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An Economic Assessment of Micro-Scale Use of Renewable Energy Sources: Two Case Studies

Corporate Environmental Management and Renewable Energy
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Abstract:

During recent times, renewable energy technologies have shown a relative fast growth in the global energy investment, global energy capacity and their integration within multiple sectors, particularly in the electricity sector. Renewable energy technologies have also experienced notorious declining costs on their manufacturing production. Nevertheless, while this growth is widely acknowledged, the share of renewables with respect total energy production has been moderate. Technological advancements in renewable energy have demonstrated the potential of renewables in energy generation and also that renewables can provide direct and indirect advantages over their counterparts. This thesis investigates two specific cases in which the renewable energy technologies of wind power and solar photovoltaics could be widely employed on micro-scale energy generation. The study's objective is to gain deeper understanding if such applications of these forms of renewables are, foremost, economically viable at micro-scale or individual level. The research was carried out by means of quantitative case study in which theoretical analysis, mathematical modelling, and experimental empirical measurements were employed in order to make a thoroughly analysis and cross validate the study's results and findings. The results from this investigation suggest that the employment of wind and solar renewables at micro-scale are economically profitable if favourable weather conditions exist at the location. If there are no favourable weather conditions, then these renewables will be economically viable if external costs such as transportation, installation and maintenance are absorbed by the owner. Moreover, this thesis suggest that better incentives, besides economically, are needed such as communication strategies and wider distribution channels in order to promote the use of renewables to the general public. This thesis also suggests that by engaging in renewable energy generation by first-hand experience encourages a sense of responsibility and the importance of saving energy which would be difficult to attain otherwise.

Keywords: wind energy, VAWT, solar photovoltaics, renewable energy, economics, micro-scale, small scale, telecom towers, diffusion of innovation, Finland.

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1 INTRODUCTION

1.1 Renewable Energy Sources

The energy available from a non-fossil renewable supply is known as renewable energy. According to the European Union (EU) Directive 2001/77/EC, renewable energy sources (RES) are: wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment and biogases (European Union 2001).

Renewable energy sources supply approximately 13% of the total world energy generation (Demirbas 2006, International Energy Agency 2013). Hydropower plants account for almost 90% of electricity generated from renewables, about 6% comes from combustible renewables and waste, while geothermal, solar and wind account only for 4.5% of electricity generation from renewable sources (IEA 2013).

Renewable energy sources are of increasing importance, mainly environmentally but also politically and economically. Renewable energy is clean, abundant, and often inexhaustible. However, currently it is more expensive than the established fossil fuel as the external costs of the later ones such as greenhouse gases and particulates and other harms associated with environmental damage, poor health, and early death, are not included in its prices (Heal 2009).

Additionally, the global financial crisis of 2008, which began with the subprime mortgage market in the United States in 2007 and then spread to other countries (Shiller 2008), has affected all types of renewable energy investments. For instance, public equity investment in photovoltaic companies declined by almost two-thirds from the end of 2007 to the end of 2008 and venture capital and private equity investment in photovoltaic companies declined over half between Q4 2008 and Q1 2009 in United States (Bartlett, Margolis & Jennings 2009), also investments in the wind market decline in 2008 (Bolinger 2010). During 2008 nearly every single biofuel plant in the United States filed for bankruptcy protection (Gardner 2008). And in 2009 Royal Dutch Shell announced that it was stopping investments in wind, solar and hydro power in favour of biofuels as the other renewable options did not offer attractive investment opportunities (Bast and Kretzmann 2009, Webb 2009). According to Shell, investing in renewable technologies but biofuels is not economically sane.

Renewable energy technologies are not currently as competitive over other well established sources. However, from above, it seems that the lack of competitiveness is mainly on the economic side.

1.2 Pollution, Climate Change and Energy Security

1.2.1 Fossil Fuels

Approximately 66% of the world's electricity production is generated from the use of fossil fuels, while over 82% accounts for the world's total primary energy supply (IEA 2007, IEA 2013). Nowadays, there is a growing concern regarding the consequences on the dependence of fossil fuels and it's impacts mainly on the environment. However, pollution from the combustion of fossil fuels has a detrimental effect not only on the environment but also on wildlife and human health. Human studies have linked long term exposures to combustions emissions and ambient fine particles and particulate organic matter from minor respiratory irritations to increased risks of cardiopulmonary mortality, lung cancer mortality, hear disease, chronic bronchitis, asthma, allergies, adverse reproductive effects, and premature mortality and reduced life expectancy (Kampa and Castanas 2007, Lewtas 2007). Toxic substances from fossil fuel combustion also contribute substantially to the nonpoint pollution of surface waters (Carpenter et al 2008). Furthermore, toxic runoff can endanger greatly surrounding vegetation, wildlife, and marine life.

Fossil fuels extraction such as oil drilling, extraction and transportation can result in human and environmental disasters. The best example in recent times is the British Petroleum (BP) oil spill in which 11 workers died from the explosion of the rig and in which the Gulf of Mexico was exposed to the biggest oil spill in U.S. history (Joye and MacDonald 2010). In Europe, the worst oil spill in a decade in the North Sea resulting from a leak at a Shell's platform off the coast of Scotland took place during summer 2011 (Bojanowski 2011). Oil companies always remind us that accidents rarely occur and are usually rapidly contained to cause little or no harm. However, pollution from oil spills carry on even after many decades of an accident. For instance the oil stranded by the 1989 Exxon Valdez spill remains in subsurface sediments of exposed shores (Boehm et al 2008, Short et al 2007). In many cases, spills from oil's operations go beyond merely environmental damage to serious human rights violations such as the recurrent spills to the Niger Delta in Nigeria (Adewale 1989, Osofsky 2010).

Furthermore, fumes from the burning of fossil fuels change the amounts of greenhouse gases, aerosols, and cloudiness in the Earth's atmosphere. These man made emissions affect the climate by altering incoming solar radiation and outgoing thermal radiation from the Earth, which consequentially can lead to a warming or cooling of the climate system (Solomon et al 2007). The jury is still out there on whether man's activities are to blame for global warming or if it is a natural variability cause. Nevertheless, there is a strong growing consensus among the international research community that human activities are responsible for a warming influence on the Earth's climate (Intergovernmental Panel on Climate Change 2007).

In addition, the global increase in oil demand and the dependence on fossil fuels has become an energy security concern as well. Those countries that depend on energy imports, e.g. gas, fuel or electricity, are vulnerable to a severe supply disruption and the resulting market exchange fluctuating prices (IEA 2007b). Therefore renewable energy is a good alternative to diversify energy sources through local generation, to reduce the vulnerability from disruptions from external factors and thus enhance energy security in a country.

1.2.2 Nuclear Energy

Nuclear energy, which accounted for 12.3% of the world's electricity production during 2012 (Nuclear Energy Institute 2015), has been labelled by some respected scientists as the only green solution for mitigating climate change (Lovelock 2004). These enthusiasts declare nuclear power as a safe means, posing almost an insignificant threat, to combat global climate change. However, many international bodies, the International Energy Agency included, have been more cautious and have gone further stating that nuclear power's share of worldwide electricity generation will drop in the future (IEA 2010) as unresolved issues and concern in nuclear plant safety, radioactive waste disposal, overall investment costs, and concerns of fabrication of nuclear weapons carry more risks compared to the possible benefits. Moreover, nuclear power has higher costs per unit net carbon dioxide displaced than other forms of energy (Sovacool and Cooper 2008). Furthermore, state aids, in the form of subsidies, low-cost bank loans and export credit guarantees to the nuclear sector have far surpassed the support for renewables. These structured energy distortions by state authorities undermine the fairplay to any other electricity suppliers. For instance in USA, from 1943 through 1999, the nuclear industry received $145.4 billion dollars, while photovoltaic and solar thermal power received a cumulative total of $4.4 billion and wind technology accounted for $1.3 billion dollars during the same period (Goldberg 2001).

In many instances, the safety aspect attached to nuclear power is often overlooked; as there have only been three major nuclear accidents: Three Mile Island, USA in 1979, Chernobyl, Ukraine in 1986 and more recently at Fukushima in Japan in 2011. However, these accidents have been catastrophic and are known to have created widespread ecological devastations, displacement of population, economic catastrophe, social disruption, health problems and psychological trauma (Blowers 2011). Furthermore, long-term environmental and health impacts of nuclear accidents take years, even decades, to fully show. It has been suggested that in the nuclear sector low probability events with high damage outcomes are not taken into account because the energy companies would not pay the full costs of a melt-down, given the limited liability in corporate law (Ramseyer 2011), as companies are only legally obliged to bear the costs of an accident only up to the fire-sale value of their net assets. Nuclear accidents may not occur very often but when these happen they will be big and devastating with long term consequences.

1.3 The Kyoto Protocol and Finland's National Climate Strategy

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change (UNFCCC) and anchored scientifically in the Intergovernmental Panel on Climate Change (IPCC). The Kyoto protocol, adopted in 1997 and entered into force in 2005, sets targets for 37 industrialised nations and the European community to reduce greenhouse gases (GHG) emissions to an average of five percent over the period 2008-2012 as compared to the levels of 1990 (UNFCCC 1997).

Finland, together with the EU countries, ratified the UNFCCC in 1994 and the Kyoto Protocol in 2002 (Ministry of Environment of Finland 2010). In order to fulfil these commitments, the government prepared the National Climate Strategy in 2001 and the Finnish Action Plan for Renewable Energy Sources, launched in 1999 and revised in December 2002 (Publication Registry of Finland 2001, Alakangas 2002). The revised Action Plan for Renewable Energy set targets for wind power deployment at 500 MW, and at 40 MW for solar power by the year of 2010 (Alakangas 2002).

In 2006, the install capacity of wind energy in Finland was 86 MW and there were 96 wind turbines in operation at the end of that year (IEA 2006). The total electrical output of wind power for the duration of 2006 was 0.153 TWh and the wind generation as percentage of national electricity demand was of 0.17% in the country (Statistics Finland 2006). The International Energy Agency has explicitly reported that the funds available for investment subsidies have been inadequate to achieve large increases in windpower-capacities (IEA 2008). And at that pace it seemed the targets from the National Climate Strategy were not going to be reached. Moreover, they were going to be way below the goals set. Not surprisingly the new energy and climate strategy approved in 2006 remove specific targets and only set one target for RES at 31.5% (IEA 2006). However, the parliament was not happy with the decision and required that specific targets for RES should be made (*Ibid.*) The new target proposed in 2008 was 2000 MW of wind power for 2020 (IEA 2008). In 2011, the total installed wind generation capacity at the end of that year was 197 MW, and the total electrical output estimation to be 500 GWh, which it would be the equivalent to 0.5% of the national electric demand in Finland (STY 2012). Unfortunately, Finland's progress of wind power capacity, specially in the area of politics and policy, has been painfully slow. In 2006, Finland became the only country of the EU-15 states that did not have any feed-in tariff or tradable green certificate scheme for wind power (Varho 2007), and unfortunately it remained in that spot until March 2011, when the introduction of a feed-in tariff was finally implemented (STY 2012). Feed-in tariffs are agreements, or guarantees, by governments, mainly in form of subsidies, to promote the investments in certain forms of energy production. In Finland, feed-in tariffs have been the cause of heated and lengthy debates (Talaus, et al 2010). Presently, wind power capacity in Finland is about 447 MW, 771 GWh or about 0.9% of electricity consumption at the end of 2013 (VTT 2015). It appears Finland's feed-in tariff scheme to be positively working as the wind power capacity has more than doubled in the past couple of years.

1.4 Research Objectives and Methods

From the above introduction, the immediate question one may ponder is why the development of some of the renewable energy sources, specifically wind power and solar energy, have not had the expansion as originally planned from the energy and climate strategy report in Finland and other parts of the world, but barely a really slow progress instead. Especially when talking about the environment, it can be appreciated that renewable sources have a significant advantage against other sources mainly due to their non-polluting aspect. However, the growth in the use of renewables, especially at the consumer level, is minimum and still lacking.

The main objective of this thesis is to gain a deeper understanding of why wind power and solar energy renewable technologies have not been embraced in Finland and, additionally, why are they not being supported by consumers at the individual level. The thesis' main research question is: are some forms of renewables, such as wind power and solar energy economically sensible especially at micro scale or individual level?

The study will attempt to enquire some of the reasons behind this delay with two case studies; and it will try to extend the findings to understand why the consumer end of the population has not shown interest for either technology at the individual level.

From the research objectives, a few dozen of hypotheses may come to one's mind. However, this study will refrain to state any formal hypothesis as the research has been designed to be exploratory, inductive and constructive, and hypotheses arising from the interpretation will be on a *post factum* basis (Kothari 2006). The exploratory research approach needs to be flexible, and so has been this study, in order to provide opportunities for considering different aspects of the problem under study. The study in turn will try to be unbiased. An exploratory study can be described as finding out what is happening by assessing current events. This study has followed two methods in the context within the exploratory research design: *i*) the survey of concerning literature, and *ii*) quantitative case study design.

Literature review about the topic in examination is crucial in order to identify previous research on the theme. It is important to establish a theoretical framework from previous research as the foundation, for building upon, the study. It will also establish and justify the importance of the research problem, and it will help the direction of the explorative research.

Quantitative case study design has been implemented in order to examine empirical phenomena (Yin 2003). Two cases have been designed, each treated as a single case, to gain better insight in the embedded analysis. The first case is conceptual and theoretical with support of mathematical simulations also involved in order to described possible scenarios within the wind energy sector. The second case is as well theoretical but in this case experimental too, also known as laboratory experiment, in which data have been collected through empirical measurements from a solar photovoltaic array system to support the theory.

Systems of innovation theory, especially technology innovation system, has also been engaged in this study in order to explain the nature and rate of technological change (Smits 2001). In addition, Roger's innovation-decision process has been used to understand the various groups of consumers adopting new technologies (Rogers 1995).

1.5 Scope and Limitations

This study is the research analysis of two particular and very specific cases. The findings in the study do not entail to global generalisation. For instance, the research data applies only to specific set of location within Finland. In the first case a hypothetical simplification of the wind profile of Finland is taken into account. While in the second case, the empirical data has been gathered within a specific location of the city of Jyväskylä. Nevertheless, two specific cases can be very instructive and good especially for further comparison with other studies. Furthermore, case studies are good ways to gain new knowledge and a better insight into the research field. In turn, case studies sometimes can provide suggestions and solutions to the study problems.

Although renewable energy sources are clean, abundant and free, and often inexhaustible, more than regularly the production of the technologies employed to harvest renewable energy are not. For instance, the great electricity consumption and the handling and disposal of the extremely toxic sludge from making solar panels, or the scarcity and high price of the raw minerals used in the solar cells, or even the interference of landscapes and disturbance of nature for the installation of the arrays, make solar photovoltaics not that sustainable (Scragg et al 2008, Stoppato 2008). This thesis does not put a blind eye into these issues, however, a full life cycle assessment from raw extraction material, through production process, assembly and recycling, is beyond the scope of this study.

2 LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Sustainable Development

"Sustainable development is development that meets the need of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987). This is the most well known definition of sustainable development from the 1987 Brundtland report. However, there are as many definitions of sustainability and sustainable development as groups trying to define it. Nevertheless, all definitions and frameworks proposed greatly acknowledge *i)* concern for the carrying capacity of the environment (living within the limits), and *ii)* the pursuit of economic prosperity with social, intergenerational and intragenerational equality without environmental deterioration.

In this respect, renewable energy has an important role to play for working towards sustainability. Renewable energy supports a sustainable development because it is non-polluting energy (i.e., clean energy), it is abundant, and often inexhaustible (i.e., it is not finite as it is the case for fossil fuels). By embracing renewable energy sources such as wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment and biogases, our energy system will be shifting towards a sustainable path that implies a clean environment, a secure long-term energy and diversified sources of energy.

2.2 Wind Power as Energy Source

The Earth's wind is a manifestation of the sun's renewable energy. Global winds are caused by the difference in air pressure across the Earth's surface due to uneven heating of solar radiation and the rotation of the Earth. The variation in incoming energy sets up convective cells in the troposphere, which basically means that air rises at the equator and sinks at the poles (Manwell et al 2009). This natural movement of air is what we denoted as wind.

Worldwide the potential of wind energy is overwhelming. The US Department of Energy has estimated that the world's wind could theoretically supply the equivalent of 5 800 quadrillion BTUs of energy each year, which is more than 15 times the current world energy demand (American Wind Energy Association 2009). In another study from Stanford University, an estimation of five times the current world energy demand was calculated as the world's wind theoretical supply if modern 80 m, 1500 W turbines were to be used in feasible locations worldwide (Archer and Jacobson 2005). Furthermore, Archer and Jacobson (2012) have calculated that saturation from wind power potential is reliably greater than 250 TW globally. Fortunately, worldwide the growth rate of wind power capacity has significantly increase since 2009 reaching nowadays about 2% of the world's electricity production (WWEA 2010). Nevertheless, this growth is still very slight when compared to conventional sources of power generation.

2.2.1 Advantages of Wind Power

The use of the wind's kinetic energy to produce mechanical energy is not new. The Persians and later the Romans were well aware of some of the advantages of the wind power and developed windmills to draw water and grind grain (Shepherd 1990).

The main advantage of wind power is that the raw energy, i.e., the wind, is cost-free and renewable, it is an abundant resource and it is inexhaustible. In addition, the generation of energy from this resource is carbon free, it does not emit air pollution or any other harmful emissions and does not produce any hazardous waste. Consequently, the impacts of wind farms with respect to wildlife are minimum, as no harmful emissions means clean air and water for flora and fauna of the region where the turbines are erected.

Moreover, windmill technology is fairly well developed and is becoming cost-competitive against other sources of electricity (Chiras 2001). The construction and formation of wind turbines can be built to be in balance aesthetically with the landscape (Gipe 2003). The time frame to set an entire wind farm is very short, and as a decentralised power, it allows smaller players to get involved in the power generation business – an opposite structure of current exclusive oil, gas and nuclear business (Rechsteiner 2008). Also wind energy does not the need water for cooling. It has been estimated that 20% share of wind energy will reduce water consumption in the electric sector by 150 billion litres (Energy Efficiency and Renewable Energy 2010). Wind power does not generate significant heat, heavy pollutants and harmful emissions, soot neither impact the ozone layer. Wind energy can also have a positive effect in job creation, income options for farmers, availability of power resources in remote areas and the promotion of further development in the region.

2.2.2 Disadvantages of Wind Power

The intermittent nature of wind is the main disadvantage of wind energy. Wind can be very unreliable, depending on weather patterns, temperature, time of the year and location. Therefore, wind turbines cannot produce constant energy and may only generate a small percentage of their total power. In turn, a wind site may or may not be cost competitive. Furthermore, wind does not always blow when is needed and when it is not needed it cannot be feasibly stored (Wagner and Mathur 2009), and usually wind farms are placed in remote locations which require expensive transmission lines to be built to bring the electricity to the power grid. Wind turbines do not provide power if there is no wind and it is difficult to predict the precise moment when they will starts providing electricity to the grid. Therefore, overloading the grid is a strong possibility with resulting widespread damage to the grid (Lund 2005).

Another disadvantage is that the developments of wind sites are often objected by people who strongly think that wind turbines disrupt the natural landscape (Clarke 1991), and that the rotor blades from the wind turbines are noisy. There is also concern that wind turbines have a detrimental effect on avian and bat populations (EREE 2010).

2.2.3 Wind Power Technologies and Classification

2.2.3.1 Types of Wind Turbines

Wind Turbines are generally classified into two types based on their structure: horizontal axis turbines and vertical axis turbines. In horizontal axis wind turbines (HAWT) the blades rotate along the horizontal axis, i.e., parallel to the ground. In contrast, in the vertical axis wind turbines (VAWT) the blades rotate along the vertical axis, i.e., perpendicular to the ground. Both HAWT and VAWT types can be split into subcategories according on whether they primarily make use of *lift* force or *drag* force to turn the rotors (Manwell, McGowan & Rogers 2009).

There are a number of technologies for each type. Both having advantages and disadvantages. Currently, the most common wind turbines are the horizontal axis ones.

2.2.3.2 HAWT

The Horizontal Axis Wind Turbines have been chosen by the market as the right choice for multi-megawatt and large-scale wind farms (Stankovic, Campbell & Harries 2009). HAWTs have the main rotor shaft and electrical generator at the top of the tower. This kind of turbine must be always pointed into the wind direction.

Traditional windmills

Traditional windmills are typically four bladed structures. They are usually employed for pumping water from low-lying land or for grinding grains. Windmills are designed to primarily make use of the drag force to turn the blades in order to operate at low wind speeds. Traditional windmills have low efficiency energy conversion.

Modern wind turbines

Modern wind turbines are currently employed in wind farms for the commercial production of electric power. Modern HAWTs are usually three-bladed designed to make use of the lift force to turn the blades, and as such, these turbines are characterised as begin fast-moving blades with low surface areas. They are placed on top of tubular steel towers ranging from 60 to 90 metres tall. Small HAWTs are pointed into the wind direction by a simple wind vane, while large turbines use a wind sensor coupled with a computer-controlled motor. The majority of these types of turbines have a gearbox to turn the slow rotation of the blade into a quicker rotation suitable to drive the electric generator.

2.2.3.3 VAWT

Although most wind turbines are of the horizontal axis type, vertical axis wind turbines (VAWT) can be advantageous to the horizontal axis wind turbines (HAWT) in several aspects. These advantages will be further reviewed in the next chapter.

The main characteristic of the VAWTs is that the shaft is vertical, and therefore these kinds of turbines do not need to be oriented with respect to wind direction. For the same reason, the transmission and generator can be mounted at the ground allowing easier maintenance.

Savonius wind turbine

A finnish engineer, S.J. Savonius, invented the Savonius turbine in 1922 (Eriksson, Bernhoff & Leijon 2006). This is a drag type VAWT that can work at low wind speeds. However, because the tip speed ratio is low, it is not ideal for electricity production. It also has a low efficiency.

Darrieus wind turbine

In 1931, George Darrieus patented his VAWT (Eriksson et al 2006). The main characteristic of this kind of turbine is that its bent blades use lift forces to create rotation. Thus, it is a lift-type VAWT which has a high tip speed ratio, meaning fast rotation compared to wind speed. The Darrieus turbine has high theoretic efficiency similar to the HAWTs.

Giromill or H-rotor wind turbine

The Giromill or H-rotor wind turbines are a variant of the Darrieus type. They are a lift type VAWT characterise for having 2 or more vertical straight blades parallel to the vertical shaft. These turbines have a decent theoretical efficiency and they are quite simple and low cost to build.

A variation of the H-rotor turbine is the vertical axis Bellshion blades. These types of turbines replace the vertical straight blades for a double-vaned blade designed to raise the efficiency by generating more lift through increased sweep speed (Suzuki and Taniguchi 2008).

2.2.4 Wind Turbines in Telecom Sites

Wind energy systems are not new and they have been used for centuries as a source of energy. Currently, there is an increase of literature concerning modern wind turbines, especially horizontal axis wind turbines (HAWT) due to the significant investments made by many countries over the last years (Stankovic, Campbell & Harries 2009). Nevertheless, growing environmental concerns have resurge interest in different types of renewables, vertical axis wind turbines (VAWT) included.

In the previous sections, some advantages of the VAWTs have been highlighted. Nowadays, several commercial models have diversified the end-use applications, especially in remote and far areas. Some of these applications have already been employed in the telecommunications sector, in particular, in remote telecommunication stations and light towers. For instance, a Bosnian Telecom company contracted VAWT to provide energy supply to seven remote GSM-stations (Islam et al 2005). More recently in Sweden, Ericsson AB, Vertical Wind Communications AB and Uppsala University have developed a wind energy conversion system employing a VAWT to power telecommunication equipment (Bülow 2011). In the Philippines, Smart Communications Inc., currently have 114 hybrid (solar and wind power) cell sites in operation nationwide, and 40 of them run purely on wind power (Reyes 2010). And there are currently additional projects of this kind projected around the world. However, HAWTs are still the mainstream choice for telecom operators when there's no grid in rural settings (Alliance for Rural Electrification 2012).

Although information about VAWT powering cellular communication towers exists, it is usually seldom found in the literature. This study hopes to provide further material and knowledge in what entails employing a VAWT for powering remote and also on-grid cellular stations.

2.3 Solar Power as Energy Source

Solar energy is by far the largest resource from all renewable energy sources. The sunlight that strikes the earth in 1 hour (4.3 x 1020 J) is more than the energy consumed on the entire planet in 1 year (Lewis and Nocera 2006). The world's solar photovoltac market is one with the fastest growth. It has experienced about 50% annual growth rate over the past five years (Smesta and Lampert 2007, IEA 2015) with roughly 67 GW of installed solar PV capacity at the end of 2011 (IEA 2015). However, even if this numbers seemed to be encouraging, of the world's energy supply only 0.3% was produced from solar thermal energy and less than 0.05% was produced by solar photovoltaics during 2005 (IEA 2008b) and nowadays accounts for less than one percent of the total yearly electricity production (IEA 2015). Interestingly, Germany is at the moment the market leader in installing photovoltaic systems, it holds the lead as the country that uses most solar panels and produces about half of the total world's solar electricity (Semanova et al 2007), in spite of Germany having much lesser sunny days than southern countries.

2.3.1 Advantages of Solar Power

Solar energy is completely renewable, it is a constant and it is a consistent power source (the sun is always shining somewhere on earth). The main environmental benefit of generating power from the sun is the significant reduction in air emissions of green house gases (GHG) and other toxic particulates. Solar energy production generates no waste from every day operations.

In contrast to wind power, solar cells and panels make absolutely no noise at all while producing electricity, as they have no moving parts. They are practically maintenance free and will last for decades. Solar panels are extremely easy to install.

Solar panels can be placed where no electricity grid connection is available, greatly improving the life of people living in rural areas mainly in developing countries. Solar energy could be use in agriculture, e.g. micro-irrigation, to power small electrical devices such as radio and telecommunication stations, to increase safe medical care, e.g. cold storage for vaccines and to power other medical devices, and for providing light during night time (Okoro and Madueme 2006).

2.3.2 Disadvantages of Solar Power

The main disadvantage is consistency and reliability. Solar power cannot be exploited during the night or on a cloudy day or a storm. That is the main reason it cannot be used as the only source of energy, it must be complemented with several different sources. At the moment the solar cells and panels tend to be very expensive. And with 95% of the manufacturing industry for solar panels based on silicon, the shortage of silicon feedstock threatens to stall the growth of this industry (Smestad and Lampert 2007).

When comparing solar energy systems with current nuclear and fossil energy production, large solar power production may initially cause more GHG and environmental degradation, as the production of solar technologies involves hazardous substances (Bezdek 1993). Large solar power stations also require a significant land area to operate. Finally, technology in solar panels changes rapidly, with new cost and energy efficient panels being built, so incentives to adopt the current technology are small.

2.3.3 Solar Power Technologies

The most common solar power technologies currently employed for the conversion of sunlight into electricity are photovoltaics (PV) and concentrated solar energy. Nevertheless there exist other solar technologies which make use of the solar energy's thermal property. Some of these technologies are: solar lighting and passive solar building design, solar water heating, solar water treatment, solar cooking, and other solar thermal processes such as water evaporation and disinfection.

2.3.3.1 Photovoltaics

A photovoltaic cell (PV), or solar cell, consists of a thin wafer of silicon or some other material usually assembled on panels for the conversion of light into electricity using the photoelectric effect. The silicon cell, or some other material, emits electrons when struck by sunlight. These electrons liberated from the material then flow out of the wafer forming a direct electric current (Chiras 2001). Materials presently used in solar cells include amorphous silicon, polycrystalline silicon, micro-crystalline silicon, cadmium telluride, and copper indium selenide/sulfide (Jacobson 2009). Confirmed terrestrial solar cell module efficiencies at 25 °C are in the range of 10% to 30% (Green et al 2010), with the commercial solar cells at around 20%.

2.3.3.1 Concentrated Solar Power (CSP)

Concentrated Solar Power (CSP) is a technology that makes use of lenses or mirrors and tracking systems to focus, or concentrate, a large area of sunlight into a small beam in order to heat a fluid in a collector at high temperature. The fluid in CSP can be pressurised steam, synthetic oil, or molten salt. The heated fluid then flows from the collector into a heat engine which drives turbines to generate electricity by conventional means. Usually, up to 30% of this thermal energy is converted to electricity (Jacobson 2009).

2.3.4 Micro Solar Photovoltaic Systems

Applications of solar photovoltaic systems (PV) are becoming widespread in developed and developing countries. Solar systems may appear in paper to be strong candidates for renewable energy generation. However, the amount of power generated by a PV system depends on the availability of solar insolation. The efficiency of a solar system is also influenced by a number of factors and the technical information provided by manufacturers at standard test conditions may never occur in practice.

There exist vast literature available on the economics of photovoltaics in residential households (i.e. Lazou and Papatsoris 2000), as well as on empirical data of energy payback for photovoltaic systems (Knapp and Jester 2001). (Crystalline silicon modules achieve an energy break-even in 3 to 4 years). However, this data comes from well designed photovoltaics systems in which many variables involved are carefully, and even sometimes meticulously, planned. For the regular household, mere calculations about the panel ratings and energy needs according to specific devices may become troublesome. But solar photovoltaic systems should not be that complicated. What about if for the regular person having a façade facing south (in the northern hemisphere) could simply tilt an array of solar panels, connect the cables to a battery and be able to charge his or her portable devices. This investigation will also try to embark into this issue with an empirical case study.

2.4 Systems of Innovation

Innovations can be considered as the emergence and diffusion of knowledge elements (e.g., scientific and technological) into the creation of new products of economic significance (Edquist 1997). Generally speaking, an innovation is an idea, object or practice that is perceived as being new. The processes through which technological innovation emerge are extremely complex and they are characterised by complicated feedback mechanisms and interactive relations involving science, technology, learning, production, policy, and demand (Ibid.) The systems of innovation approach "consist of all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovation" (Ibid.: 10). This approach has been found suitable for the study as it encompasses a holistic analysis of innovation processes and the different factors that influence this process. For instance, the establishment of an innovation can be shaped by institutions, such as laws, regulations, cultural norms, social rules and technical standards. By using this approach the study aims to understand where the adoption of renewable energy technologies for this particular cases currently stands.

2.4.1 Diffusion of Innovation

In the same context diffusion of innovation, a theory which attempts to explain how, why, and at what rate new innovations (mainly technological) spread through society, may help us to understand the adoption process of renewable energy technologies. Diffusion of innovation has been defined as "the process by which an innovation is communicated through certain channels over time among members of a social system" (Rogers 1995). Diffusion research focuses on the likelihood that the innovation, e.g., an idea, product, or new practice, will be adopted by the members of society.

Diffusion is a special type of communication in which the message about the properties of the innovation is conveyed to target the main population. According to Rogers, the diffusion of innovation is a decision-making process that occurs though five stages: knowledge, persuasion, decision, implementation, and confirmation (Rogers 1995). During this process the individual is first exposed to the innovation and he or she will make and assessment going through different stages until, finally, fully adopting it or perhaps rejecting it.

3 AN ASSESSMENT STUDY OF VERTICAL AXIS WIND TURBINES (VAWT) ON CELLULAR COMMUNICATION TOWERS

3.1 Cellular Communication Towers

The cellular communication towers, also known as cell sites, radio masts, base stations or base transceiver stations (BTS), consist of electronic communication equipment (transmitter/receivers transceivers) usually located at the base level of the tower, and antennas which are placed at the top tower. The towers are usually tall structures supporting antennas at the top for telecommunications (a cell in a wider cellular network) but also for broadcasting purposes (radio or television).

3.1.1 Types

There are different types of cellular towers. Some of the most common tower designs used are the cylindrical steel monopole, the self-standing steel lattice tower and the guy-wired-supported mast, with height ranging from 30 up to 100 metres (Wikle 2002).

The Finnish Communications Regulatory Authority has stated that no information about the number of cell sites is publicly available and that the mobile operators regard that information as private (FICORA 2010). However, according to a publication from the Ministry of Environment in Finland, the number of masts in the country for the year of 2003 was 6 400 with about 200 masts being built on a yearly basis (Weckman and Yli-Jama 2003). From the same publication the information about the cell sites elevation was: antenna monopoles height 15-40 metres, self-standing lattice tower height varies from 30-60 metres and the wired-guyed mast ranges from 70-100 metres (Ibid.)

Usually cellular towers are built according to specification. This means that the tower height and the structural loading information are usually custom-made according to the carrier's loading conditions and specifications, and local building regulations. For instance, a 77 metres high self-support lattice cell tower has maximum tower loads of:

Vertical (Downward) Load: 800 kips*
Uplift: 600 kips.
Horizontal Shear: 100 kips. (Patriot Engineering 2010).

* 1 kip is equal to 454 kg.

3.1.2 Power Consumption

The power consumptions of GSM/3G base transceiver stations, or BTS, greatly vary according to the manufacturer, the site configuration, and the desired coverage. For example, the Siemens BTS 240 consumes 1300 W while the Huawei BTS 4th G is quoted as 2000 W of consumption (Forster et al 2009). For this reason it is very difficult to meticulously established the overall consumption of, for instance, a nation-wide cell sites. However, for assessment purposes figures indicate, and agree, that the continuous power consumption of a BTS is about 1.5 kW, and, after including other ancillaries such as supportive equipment, power conversions and losses, and cooling systems, the total power consumption of a cell site is around 3 kW (European Business Press 2007, Forster et al 2009, Wujun 2008). Nevertheless, the stand-by load of a site when there are no calls or data activity (off-peak times) where radio resources are off can lead to around 25% power saving (Forster et al 2009). Typically, cell sites can run at anywhere from 0.5 to 4 kW.

3.1.3 Compound Power Consumption of Cell Towers in Finland

Following the data from above, in order to gain a reasonable assessment of the compounded power consumption for all cellular towers in Finland. Firstly, we must assume a supposedly 8 000 cell sites that exist in Finland (see Section 3.1.1) and then multiply this number by their figurative individual power consumption of 3 kW discussed earlier, and

$$TP = (8000\,cells) \times (3000\ W / cells) = 24\,MW \tag{1}$$

it gives us a total power consumption of 24 MW. For comparison, this would be roughly the equivalent of one of Fortum's hydroelectric power plants, Leppikoski, along the Emäjoki river (Fortum 2005) just for producing the energy required to power all cellular telecommunication towers in Finland.

3.1.3 Cell Sites on Remote Areas

Increasing the coverage of cellular networks is a continuous battle between mobile operators. In areas where grid electricity is non-existent and when coverage is needed, cell towers are erected and usually powered by diesel generators (WindPower Engineering 2009). This set up requires regular re-fuelling, and in turn periodic visits to the site to bring the fuel and for maintenance to replace engine oil and filters. However, cell operators and manufacturers are starting to consider alternative sources of energy such as renewables for powering cellular sites, especially in off-grid locations.

Smart Communications Inc., a wireless service provider in the Philippines, has been a pioneer in setting up "green" cell sites since 2006. Currently they have 114 hybrid (solar and wind power) cell sites in operation nationwide, and 40 of them run purely on wind power (Reyes 2010). For this reason, Smart Communications was honoured with the first Green Mobile Award at the prestigious Global Mobile Awards in 2009 for his alternative power for cell sites program and for having the most extensive deployment of stand-alone wind-powered cell sites (Global Mobile Awards 2009).

In 2007, Motorola and Mobile Telecommunication Limited Namibia started a pilot project of a wind and solar powered system to operate cell sites in Namibia. And although the results are not public, Motorola did state that a combination of solar cell and wind turbines of 1.2 kW continuous power were needed to provide energy to a mid-size BTS and support a microwave backhaul installation (Motorola 2007).

At the end of 2009, Helix Wind Corporation from California started a telecom infrastructure project in Nigeria. Helix Wind has deployed vertical wind turbines in order to "lower the costs of expensive off-grid cell sites powered by diesel, which are bad to the environment and are extremely expensive to operate" (Helix Wind Corp. 2009). Exact details of the project and current status are, as usual, kept confidential.

In 2010, the carrier provider T-Mobile announced its first solar cell site in the USA powered by 12 solar panels. Specifics were not provided but T-Mobile stated that the power was enough to take the cell site off-the-grid and even at times feed power back into the grid (Fehrenbacher 2010).

3.2 Understanding Vertical Axis Wind Turbines

In vertical-axis wind turbines (VAWT) the blade axis is perpendicular to the ground. There are several designs and concepts for VAWT, however the most widely used are the Savonius rotor, the Darrieus turbine, the H-rotor and recently the Bellshion blade (Eriksson et al 2008, Manwell et al 2009, Suzuki and Tanihuchi 2008).

3.2.1 Theoretical Background

The wind has kinetic energy, as the air has mass and it moves at a velocity to form wind. The kinetic energy (*J*) can be obtained by multiplying half the mass (*m*) by the square of the velocity (v^2). And since power is energy divided by time, and the mass of air can be expressed multiplying its density (ρ) by the volume (or area x distance *Ad*), we can then calculate the power (*P*) of the wind on a given area using:

$$P = \frac{1}{2}\rho A v^3 \tag{2}$$

The equation describing the amount of power, P, that can be captured by a wind turbine is:

$$P = \frac{1}{2} C_p \rho A v^3 \tag{3}$$

where C_p is the power coefficient, ρ is the density of the air (the standard sea level air density is 1.225 kg/m^3), A is the swept area of the turbine and v the wind's velocity. In ideal conditions, when there is no drag, the optimum C_p equals 0.5926. This is also known as the Betz limit, after Albert Betz who developed it in 1919 (Manwell et al 2009). According to Betz's law, no turbine can capture more than 59.3 percent of kinetic energy in wind. In optimal conditions, i.e. assuming no drag, the vertical axis wind turbines have the same Betz limit as do horizontal axis wind turbines (Ibid, p.151).

The power coefficient C_p represents the aerodynamics efficiency of the wind turbine and is a function of the tip speed ratio, λ, which is defined as the ratio between the rectilinear speed of the blade tip and the wind speed, as shown:

$$\lambda = \frac{\omega R}{v} \tag{4}$$

where ω is the rotational frequency of the turbine, R is the turbine radius and v is the wind speed.

Table 3.1 HAWT and VAWT C_P Range Comparison

Turbine Type:	**C_P Range:**
HAWT	0.40 - 0.50
VAWT	0.20 – 0.40
(Betz Theoretical Max.)	(0.59)

For horizontal axis wind turbines (HAWT), the C_p values are usually between 0.40 and 0.50 (Muljadi et al 1989). VAWT values of C_p usually range between 0.20 and 0.40, although theoretical results for VAWTs predict a maximum C_p of 0.54 at a tip speed ratio of 2.5 for small H-rotor (Roynarin et al 2002).

Why are the C_p values of the HAWT significantly much higher than in the VAWT? Arguably, it has been stated that lower values of C_p in VAWT are due to the less effort from the wind industry to make significant technological improvements in that area, which, consequently, can be linked due to a lesser financial support and interest of the market for VAWT (Eriksson et al 2008).

3.2.2 VAWT versus HAWT

The choice of using a vertical axis wind turbine (VAWT) over a horizontal axis wind turbine (HAWT) in this study is because of the following aspects: power rating, yaw mechanism, size, design, positioning of the turbine, and environmental concerns.

3.2.2.1 Power Rating

The power rating of any wind turbine greatly varies accordingly to its size, i.e. its rotor diameter. The rated power of commercial available VAWT is in the range from less than 100 W for small turbines up to 3.8 MW for the world's largest (Industcards 2010). This means that in operation VAWT are able to supply electricity to power few light bulbs, a small appliance, a single house or a significant amount of houses.

In contrast, commercial HAWTs range in capacity from 1 kW to 2.5 MW onshore, while the offshore turbines may even be rated at 6 MW (Siemens 2013).

3.2.2.2 Yaw Mechanism

The wind turbine yaw mechanism is a system used to turn the wind turbine rotor against the direction of the wind (Manwell et al 2009). However, vertical axis wind turbines are omni-directional, i.e., they have the ability to accept the wind from any direction. This means that the VAWT system does not require a yaw mechanism.

The lack of a yaw system, which includes both a control system and a drive mechanism, in this case is an advantage as there are no extra costs associated with such a system in the equipment itself as well as in the installation, operation and maintenance. Furthermore, there are no additional power losses during the time it may take for the turbine to yaw (Eriksson et al 2008).

3.2.2.3 Size

The trend in wind power development has been to increase the size of the HAWTs, as large installations become more economical with larger turbines (Eriksson et al 2008). For this reason VAWTs are the good small option in areas where HAWTs do not fit or do not work that well, for instance in mountain areas, urban areas or regions with extremely strong or gusty winds (Riegler 2003).

3.2.2.4 Design and Manufacturers

Although not as evolved technologically as their HAWT counterpart, VAWTs already have a strong presence in the market. There also exist a vast range of designs of VAWT which can easily fit into the structure, geometry and characteristics of a cellular tower. Moreover, there are many commercial companies that already produce several turbines, of different sizes and rated power, based on VAWT technology. For instance, in Finland there are two well known companies manufacturing VAWTs that claim to have the best technology in the market: Windside Production Ltd and Shield Innovations (Windside 2015, Shield Innovations 2015). The wide range of designs and power ratings, and the availability of VAWT by different companies, is another benefit as the required specifications for a given site could be easily covered without too much troubleshooting.

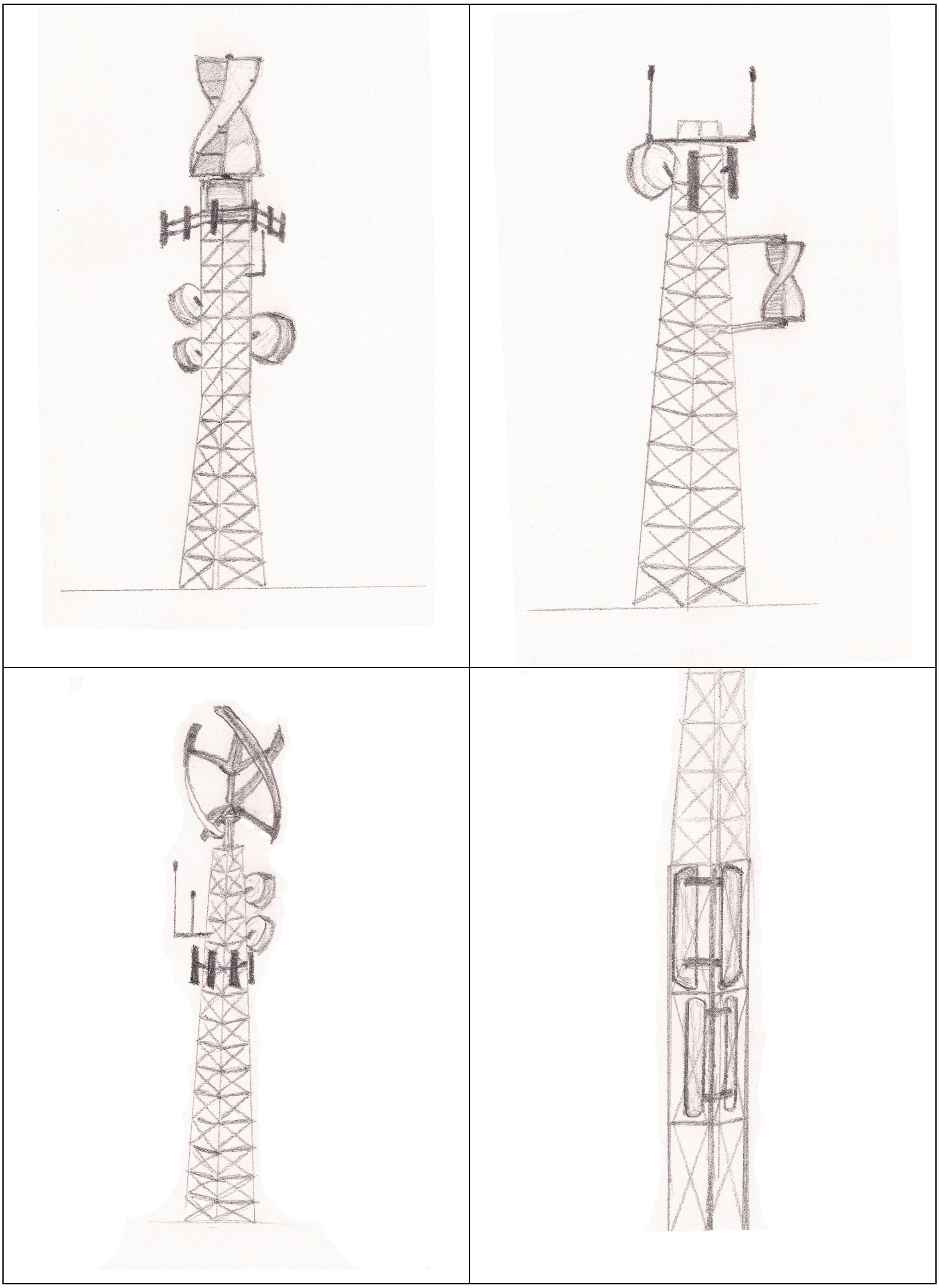

Figure 3.1. Sketches of VAWTs on cellular communication towers.

3.2.2.5 Location

One main advantage of VAWTs is that they are omni-directional. The ability to receive the wind from any direction implies that the turbine can be situated at places where the wind is turbulent or where it changes its direction very often. In addition, because a yaw mechanism is not needed in VAWT, it also means that the turbine could be place anywhere along the tower where it could be most suitable. This implies having many possibilities on the turbine placement.

3.2.2.6 Environmental Impacts

There are few environmental factors which the VAWTs have an advantage over the HAWTs. Noise is one of them. VAWTs produce less noise that the HAWTs. This is due to the aerodynamic noise from the turbine is proportional to the blade tip speed (Manwell et al 2009), which in HAWTs is usually high. VAWTs have relatively low rotational speed and thus are typically quieter. Slower blade tip speed also means that icing is not a big problem. In contrast, in HAWTs, ice that comes loose may seriously cause harm and that is why a security distance placed as buffer zone is required. In VAWT less security distance is required (Eriksson et al 2008).

Because VAWTs operate at lower speeds, also benefit wildlife such as birds and bats. The blades in VAWTs have less whipping area than the counterpart HAWTs, and thus reducing the risk for bird coalition. In addition, VAWTs when spinning have the appearance to be a complete solid element, making them even less harmful for birds and bats (Berardelli 2009).

3.2.3 VAWT on Cellular Telecom Towers

As we have seen, designing and placing a VAWT on a telecom tower allows for flexibility and creativity. There are as many ways as one could imagine for placing a VATW on given tower. Towers could be easily modified in order to fit a suitable VAWT or new towers could be harmonically designed to fit the turbine in an integral way.

3.3 The Power of Wind at Cell Sites in Finland

The weather in Finland is dominated by troughs of low pressure that form over the North Atlantic Ocean reaching Finland from the west or southwest, and least commonly by northern and north eastern winds coming from the Arctic Ocean (Finnish Meteorological Institute 1990). These great variations in air pressure and winds place the country in the zone of westerly air disturbances (Ibid.) According to the International Energy Agency, the wind power potential in Finland in the short-term, is more than 300 MW on the coastal areas and nearly 10 000 MW offshore (IEA 2008a).

3.3.1 Calculating the Wind Energy Potential at Cell Sites

Using the wind speed average we can estimate the energy content of the wind for a given location. According to the Finnish Meteorological Institute, observations from 1961 to 1990 have shown that the average wind speed in Finland is 3 to 4 metres per second inland and slightly higher on the coast (Finnish Meteorological Institute 1990). Usually, this meteorological information is gathered from weather stations placed at 10 metres height above low-lying obstructions, following WMO guidelines (World Meteorological Organization 1983).

For calculating the wind energy potential at a site, we need to determine the hub height in which, hypothetically, the vertical wind turbines would be placed. The information available about cellular towers indicates that the cellular towers height range from 15 to 100 metres. Because specific information is not made public, we therefore must rely on the arithmetic mean of the maximum and minimum values of the towers, i.e., we must employ the mid-range equation in order to obtain the midpoint value as a measure of the central tendency of all the towers' height (Boundless 2013):

$$M = \frac{\max x + \min x}{2} \tag{5}$$

And substituting values,

$$M = \frac{15 + 100}{2} = 57.5 \tag{6}$$

However, 50 m is preferably to use in order to simplify calculations and to avoid a possible over estimation of wind potential (as there is no public info about exact numbers and types of cell towers).

The next step is to find out the average wind speed at the height of 50 metres. According to the Finnish Wind Atlas, the average wind speed at the height of one kilometre is about 9 m/s (Finnish Wind Atlas 2009a). It is possible then to extrapolate the wind speed by using the logarithmic model of wind shear (Gipe 2004). The logarithmic extrapolation of wind speed with height is given by:

$$V = V_0 \frac{\ln(H/z_0)}{\ln(H_0/z_0)}, \tag{7}$$

where, V_0 and H_0 are the wind speed and height at origin, H is the new height and z_0 is the roughness length value. Because of Finland is covered with forest; more than two-thirds covered with forest and more forest area per capita than any other country in Europe (Lee Tan 2007), we can use a roughness length value of 0.3 for this kind of topography (Gipe 2004). Thus, using Eq. (7) and substituting values:

$$V_{50} = 9 \cdot \frac{\ln(50/0.3)}{\ln(1000/0.3)} = 9 \cdot \frac{5.116}{8.112} = 5.679 \quad m/s \tag{8}$$

This result for wind speed average is in agreement with the information from the Finnish Meteorological Institute as we can expect to find a slightly higher wind speed at higher altitude. Additionally, and in order to reassure our estimate, we can have obtain another evaluation of the wind speed average at 50 metres by using again the logarithmic law, but this time we use the information of the average wind speed in Finland, which is 4 m/s, measured from weather stations around the country. We also assume that these stations are placed at about 10 metres high for weather measurements.

$$V_{50} = 4 \cdot \frac{\ln(50/0.3)}{\ln(10/0.3)} = 4 \cdot \frac{5.116}{3.507} = 5.835 \quad m/s \tag{9}$$

This result is well in agreement with what was previously found. It is important to be confident in the data and, therefore, it is desirable to verify and validate the results in order to analyse the model to find mistakes or defects, and to avoid potential misrepresentations of the real life situation (Oberkampf and Roy 2010).

Nonetheless, for calculating wind energy, and to err in the side of caution, it is always advisable from the average of the results to round down and not up (Woofenden 2010). Let us say, for the sake of simplicity and to avoid over-estimations, that the average wind speed at 50 metres in Finland is around 5 m/s.

We have now the wind speed average, however, that information is not yet sufficient, as we also need to know the different wind speeds throughout the year, i.e. we need the *frequency distribution* of wind speed. This is because, recalling the power equation of the wind Eq. (1), the average of the cube of many different wind speeds will always be greater than the cube of the average.

For a known specific location in Finland we could use the Finnish Wind Atlas as a tool for estimation of local wind energy potential (Finnish Wind Atlas 2009b). However because locations for cellular towers are scattered around the country and their specific sites are not in the public domain, a generalised estimation for the whole country has to be made instead. Nevertheless, the Finnish Wind Atlas can be a good reference and source of information for validating data.

The frequency distribution of the wind has proved to fit quite well to a probability distribution called the Weibull distribution (Wizelius 2007):

$$f(x;\lambda,k)=\begin{cases}\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1}e^{-(x/\lambda)^k} & x\geq 0,\\ 0 & x<0,\end{cases} \tag{10}$$

where $k>0$ is the shape parameter and $\lambda>0$ is the scale parameter of the distribution. The Weibull distribution follows a bell-shaped curve and it can be used to characterise wind speeds when the actual distribution of wind speeds over time is unavailable. The *Rayleigh distribution* is a special case of the Weibull distribution (when the shape parameter is equal to 2) and it successfully describes wind distributions in mid latitudes such as most parts of Europe including the Nordic countries (Lundberg 2006). However, some sites on earth cannot be described by the Weibull distribution. But according to the Finnish Wind Atlas in Finland the wind speed distribution follows the Weibull distribution (Finnish Wind Atlas 2009c).

There exists a relationship between the power density computed from the average speed alone and that from the speed distribution. This relationship is what Jack Park called the cube factor (Park 1981) or what Golding labelled as the energy pattern factor (Golding 1976). The relationship, or cube factor, we are looking is that for the Rayleigh distribution which is we already know from the literature that is 1.91 (Gipe 2003, Wizelius 2007).

Finally, we just need to know the average density of the air in Finland. According to the Finnish Wind Atlas the standard value of the density of air (1.225 kg/m^3 at sea level and 15 °C) can be used to calculate power production (Finnish Wind Atlas 2009d).

At this point we have the information and values needed in order to estimate the power of the wind for our hypothetical cell tower of 50 m of height with a mean wind speed of 5 m/s. We then use Eq (1), the wind power equation:

$$P = \frac{1}{2}(1.225)(1.91)(5^3) = 146.234 \text{ W/m}^2 \,. \tag{11}$$

From Section 3.1.1 we know that there were 6 400 cell towers in 2003 and that about 200 new towers are built yearly, which means a total of 7 800 towers for 2010. Therefore, with those estimates we can calculate the combined power for all cell sites in Finland:

$$P_{Total} = 146 \cdot 7800 = 1138800 \text{ W/m}^2 \,. \tag{12}$$

or about 1 MW per square metre. Multiplying this last result by the number of hours in a year we can obtain the energy content of the wind per year as:

$$\begin{aligned} 1138800 \cdot 8760 &= 9975888000 \text{ Wh/m}^2\text{/year} \\ &\approx 10 \text{ GWh/ m}^2\text{/year.} \end{aligned} \tag{13}$$

Furthermore, the above results have been found using an analytical method, i.e., finding a simplified equation which can provide a solution to our problem by analysis. However, as mentioned earlier, it is appropriate to verify and validate the results obtained from that equation with the means of other methods. Usually, there are three types of techniques for solving these kinds of problems: *experimental*, *analytical*, and *numerical*. Because experiments are slow to make and expensive, and often do not allow flexibility in parameter variation, in this case the last two techniques need to be employed instead. Therefore, computing a numerical solution and having both results in agreement, would increase the validity of this study. And for this reason, a numerical algorithm particularly for this case has also been developed and programmed which make use of a random number generator and a Weibull distribution (Eq. 10) in order to find a numerical approximate solution to our same problem. This numerical algorithm (see Appendix 1) has been implemented in the computing environment Matlab, and the results have been compared to those of the analytical solution.

3.4 VAWTs on Cell Towers

The calculations from the previous section are mere estimations from assumptions far from the empirical world (not all towers' heights are 50 metres nor the wind is 5 m/s at all locations). However, they give us a general idea and knowledge of what we could expect if that would be the case. The same applies to the calculations in this section; they will give us an idea of the energy that could be generated by placing a vertical wind turbine at the top of a cellular communication tower.

The main rationale for choosing a telecommunication tower to place a vertical axis wind turbine is: the *tower*. Generally, the cost of a tower for a wind turbine is around 20 % to 30% of the total price of the turbine (Gipe 2004). Thus, it would be appropriate and desirable to make use of the infrastructure in place for additional utilisation such as wind power.

3.4.1 Choosing the cell tower and appropriate turbine

There exist different cell tower types (Section 3.1.1), from these the self-support lattice tower is the one with greatest flexibility used in heavy loading conditions. Its typical geometry, three sided with triangular base or four sided square base, gives this tower its structural strength. Therefore, this is the cell tower of choice that could accommodate a vertical wind turbine with little modifications. In Finland, these towers' heights range between 30 to 60 metres and widths of 1 to 2.5 metres at the top, so it would be of interest to find out what the power output would be at those heights. Let us then continue the calculation using already our previous calculations for the height of 50 metres, as the difference of wind speeds between those weights can be considered relatively small.

At this point we have to select from the wide range of vertical axis wind turbines available, which ones are the most suitable for our analysis. These VAWTs should be suitable to be placed on top of the cell tower. This means that their width should be 2.5 metres or less. More importantly, a wind turbine with low cut-in wind speed is desirable. There are many manufacturers of VAWTs, however, many of these manufacture wind turbines for high speed winds and with high cut-in wind speeds. After a long and exhaustive examination, the search was narrowed to three manufacturers. Among these a local manufacturer, Winside Oy from Finland, was chosen mainly because it makes more sense to purchase the turbine locally than bring it from overseas and waste energy and resources in transportation.

The three VAWTs selected were the Windside WS-4B, a 240 watt rated turbine manufactured by Windside Oy (Windside 2009) with cut-in wind speed of 1.5 m/s and width of 1.2 m; the GUS-10, a 600 W turbine with cut-in speed of 2 m/s and width of 1.5 m, manufactured by Green Utility Systems (Green Utility Systems 2009); finally, the UGE-4kW, a rated turbine of 4 000 W with cut-in speed of 3.5 m/s and bottom width of 1 m, manufactured by Urban Green Energy (Urban Green Energy 2010). The full comparison chart between these vertical axis wind turbines with its characteristic and technical specification is shown in Table 3.2.

Table 3.2 VAWT Technical Details Comparison

	Windside WS-4B	GUS 10	UGE-4k
Rated Power	240W	600W	4kW
Cut-in wind speed	1.5 m/s	2 m/s	3.5 m/s
Cut-out wind	none	27 m/s	25 m/s

speed			
Swept area	4 m²	4.6 m²	12.5 m²
Cp at 5 m/s	0.23	0.22	0.33
Weight	700 kg	360 kg	444 kg
System width	1.2 m	1.5 m	3 m (1m)
System height	5 m	4.27 m	4.4 m
Generator	Permanent magnet	Permanent magnet	Perm. magnet
Retail Price (approx.)	26 000 €	25 000 €	18 000 €

3.4.2 VAWTs Annual Electricity Production

In order to calculate the annual electricity output from these turbines we employ the equation describing the amount of power that can be captured by a wind turbine, Eq. (3) in Section 3.2.1, then multiply it by the energy pattern factor (cube factor) for the Rayleigh distribution of 1.91 and multiplying again by the number of hours in a year (*T*):

$$E_{/year} = \frac{1}{2} C_p \rho A (1.91) v^3 T \tag{14}$$

The next calculations are done assuming a vertical axis wind turbine is placed on top of a cellular telecom steel-lattice tower at 50 m of height and the annual average wind speed is estimated to be 5 m/s at that height (see Section 3.3).

3.4.2.1 Windside WS-4B

Windside Oy produces a range of turbines mainly designed for rugged and tough conditions (Windside 2009). However, these Savonius type turbines also required high wind speeds in order to produce greater power. Nevertheless, this model stands out due to its low cut-in wind speed. Additionally, the turbine is manufactured in Finland which would mean saving energy and resources by avoiding long distance transportation.

By employing Eq. (14) and substituting the turbine's characteristic values we get:

$$E_{/year} = \frac{1}{2}(0.23)(1.225)(4)(1.91)(5^3)(8760) = 1178.5 \text{ kWh/year}. \tag{15}$$

As discussed in Section 3.3.1, the study should include some form of verification and validation of the results. Therefore, tackling our problem with a different method and getting similar results would corroborate we are in the right path of finding the right solution.

Moreover, in our previous analysis we have not included information regarding cut-in and cut-out speeds, which also rises the question of how accurate or valid our previous result really is. In order to validate our finding let us write a code in Matlab (Appendix 1) which generates a Weibull distribution, specifically a Rayleigh distribution (shape parameter equals to 2), from random numbers using a random number generator and then calculates the annual electricity output disregarding the wind speed values for the cut-in wind speed (with the cut-out not needed in this particular case as the wind speed is very low) for each random number per hour during one year. In this estimation we also used the original value obtained by calculating the average wind speed at 50 m in Eq. (8) which was of 5.7 m/s (because we are no longer using the compound cube factor as previously).

$$\text{Total Energy}_{/\text{year}}\ (\text{Matlab}) = 1207\ \text{kWh/year} \qquad (16)$$

For the reader unfamiliar with the Matlab computing environment, the code and full output can be found at the end of this thesis shown as appendices (see Appendix 1 and 2).

Now, if we compare the results from Eq. (15) and (16), we realise the figures are extremely close. Both results are very similar from each other, which reassures us that these two results can be considered reliable.

However, it could also be possible that by a strike of luck those two results happened to be close from each other. Fortunately, there exist many tools available online that can be use to estimate the annual electricity output from wind turbines, which are usually numerical in method such as our Matlab code. The online tool employed for a second validation of the results was the Wind Turbine Annual Electricity Output Calculator from the renewable energy website Reuk (REUK 2010). The results are:

$$\text{Total Energy}_{/\text{year}}\ (\text{Online}) = 1210\ \text{kWh/year} \qquad (17)$$

Again this result is close from the two previous ones which leads us to believe that our first approximation can be considered a good and reliable estimation. The same applies for the second numerical approximation. The total energy computing tool found online can be seen as a black box in which we set some input data and get some output without regarding the internal workings of the process. Usually black boxes are devices or programmes which have been developed, executed and tested in order to provide an accurate output. Assuming this is true for our online computing tool, we can estimate the approximation error in order to have an idea of the discrepancy between our results. Given some value *v* and its approximation, the *absolute error* is:

$$\varepsilon = \left| \upsilon - \upsilon_{approx} \right| , \tag{18}$$

where the vertical bars denote the absolute value. If *v* is different from 0, we can also calculate the *relative error* and the *percent error* given respectively by:

$$\eta = \frac{\varepsilon}{|\upsilon|} \quad \text{and} \quad \delta = 100 \times \eta . \tag{19}$$

The following Table 3.3 compares the approximation errors for our calculations.

Table 3.3 Approximation Errors in Energy Estimation Calculations

Method	Absolute Error	Relative Error	Percent Error
Analytical	31	0.026	2.6
Numerical	3	0.0025	0.25

We all know wind does not blow all the time and it is not always the same. Therefore, this exercise to find errors related to our calculations cannot be treated as absolute and it should be looked judiciously. However, when the errors found are systematically small, it is reassuring that the calculations are reliable and empirically meaningful. On the other hand if the errors are systematically large, it is an indication that our calculations are in the wrong track. Nevertheless, this is not the case here and we can consider our analysis having a solid validity.

3.4.2.2 Green Utility Systems GUS-10

The GUS vertical axis wind turbines are Savonius wind turbine types designed for urban rooftops and cottages (Green Utility Systems 2009). The blades are made from fiberglass and the blade configuration is twin helical.

The annual electricity output from the simplified Equation (14) is:

$$E_{/year} = \frac{1}{2}(0.22)(1.225)(4.6)(1.91)(5^3)(8760) = 1296 \text{ kWh/year}. \tag{20}$$

And the corresponding comparative results are:

$$\text{Total Energy}_{/\text{year}} \text{ (Matlab)} = 1346 \text{ kWh/year}, \tag{21}$$

and

$$\text{Total Energy}_{/\text{year}} \text{ (Online)} = 1303 \text{ kWh/year} \tag{22}$$

3.4.2.3 Urban Green Energy UGE-4kW

The Urban Green Energy VAWTs (2010) are modified Darrieus type turbines in which the blades are moulded to have always some angle of attack relative to the wind. The main advantage is that the torque generated remains constant allowing the turbine to generate in theory more power.

The calculation of the annual electricity output from the simplified Equation (14) is:

$$E_{/year} = \frac{1}{2}(0.33)(1.225)(12.5)(1.91)(5^3)(8760) = 5284 \text{ kWh/year}. \tag{23}$$

And the corresponding comparative results from the numerical and online configurations are:

$$\text{Total Energy}_{/\text{year}} \text{ (Matlab)} = 5268 \text{ kWh/year}, \tag{24}$$

and

$$\text{Total Energy}_{/\text{year}} \text{ (Online)} = 5321 \text{ kWh/year} \tag{25}$$

The following is a comparison table and a graph chart describing the results from the computations.

Table 3.4 Comparing of Different Methods of Energy Estimation (kWh)

Mehod \ Turbine	WS-4B	GUS 10	UGE-4k
Analytical	1 179	1 296	5 284
Numerical	1 207	1 346	5 268
Online	1 210	1 303	5 321

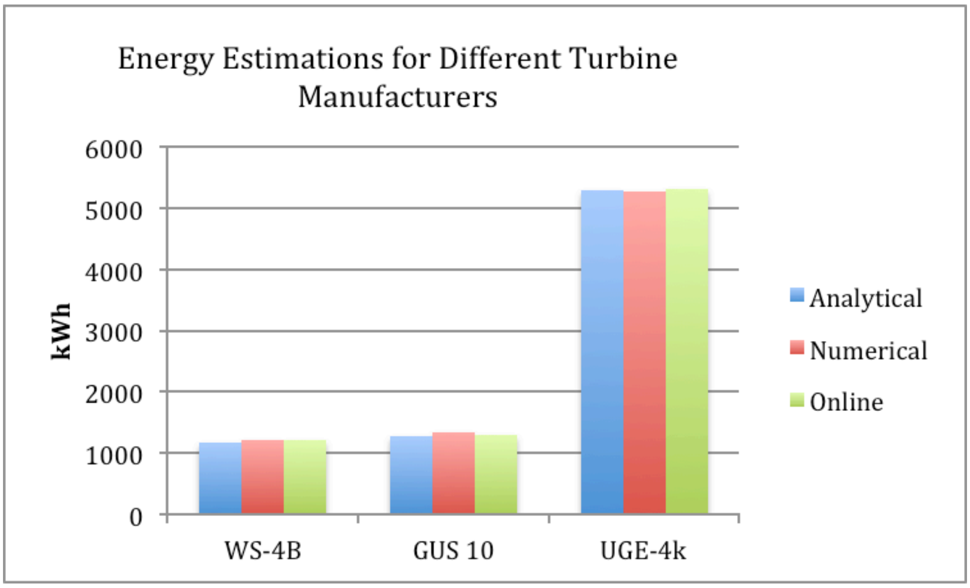

Figure 3.2. A Comparison Chart of Different Energy Estimations for the Different Vertical Axis Wind Turbines in Examination.

3.4.3 VAWT Energy Generation Assessment

We know that placing a vertical axis wind turbine on top of a cellular communication tower will produce some energy, and the estimations of how much energy can be produced using three different wind turbines as case examples have been calculated in the previous section. However, an assessment of the energy generated by the vertical wind turbine and how it compares to the energy consumed by the cellular tower is desirable in order to find out what percentage of the energy produced by the VAWT would cover that of the energy consumed of the cell tower. Therefore, the following comparison table has been made with these new estimations.

Table 3.5 Percentage of VAWT Energy Generation to Cell Tower Consumption

Tower \ VAWT		WS-4B	GUS 10	UGE-4k
	kWh / year	1 179	1 296	5 284
Small 1.2kW	10 512	**11%**	**12%**	**50%**
Avg. 1.6kW	14 016	**8.4%**	**9.2%**	**38%**
Big 3kW	26 280	**4.5%**	**4.9%**	**20%**
Big 3.5kW	30 660	**3.8%**	**4.2%**	**17%**

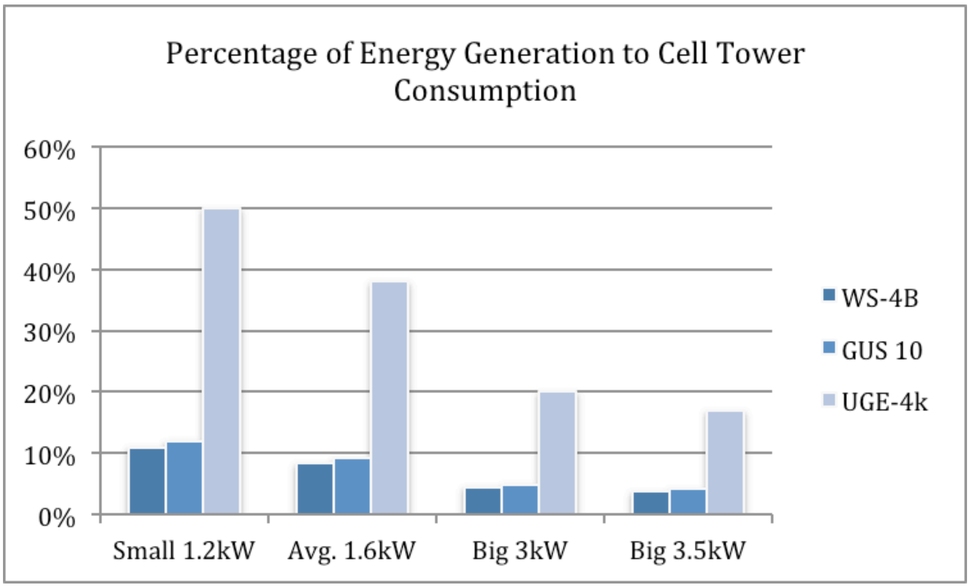

Figure 3.3. Comparison of Percentages of Energy Estimations to Cell Tower Power Consumption for the Different Vertical Axis Wind Turbines.

As it can be appreciated from Table 3.4 and Figure 3.2, one half of the electricity consumption of a small 1.2 kW GSM transceiver station could be powered by a VAWT (given the assumptions established previously). This result could be particularly appealing for cell stations located in remote areas where there is not too much data traffic.

Now it is time to find out, in according with the figures from this investigation, what are the advantages of placing a VAWT on top a cellular communication tower.

3.4.4 Environmental Advantages

The environmental benefits of having energy produced from wind power have been summarised on the previous chapter. Those benefits will not be mentioned here but instead a best case scenario which assumes a one-to-one reduction in CO2 emissions for every unit of electricity produced from the wind turbines, will be consider in order to calculate the amount in kilograms of carbon dioxide equivalent that would be hypothetically saved from the atmosphere.

The Urban Green Energy VAWT UGE-4k will be used for the calculations as it was the turbine that produces the most energy per year with respect to the others. The conversion factors used here, from kWh into kg CO2 equivalent, are the ones in use by Carbon Trust (Carbon Trust 2010), a not-for-profit company that provides support to business and the public sector on carbon emissions and their reduction.

Table 3.6 Savings/Reduction of Carbon Emissions per year using a VAWT

	VAWT UGE-4k annual production of 5 284 kWh/year		
Energy Source	kg CO2/kWh	kg CO2 savings /year	in litres or tonnes
Grid Electricity	0.544	2 874.5 kg	na

Natural Gas	0.184	972.3 kg	475.31 m³
Fuel Oil	0.266	1 405.5 kg	447.80 l
Coal	0.313	1 653.9 kg	0.74 t
Industrial wood	0.026	137.4 kg	1.39 t

3.4.5 Economic Analysis

According to the Energy Market Agency (Energiamarkkinavirasto) in Finland, the total electricity price for households in residential areas in Finland at the end of 2012 was 19.36 cent/kWh (Statistics Finland 2013). This price includes the energy generation and the electricity transmission. Energy prices vary a lot depending on the contract with the energy company and the energy consumption, and whether is destined for households or for industry. For instance the electricity price per hour during the month of March 2015 ranged between 15.11 cents and 58.13 cents per kWh (Fingrid 2015). In this analysis, the basic energy price shown above for households will be use as the reference price. The following graph displays the economic savings that would entitle when using each of the VAWT reviewed in this study.

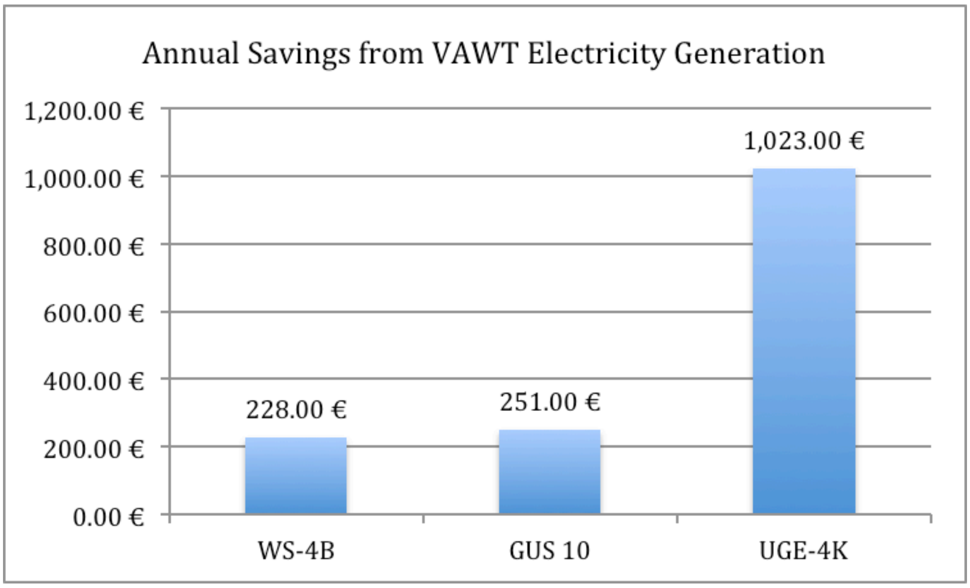

Figure 3.4. Comparison of the Economic Savings for the Different Vertical Axis Wind Turbines Energy Generation per Year.

Table 3.7 VAWT Energy Generation to Cell Tower Consumption Savings

Tower \ VAWT		Annual cost	UGE-4k - 5 284 kWh/year	
	kWh / year	(19.36 c/kWh)	VAWT savings	Total
Small 1.2kW	10 512	**2 035 €**	**1 023 €**	**1 012 €**
Avg. 1.6kW	14 016	**2 714 €**	**1 023 €**	**1 691 €**
Big 3kW	26 280	**5 088 €**	**1 023 €**	**4 065 €**
Big 3.5kW	30 660	**5 936 €**	**1 023 €**	**4 913 €**

Table 3.8 VAWT Energy Savings Windside WS-4B

Tower \ VAWT		Annual cost	1 179 kWh/year	
	kWh / year	(19.36 c/kWh)	VAWT savings	Total
Small 1.2kW	10 512	**2 035 €**	**228 €**	**1 807 €**
Avg. 1.6kW	14 016	**2 714 €**	**228 €**	**2 486 €**
Big 3kW	26 280	**5 088 €**	**228 €**	**4 860 €**
Big 3.5kW	30 660	**5 936 €**	**228 €**	**5 708 €**

Table 3.9 VAWT Energy Savings GUS 10

Tower \ VAWT		Annual cost	1 296 kWh/year	
	kWh / year	(19.36 c/kWh)	VAWT savings	Total
Small 1.2kW	10 512	**2 035 €**	**251 €**	**1 784 €**
Avg. 1.6kW	14 016	**2 714 €**	**251 €**	**2 463 €**
Big 3kW	26 280	**5 088 €**	**251 €**	**4 837 €**
Big 3.5kW	30 660	**5 936 €**	**251 €**	**5 685 €**

It can be appreciative that for a small telecom tower, a highly efficiency VAWT could provide savings of one half from the total energy consumption costs. Taking in consideration the reference electricity price, the UGE-4k vertical axis wind turbine will repay itself in under 18 years. We can appreciate why companies may be reluctant to wait 18 years to break even on the investment, and, moreover, with a design life of 30 years, there is little incentive to make a VAWT investment base solely on the economic factors. Furthermore, it can take even more than 100 years to repay the investment for the other turbines, as it can be seen in Table 3.10. Those kind of turbines are only considered where grid electricity is definitely non-available, and a rough designed is needed such as in extreme climatic conditions.

However, it is important to note that in this analysis, the retail price of the VAWT has been considered. A wholesale price would reduce significantly the return of investment. In most of the industries wholesale prices are typically between 20 to 40 percent off the retail price (Gabriel 2010, Wisner 2010). In the following economic analysis, a wholesale price of 30 percent price reduction will be consider for each VAWT.

Table 3.10 VAWTs Repayment details

	Windside WS-4B	GUS 10	UGE-4k
Retail Price	26 000 €	25 000 €	18 000 €
Wholesale Price	18 200 €	17 500 €	12 600 €
Electricity / year	1 179 kWh	1 296 kWh	5 284 kWh
Energy savings/ year	**228 €**	**251 €**	**1 023 €**
Repayment retail	114 years	100 years	17.5 years

Repayment wholesale	80 years	70 years	12.5 years

As it was mentioned, there is little incentive for purchasing a wind turbine that has a repayment price of over 100 years. However, there exist competitive VAWTs already available in the market that are worth considering, as we can appreciate from the Table 3.9. Hopefully, in a new future a 10 year repayment period is not too far from reality so consumers could start definitely considering wind power technologies.

Nevertheless, further economic advantages can be found in a broader context. For instance, it has been mentioned that Windside Oy is a Finnish company that manufactures VAWTs. If they could provide a competitive turbine, and manufacture and install a significant amount of VAWTs on top of cellular communication towers, it would provide many economic opportunities. It would boost the local economy, as money would be spent locally to procure material and services during the manufacturing and installation stages, and consequently contribute as well to local taxes. Furthermore, placing VAWTs on cell towers is a very good advertisement campaign for both the wind turbine manufacturers and the cell phone operators that choose to place the VAWTs. In turn, that would encourage the purchasing of the turbines from the general population, and the incentive to choose a "greener" mobile operator.

3.4.6 Social Benefits

The immediate benefits for the society are directly linked with the environmental advantages of using renewable energy sources. The VAWTs do not emit air pollution, particularly CO_2, or other harmful emissions and the noise from these turbines is minimum. Additionally, VAWTs on top of cellular communication towers can serve as useful educational resources. The turbines can help raising awareness of clean energy solutions, renewable energy sources in general and about climate change mitigation. This awareness can incite homeowners to explore different ideas and to become involve in micro renewable energy generation. Exposure of the wind turbines to the general population is the best way to advertise and promote renewable energy generation. In the future, it could be trendy and proud to own a wind turbine at home in the same way that people are proud paying the same amount and even more to have a high fashion designer bag.

3.4.7 VAWT on a cell tower at 100 metres

Let us assume in this analysis that we can place the VAWT on top of the telecom towers that have a height of 100 metres. Using again the logarithmic extrapolation of wind speed formula, i.e. Eq. (7), and the data of 4 m/s from the

Finnish meteorological institute as well as the roughness length value of 0.3 (see Section 3.3.1), we can calculate the wind speed average at 100 metres to be:

$$V_{100} = 4\frac{5.809}{3.507} = 6.626 \text{ m/s}. \quad (26)$$

For reference purposes let us consider 6.5 m/s wind speed average at the height of 100 m. In order to have a more general overview, calculations of the annual electricity output for the UGE-4k turbine at 6 m/s and 6.5 m/s, using Eq. (14), have been performed and are shown in a comparison table in Table 3.11.

$$E_{6m/s} = \frac{1}{2}(0.33)(1.225)(12.5)(1.91)(6^3)(8760) = 9131 \text{ kWh/year}. \quad (27)$$

$$E_{6.5m/s} = \frac{1}{2}(0.33)(1.225)(12.5)(1.91)(6.5^3)(8760) = 11609 \text{ kWh/year}. \quad (28)$$

Table 3.11 VAWT Energy Generation to Cell Tower Consumption 6 and 6.5m/s.

VAWT / Tower		UGE-4k (6m/s)	UGE-4k (6.5m/s)
	kWh / year	9 131	11 609
Small 1.2kW	10 512	**86%**	**110%**
Avg. 1.6kW	14 016	**65%**	**83%**
Big 3kW	26 280	**35%**	**44%**
Big 3.5kW	30 660	**30%**	**38%**

As it can be appreciated, at 100 metres the VAWT delivers a significant amount of energy and, depending on the telecom tower size, it can deliver from a third to up to 100 percent of the energy needs of the cell site. If the wind turbine can cover fully all energy requirements for a cell site that needs to be placed off the grid, then the VAWT can be a good option. Furthermore, it can well replace gasoline or diesel powered cell site especially in rural areas where there is no access to grid electricity. Now, let us look at the annual energy consumption savings that this type of VAWT will entail at 6 m/s and 6.5 m/s as shown in the next graph and the subsequent table.

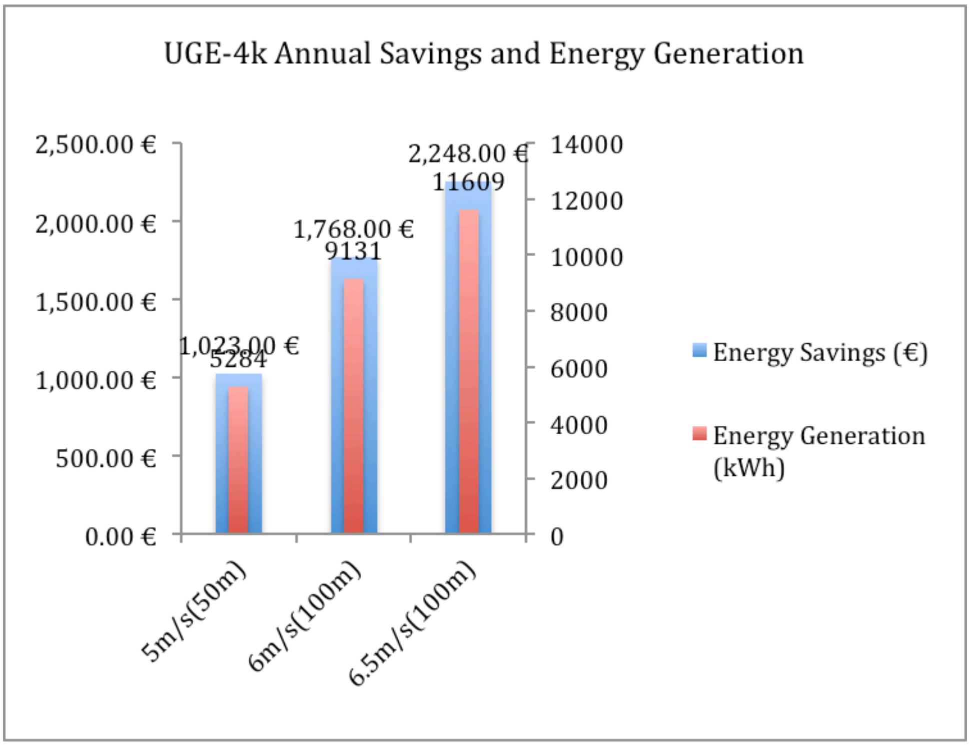

Figure 3.5. Comparison of the Economic Savings and Energy Generation for the UGE-4K VAWT with Different Parameters per Year.

Table 3.12 VAWT Energy Generation to Cell Tower Consumption Savings

Tower \ VAWT		Annual cost	UGE-4k	
	kWh / year	(19.36 c/kWh)	6 m/s	6.5 m/s
Small 1.2kW	10 512	**2 035 €**	**1 768 €**	**2 248 €**
Avg. 1.6kW	14 016	**2 714 €**	**1 768 €**	**2 248 €**
Big 3kW	26 280	**5 088 €**	**1 768 €**	**2 248 €**
Big 3.5kW	30 660	**5 936 €**	**1 768 €**	**2 248 €**

It can be seen that from 6 m/s the VAWT becomes a realistic option for providing electricity to small cellular telecom towers. Furthermore, at 6.5 m/s the repayment period in the best case scenario, as observed in Table 3.13, becomes 5.5 years, which definitely could compete with existing energy sources as it would produce free clean energy during the turbine's lifetime.

Table 3.13 VAWTs Repayment details UGE-4k 100m

	UGE-4k	
	6 m/s	6.5 m/s
Retail Price	18 000 €	18 000 €
Wholesale Price	12 600 €	12 600 €
Electricity / year	9 131 kWh	11 609 kWh
Energy savings/	**1 768 €**	**2 248 €**

year		
Repayment retail	10 years	8 years
Repayment wholesale	7 years	5.5 years
30 year lifetime energy savings (inflation and price rise not adjusted)	Retail: **35 040 €** Wholesale: **40 440 €**	Retail: **49 440 €** Wholesale: **54 840 €**

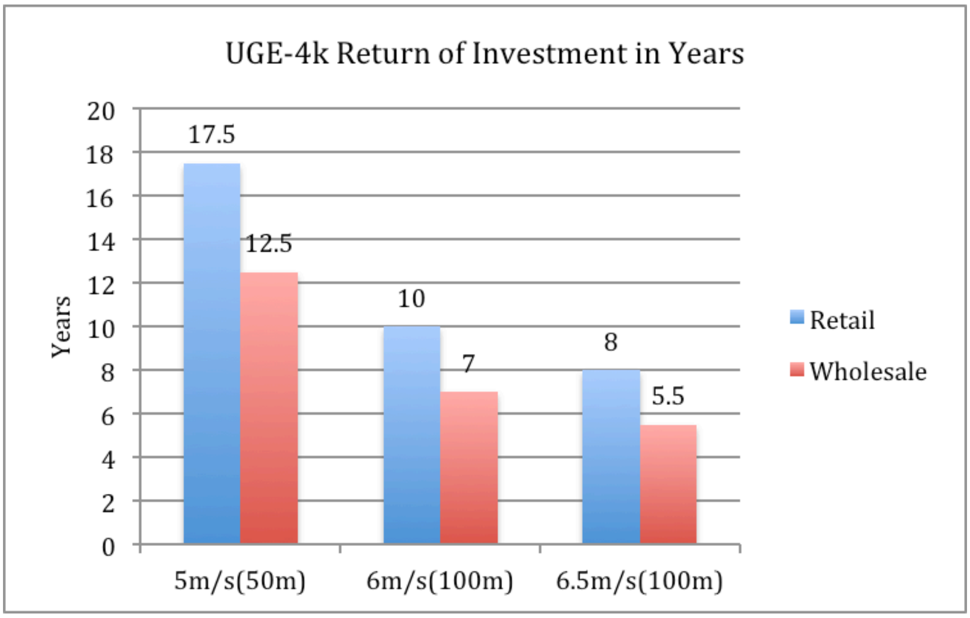

Figure 3.6. Comparison of the Return of Investment for the UGE-4K VAWT with Different Parameters in Years

In the next table, a one-to-one reduction in CO2 emissions for every unit of electricity produced from the wind turbines has been used to calculate the amount in kilograms of carbon dioxide equivalent that, in theory, would be saved from the atmosphere.

Table 3.14 Savings/Reduction of Carbon Emissions per year at 6 m/s

	VAWT UGE-4k annual production of 9 131 kWh/year		
Energy Source	kg CO2/kWh	kg CO2 savings /year	in litres or tonnes
Grid Electricity	0.544	4 967.3 kg	na
Natural Gas	0.184	1 680.1 kg	821.35 m^3
Fuel Oil	0.266	2 428.8 kg	773.81 l
Coal	0.313	2 858 kg	1.27 t
Industrial wood	0.026	237.4 kg	2.40 t

Table 3.15 Savings/Reduction of Carbon Emissions per year at 6.5 m/s

	VAWT UGE-4k annual production of 11 609 kWh/year		
Energy Source	kg CO2/kWh	kg CO2 savings /year	in litres or tonnes
Grid Electricity	0.544	6 315.3 kg	na
Natural Gas	0.184	2 136.1 kg	1044.26 m^3
Fuel Oil	0.266	3 088 kg	983.81 l
Coal	0.313	3 633.6 kg	1.62 t
Industrial wood	0.026	301.8 kg	3.05 t

The above calculations clearly show that, with the appropriate conditions, the wind turbine can be considered not only environmental but also economically viable.

4 MICRO SCALE SOLAR POWER SYSTEMS: AN EXPERIMENTAL INVESTIGATION

4.1 Solar Energy Use

Solar energy technologies, such as photovoltaic (PV), currently face cost and scalability impediments (Lewis 2007, Ma et al 2013). Researches and markets have been struggling for years to bring down the cost of production and manufacturing of photovoltaic panels and consequently the cost of the generated power. Solar photovoltaic panels are very costly, which it is the main deterrent to the PV's market penetration. Nevertheless, in some countries, there exist grants and incentives in place to provide some subsidy to the energy generated by PV panels. Additionally, the growth of global solar energy utilisation has grown exponentially in recent years (Ma et al 2013).

4.1.1 Household solar systems

The advantages of solar systems cannot be understated, and these advantages have been described in Chapter 2. However, when talking about small household scale, it seems there are more disadvantages than advantages on the use of solar energy to generate electricity.

Firstly, the initial cost of the equipment needed and the fact that it can only be used when the sun is shining, definitely put the majority of people off. Moreover, the farther from the equator, the less efficient the solar energy system is. Secondly, the solar energy installation requires a large area for the system to be efficient. Small households or people living in apartment buildings may believe they have no chance in installing a small solar system or that it would prove to be really expensive, especially in the Northern countries. This investigation will try to uncover the possibilities for household micro scale solar power systems.

4.2 The Price of PV Panels

The price of energy generated by solar panels remains more expensive compared to other traditional sources. Nevertheless, the costs of PV has declined by a factor of nearly 100 since 1950 (Nemet 2006). No energy technology has experience this kind of change ever (Ibid.).

Besides the usual demand and supply price functions, the most important factors affecting the cost of PV have been summarised by Nemet (2006) as being: plant size, module efficiency and cost of silicon. Additionally, a broader set of influences such as market demand, subsidies and competition, has an intrinsic effect in the overall market price of solar panels. Furthermore, at the retail level, the customer is forced to pay a staggering premium that includes the margin for retailer to fully cover their operating costs and return a profit, such costs include taxes (import duties and sale tax), transportation costs, wages and premises. Not surprisingly, the price of PV panels for the general population is indeed extremely high. According to Borenstein's calculations, which considered exhaustively these external variables, the cost of a photovoltaic household system is around 80% greater than the total value of the electricity the system will produce during its lifetime (Boresntein 2008).

4.2.1 Base price of a solar panel

The only option for a consumer to acquire a solar panel with a competitive price would be to contact the manufacturer directly. Until recently, this option was not available to the consumer unless a high volume of goods would have been purchased. However, e-commerce has changed the original business model and sites such as ebay, Amazon, and Alibaba have provided manufacturers from over the world with the opportunity to carry out trading directly with the end user (Lihua, Hu and Lu 2009). By narrowing the search to reach solar PV manufacturers, it was possible to find a solar panel rated 5 Watts for 0.51 EUR on the exchange rate at the time of purchase in 2010. Presently, in 2015, it is possible to buy similar solar panels directly from the manufacturer with their cost between 0.78-0.87 euros (Alibaba 2015). The solar panel's cells are made from monocrystalline or single crystal technology, and although, monocrystalline is more expensive to manufacture than conventional polycrystalline cells, it was the cheapest solar panel that was possible to find.

4.3 A Room Apartment Micro Solar Power System

The small solar power system consists on 5 x 5 W monocrystalline solar panels giving a total of 25 W solar system. The panels were placed on the balcony of a one room apartment in the centre of the city of Jyväskylä, Finland (62°14.5′N 025°44.5′E). The balcony of the apartment was facing south and the solar panels were inclined on the windows with an array tilt of about 70 degrees. The panel array can be appreciated with its technical characteristics in Appendix 3 and 4.

Energy measurements were made by wiring a watt metre between the solar system and a small 12 V 12 Ah sealed lead acid battery. The watt metre measures energy (Wh), charge (Ah), power (W), current (A) and voltage (V) with a resolution 0.01 for current and voltage values, and one decimal fraction for the rest. The device has a circuitry sensor resistance of 0.001 Ohms and an operation current of only 7 mA, which can be considered for this study as negligible. Information regarding the watt metre and its specifications can be found from Appendix 5.

4.3.1 Theoretical estimations

The easiest and simplest way to estimate the energy to be generated by the micro solar system is to multiply the solar system's rating times the daylight hours the sun's light strikes directly in the panels times 70% which accounts for several inefficiencies and losses in the power generation, capture and transport:

E (Wh) = Solar panel rating (W) x direct sunlight to panels (h) x efficiency (70%)

Luckily for us, data from the sun's insolation with monthly and annual average levels have been gathered by the NASA Atmospheric Science Data Center at the NASA Langley Research Center (NASA Langley 2011) during the last 22 years. This data corresponding the latitude and longitude to that of the city of Jyväskylä has been summarised on Table 4.1.

Table 4.1. NASA Monthly Averaged Insolation Data for Jyväskylä

Month	Insolation Incident (kWh/m2/day)	Midday Insolation (kW/m2)	Clear Sky (days)	No-Sun Days (days)	Daylight Hours (hours)
1	0.25	0.04	4	3.5	6.28
2	0.94	0.14	2	3.6	9.01
3	2.27	0.30	2	3.8	11.7
4	3.88	0.44	2	3.9	14.7
5	5.19	0.50	2	4.8	17.6
6	5.64	0.52	2	2.1	19.5
7	5.31	0.50	2	2.9	18.6
8	4.00	0.41	2	3.5	15.9
9	2.39	0.28	1	3.7	13.0
10	1.06	0.16	1	2.2	10.0
11	0.39	0.07	3	4.1	7.23
12	0.10	0.02	5	2.1	5.40

The micro solar system rated at 25 W is too small to capture energy when the sun is not striking directly into the panels. Therefore, it will only be fully functional when there are clear skies. Additionally, because we are in a city location the buildings on the surroundings impede the rays from the sun to directly hit the panels in the morning and at sunset, so the daylight hours will need to be halved. Taking this into consideration on the formula described previously, the rough estimation of the energy to be captured by the micro solar systems is shown on Table 4.2.

From Table 4.2 it can be appreciated that the midday insolation incident for January and December are indeed so small that these figures have been fairly excluded from the calculations.

Table 4.2. Yearly Solar Energy Estimation for 25 W Micro System

Month	Energy Estimation (Wh)
1	0
2	157.7
3	204.8
4	257.3
5	308.0
6	341.3
7	325.5
8	278.3
9	113.8
10	87.5
11	189.8
12	0
Total:	2 264 Wh/year

In addition, it is possible to use the insolation incident ($kWh/m^2/day$) data, which is commonly employed when calculating solar power systems, for energy estimations. However, this data consists of energy from direct radiation, diffuse radiation and reflected radiation. For a bigger and more efficient solar system, using the insolation incident is appropriate, but with small system it can be overestimating. Nevertheless, we know that direct radiation is usually around 50 percent in higher latitudes (Watson and Watson 2011), and we can measure the solar panels in square metres and calculate their energy conversion efficiency. Furthermore, we know that partial shading from clouds can reduce a solar electric panel's power to up to 50 percent (Sunso 2006), so all these factors must be taken into account.

The solar panels have been tested in the standard AM1.5 (Air mass), $1000W/m^2$ at 25 °C. The 25 W system measures 80 cm x 39 cm, or 0.31 m^2, which gives a conversion efficiency of 25/310 x 100% = 8 %. Thus, the multiplication factor would be 0.31 m^2 (solar panel dimensions) x 0.08 (conversion efficiency) x 0.5 (direct radiation percentage) x 0.5 (light obstruction city) x 0.75 (clouds/shadows on panels) x 0.70 (inefficiencies and losses in system) x 1000 (conversion from kW to W) = 3.26 Wh m^2 / kWh. Now we have all data needed to estimate the energy generation using the insolation incident information.

Table 4.3. Solar energy estimation using insolation data

Month	Energy Estimation (Wh)
1	0
2	73.5
3	199.8
4	328.7
5	439.9
6	514.8
7	484.7
8	352.1
9	202.6
10	100.2
11	33.0
12	0
Total:	2 729 Wh/year

Now we have two estimations for our 25 W household micro solar system: one that was straightforward and a second one that required significant more calculations. It can be presumed the second one to be more accurate than the first one, although assumptions on weather forecast, sunny and cloudy days, are never as straightforward so we should expect variations without being surprised of big deviations in the estimations.

4.3.2 Empirical measurements

The 25 W solar system was placed on the balcony of a one room apartment facing south with a 70° tilt. The micro solar system array can be seen in Appendix 3. The solar panels were left on the same position throughout the year, even though keeping them steady meant a lower conversion efficiency as tracking the sun by moving the panels represents an increase of more then 20% of output power (Al Mohamad 2004). This was done intentionally because the end user should not be worrying about where the panels should be facing all the time.

The panel array was not particularly fixed as they were only attached with some ribbon and tape. This implied that when the wind was blowing hard, some of the panels fell, but they resisted the wind and rain quite strongly. The panels also needed to be cleaned sporadically as the dust gathered on top reduces the solar system's efficiency. Measurements were recorded every evening whenever it was possible in order to have back up data and to avoid any possible data loss. Finally, measurement were compiled every month and the metre was reset every months too. The summary of the measurements per month during 2010 can be seen in Table 4.4.

Table 4.4. Solar 25W measurements 2010

Month	Energy Generation (Wh)
1	0
2	219.3
3	359.5
4	358.3
5	346.3
6	425.2
7	439.0
8	174.6
9	81.1
10	101.6
11	0
12	0
Total:	2 504.9 Wh/year

As expected, there were some months during winter that the solar system did not produce any electricity. Actually, it did produce but the energy was very low and therefore it did not manage to charge the 12 V battery. For that reason, the watt metre did not record any energy going into the battery. This is one of the disadvantages of having a micro solar system. January, November and December were the months when there was not sufficient energy to charge the battery. Thus, the micro solar system only managed to produce energy during nine months of the year, from February to October.

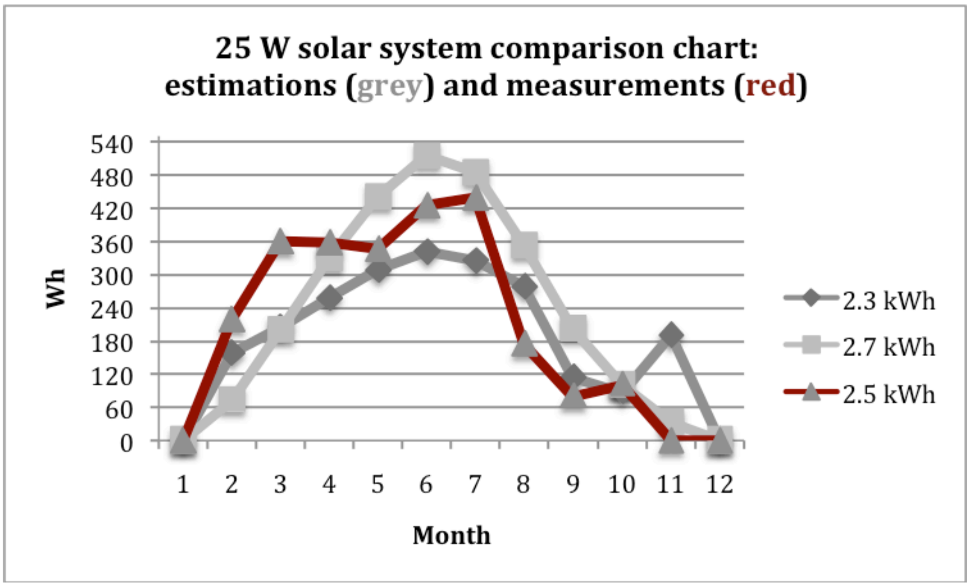

Figure 4.1. 25 W household solar system comparison chart.

As it can be appreciated from the comparison chart. The measurements correlate nicely with both of the previous estimations. June and July, as expected, were the months in which more energy was generated.

Measurements were also taken on the first half of 2011, and the energy generated is shown in the following table.

Table 4.5. Solar 25W measurements 2011

Month	Energy Estimation (Wh)
1	0
2	190.9
3	357.7
4	211.3
5	235.0
6	224.7
Total:	1 219.6 Wh/half year

The measurements are consistent with the ones obtained from 2010, which ensures reliability. However, it can also be appreciated that summer of 2011 was not as sunny as in the previous year. For the subsequent calculations and for simplification, the measurements taken during 2010 will only be used.

4.3.3 Environmental advantages

Here again a one-to-one reduction in CO2 emissions for every unit of electricity produced from the solar power has been considered in order to calculate the amount in kilograms of carbon dioxide equivalent that would be hypothetically saved from the atmosphere by using the photovoltaic system. The conversion factors used here, from kWh into kg CO2 equivalent, are the ones in use by Carbon Trust (Carbon Trust 2010), a not-for-profit company that provides support to business and the public sector on carbon emissions and their reduction.

Table 4.6. Savings/Reduction of Carbon Emissions per year 25 W solar system

	25W photovoltaic annual production of 2.5 kWh/year		
Energy Source	kg CO2/kWh	kg CO2 savings /year	in litres or tonnes
Grid Electricity	0.544	1.36 kg	na
Natural Gas	0.184	0.46 kg	0.22 m^3
Fuel Oil	0.266	0.665 kg	0.21 l
Coal	0.313	0.78 kg	0.35 kg
Industrial wood	0.026	0.065 kg	0.26 kg

4.3.4 Economic Analysis

In this analysis, the same energy price from our previous case study will be employed for the following economic calculations. In 2012 the electricity price was 19.36 cent/kWh at the end of the year (Statistics Finland 2013). This price includes the energy generation and the electricity transmission. Electricity prices vary a lot depending on the contract with the energy company and the energy consumption, and whether is destined for households or for industry. For instance the electricity price per hour during the month of March 2015 ranged between 15.11 cents and 58.13 cents per kWh (Fingrid 2015). In this analysis employs the official averaged basic energy price for households as the reference price.

Table 4.7 Solar System 25W Repayment details

	25 W Photovoltaic system
Wholesale Price	2.55 €
Electricity generated / year	2.5 kWh
Energy savings/ year	**48.4 cent**
Repayment	5.3 years
25 year lifetime energy production (inflation and price rise not adjusted)	**12.10 €**
Net profit	**9.53 €**

It can be observed that, although the numbers are indeed small, the repayment time of 5.3 years is not bad at all. Furthermore, with a lifetime of about 25 years for solar panels (Kamalapur and Udaykumar 2011) the micro solar system represents a net saving of 9.53 Euros. This number may appear to be too small and perhaps also too much trouble for 9.53 Euros. But let us look deeper what the energy production of the micro solar system over its lifetime of 25 years (62.5 kWh) represents. For instance, let us take into consideration the popular portable devices from Apple Inc. and how many times these could be charged by using the micro solar system.

Table 4.8. Charge Cycles for Portable Devices

	MP3 Player		Phone	Tablet
	iPod Nano	iPod Classic	iPhone 3GS	iPad 2
Battery Rating	0.39 Wh	2.92 Wh	4.51 Wh	24.8 Wh
Charge cycles per year	6 423	858	555	101

Charge cycles per lifetime	160 577	21 447	13 886	2 525

The numbers seem encouraging for using a micro solar system to charge portable devices. For instance, all energy needs of a mobile phone and mp3 player could be covered by the solar system. However, when considering more energy demanding devices such as the iPad, the annual production of our little solar system will only be adequate for charging it for three months of the year, if we need to charge the device every day. A more demanding device such as a laptop will mean that we would need one's year of solar energy for charging our device for one month, with the same considerations. Nevertheless, small portable devices such as mp3 and mobile phones could well be charge with this kind of solar system year around, and knowing this is encouraging.

4.3.5 Social implications

Although the CO2 and other emissions reductions are significantly small for the micro solar system, we can find other advantages in the social side. The solar PV system are good educational resource. People can learn that energy cannot be generated just that easy as we are use to getting it, and that a mini solar system is only able to charge very small devices. In turn, they will understand that the generation of vast amounts of electricity needs a lot of resources, and perhaps people will be encourage to commit themselves to more energy savings. However, they will also realise that energy can be generated at home at affordable prices, even in Finland where there is not much sun insolation. A micro PV system in a household can also help to raise awareness with the neighbours about clean energy solutions, renewable energy sources in general and about climate change mitigation. This awareness in turn can encourage other neighbours to get involve in micro renewable energy generation.

5 DISCUSSION

5.1 Evaluation of the Studied Renewable Energy Technologies

5.1.1 Case 1: VAWTs on Cellular Telecom Towers

This study started with the premise that if there exists infrastructure in place, such as the tower, and there is energy need on the site, it would be desirable and even logical to place a vertical axis wind turbine (VAWT) on top of the cellular tower in order to power some of the telecom tower's energy needs. Furthermore, if the tower is about one third of the total cost of a wind turbine, then the total cost of placing a VAWT in named structures could be significantly reduced.

Throughout the study we have seen that placing a VAWT on top of a telecom tower is indeed possible. The majority of towers are designed to be able to sustain big loads, and, thus, placing a VAWT only needs some positioning and tweaking. Furthermore, we have seen that these kinds of telecom towers powered by VAWTs already exist, although they are very seldom. And although, there are many advantages attached to this scheme, especially on the environmental and social side, the economic incentives to do it are rather slim; as placing the wrong VAWT at the wrong site may entail a repayment of 100 years.

However, not all is lost for VAWTs on telecom towers or other already built structures. With remote cell sites located outside the grid electricity, there is an incentive to have a wind turbine powering the telecom equipment; especially when the cost of the mast of the wind turbine can be discarded. Also, by placing efficient VAWTs on top of tall towers of over 50 metres, the repayment time is significantly reduced. And in some cases, the VAWT can provide double electricity for the amount that it was purchased during its lifetime. This means making a 100 percent profit. Therefore, in this case, we have a big incentive and VAWT can be serious candidates then.

The next question is when are we going to start seeing VAWT on top of cellular towers or other already built structures? The existing ones are in rural distant areas so no one can really see them as they are seldom. This study has hypothetically demonstrated that it could be perfectly possible and profitable, with the right technology in the appropriate location, to place VAWTs on telecom towers right away. The current technology is sufficient and favourable in order to invest in it and, moreover, obtain economic gains besides the well known environmental ones. This study has shown that the right VAWT at the right windy place can be very profitable. Telecom operators could also benefit by differentiating themselves by encouraging these particular conceptual towers. Hopefully similar turbines placed on already built structures will make their way into the general landscape of urban and rural areas.

However, it seems that it will require more than just awareness of the existing of these technologies for making the leap into adopting them. Some of these factors can be further analysed using diffusion of innovation theory.

5.1.2 Case 2: Micro Solar PV System

The higher costs of solar PV systems have impeded this technology to be competitive in the energy market. Additionally, articles in the media always remind us that solar energy is still a technology under development and that there are little real benefits for the end consumer if there exist grid electricity available at hand. Furthermore, it is a general presumption that solar energy is only available in southern countries and that it is not realistic to use solar PV systems, for instance, in the Nordic countries. This particular case study has tried to uncover empirical evidence about the possible use of a micro solar system in a housing apartment, with the only prerequisite that the flat had a façade facing south. This was done in order to test if the average person could place the PV system as easily as hanging the cloths out for drying.

During one year, the 25 W solar system managed to produced 2.5 kWh. This figure may appear almost insignificant, especially with present energy hungry appliances. In monetary terms it means the equivalent of half of a euro electricity expenditure in Finland. However, it entails that the solar PV system will be repay in a bit over five years, even tough the full potential of the PV modules was not fully exhausted due to the location in Nordic latitudes. Moreover, during its lifetime the solar system would produce clean energy for the equivalent of 12 euros. This kind of micro solar system is capable of fully charge over 6000 small mp3 –players, under 900 medium size mp3-players, over 500 mobile phones, or some of those in combinations, during one year. In colloquial terms, the solar PV system can fully cover the energy needs of one mp3 player and one mobile phone (if it does not need to be charged more than once in a day) over the course of the year.

The results from this investigation are encouraging in favour to build a case for the use of PV systems for individual use also in economic terms, and even at Nordic latitudes. The base price of PV panels is also competitive, as we could appreciate a return of investment in about five years. The big hurdle PV systems currently face, especially for the retail consumers, is the additional expenses from the supply chain, all of which are passed downstream to the consumer. In many countries, where there are no governmental incentives, import duties and sale tax further aggravate this problem. For instance, assuming the panels would be produced locally, the minimum shipping cost within Finland would be a post package of 9.00 euros (Posti 2015) and the value added tax of 24 percent (Vero 2015) entails that our micro solar system instead of only being 2.55 Euros, it would cost a staggering 12.16 euros. This price would completely change the picture, as it would represent a repayment period of over 26 years instead of the original 5 years. Therefore, we can realise that it is important that incentive mechanisms exist and these should be steered appropriately by governments, which brings us to the next discussion about diffusion of innovation.

Finally, the reader can surely ponder why bother to go to so much trouble to set up such a small system to save a mere half euro in the electricity bill in a year. However, in perspective, assuming that half of the total of private households in Finland, which is 2 579 781 (UNECE 2012), would have access to south-west sun light, i.e., 1 289 890. Then it would imply a combined saving of EUR 644 945, or over six hundred thousand euros saving in a year. This is besides the environmental advantages already stated, as well as contributing and supporting solar photovoltaics R&D and its production which consequently helps to reduce the prices of the panels in the future.

5.2 Diffusion of Innovations and Innovation Decision Process

Diffusion of innovation can be employed in this analysis in order to understand further the factors undermining the adoption of new technologies in society. An innovation is usually an idea, object or practice that is perceived as new, in this case the innovation would be the renewable energy technologies of vertical axis wind turbines (VAWTs) and solar photovoltaic (PV) panels. Besides the innovation, there are other key elements in the diffusion process: the communication channel, the adoption time, and the social system.

Following this study, three types of innovation-decisions have been identified within diffusion of innovation theory: optional, collective and authority. The *optional innovation-decision* is the decision made by a certain individual, or by a group of individuals, who in some way distinguished from others in society. In the *collective innovation-decision* the decision is made collectively by all individuals of a social system. Finally, the *authority innovation-decision* entails a decision made by few individuals in positions of influence or power for the entire society (Rogers 1905). The lack of usage of these kinds of renewable energy sources by the general population suggests that this innovation is currently in the optional innovation-decision type, where few individuals have decided to adopt the innovation due to their knowledge and interest about it.

Regardless of the three types of innovation-decisions from above, diffusion of innovation occurs through a five-step decision-making process. These five stages are: knowledge, persuasion, decision, implementation, and confirmation. During the first stage the individual is first exposed to the innovation but lacks deeper knowledge about it. In the persuasion stage the individual gets interested after having learned more about the innovation and actively seeks more detail information about it. In the decision stage the individual weights the advantages and disadvantages of using the innovation and decides whether to adopt it or reject it. In the implementation stage the individual employs the innovation and further determines its usefulness. Finally, the confirmation stage is the step where the individual is reassured by the innovation and will continue using it to its fullest potential.

In the case of renewables, it appears that society is in the first two stages. Society is aware of the existence of renewable energy technologies. And although knowledge of renewables can be extensively found, the members of society lack deeper knowledge of renewables and have not been inspired to attempt to find more information in the subject. Some societies and groups within societies, mainly at the industrial and governmental level, have proceeded to the second stage, i.e. persuasion, as they have found real interest in renewable energy sources. Some of these groups, even countries, have already adopted these innovations and decided to implement the use of renewable energies. These groups are also known as the early adopters, and these are usually the big players in the market. It can be said then that the diffusion of innovation of renewable energy technologies is still situated in the optional-innovation stage. However, from the worldwide society perspective which goes down to the individual, renewable energy sources are in the first stage of the diffusion of innovation, i.e. knowledge. From diffusion of innovation theory, it indicates us the individual members of society are still lacking deep knowledge and good communication channels about the use of renewable energy sources at all spheres.

5.3 Renewable Energy Technology Diffusion and Commercialisation

Following the previous analysis, it is reassuring to find out that other studies have come to similar findings. Nygren et al (2015) have identified that diffusion of innovation in small-scale renewable energy solutions is at the early adopters stage and it has developed very slowly. In their study they found that early adopters of sustainable small-scale energy solutions have faced different barriers such as lack of relevant information, poor product quality and lack of economic and institutional support, which have slowed these down and to some degree stagnated the early adopters stage, refraining to move forward the wider embracing of the innovation (Nygren et al 2015).

Jacobsson and Johnson (2000) have described that commercialisation of renewable energy as a slow, painful and highly uncertain process, because it would imply to create drastic change into the energy system currently in place.

Jacobsson and Lauber (2006) also state that despite the widely availability of renewable energy technologies in the market for few decades, their impact on the current energy system is hitherto minor.

Additionally, cheap alternatives from existing energy sources and lack of incentives and support schemes for the end user, make the diffusion and commercialisation of renewable energy technologies an ongoing difficult challenge (Radomes and Arango 2015).

Furthermore, the recurrent crises from our present economic system (Ackroyd and Murphy 2013), which directly affects individual pockets and purchasing decisions (McGuigan 2012), can be placed into the many factors influencing the speed of the diffusion of this innovation. People have other problems and more important things to deal in addition to taking good care of their finances. There is certainly a need to consume energy, but this need is already well covered by the energy producers. Trying to change an established system that works and covers satisfactorily the need for energy is debatable but still it makes little sense because it is already there, it is cheap, there is not need to worry about it, except for paying the bill, and if one is of the assumption that energy producers should work towards more environmentally friendly generation instead of the consumer.

5.4 Future Outlook for Micro-Scale Use of Renewable Energy

This study follows as well those findings and suggestions of Jacobsson and Johnson (2000), Jacobsson and Lauber (2006), and Radomes and Arango (2015) discussed above. As it stands, the progress of renewable energy commercialisation will keep growing steadily but also painfully slow. In contrast, oil prices have been falling dramatically during the second half of 2014 and beginning of 2015 which intrinsically will create severe repercussions with the wider energy market in complex ways (Hope and Pearce 2015). These will affect and perhaps even threaten the renewable energy market. It seems that more subsidies will be needed from governments to keep encouraging renewable energy generation at a time when governments already had plans for decreasing these subsidies (Bawden 2004). Moreover, the cheap oil prices really complicates things further as government policies and subsidies are typically based on the premise that fossil fuel prices would get more expensive over time and then giving chance of fair play to renewable energy.

In addition, Nygren et al (2015) also stated appropriately that besides current subsidies other incentives must be developed as well such as more interaction and good communication strategies to promote the diffusion of renewables. This study strongly agrees that besides economic incentives in the form of subsidies or feed-in-tariffs or other economic schemes, governments need to play an important role in promoting renewables and educating the populations about them by using wider communications channels in order to successfully stimulate an expansive use of renewables further down the path of diffusion of innovation.

6 CONCLUSIONS

This thesis has been and interesting journey into discovering if micro scale use of renewable energy, in this case wind and solar, is doable, sensible, and realistic, particularly economically speaking. The study has tried to be reliable and verifiable by covering theoretical, numerical and empirical aspects of renewable energy generation and by validating theoretical results to be consistent with the numerical simulations performed and the empirical field data carried out.

Trying to answer the main research question, the results from this investigation indicate that: *i)* Yes, the use of micro scale wind and solar renewables are economically viable even in Nordic latitudes only if it is done as a do-it-yourself (DIY) project, ii) Yes, if there exist favourable weather conditions, and *ii)* No, these are not economic profitable if external costs are added into the setting up and running of the system without favourable weather conditions in the location.

Having a micro scale renewable system as a DIY project means that the consumer needs to have the knowledge, or at least the interest to acquire that knowledge, of the overall system. It means that he or she needs to engage in making the purchase, the transportation, the installation and maintenance of the system, and only then the system will become profitable and generate extra electricity during its lifetime. Unfortunately, if the consumer decides not to engage in any of these activities, the renewable micro system becomes almost instantly insolvent, unless favourable weather conditions are present at the location.

If there exist good weather conditions this thesis certainly proposes and advocates the use of existing infrastructure to place vertical axis wind turbines (VAWT) or solar photovoltaic (PV) panels such as the examples highlighted in here. It has been encouraging to find out that an upgraded model from one of turbines reviewed in here has been recently placed above the second level of the Eiffel Tower in Paris, France, on February of this year (UGE 2015), and such project gives definitely confidence to the foundations and results of this thesis.

This study also strongly suggests that it is safe and reliable to use available data from statistical weather records in order to provide a good estimation of the energy generation from a micro renewable installation, as long as the proper tools are employed to carry out such calculations.

Letting the market to decide the future of renewables means for instance that the reduction of price of solar panels of over 70% during the last decades has to compete with the reduction of price of crude oil of nearly 50% during the last year (World Bank 2015). Moreover, it is expected the price of oil to rise only marginally until the beginning of 2016 (Ibid.). Conclusively, subsidies and economic incentive mechanisms are needed more than ever in order for wind and solar renewables to compete with other energy sources. For example, in Germany due to economic incentives, all household solar PV systems have been found to be profitable (Johann and Madlener 2014). Renewables can also help in terms of energy security and other kinds of externalities. For instance in Finland the delay of the Olkiluoto 3 nuclear unit and the current crisis in Ukraine, has forced the country to become highly dependent on the import of electricity (Fingrid 2015b). Furthermore, the recurrent crises and the highly dynamic political systems we are currently experiencing will only exacerbate this problem (Ackroyd and Murphy 2013).

Additionally, other forms of incentives are also needed such as better communication strategies and wider distribution channels in order to promote and give diffusion of renewables to the general public. The owner, or micro producer, of renewable energy for personal consumption should be, additionally, highly regarded and valued and only mass media can construct and convey that effect. This in turn would accelerate the diffusion of innovation into the later stages as we have been able to see that it has remained stagnated in the early stages of the diffusion process.

Another important aspect, which was enlightening while carrying out this thesis and working with renewable energy micro production, was the knowledge and appreciation attained about energy generation: it is actually quite difficult to generate vast amount of electricity in order to power even small devices. Consequently, the sense of responsibility towards the importance and willingness to save energy becomes stronger. Therefore, setting a micro renewable energy system also serves as a great learning platform to encourage energy efficiency and energy saving among the users. This engagement would be difficult to attain otherwise without first-hand experience. Similar findings and recognising this importance have also been acknowledged in the literature (Spence et al 2011).

Finally, there is additionally a pronounced advantage of wind and solar energy renewables that is not being widely spoken and conveyed. Wind turbines and solar panels are available in different sizes with a wide range of different capacities, which means they can be utilised and tailored for the different needs of people and industries. They can be used to power a single device, a single household to even a small village, or just to complement generally electricity production. These wind turbines and solar panels could occupy only a small plot of land or they could cover a vast significant one. Nevertheless, at the end of their life if for any reason the energy generating station needs to be dismantled, it will leave a considerably lesser footprint in its surrounding ecosystem, landscape, and even greenhouse gasses than its counterparts (Amponsah et al 2014). This in turn means that the land can still be used for other purposes, also the change in the landscape would be minimal. Something that fossil fuels, nuclear, coal and biomass power plants, and additionally hydroelectric stations cannot really say.

In sum, this thesis strongly advocated the use of wind and solar power not only due to their capacity of energy generation but because of their wider implications for society and nature that have been studied and uncovered in this investigation.

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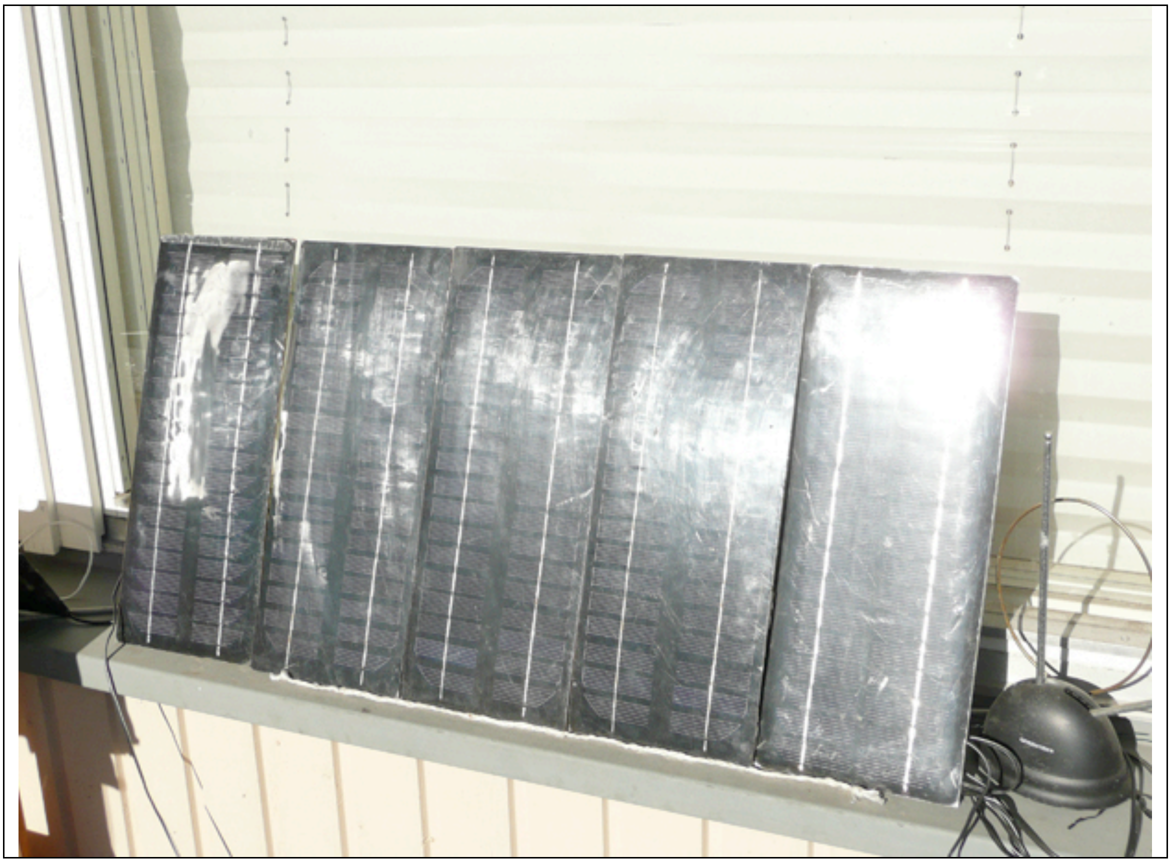
APPENDIX 1: Matlab Programming Code For Wind Energy Estimation

```
density=1.225;
area=4.6;
meanspeed=5.7;
shape=2;
scale=meanspeed%/(sqrt(1+(1/shape)))
%scalefactor=1-exp((-100/shape) * 1/scale)
noOfRandomNumbers=8760;
WeibullRandomNumbers = scale.*( -log(1-rand(noOfRandomNumbers,1))).^(1/shape);
[y x]=hist(WeibullRandomNumbers, 20);
plot(x,y)
cutin=2;
Cp=.22;
Et=0;
A=0;
for i=1:noOfRandomNumbers
   if (WeibullRandomNumbers(i) < cutin)
      E=0;
   else
      E=0.5*density*area*Cp*(WeibullRandomNumbers(i)^3);
   end
  Et=Et+E;
  A=A+WeibullRandomNumbers(i);
end
Average=A/8760
Et
```

APPENDIX 2: 5W Solar Panel

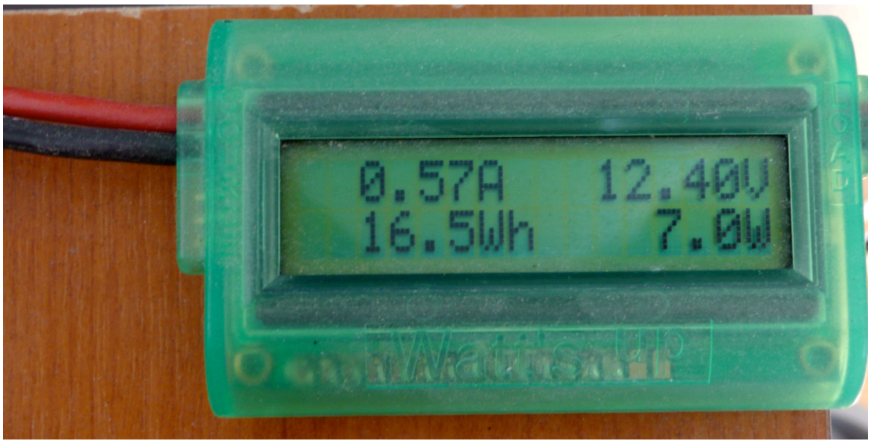


APPENDIX 3: 5W Solar Panel Technical Specifications

Electrical and Mechanical Characteristics and Temperature Coefficient Features

MONO or POLY	MONO
Maximum power (Wp)	5w
Maximum power voltage (V)	17.2
Maximum power current (A)	0.3
Open circuit voltage (V)	21.6
Short circuit current (A)	0.318
Number of cells (Pcs)	36
Size of module (mm)	250*200*23mm
Maximum system voltage (V)	715
Temperature coefficients of Isc (%)	0.065+/-0.015%/°C
Temperature coefficients of Voc (%)	-(2.23+/-0.1) / °C
Temperature coefficients of Pm (%)	-(0.5+/-0.05)/ °C
Temperature coefficients of Im (%)	+0.1/ °C
Temperature coefficients of Vm (%)	-0.38/ °C
Temperature Range	-40°C~+85°C
Tolerance Wattage (e.g. +/-5%)	+/-5%
Surface Maximum Load Capacity	60m/s(200kg/sq.m)
Allowable Hail Load	steel ball fall down from 1m height
Weight per piece (kg)	1
Junction Box Type	GY-BOX-5C
Length of Cables (mm)	None
Cell Efficiency (%)	>16%
Module Efficiency (%)	>13.2%
Output tolerance (%)	+/-5%
Frame (Material, Corners, etc.)	n/a
Standard Test Conditions	AM1.5 100mw/cm2 25°C
Warranty	5 years product warranty and 25years 80% of power
FF (%)	74%

APPENDIX 4: Watt Meter/Power Analyser and Technical Specifications



Parameter	Value	
	Range	**Resolution**
Voltage	0 - 60 V	0.01 V
Current	0 – 100 A peak	0.01 A
Power	0 – 6554 W	0.1 W
Charge	0 – 65 Ah	0.001 Ah
Energy	0 – 6554 Wh	0.1 Wh
Measurement Update Period	400 mS	
In Circuit Resistance	0.001 Ohms	
Operation Current	7 mA	
Dimensions	2.8" L x 1.7" W x 0.83" D	
Weight	2.3 oz	
Display Screen	16 character x 2 row STN LCD	
Nominal Operating Conditions	0° - 50° C ambient temperature, non condensing humidity	

Source: Total Power Solutions (2014)