need to inspect the wiring and general panel appearance only occasionally. If your system has an adjustable mounting, you can carry out this routine maintenance check at the same time as you adjust the tilt angle of the array. When you adjust the angle of the array for winter operation, snow loading is not a problem because the array is tilted steeply. If the array becomes dusty, clean it with a mild soap or plain water and a soft cloth. Do not use solvents or strong detergents.

Periodic Inspection List

Collector Shading: The performance of solar collectors / panels can be greatly affected by shading. Vegetation growth over time or new construction on your house or your neighbour's property may produce shading that did not occur when the collectors / panels were installed. Even the shade from something as small as an overhead wire can reduce the output of some types of PV panels. Shading of one part of even one module in a PV array can reduce the array output significantly. Visually check for shading of the collectors / panels during the day (mid-morning, noon, and mid-afternoon) on an annual basis.

Collector Soiling: Dusty or soiled collectors / modules will perform poorly. Periodic cleaning may be necessary in dry, dusty climates. Bird droppings on PV panels should be cleaned off as soon as they are noticed.

Collector Glazing and Seals: Look for cracks in the collector glazing, and check to see if seals are in good condition. Plastic glazing, if excessively yellowed, may need to be replaced.

Plumbing, Ductwork, and Wiring Connections: Look for fluid leaks at pipe connections. Check duct connections and seals; ducts should be sealed with a mastic compound. All wiring connections should be tight.

Support Structures: Check all nuts and bolts attaching the collectors / panels to any support structures for tightness.

Because the maintenance of such a system can't be measured in the LCA analysis we decided to apply a small amount of energy consumption for this service. So we assumed that for every year the maintenance of the system will be equal to 10 kWh of energy.

With this amount we are going to estimate the environmental impact for the maintenance of the PV in the period of 20 years. For 20 years the consumption is 200 kWh.

We know that 1 kWh equals to 3.6 MJ, so in MJ is 7.2E+02.

In the table below we can see the impact from the electricity usage for 1 MJ.

Description	***NRE (MJ)***	***GWP (kg CO2)***	***AP (kg Sox)***	***POCP (kg NOx)***
Electricity Usage	**3.555E+00**	**1.681E-01**	**1.201E-03**	**2.441E-04**

Table 5.27: Impact from Electricity Usage of 1MJ

For the amount we calculated the impact is.

Description	***NRE (MJ)***	***GWP (kg CO2)***	***AP (kg Sox)***	***POCP (kg NOx)***
Electricity Usage	**2.56E+03**	**1.21E+02**	**8.65E-01**	**1.76E-01**

Table 5.28: Impact from 20 years of Electricity Usage

Transport to the landfill

To find the transportation emissions we need to know the distance from the factory to the house and the mean of transport.

Description	***Distance (km)***	***Mean***	***NRE (MJ/tkm)***	***GWP (kg CO2/tkm)***	***AP (kg SOx/tkm)***	***POCP (kg NOx/tkm)***
Silicon	**200**	**Delivery van, < 3.5 tonnes**	**1.10E+01**	**7.00E-01**	**5.80E-03**	**1.80E-03**

Table 5.29: Impact of transport 1 tkm of Silicon

For 396 tkm (396 kg = 0.396 t * 200 km = 79.2 tkm) the factors are changing to.

Description	***NRE (MJ)***	***GWP (kg CO2)***	***AP (kg Sox)***	***POCP (kg NOx)***
Silicon	**8.71E+02**	**5.54E+01**	**4.59E-01**	**1.43E-01**

Table 5.30: Impact of transport 79.2 tkm of Silicon

The total emissions for the PV are.

Description	***NRE (MJ)***	***GWP (kg CO2)***	***AP (kg SOx)***	***POCP (kg NOx)***

PV	**4.36E+03**	**2.77E+02**	**2.30E+00**	**7.13E-01**

Table 5.31: Impact of transport all the PV

Elimination to landfill

The emissions for 1 kg of silicon to the landfill are.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Silicon	**8.23E-03**	**5.57E-04**	**5.29E-06**	**5.75E-06**

Table 5.32: Impact of 1 kg Silicon in the landfill

For 396 kg.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Silicon	**3.26E+00**	**2.21E-01**	**2.09E-03**	**2.28E-03**

Table 5.33: Impact of 396 kg of Silicon in the landfill

The total emissions for the PV are.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
PV	**1.63E+01**	**1.10E+00**	**1.05E-02**	**1.14E-02**

Table 5.34: Impact of the PV in the landfill

Total Emissions from the PV

If we combine all the previous phases together we will have the total emissions that the PV causes from the beginning of the material production until the disposal of it in the landfill.

In the table below we can see all the five phases together.

Life Cycle Phases	Total NRE (MJ)	Total GWP (kg CO2)	Total AP (kg Sox)	Total POCP (kg NOx)
Manufacture	1.15E+05	4.48E+03	6.29E+01	2.53E+01
Transport	2.18E+04	1.39E+03	1.15E+01	3.56E+00
Utilisation	2.56E+03	1.21E+02	8.65E-01	1.76E-01
Transport	4.36E+03	2.77E+02	2.30E+00	7.13E-01
Landfill	1.63E+01	1.10E+00	1.05E-02	1.14E-02

Table 5.35: Impact from all Life Cycle Stages for the PV

The final table then is.

Life Cycle Phases	Total NRE (MJ)	Total GWP (kg CO2)	Total AP (kg SOx)	Total POCP (kg NOx)
Pre-Use Phase	1.37E+05	5.86E+03	7.43E+01	2.89E+01
Use Phase	2.56E+03	1.21E+02	8.65E-01	1.76E-01
Elimination Phase	4.37E+03	2.78E+02	2.31E+00	7.24E-01

Table 5.36: Impact from the three phases for PV

We will see now in a graphical representation, the distribution of the environmental impact of GWP from the PV in the three main phases.

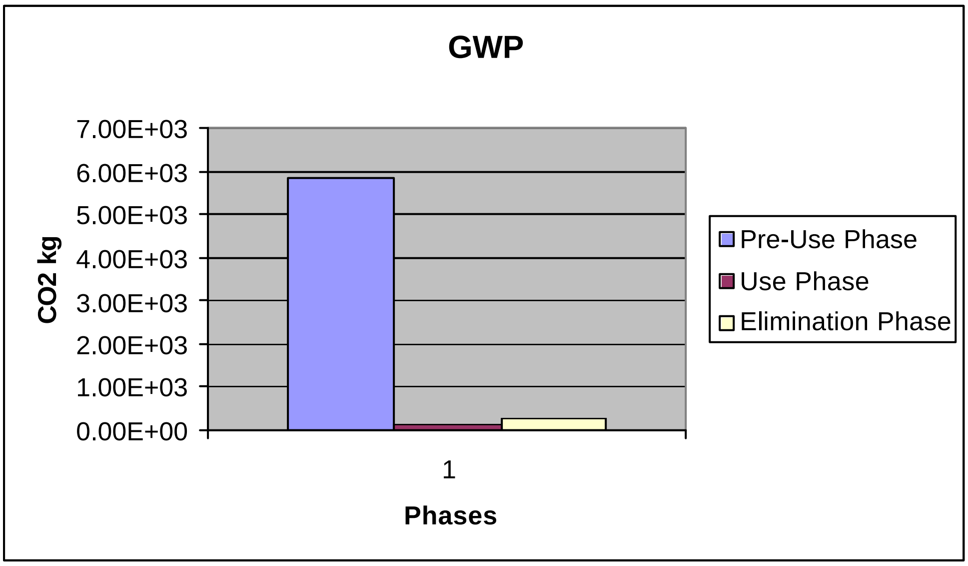

Figure 5.12: GWP Impact for each phase

From the figure above we can see that the main environmental impact comes from the pre use phase. The same is being observed in the other three impact factors. This can be also seen from the figure below where the use phase counts almost the 95% of the total emissions.

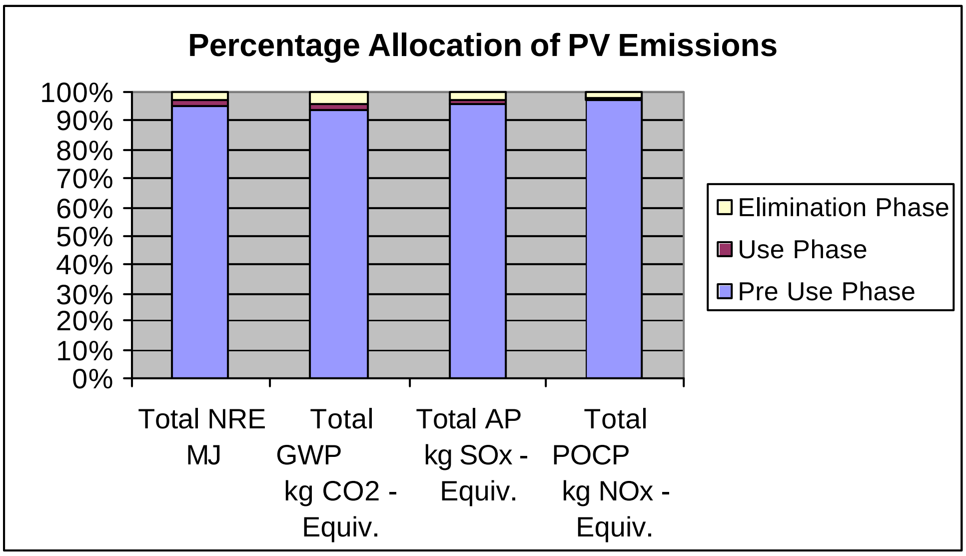

Figure 5.13: Percentage Allocation of PV Emissions

LCA for Wind Turbine

The general characteristics of the wind turbine are:

The two different renewable systems, one with batteries and one with the fuel cell give different values. One with 15.306 kW and the other with 24.956 kW.	***A wind turbine consists of the blades, the nacelle, the generator, the gear box, the tower, the base.***
Cause of the previous situation we tried to get a mass number that would be close to both of systems	***The materials that was used in order to manufacture a wind turbine were HDPE, Copper, Aluminium, Fibreglass, Steel, Concrete and Paint***

Table: 5.37: General Characteristics of Wind Turbine

Material Manufacture

Description	*NRE (MJ/kg)*	*GWP (kg CO2/kg)*	*AP (kg SOx/kg)*	*POCP (kg NOx/kg)*
Copper	9.92E+01	5.51E+00	1.43E-01	8.61E-03

Table 5.38: Impact from 1 kg of Copper

For 49.5 kg the factors are changing to:

Description	*NRE (MJ/kg)*	*GWP (kg CO2/kg)*	*AP (kg SOx/kg)*	*POCP (kg NOx/kg)*
Copper	4.91E+03	2.727E+02	7.079E+00	4.262E-01

Table 5.39: Impact from 49.5 kg of Copper

For the whole materials used for the turbine we have:

Description	*NRE (MJ/kg)*	*GWP (kg*	*AP (kg*	*POCP (kg*

		CO_2/kg)	SOx/kg)	NOx/kg)
Wind T.	**7.65E+04**	**4.579E+03**	**2.525E+01**	**7.718E+00**

Table 5.40: Impact from the whole Wind turbine

Transport to the installation point

For 1kg of copper the impact is:

Description	*Distance (km)*	*Mean*	*NRE (MJ/tkm)*	*GWP (kg CO_2/tkm)*	*AP (kg SOx/tkm)*	*POCP (kg SOx/tkm)*
Copper	**2000**	**Lorry,16t**	**5.1E+00**	**3.3E-01**	**3.8E-03**	**7.6E-04**

Table 5.41: Impact from transport 1 tkm of Copper

For 49.5 kg or 0.0495 t or 99 tkm:

Description	*NRE (MJ)*	*GWP (kg CO_2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Copper	**5.05E+02**	**3.27E+01**	**3.76E-01**	**7.52E-02**

Table 5.42: Impact from transport 99 tkm of Copper

For the whole turbine:

Description	*NRE (MJ)*	*GWP (kg CO_2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Wind T.	**3.32E+04**	**2.15E+03**	**2.47E+01**	**4.94E+00**

Table 5.43: Impact from the whole Wind turbine

Utilisation Phase

In the use phase we assume that the maintenance of a system like a wind turbine cause negligible emissions compared with the other two phases.

The manufacturer usually specifies what is required for the maintenance of a wind turbine. The entire wind system, including the tower, storage devices and wiring should be inspected at least once a year. Routine maintenance might include changing the transmission oil, greasing the bearings and visually inspecting the condition of the blades, tower and electrical connections. Instead of doing the maintenance work yourself (which may require climbing the tower), you can arrange a maintenance contract with the dealer.

In the field of wind turbine the maintenance should including:

- Blade cleaning and surface repair
- Survey and testing
- Ice removal systems and techniques (including a call-out service)
- General site maintenance / pylon maintenance etc.

With the same way as in the PV system we assume that for every year the maintenance of the wind system will be equal to 15 kWh of energy.

With this amount we are going to estimate the environmental impact for the maintenance of the wind turbine in the period of 20 years. For 20 years the consumption is 300 kWh.

We know that 1 kWh equals to 3.6 MJ, so in MJ is 1.08E+03.

In the table below we can see the impact from the electricity usage for 1 MJ.

Description	***NRE (MJ)***	***GWP (kg CO2)***	***AP (kg Sox)***	***POCP (kg NOx)***
Electricity Usage	**3.555E+00**	**1.681E-01**	**1.201E-03**	**2.441E-04**

Table 5.44: Impact from the Electricity Usage of 1 MJ

For the amount we calculated the impact is.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
Electricity Usage	**3.84E+03**	**1.81E+02**	**1.29E+00**	**2.63E-01**

Table 5.45: Impact for 20 years from the Electricity Usage

Transport to the landfill

For 1kg of copper the impact is:

Description	*Distance (km)*	*Mean*	*NRE (MJ/tkm)*	*GWP (kg CO2/tkm)*	*AP (kg SOx/tkm)*	*POCP (kg SOx/tkm)*
Copper	**200**	**Lorry,16t**	**5.1E+00**	**3.3E-01**	**3.8E-03**	**7.6E-04**

Table 5.46: Impact from transport 1 tkm of Copper

For 49.5 kg or 0.0495 t or 9.9 tkm:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Copper	**5.05E+01**	**3.27E+00**	**3.76E-02**	**7.52E-03**

Table 5.47: Impact from transport 9.9 tkm of Copper

For the whole turbine:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Wind T.	**3.32E+03**	**2.15E+02**	**2.47E+00**	**4.94E-01**

Table 5.48: Impact from transport the whole Wind turbine

Elimination to the landfill

The emissions for 1 kg of copper to the landfill are.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg SOx)	POCP (kg NOx)
Copper	8.23E-03	5.57E-04	5.29E-06	5.75E-06

Table 5.49: Impact from 1 kg of Copper in the landfill

For 49.5 kg.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg SOx)	POCP (kg NOx)
Copper	4.07E-01	2.76E-02	2.62E-04	2.85E-04

Table 5.50: Impact from 49.5 kg of Copper in the landfill

The total emissions for the wind turbine are.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg Sox)	POCP (kg NOx)
Wind T.	2.68E+01	1.81E+00	1.72E-02	1.87E-02

Table 5.51: Impact from the whole Wind turbine in the landfill

Total Emissions from the Wind Turbine

If we combine all the previous phases together we will have the total emissions that the wind turbine causes from the beginning of the material production until the disposal of it in the landfill.

In the table below we can see all the five phases together.

Life Cycle Phases	Total NRE (MJ)	Total GWP (kg CO2)	Total AP (kg Sox)	Total POCP (kg NOx)
Manufacture	7.65E+04	4.579E+03	2.525E+01	7.718E+00

Transport	**3.32E+04**	**2.15E+03**	**2.47E+01**	**4.94E+00**
Utilisation	**3.84E+03**	**1.81E+02**	**1.29E+00**	**2.63E-01**
Transport	**3.32E+03**	**2.15E+02**	**2.47E+00**	**4.94E-01**
Landfill	**2.68E+01**	**1.81E+00**	**1.72E-02**	**1.87E-02**

Table 5.52: Impact from all Life Cycle Stages for the Wind Turbine

The final table then is.

Life Cycle Phases	***Total NRE (MJ)***	***Total GWP (kg CO2)***	***Total AP (kg SOx)***	***Total POCP (kg NOx)***
Pre-Use Phase	**1.097E+05**	**7.725E+03**	**4.996E+01**	**1.266E+01**
Use Phase	**3.84E+03**	**1.81E+02**	**1.29E+00**	**2.63E-01**
Elimination Phase	**3.34E+03**	**2.16E+02**	**2.49E+00**	**5.13E-01**

Table 5.53: Impact from the three phases for the Wind Turbine

We will see now in a graphical representation, the distribution of the environmental impact of GWP from the wind turbine in the three main phases.

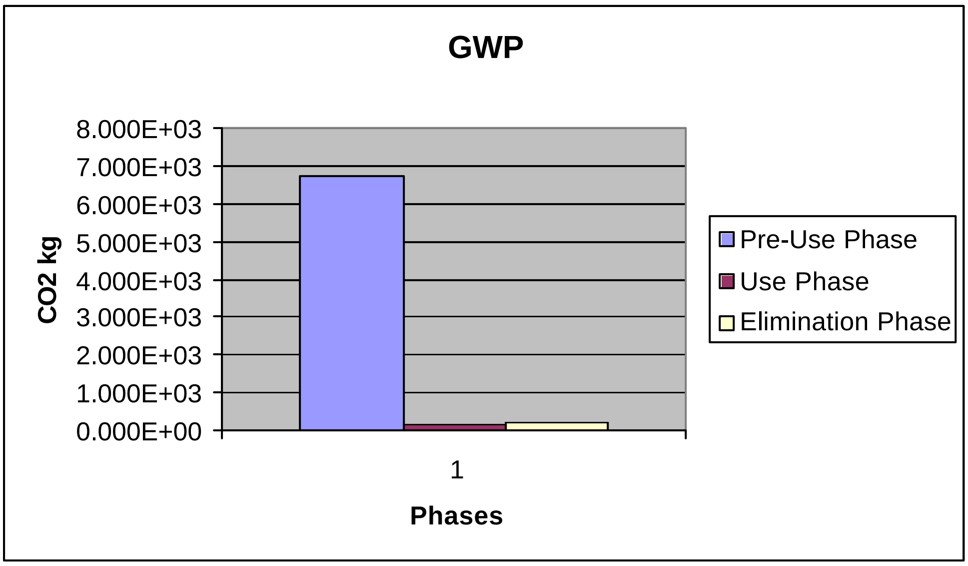

Figure 5.14: GWP Impacts for each phase

From the figure above we can see that the main environmental impact comes from the pre use phase. The same is being observed in the other three impact factors. This can be also seen from the figure below where the use phase counts almost the 95% of the total emissions.

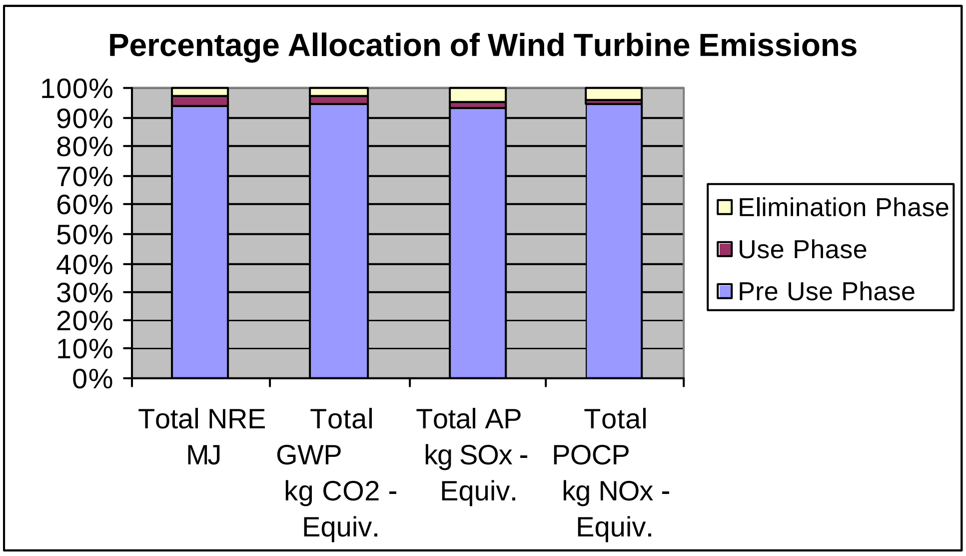

Figure 5.15: Percentage Allocation of Wind Turbine Emissions

LCA for the Batteries

The general characteristics of the batteries are:

The capacity of one battery is 36 kWh and the total is 180 kWh. The battery is of a deep cycle type with 2V and 1500 A*h capacity.	***The material that the batteries are made of is: Alloy-Calcium, Lead, Polyethylene, Acid and Glass Fiber***
Because the batteries have a life time of 8 years we assume that we have 2.5 times more batteries analysed.	***The mass of each 2V battery is 30 kg and the analysed units are 144.***

Table 5.54: General Characteristics of the Batteries

Material Manufacture

Description	*Mass for 1 battery (kg)*	*Items*	*Assembly Losses (%)*	*Total Mass (kg)*
Polyethylene	**4.5**	**144**	**10**	**712.8**

Table 5.55: Total Mass of the Polyethylene for the Batteries

For 1kg of polyethylene:

Description	*NRE (MJ/kg)*	*GWP (kg CO2/kg)*	*AP (kg Sox/kg)*	*POCP (kg NOx/kg)*
Polyethylene	**8.68E+01**	**2.54E+00**	**2.05E-02**	**2.67E-02**

Table 5.56: Impact from 1 kg of Polyethylene

For 712.8 kg:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
Polyethylene	**6.19E+04**	**1.81E+03**	**1.46E+01**	**1.90E+01**

Table 5.57: Impact from 712.8 kg of Polyethylene

For the whole system of batteries:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Batteries	**2.43E+05**	**1.12E+04**	**6.93E+01**	**5.13E+01**

Table 5.58: Impact from the all Batteries

Transport to the installation point

Description	*Distance (km)*	*Mean*	*NRE (MJ/tkm)*	*GWP (kg CO2/tkm)*	*AP (kg SOx/tkm)*	*POCP (kg NOx/tkm)*
Polyethylene	**800**	**Delivery**	**1.10E+01**	**7.00E-01**	**5.80E-03**	**1.80E-03**

	van,3.5 t

Table 5.59: Impact from transport 1 tkm of Polyethylene

For 570.24 tkm:

Description	***NRE (MJ)***	***GWP (kg CO2)***	***AP (kg SOx)***	***POCP (kg NOx)***
Polyethylene	**6.27E+03**	**3.99E+02**	**3.31E+00**	**1.03E+00**

Table 5.60: Impact from transport 570.24 tkm of Polyethylene

For the whole system:

Description	***NRE (MJ)***	***GWP (kg CO2)***	***AP (kg SOx)***	***POCP (kg NOx)***
Batteries	**4.18E+04**	**2.66E+03**	**1.29E+01**	**6.84E+00**

Table 5.61: Impact of transport all the batteries

Utilisation Phase

In the use phase we assume that the maintenance of a system like batteries cause negligible emissions compared with the other two phases.

Battery Maintenance is an important issue. The battery should be cleaned using a baking soda and water mix. Cable connection needs to be clean and tightened. Many battery problems are caused by dirty and loose connections. A serviceable battery needs to have the fluid level checked. Use only mineral free water. Distilled water is best. Don't overfill battery cells especially in warmer weather. The natural fluid expansion in hot weather will push excess electrolytes from the battery. To prevent corrosion of cables on top post batteries use a small bead of silicon sealer at the base of the post and place a felt battery washer over it. Coat the washer with high temperature grease or petroleum jelly (Vaseline), then place cable on the post and tighten. Coat the exposed cable end with the grease. Most don't know that just the gas from the battery condensing on metal parts causes most corrosion.

With the same way as in the previous systems we assume that for every year the maintenance of the batteries will be equal to 12 kWh of energy.

With this amount we are going to estimate the environmental impact for the maintenance of the wind turbine in the period of 20 years. For 20 years the consumption is 240 kWh.

We know that 1 kWh equals to 3.6 MJ, so in MJ is 8.64E+02.

In the table below we can see the impact from the electricity usage for 1 MJ.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
Electricity Usage	**3.555E+00**	**1.681E-01**	**1.201E-03**	**2.441E-04**

Table 5.62: Impact from Electricity Usage of 1 MJ

For the amount we calculated the impact is.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Electricity Usage	**3.07E+03**	**1.45E+02**	**1.04E+00**	**2.11E-01**

Table 5.63: Impact from 20 years of Electricity Usage

Transport to the landfill

Description	*Distance (km)*	*Mean*	*NRE (MJ/tkm)*	*GWP (kg CO2/tkm)*	*AP (kg SOx/tkm)*	*POCP (kg NOx/tkm)*

Polyethylene	**200**	**Delivery van,3.5 t**	**1.10E+01**	**7.00E-01**	**5.80E-03**	**1.80E-03**

Table 5.64: Impact from transport 1 tkm of Polyethylene

For 142.56 tkm:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Polyethylene	**1.57E+03**	**9.98E+01**	**8.27E-01**	**2.57E-01**

Table 5.65: Impact from transport 142.56 tkm of Polyethylene

For the whole system:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Batteries	**1.05E+04**	**6.65E+02**	**5.51E+00**	**1.71E+00**

Table 5.66: Impact of transport for all Batteries

Elimination to landfill

The emissions for 1 kg of polyethylene to the landfill are.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Polyethylene	**8.23E-03**	**5.57E-04**	**5.29E-06**	**5.75E-06**

Table 5.67: Impact from 1 kg of Polyethylene in the landfill

For 712.8 kg.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Polyethylene	**5.86E+00**	**3.97E-01**	**3.77E-03**	**4.10E-03**

Table 5.68: Impact from 712.8 kg of Polyethylene in the landfill

The total emissions for the batteries are.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Batteries	**3.91E+01**	**2.65E+00**	**2.51E-02**	**2.73E-02**

Table 5.69: Impact from all the Batteries in the landfill

<u>Total Emissions from the Batteries</u>

If we combine all the previous phases together we will have the total emissions that the batteries cause from the beginning of the material production until the disposal of it in the landfill.

In the table below we can see all the five phases together.

Life Cycle Phases	*Total NRE (MJ)*	*Total GWP (kg CO2)*	*Total AP (kg Sox)*	*Total POCP (kg NOx)*
Manufacture	**2.43E+05**	**1.12E+04**	**6.93E+01**	**5.13E+01**
Transport	**4.18E+04**	**2.66E+03**	**1.29E+01**	**6.84E+00**
Utilisation	**3.07E+03**	**1.45E+02**	**1.04E+00**	**2.11E-01**
Transport	**1.05E+04**	**6.65E+02**	**5.51E+00**	**1.71E+00**
Landfill	**3.91E+01**	**2.65E+00**	**2.51E-02**	**2.73E-02**

Table 5.70: Impact from all the Life Cycle Stages of the Batteries

The final table then is.

Life Cycle Phases	*Total NRE (MJ)*	*Total GWP (kg CO2)*	*Total AP (kg SOx)*	*Total POCP (kg NOx)*
Pre-Use Phase	**2.85E+05**	**1.39E+04**	**8.22E+01**	**5.82E+01**
Use Phase	**3.07E+03**	**1.45E+02**	**1.04E+00**	**2.11E-01**

Elimination Phase	**1.05E+04**	**6.68E+02**	**5.54E+00**	**1.74E+00**

Table 5.71: Impact from the three phases for the Batteries

We will see now in a graphical representation, the distribution of the environmental impact of GWP from the wind turbine in the three main phases.

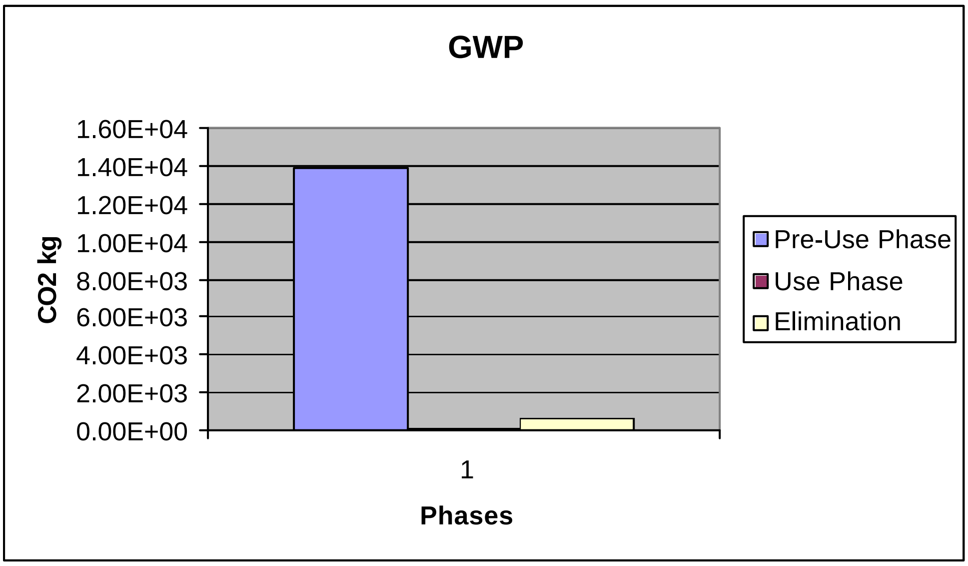

Figure 5.16: GWP Impact for each phase

From the figure above we can see that the main environmental impact comes from the pre use phase. The same is being observed in the other three impact factors. This can be also seen from the figure below where the use phase counts almost the 95% of the total emissions.

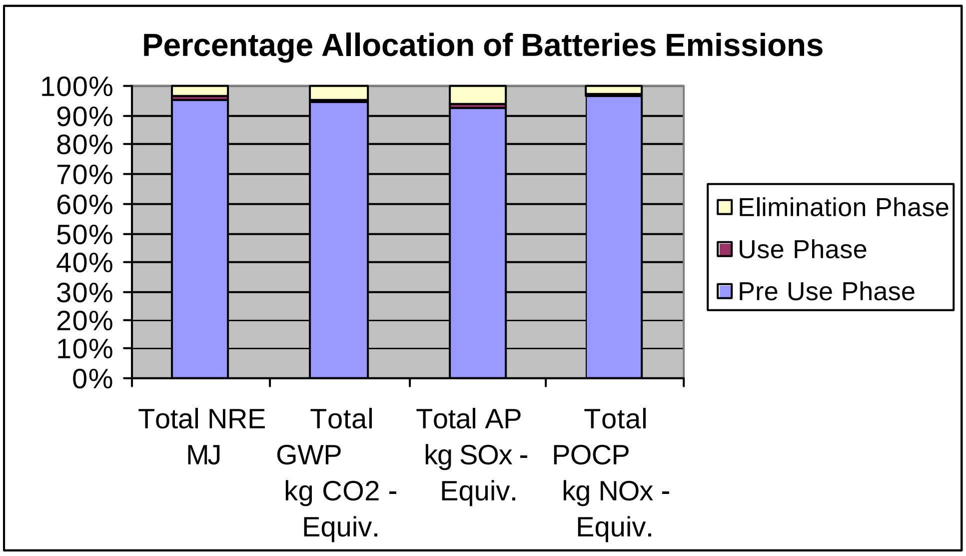

Figure 5.17: Percentage Allocation of Batteries Emissions

LCA of Electrolyser and Fuel Cell

The general characteristics of an electrolyser and a fuel cell are:

The electrolyser has the ability to generate 3.27 m3/h of hydrogen and the fuel cell is 5.4 kW and can generate 130 kWh per day.	***The materials that the electrolyser and the fuel cell use are: Nickel, Platinum, Polymers, Steel and Aluminium***
Because both systems have opposite procedures but the same logical structure their materials will be the same.	

Table 5.72: General Characteristics of the EL / FC

Material Manufacture

For 1kg of platinum:

Description	*NRE (MJ/kg)*	*GWP (kg CO2/kg)*	*AP (kg SOx/kg)*	*POCP (kg NOx/kg)*

Platinum	**5.05E+01**	**1.88E+00**	**1.10E-02**	**1.35E-02**

Table 5.73: Impact from 1 kg of Platinum

For 170.5 kg:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Platinum	**8.61E+03**	**3.21E+02**	**1.88E+00**	**2.30E+00**

Table 5.74: Impact from 170.5 kg of Platinum

For the whole system of EL / FC:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
EL/FC	**4.54E+04**	**1.83E+03**	**1.00E+01**	**1.09E+01**

Table 5.75: Impact from all the EL / FC System

Transportation to installation point

Description	*Distance (km)*	*Mean*	*NRE (MJ/tkm)*	*GWP (kg CO2/tkm)*	*AP (kg SOx/tkm)*	*POCP (kg NOx/tkm)*
Platinum	**1500**	**Delivery van,3.5 t**	**1.10E+01**	**7.00E-01**	**5.80E-03**	**1.80E-03**

Table 5.76: Impact from transport 1 tkm of Platinum

For 255.75 tkm:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
Platinum	**2.81E+03**	**1.79E+02**	**1.48E+00**	**4.60E-01**

Table 5.77: Impact from transport 255.75 tkm of Platinum

For the whole system:

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg SOx)*	*POCP (kg NOx)*
EL/FC	**1.65E+04**	**1.05E+03**	**8.71E+00**	**2.70E+00**

Table 5.78: Impact of transport all the EL / FC System

Utilisation Phase

In the use phase we assume that the maintenance of a system like EL / FC cause negligible emissions compared with the other two phases.

This is a brand new technology crossing a diverse number of industries. Qualified service and maintenance personnel will be needed.

With the same way as in the previous systems we assume that for every year the maintenance of the EL / FC will be equal to 13 kWh of energy.

With this amount we are going to estimate the environmental impact for the maintenance of the wind turbine in the period of 20 years. For 20 years the consumption is 260 kWh.

We know that 1 kWh equals to 3.6 MJ, so in MJ is 9.36E+02.

In the table below we can see the impact from the electricity usage for 1 MJ.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
Electricity Usage	**3.555E+00**	**1.681E-01**	**1.201E-03**	**2.441E-04**

Table 5.79: Impact from Electricity Usage of 1 MJ

For the amount we calculated the impact is.

Description	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*

Electricity Usage	**3.32E+03**	**1.57E+02**	**1.12E+00**	**2.28E-01**

Table 5.80: Impact from 20 Years Electricity Usage

Transport to the landfill

Description	Distance (km)	Mean	NRE (MJ/tkm)	GWP (kg CO2/tkm)	AP (kg SOx/tkm)	POCP (kg NOx/tkm)
Platinum	**200**	**Delivery van,3.5 t**	**1.10E+01**	**7.00E-01**	**5.80E-03**	**1.80E-03**

Table 5.81: Impact for transport 1 tkm of Platinum

For 34.1 tkm:

Description	NRE (MJ)	GWP (kg CO2)	AP (kg SOx)	POCP (kg NOx)
Platinum	**3.75E+02**	**2.39E+01**	**1.98E-01**	**6.14E-02**

Table 5.82: Impact for transport 34.1 tkm of Platinum

For the whole system:

Description	NRE (MJ)	GWP (kg CO2)	AP (kg SOx)	POCP (kg NOx)
EL/FC	**2.20E+03**	**1.40E+02**	**1.16E+00**	**3.60E-01**

Table 5.83: Impact for transport all the EL/FC System

Elimination to landfill

The emissions for 1 kg of platinum to the landfill are.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg SOx)	POCP (kg NOx)
Platinum	**8.23E-03**	**5.57E-04**	**5.29E-06**	**5.75E-06**

Table 5.84: Impact of 1 kg Platinum in the landfill

For 170.5 kg.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg SOx)	POCP (kg NOx)
Platinum	1.40E+00	9.50E-02	9.02E-04	9.80E-04

Table 5.85: Impact of 170.5 kg Platinum in the landfill

The total emissions for the EL/FC are.

Description	NRE (MJ)	GWP (kg CO2)	AP (kg SOx)	POCP (kg NOx)
EL/FC	8.23E+00	5.58E-01	5.29E-03	5.75E-03

Table 5.86: Impact of all the EL/FC System

Total Emissions from the Electrolyser and Fuel Cell

If we combine all the previous phases together we will have the total emissions that the EL/FC causes from the beginning of the material production until the disposal of it in the landfill.

In the table below we can see all the five phases together.

Life Cycle Phases	Total NRE (MJ)	Total GWP (kg CO2)	Total AP (kg SOx)	Total POCP (kg NOx)
Manufacture	4.54E+04	1.83E+03	1.00E+01	1.09E+01
Transport	1.65E+04	1.05E+03	8.71E+00	2.70E+00
Utilisation	3.32E+03	1.57E+02	1.12E+00	2.28E-01
Transport	2.20E+03	1.40E+02	1.16E+00	3.60E-01
Landfill	8.23E+00	5.58E-01	5.29E-03	5.75E-03

Table 5.87: Impact of all the Life Cycle Stages for the EL/FC System

The final table then is.

Life Cycle Phases	***Total NRE (MJ)***	***Total GWP (kg CO2)***	***Total AP (kg SOx)***	***Total POCP (kg NOx)***
Pre-Use Phase	**6.20E+04**	**2.89E+03**	**1.87E+01**	**1.36E+01**
Use Phase	**3.32E+03**	**1.57E+02**	**1.12E+00**	**2.28E-01**
Elimination Phase	**2.21E+03**	**1.41E+02**	**1.17E+00**	**3.66E-01**

Table 5.88: Impact of the three phases for the EL/FC System

We will see now in a graphical representation, the distribution of the environmental impact of GWP from the wind turbine in the three main phases.

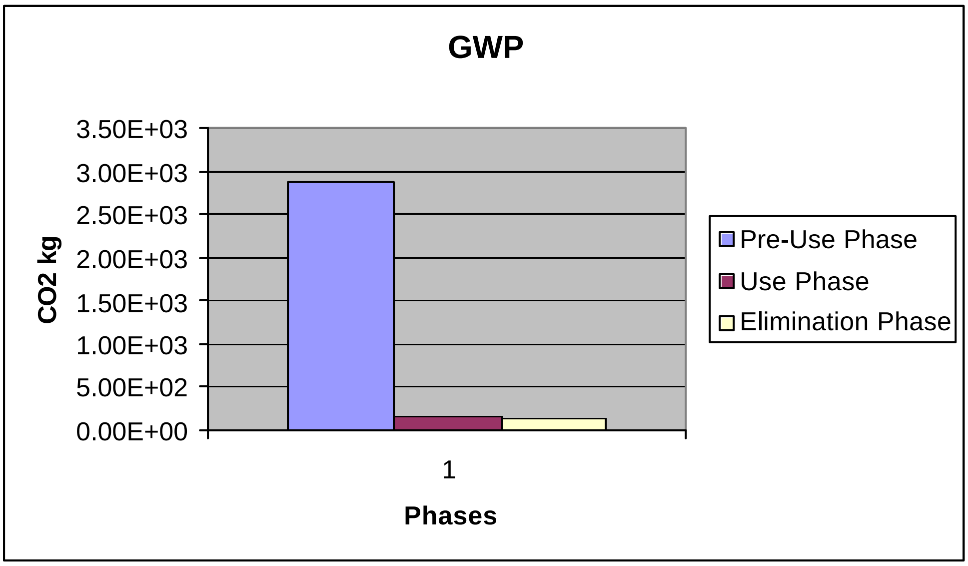

Figure 5.18: GWP Impact for each phase

From the figure above we can see that the main environmental impact comes from the pre use phase. The same is being observed in the other three impact factors. This can be also seen from the figure below where the use phase counts almost the 90% of the total emissions.

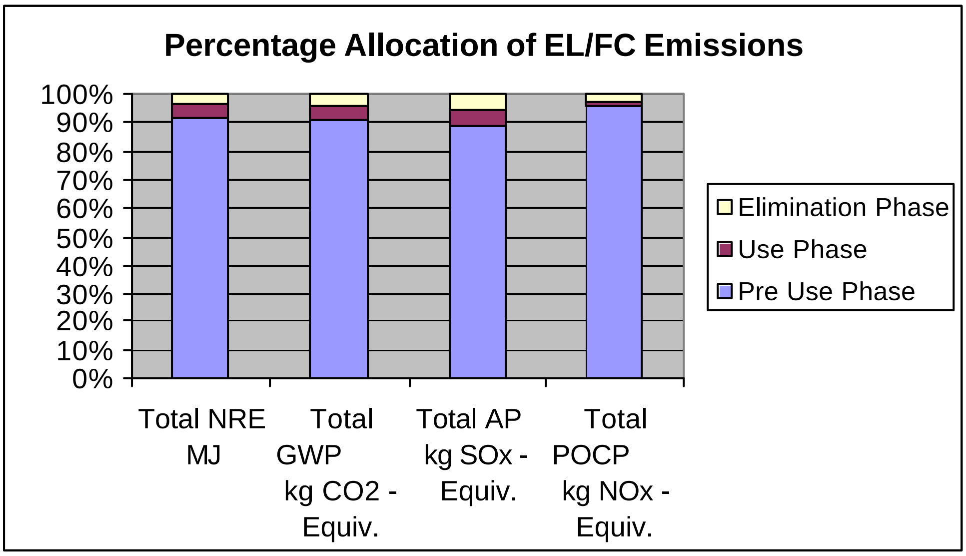

Figure 5.19: Percentage Allocation of EL / FC Emissions

LCA of the Total House and Renewable System

In this part we will try to show with diagrams the environmental impacts of the house in comparison with the renewable system with the batteries and with the fuel cell system.

First of all in the table below we can see all the final results from the analysis that has been carried out so far.

Description	*Life Cycle Phase*	*NRE (MJ)*	*GWP (kg CO2)*	*AP (kg Sox)*	*POCP (kg NOx)*
House	**Pre Use Phase**	**9.17E+05**	**7.91E+04**	**4.63E+02**	**2.02E+01**
House	**Use Phase**	**9.25E+06**	**4.38E+05**	**3.13E+03**	**6.35E+02**
House	**Elimination Phase**	**4.19E+05**	**2.71E+04**	**3.12E+02**	**6.42E+01**
PV	**Pre Use Phase**	**1.37E+05**	**5.86E+03**	**7.43E+01**	**2.89E+01**

PV	**Use Phase**	**2.56E+03**	**1.21E+02**	**8.65E-01**	**1.76E-01**
PV	**Elimination Phase**	**4.37E+03**	**2.78E+02**	**2.31E+00**	**7.24E-01**
Wind T.	**Pre Use Phase**	**1.097E+05**	**7.725E+03**	**4.996E+01**	**1.266E+01**
Wind T.	**Use Phase**	**3.84E+03**	**1.81E+02**	**1.29E+00**	**2.63E-01**
Wind T.	**Elimination Phase**	**3.34E+03**	**2.16E+02**	**2.49E+00**	**5.13E-01**
Battery	**Pre Use Phase**	**2.85E+05**	**1.39E+04**	**8.22E+01**	**5.82E+01**
Battery	**Use Phase**	**3.07E+03**	**1.45E+02**	**1.04E+00**	**2.11E-01**
Battery	**Elimination Phase**	**1.05E+04**	**6.68E+02**	**5.54E+00**	**1.74E+00**
EL/FC	**Pre Use Phase**	**6.20E+04**	**2.89E+03**	**1.87E+01**	**1.36E+01**
EL/FC	**Use Phase**	**3.32E+03**	**1.57E+02**	**1.12E+00**	**2.28E-01**
EL/FC	**Elimination Phase**	**2.21E+03**	**1.41E+02**	**1.17E+00**	**3.66E-01**
RE+Batteries	**Pre Use Phase**	**5.32E+05**	**2.64E+04**	**2.06E+02**	**9.97E+01**
RE+Batteries	**Use Phase**	**9.47E+03**	**4.47E+02**	**3.20E+00**	**6.50E-01**
RE+Batteries	**Elimination Phase**	**1.82E+04**	**1.16E+03**	**1.03E+01**	**2.98E+00**
RE+EL/FC	**Pre Use Phase**	**3.088E+05**	**1.547E+04**	**1.43E+02**	**5.521E+01**

RE+EL/FC	**Use Phase**	**9.72E+03**	**4.59E+02**	**3.28E+00**	**6.67E-01**
RE+EL/FC	**Elimination Phase**	**9.93E+03**	**6.35E+02**	**5.96E+00**	**1.60E+00**
House+RE+BA	**Pre Use Phase**	**1.45E+06**	**1.06E+05**	**6.69E+02**	**3.02E+02**
House+RE+BA	**Use Phase**	**9.47E+03**	**4.47E+02**	**3.20E+00**	**6.50E-01**
House+RE+BA	**Elimination Phase**	**4.37E+05**	**2.83E+04**	**3.22E+02**	**6.72E+01**
House+RE+EL/FC	**Pre Use Phase**	**1.23E+06**	**9.46E+04**	**6.06E+02**	**2.58E+02**
House+RE+EL/FC	**Use Phase**	**9.72E+03**	**4.59E+02**	**3.28E+00**	**6.67E-01**
House+RE+EL/FC	**Elimination Phase**	**4.29E+05**	**2.77E+04**	**3.18E+02**	**6.58E+01**

Table 5.89: All the results for each phase

After we have presented the results in a table form we will show now in a graph form the same results but with comments.

In the figure below we can see the comparison of the house without the renewable system with the house with the renewable system. It is obvious that by generating electricity from renewable energy we reduce the environmental impacts especially in the use phase almost in a 100%.

In the same time we observe a small increase in the pre use and the elimination phase cause of the production and elimination of the renewable system. But as we see comparing with the big reduction from the electricity it is negligible.

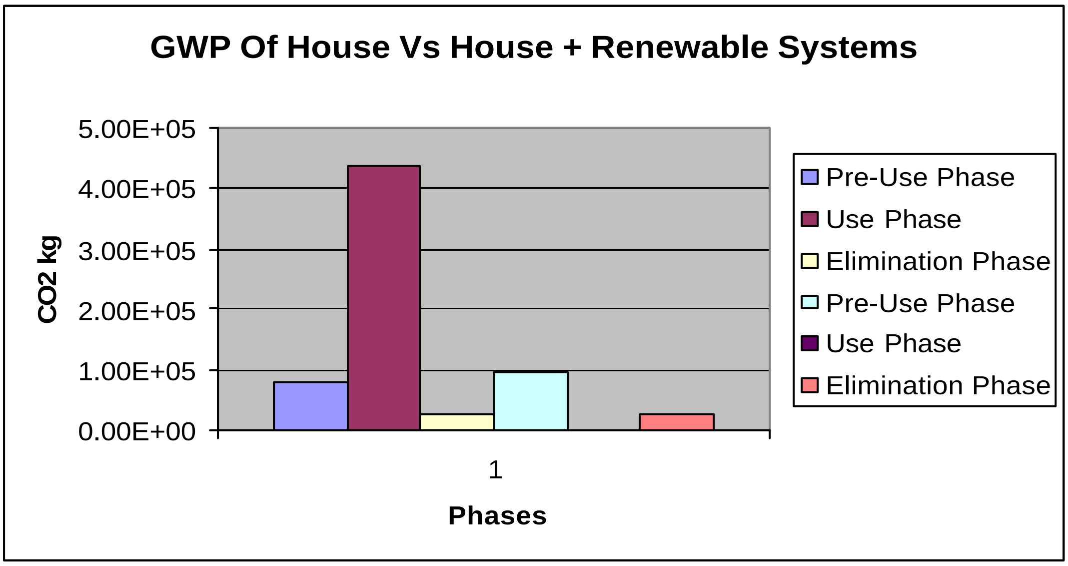

Figure 5.20: GWP Impact of House Vs House + Renewable System with EL/FC

In the figure below we can see again the same comparison but this time in the renewable system we have the batteries as the storage device in relation with the previous figure that we had the electrolyser and the fuel cell.

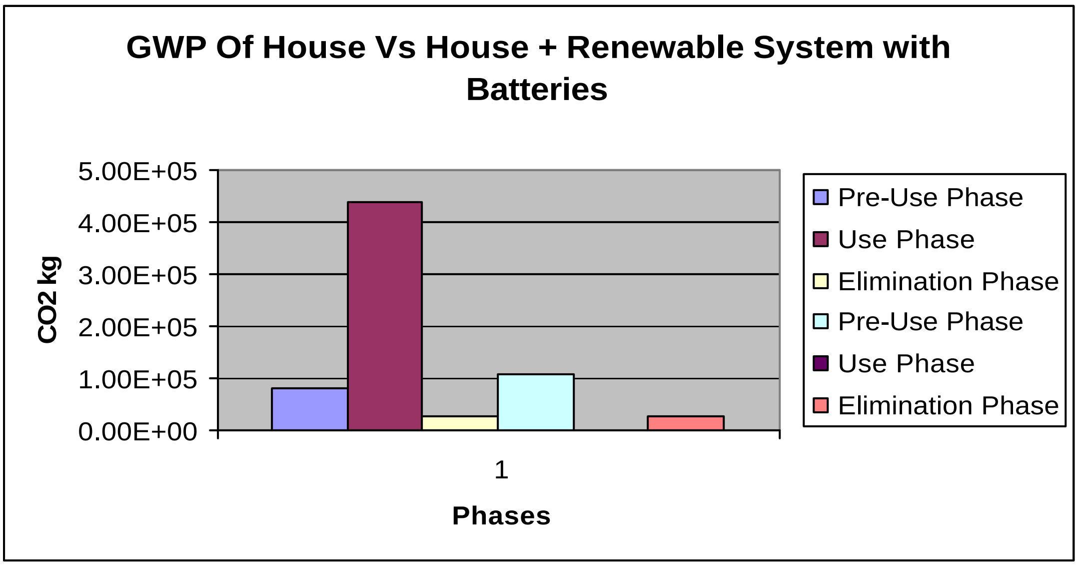

Figure 5.21: GWP Impact of House Vs House + Renewable System with Batteries

In the figure below we can see clearly the difference of the house with the renewable system with the electrolyser/fuel cell and with the batteries.

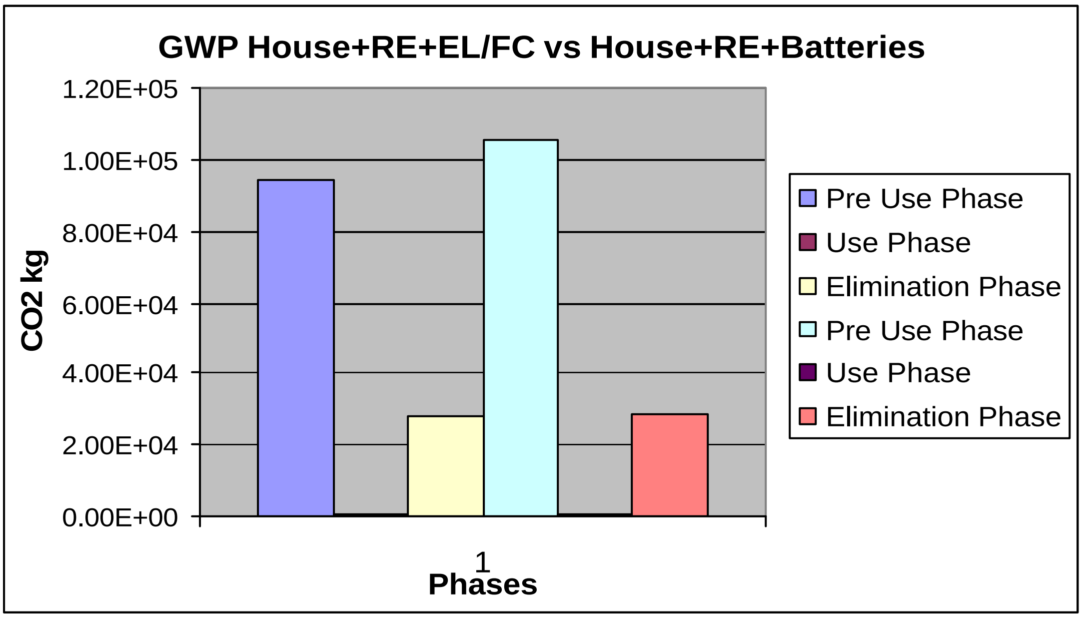

Figure 5.22: GWP Impact of House+RE+EL / FC Vs House+RE+Batteries

Here is only the renewable system with the fuel cell and with the batteries.

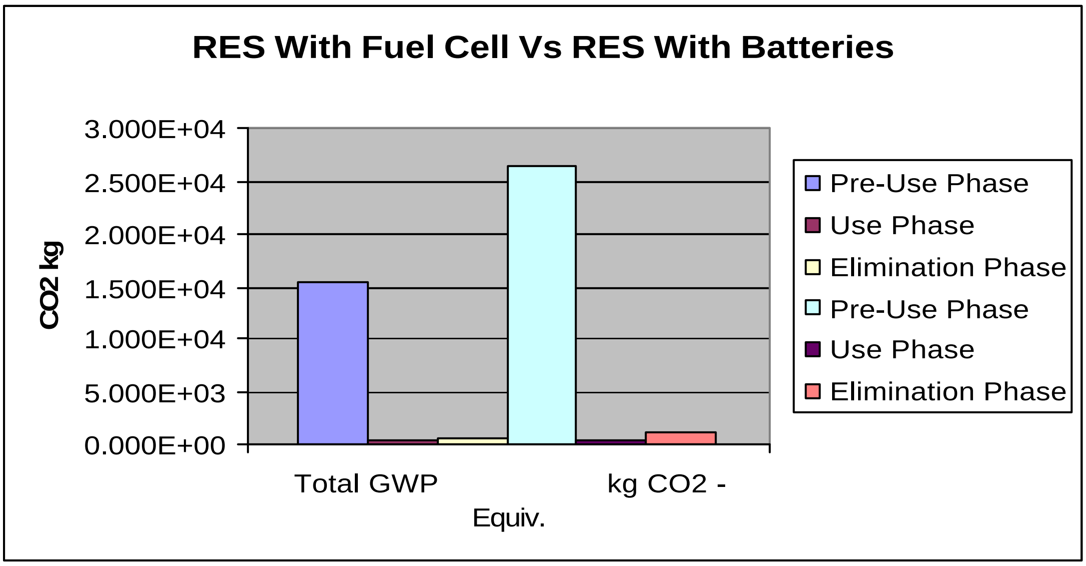

Figure 5.23: RES with EL / FC Vs RES with Batteries

In the next figure we can see the comparison between the batteries and the electrolyser / fuel cell system. Here we can see the big difference between the two systems. Fuel cell is obvious that is a more environmental friendly device than the battery and this because of the lower weight that was used in order to produce it.

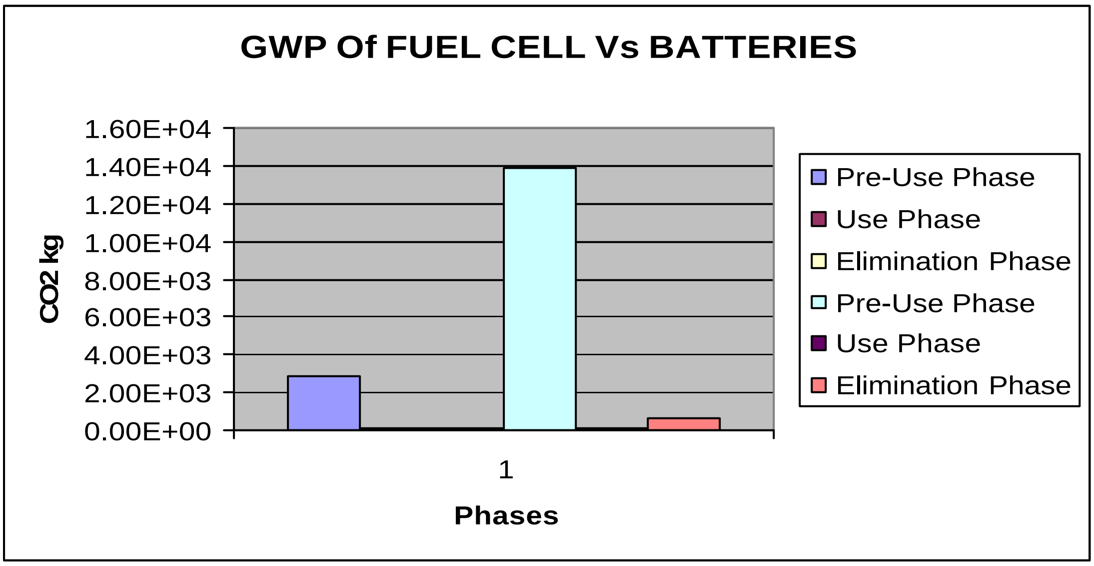

Figure 5.24: GWP Impact of EL / FC Vs Batteries

Here we can see how much each renewable device is being contributing to the entire system. We see that the wind turbine causes the biggest impact from the other equipment cause of the biggest weight. Second is coming the PV with the 120 m2 of panels and last the fuel cell.

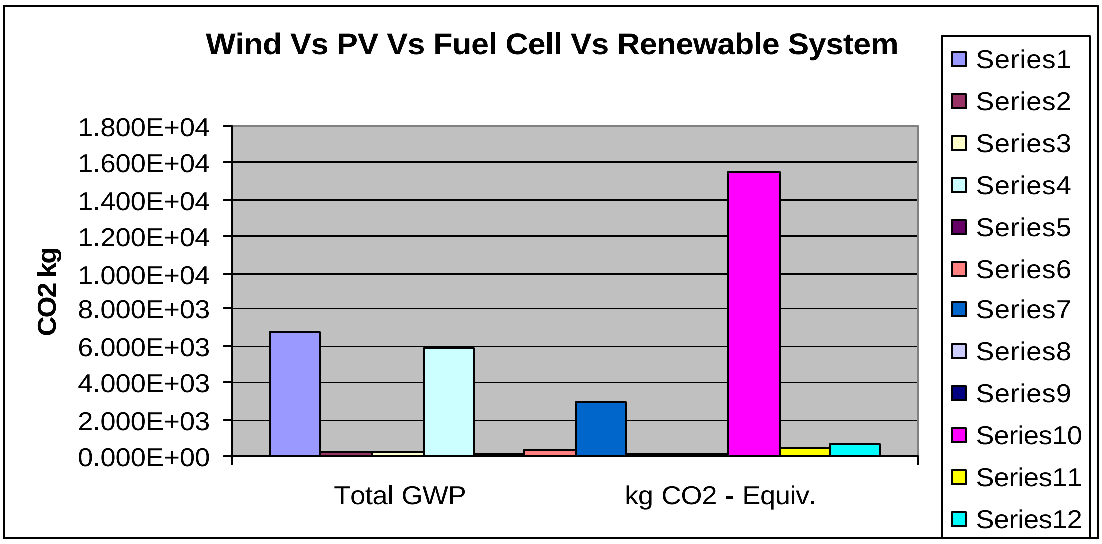

Figure 5.25: Wind Vs PV Vs EL / FC Vs Renewable System

Something similar we can see in the figure below were this time the systems environmental impact is being dominated by the use of the batteries.

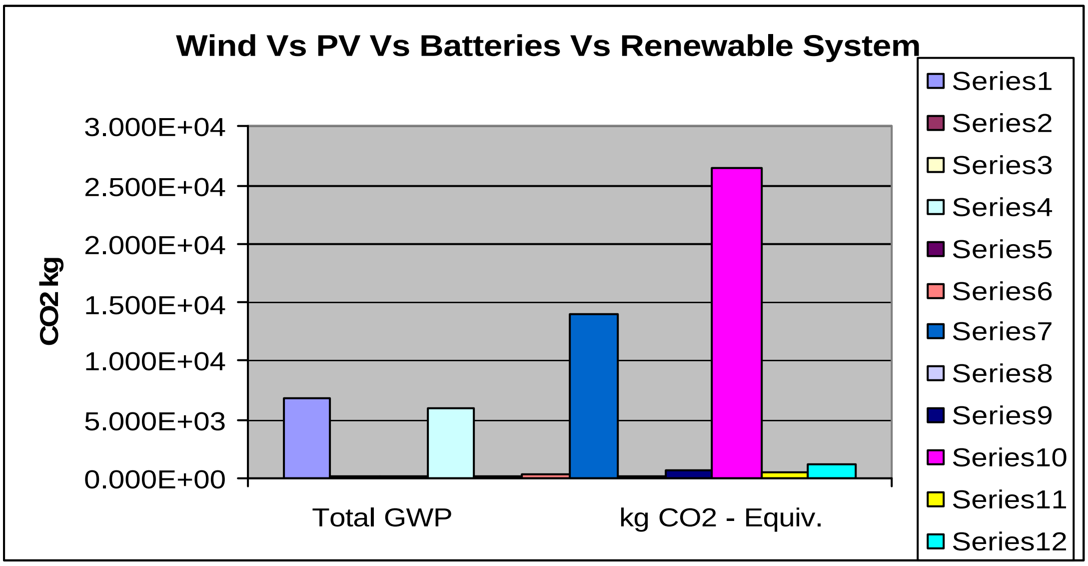

Figure 5.26: Wind Vs PV Vs Batteries Vs Renewable System

In this figure again we can see all the equipment that was used and observe the difference that the batteries have in relation with the other three systems. This is also due to the fact that while the Wind, PV and Fuel Cell have a lifetime service of almost 20 years this is not the same with the batteries that is only 8. That's why someone is forced to buy almost three times the same amount of batteries in order to cover the 20 years of service.

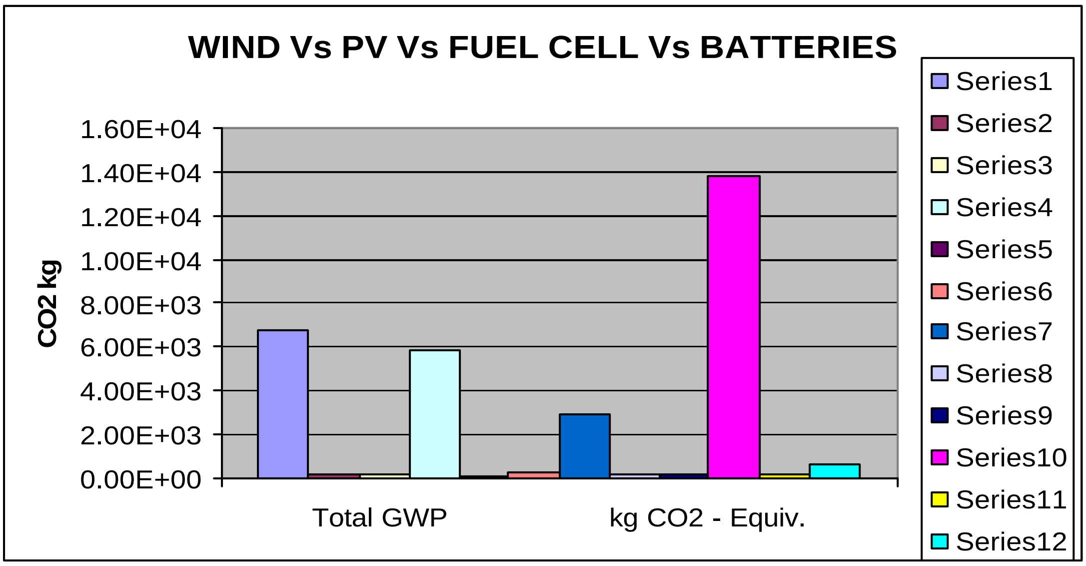

Figure 5.27: Wind Vs PV Vs EL / FC Vs Batteries

In all the previous figures we observed that the biggest impact was in the pre use phase. In the use phase as we mentioned earlier the maintenance of these systems wasn't causing any significant impacts or in the elimination phase that the amount of impact was very small compared with the production phase. Something that it means, that if we manage to reduce the impact during the production phase with less harmful materials, then it would be even more environmental friendly systems than they are now.

In the next two figures we see the environmental impacts of the house alone and with the renewable system on each phase as a percentage.

In the first figure the use phase was the dominant factor with almost 90% of the total emissions.

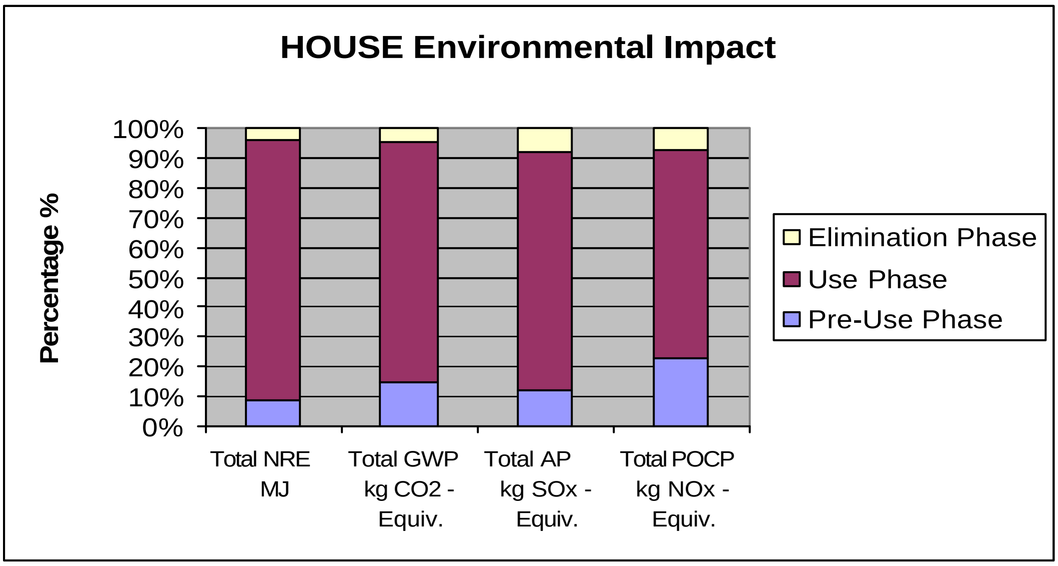

Figure 5.28: Percentage of House Environmental Impact from each phase

In the second figure the completely elimination of the use phase cause of the 100% reduction in the energy consumption from a conventional plant change the percentage of the emissions. Now the dominant factor is the pre use phase with a 75% of the total emissions.

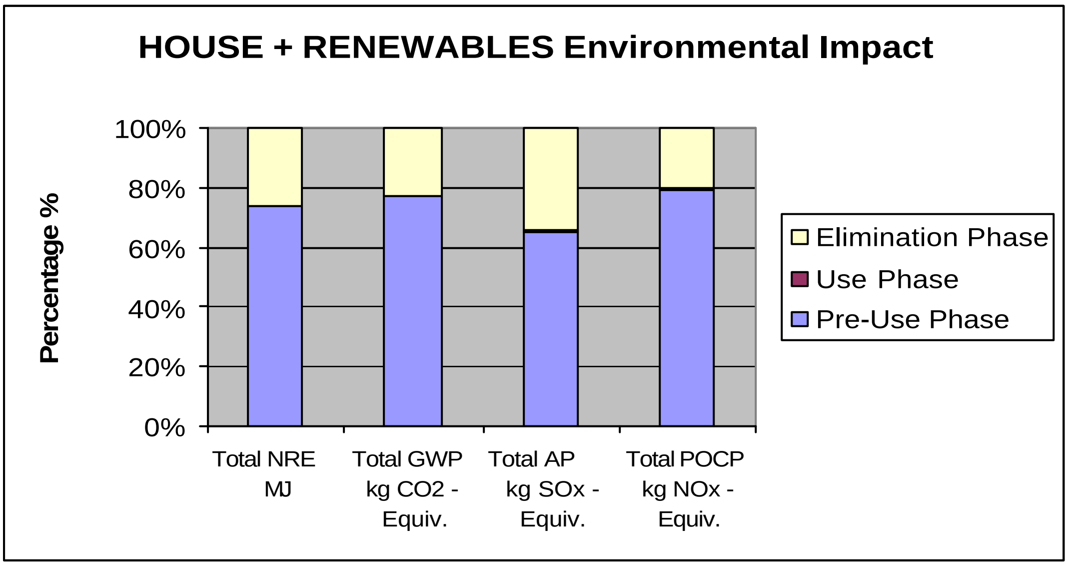

Figure 5.29: Percentage of House + Renewable System Environmental Impact from each phase

The next three figures show as the percentage contribution of the wind, PV and fuel cell devices in the total emissions in each one of the three phases.

As far as consider the GWP emissions the biggest impact in the pre use phase was coming from the wind turbine with a 41% followed from the PV with a 39% and last with the Fuel Cell with a 20%.

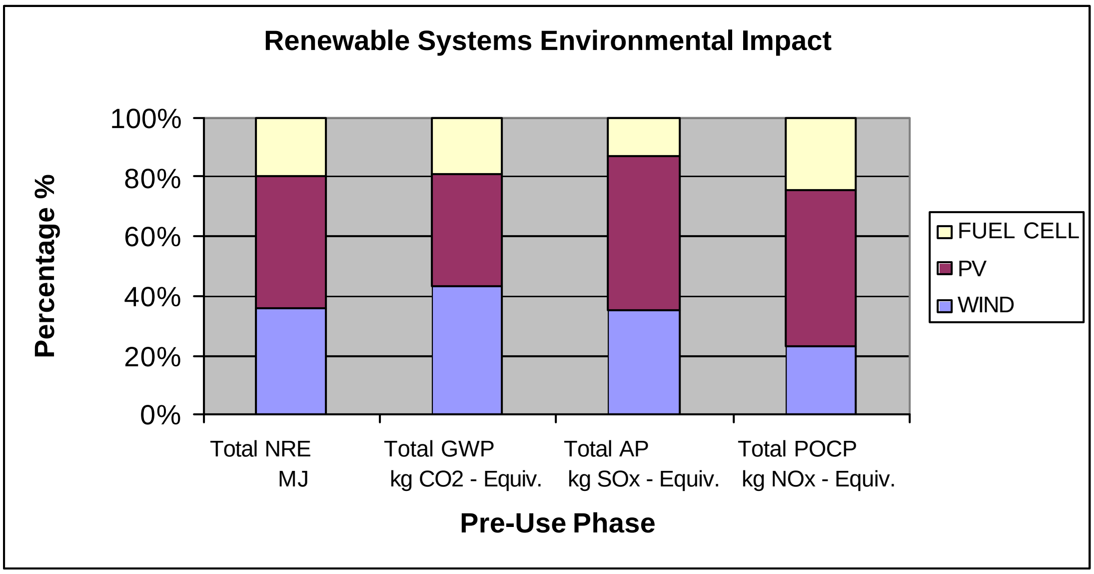

Figure 5.30: Percentage of Renewable System Environmental Impact of Pre-Use Phase

In the use phase where the emissions was due to the fact of the annual maintenance, the wind and the fuel cell systems was the main factors with 40% and 35% respectively, and only with 25% for the PV.

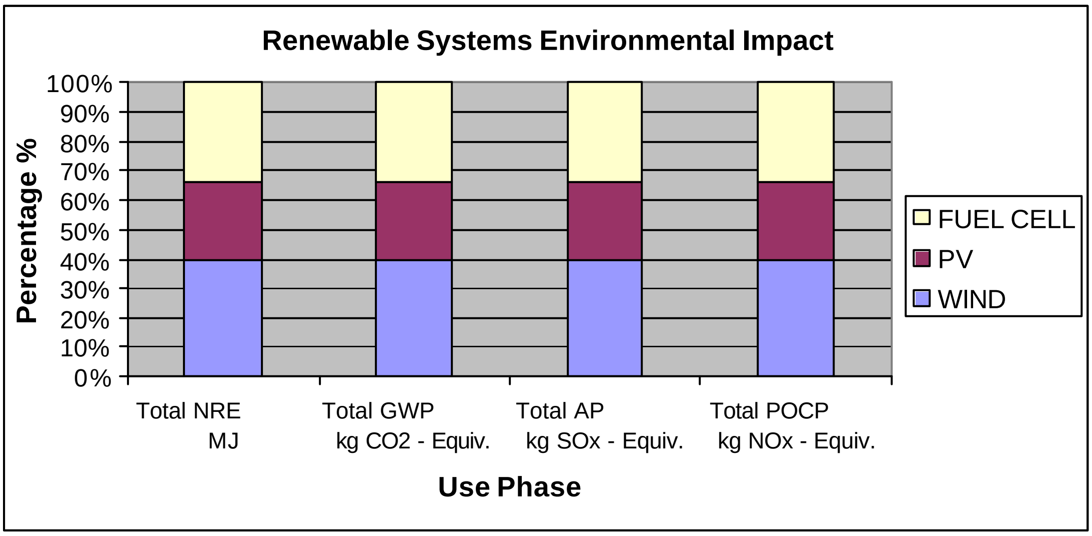

Figure 5.31: Percentage of Renewable System Environmental Impact of Use Phase

In the opposite direction were the emissions in the elimination phase. The weight of the materials that was used from the PV but also the type of them was causing the biggest impact with 45% compared with the wind and the fuel cell that only contributed 32% and 23% respectively.

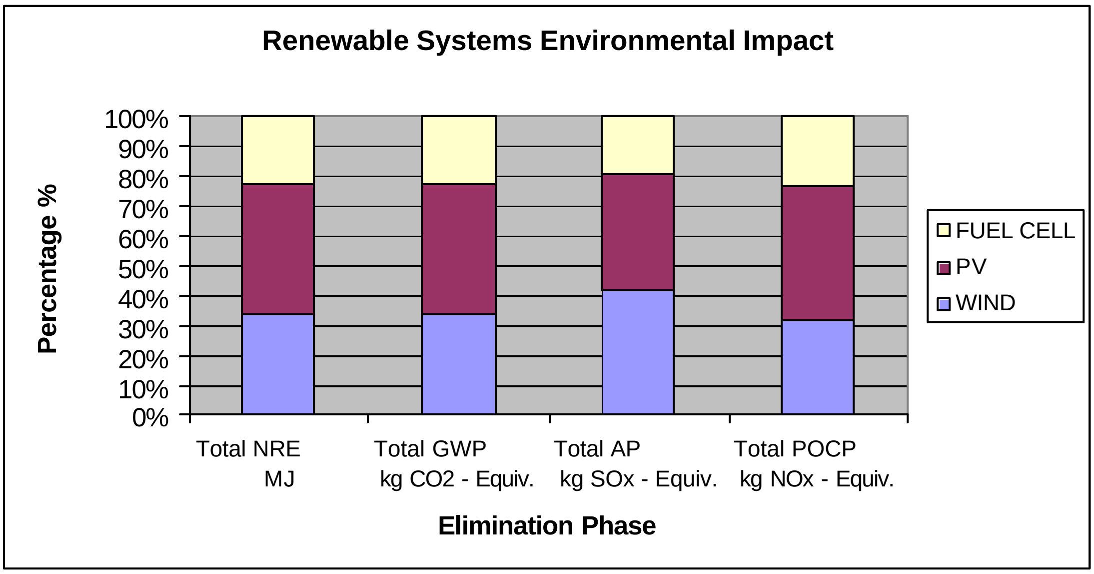

Figure 5.32: Percentage of Renewable System Environmental Impact of Elimination Phase

The same analysis is being done in the next three figures but this in the renewable system is the batteries as the back up power contributor.

In the pre use phase the dominant factor that causes the biggest impacts is the batteries used in the period of the 20 years with a percentage of 52% as far as consider the impact from the CO2 emissions. The wind and the PV was only 22% and 26% respectively.

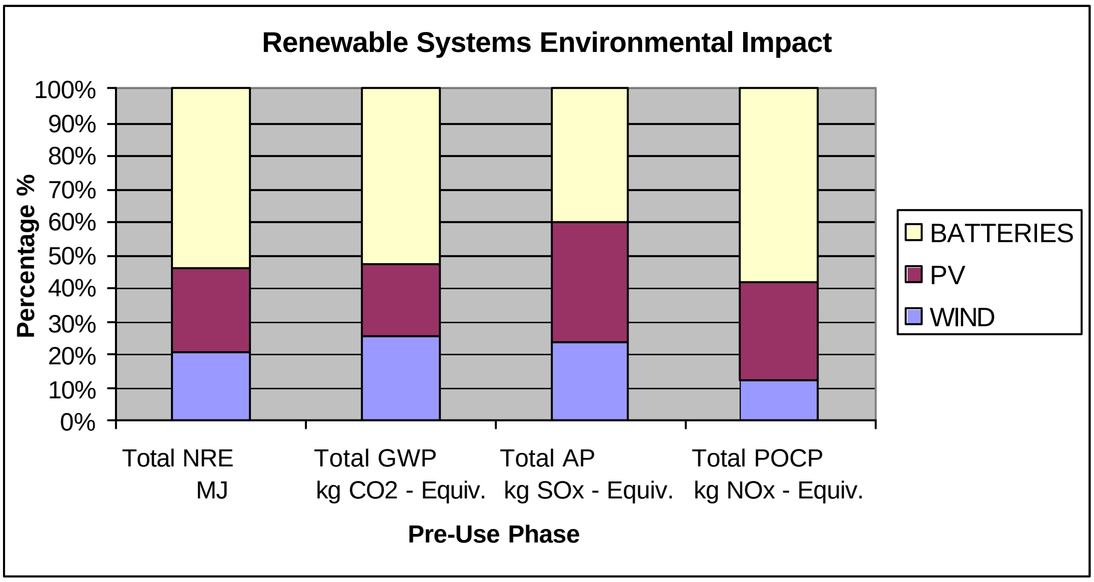

Figure 5.33: Percentage of Renewable System Environmental Impact of Pre-Use Phase

In the use phase the biggest impact is coming from the maintenance of the wind turbine with a 40% and the PV with the Fuel Cell from 30% respectively.

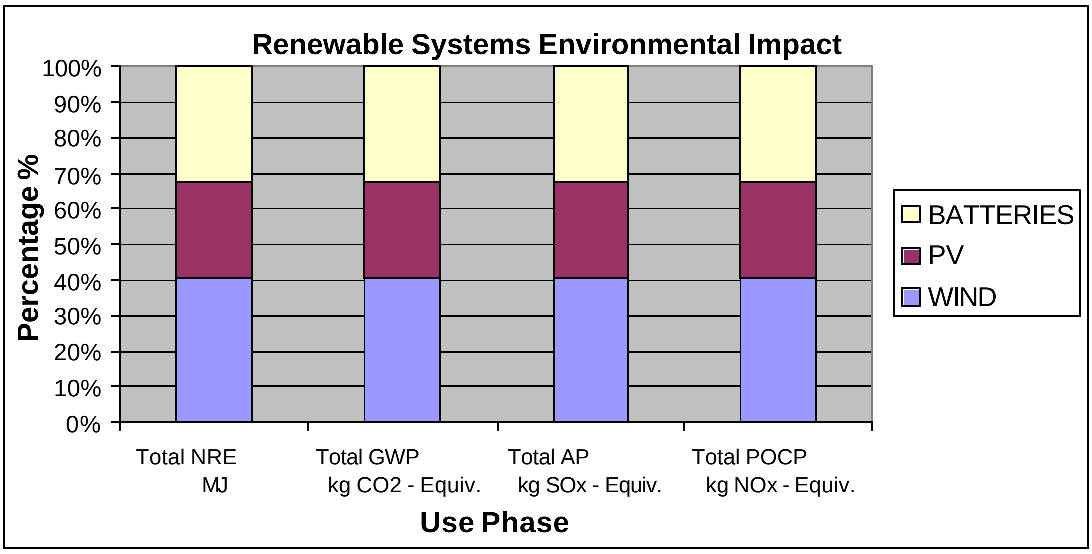

Figure 5.34: Percentage of Renewable System Environmental Impact of Use Phase

In the elimination phase cause of the materials type and weight that the batteries are made of we see that is the dominant pollutant to the atmosphere with a 60%. The second most polluting equipment is the PV with 24% and last the wind turbine with 16%.

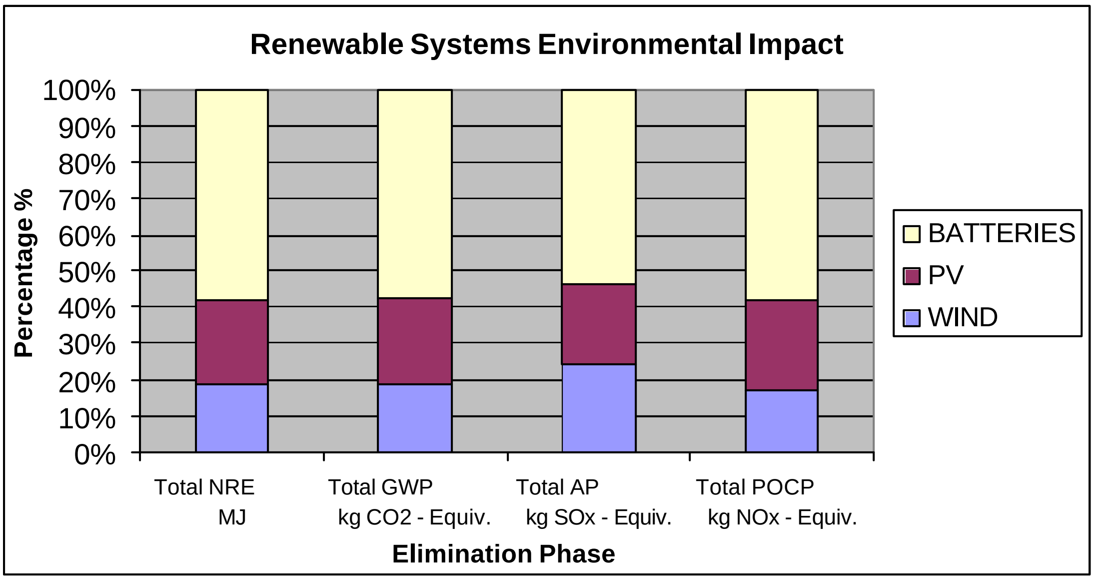

Figure 5.35: Percentage of Renewable System Environmental Impact of Elimination Phase

From all the figures above we saw that the renewable system can contribute positively in reducing the environmental impacts from the use of electricity with the use of fossil fuels.

Despite the emissions that the renewable system extracted, wasn't significant in order to say that cause also the same impact to the environment.

As far as consider the fuel cell system with the batteries, we can say that the first gives a more environmental friendly solution as the batteries.

What Are the Benefits of Conducting an LCA?

An LCA will help decision-makers select the product or process that result in the least impact to the environment. This information can be used with other factors, such as cost and performance data to select a product or process. LCA data identifies the transfer of environmental impacts from one media to another (e.g., eliminating air emissions by creating a wastewater effluent instead) and / or from one life cycle stage to another (e.g., from use and reuse of the product to the raw material acquisition phase). If an LCA was not performed, the transfer might not be recognized and properly included in the analysis because it is outside of the typical scope or focus of product selection processes.

This ability to track and document shifts in environmental impacts can help decision makers and managers fully characterize the environmental trade-offs associated with product or process alternatives. By performing an LCA, researchers can:

- Develop a systematic evaluation of the environmental consequences associated with a given product.

- Analyze the environmental trade-offs associated with one or more specific products / processes to help gain stakeholder (state, community, etc.) acceptance for a planned action.
- Quantify environmental releases to air, water, and land in relation to each life cycle stage and / or major contributing process.
- Assist in identifying significant shifts in environmental impacts between life cycle stages and environmental media.
- Assess the human and ecological effects of material consumption and environmental releases to the local community, region, and world.
- Compare the health and ecological impacts between two or more rival products / processes or identify the impacts of a specific product or process.
- Identify impacts to one or more specific environmental areas of concern.

Limitations of Conducting an LCA

Performing an LCA can be resource and time intensive. Depending upon how thorough an LCA the users wish to conduct, gathering the data can be problematic, and the availability of data can greatly impact the accuracy of the final results.

Therefore, it is important to weigh the availability of data, the time necessary to conduct the study, and the financial resources required against the projected benefits of the LCA.

LCA will not determine which product or process is the most cost effective or works the best. Therefore, the information developed in an LCA study should be used as one component of a more comprehensive decision process assessing the trade-offs with cost and performance.

What are the Challenges?

LCA requires specific and well researched information to establish baseline environmental impact data for even basic raw materials, and can thus be extremely resource intensive. Also, the environmental impacts of raw material extraction and production processes may vary from country to country, and even from region to region. For example, the impacts of extracting one tonne of coal in Australia differ from those in the USA, because of different mining and transport techniques and technologies, and also a different environment. Indeed, the impacts differ depending from which Australian State the coal is extracted.

Other problems with LCA include:

- the inherent subjectivity of assessments (e.g in determining relative weighting for emissions);
- the lack of a widely accepted methodology for conducting LCA;
- difficulties on clearly defining the scope of and LCA;
- confidentiality issues that restrict the availability of data; and
- the cost, complexity and time consumed in undertaking a comprehensive LCA.

A comprehensive LCA is unlikely to be relevant, or indeed, possible for smaller organisations. However it is still possible to reap the benefits by adopting a 'life cycle' approach. The LCA process can be streamlined with a company examining only those parts or operations that have the most impact or potential for improvement. This can maximise the benefits and minimise the cost of LCA.

CHAPTER 6

Discussion

Energy fuelled the industrial revolution and has continued to drive economic development. The graph below shows the close link between economic prosperity and energy use - especially electricity.

The graph also shows how greenhouse gas emissions have followed the curve of energy use, and are expected to continue to rise even without stringent action to limit emissions.

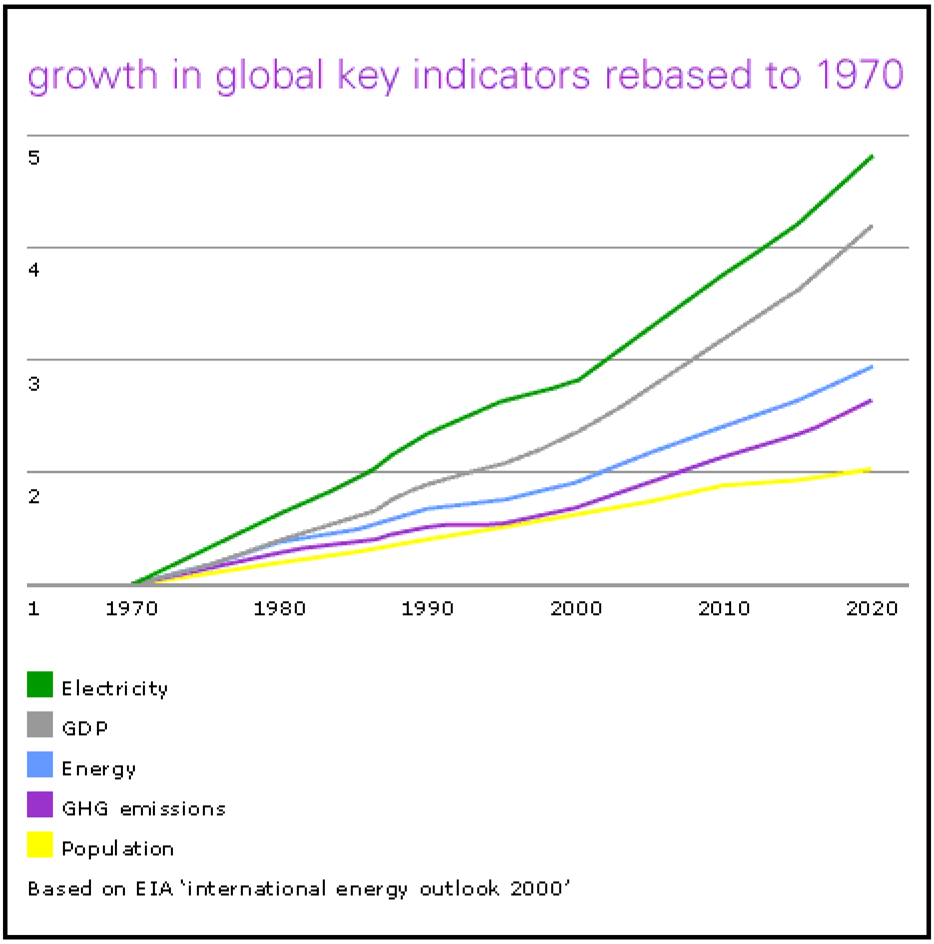

Figure 6.1: Growth In Global Key Indicators Rebased To 1970

Fuelling social and economic development around the world without harming the environment is the challenge all face in the 21st century. Many believe that it is essential to stabilize the amount of greenhouse gases in the atmosphere while still providing the energy that is needed for development.

Clean, renewable energy is the ultimate goal. But this is a long way off as the graph below shows. Hydrocarbons are expected to remain as the dominant source of energy for several decades.

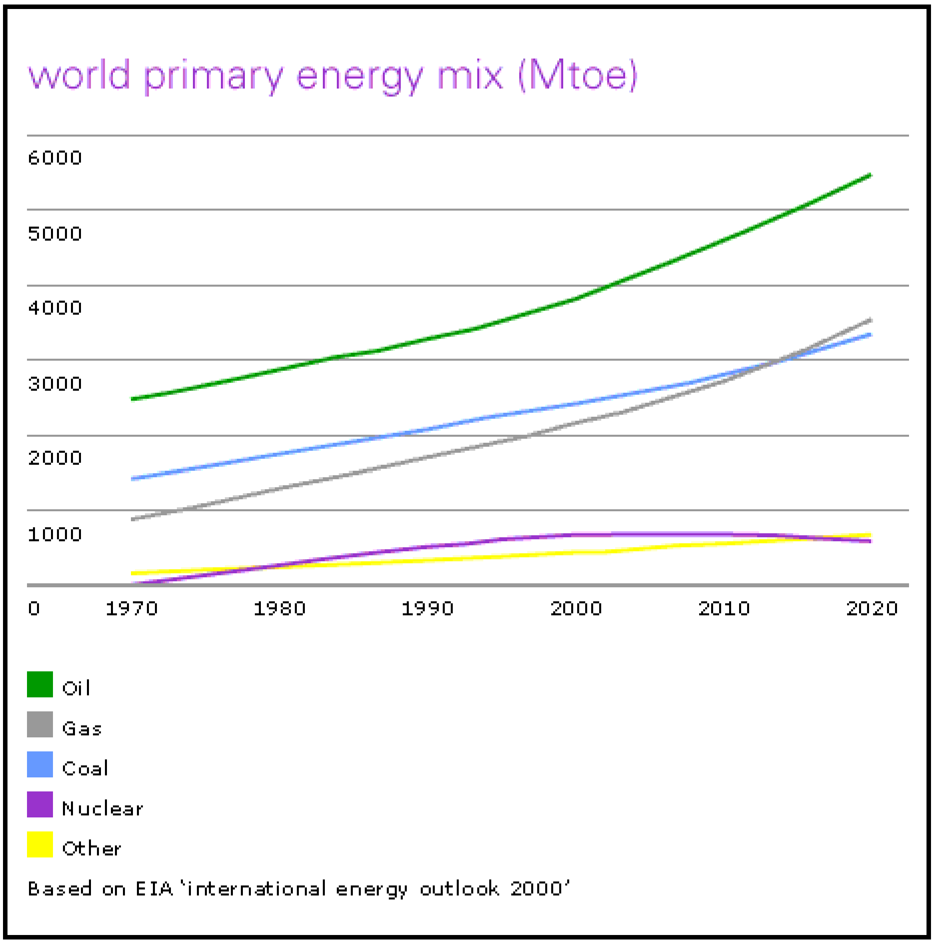

Figure 6.2: World Primary Energy Mix

All the signs are that the world's demand for energy will continue to increase in the future. As populations increase and living standards improve around the globe, more and more energy will have to be generated unless substantial improvements in energy efficiency are achieved.

As we see in the figure below renewable energy had the biggest growth in the last decade.

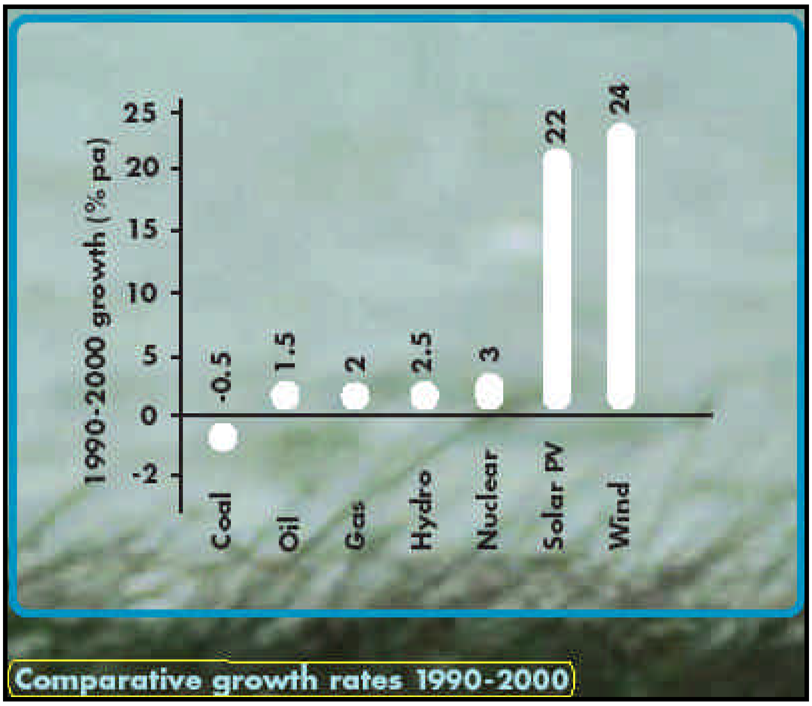

Figure 6.3: Growth Rates Of Energy Sources

This means that the energy mix in the next decades may change to more environmental friendly sources of energy.

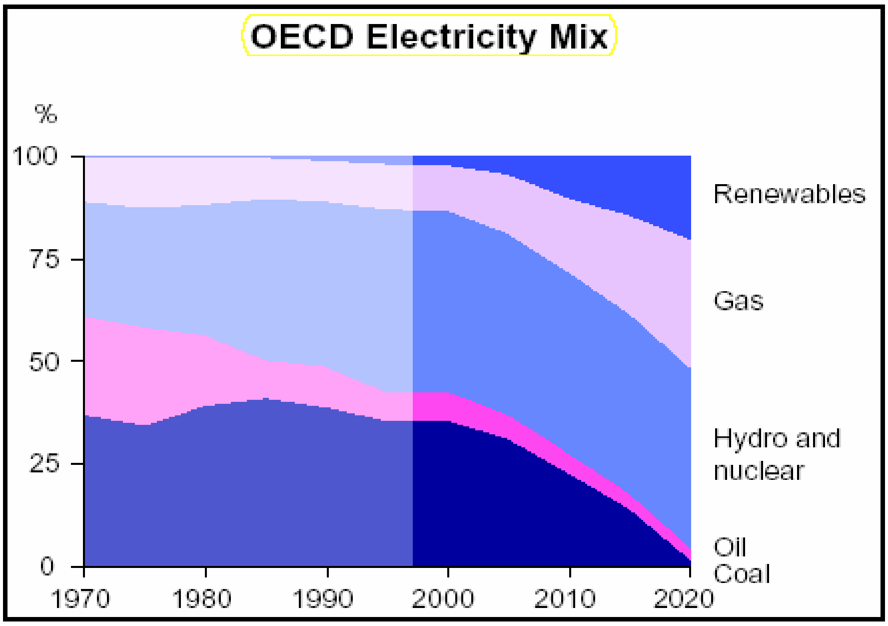

Figure 6.4: OECD Electricity Mix

The greatest challenge will be to replace all conventional technologies and fossil fuels with renewable that could have the ability to meet energy needs of the entire world.

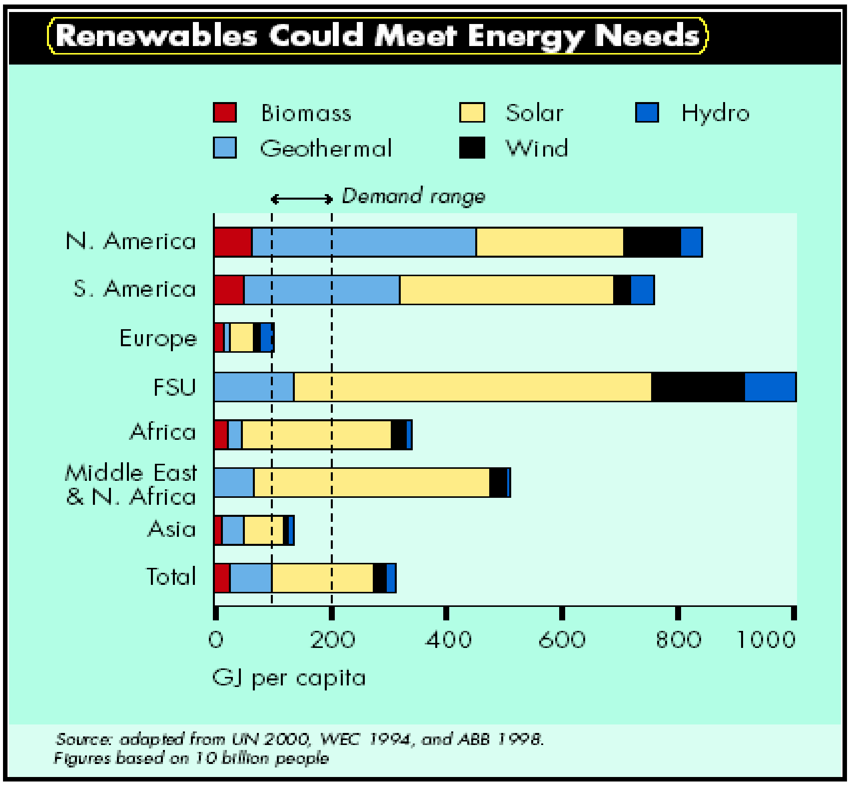

Figure 6.5: Renewables Could Meet Energy Needs

Exploring opportunities in renewable energy

As we mentioned before “Renewable energy markets are expanding rapidly, with an annual growth rate of more that 20%.”

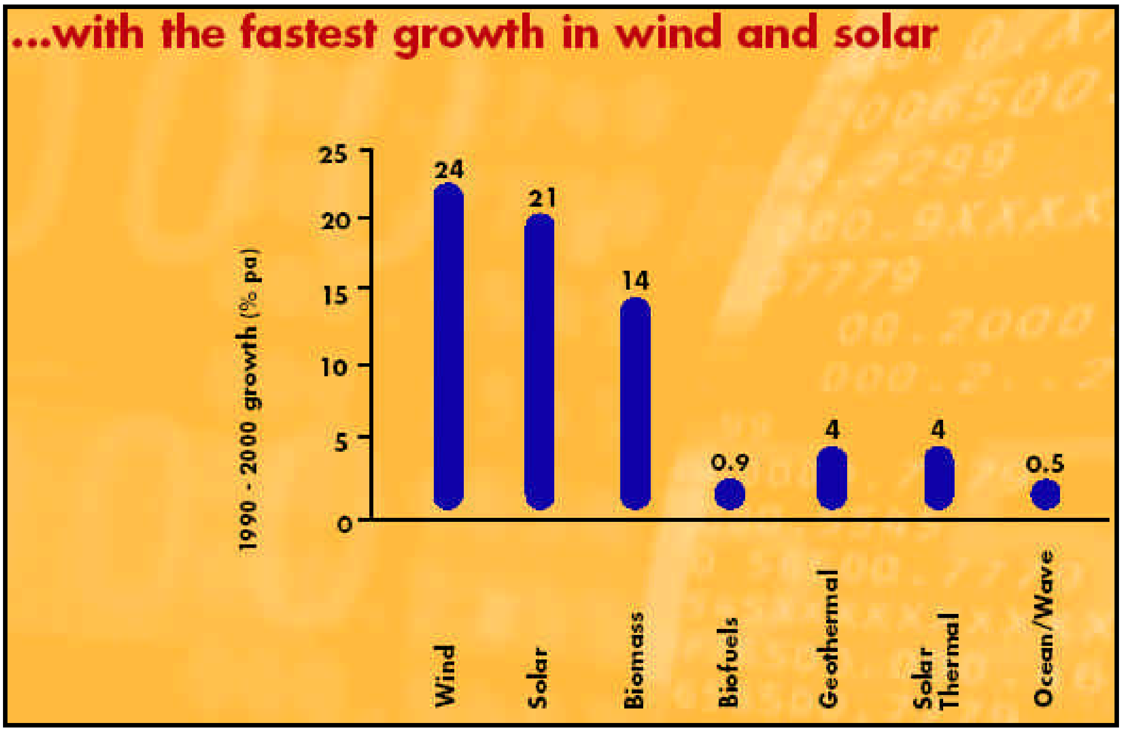

Figure 6.6: Growth Rate Of Renewable Energy Sources

It is always necessary to look in to the future. Therefore a major part of investment should go in to developing other forms of energy.

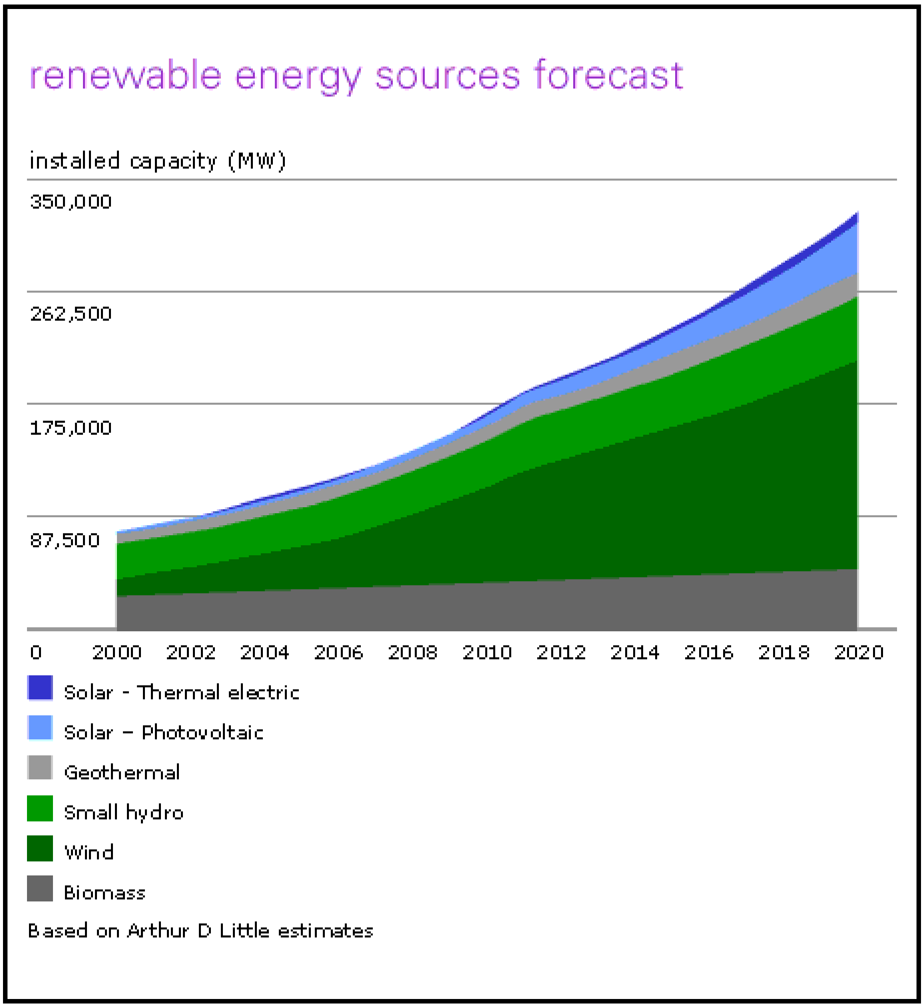

Figure 6.7: Renewable Energy Sources Forecast

Other forms of technology using new fuels have to be developed with considering the future in mind. Both the society and the companies must support projects to develop hydrogen systems and technological improvements in the storage of hydrogen, which could help to make it a more commercially attractive fuel.

In the long term, two potentially transforming energy technologies are:

Solar photovoltaic, which offer the possibility of abundant direct and widely distributed energy, and

Hydrogen fuel cells, which offer the possibility of high performance and clean energy from a variety of fuels.

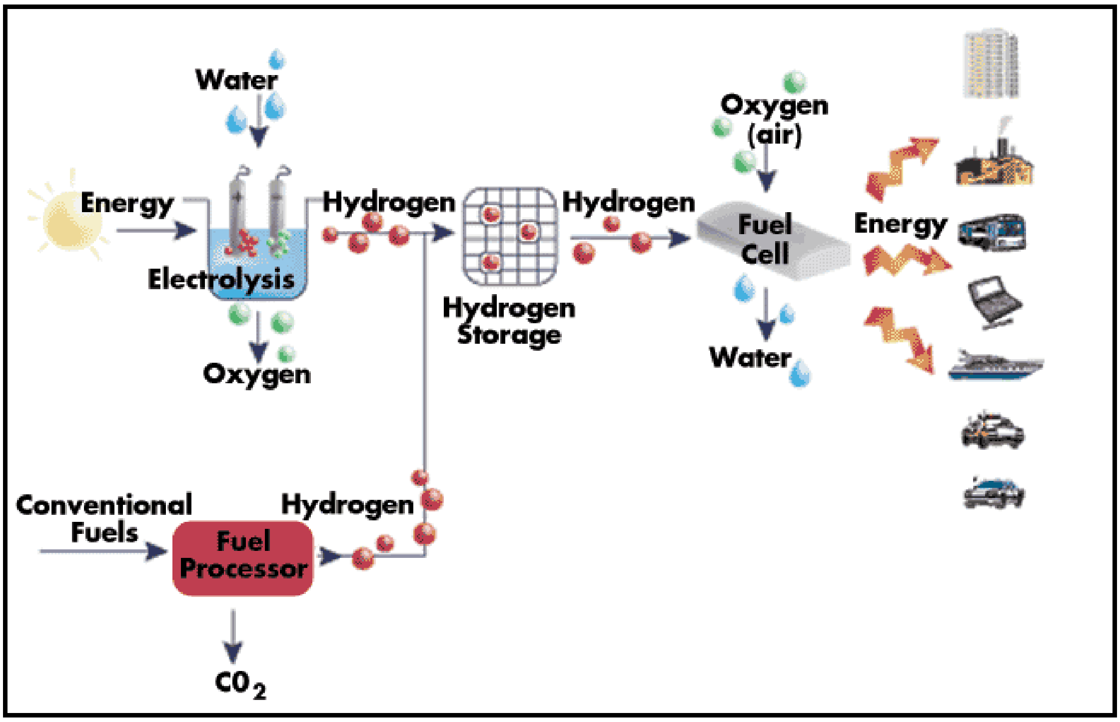

Figure 6.8: Production And Use Of Hydrogen

Conclusion

This paper has illustrated the potential of a hydrogen and fuel cell storage system for electricity from wind and photovoltaic energy in an isolated house compared with a battery system.

With this analysis we saw that a system like this can not only work effectively but also to provide in the whole world a more environmental friendly solution for the future.

Figure 6.9: A Renewable Hydrogen Energy System

The difference between the battery and the fuel cell system laid in the environmental concerns of the two systems. From the LCA model we concluded that the fuel cell system is a more environmental system than the battery because the material that uses together with the high reliability and effective operation gives a greater lifetime than the battery system does.

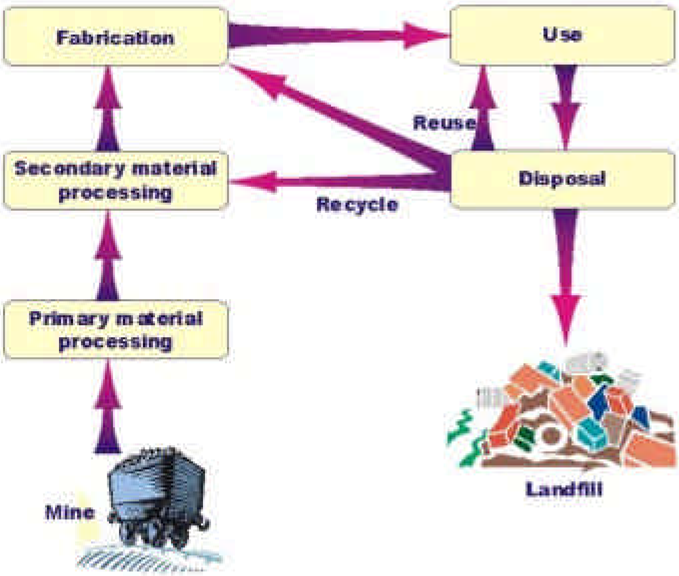

Figure 6.10: The Life Cycle Stage

Recommendation for Future Work

Any further work would have to involve site specific wind and photovoltaic data for the estimation of the annual energy that is needed for the consumption of the house or for a remote community.

An economic analysis would also be required to assess the start up capital and the cost of electricity from such a system.

Hydrogen production, storage and the energy produced from this is an important issue for consideration and a more detailed investigation in terms of performance, economics and practicality would be necessary.

As far as consider the LCA, we would for better analysis and estimation of the environmental impact from such a system, to conduct the specific companies and ask what materials and in what weight are being used for the production of renewable equipment in order to have more accurate information.

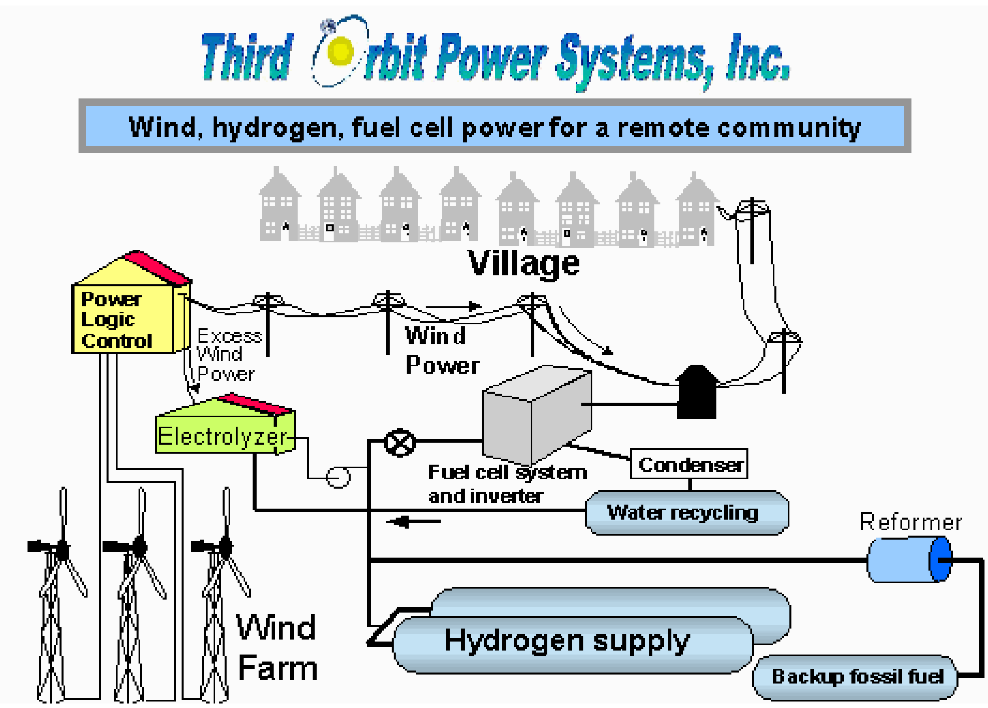

Figure 6.11: Wind, PV, Hydrogen, Fuel Cell Power for a Remote Community

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Appendices

Figure 0.7.1: Comparison of Life Cycle Carbon Dioxide Emissions from Renewables and Fossil Fuel Generation

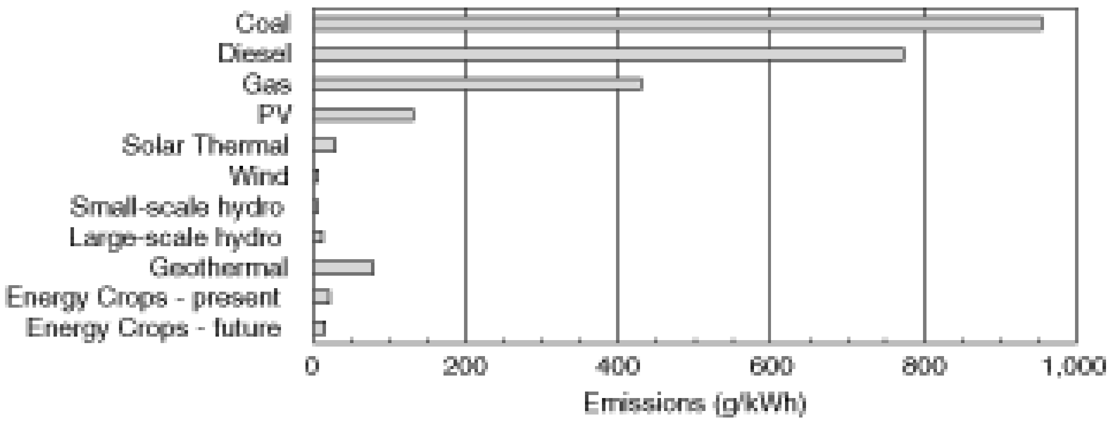

Figure 0.7.2: Comparison of Life Cycle Sulphur Dioxide Emissions from Renewables and Fossil Fuel Generation

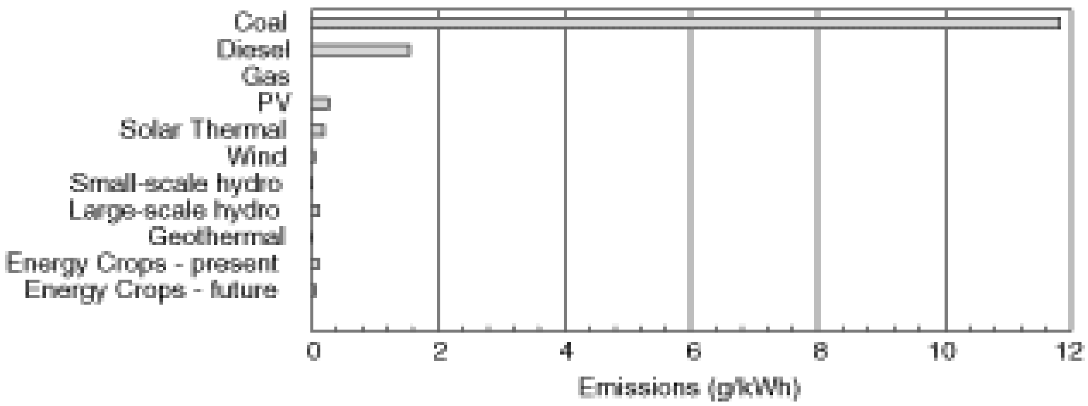

Figure 0.7.3: Comparison of Life Cycle Nitrogen Oxides Emissions from Renewables and Fossil Fuel Generation

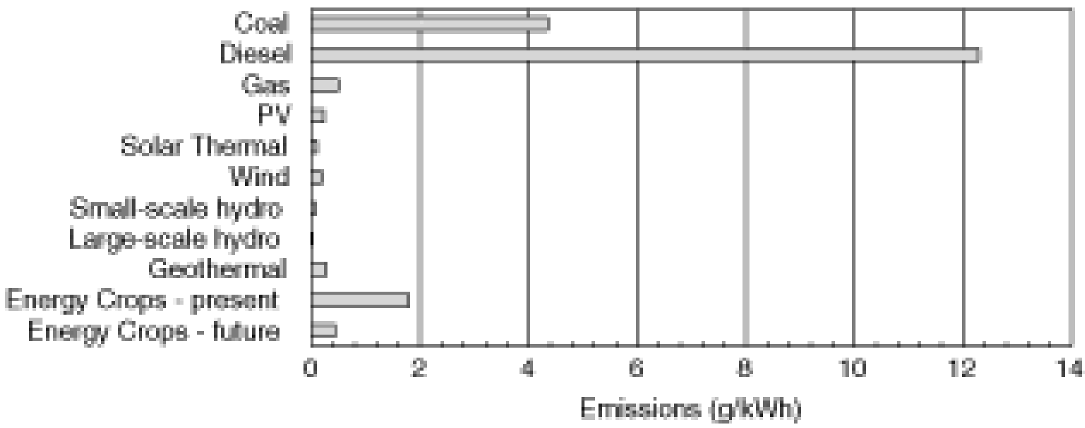

Table 0.7.1: Summary of Potential Environmental Burdens for Photovoltaic Systems

Burden	*Receptor*	*Impact*	*Range*	*Priority*
RESOURCE EXTRACTION[1]	**Various**	**Emissions/Noise**	**L/R/G**	**Low**
RESOURCE TRANSPORTATION[1]	**Various**	**Emissions/Noise**	**L/R/G**	**Low**
MATERIALS PROCESSING[1]	**Various**	**Emissions/Noise**	**L/R/G**	**Medium**
COMPONENT MANUFACTURE[1]	**Various**	**Emissions/Noise**	**L/R/G**	**High**
COMPONENT TRANSPORTATION[1]	**Various**	**Emissions/Noise**	**L/R/G**	**Low**
CONSTRUCTION				
Construction work/road traffic	**Various**	**Atmospheric emissions**	**L/R/G**	**Low**

Occupational impacts	**Employment**	**Increased employment**	**Loc/Reg**	**Low**
	Workers	**Accidents**	**Local**	**Low**
Amenity				
Noise (including road traffic)	**General public**	**Noise amenity**	**Local**	**Low**
Visual impact	**General public**	**Visual amenity**	**Local**	**Low**
Ecology				
Land use	**Ecosystems**	**Land use - loss of habitat**	**Local**	**Low-High[2]**
Noise/construction activity	**Ecosystems**	**Disturbance**	**Local**	**Low**
GENERATION				
Emissions	**None**			
Amenity				
Visual impact	**General public**	**Visual amenity**	**Local**	**Low-High[2]**
Ecosystems			**Local**	**Low**
Public Health				
Occupational health	**Workers**	**Accidents**	**Local**	**Low**
	Employment	**Increased employment benefits**	**Local**	**Low**
DECOMMISSIONING	**Various**	**Emissions/Noise**		**Low**

Table 0.7.2: Summary of Potential Environmental Burdens for Wind

Burden	Receptor	Impact	Range	Priority
RESOURCE EXTRACTION[1]	Various	Emissions/Noise	L/R/G	Low
RESOURCE TRANSPORT[1]	Various	Emissions/Noise	L/R/G	Low
MATERIALS PROCESSING[1]	Various	Emissions/Noise	L/R/G	Low/Med
COMPONENT MANUFACTURE[1]	Various	Emissions/Noise	L/R/G	Low/Med
COMPONENT TRANSPORT[1]	Various	Emissions/Noise	L/R/G	Low
CONSTRUCTION[1]				
Construction activity/traffic	Various	Atmospheric emissions	L/R/G	Low
Road construction		Increased local access	Local	Low
Amenity				
Noise (including road traffic)	General	Noise amenity	Local	Low
Visual intrusion	General public	Visual amenity	Local	Low
Construction activities	General public	Loss/change in recreational	Local	Low

		activity		
Ecology				
Noise/construction activity	**Ecosystems**	**Disturbance**	**Local**	**Low**
Land use/excavation	**Ecosystems**	**Loss of habitat**	**Local**	**Low**
Occupational health	**Workers**	**Accidents**	**Local**	**Low**
	Employment	**Increased employment**	**Local**	**Low**
GENERATION				
Emissions	**None**			
Amenity				
Noise	**Residents**	**Noise amenity**	**Local**	**Low-High[2]**
	Others		**Local**	**Low**
Visual impact	**Residents**	**Visual intrusion**	**Local**	**Low-High[2]**
		Flicker annoyance	**Local**	**Low**
	Visitors	**Visual intrusion**	**Local**	**Low-High[2]**
	Travellers/Others Others	**Visual intrusion**	**Local**	**Low**
Radio interference (scattering of radio waves)	**Residents**	**Interference with electromagnetic communication systems**	**Local**	**Low**

GENERATION				
Occupational health	**Workers**	**Accidents**	**Local**	**Low**
	Employment	**Increased employment**	**Local**	**Low**
Public Health				
Accidents	**General public**	**Turbine accidents**	**Local**	**Low**
	Road travellers	**Driver distraction**	**Local**	**Low**
Epileptic fits	**Epileptics**	**Attacks**	**Local**	**Low**
Ecosystems				
Turbine motion	**Birds**	**Bird strike, disturbance**	**Local**	**Low**
Land use	**Ecosystems**	**Loss of habitat, disturbance**	**Local**	**Low**
	Agriculture	**Loss of land**	**Local**	**Low**
DECOMMISSIONING	**Various**	**Emissions/Noise**	**L/R/G**	**Low**