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Abbreviations

EV	Eco-Village
BOS	Balance-of-System
AC	Alternative Current
CoSiMReTsI	Computer Simulation Methods for Renewable Technologies Integration
DC	Direct Current
D-SM	Demand-Supply Matching
GEN	Global Eco-Village Network
PV	Photovoltaic
ReST	Renewable Supply Technologies
FC	Fuel Cell
PWD	Principal Weather Database
QPA	Qualitative Parametrical Potential
CEACP	Consecutive Elimination Assessment and Comparison Plan
PES	Primary Energy Source
SES	Secondary Energy Source
MP	Main Phase for Scenario 1
PP	Preliminary Phase for Scenario 1
OM	Operation Modes
OCR	Operational Capacity Range for Fuel Cell
CC	Capacity Cushion for the Fuel Cell
BB	Batery Bank
CFC	Critical Fuel Consumption
CNST	Critical Number of Storage Tanks
CNCD	Critical Number of Charging Days
BC	Boundary Conditions
CHP	Combined Heat and Power
CGP	Central Guidance Panel
FR	Fuel Regulator
SN	Sorting Numbers
ECA	Environmetal Change Network
BADC	British Atmospheric Data Centre
BWEA	British Wind Energy Assossiation
PEMFC	Polymer Electrolyte Membrane Fuel Cell
ESRU	Energy Systems Research Unit
OS	Operating System

Synopsis

With the dawn of the 21st century many engineering councils, institutions and organizations around the world are found to prepare and develop their country's infrastructure according to the green directions as dictated by the notion of **Sustainable Development**. As in every inbound trend that seeks establishment into the mainstream of today's development the engineering practice requires the testing of this trend in a miniature-like specialised applications to examine its behaviour and plan ahead for its dissemination in the most efficient and economic way. The **Eco-Village** movement is an idea of a small community of people leaving together in a selected area of their choice, which embraces green and sustainable practices under which their lives are experiencing the benefits of modern technology comforts and the pleasure of habituate close to the nature. This microcosm is a hestia of sustainable development applied in reality and not in papers and books. In most of the occasions these villages require an **autonomous** operation including methods of food, water and **energy** production for the community's needs. In principle this condition is very difficult to establish but it is not impossible. The issue addressed by this project is relating to the technological aspects of the **Tweed Valley Eco-Village** project (Scotland) and more specifically to the provision of Energy for electrical and heating purposes to an autonomous and sustainable extent for that community. Obstacles like **sizing**, **integrity of supply**, and **efficiency** are all examined with the help of a computer program, namely **MERIT** ©, to see if it is viable for this project to use a renewable energy scheme for supporting its existence using **Wind Turbine**, **Photovoltaic** and a **Fuel Cell** Plant modules. There were two scenarios that studied different aspects of the autonomous condition. **Scenario 1** was targeted to examine Electrical Energy absorption by the Eco-Village as that would be produced by Photovoltaic and Wind Turbine Units whereas **Scenario 2** was broader in studying Electrical and Thermal Energy loads ingestion provided by a Fuel Cell Plant which was designed to operate in realistic modes to cover the energy demands of the village according to **seasonal** fluctuations. The use of MERIT was the **administrative** and **planning** tool needed for a sound evaluation of the experiments conducted within the computerised study interface. The experiments were case studies that were intended to **simulate** the renewable energy supply technologies behaviour (primary source of electrical energy) under the **weather profile** for the area of study. The profile itself was attempted to be as homogeneous as possible to the **Thornylee Forest** weather identity with data arising from stations around that location and a **methodology** was devised to overcome availability and reliability problems.

Chapter 1-Introduction

The first chapter will look at the civilisation throughout time, from ancient times to synchronous eras, in an attempt to identify any changes in the sensitive relationship involving evolution, engineering and environmental impacts. Modern environmental problems will be addressed briefly to probe the creation of the Eco-Village notion. The meaning of sustainable principles in engineering will also be addressed to conclude with the role of engineering in supporting the design of Autonomous communities reflecting preclusively the Energy sector of such a task.

1.1 Civilisation and Environment- A Brief Historical Review

The evolutionary process can describe much of man's development. Quite simply, those humans which were able to adapt to new environments and had the most resources available to them, were most likely to survive, and were therefore most likely to reproduce.

Mankind evolved at different rates across the globe, with some settlements evolving faster than others. The wake of evolution drifted and shaped not only the societies themselves but accordingly the more sensitive relationship between the renditions of human acts with the place of living i.e. the environment. Where those rates met (at least for today's industrialised nations) was at the critical point of industrial revolution transitional time span, the latter being the saddle point between an old "benign" epoch (management of flows) and a new one of more "turbulent" characteristics (consumption of stocks) –our epoch! The following picture of human evolution is therefore only an insight into the general history of mankind

Ever since humanity capacitated a social-metabolic regime *Definition* thousands of years ago the crucial relationship between actions of progression and environment was undermined. The degree of this undermining varied over the years but throughout the timeline of evolution it was always constant with intense accelerating rates in the last two centuries of this millennium (See Table 1.1). The three groups of social-metabolic regimes i.e. Hunter-Gatherers, Agrarian Societies and Transformation Societies range from 100,000 years to today, all with different characters and modes of dominance and control of the surroundings.

Definition "A stable form in which the material and energetic exchange processes between human societies and their physical environment are organised"- *Reference: LE-1*

Table 1.1/ Annual per capita use of energy and material in different regimes Reference: LE-2 and LE-3

	Energy	Material
Basic Metabolism	3,5 GJ	1-2 t
Hunter-Gatherers	10-20 GJ	2-3 t
(Factor 3-5)		
Agrarian Societies	60-80 GJ	4-5 t
(Factor 20)		
Transformation	250 GJ	20-22 t
(Factor 100)		

1.1.2 Hunter-Gatherers

The first group, the Hunter-Gatherer societies, in terms of exploitation, are treating the environment in a benign way. They are social-metabolically based on an uncontrolled use of solar energy flows. Palaeolithic hunter-gatherer societies tap more or less passively existing solar energy flows without much trying to control these flows actively. They skim off free energy available in their habitat but do not take systematic measures to influence the availability or the amount of these energy flows. This epoch in world history ended about 10,000 years ago in which no major effects on the biosphere occurred save the use of fire to deforestation as part of their hunting strategy- 60,000 years before present there is probable evidence of fire used deliberately to clear forests in the Kalambo Falls site in Tanzania Reference: LE-4. This fire use for hunting purposes is the first indication of ecological changes. Big game hunters thus artificially created the steppe landscapes (by burning savannahs) on which their prey could pasture and insofar a first incidence of a (indirect and unintended) control of the physical environment can be observed.

1.1.3 Agrarian Societies

The second group, the Agrarian Societies, are social-metabolically based on a controlled use of solar energy flows. This epoch began about 10'000 years ago and ended about 200 years ago. The larger agrarian era can be divided into the period of simple peasant societies and the period of complex agrarian civilisations, the latter beginning about 5'000 years ago. Like hunter-gatherer societies agrarian societies tap natural solar energy flows, but unlike them their basic strategy aims at controlling these flows. They developed two strategies to achieve this goal:

- Biotechnology. Energy radiating from the sun is primarily caught and chemically fixed by plant photosynthesis, and then it is secondarily converted by animals and finally processed by humans.

- Mechanical devices. Here solar energy flows available in the biosphere as wind or running water are mechanically converted. The total amount of these energy flows can not be influenced, but people can increase the efficiency of energy conversion, albeit no great breakthrough can be expected. Technological progress is slowly pushing at elastic limits.

Energy use in agrarian societies has a general structure which can be reconstructed as a technically modified solar energy system. Its main characteristics are dependence on an energy flow, low energy density and the limited possibilities of converting one energy form into another. Thus particular energy forms like heat, movement, light or food appeared as qualities, not as aspects of one energy flow. Material is mobilised by the use of energy so that in the last instance the social-metabolic material flow is limited by the available amount of energy. The sharp energetic restrictions set by the agrarian regime thus had a limiting effect on material processes. Industrial material like metals, salt and other chemicals provided specific resource and pollution problems, above all in settlements. Here we find the classical forerunners of actual "environmental destruction", originating by uncontrolled mining and diffusion of substances into the biosphere, which causes unintended side-effects.

BC-1200 *Reference: IS-1*

- Air pollution was common in large towns long before the industrial revolution. The pollution came from dust, wood smoke, tanneries, animal manure and other things.
- Water pollution was less severe in some civilizations. Israeli and Hindu cities tended to have less water pollution due to strict religious codes about cleanliness. On the other hand, ancient Rome was notorious for sewage-filled streets.
- Timbering stripped the forests of Babylon, Greece, Phoenicia (Lebanon) and Italy with the rise of civilization. The wood energy crisis led Greeks to use passive solar energy by orienting their cities and houses toward the sun. Romans made some use of solar energy but imported wood for timber and fuel from as far away as the Black Sea. Both Greeks and Romans kept sacred groves of trees from being timbered.
- Soil conservation was not widely practiced in the Mediterranean, but cultures in China, India and Peru understood the long term impact of soil erosion and tried to prevent it.
- Lead poisoning was common among upper class Romans who used lead-sweetened wine and grape pulp sweetened with "sugar of lead" as a condiment.

1200-1750 (Middle Ages and Renaissance) [Reference: IS-1]

- Timbering in the forests of England, France and Germany leaves large tracts totally denuded by around 1550 in England and the 1600s in Europe.
- Soil conservation was not widely practiced in the Mediterranean, but cultures in China, India and Peru understood the long term impact of soil erosion and used terracing, crop rotation and natural fertilizer to prevent it.

1750-1830 (Enlightenment) [Reference: IS-1]

- New technologies create new pollution. Town gas from coal drips tar into the rivers. Vulcanized rubber plants discharge noxious chemicals directly into the streams. Coal smoke chokes the air in big cities. Chemical factories operate without thought to people downwind.

1.1.4 Transformation Society

The last group, the transformation society which began about 250 years ago is social-metabolically based on the use of fossil energy stocks. This society has not yet developed a stable structure but is involved in a process of accelerating transformation. The energetic foundation of the transformation is the switch to the use of fossil energy carriers: coal, mineral oil and mineral gas. This has two major implications: Very large stocks became available within short periods of time, and the mobilisation of material was fed by comparatively cheap and abundant energy supplies. Thus the newly formed social regime soon will transgress the physical boundaries of the agrarian solar energy system. The new energy regime moved far from the sustainable scope of the older regime and reached dimensions which were incomprehensible in the context of an agrarian society. It is self-evident that this is the physical basis of an unsustainable economic and ecological regime. As an immediate consequence the availability of large energy stocks allowed mobilising material in similar dimensions. Accordingly exponential growth of metal production over 200 years is observed, fed exclusively by fossil energy, and no surprisingly the emergence of the first pollution problems are a fact – a mere backside of this process: they provide the sink aspect of material mobilisation [Reference: LE-5].

1.1.4.1 The Turning Point- Industrial Revolution

The transformation society was the integration of knowledge and experimentation primarily on the fields of mechanics, thermodynamics, chemistry, physics, materials, and manufacturing- a continuation of a brilliant scientific past as configured through the previous two stages of evolution. What we call today industrial revolution was then, to the matured agrarian society, the triggering mechanism for a metamorphosis to the next social regime.

The Industrial Revolution began in the late 18^{th} and early 19^{th} centuries in Britain, before spreading around the world, and is synonymous to the ideas of increased productivity and over-consumption. Literally that occurred with James Watt's interest in the efficiency of the newcomer steam engine in 1765, an interest that grew from his work as a scientific-instrument maker and that led to his development of the separate condenser that made the steam engine an effective industrial power source. As in a chain reaction this invention set the trends for rapid progress and development. Coal, oil and gas (fossil fuels) offered levels of energy production previously undreamed of, leading to shifts towards factory-based systems and the mass production of goods such as cotton. Fossil fuels, principally coal at the beginning of the Industrial Revolution, were primarily used to generate steam power and electricity, but their applications were vast, with many industries becoming automated, hence increasing their output.

Amongst the technological traits- technological changes, of this revolution (socioeconomic and social are out of the scope of this text) some distinctive ones link directly to the large environmental impacts that were to follow in the years to come. To start we have the use of new basic materials, chiefly iron and steel and we mentioned above the use of new energy sources, including both fuels and motive power, such as coal, the steam engine, electricity, petroleum, and the internal-combustion engine. The burning of fossil fuels led to a massive increase in urban air pollution although most people felt that such a disadvantage was not significant in the context of their new found prosperity. In addition to urban air pollution however, other impacts of industrialisation were felt like the drastic changes to land use with the construction of new buildings, including factories and houses for employees, and transport facilities, including new roads and rail tracks. Areas of countryside were destroyed and replaced by industrial developments. In order to make best use of the remaining land, agricultural machinery was modernised to make the production of food more efficient. Finally there were important developments in transportation and communication, including the steam locomotive, steamship, automobile, airplane, telegraph, and radio. Water could not escape from the general situation with rivers and lakes being the direct receivers of the pollution wave.

1.2 Environmental Crisis of the 21st Century

The industrial revolution (which began in the late 1700s) and ongoing advances in science and technology during the last two hundred years have had profound effects for humanity and earth. Life in an industrial society offers many of us incredible opportunities, including greatly increased life spans and a higher standard of living. An industrial society also uses more resources and has greater impacts on the environment than an agrarian society. Initially these new chemical, physical, and biological impacts remained local or regional in scale. Only in the 1940s, after World War II, did the environmental ramifications of human activities begin to affect the functioning of major earth systems. The U.S. alone has consumed more mineral resources in the last few decades than all of civilization did before that [Reference: IS-2]. Certain global environmental problems that arose in the closing decades of the twentieth century demonstrate the absolutely unprecedented extent of human impacts on the environment. These grave global problems include climate change, depletion of the ozone layer, and loss of biodiversity.

Two over-riding trends characterize the beginning of the third millennium [Reference: LE-6]. First, the global ecosystem is threatened by grave imbalances in productivity and in the distribution of goods and services. A significant proportion of humanity still lives in dire poverty, and projected trends are for an increasing divergence between those that benefit from economic and technological development, and those that do not. This unsustainable progression of extremes of wealth and poverty threatens the stability of society as a whole, and with it the global environment. Secondly, the world is undergoing accelerating change, with environmental stewardship lagging behind economic and social development. Environmental gains from new technology and policies are being overtaken by population growth and economic development. The processes of globalization that are so strongly influencing social evolution need to be directed towards resolving rather than aggravating the serious imbalances that divide the world today. Resolving these imbalances is the only way of ensuring a more sustainable future for the planet and society.

Although earth's environment has gone through significant changes over geological time, nothing like these global environmental problems – climate change, depletion of the ozone layer, and loss of biodiversity – has taken place during the history of human civilization. The breadth and depth of environmental problems facing the world have pressed political leaders to recognize that nature's abundance and resilience can not be taken for granted.

1.2.1 Anthropogenic Climate Change

One of the largest specific environmental concerns facing us is anthropogenic climate change, a complex global problem related primarily to the use of fossil fuels, particularly by industrialized countries [Reference: LE-7]. Burning peat, coal, oil, and natural gas releases stored carbon into the atmosphere with profound consequences. Clearing land and cutting or burning forests also increases the atmospheric carbon dioxide level. Although the global carbon balance has shifted over geologic time, it had been in a state of relative equilibrium since the last Ice Age, with balanced amounts of carbon moving into and out of the atmosphere each year. The climate and ecosystems that had prevailed during the development of human civilization were linked to this balance. Carbon dioxide, the major greenhouse gas affecting global climate (along with methane, nitrous oxide, and others) is now at levels about 30% higher than in pre-industrial times. After light energy from the sun penetrates our atmosphere and is absorbed by the Earth's surface, it gets reradiated in the form of heat energy. It is natural and beneficial that gases in the atmosphere trap this heat energy, as this maintains our planet's average surface temperature near a comfortable 16°*C*. But the changes we have created in the composition of the Earth's atmosphere, increasing the levels of greenhouse gases, results in more heat being trapped by the atmosphere. On average, global temperatures have already warmed over the last century, and the Intergovernmental Panel on Climate Change estimates that temperatures will increase another 1.5 to 4.5°*C* over the next century. This would be a rate of climate change unlike anything that has occurred in the last 10,000 years. The ramifications include inundation of coastal cities, severe droughts in some areas, severe storms and flooding elsewhere, shifts in availability of fresh water, changes in agricultural productivity, spread of tropical diseases, and wildlife and plant communities unable to adapt- with increased political unrest and international tensions likely to follow[Reference: LE-7].

1.2.2 Depletion of Stratospheric Ozone

Another global concern is depletion of stratospheric ozone [Reference: LE-8].A natural concentration of ozone is found in a sort of "layer" about 19*km* above the Earth's surface, in the Earth's upper atmosphere. This protective ozone layer shields the Earth and all living things from lethal ultraviolet (UV) radiation emitted by our sun and thus are essential in making Earth's lands and upper oceans habitable. Chlorofluorocarbons (CFCs), halons, and other artificial compounds, which were in common use in developed countries for decades as coolants for refrigerators and air conditioners, propellants for aerosol sprays, and other purposes, gradually loft to the upper atmosphere after release. There they act to increase chemical reactions that break down ozone. This allows more UV radiation to reach the Earth's surface, where the UV rays increase the incidence of skin cancer and cataracts and may damage the human immune system as well as harm other animals and plants on land and in the sea.

1.2.3 Loss of Biodiversity

A third major global environmental problem is the loss of biodiversity, which respected biologist E.O Wilson has called *"our most valuable but least appreciated resource"* [Reference: LE-9].The significance of biodiversity loss was first recognized as a global problem in 1980 in the Global 2000 report that resulted from a study authorized by U.S. President Jimmy Carter.

Biodiversity or the diversity of life can be studied at different levels. Genetic diversity involves the diversity of genes and thus of adaptive traits (e.g., behavioural traits, and resistance to drought, disease, and toxins) within a species or other taxonomic division; genetic diversity increases the likelihood that a species can avoid extinction. Species diversity refers to the number of species; each species is interdependent with other species in many ways. Ecological diversity involves diversity of ecological communities. Habitat degradation and destruction is the major cause of species loss. Much of the loss is occurring in tropical forest and other species-rich ecosystems that are not well studied and where millions of species remain unidentified. Some scientists think that as many as one-third of all species on Earth could be extinct by 2100. The loss of each species and the ecosystem services it provides may affect society in a number of ways. Biodiversity, along with a few other factors including climate, species composition, disturbance, and availability of nutrients, is a major controller of the dynamics and structure of populations and ecosystems [Reference: LE-10]. Because biodiversity acts to stabilize community and ecosystem processes, we can expect human-caused losses of biodiversity to result in significant long-term changes in the functioning of ecosystems.

1.2.4 Other Problems and Future Threats

Anthropogenic climate change, stratospheric ozone depletion, and loss of biodiversity are the three most significant worldwide problems facing us today. Other local, regional, or global environmental concerns include air pollution, acid rain, water pollution, decline of fish stocks, soil erosion, deforestation, eutrophication, desertification, solid waste, and hazardous and radioactive waste. Many of these concerns are linked to the size of the human population, to consumption of goods and services by the human population, and to policies and technologies that affect production and distribution of goods and services. In addition to existing problems, we face the possibility that entirely new problems (or unanticipated consequences of current problems) could develop in the future.

1.3 Sustainability, Ecology and Engineering

As we saw from the last paragraph there is not such thing as "unprecedented" environmental impacts or "phenomenal" catastrophic occurrences in the 21^{st} century but what it is clearly is a great environmental problem, an accumulation of a series of undermining industrial and engineering practices over the centuries and more importantly over the last 20 decades.

Many scientists today vindicate the fact that these practices were necessary and vital for humanity to jump ahead in the evolution process and that any accusations made for the results of them should be directed at the soundness of their design and planning as these are the real culprits of the problem itself. Others believe that the 21st century civilisation is found facing a crisis of economic, social and environmental projections. They state that the extent of the crisis is such that we should be worried about the continuity of our species, on this planet, for the years to come. According to this party of people the human civilization has never encountered so big a dilemma such a complex situation of accepting the current face of society, and with it automatically the possibility of a future catastrophe, or rethinking and redesigning today's endless set of priorities and values that have caused this crisis to ensure a better course of life. And complex this situation is. Over consumption, industrialisation, the fight for economic consolidation and the strife for rampant rates of growth, are some of the most important characteristics of the face of the menace.

Humanity can today be proud of numerous amazing and impalpable breakthroughs and achievements in every science of our intellectual expressionism. These creations though, when viewed from a different angle, they can be deemed as detrimental and corrosive to the environment primarily and to society and economy secondarily as they can be proved beneficial at the same time, a fact that overshadows their glamour and importance to us. The spinal chord of our revolutionary methods to flourish has been found today of having a negative effect on the planet. The choice of materials for our products, the way manufacture our products, the way we produce our energy, the way we produce our food, the way we dispose our wastes and many others are an example of the synchronous case of the environmental problem we experience today. To no dereliction and as an integral part of the crisis there are other sectors that flaw in today's polis, economical and social in nature (like the huge differences in the monetary status of many countries of the west and the south or the social paralysis of minorities in many nations [Reference: LE-6]) , which constitute the range of the problem. It was soon realised that these three flaws of today's civilisation are so detrimental to the next generations to be left unnoticed and ungoverned and the term **sustainability** was readily appointed to the problem as a scientific description for studying it.

The conceptual underpinnings for our current use of the term sustainability originate in the early 1970s. The book *"Blueprint for Survival"* called for *"a stable society - one that to all intents and purposes can be sustained indefinitely while giving optimum satisfaction to its members"* [Reference: LE-11]. In the early 1980s, the phrase **sustainable development** began to appear in publications of the United Nations and the idea of sustainability was discussed by the private sector as well, such as in the Worldwatch Institute book "*Building a Sustainable Society*" [Reference: LE-12]. Yet it was not until the 1987 publication of *"Our Common Future"* by the World Commission on Environment and Development that sustainable development was discussed as a major political goal and defined in a way that drew the attention of the world. Often called the "*Brundtland Report*" after the Norwegian prime minister who chaired the commission, this report to the United Nations decried the usual narrow approach to environmental issues or economic development issues and called for new approaches that would integrate ecological, economic, and social concerns [*Reference: LE-13*].The report discussed the need to apply integrated, sustainable solutions to a broad range of problems related to population, agriculture and food security, biodiversity, energy choices, industry, and more. It emphasized that building a sustainable society will require enhancing the quality of life for all humanity without impacting the long-term carrying capacity of natural systems. At the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, also called the Earth Summit, sustainable development was an underlying theme. The "*Rio Declaration on Environment and Development*" outlined the obligations and rights of countries in pursuing sustainable development, and an ongoing UN Commission on Sustainable Development was created [*Reference: LE-14*].

In *Our Common Future*, the Brundtland commission proposed the definition[Definition] for sustainable development that was to become so broadly used by so many scientific teams [*Reference: LE-13*]. The Brundtland report described seven strategic imperatives for sustainable development:

- Reviving growth,
- Changing the quality of growth,
- Meeting essential needs for jobs, food, energy, water, and sanitation,
- Ensuring a sustainable level of population,
- Conserving and enhancing the resource base,
- Reorienting technology and managing risk and
- Merging environment and economics in decision-making.

It also emphasized that the state of our technology and social organization, particularly a lack of integrated social planning, limits the world's ability to meet human needs now and in the future. Sustainable development or sustainability involves three broad interacting realms: environment, economics, and social equity. These three realms could be called the ecological imperative, the social imperative, and the economic imperative. It has been said that: "*These three aspects are inseparable and our ability to develop a deeper understanding of this linkage is critical to our prospects for sustainability*" [*Reference: LE-15*].

Definition "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

1.3.1 The Principle of Environmental Health and Engineering

The long-term health and stability of natural systems are critical to human society. Not only do natural systems provide natural resources or ecosystem goods but also a range of other ecosystem services that support human life and endeavours [Reference: LE-16].Environmentally sustainable choices would include those which contribute to conserving natural resources, protecting biodiversity, stabilizing atmospheric composition and global climate, and otherwise protecting the stability and productivity of Earth systems. Social equity and economic development can support healthy environmental systems (See Table 1.2)

Table 1.2/ Ecosystem services and functions [Reference: LE-16]

Biological control	Natural regulations of populations by keystone predators or other tropic relations
Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes
Cultural	Non-commercial aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems
Disturbance regulation	Dampening of ecosystem response to environmental fluctuations – protection from storms, flood control, drought recovery, and other processes mediated by vegetation structure
Ecosystem service	Examples of ecosystem functions
Erosion control / sediment retention	Retaining soil within an ecosystem / prevention of loss by wind, runoff, or other processes
Food production	Production of food crops, nuts, fruits, fish, game
Gas regulation	Regulation of atmospheric chemical composition - CO_2/O_2 balance, O_3 for UVB protection
Genetic resources	Sources of unique biological materials– medicine, genes, products for materials science
Nutrient cycling	Storage, cycling, processing, acquisition of N, P, and other elements or nutrients; nitrogen fixation
Pollination	Movement of floral gametes, allowing reproduction of wild plant populations and crop plants
Raw materials	Production of lumber, fuel, and fodder
Recreation	Recreational opportunities like ecotourism, sport fishing, and other outdoor activities
Refugia	Habitat for resident and migratory populations of harvested or other species
Soil formation	Weathering of rock and the accumulation of organic material
Waste treatment	Breakdown of certain nutrients, compounds, or materials, including absorption of pollution and detoxification
Water regulation	Regulation of hydrological flows and provisioning of water for agriculture, industry, transportation
Water supply	Storage and retention of water by watersheds, reservoirs, aquifers

For today's "developing" sciences like engineering the challenge of ratifying the above principle is grater than ever. Technology, which has been largely responsible for the decay of the environment, is by definition the birth of engineering minds. It would be a true disappointment for the science which focus has always been the improvement of our lifestyle to relinquish to a superficial role coming from disrespecting environmental appeals. To prevent this degradation the purity of engineering has been reassessed to a sustainable level. The term "Green engineering" is given today to the systems-level design of a process or product using environmental attributes as a primary design variable. These design variables are:

- Pollution prevention and waste minimization
- Solid waste reduction
- Recycling-based manufacturing
- Energy efficiency
- Renewable energy development
- Green business and environmental technologies development
- Link economics, environment, and social equity
- Informed citizens
- Use of market forces

Green Engineering is now a cross-disciplinary topic addressing a wide range of methodologies, approaches, and areas of concern across various engineering disciplines. The ultimate goal of such a discipline is to establish a set of Green Engineering Principles that can serve as guidance for engineers in the design of products and processes within the constraints of sustainable development. The principles will not be prescriptive rules, but rather a set of guidelines for the engineer to use that will improve the environmental performance of the design as it interacts in a larger system and affects the global ecosystem.

1.3.2 The Dark Side of the Energy Industry

Energy is both a solution and a problem for sustainable development. It makes development possible, yet it is also a major cause of air pollution and other damage to human health and the environment. Modern energy services, dominated by the burning of fossil fuels, can vastly expand the number of opportunities and choices available to people as they seek to improve their standard of living and to power automobiles, airplanes, factories and homes. Yet such energy generation results in air pollution and emissions of greenhouse gases that contribute to global warming and potential climate change.

Almost all energy production and use involves some form of pollution of our environment. Each different source of energy, from fossil fuels to nuclear, pollutes in a different way and to a different degree (Table 1.3). Just how much pollution and what type of pollution are acceptable and which source of energy should be used has generated a lot of controversy [Reference: IS-3] .Carbon dioxide, one of the most prevalent greenhouse gases in the atmosphere, has two major anthropogenic (human-caused) sources: the combustion of fossil fuels and changes in land use. Net releases of carbon dioxide from these two sources are believed to be contributing to the rapid rise in atmospheric concentrations since pre-industrial times. Because estimates indicate that approximately 80 percent all anthropogenic carbon dioxide emissions currently come from fossil fuel combustion, world energy use has emerged at the centre of the climate change debate [Reference: IS-4]. Many countries currently have policies or regulations in place that limit energy-related emissions other than carbon dioxide.

Criteria pollutants such as sulphur oxides and nitrogen oxides are also emitted as a result of fossil fuel combustion, contributing to a variety of health and environmental problems that include acid rain, deterioration of soil and water quality, and human respirator illnesses. Nitrogen oxide emissions additionally contribute to the formation of ground-level ozone (smog). Furthermore, criteria pollutants indirectly affect the global climate by reacting with other chemical compounds in the atmosphere to form greenhouse gases or, in the case of sulphur dioxide, by affecting the absorptive characteristics of the atmosphere. To date, the measures taken to mitigate criteria pollutant emissions have been focused primarily on the main sources. Fossil fuel combustion for electricity generation, particularly coal-fired power, represents the largest source of sulphur dioxide emissions in many countries. Other significant energy-related sources include fuel combustion for manufacturing industries, vehicles, and petroleum refining. Nitrogen oxides are emitted as a result of fossil-fuel-based electricity generation, although oil use for road transportation is generally the single largest source.

Energy production has another contributor to the environmental hazards of the planet. The fission nuclear power plants that are already in use have produced thousands of tons of radioactive waste that are sitting in drums waiting for disposal. This waste will be toxic for thousands of years and where to put it has become a gigantic technical and political problem. For this kind of wastes there is still no safe storage methods and if any proposed they are usually unproved and still under development for their environment and public protection standards. While radiation leaks are rare, there have been some small leaks and even a few larger ones. Small leaks allow radioactive gases to get into the atmosphere, which if breathed, could help cause cancer. The water from the cooling towers contains excess heat energy and is released into the local rivers or lakes. The warmer temperatures that are created allow organisms that would not normally thrive to grow and kill off some of the previous inhabitants.

Table 1.3/ Pollutants and their Effects from Energy Power Plants

Coal & Oil Power Plants	
Pollutant (air)	Environmental Effects
Nitrous Oxides (air)	Global Warming
Carbon Dioxide (air)	Smog
Particulate or Dust (air)	Causes lung cancer and other lung ailments
Nuclear Power Plants	
Radioactive Waste (liquid or solid)	Difficult to dispose of
Radiation Leaks (air)	Radiation poisoning and increased risk of cancer
Heat Emissions (water)	Causes growth of algae and kills marine life

1.4 A New Spawn

In an effort to deal holistically with the problem of sustainability groups of people put together their efforts and their knowledge to gene communities of 500-2000 members in which the ideals of life, environment and progress were accepted as a balanced qualitative mix within a well defined region. These villages append environmental and sustainability problems into a radical form of natural inhabiting, endowed with the term Eco-Village (EV) living.

Eco-Villages are in essence a modern attempt by humankind to live in harmony with nature and with each other. They represent a "leading edge" in the movement towards developing sustainable human settlements and provide a testing ground for new ideas, techniques and technologies which can then be integrated into the mainstream. The need for developing sustainable human settlements relates directly to the commitment by the world leaders at the *Earth Summit* in Rio (1992) to programs that will move humanity to sustainability in the 21st century (Agenda 21). To achieve the goals of sustainable human settlements, there is a need for pilot communities, and for an exchange of information between them and the mainstream. The EV movement embodies theory and practice centred on a move from the current system which is deemed "narrow", "utilitarian", "materialistic" and "reductional" to one which is "holistic", "just", "ecologically sound" and controlled by local communities [Reference: IS-5]. The formation of and ongoing operation of eco-villages has two major lessons for the wider framework of sustainability:

1. It is an ongoing experiment in sustainable communal living where new (and re-discovered old) solutions can be tried out on a smaller scale before they can be applied at larger societal levels. As such they act as demonstration sites for new technologies, new social and economic arrangements.
2. They can be evolutionary in their practices as understanding of the multi-faceted nature of sustainability increases, and as the need for

resource conservation / reduced environment impact at both a global and local scale increases.

Such ecologically-based communities on a village scale start small, mainly due to a lack of resources. However, they are large enough to encompass all the necessary and essential elements of the human habitat in need of transformation, and can continue with little support and minimal opposition. For these villages the provision of goods comes directly from natural resources including energy, food and water- **autonomous communities**- with very little or not at all help required by exogenous sources. Many are the merits of these communities concerning social and economic breakthroughs but surely from an engineering perspective there is a great interest for the ingenious techniques and practices that they utilise to succeed their modernised needs in terms of efficiency and quality. One of the most important EV issues is how to make technology ecologically, socially and spiritually responsive to human needs, rather than the opposite. For these micro societies it is the technology that tends to determine the structure and organisation of society contrary to the contemporary society's technology, which promotes unliveable mega cities, separation of work and home, institutionalisation of family support functions, environmental degradation, un-sustainability, and over-consumption, in a centralised, hierarchical structure. A vision of Eco-Villagers requires a radical change in structure that would reverse all of these tendencies. To succeed that they have adopted a renewable strategy concerning production, management, distribution and conservation of energy and that is no other than promoting sustainable technologies. Three key criteria have emerged in assessing appropriate technologies for eco-villages, over and above commercial viability:

1. Ecological sustainability.
2. Human scale, decentralised production.
3. Allowance for a non-stressful, meditative life style.

1.5 Autonomous Energy Rendition and Renewable Energy Integration

The idea of rendering a community self-sustained is the ultimate goal of an EV. But this is no easy task for any of the dimensions of making this autonomy a reality never mind the energy field. This task becomes even more difficult if the study has to employ power technologies that not only are efficient but they would need to be appropriate enough for the type of energy demand of a given EV and above all they would subject to the conditions of being green and sustainable. Under these conditions the autonomy can only come true with the use of Renewable Supply

Technologies (ReST). The true nature of the energy demand has two faces. One is the Electrical Energy supply and the other is the Thermal Energy supply. These two constitute the magnitude of the energy requirements for any modern community and that is also the case for the EV. For both parts there are plenty of candidates to utilise but the crux for the engineers is to test the ability of ReST to mix in with the specialised energy needs of the EV communities. The most widely used method for testing the potential of ReST and thus aiding their integration is by Demand-Supply Matching (D-SM) [Reference: LE-17].

The matching procedure described by Ramakumar et al. [Reference: LE-23] employs a knowledge-based approach in the design of integrated renewable energy systems. The procedure uses seasonal data sets to characterise each season by a set of available RE resources and load requirements. By systematically attempting to satisfy each of the seasonal demands with the cheapest supplies available, seasonal supply systems are constructed, from which an annual design is proposed. The work is primarily concerned with finding the most economic supply technologies to satisfy a number of prioritised demands. Again the high levels of variability involved in both demand and supply profiles are neglected in a seasonal approach. Profile variability is critical in any supply and demand matching exercise, as net supply and demand totals give no indication as to whether demands are satisfied at the time when they are required. The design of a renewable energy system should ensure that times of renewable energy availability coincide with periods of consumption.

So D-SM is a very arduous technique especially when the energy engineers have time limitations upon delivery of the decisions plans and in the case where the study has to be a realistic simulation (not a mere estimation) of the pragmatic energy loads with respect to the topology and the climatic characteristics of the area under development. For their aid, as this is the case now for most of the engineering disciplines, computers are utilised where very specialised programs can be run to improve the D-SM process and so offer an incredible amount of capabilities for the integration of ReST. Computer power has been largely responsible for the advances in renewable technologies and will be equally instrumental in their dissemination. The use of computer systems has had a direct effect on renewable energy technologies by advancing design and improving efficiencies [Reference: LE-18]. Examples include improving the conversion efficiency of photovoltaic cells, increasing the aerodynamic performance of wind turbines and the development of power electronic devices to allow variable-rotor-speed operation of wind turbines, which reduce structural loads and improve power quality.

Post-Development Phase

For the **post development phase** of an EV i.e. after the buildings have erected, there is a variety of energy tracking and decision support systems are currently available (e.g. QuickPlan and Entrack *Reference: LE-19*). These software tools enable users to monitor energy consumption in order to detect inefficiencies and faulty control systems, and evaluate the effects of building retrofits. They also provide spatial information related to enable renewable energy resource estimation by site, as well as environmental and socio-economic impact assessment. The EEP system *Reference: LE-20* enables sustainable planning via emissions tracking and enables users to assess progress towards agreed reductions in emissions. Furthermore about the simulation of building demands involved in the appraisal of energy efficiency technologies there is range of software design tools are available, encompassing simple appraisal tools (e.g. ASEAM *Reference: LE-24*, Energy 10 *Reference: LE-25* and sophisticated packages (e.g. DOE-2 *Reference: LE-26*, Esp-r *Reference: LE-27* .These tools are employed to evaluate a variety of energy dependent design measures, with the more advanced packages including features to assess comfort, daylight and analyse different control systems. Furthermore, some of the building simulation tools incorporate renewable energy technology modelling, allowing building integrated system analysis (e.g. Esp-r).

Pre-Development Phase

When the study is at the **pre-development phase** there is still a large family of computer software that can assist and facilitate the decision making for ReST for an EV. The author is referring to that family as Computer Simulation Methods for Renewable Technology Integration or $C_oS_iMR_eT_sI$. There are many specialised simulation tools that are available for the analysis of renewable systems. Examples include solar ventilation air heating; biomass heating; wind energy; small hydro and photovoltaic systems (e.g. RETScreen *Reference: LE-21*, IRES-KB *Reference: LE-22*.Such programs facilitate the pre-feasibility analysis of renewable technologies and aid the procedure of evaluating the optimum technology for a given site by the evaluating supply potentials. Among others there is MERIT *Reference: IS-6*, the program that we used in this study is, which is a very versatile software to facilitate the simulation for the D-SM of the Tweed Valley EV. The fundamental aim in the creation of MERIT is to ensure its use was not limited to specialist knowledge and could be used by computer literate individuals to investigate various supply and demand strategies, without the need for prior knowledge of different technologies.

End of Chapter 1

Chapter 2-Literature Review

This chapter is dedicated to the essential background information accompanying the experimental phase of the project. The focus will be addressing the renewable technologies that will be used in later chapters providing basic and advanced knowledge of their technical characteristics that will endorse the experimental study. The Eco-Village notion as a global phenomenon and as a Scottish reality at the Tweed Valley will also be acknowledged to deliver an understanding of the values and principles of these radical communities.

2.1 A Brave New World

Eco-Villages are in essence a modern attempt by humankind to live in harmony with nature and with each other. The need for developing such sustainable human settlements relates directly to the commitment by the world leaders at the *Earth Summit* in Rio (1992) to programs that will "move humanity to sustainability in the 21st century" (Agenda 21). To achieve such goals of sustainable human settlements, there is a need for pilot communities, which will provide a testing ground for new ideas, techniques and technologies which can then be integrated into the mainstream. These housing models would seek to encourage the social, economic and environmental notions of sustainability through good design, green technologies and fostering of community.

This movement towards sustainable communities has a number of precedents, notably in the utopian literature [Reference: LE-28, 29, 30,31], and in various historical attempts to establish social utopian experiments in many countries around the world like the Tolystoyian communes in Tsarist Russia, umayaa villages in Tanzania, New Harmony, Brook Farm and other experiments in 19th century United States. Today the Eco-Village movement is represented by the Global Eco-Village Network (GEN) [Reference: IS-5] which comprises projects from all over the world at different stages of development, the oldest established more than 25 years ago and the most recent being under establishment. The first groups (seed groups) were a splendid effort of experiments to put together a rather virtual and extemporaneous dream of an alternative but concrete society within the limits of contemporary society. The experiments were implemented on a trial and error basis and the results were plain but impressive. Over the years, science was included in the planning to provide design and application guidelines in the directions of sustainability and spirituality. Some of the initial projects include:

- The Findhorn Foundation, Scotland.
- Lebensgarten, Germany
- Ecoville Nevo and Rysovo, Russia
- Gyûrûfû, Hungary
- Crystal Waters, Australia
- The Farm, USA

- The Manitou Foundation, USA
- The Ladakh project, India
- Danish Eco-village Association

Most of these projects are now internationally well recognised, while the projects in Eastern and Central Europe are in the start-up phase [Reference: IS-5]. Common to all of the projects is their focus on education and a desire for the integration of ecology, spirituality, community, and business development. Each of the projects functions as an eco-village training centre for their area. The range of skills that are on offer is very extensive, covering all aspects of sustainable community living.

2.1.1 Organizational and Design Principles

An eco-village, as defined by Robert Gilman of the GEN [Reference: IS-5], is a:

"Human scale, fully featured settlement,
Which integrates human activities harmlessly into the natural environment,
supports healthy human development,
And can be continued into the indefinite future".

He believes that to achieve a truly sustainable community it must have:

1. Conscious awareness of the interrelationships of all life and the cyclic sustainable systems of nature,
2. Understanding of and support for cultural, social and spiritual values of this awareness and how humans can live ecologically balanced lives
3. Viable technologies that do not further harm, but which help to heal the planet.

He suggests that eco-villages can also be testing grounds for new ideas, technology and techniques which can then be integrated into the mainstream. Eco-village settlements need to meet various **organizational challenges** in building and in operating more sustainable systems. These challenges are:

- The bio system challenge of integrating eco-village activities harmlessly into the surrounding environment,
- The built environment challenge of using sustainable materials and technology for shelter, transport and economic activity,
- The economic system challenge of providing sustainable economic activity that is non-exploitative of nature and humans and which is satisfying,

- The governance challenge of defining the roles, expectations and practices of decision making and resource allocation within such communities, and their relationship with others,
- The "glue" challenge of setting out an ideal of a shared vision, and the resulting tensions between unity of purpose and diversity of practice,
- The "whole system" challenge of integrating and meeting the above challenges in a personally satisfying and sustainable process within an existing economic and social system which currently wasteful of resources and unsustainable.

Eco-villages attempt to meet these challenges by adopting **design principles** to guide their initial establishment and continued functioning. These principles or design features attempt to define an ideal situation which any given eco-village may be in process of moving towards. The five principles *Reference: LE-32, 33* are defined as being:

- Human scale – of such a size and proximity that face to face relations are possible. This applies also to neighbour-hoods as well as hamlets and villages.
- Fully featured – where all the major functions of living-work, recreation, social and commerce are present and where design caters for the full span of human age (infants to elderly) and for various physical conditions.
- Ecologically sensitive in that the design respects other life forms, and obeys cyclical patterns of resource use instead of once-through and dispose.
- Healthy human development – where there is a balanced and integrated development of all aspects of human life – the physical, emotional, mental and spiritual; and where both individual and community well-being is recognised and catered for; and where structures are established for community economics, community governance and satisfying social relationships.
- Sustainability obedience – where there is recognition of and commitment to not live off accumulated capital and anti-ecological activities elsewhere.

Clearly these are challenging principles and existing eco-villages are at different stages in their evolution in recognising and meeting these requirements.

2.1.2 The Secrets for Green Practices

To these communities there are no so called secrets of living harmonically with the natural environment and enjoy the luxuries of modern civilisation at the same time. That is because common to all of the projects is their focus on education and a desire for the integration of ecology, spirituality, community, and business development.

Eco-Villages recognition of environmental impacts and principles is strong. Most of the eco-villages are using the environment to cover there needs to an **autonomous** level and so energy, waste treatment, water, and food production are provided on site. Energy needs are met usually by solar and wind, water is supplied by rainwater catchments, wastes and nutrients are recycled and treated as resources, local forests provide building materials, and annual vegetable production and perennial fruit production are integrated into the project. Common land contains the infrastructure network–roads and walkways, power and communication systems, as well as dams for water supply and fire fighting. Common land also safeguards natural features and gives space to wildlife. Most householders compost their organic waste; inorganic waste is likely to be recycled for building materials. Water for household needs is collected from rainwater tanks, and additional garden supplies are available from storage dams. Sewage or black waste is either taken care of by composting toilets or through septic tanks. Some households install grey water subsurface or reed bed systems.

2.1.2.1 Permaculture

One of the three characteristics, for which eco-villages are known to wider public, is the practice of permaculture as a mandatory planning issue. The word "permaculture" was coined in 1978 by Bill Mollison, an Australian ecologist, and one of his students, David Holmgren. It is a contraction of “permanent agriculture” or “permanent culture”.

Permaculture is about designing ecological human habitats and food production systems. It is a land use and community building movement which strives for the harmonious integration of human dwellings, microclimate, annual and perennial plants, animals, soils, and water into stable, productive communities. The focus is not on these elements themselves, but rather on the relationships created among them by the way we place them in the landscape. This synergy is further enhanced by mimicking patterns found in nature. A central theme in permaculture is the design of ecological landscapes that produce food. Emphasis is placed on multi-use plants, cultural practices such as sheet mulching and trellising, and the integration of animals to recycle nutrients and graze weeds. However, permaculture entails much more than just food production. Energy-efficient buildings, waste water treatment, recycling, and land stewardship in general are other important components of permaculture. More recently, permaculture has expanded its purview to include economic and social structures that support the evolution and development of more permanent communities, such as co-housing projects and eco-villages. As such, permaculture design concepts are applicable to urban as well as rural settings, and are appropriate for single households as well as whole farms and villages.

"Integrated farming" and "ecological engineering" are terms sometimes used to describe permaculture, with "cultivated ecology" perhaps being the closest. Though helpful, these terms alone do not capture the holistic nature of permaculture; thus, the following definitions are included here to provide additional insight.

2.1.2.2 Co-Housing

The other characteristic of eco-villages is the practice of co-housing. Co-housing is the name of a type of collaborative housing that attempts to overcome the alienation of modern subdivisions in which no-one knows their neighbours, and there is no sense of community. It is characterized by private dwellings with their own kitchen, living-dining room etc, but also extensive common facilities. The common house may include a large dining room, kitchen, lounges, meeting rooms, recreation facilities, library, workshops, and children's space.

Usually, co-housing communities are designed and managed by the residents, and are intentional neighbourhoods: the people are consciously committed to living as a community; the physical design itself encourages that and facilitates social contact. The typical co-housing community has 20 to 30 single family homes along a pedestrian street or clustered around a courtyard. Residents of co-housing communities often have several optional group meals in the common building each week. This type of housing began in Denmark in the late 1960s, and spread to North America in the late 1980s. There are now more than a hundred co-housing communities completed or in development across the United States and Canada. The main characteristics of Co-housing are [Reference: LE-34]:

1. Participatory Process. Residents participate in the planning and design of the development of the community so that it directly responds to their needs.
2. Neighbourhood Design. The physical design encourages a sense of community as well as maintaining the option for privacy.
3. Private homes supplemented by common facilities. Common facilities are designed for daily use; they are an integral part of the community and typically include a dining area, sitting area, children's play room, guest room, as well as garden and other amenities. Each household owns a private residence (complete with kitchen) but also shares extensive common facilities with the larger group.
4. Resident management. After move-in.
5. Non-hierarchical structure and decision-making. There are leadership roles, but not leaders.
6. The community is not a primary income source for residents.

2.1.2.3 Ecological and Sustainable Building Design

The last of the three most important characteristics and maybe the one with the uppermost significance from an engineering perspective is the practice of sustainable constructions for the people of the EV. There are two approaches that Eco-Villagers implement the design of their buildings: the **green** or ecological approach and the **sustainable** one. The two are too difficult to distinct as they both focus on the improvement of habiting and the protection of the environment, but still there are some slight differences that separate them.

Green Building

A **green** approach to the built environment involves a holistic approach to the design of buildings. The design methods usually integrate passive solar, energy efficiency and other renewable energy technologies that can be used to reduce building energy consumption. This high performance, holistic approach to design examines how a building interacts with its systems, activities and surrounding environment. Thus by optimising the building's standard components- site, windows, walls, floors and mechanical systems- building owners can substantially reduce energy use without increasing construction costs. All the resources that go into a building, be they materials, fuels or the contribution of the users, need to be considered if a sustainable architecture is to be produced. Producing green buildings involves resolving many conflicting issues and requirements. Each design decision has environmental implications. Measures for green buildings can be divided into four areas:

- Reducing energy in use,
- Minimising external pollution and environmental damage,
- Reducing embodied energy and resource depletion,
- Minimising internal pollution and damage to health

A green building places a high priority on health, environmental and resource conservation performance over its life-cycle. These new priorities expand and complement the classical building design concerns: economy, utility, durability, and delight. Green design emphasizes a number of new environmental, resource and occupant health concerns:

- Reduce human exposure to noxious materials,
- Conserve non-renewable energy and scarce materials,
- Minimize life-cycle ecological impact of energy and materials used,
- Use renewable energy and materials that are sustainably harvested,
- Protect and restore local air, water, soils, flora and fauna,
- Support pedestrians, bicycles, mass transit and other alternatives to fossil-fuelled vehicles.

Most green buildings are high-quality buildings; they last longer, cost less to operate and maintain, and provide greater occupant satisfaction than standard developments.

Sustainable Building

A **sustainable construction** on the other hand is defined as "*the creation and responsible management of a healthy built environment based on resource efficient and ecological principles*". Sustainable designed buildings aim to lessen their impact on our environment through energy and resource efficiency. It includes the following principles:

1. minimising non-renewable resource consumption
2. enhancing the natural environment
3. eliminating or minimising the use of toxins

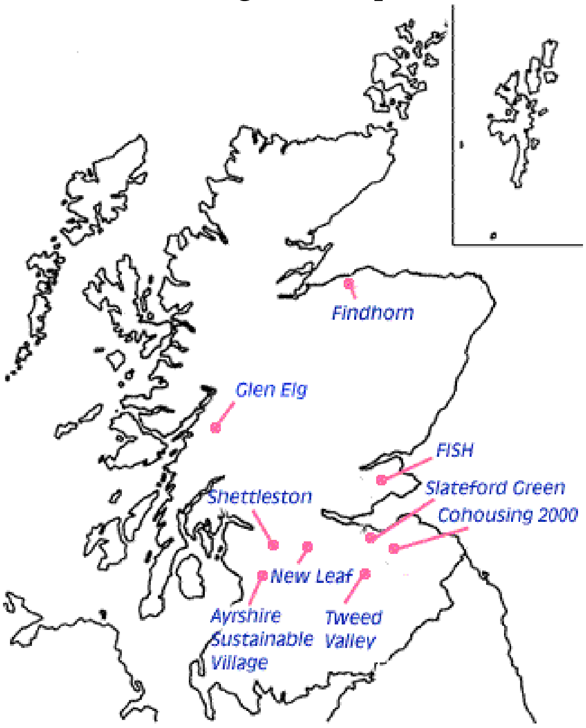
Sustainable buildings have minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their immediate surroundings and the broader regional and global setting. A sustainable building will strive for integral quality (including economic, social and environmental performance) in a very broad way. Thus, the rational use of natural resources and appropriate management of the building stock will contribute to saving scarce resources, reducing energy consumption (energy conservation), and improving environmental quality. Sustainable building concept involves considering the entire life cycle of buildings, taking environmental quality, functional quality and future values into account. The latter is dictated by a set of five objectives, which are reckoned as architectural guidelines for the villagers:

- Resource Efficiency,
- Energy Efficiency (including Greenhouse Gas Emissions Reduction),
- Pollution Prevention (including Indoor Air Quality and Noise Abatement),
- Harmonisation with Environment (including Environmental Assessment),
- Integrated and Systemic Approaches (including Environmental Management System),

2.1.3 The Vision of the Tweed Valley Eco-Village

The Tweed Valley EV is a concept of seven families living in Innerleithen and Traquair of the Peeblesshire County in Scotland. The project will involve 17 houses where these families and other will stay. Scotland is not inexperienced in the development of EV (See Figure 2.1).

Figure 2.1/Eco-Village developments in Scotland



In search of new homes they came up with the idea of an Eco-Village. The most appropriate site they could find was the Thornylee Forest (See Figure 2.2) provided by the Forest Enterprise. According to the overview of the project by their prospect villagers this site has the following advantages *Reference: LE-35*.

- "South Facing Slope. This maximises the potential for solar energy collection of all types including passive, photovoltaic, water heating and it is important for the walled organic garden planned for the paddock that will enable the villagers an autonomy on the food following the principles of permaculture".
- "Low Environmental Impact. Thornylee is a sheltered and unobtrusive site. The houses will be designed to integrate into the surrounding landscape with a very low visual impact using environmental responsible materials (See P.2.1.2.3)".
- "Rural Location. As a stated aim of the EV development its construction on the Thornylee site would be a positive enhancement on the countryside amenities, landscape and nature conservation through the creation of new possibilities for leisure, relaxation and tourism".
- "Regeneration of Degraded Land. Vast areas around Thornylee are dominated by plantation monoculture that supports few other species and prevents biodiversity. A change of land use at Thornylee

from uneconomical forestry to recreational, educational and residential use will promote local involvement and increase its biodiversity through the planting of native species".

- "Transport Corridor. The site is situated just off the main Peebles to Galashiels road (A72) and is served by the Edinburgh to Galashiels bus (No. 62)".
- "Space. It is important to have a site where space is not restricted. Thornylee Forest covers a large area (approximately 300*acres*) which will provide ample space for living, working, the positioning of energy systems and the provision of waste management through Wetland (Reed Bed System) construction".

Figure 2.2/Thornylee Forest and surroundings

As a genuine representative of the Eco-Village movement the Tweed Valley project will embody all the organisational and design principles as described in P.2.1.1.

When the author visited the Thornylee Forest for identifying the prospects of installing ReST at that site he was surprised by the tremendous potential that slope and hill composition could offer. The south face slope could offer indeed the maximisation of solar energy collection (See Figure 2.3) and at the top of the hill there is an amazing opportunity for wind energy collection (See Figure 2.4). There is also a natural trough that acts as an natural water capture reservoir where the other study (*"Wind and Hydro Power System for the Tweed Valley Ecovillage"* [Reference: LE-36]) would be based (See Figure 2.5). It is thus not surprising that this study will examine the integration of photovoltaic and wind turbines as the given ReST modules and will try to simulate for the D-SM method (See P.1.5)

Figure 2.3/ South Facing slope

Figure 2.4/ Top of the Thornylee Hill

Figure 2.5/ Natural Reservoir

2.2 Let There Be Power

As we saw in paragraph P.1.3.3 one of the culprits for the environmental integrity of the planet is the Energy Sector. The first of the two divisions, the Electrical Generation Division (end-use electrical energy), is the most dangerous with Energy Industry for Decentralised Fuel Demand (refined oil, gasoline and natural gas fuels for domestic, transportation and industrial use) following the track. Almost every hazardous element that can contribute to the pollution and perturbation of the environment (land, air, water) is found to have a direct or indirect connection with some means of energy production.

Over the years, since the first realisation of the problem, the Energy Sector was "revived" to a reasonable extend partly by introducing statutory guidelines on the degree and nature of pollution and efficiencies or by incorporating alternative (**renewable**) sources of energy generation to an ancillary degree, where possible. One approach to reducing emissions is to focus on increasing energy efficiency. Energy efficiency equates to money saved while securing the energy supply [Reference: LE-37]. The first statutory amendments were applied to establish and enforce air pollution standards and to set emission standards for new factories and extremely hazardous industrial pollutants [Reference: LE-38]. The energy industry was highly affected by that as it was required to meet "ambient air quality standards" by regulating the emissions of various pollutants from existing stationary sources, such as power plants and incinerators, in part by the installation of smokestack scrubbers, electrostatic precipitators, and other **filters**. Later amendments also expanded the scope and strength of the regulations for controlling industrial pollution. The result has been limiting progress in reducing the quantities of sulphur dioxide, carbon monoxide, nitrogen oxide, ozone, particulate matter, and lead in the air. Some of these act also regulated hazardous air pollutants such as mercury, beryllium, asbestos, vinyl chloride, benzene, radioactive substances, and inorganic arsenic (EPA 1992).

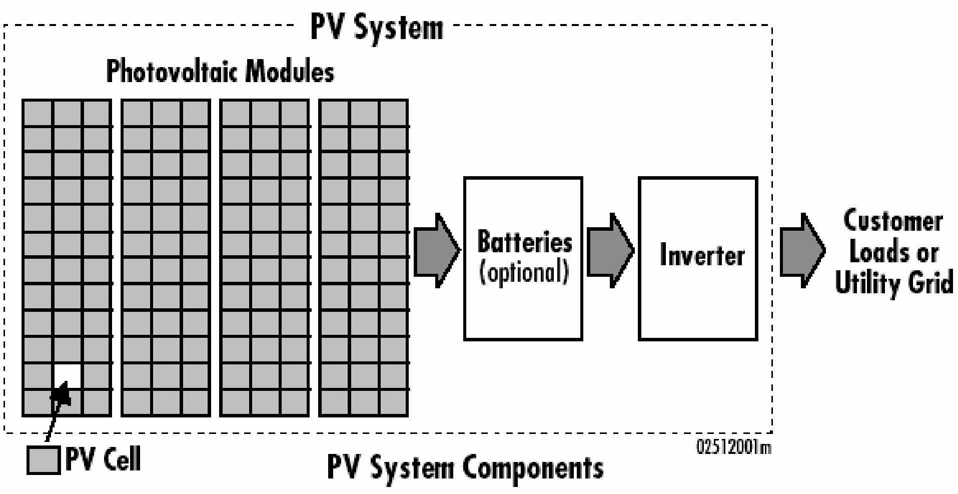
But what really is a longer and more solid and robust solution to the actual environmental problem is the use of technology capable of capturing the renewable energy diffusion on the planet in terms of solar, wind, elevation, fluid power, gravitational and bio-materials potential. Renewable energy technologies were developed, in part, to combat the results of fossil fuel depletion [Reference: LE-37] but it was soon realised that these clean and abundant tools of producing energy can have other benefits on areas of economy and social promotion for both industrialised and developing countries. As part of this project we are only interested to any solution that can and it is used by the Eco-Village grid for covering the demand of these organisations in energy consumption. It should be clear by now that the selection of the following systems is in accordance to the relative need for sustainable technology use within specific economic and regional availability requirements for the habitats of eco-villages as described before in P.2.1.

With a combination of this technologies to the other sustainable principles for housing planning the eco-villages are truly a purely form of static success of a natural energy assimilation system.

2.2.1 Photovoltaic Systems

Photovoltaic (PV) technologies, also commonly known as "solar cells", are solid-state semiconductors. PV systems consist of two major subsystems of hardware: PV modules and the Balance-of-System (BOS). PV modules house an array of solar cells that deliver Direct Current (DC) power, whereas BOS equipment include components needed for mounting, power storage, power conditioning and site-specific installation (See Figure 2.6). A BOS system usually includes battery charge controllers, batteries, inverters (for loads requiring alternating current), wires, conduit, a grounding circuit, fuses, safety disconnects, outlets, metal structures for supporting the modules, and any additional components that are part of the PV system.

Figure 2.6/ PV system components *Reference: LE-39*.



PV systems have several advantages: they are cost-effective alternatives in areas where extending a utility power line is very expensive, they have no moving parts and require little maintenance, and they produce electricity without polluting the environment. Thus in a quick view the selection of PV systems will depend on a variety of reasons such as:

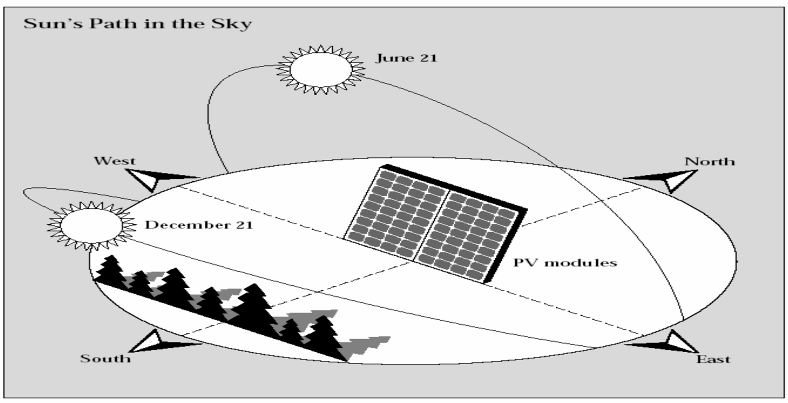
- Cost-when the cost is high for extending the utility power line or using another electricity generating system in a remote location, a PV system is often the most cost-effective source of electricity.
- Reliability-PV modules have no moving parts and require little maintenance compared to other electricity-generating systems.
- Modularity-PV systems can be expanded to meet increased power requirements by adding more modules to an existing system.

- Environment-PV systems generate electricity without polluting the environment and without creating noise.
- Ability to combine systems-PV systems can be combined with other types of electric generators (wind, hydro, and diesel, for example) to charge batteries and provide power on demand.

2.2.1.1 PV Technology

The basic element of photovoltaic technology is the solar cell (typically 10*10 cm^2). Solar cells are constructed by joining two dissimilar layers of semi-conducting materials, referred to as p-type (positive) and n-type (negative) semiconductors. “Doping” a semiconductor, usually crystalline silicon, with an impurity (typically boron) creates a deficit of negatively charged electrons, producing a “p-type” semiconductor. Similarly, n-type semiconductors are doped with small impurities, typically phosphorous, that result in a surplus of free electrons. A solar cell is constructed by joining these two semiconductors in a “p-n junction”, producing an electric field. The photovoltaic effect is enacted when sunlight, comprised of positively charged photons, is absorbed by the solar cell, transferring energy to the electrons that then become part of a current in an electrical circuit. In addition to the semiconductors, a solar cell consists of a transparent encapsulant (typically glass) to prevent weathering, an anti-reflective layer, and a contact surface to transfer the electric current to the load. Unlike utility power plants, which produce electricity constantly despite the time of day and year or the weather, the output of PV modules is directly related to these three factors. Because different geographic regions experience different weather patterns the location where the PV will be situated will greatly vary the number of PV modules for a given power output. Furthermore any seasonal variations can affect the amount of sunlight available to power a PV system and thus its power output (See Figure 2.7). The latter is also affected by fluctuations in the module temperature.

Figure 2.7/ The Sun’s path as a design factor for correct sizing, sitting and positioning the PV



PV Modules

A PV module is an array of packaged solar cells that convert solar energy directly into Direct-Current (DC) electricity. Individual PV module outputs range between 10 W_p (peak Watts) to 300 W_p (each cell, measuring approximately 10*10 cm^2, generating 1W_p), but scaling allows PV modules to be linked into panels and further, panels into arrays to meet the desired electrical load Reference: LE-39. Virtually all of the installed PV systems in the world are "flat-plate" systems that use large areas of semiconductors to convert direct and diffuse solar radiation. While some flat-plate systems are made to rotate to track the sun, most are fixed and have no moving parts. Alternatively, PV systems known as "concentrators", utilize optic lenses to focus direct sunlight onto comparatively smaller areas, thereby reducing the amount of necessary semi-conducting material. It is quite obvious that dimension-wise these systems are in need of docking areas their size being proportional to the power output of the PV modules. Figure 2.8 below is a good example of how these two factors affect each other.

Figure 2.8/ Roof Area (*sfeet*^{2}) as a function of PV capacity

PV module efficiency* (%)	PV capacity rating (watts)							
	100	250	500	1,000	2,000	4,000	10,000	100,000
4	**30**	**75**	**150**	**300**	**600**	**1,200**	**3,000**	**30,000**
8	**15**	**38**	**75**	**150**	**300**	**600**	**1,500**	**15,000**
12	**10**	**25**	**50**	**100**	**200**	**400**	**1,000**	**10,000**
16	**8**	**20**	**40**	**80**	**160**	**320**	**800**	**8,000**

Crystalline Silicon PV

Silicon is the most common semi-conducting material in use in PV modules due to its abundance. Single-crystal silicon, or mono-crystalline silicon, semiconductors are the most efficient in transferring electrons due to their uniform structure, but are also the most expensive. Excluding the market for indoor-consumer-equipment with low power requirements, for example a calculator, mono-crystalline silicon modules accounted for 48.4 MW_p, or 60% of the 82.4 MW_p global PV market in 1996 Reference: LE-40. A newer variation of the mono-crystalline cell are silicon "ribbon" cells which are formed by cutting ribbons from a thin mono-crystalline sheets. While silicon ribbon cells hold promise of future manufacturing cost reductions, they constituted just 3% or 3 MW_p of the global market in 1996 Reference: LE-40. Crystalline silicon PV cells have figured prominently in the commercial marketplace because of their durability and efficiency performance. Today, modules constructed of mono-crystalline silicon, yield efficiencies of 12% in the field. In laboratory environments, module of crystalline silicon cells achieved efficiencies of

22.7% in 1998, up from 7% in 1976. Factors such as dust and encapsulants reduce the light reaching the solar cells in the field and thus limit the efficiency. The next most prevalent type of semiconductor is cast "multi-crystal" or polycrystalline silicon, accounting for 24 *MW*, or roughly 30% of the PV modules shipped in 1996. Polycrystalline silicon is less expensive to manufacture than mono-crystalline silicon, however, it is less efficient in transmitting electrons due to the existence of grain boundaries. Polycrystalline silicon modules exhibit 9% efficiencies in the field.

Thin-film PV

An emerging alternative to crystalline silicon is thin-film PV. Thin-film, flat-plate systems use 1/20 to 1/100 of the material needed for crystalline silicon semiconductors by employing a film of semi-conducting material only 1 micron (10^{-6} *m*) thick. The most prominent type of thin-film photovoltaic in production, Amorphous Silicon (a-Si), accounted for 5.9 *MW* or 7% of the outdoor PV market in 1996 [Reference: LE-40] .Two other thin-film PV under development that demonstrate potential for large-scale PV module manufacture are Cadmium Telluride (CdTe) and Copper Indium Diselenide (CIS), though they held less than 1% of the PV market in 1996. Lower material volumes for thin-film PV, as compared with crystalline silicon, result in lower material costs. In principle, thin-film PV cells also exhibit a greater propensity for mass-manufacturing cost reductions as compared with crystalline silicon. However, commercially available thin-film PV have not attained field efficiencies greater than 6%, as compared with the 12% efficiency of crystalline silicon PV modules. Though laboratory tests have yielded promising thin-film efficiencies, manufacturers have not yet translated the high-efficiencies and high-yields of smaller, laboratory-constructed thin-films up to production volumes. The economic competitiveness of a PV module is measured in monetary currency per peak watt (that is $\$/W_p$ for the USA and $£/W_p$ for the UK) and is therefore impacted by both unit cost and efficiency. The challenge for thin-film PV manufacturers is to consistently produce cells at commercial-scale geometries and volumes with efficiencies akin to crystalline silicon cells, if they are to capture more of the photovoltaic market.

2.2.1.2 Balance of System (BOS)

Ancillary equipment, referred to as the balance-of-system (BOS), is necessary to install and deliver electricity from a PV module. BOS requirements vary between applications due to site-specific power and reliability requirements, environmental conditions, and power storage needs. BOS components include mounting equipment such as frames and ballasts to support and elevate the PV module/panel. A small portion of installed PV systems also use tracking systems to follow the sun, thereby increasing the exposure to incident sunlight. Power conditioning equipment limits current and voltage, maximizes power output, and converts Direct-Current (DC) electricity generated by the PV array into Alternating Current (AC) electricity through a DC/AC inverter. Power storage is a desirable- or in many instances a compulsory- power system requirement, and thus a battery and a "charge controller" device must be added to the BOS. PV systems necessitate protective electrical hardware such as diodes, fuses, circuit breakers, safety switches and grounds, as well as wiring to connect the PV module and BOS components [Reference: LE-39]. In applications where a PV system will be supplementing a "base load" or where power must always be available (i.e. nights or cloudy days), a PV system is usually integrated with an auxiliary electric generator. This hybrid system does not necessarily fall under the definition of BOS, but an additional electric generator will impact the overall sizing of the PV system, the battery and other BOS components.

2.2.1.3 PV Applications

Solar cells are ideal energy candidates in niche markets where:

- Electric-grid extensions are not economical
- Peak electrical demand is coincident with maximum solar intensity (e.g. cooling loads), or
- Where the attributes of PV technology as a clean and modular power source are valued at a premium.

The PV market can be grouped into grid-connected and "stand-alone" applications. Grid-connected applications- accounting for approximately 20-30% of worldwide PV installations- include central PV stations or distributed, small-scale PV systems sited near consumers. Stand-alone PV applications are the most prevalent, constituting 60-70% of PV installations. Some common examples of stand-alone PV system applications include roof-top residential/commercial systems, remote water pumping stations, telecommunications equipment, and individually powered appliances or lights. As for every technology there is always a balancing set of characters for the positive and negative side of PV Modules. For any application we must weigh between them to check their suitability for the specific reasons there are to be utilised. In general their advantages and disadvantages are respectively:

Advantages

- Production of high quality electrical power (better than utility power in most cases),
- On-site green power production – absolutely no emissions,
- Longevity, 20-30 year lifetime for most components, some will last longer,

- Reliability, long periods between regular maintenance, 6-12 months,
- Provision of an uninterrupted power supply or UPS (when batteries are included) during utility power outages,
- Silent & low maintenance, replaces noisy & unreliable generators,
- Solid State, no moving parts, nothing to break,
- Available anywhere in the world where there is light (even if no direct sun!),
- Transportable, lightweight, good for mobile applications,
- Modular - expandable & easily up-gradable.

Disadvantages

- High initial cost
- Higher overall cost depending on situation

2.2.2 Wind Turbines

Wind turbines transform kinetic energy in the wind to electricity. The power that can be generated from a modern wind turbine is practically related to the square of the wind speed, although theoretically it is related to the cube of the wind speed. This means that a site with twice the wind speed of another will generate four times as much energy. Consequently, the availability of good wind speed data is critical to the feasibility of any wind project. Data is usually gathered over a period of time using anemometers installed at the prospective site. Normally, one year is the minimum time a site is monitored [Reference: LE-40]. Most commercial wind turbines operating today are at sites with average wind speeds greater than 6 *m/s* or 22 *km/h*. A prime wind site will have an annual average wind speed in excess of 7.5 *m/s* (or 27 *km/h*).

Key Points:

- Wind is an intermittent but predictable resource.
- Good wind speed data is critical to determining the economic feasibility of a wind project.
- Prime sites have average wind speeds greater than 7.5 metres/sec (27 km/hr).
- Most common wind turbines in commercial operation average 600 kW in power capacity.
- Capacity factors range from 20 to percent; availability is greater than 95 percent.
- Wind is a modular technology that can be erected quickly.
- Wind turbines can be integrated into existing grid and off-grid applications.
- Possible environmental issues include, visual, cultural, land use, and bird impacts, and noise.

- Planning approval and environmental assessment are usually necessary.

2.2.2.1 WT Technology

Almost all wind turbines are "horizontal axis" machines with rotors using two or three airfoil blades. The rotor blades are fixed to a hub attached to a main shaft, which turns a generator – normally with transmission through a gearbox. The shaft, generator, gearbox, bearings, mechanical brakes and the associated equipment are located inside the nacelle on top of the tower. The nacelle also supports and transfers structural loads to the tower, and together they house all automatic controls and electric power equipment. The wind turbine automatically turns the nacelle to the direction facing the wind for optimal energy production. The turbines are stopped at very high wind speeds to protect them from damage.

Wind turbines range in capacity (or size) from a few Kilowatts to several Megawatts. The crucial parameter is the rotor diameter – the longer the blades the larger the area swept by the rotor, and thus the volume of air hitting the rotor plane. At the same time, the higher towers of large wind turbines bring rotors higher above the ground where the energy density in the wind is higher. Larger wind turbines have proven to be more cost efficient, due to improvements in designs and economics of scale, but also with a higher energy production per swept m^2, due to the higher towers. For commercial utility-sized projects, the most common turbines sold are in the range of 600 kW to 1 MW – large enough to supply electricity to 600-1,000 modern homes. Rotors may operate at constant or variable speeds, depending on the design. MW-size machines are all variable speed concepts. Typical rotor speeds at rated power range from 15 to 50 revolutions per minute – a factor that influences the visual impact. The larger the rotor the lower the rotational speed, in order to keep the blade tip speed in the optimal range from 60 to 80 m/s. A typical 600 KW turbine has a blade diameter of 35 metres and is mounted on a 50 metre concrete or steel tower. Power output is regulated automatically as wind speed changes, to limit loads and to optimise power production. The present state-of-the-art large wind turbines have:

- Power control by active stall or pitch control (in both cases pitching blades) combined with some degree of variable speed rotor and
- A two-speed asynchronous generator or a gearless transmission to a multi-pole synchronous generator and power electronics.

Virtually all wind turbines installed at present are based on one of the three main wind turbine types (See Figure 2.9):

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common, but more recent developments include wind-photovoltaic units, a hybrid option which offers power generation from 100% renewable sources.

Table 2.1/ Range of Power Outputs for WT installations

Nominal Power	Typical Application
<1kW	Micro's
1-10kW	Wind Home
10-200kW	Hybrid Isolated Systems
200-1MW	Grid Connected- single or in cluster
>1MW	Offshore (or onshore wind farms)

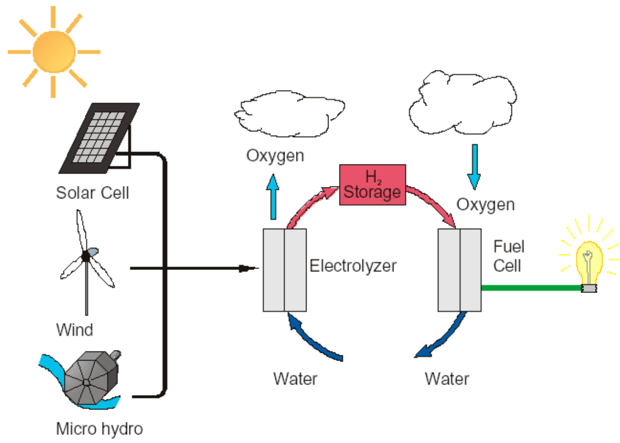
Utility-sized commercial wind projects are usually constructed as wind farms where several turbines are erected at the same site. Wind projects have been successfully built to power a wide range of applications in diverse and often extreme environments. One of the newest applications is to place wind farms in shallow offshore areas where environmental impacts are often lower and the availability of a steady, non-turbulent wind flow allows turbines to operate more efficiently and generate more power. In off-grid applications, wind generators can be combined with other energy sources, such as diesel generators. The feasibility of a wind project, however, can be influenced by access to the electrical grid. The need to install or upgrade high voltage transmission equipment can significantly add to the cost of a wind project. For off-grid and mini-grid applications, the combination of wind/diesel or other sources can provide a greater percentage of overall capacity.

Wind turbines are also a modular technology, which means they can be installed as the capacity is needed. A small wind farm can usually be constructed within year. Wind farms can be constructed as either "builddown-operate" facilities under long-term power purchase contracts or as turnkey facilities.

2.2.3 Hydrogen Fuel Technologies

Hydrogen is a fascinating carrier of energy. Its conversion to heat or power is simple and clean and when combusted with oxygen it forms water which means that no pollutants are generated or emitted. The water is returned to nature where it originally came from. But hydrogen, the most common chemical element on the planet, does not exist in nature in its pure form. It has to be generated or produced by separating it from chemical compounds. The two most common methods to produce hydrogen is from water by electrolysis (green production) or from hydrocarbon fuels (or any other hydrogen carriers) by reforming or thermal cracking (pollution-intensive production). Other production methods include thermo-chemical water decomposition, photo conversion and production from biomass. Clean energies such as electricity from solar, wind and hydro can be applied to produce clean hydrogen i.e. without greenhouse gases or nuclear waste being generated in the production process (See Figure 2.14). At current times hydrogen may actually be the only meaningful link between renewable energy and chemical energy carriers [Reference: LE-45].

Figure 2.14/Renewable technologies are the most sustainable and clean method to produce hydrogen

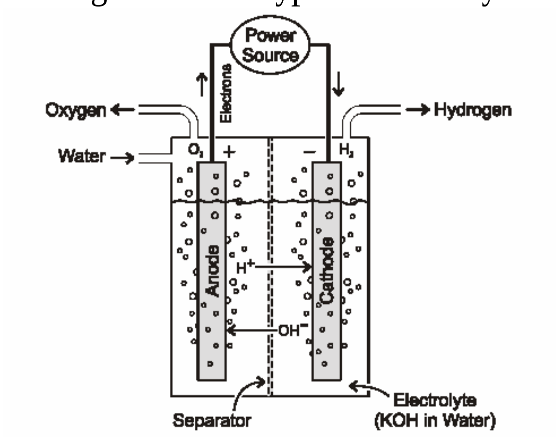


2.2.3.1 Hydrogen Manufacturing, Electrolyser

The process of extracting hydrogen from water is called electrolysis. In principal, electrolysis can be entirely non-polluting and renewable, but it requires the input of large amounts of electrical energy. Consequently, the total environmental impact of acquiring hydrogen through electrolysis is largely dependent on the impacts of the source power.

In electrolysis, electricity is used to decompose water into its elemental components: hydrogen and oxygen (Figure 2.15). Electrolysis is often touted as the preferred method of hydrogen production as it is the only process that need not rely on fossil fuels. It also has high product purity, and is feasible on small and large scales. Electrolysis can operate over a wide range of electrical energy capacities, for example, taking advantages of more abundant electricity at night. At the heart of electrolysis is an electrolyser. An electrolyser is a series of cells each with a positive and negative electrode. The electrodes are immersed in water that has been made electrically conductive, achieved by adding hydrogen or hydroxyl ions, usually in the form of alkaline potassium hydroxide (KOH). The anode (positive electrode) is typically made of nickel and copper and is coated with oxides of metals such as manganese, tungsten and ruthenium. The anode metals allow quick pairing of atomic oxygen into oxygen pairs at the electrode surface. The cathode (negative electrode) is typically made of nickel, coated with small quantities of platinum as a catalyst. The catalyst allows quick pairing of atomic hydrogen into pairs at the electrode surface and thereby increases the rate of hydrogen production. Without the catalyst, atomic hydrogen would build up on the electrode and block current flow. A gas separator, or diaphragm, is used to prevent intermixing of the hydrogen and oxygen although it allows free pas-sage of ions. It is usually made of an asbestos-based material, and tends to break apart above 80 ºC.

Figure 2.15/ Typical Electrolysis Cell



The rate of hydrogen generation is related to the current density (the amount of current divided by the electrode area measured in amps per area). In general, the higher the cur-rent density, the higher the source voltage required, and the higher the power cost per unit of hydrogen. However, higher voltages decrease the overall size of the electrolyser and therefore result in a lower capital cost. State-of-the-art electrolysers are reliable, have energy efficiencies of 65 to 80% and operate at current densities of about 2000 A/m^2. For electrolysis, the amount of electrical energy required can be somewhat offset by adding heat energy to the reaction. The minimum amount of voltage required to decompose water is 1.23 *V* at 25 ºC. At this voltage, the reaction requires heat energy from the outside to proceed. At 1.47 *V* (and same temperature) no input heat is required. At greater voltages (and same temperature) heat is released into the surroundings during water decomposition. Operating the electrolyser at lower voltages with added heat is advantageous, as heat energy is usually cheaper than electricity, and can be re-circulated within the process. Furthermore, the efficiency of the electrolysis increases with increased operating temperature.

When viewed together with fuel cells, hydrogen produced through electrolysis can be seen as a way of storing electrical energy as a gas until it is needed. Hydrogen produced by electrolysis is therefore the energy carrier, not the energy source. The energy source derives from an external power generating plant. In this sense, the process of electrolysis is not very different from charging a battery, which also stores electrical energy. Viewed as an electricity storage medium, hydrogen is competitive with batteries in terms of weight and cost. To be truly clean, the electrical power stored during electrolysis must derive from non-polluting, renewable sources. If the power is derived from natural gas or coal, the pollution has not been eliminated, only pushed upstream. In addition, every energy transformation has an associate energy loss. Consequently, fossil fuels may be used with greater efficiency by means other than by driving the electrolysis of hydrogen. Furthermore, the cost of burning fossil fuels to generate electricity for electrolysis is three to five times that of reforming the hydrogen directly from the fossil fuel. Non-polluting renewable energy sources include hydroelectric, solar photovoltaic, solar thermal and wind.

2.2.3.2 Hydrogen Utilisation, Fuel Cells

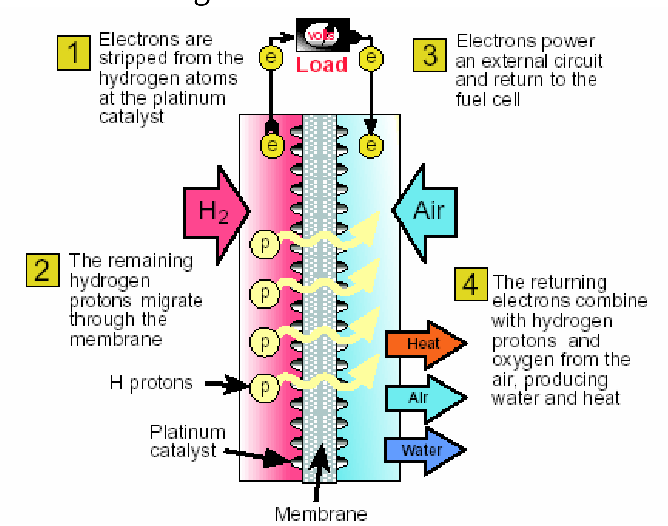
A fuel cell is a device for directly converting the chemical energy of a fuel into electrical energy in a constant temperature process. In many ways the fuel cell is analogous to a battery, but a battery which is constantly being recharged with fresh reactants. As well as offering a high theoretical efficiency, especially at low temperatures, fuel cells emit low or zero levels of pollutants, the have a quiet operation and few moving parts (only pumps and fans to circulate coolant and reactant gases, respectively). They can run on a wide range of fuels, ranging from gaseous fuels such as hydrogen and natural gas to liquid fuels such as methanol and gasoline. Fuel cells could potentially be used to replace conventional power equipment in many cases. The main applications are likely to be in stationary power generation, transportation, and battery replacement.

2.2.3.2.1 Generic FC Technology

The principle behind fuel cells was discovered as early as 1839 by Welsh physicist and Judge Sir William Grove. However, due to high costs, the technology was not significantly used until the American Gemini space missions of the 1960's. For this and subsequent space missions, fuel cells were thought to be safer than nuclear electric generation and cheaper than solar. They have been thrust to the forefront of energy technology in the 1990's, however, as high power densities have made them feasible for both stationary and portable applications.

The basic physical structure or building block of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side. A schematic representation of a fuel cell with the reactant/product gases and the ion conduction flow directions through the cell is shown in Figure 2.16.

Figure 2.16/ How a FC works



In a typical fuel cell, gaseous fuels are fed continuously to the anode (negative electrode) compartment and an oxidant (i.e., oxygen from air) is fed continuously to the cathode (positive electrode) compartment; the electrochemical reactions take place at the electrodes to produce an electric current. A fuel cell, although having components and characteristics similar to those of a typical battery, differs in several respects. The battery is an energy storage device. The maximum energy available is determined by the amount of chemical reactant stored within the battery itself. The battery will cease to produce electrical energy when the chemical reactants are consumed (i.e., discharged). In a secondary battery, the reactants are regenerated by recharging, which involves putting energy into the battery from an external source. The fuel cell, on the other hand, is an energy conversion device that theoretically has the capability of producing electrical energy for as long as the fuel and oxidant are supplied to the electrodes. In reality, degradation, primarily corrosion, or malfunction of components limits the practical operating life of fuel cells.

Gaseous hydrogen has become the fuel of choice for most applications, because of its high reactivity when suitable catalysts are used, its ability to be produced from hydrocarbons for terrestrial applications, and its high energy density when stored cryogenically for closed environment applications, such as in space. Similarly, the most common oxidant is gaseous oxygen, which is readily and economically available from air for terrestrial applications, and again easily stored in a closed environment. A three-phase interface is established among the reactants, electrolyte, and catalyst in the region of the porous electrode. The nature of this interface plays a critical role in the electrochemical performance of a fuel cell, particularly in those fuel cells with liquid electrolytes. In such fuel cells, the reactant gases diffuse through a thin electrolyte film that wets portions of the porous electrode and react electrochemically on their respective electrode surface. If the porous electrode contains an excessive amount of electrolyte, the electrode may "flood" and restrict the transport of gaseous species in the electrolyte phase to the reaction sites. The consequence is a reduction in the electrochemical performance of the porous electrode. Thus, a delicate balance must be maintained among the electrode, electrolyte, and gaseous phases in the porous electrode structure. Much of the recent effort in the development of fuel cell technology has been devoted to reducing the thickness of cell components while refining and improving the electrode structure and the electrolyte phase, with the aim of obtaining a higher and more stable electrochemical performance while lowering cost.

The electrolyte not only transports dissolved reactants to the electrode, but also conducts ionic charge between the electrodes and thereby completes the cell electric circuit, as illustrated in Figure ?? (above). It also provides a physical barrier to prevent the fuel and oxidant gas streams from directly mixing. The functions of porous electrodes in fuel cells are:

1. To provide a surface site where gas/liquid ionization or de-ionization reactions can take place
2. To conduct ions away from or into the three phase interface once they are formed (so an electrode must be made of materials that have good electrical conductance), and
3. To provide a physical barrier that separates the bulk gas phase and the electrolyte.

A corollary of the 1st function is that, in order to increase the rates of reactions, the electrode material should be catalytic as well as conductive, porous rather than solid. The catalytic function of electrodes is more important in lower temperature fuel cells and less so in high temperature fuel cells because ionization reaction rates increase with temperature. It is also a corollary that the porous electrodes must be permeable to both electrolyte and gases, but not such that the media can be easily "flooded" by the electrolyte or "dried" by the gases in a one-sided manner.

A variety of fuel cells are in different stages of development. They can be classified by use of diverse categories, depending on the combination of type of fuel and oxidant, whether the fuel is processed outside (external reforming) or inside (internal reforming) the fuel cell, the type of electrolyte, the temperature of operation, whether the reactants are fed to the cell by internal or external manifolds, etc. The most common classification of fuel cells is by the type of electrolyte used in the cells and includes:

- Polymer Electrolyte Fuel Cell (PEFC) or Proton Exchange Membrane Fuel Cell (PEMFC),
- Alkaline Fuel Cell (AFC),
- Phosphoric Acid Fuel Cell (PAFC),
- Molten Carbonate Fuel Cell (MCFC),

- Intermediate Temperature Solid Oxide Fuel Cell (ITSOFC), and
- Tubular Solid Oxide Fuel Cell (TSOFC).

These fuel cells are listed in the order of approximate operating temperature, ranging from ~80*C* for PEFC, ~100*C* for AFC, ~200*C* for PAFC, ~650*C* for MCFC, ~800*C* for ITSOFC, and 1000*C* for TSOFC. The operating temperature and useful life of a fuel cell dictate the physicochemical and thermo-mechanical properties of materials used in the cell components (i.e., electrodes, electrolyte, interconnect, current collector, etc.). Aqueous electrolytes are limited to temperatures of about 200*C* or lower because of their high water vapour pressure and/or rapid degradation at higher temperatures. The operating temperature also plays an important role in dictating the type of fuel that can be used in a fuel cell. The low-temperature fuel cells with aqueous electrolytes are, in most practical applications, restricted to hydrogen as a fuel. In high-temperature fuel cells, CO and even CH_4 can be used because of the inherently rapid electrode kinetics and the lesser need for high catalytic activity at high temperature. However, descriptions later in this section note that the higher temperature cells can favour the conversion of CO and CH_4 to hydrogen then use the equivalent hydrogen as the actual fuel.

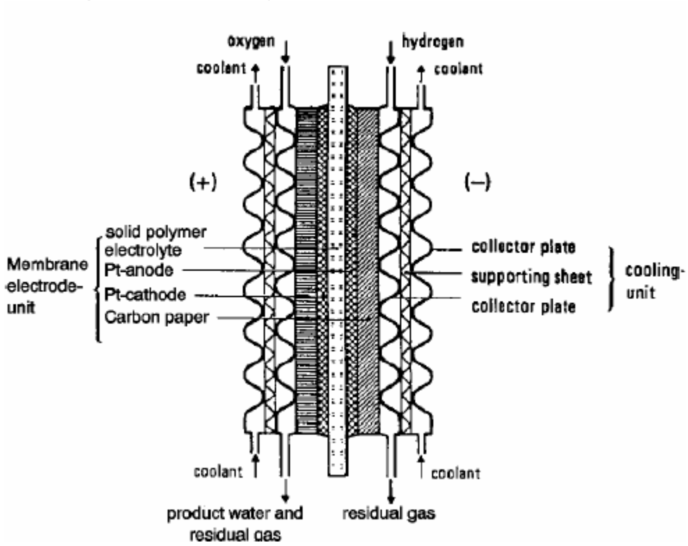
Table 2.2/ Summary of Major Differences of the Fuel Cell Types

	PEFC	AFC	PAFC	MCFC	ITSOFC	TSOFC
Electrolyte	Ion Exchange Membranes	Mobilized or Immobilized Potassium Hydroxide	Immobilized Liquid Phosphoric Acid	Immobilized Liquid Molten Carbonate	Ceramic	Ceramic
Operating Temperature	80°C	65°C - 220°C	205°C	650°	600-800°C	800-1000°C
Charge Carrier	H^+	OH^-	H^+	$CO3^{=}$	$O^{=}$	$O^{=}$
External Reformer for CH_4 (below)	Yes	Yes	Yes	No	No	No
Prime Cell Components	Carbon-based	Carbon-based	Graphite-based	Stainless-based	Ceramic	Ceramic
Catalyst	Platinum	Platinum	Platinum	Nickel	Perovskites	Perovskites
Product Water Management	Evaporative	Evaporative	Evaporative	Gaseous Product	Gaseous Product	Gaseous Product
Product Heat Management	Process Gas + Independent Cooling Medium	Process Gas + Electrolyte Calculation	Process Gas + Independent Cooling Medium	Internal Reforming + Process Gas	Internal Reforming + Process Gas	Internal Reforming + Process Gas

PEMFC- A Brief Analysis

The type of fuel cell currently receiving the most attention is the PEM fuel cell; PEM stands variously for "proton exchange membrane" or "polymer electrolyte membrane". The membrane is usually a perfluorosulfonic acid polymer. This is a polytetrafluoroethylene (PTFE, trade name Teflon) chain with side chains terminating in an SO_3H group. It is the hydrogen on this sulfonate group that dissociates from the polymer when wet and appears as protons in the solution; polymer acids have the advantage that the anion (–SO_3 - tail) is fixed in the electrolyte rather than dissolved. In the stack, the fuel cells are arranged so that ions (protons) pass through the membrane, while electrons are conducted through the separating graphite plates in the opposite direction (Figure 2.17)

Figure 2.17/ Typical PEMFC schematic.



The PEMFC cell operates at a low 80*C*. This will result in a capability to bring the cell to its operating temperature quickly, but the rejected heat cannot be used for cogeneration or additional power. Test results have shown that the cell can operate at very high current densities compared to the other cells. However, heat and water management issues may limit the operating power density of a practical system. The PEMFC tolerance for CO is in the low *ppm* level. In general PEMFC deliver high power density, which offers low weight, cost, and volume. The immobilized electrolyte membrane simplifies sealing in the production process, reduces corrosion, and provides for longer cell and stack life. PEMFC operate at low temperature, allowing for faster start-ups and immediate response to changes in the demand for power. The PEFC system is seen as the system of choice for vehicular power applications, but is also being developed for smaller scale stationary power.

2.2.3.2.2 Fuel Cell Stacking

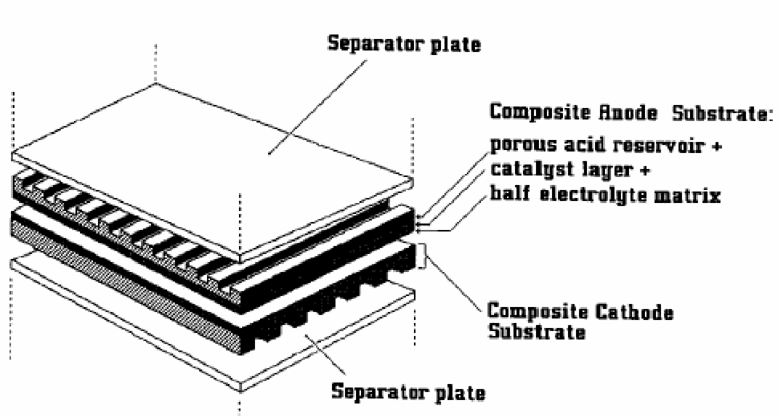
Additional components of a cell are best described by using a typical cell schematic, (See Figure 2.18). This figure depicts a PAFC. As with batteries, individual fuel cells must be combined to produce appreciable voltage levels and so are joined by interconnects. Because of the configuration of a flat plate cell, the interconnect becomes a separator plate with two functions:

1. To provide an electrical series connection between adjacent cells, specifically for flat plate cells, and
2. To provide a gas barrier that separates the fuel and oxidant of adjacent cells.

The interconnect of a tubular solid oxide fuel cell is a special case, and the reader is referred to Section 8 for its slightly altered function. All interconnects must be an electrical conductor and impermeable to gases.
Other important parts of the cell are:

- The structure for distributing the reactant gases across the electrode surface and which serves as mechanical support, shown as ribs in Figure 2.18,
- Electrolyte reservoirs for liquid electrolyte cells to replenish electrolyte lost over life, and
- Current collectors (not shown) that provide a path for the current between the electrodes and the separator of flat plate cells.

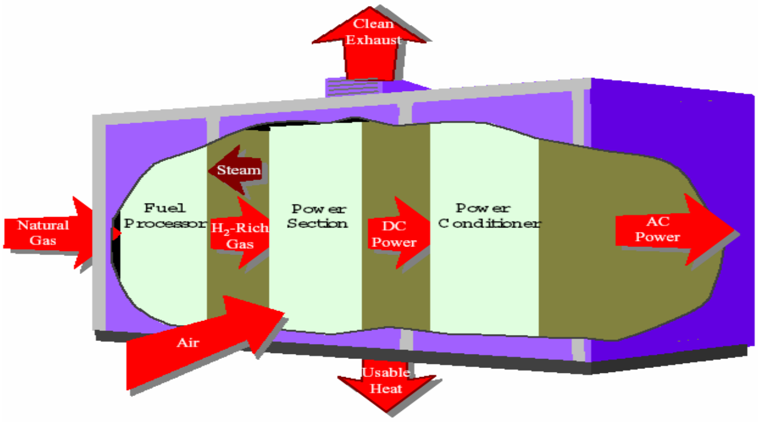
Figure 2.18/ Expanded View of a Basic Fuel Cell Repeated Unit in a Fuel Cell Stack [Reference: LE-46].



2.2.3.2.3 Fuel Cell Plant Description

As shown in Figure 2.16, the fuel cell combines hydrogen produced from the fuel and oxygen from the air to produce DC power, water, and heat. In cases where CO and CH_4 are reacted in the cell to produce hydrogen, CO_2 is also a product. These reactions must be carried out at a suitable temperature and pressure for fuel cell operation. A system must be built around the fuel cells to supply air and clean fuel, convert the power to a more usable form such as grid quality ac power, and remove the depleted reactants and heat that are produced by the reactions in the cells. Figure 2.19 below shows a simple rendition of a fuel cell power plant. Beginning with fuel processing, a conventional fuel (natural gas, other gaseous hydrocarbons, methanol, naphtha, or coal) is cleaned, then converted into a gas containing hydrogen. Energy conversion occurs when dc electricity is generated by means of individual fuel cells combined in stacks or bundles. A varying number of cells or stacks can be matched to a particular power application. Finally, power conditioning converts the electric power from dc into regulated dc or ac for consumer use. Section 9.1 describes the processes of a fuel cell power plant system.

Figure 2.19/ Fuel Cell Power Plant Major Processes



2.2.3.2.4 Applications

One of the characteristics of fuel cell systems is that their efficiency is nearly unaffected by size. This means that small, relatively high efficient power plants can be developed, thus avoiding the higher cost exposure associated with large plant development. As a result, initial stationary plant development has been focused on several hundred *kW* to low *MW* capacity plants. Smaller plants (several hundred *kW* to 1 to 2 *MW*) can be sited at the user's facility and are suited for cogeneration operation, that is, the plants produce electricity and thermal energy. Larger, dispersed plants (1 to 10 *MW*) are likely to be used for distributed generation. The plants are fuelled primarily with natural gas. Once these plants are commercialized and price improvements materialize, fuel cells will be considered for large base-load plants because of their high efficiency. The base-load plants could be fuelled by natural gas or coal. The fuel product from a coal gasifier, once cleaned, is compatible for use with fuel cells. Systems integration studies show that high temperature fuel cells closely match coal gasifier operation.
Some positive characteristics that fuel cells and fuel cell plants offer are:

- Direct energy conversion (no combustion),
- No moving parts in the energy converter,
- Quiet operation,
- Demonstrated high availability of lower temperature units,
- Sitting ability,
- Fuel flexibility,
- Demonstrated endurance/reliability of lower temperature units,
- Good performance at off-design load operation,
- Modular installations to match load and increase reliability,

- Remote / unattended operation,
- Size flexibility,
- Rapid load following capability.

General negative features of fuel cells include:

- Market entry cost high; N^{th} cost goals not demonstrated,
- Unfamiliar technology to the power industry,
- No infrastructure.

2.2.3.3. Hydrogen Storage, High Pressure Storage Tanks

If the greatest challenge in hydrogen use is to extract it, the second greatest challenge is how to store it. Hydrogen has the lowest gas density and the second-lowest boiling point of all known substances, making it a challenge to store as either a gas or a liquid. As a gas, it requires very large storage volumes and pressures. As a liquid, it requires a cryogenic storage system. Hydrogen's low density, both as a gas and a liquid, also results in very low energy density. Stated otherwise, a given volume of hydrogen contains less energy than the same volume of other fuels. This also increases the relative storage tank size, as more hydrogen is required to meet a given vehicle's range requirements.

The amount of hydrogen needed for fuel cells is offset somewhat by the fact that it is used more efficiently than when burned in an internal combustion engine, so less fuel is required to achieve the same result. Despite its low volumetric energy density, hydrogen has the highest energy-to-weight ratio of any fuel. Unfortunately, this weight advantage is usually overshadowed by the high weight of the hydrogen storage tanks and associated equipment. Thus, most hydrogen storage systems are considerably bulkier and / or heavier than those used for gasoline or diesel fuels. For all practical purposes, hydrogen can be stored as either a high-pressure gas, a liquid in cryogenic containers, or a gas chemically bound to certain metals (hydrides).

High-Pressure Gas Storage

One of the most practical of the methods of storing hydrogen is to simply compress it as a gas. This increases its density. The major concerns are the large volume required to store the gas even when compressed, and the ability of the container to resist impact. Storage conditions are set at 3600*psi* or 248*bar* (standard for natural gas cylinders) at ambient temperature (300 *K*). The amount of work required to compress the hydrogen gas into the cylinder means that there is an energy penalty of approximately 5-10%. The temperature increases when the hydrogen cylinder is filled with compressed hydrogen, and the pressure is higher than the nominal operating pressure until the cylinder has a chance to cool; care must be taken not to over-pressurize the cylinder. The decrease in temperature during usage due to expansion of hydrogen is not as great a concern, because the release rate is much slower. Current hydrogen gas storage containers are made from steel alloys that are resistant to hydrogen embrittlement; more advanced cylinders made from aluminium and wrapped with carbon fibre laminate for stiffness are lighter and currently used to contain both natural gas and hydrogen. Less well developed are fully-composite cylinders made solely from carbon fibre impregnated with resin or some other binder; these can have hydrogen gravimetric densities of as much as 9.5% due to their light weight. However, they are more fragile and currently expensive. Cylinder manufacturers strive to attain the highest storage pressures possible in order to reduce the required storage volume. High-pressure cylinders typically store hydrogen at up to 3600*psi* (250*bar*) although new designs have been certified for 5000 psig (350*bar*) operation.

Liquid Storage

Liquid hydrogen storage systems overcome many of the weight and size problems associated with Liquid hydrogen can be stored just below its normal boiling point of –424 ºF (–253 ºC; 20 K) at or close to ambient pressure in a double-walled, super-insulating tank (or "dewar"). Hydrogen cannot be stored in liquid form indefinitely. All tanks, no matter how good the insulation, allow some heat to transfer from the ambient surroundings. The heat leakage rate depends on the design and size of tank- in this case, bigger is better. This heat causes some of the hydrogen to vaporize and the tank pressure to increase. Stationary liquid hydrogen storage tanks are often spherical since this shape offers the smallest surface area for a given volume, and therefore presents the smallest heat transfer area. Tanks have a maximum overpressure capacity of about 72 *psi* (5 *bar*); if the hydrogen is not consumed as quickly as it vaporizes, the pressure builds to a point where it vents through a pressure relief valve. Liquid hydrogen is considerably denser than gaseous hydrogen but is still much more bulky than gasoline on an equivalent energy basis. Liquid hydrogen storage systems can be four to ten times larger and heavier than an equivalent gasoline tank. Hydrogen liquefaction is a very energy intensive process due to the extremely low temperatures involved. Liquefaction involves several steps, including:

1. Compression of hydrogen gas using reciprocating compressors; pre-cooling of the compressed gas to liquid nitrogen temperatures –319 ºF (–195 ºC; 78 K),
2. Expansion through turbines,
3. Catalytic conversion to its stable "parahydrogen" form.

Metal Hydrides

Metal hydride storage systems are based on the principle that some metals readily absorb gaseous hydrogen under conditions of high pressure and moderate temperature to form metal hydrides. These metal hydrides release the hydrogen gas when heated at low pressure and relatively high temperature. In essence, the metals soak up and release hydrogen like a sponge.

The advantages of metal hydride storage systems revolve around the fact that the hydrogen becomes part of the chemical structure of the metal itself and therefore does not require high pressures or cryogenic temperatures for operation. Since hydrogen is released from the hydride for use at low pressure (and must be released before it can burn rap-idly), hydrides are the most intrinsically safe of all methods of storing hydrogen. There are many types of specific metal hydrides, but they are primarily based on metal alloys of magnesium, nickel, iron and titanium. In general, metal hydrides can be divided into those with a low or high hydrogen desorption (release) temperature. The high temperature hydrides may be less expensive and hold more hydrogen than the low temperature hydrides, but require significant amounts of heat in order to release the hydrogen. Low temperature hydrides can get sufficient heat from an engine, but high temperature hydrides require an external source of heat. The low desorption temperatures associated with some hydrides can be a problem since the gas releases too readily at ambient conditions. To overcome this, low temperature hydrides need to be pressurized, increasing the complexity of the process.

The main disadvantage of metal hydride storage systems is not so much the temperatures and pressures needed to release the hydrogen, but rather their low mass energy density. Even the best metal hydrides contain only 8% hydrogen by weight and therefore tend to be very heavy and expensive. Metal hydride storage systems can be up to 30 times heavier and ten times larger than a gasoline tank with the same energy content. Another disadvantage of metal hydride storage systems is that they must be charged with only very pure hydrogen or they become contaminated with a corresponding loss of capacity. Oxygen and water are prime culprits as they chemically adsorb onto the metal surface displacing potential hydrogen bonds. The storage capacity lost through contamination can to some extent be reactivated with heat.

End of Chapter 2

Chapter 3-Methodology

The backbone of this study is unambiguously the theoretical and practical analysis. To perform the D-SM technique with MERIT it is necessary to define an appropriate climatic model and then appropriate ReST to sustain the D-SM simulation for the Eco-Village. There are a lot of numerical calculations involved with the selection of a sound FC plant as well as technical digestion about it that had to be examined simultaneously to allow the best potential choice; the same applies for the investigation about ReST.

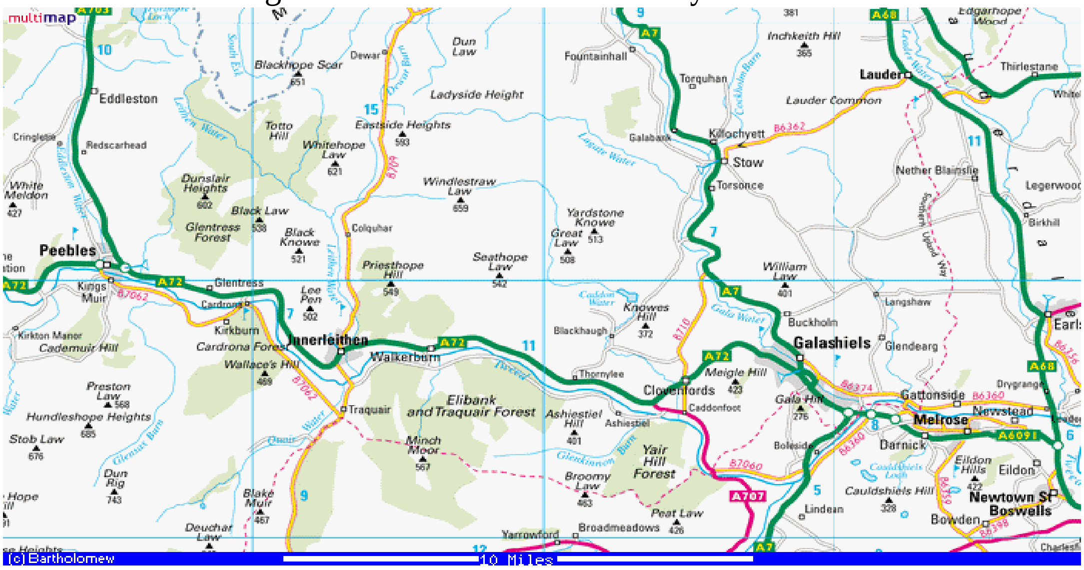
3.1 Selection of Climatic Profile

The first essential step into performing a computer simulation, with the aid of MERIT©, is to satisfy the boundary conditions of the simulation. In this case the software required three sets of boundary conditions namely the *"Specify Analysis conditions"*, the *"Specify Demand"* and the *"Specify Supply"* components. It is impossible to move on to the simulation without determining these three conditional clusters. It is also impossible, as an act of guidance and denotation to the user, to determine either the demand or the supply conditions without having firstly defined the analysis conditions. This electronic mechanism is assigned to process the introduction of a set of weather data, from a geographic area of interest, in a predefined form of files that the rest of the program can identify. These files are called *".clm"* files and some are built in to the available version of the software to provide a sufficient help and reference to the beginner for simulations of elementary basis. For the more experienced and stern user there is another component, into the program's framework, that allows the electronic conversion of a given (again in a pre-specified type) file to the one mentioned above to establish a more customised simulation. This file is usually a *".csv"* file that can be created from a Microsoft Excel© interface to the required configuration. The following methodology is referring to gathering and manipulation of raw weather data into the formation of the required *".clm"* file for MERIT.

3.1.1 Data Acquisition

Geographically the eco-village is located at the Thornylee Forest, which belongs to the Peeblesshire County of south Scotland as we saw in P.2.1.3 and it is close to the town Innerleithen (See Figure 3.1). Any weather station, chosen for an appropriate set of weather variables, should therefore be around Thornylee Forest so that realistic values of a weather profile could be retrieved. It must be clear at this point that since the beginning of the project it was decided that a **radius-to-centre** approach must be followed, with the centre always being the Thornylee Forest (**C**), so that the Aim II of the project, about a pragmatic collection of weather information, was satisfied to offer a considerable realisation of the weather effect on the study.

Figure 3.1 / Area around Thornylee Forest

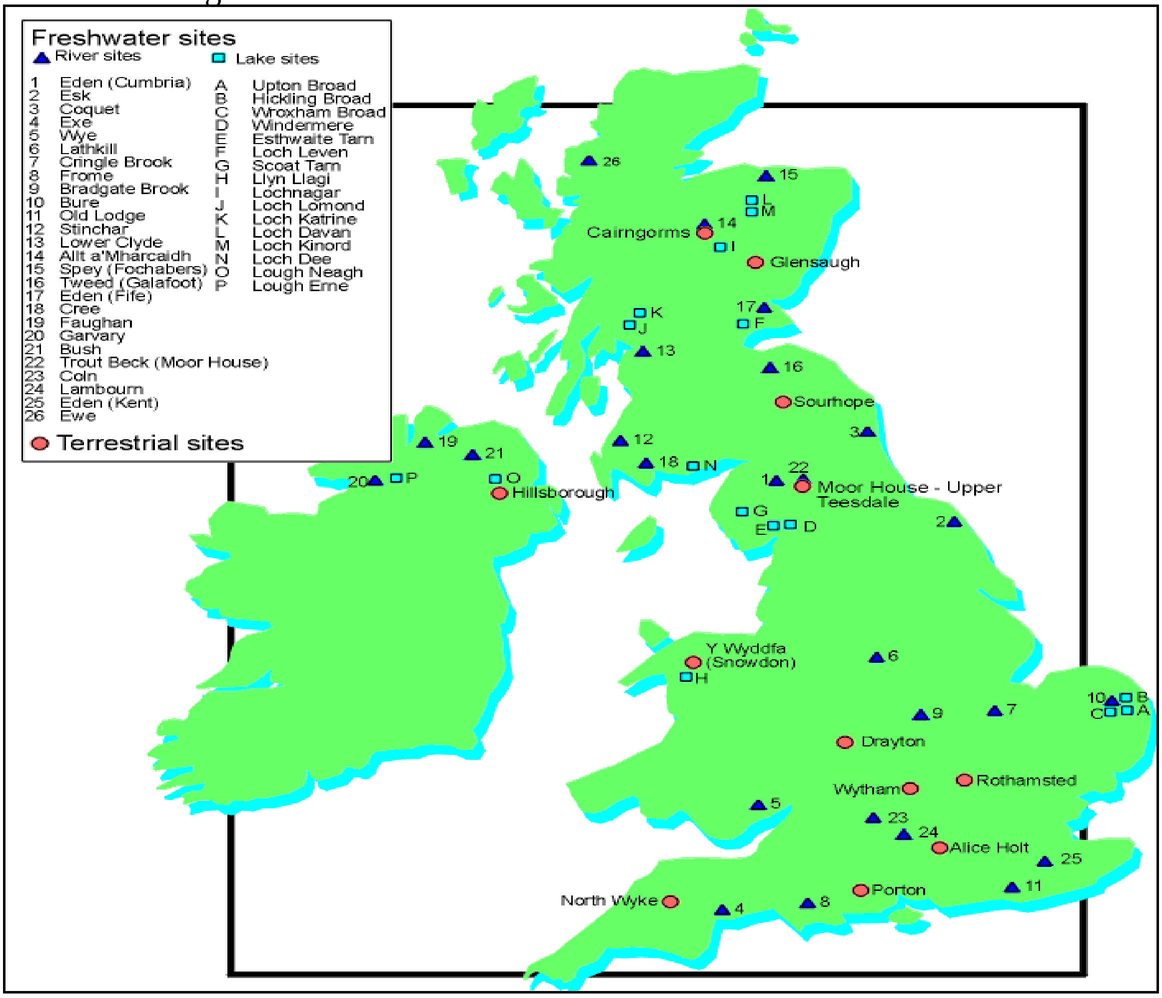


At the beginning of the project there were three possible weather databases that were examined for there potential use. These were:

- *"The UK Environmental Change Network* or *ECN"* Reference: IS-7,
- *"The British Atmospheric Data Centre* or *BADC"* Reference: IS-8 and
- *"EnergyPlus Weather Data - International Locations"* Reference: IS-9 by the Office of Building Technology, State and Community Programs in USA.

From these three possible database candidates only one could prove sufficient enough to be accepted as the project's Principal Weather Database (PWD). To start with ECN the first site that was of immediate interest was the River site at river Tweed (Galafoot- Number 16 in Figure 3.2) since it is very close to the Thornylee Forest, approximately 14*km* (**R1**) according to the **radius-to-centre** requirement that we mentioned above. Contact was made with this service and upon receiving an e-mail from them it was specified that site could only provide freshwater indicators as this site truly was a Freshwater site. The closest suggested terrestrial site for the meteorological indicators that we were looking for was Sourhope (Figure 3.2), approximately 50*km* (**R2**) from (**C**).

Figure 3.2/ Observation Stations for ECN Database



Chronologically, at this point BADC had approved the access to the their databases supported by the Met Office [Reference: IS-10] of UK and all the necessary data that we required could be equally and adequately found from this organisation and so the weather data search by ECN was terminated. The last candidate was also rejected as the sites of meteorological observations were too far away from our target area (**C**). In the USA there is a governmental department about energy issues. This department has a body about renewable energy applications and utilizations, namely the Office of Energy Efficiency and Renewable Energy, which has a division about building efficiency optimization, namely The Office of Building Technology, State and Community Programs. The latter has supported the development of a variety of building energy software tools one if which is the *EnergyPlus*©. This software has a weather database of national and international character and it is this database that we examined for adaptation. Amongst the UK databases that the software uses there were three that represented Scotland i.e. Aberdeen, Leuchars, and Oban with radii **R3**=97*km*, **R4**=46*km* and **R5**=200*km* respectively, all of which are forbiddingly too large for our condition. Thus the nature of this database was also inadaptable and was turned down. This left us with the BADC database which we will present here.

BADC allowed access to the Land Surface Observation restricted database after the completion of a form on behalf of the author, the data coming from the Met Office. In effect these data are daily measurements form a long-term record of historical weather conditions. There are also hourly measurements, which were more attractive to this project, allowing the analysis of current weather systems with hourly resolution. The daily data are available from UK stations in 110 UK counties over the period 1853 to July 2000. The hourly data are available from stations in 110 UK counties from 1983 to July 2000.

3.1.2 Interpretation

The BADC database is categorised by two main sections: the *"Data Availability"* and the *"File Format"*. Both of these sections had to be examined for their relative coupling with this project's objectives. For the "*Data Availability*" we required a continuous and as far as possible a complete concatenation of data with a focus on the years between 1990-nowdays, since the study refers to a modern design. For the *"File Format"* of the data we had to choose amongst those with the most germane character to those parameters that would fortify the simulation.

Availability is differentiated according to a 24*h* or a 1*h*-basis data measurements, that being the first step in identifying their potential exploitation. So within the internet site of BADC we can find the *"UK daily observations (1853-July 2000), in 110 UK counties"* and the *"UK Synoptic (hourly) Stations (1983-July 2000), in 110 UK counties"* sectioned databases for the British Isles (there is also a third one but it was of no important value to us). MERIT can *recognise* a certain type of weather files in which the weather profiles are described by six fields on a 1*h*-basis (see P.3.1.4) on 24*h*/daily cycles. This requirement clearly guided us to choose the *"UK Synoptic (hourly) Stations (1983-July 2000)"* database. The File Formats in this database are shown in the table below Table 3.1. These formats have many other sorting parameters that the user needs to know in order to effectively select the correct data for his/her study. That information is provided in Tables 3.2 and 3.3. In these tables the *.hsun* file type is not included for description since the study could sufficiently be integrated by the other three data formats. The Sorting Number column refers to a personal identification of the Message Type Domain for each one of the three parameters that will be useful in later stages of the analysis.

Table 3.1 / File Formats of the BADC database

Data Sorting Name	File Format (Type)	Description
UK Hourly Weather Observations data	*.hwx*	Weather observations file format
UK Hourly Solar Radiation data	*.radt*	Radiation file format
UK Hourly Sun data	*.hsun*	Hourly sunshine observations file format
UK Wind data	*.wind*	Wind data file format

Table 3.2 / Sorting Parameters

File Format (Type)	Sorting Number	Message Type Domain (in BADC)	Description (by BADC)	ID Type	Comments
.hwx	***{1}***	SYNOP	Elements from full FM 12-VII SYNOP message - WMO Standard Synoptic report - Hourly	WMO	Hourly synoptic observation received in SYNOP report
.hwx	***{2}***	AWSHRLY	?	DCNN	Hourly synoptic observations received from Climate Data Loggers (CDLs)
.hwx	***{3}***	METAR	?	ICAO	Half-hourly synoptic observation received in METAR report from station in aviation network
.hwx	***{4}***	DLY3208	Elements from Metform 3208 - Monthly Return of Daily Obs.	DCNN	Daily synoptic report at 0900 or other hour from an Ordinary Climatological Station
.radt	***{5}***	DRADR35	MetO1 Form R35 elements - Daily Totals of Radiation/Sunshine	DCNN	Daily radiation from Form R35
.radt	***{6}***	MODLERAD	Hourly radiation values from MODLE (Met Office Data Logging Equipment)	DCNN	Hourly radiation from MODLE
.radt	***{7}***	ESAWRADT	Hourly radiation values from ESAWS (Enhanced Synoptic AWS)	DCNN	Hourly radiation from automatic stations

.radt	***{8}***	AWSHRLY	?	DCNN	Hourly radiation from CDLs
.wind	***{9}***	HWND6910	Elements from Metform 6910 - Analysis of Anemograms	WIND	Mean hourly wind and gust from analysis of anemograph record reported on Form 6910
.wind	***{10}***	HWNDAUTO	Elements from automatic wind recording devices	WIND	Mean hourly wind and gust from Digital Anemograph Logging Equipment (DALE)
.wind	***{13}***	ESAWWIND	Mean hourly wind observations from ESAWS (Enhanced Synoptic AWS)	WIND	Mean hourly wind and gust from automatic station
.wind	***{12}***	DLY3208	Elements from Metform 3208 - Monthly Return of Daily Obs	DCNN	24 hour run of wind from an Ordinary Climatological Station
.wind	***{11}***	AWSHRLY	?	WIND	Hourly mean wind from CDLs

Table 3.3/ Explanation of ID Type

ID Type	**Description (by BADC)**
WMO	Synoptic stations selected as suitable for possible international exchange are give a 5-figure WMO number which is used as the identifier for all SYNOP and SREW reports. It is also used as identifier for climate reports, NCM and HCM, exchanged within the UK in real time. The first 2 figures of the WMO number are 03 which is the block number for the UK and Ireland. Numbering runs from north to south across Britain followed by Ireland.
DCNN	All stations that are part of the climate network have a 4-figure DCNN (district county number). In general, if a station moves more than 800m in a region of homogeneous terrain it is allocated a new DCNN, while a lesser distance will justify a new DCNN only if it is considered that the exposure at the new site is sufficiently different to affect the measured climatology.

ICAO	Stations that are part of the aviation network have a 4-character international ICAO number. The first two characters are EG which represent Europe-UK.
WIND	Like rainfall number the wind number identifies the characteristics of the observing site. Each anemometer mast has a 6-figure wind number of the format DCNNnn, where nn=01, 02… is the anemometer site number. A new site number is allocated to the observations if the mast is repositioned but not if the height of the anemometer on the mast is changed. A station may therefore be associated with several wind numbers

Each one of the file formats is recording a number of parameters. Some of these are not important at all whereas others are the essential data that we were boking for. Table 3.4 shows these parameters for each one of the three formats with the corresponding headers as there are presented at the BADC databases.

Table 3.4/ File Formats explanation

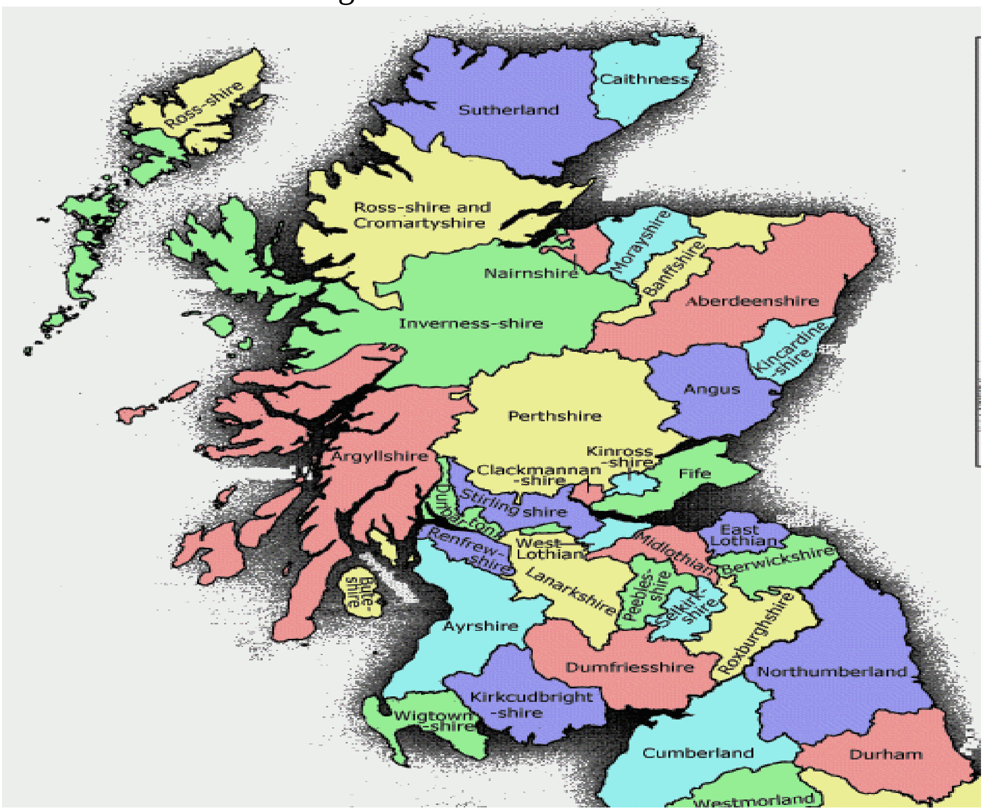
File Format	Header	Parameter	Units	Comments (by BADC)
.hwx	HOUR	Hour	-	Hour of observation from 0 to 2300
	DIR	10 minutes wind direction	Degree true	From 0 to 360 degrees, clockwise.
	SPEED	10 minutes wind speed	Knots	Horizontal wind is a 2-dimensional vector and is usually reported as an averaged direction from which the wind is blowing and a speed. The maximum observed speed over a specified time interval and the time of occurrence may also be reported. The unit of speed used at UK stations is the knot (0.515 ms-1) and the unit of direction the degree.
	TEMP	Dry-bulb air temperature	0.1 Degrees Celcius	Temperature was recorded in degrees Fahrenheit before 1961 and in degrees Celsius after that date. The precision of the measurement in the meteorological report has varied over the years: • 0.1C for all temperatures that are reported today
	DEW	Dew-point temperature	0.1 Degrees Celcius	The dew point temperature (in degrees Celsius) is the temperature to which the air must be cooled to produce saturation with respect to water at its existing atmospheric pressure and humidity.
	WETB	Wet-bulb temperature	0.1 Degrees Celcius	The web-bulb temperature is the lowest temperature (in degrees Celsius) that can

				be obtained by evaporating water into the air. It measures the humidity of the air. See Met Office documentation
.radt	END_HOUR	Hour	-	Hour of observation from 0 to 2300
	GLOBAL	Global Solar irradiation amount	W.hour/sq.m	'Global' radiation is that received from both the sun and the surrounding environment
	DIFFUSE	Diffuse Solar irradiation amount	W.hour/sq.m	'Diffuse' radiation is that obtained when a shade ring is used to block out the sun's direct radiation.
	DIRECT	Direct Solar irradiation amount	W.hour/sq.m	Global radiation is the amount of Direct and Diffuse radiation which reaches the Earth's surface at a given location.
.wind	END_HOUR	Hour	-	Hour of observation from 0 to 2300
	MDIR	Mean Wind Direction	degree true	The wind direction from which the wind blows is measured in Degrees (true). The entry for an east wind is 090 that for a south wind 180 and so on clockwise.
	MSPEED	Mean Wind Speed	Knots	Horizontal wind is a 2-dimensional vector and is usually reported as an averaged direction from which the wind is blowing and a speed. The maximum observed speed over a specified time interval and the time of occurrence may also be reported. The unit of speed used at UK stations is the knot (0.515 ms-1) and the unit of direction the degree.

3.1.3 Validation

The three data formats that we presented before are the essential part of the search in need for climatic information. Soon it was realised that the best way to check the weather stations for these data sets was geographically. BADC has divided the UK into counties every one of which has a number of weather stations Figure 3.3. Thornylee Forest is in Peeblesshire County so the hunt started from examining the stations in this county for the variables of interest. A record of the stations reviewed was kept and can be seen in Table 1 in Appendix A. From 27 stations investigated only 1 was of relative interest - Glentress. The file format of the weather data for this station was of *.hwx* type, an apparently convenient file until further examination described later in this chapter (see P.3.1.4) cast it insufficient for a potential simulation file. This was not obviously the case for a sound file construction leaving the author to expand the search [**Delimitation Plan-A**] from the area of interest (Peeblesshire County) to the neighbouring counties namely Selkirkshire, Dumfriesshire, Lanarkshire and Midlothian (in Borders and in Lothian Region) and Berwickshire, following a clockwise route from Selkirkshire to Berwickshire (See Figure 3.3). Any other counties apart from the surrounding counties would associate a too large an area for a pragmatic simulation of wind and radiation configurations. Thus at the vicinity of Peeblesshire we searched 28, 71, 109, 1, 94 and 43 stations respectively for the counties mentioned above, thought this time only a specific record was kept for the vast number of the stations reviewed which corresponds to those stations with *.hwx*, *.radt*, *.wind* weather attributes. The latter can be seen in Table 2 in Appendix A.

Figure 3.3/ UK Counties



Of course even with 29 stations the choice of selecting the proper ones for our case needed to be cut down to the very important so that a sincere evaluation could follow to leave us with a sound set of weather data. So we had to think of a number of criteria to refine those numbers. These were:

1. No station should be left out of the volition if it contains a *.radt* file. The thought was that since out of 29 stations only 3 had the required radiation files they should be chosen for the next phase.
2. Any station with three weather fields (*.hwx*, *.radt* and *.wind*) should be included in the next phase. Since wind and radiation are both required for the simulation a station with both of these data is valid source of the climatic configuration of the area and so it should be selected appropriately.
3. All stations with wind data should be selected unless their relative distance from the (**C**) point is too big (more than **R***=48.3Km) or it contains a radiation file.

These criteria once applied to the 29 stations revealed the possible station selection for getting the appropriate weather data. The summary of the remained stations can be seen in Table 3.5 below.

Table 3.5 / Selected Stations for **Delimitation Plan-A**

Station	**County**	**Sorting Number (s)**			**Association Number**
		.hwx	*.radt*	*.wind*	
GLENTRESS	PEEBLESHIRE	***{4}***	x	x	***W1***
BOWHILL	SELKIRKSHIRE	***{4}***	x	***{11}***	***W3***
GALASHIELS	SELKIRKSHIRE	***{4}***	x	x	***W2***
ESKDALEMUIR	DUMFRIESSHIRE	***{1}***	***{5},{6}***	***{9},{10}***	***Rad1***
CARNWATH	LANARKSHIRE	***{4}***	x	***{11}***	***W4***
ABINGTON	LANARKSHIRE	***{4}***	x	***{11}***	***W5***
DRUMALBIN SAWS	LANARKSHIRE	***{1}***	***{5},{6},{7}***	***{9},{13}***	***Rad2***
CAMPS RESERVOIR	LANARKSHIRE	***{4}***	x	x	***W6***
BUSH HOUSE	MIDLOTHIAN IN LOTHIAN	***{4}***	x	x	***W7***
PENICUIK	MIDLOTHIAN IN LOTHIAN	***{4}***	x	x	***W8***
CHARTERHALL SAWS	BERWICKSHIRE	x	***{5},{7}***	x	***Rad3***

At Table 3.5 we can observe the occurrence of two or three Sorting Numbers (SN) for a parameter, which is just a characteristic of that specific database containing a variety of weather data of similar type. The last stage in this section is a validity check for the weather parameter file types that will allow us to qualify the number of weather data into working values for the evaluation stage. The validity check will be used insofar as a simple basis of recognising the particular points of each parameter on an arbitrary measurement scale. From the BADC site we were able to access any *"Message Type Domains"* for any of the three *"File Formats"* to discover that there were disparities in the absolute measurement of the parameters addressing time intervals; something that we mentioned before in Table 3.2. So under the requirement of *"a 1h-basis measurement steps on 24h/daily repeating cycles"* climatic measurements a favouring should be submitted to these *Domains* that obey that prerequisite. Table 3.6 shows the validity check for the 13 *Domains* of the databases grouped under sections of *"File Formats"*.

Table 3.6/ Validity check for the 13 Domains

Domain	**Format**	**Sorting Number**	**Ordinance**	**Ranking (points)**
SYNOP	*.hwx*	***{1}***	***{1} > {4}.*** For *{2}, {3}* there is no accessible configuration to validate	2>1
AWSHRLY		***{2}***		
METAR		***{3}***		
DLY3208		***{4}***		
DRADR35	*.radt*	***{5}***	***{6}, {7} > {5}.*** For *{8}* there is no accessible configuration to validate.	2>1
MODLERAD		***{6}***		
ESAWRADT		***{7}***		
AWSHRLY		***{8}***		
HWND6910	*.wind*	***{9}***	***{10} , {13} > {9} >{10}*** For *{12}* there is no accessible configuration to validate.	3>2>1
HWNDAUTO		***{10}***		
ESAWWIND		***{11}***		
DLY3208		***{12}***		
AWSHRLY		***{13}***		

With this information in hand we could then proceed to the next stage of the weather station selection with an extended evaluation of these stations under the specific criteria for a rectified profile (see P.3.1.5).

3.1.4 Evaluation

The 11 stations that were validated for the objectives of the project in the last section (Table 3.5) had to be evaluated in a two-gear process that will allow the selection of correct values of wind and radiation parameters. The first gear mechanism is to leave out those with low scores and the second to identify which ones of the high score group would be the most effective for utilisation (profile for simulation).

The first gear mechanism was conceived to ensure that any station, chosen for the next level, would have the necessary parametrical format and quality of information with the one that MERIT operates so that we could put together an effective profile for a sound simulation. The stations were evaluated for:

1. Qualitative Parametrical Potential or QPA (where parameters are hourly measurements for wind, radiation and temperature attributes) based on the Ordinance values as taken from Table 3.6.
2. Availability of Data; in years.
3. Distance from the area of interest (Thornylee Forest); a personal scaling relative to the position of the station on the map.

The evaluation is presented in Table 3.7 below.

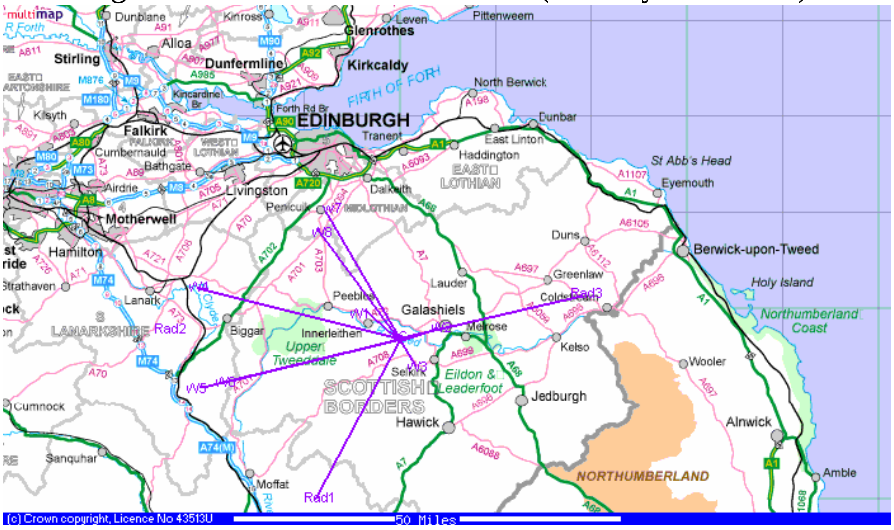
Table 3.7 - Comments:

- The Sorting Number for the File Formats can be found in Table 3.5.
- The scoring is in simple arithmetic points –no units are involved.
- Total score is a simple arithmetic addition.
- The Distance scoring is conversely proportional to the distance of the station from (**C**) i.e. the closest the station to (**C**) the highest the points it will score. Distances can be seen in Figure 3.4.
- Association Numbers are descriptive of the potential application of the stations for the nature of information that they can provide i.e. **W** for wind and **R** for solar radiation variables.

Table 3.7/ Stations Evaluation

Station Name	**QPA**			**Availability**			**Distance**	**Total Score**	**Association Number**
	.hwx	*.radt*	*.wind*	*.hwx*	*.radt*	*.wind*			
GLENTRESS	1	0	0	83/ 97	-	-	5	6	***W1***
BOWHILL	1	0	1	83/ 99	-	89	4	6	***W3***
GALASHIELS	1	0	0	83/ 99	-	-	4	5	***W2***
ESKDALEMUIR	2	2	3	83/ 00	71/ 00	84/ 94	1	**8**	***R1***
CARNWATH	1	0	1	83/ 99	-	83/ 86	2	4	***W4***
ABINGTON	1	0	1	83/ 94	-	83/ 94	2	4	***W5***
DRUMALBIN SAWS	2	2	3	91/ 00	91/ 00	97/ 00	1	**8**	***R2***
CAMPS RESERVOIR	1	0	0	83/ 99	-	-	2	3	***W6***
BUSH HOUSE	1	0	0	83/ 99	-	-	2	3	***W7***
PENICUIK	1	0	0	83/ 99	94/ 00	-	3	4	***W8***
CHARTERHALL SAWS	0	2	0	-	-	-	1	3	***R3***

Figure 3.4/ 11 Stations from C (Thornylee Forest)



For reasons explained in P.4.1.1 as part of a stretched Evaluation phase we performed an extended search in the surrounding counties (**Delimitation Plan-B**) on look for a valid station that could provide a *.radt* file for I_d and I_n values. This plan included the following counties of interest: Roxburghshire, Cumberland, Kirkcudbrightshire, Ayrshire, Renfrewshire, Dumbarton, Stirlingshire, Clackmannanshire, Kinross Shire, West Lothian, East Lothian, Fife, Northumberland, , and Durham. Unfortunately none of these counties had a station with *.radt* files and so stretched Evaluation phase was terminated, never concluded, to adopt the solution given in P.4.1.1.

As part of the second gear mechanism the two highest score stations were to be assessed for their relative potential to provide the necessary wind data. To do such an assessment we had to devise a Consecutive Elimination Assessment and Comparison Plan (CEACP) which was completed within 4 steps. Description of Steps 1-3 analysis can be found in Table 3.8 and that for Step 4 in Tables 3 and 4 in Appendix A. In Step 1 the relative distance of ***R1*** and ***R2*** from Thornylee forest was to be considered (See Figure 3.4). In Step 2, according to the conditions of assumption **A3** (See P.4.1.1.2), we had to compare the elevation of the areas of the stations with that of the Thornylee forest. In Step 3 (elimination step), for the same reason as in previous step, we had to compare the divergence of the annual values for average wind speed velocity of the areas of the stations with that of the Thornylee Forest. Finally in Step 4, again according to the conditions of assumption **A3**, the CEACP was concluded by comparison of two seasonal weather profiles for two random years concerning Eskdalemuir and Bowhill stations. For the most possible experimental success the weather profiles were a robust hybrid of seasonal observations (4 representative months for each season divided in 7 monthly segments - in 5 consecutive day steps- at 9:00am measurements) and 5 critical weather parameters (wind direction, wind speed, total cloud amount, visibility and temperature). We wish the databases could give us more recordings for more parameters but that was not true – incomplete files.

Table 3.8 - Comments:

- The annual mean wind speed is retrieved by the relative map of the BWEA *Reference: IS-11* shown in Figure 3.6.
- Obviously Bowhill (See Figure 3.4) is nowhere close to Thornylee Forest but it is the only station within a reasonable distance R_B =8.85Km from that area and more importantly it is the only station with a respectable type of wind observations, Domain :***{ 11}***, for an R<10Km. The latter is also the only station within the R<10Km condition that has a complete data range for the years of examination. All of these stations belong to a homogeneous geographical region (as assumption **A3** states), see Figure 3.5.

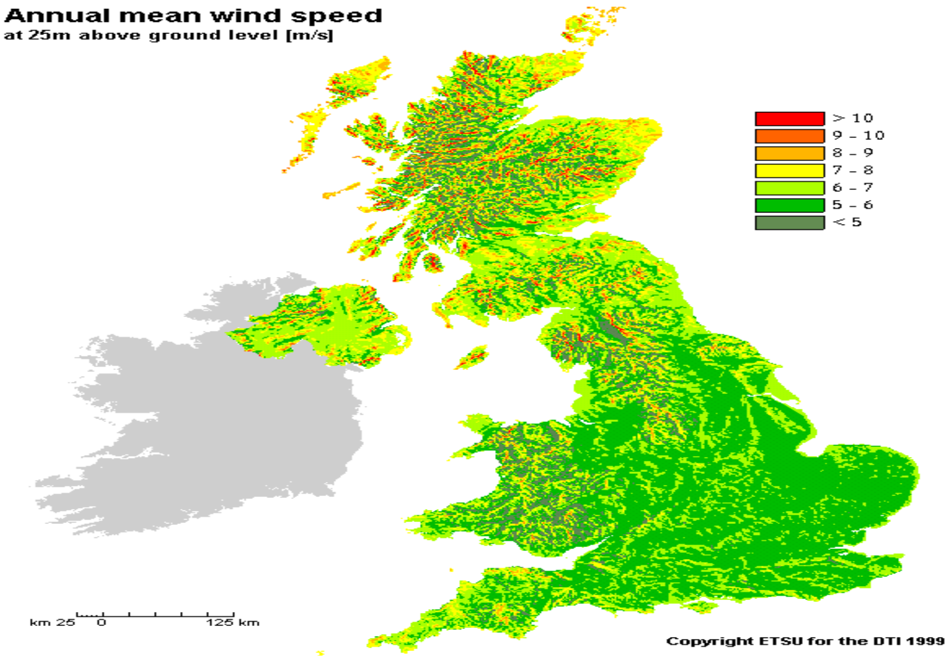
Table 3.8/ 3 steps of CEACP

	Step 1	**Step 2**	**Step 3**
	Elevation (from sea level)	**Distance**	**Annual Mean Wind Speed**
ESKDALEMUIR	242m	$R_E = 45.5Km$	7-8 m/s
DRUMALBIN SAWS	245m	$R_{DS} = 45.2Km$	5-6 m/s
Thornylee Forest	144m	0	10 m/s

As we can see from P.4.1.1.2 after completing CEACP the choice of using Eskdalemuir for wind data was justified sufficiently from the findings and so the last phase of the Climate Selection was to be completed with the creation of the proper climatic file for MERIT to sustain the simulation.

Figure 3.5/ Geographical Similarities of the areas of the two stations (Eskdalemuir and Drumalbin Saws)

Figure 3.6/ annual mean wind speed for UK Reference: IS-11.



3.1.5 Formation

A retrospection of the previous phases of Climate Selection is leaving us with the following points:

1. Out of 11 qualifying stations, chosen for their meteorological observations of weather behaviour at several places around Thornylee Forest, only one (Eskdalemuir) was found possible to support the climate creation for MERIT with partial provision of the necessary parameters.
2. None of these stations could provide the ReST of the crucial parameters with information from BADC databases, and so a discursive file was used from another source that bounded to assumptions A1 and A2 and was used conditionally to succeed this goal.
3. The Eskdalemuir station has two *Domains* of weather files, in the BADC database, the *.synop Domain* or ***{1}*** and the *.hwdnauto Domain* or ***{10}*** which will provide hourly measurements of dry bulb air temperature, dew point temperature and wet bulb temperature for ***{1}*** and mean wind speed and mean wind direction for ***{10}*** respectively. These *Domains* extend from 1983-2000 for ***{1}*** and 1984-1999 for ***{10}*.**
4. The diffuse solar intensity (I_d) on the horizontal and direct normal solar intensity (I_n) values were provided by the discursive file for the year 1978 at the same area as that of Eskdalemuir station.

5. The *.clm* file that MERIT requires for the simulation it must be constructed by a *.csv* Excel file which with help of file conversion software (component of MERIT) will change into the right form.

These are the key issues so far. To build the *.csv* Excel file we need to know some things about MERIT and the way it uses external weather information into a structured *.clm* file. This file requires 6 **fields**, arranged in columns on a 1h-step daily cycles. These fields are:

a) Diffuse solar intensity on the horizontal (W/m2)
b) External dry bulb temperature (Tenths of Degrees C)
c) Direct normal solar intensity (W/m2)
d) Prevailing wind speed (Tenths m/s)
e) Wind direction (Clockwise degrees from north)
f) Relative humidity (%)

The purpose of this paragraph is to explain the process followed to turn the Eskdalemuir station values into the formats explained above and then produce the *.csv* file for MERIT conversion. The first thing we had to examine was to find out which one of the *.hwdnauto* and *.synop* yearly **combinations** of Eskdalemuir's *Domains* was appropriate for later stages of climatic creation according to a yearly validity check for a time scale of ten years. Since the project requires a realistic simulation a ten years span was chosen as representing the last decade of the past century i.e. 1990-1999. The validity check was accurate for *.synop* files but with *.hwdnauto* there where many data inconsistencies that could prove fatal in the *.csv* file construction. The check was attributed to the fact that since one complete year with measurements about a weather parameter on a 1h-step daily cycles (e.g. one daily cycle from 00:00*h* to 00:00*h* would have 24 hits for a 1*h*-step measurements) would give 8760 hits (24*365). The two years marked out for their completeness in data hits for both of the two *Domains* are presented in Table 3.9 below. It is obvious that a clear selection can be made for which year should we use, according to the maximum number of hits of *.hwdnauto* files; 1997 was that year.

When it was clear of which year was available with the more complete file data we had to bring them into the right form, the one that MERIT requires. Initially an Excel file (*Eskdalemuir97DM.xls*) was used to make all the necessary modifications to the texture and the numeric aspects of the **raw data**, from the *.hwdnauto* and *.synop Domain* files of the 1997 year, and then the conversion of the Excel file was attempted into a *.csv* and then into a *.clm* file. By changes in texture we mean the process of altering the **raw data** into the right configuration that MERIT requires, that is including magnitude and units.

Table 3.9/ Completeness in data for the two *Domains*

Domain	BADC hits	Theoretical hits for 1 year
1997		
.hwdnauto	8655	8760
.synop	8760	8760
1998		
.hwdnauto	*8634*	*8760*
.synop	*8760*	*8760*

From the beginning of the paragraph we stated that the *.hwdnauto Domain* will provide hourly measurements of dry bulb air temperature, dew point temperature and wet bulb temperature whereas *.synop Domain* is responsible for mean wind speed and mean wind direction measurements. Some of these parameters can be used without changes for the 6 **fields** of the *.clm* file but some others do require one or many-sided changes for the shaping of fields. All the changes can be seen in Table 3.10 below. At this table we also present the two parameters of I_d and I_n, vital for the complete image of the configuration.

Table 3.10/ Modifications in Data nature

Domain	Parameters	Change in Magnitude	Change in Units	Field Shaped for MERIT
.hwdnauto	Dry bulb air temperature	Not required	Not required – already in tenths of degrees C	External dry bulb temperature
	Dew point temperature	Relative humidity (%)	Not required	Relative humidity
	Wet bulb temperature			
.synop	Mean wind speed	Not required	Data in Knots – change them to m/s. (1Knot=0.514m/s)	Prevailing wind speed
	Mean wind direction	Not required	Not required – already in clockwise degrees from north	Wind direction
?	Diffuse solar intensity on the horizontal	Not required	Not required	Diffuse solar intensity on the horizontal
?	Direct normal solar intensity	Not required	Not required	Direct normal solar intensity

Apart from any modifications made in the texture of the **raw data**, we also had to make some numerical modifications at them namely the make up of 105 hits shortage that the *.hwdnauto* file was found to possess (Table 3.9). At this point we simply capped the gaps with values from the neighbouring values after we produced an average for them.

When the *Eskdalemuir97DM.xls* file was prepared we combined it with *Eskdalemuir1978.xls* to make the *Eskdalemuir1997Final.xls* file which was the cornerstone for the creation of the *Eskdalemuir1997Final.csv* file the file to be converted into the *.clm* file that we required. *Eskdalemuir97DM.xls* was checked for invalid values (999), that might they would have carried forwardly from BADC database, and it was tested against *Eskdalemuir1978.xls* for calendar and arithmetic data inconsistency levelling. When these checks were over and both files were matched the *Eskdalemuir1997Final.xls* file was saved as a *.csv* file and named *Eskdalemuir1997Final.csv*. This was then added to the climate folder of the MERIT (version 2.2) directory and the module *CreateClimate.exe* of that software was used to be converted into the right climate file i.e. *.clm*. Thus the *Esk(97).clm* file was created and it was introduced into the climatic database of MERIT to aid in the realistic simulation of renewable technologies against the Thornylee Forest's weather profile for the year 1997. The entries for the *CreateClimate.exe* module were:

- File Name: *Esk(97)*
- Latitude: 55.331
- Longitude: -3.205
- Start (Date):1/1/1997
- End (Date): 31/12/1997
- Time Step: 1

3.1.5.1 Final Selection

It is really very sad the fact that this file was never to be used, for reasons explained in P.4.1.2, a totally incoherent file finally being employed from MERIT's database against the one for which this meteorological methodology was attributed and was to be conducted in a three months period of time. Still we believe that the methodology followed for this project can be repeated by other workers for relative studies and so we decided to presented for educational and guidance reasons.

This time the final selection is a mater of a simple comparison or the relative radii of the Glasgow and Kew stations for which the climate files are under consideration. So R_G =90Km for Glasgow and R_K =570Km for Kew, the centre of the imaginary circle again being the Thornylee Forest. It is more than clear that Glasgow station is far more close to the vexed area of study and so we hope that there will be more similarities in the weather profiles of these two areas than in the other combination. Thus the chosen file for the simulation would be *Glasgow.clm* which was accepted as the most valid choice from a very narrow set of options

3.2 Selection of Power Plant

The energy simulation of match and supply for the Eco-village will be based on the use of Renewable Supply Technologies (ReST) to provide enough electrical energy for the power requirements of the 17 houses of that community. This energy will be provided by Wind Turbines and Photovoltaic systems, operating as Primary Energy Source (PES) and the Fuel Cell module which will operate as Secondary Energy Source (SES). The selection for the PES was through a numerical approach that will be explained in later stages in this chapter in P.3.3.2.1, though the corresponding selection for the SES was a mixture of technical and numerical oriented analysis based on knowledge digestion about Fuel Cell modules married with the needs of the Eco-Village for a green and efficient heat and electricity energy system. Since the PES selection is pretty straightforward we will only present the particular annotations for the selection of the Fuel Cell module, as this will be proved handy later on, in the following paragraph.

3.2.1 Technical Orientation for SES Modules

A Fuel Cell plant can be created principally by a hydrogen source, a fuel cell that will make use of that hydrogen by converting its chemical energy into electricity and heat and a means of a hydrogen reservoir that will store hydrogen fuel for use when direct availability is deficient, designated as an "independent operation" power mode.

3.2.1.1 Electrolyser

The hydrogen source has two most commercially available ways to be exploited. One way is by connection to a natural gas network, where the H_2 is involved in the chemical bounds of that combination, and the other way involves the installation of an Electrolyser which will dissociate water into H_2 and O_2, provided there is a water reservoir and energy to run this component. The Eco-Village requirement for clean production of energy is very conditional to allow the first option to be considered. This is oxymoron as the polluting gases that come by the "burning" of the natural gas are extremely low [Reference: LE-45], compared with those coming from any other fossil fuel combustion mechanisms, but still there are essentially of considerable quantities to be allowed our study. Electrolysers have many characteristics which should be considered for a valid selection of an appropriate module. Many of them usually have a number of ancillary and accessorial units but in our case we will only concentrate on the main unit. An internet search was conducted to find out companies which could give us information about the electrolyser so to establish a sound validity check and to select a fine model. Unfortunately not all the companies replied back and at the end only one company was kind enough to offer some information about the model that it was advertised on the internet. The model that we were looking for had to employ attributes such as:

1. Hydrogen generation at a mass flow rate of $\dot{m}_{H_2} \geq 1.94*10^3 Kg/s$ or a volume flow rate of $\dot{V}_{H_2} \geq 7.87 Nm^3/h$ (at base load operating mode) – see P.3.2.2,
2. Lowest possible energy consumption as a function of $\dot{m}_{H_2}$ and ,
3. Highest possible outlet pressure of gases P_{gas} at the given $\dot{m}_{H_2}$ (the highest the P_{gas} is the lesser the amount of energy required for compression of gases for their subsequent pressurisation for the storage tank)
4. A benign electrolyser, considering fewer possible environmental hazards,
5. 0-100% range of nominal power capacity,
6. Lowest possible feed-water consumption,
7. High purity of H_2.

Indeed the electrolyser that we located could satisfy all of the following attributes so it was conveniently selected for this study. The company providing the imminent electrolyser was "Vandenborre Technologies N.V.", its acclaimed accomplishment being the development of the IMET® technology which forms the core component of the H2 IGEN® hydrogen and oxygen generator. The series comprises three models: the 300, 1000 and 2500 with volume flow rate range capacities of 1-3 Nm^3/h, 3-60 Nm^3/h and 15-80 Nm^3/h respectively. Under internal office clarification about the fact that the three Series have more or less the same attributes except from their volume flow rate range capacities and in accordance with the biding requirement for a $\dot{V}_{H_2} \geq 7.87 Nm^3/h$ we accepted the **H2 IGEN® 1000 Series** Electrolyser which proprietary attributes are presented below:

1. Hydrogen generation at a capacity volume flow rate range $\dot{V}_{IGEN}$ = 3-60 Nm^3/h,
2. Energy consumption of $5 KWh/Nm^3$,
3. The outlet pressure can be provided at 10 and 25 *bar*; the requirement for highest possible outlet pressure guided us to select the model with $P_{gas} = 25 bar$.
4. The electrolyte is a concentration with 30 % KOH, one of the most environmentally friendly solutions available [Reference: IS-12],

5. 0-100% range of nominal power capacity,
6. Feed-water consumption of $1lt/1Nm^3$,
7. Hydrogen purity of 99.9%.

3.2.1.2 Fuel Cell

In the case of the Fuel Cell we had to decide upon the nature of the fuel cell and as in the previous case (Electrolyser) to identify a possible model that would give us technical characteristics for the determination of the other two modules of the plant. The Fuel Cell would be the hart of the system and so its study was very thorough on both paper literature and internet-based information material. Nevertheless it was not possible to discover a potential model for the requirements of this study and so we had to follow a theoretical approach to derive its technical characteristics, presented later in P.3.2.2. Deciding on the nature of the Fuel Cell it was no easy task. As we have seen in P.2.3.2.1 there many different types of Fuel Cells each with different characteristics and advantages. We had to identify the most compatible type of Fuel Cell for the needs of this project and the only way to achieve that was by establishing a set of features/requirements to look for in the six types of Fuel Cells for a possible distinction. This set is requiring for the Fuel Cell to:

1. Have a minimum power output of $25kW$ at 100% operation capacity (See later at P.3.3.2.2.1),
2. Utilise hydrogen gas as the principle fuel for the power generation,
3. Have the fast "start-up time" feature and support continuous operation capability for base load power coverage-"independent operation" power mode,
4. Acquire a flexible operation power range (15%-100%) for potential exploitation in different modes for the Eco-Village,
5. Have the capability of providing both heat and electrical power (a combination known as "cogeneration"),
6. Capacitate the highest possible electrical efficiency,
7. Capacitate the highest possible overall efficiency (including electrical and thermal exploitation as part of the cogeneration scheme).

After a deep examination of literature it was quite clear that the best possible choice would be to go along with a Polymer Electrolyte Membrane (PEM) Fuel Cell for that it would satisfy in the best way the 7 features/requirements as presented above. PEMFC come in many different plant sizes varying from $500W$-$100kW$ (commercial numbers) and more specifically there are a few companies around (like "Hydrogenics Corp." [Reference: IS-13]) that produce this medium range of PEMFC at capacities of 5-$25kW$ which is very close to what we are looking for [Reference: IS-14]. This power output can be found in other types of fuel cells but the critical requirements combination for hydrogen fuel at that power output value was only verified for the PEMFC type. The latter are largely known for their profound ability to utilise hydrogen as well as hydrocarbons as part of the fuelling system and there are also known for their fast "start-up time" features [Reference: LE-46]. "Independent operation" is possible with PEMFC most of the tests encountered reporting 4000-9000*h* problems free operation.

Cogeneration for PEMFC is possible although some conditions should be applied to the scheme if thermal efficiency is required. In a cogeneration scheme heat, the by-product of electrical power generation is transferred from the fuel cell to a heat exchanger. The exchanger transfers the heat to a water supply, providing hot water to local customers. Since the PEMFC are based on a low temperature operation basis (80*C*) it is obvious that the hot water pipeline network should not very extended, a fact that must be respected if relatively high temperatures of the working fluid are required-high enthalpy level. Furthermore PEMFC have good electrical and overall efficiencies the first reaching 50% and the second being around 70-80% depending on the materials and the design of the cells stack.

Table 3.11/ PEM Fuel Cell Characteristics.

Electrical Efficiency (h_{El})	≈ 50% [Reference: LE-47]
Cell Voltage ($^{*}V$)	≈ 0.8V [Reference: LE-47]
Fuel Utilisation	≈ 80% [Reference: LE-47]
Operating Temperature	80C
Operating Pressure	1*bar*

3.2.1.3 Low Pressure Storage Tank

The Storage Tank has the role of supplying hydrogen when the normal channel i.e. the Electrolyser, for such a task fails. Any imponderable factor that can affect the normal flow of energy from PES to Electrolyser and can not be readily accounted for in the designing of the system (a violent storm, extreme freezing temperatures, a discharging lighting or dead calm days and any other mechanical, electrical or climatic pouts) must be confronted with an backup plan so that energy will still flow to the inhabitants of the Eco-Village and will allow for maintenance and repairing operations. There are quite a few choices for the storing of H_2, and as it is expected some of them require energy input to the H_2 gases to change their thermodynamic properties whereas other simply take advantage of their special chemical configuration to accommodate them respectively (P.2.3.3). In today's marketing options for H_2 storage the choices will depend on the application that hydrogen fuel will be provided to. Thus there are mobile applications that require high energy density from the fuel and a lightweight arrangement of the storage option. For these applications highly compressed H_2 gas or liquefied H_2 gas cylinders are recommended. Stationary applications are less demanding in that the weight and size of the container is not a priority and so in this case we can use a low or high compressed H_2 gas vessel, metal hydrides arrangements and possibly liquid hydrogen options. The characteristics of an appropriate Storage Tank are:

1. Highest possible working pressure for the hydrogen gases $P_{storage}$ (the storage pressure is proportional to the size of the vessel dictated by material and shape limitations),
2. Highest possible nominal capacity of hydrogen gases $C_{storage}$,
3. Satisfactory Flow Capability (at least the same, or more than $\dot{V}_{H_2}$ for the Fuel Cell)

Amongst the companies that we examined the most suitable information-wise was Chart Industries. Chart's Bulk Storage Systems comprise a standard line of pre-engineered tankage (up to $68.2m^3$) and custom engineered storage containers (up to $455m^3$) for nitrogen, argon, LNG, and carbon dioxide for industrial gas customers. These gases have different properties from hydrogen and so it is not clear if the model that we were to choose was suitable for this element, and since that point could not be clarified via e-mail communication we had to make the following assumption:

A4: "If a pressurised vessel can accommodate nitrogen gas with atomic weight of $14.0067gr$ then it can possibly do the same for a gas with a smaller atomic weight such as $1.00794gr$ for the same thermodynamic conditions provided that chemical effects are not important and so only mechanical phenomena are considered.

A very important issue that our investigation brought up was that there is a compromise between, $P_{storage}$ $C_{storage}$ and the size of the tank. In our case we need the highest possible $C_{storage}$ for an $P_{storage}$ equal to P_{gas} i.e. $25bar$. This is done to avoid any extra energy spent over the pressurisation of hydrogen gases. Thus the appropriate tank for our case would be from the VS-High Pressure Bulk Stations Series and more specifically the **VS11000NC** model. This has the following characteristics:

1. $P_{storage} = 27.6bar$

2. $C_{storage} = 192 m^3$

3. Flow Capability $= 414 Nm^3/h > \dot{V}_{H_2} = 7.87 Nm^3/h$ that the Fuel Cell requires.

3.2.2 Numerical Guidelines for SES Modules

The building block of the analysis for the SES Modules is the definition of the operational characteristics of the Fuel Cell. If we know the hydrogen fuel consumption for the latter then we can define the Electrolyser and Storage Tanks sizes.

We start the analysis by calculating the energy requirements of the Eco-Village. According to the "*Tweed Valley Ecovillage Project Overview*" *Reference: LE-35* the average use of Electrical Energy (E_{El}), in the UK, is for a standard house is between 3000 and 4000 kWh and around 4000 kWh for Thermal Energy (E_{Th}) for one year. Since the Eco-Village will be situated in an area where there is no shelter we would expect the thermal requirements to exceed the thermal value but since the village could also consider the use of electrical equipment and lighting devises that are less electricity intensive *Reference: IS-15* than the standard house and possibly house designs of passive solar lighting we would expect the electricity requirements to deceed the electricity requirements. These trends mutually cancel each other and so we can choose $E_{El} = 4000 kWh$ to counterbalance the E_{Th} increased behaviour.
So for the Eco-Village we have:

$E_{El_1} * 17 = E_{El_V} = 68{,}000 kWh$, for the Electrical Demand and

$E_{Th_1} * 17 = E_{Th_V} = 68{,}000 kWh$ for the Thermal Demand.

Thus the total energy demand for the village, for 1 year will be:

$$E_D = 132{,}000 kWh \ldots \text{ (Equation 3.1)}$$

So for one day then the energy demand for the village will be:

$$E_{D_1} = \frac{132{,}000}{365} = 361.64 kWh \ldots \text{ (Equation 3.2)}$$

And the Critical Power that the Fuel Cell is required to distribute to the 17 houses in 24h (one day) will be:

$$^{*}P_{D^1} = \frac{361.64}{24} = 15kW \ldots \text{ (Equation 3.3)}$$

This Critical Power will drive electrical and thermal loads over 24h so the *independent operation* mode, describing a base load configuration, will be fixed at this value and so will the hydrogen fuel consumption. Later, when we will have to produce a more realistic demand for the Eco-Village, we will calculate three different fuel consumptions relative to the three operational modes that the Fuel Cell will work.

3.2.2.1 Critical Fuel Consumption for the FC

Having defined the Critical Power we can now proceed into finding what the Critical Fuel Consumption will be and so sizing the Electrolyser and the Storage Tank. We start by assuming that all the current that is reaching the electrolyser is DC that is current from the Wind Turbines and the Photovoltaic system. That is not the case with Wind Turbines since they produce AC current, but for simplification of the analysis we accept a perfect Inverter with efficiency $h_{Invter} = 100\%$ (a good commercial transformer will be around 96-97%) and so none of the power will be lost in the inversion. Assuming a cell voltage of $0.8V$ (Table 3.11) and knowing that the power output will be equal to $^{*}P_{D^1}$, we can calculate the sum of all the cell currents in the stack:

$$I = \frac{^{*}P_{D^1}}{^{*}V} = 18{,}750A \ldots \text{ (Equation 3.4)}$$

So for the stack:

$$\dot{m}_{H_2} = \frac{I}{F} = \frac{19.53*10^3}{96{,}490{,}000} = 1.94*10^{-3}\,Kg/s \ldots \text{ (Equation 3.5)},$$

Where F is Faraday's Constant with units of coulombs per mole of electrons. This value is measured at pressure P=1*bar* ($\approx$1*atm*, 0.1*MPa* and 14.5*psi*) and T=80*C*=353*K*. With compressible gases, like H_2, industry uses standard units of volume flow rate like Nm^3/h or $Nm^3/\min$ at P=1*bar* and T=0C. In that way engineers can ensure that every volume measured has the same amount of product in it i.e. same density. So in our case in order to keep an industry-oriented approach we will try to convert $\dot{m}_{H_2}$ into a useful expression that will help us locate the Electrolyser model easier. We will use the following expression to do that:

$$P = Z\,rRT \ldots \text{ (Equation 3.6)}$$

Where,
P: Pressure of the hydrogen gases, here P=0.1 MPa
Z: Compressibility Factor for hydrogen gas relative to the pressure and temperature of the pressurised volume, here Z=1,
r : Density in Kg/m^3,
R: Specific Gas constant for H_2 gas or R=4,128.18 Nm/KgK and
T: Temperature of the gases, here T=353K

Thus we have from (Eq.3.6):

$$r = \frac{P}{ZRT} \text{ … (Equation 3.7)}$$

$$r = 0.0686 \; Kg/m^3$$

In **standard conditions** where **P=1*atm*** and **T=273*K***, density of the gases is:

$$r_{SC} = 0.0886 \; Kg/m^3 \text{ … (Equation 3.8)}$$

So between the two densities r_{SC} and r there is a difference of 0.020 Kg/m^3 . Since this difference is quite small we can use the standard conditions density to make up an expression for the volume flow rate $\dot{V}_{H_2}$ that will be based on common industrial units. From (Eq.3.5) we know that $\dot{m}_{H_2}$ = $1.94*10^{-3} Kg/s$, so:

$$\dot{V}_{H_2} = \frac{\dot{m}_{H_2}}{r_{SC}} = 2.19*10^{-3} m^3/s \text{ … (Equation 3.9)}$$

Now to achieve the appropriate conversion we use Table 3.12 below:

Table 3.12/ Conversions for Volume flow units

Volume Flow Rate in *h* @ P=1*atm* and T=0*C*		
Nm^3/h	Lt/h	m^3/h
1	960	0.96
Nm^3/s	Lt/s	m^3/s
1	$1.037*10^{-3}$	1.0036
Volume Conversions		
1 $Nm^3 = 0.931 m^3$		

So:

$$\dot{V}_{H_2} = 2.18*10^{-3} Nm^3 / s,$$

Or

$$\dot{V}_{H_2} = 7.87 Nm^3 / h \ \ldots \text{(Equation 3.10)}$$

This is the Critical Fuel Consumption (CFC) for the Fuel Cell. With this in hand we can now calculate the Critical Number of Storage Tanks (CNST) (**VS11000NC** model) for the Eco-Village as well as the Critical Number of Charging Days (CNCD) that it will take to charge these vessels.

Feed-water Consumption for CFC

The **H2 IGEN® 1000 Series** Electrolyser has a feed-water consumption of $1lt/1Nm^3$. If the Fuel Cell is to be used for a continuous operation then it will require an uninterruptible feed-water supply to the Electrolyser equal to the CFC of the Fuel Cell. So if for an hour the Fuel Cell requires 7.87 Nm^3/h then for 24*h* this will be equal to 188.88Nm^3 and the equivalent feed-water consumption for the same time interval (1 day) will be equal to 188.88*lt* or 0.189m^3. If this is integrated for the year (365 days) then the yearly feed-water consumption will be 68,941.2lt or 68.9 m^3. These of course are not a realistic type of numbers since the Electrolyser will be working more intensively in the real case to cover the demand of the Fuel Cell at any of the three OM (See P.3.3.2.2.1) which means that more feed-water will be required. Furthermore this numbers are not sensitive to the extra utilisation of feed-water by the Electrolyser to cover the hydrogen demand of the Storage Tanks if the latter are to be unexpectedly introduced to the primary energy production scheme (PES). Nevertheless we can still use those values as a convenient type of the minimum feed-water consumption indicators that we would require to construct a natural deposit that will concentrate fresh (rain) feed-water fuel for SES plant.

From the other study on the Eco-Village Reference: *LE-36* by Mr Angelos Mademlis and from the descriptions given in P.2.1.3 about the morphology of the area on the Thornylee hill, where the village will be situated, we know that the natural reservoir will have a volume of 4,500 m^3 which is much bigger than the modicum value of 68.9 m^3 that the SES scheme would require for a successful operation.

3.2.2.2. Critical Number of Storage Tanks and Critical Number of Charging Days

As we have said before it is important to keep an undisturbed flow of energy from the Storage Tanks to the Fuel Cell when the front line channel (PES-Electrolyser-Fuel Cell) will fail due to any imponderable factors, that is mechanical, electrical or climatic anomalies. A reasonable number of days for that backup channel could be 15 days or 360*h* in which time all maintenance and repairing operations could be completed. Thus in that time frame we have from (Eq.3.10):

$$\dot{V}_{H_2} = \frac{V_{H_2}}{t}$$

Or,

$$V_{H_2} = \dot{V}_{H_2} * t = 7.87 Nm^3/h * 360h$$

$$V_{H_2} = 2{,}637.7 Nm^3 \ldots \text{ (Equation 3.11)}$$

Or in cubic meters from Table 12 above,

$$V_{H_2} = 2{,}455.7 m^3 \ldots \text{ (Equation 3.11.1)}$$

Or in litres

$$V_{H_2} = 2{,}460{,}000 lt \ldots \text{ (Equation 3.11.2)}$$

This is a very large number, mainly because it refers to a calculation based on standard conditions density. But the selected container (**VS11000NC** model) will have different conditions for the accommodated gases, higher pressure and temperature so there should be a theoretical decrease in that volume since density is a function of pressure of and temperature for hydrogen gases and in those conditions we would expect to increase as the other two variables increase. So to decrease the volume we must calculate the new density $r_{PVessel}$ for the same mass. Use (Eq.3.7) again where,

P: Pressure of the hydrogen gases, here P=26.7*bar* or 27.6*MPa* (seeP.3.2.1.3)
Z: Compressibility Factor, here Z=1.014,
$r_{PVessel}$: Density in Kg/m^3,
R: Specific Gas constant for H_2 gas or R=4,128.18 Nm/KgK and
T: Temperature of the gases, here T=353*K* (seeP.3.2.1.3)

Therefore we have:

$$r_{PVessel} = 2.21 \; Kg/m^3 \ldots \text{ (Eq.3.12)}$$

If the mass of the hydrogen gases is in standard conditions:

$$m_{SC} = r_{SC} * 2{,}455.7 m^3 = 2{,}175.75 Kg$$

Then the new volume of the gases will be:

$$V_{H_2(PVessel)} = \frac{m_{SC}}{r_{PVessel}}$$ … (Equation 3.13)

$= 984.5m^3 = 985{,}000lt = 1{,}056.36Nm^3$ (See Table 3.12)

Thus the volume of the gases was considerable reduced at these conditions. So the Critical Number of Storage Tanks will be:

$$N_{CPVessels} = \frac{984.5}{192} \approx 5$$ … (Equation 3.14)

From P.3.2.1.1 we selected the **H2 IGEN® 1000 Series** Electrolyser which can provide $\dot{V}_{IGEN} = 60\,Nm^3/h$. So the Electrolyser can offer in 1 hour: 60-7.87Nm^3 =52.13Nm^3 (the 7.87 Nm^3 will be used directly for the Fuel Cell) and so for the 1056.36Nm^3 of the containers the critical day(s) for charging will be:

$$N_{CCDays} = 20.26h \approx 1\text{day}$$ … (Equation 3.15)

If the analysis was for 1 month (720*h*) then we would have:

$$V^*_{H_2(PVessel)} = 1924.5m^3$$

$$N^*_{CPVessels} \approx 10$$

$$N^*_{CCDays} = 39.61h \approx 2\text{days}$$

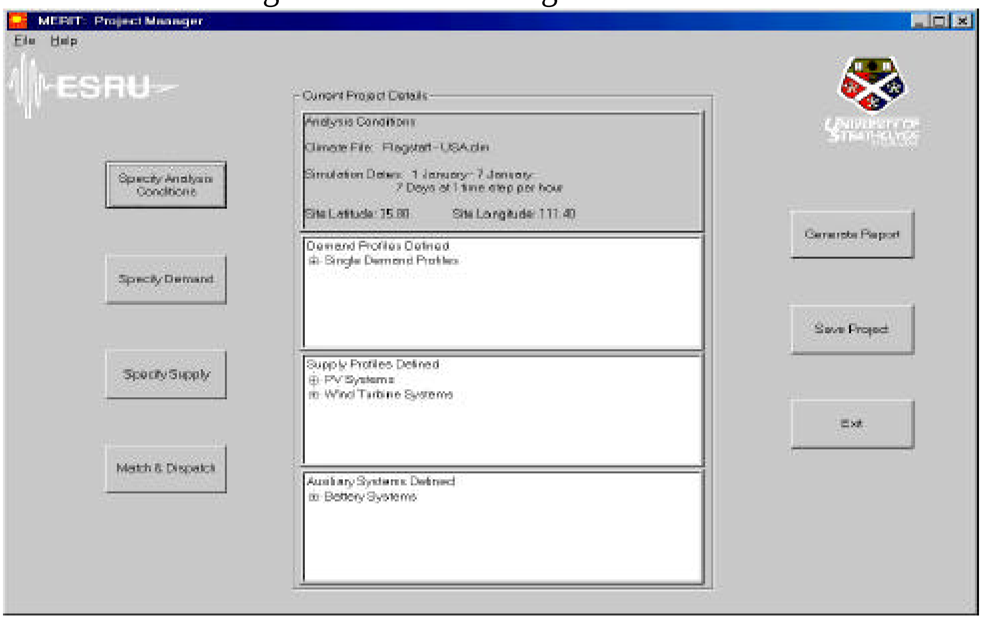
3.3 Rudimentary Simulations

With the use of computer software the complex analysis of REST integration to the Eco-Village can become very straightforward. The thought is to take advantage of that powerful assistance and simulate two cases of energy supply to appropriate demands under real weather conditions as we defined before. The two scenarios for these cases reveal our intention to examine, according to the objectives of the project, as much as possible a justifiable and realistic demand-supply relationship with all the possible inventory that we could dig out from the software's databases or that we could assemble ourselves with the appropriate designing tools within the program. The first step was to get familiar with the "facilitator", that is MERIT, to discover its full potential and then to start fitting together the two plans.

3.3.1 MERIT- Analysis

In our hands there were two versions of MERIT, the v.2.2 and v.1.0 respectively. For reasons explained in P.4.3.1 we will present here the partial investigation on the oldest version i.e. v.1.0 which was the one for conducting the simulation for the two scenarios *Reference: IS-16*. In this paragraph we intend to give some light to the program itself and especially to describe those aspects and components that will help to the understanding of the procedures followed to establish the simulations of the two demand scenarios (Scenario 1 and 2). When the user firstly runs the *"MERIT.exe"* program it will see a set two columns of buttons on the left and the right hand side of the main window that is called the **Main Program Window** (Figure 3.7).

Figure 3.7/ Main Program Window

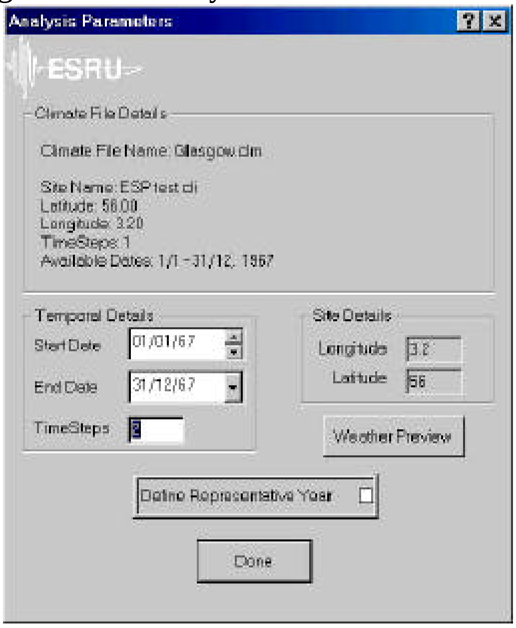


On the top there are the menus *"File"* and *"Help"* and in the centre there are four windows referring briefly to the variables selected at the three components of the preliminary and middle-phase control platforms. The preliminary-phase control platform corresponds to the first of the four buttons of the left-hand-side-column, namely the *"Specify Analysis Conditions"* button, and the middle-phase control platform to the second and third buttons (from the top), namely the *"Specify Demand"* and the *"Specify Supply"* buttons. The simulation-phase control platform can be reached by the last of the left hand side column buttons i.e. the *"Match and Dispatch"* one. The right-hand-side-column buttons are pretty much self explanatory for their operations. Since our work was involved with all the control platforms we will look upon the most critical points of these components so that the reader can have a complimentary theoretical idea to the practical analysis facts.

Specify Analysis Condition

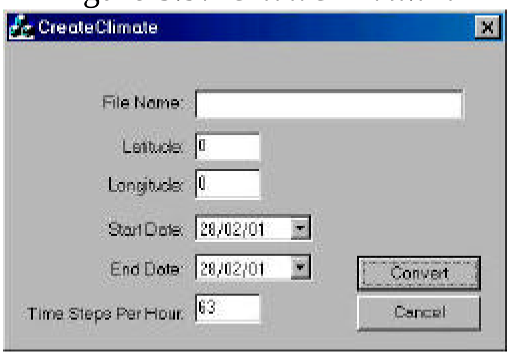
This is the preliminary-phase control platform and through that someone can set the parameters for the initial stage of the simulation. From here, the **Analysis Parameter Window** (Figure 3.8) someone can select a climatic profile already bestowed in the climatic database of this section.

Figure 3.8/ Analysis Parameter Window



Someone can also select a customised profile that has developed with the help of *"CreateClimate.exe"* (See Figure 3.9) and has delivered into the same climatic database in the MERIT directory in the hard drive space. The *"CreateClimate.exe"* is a program that could not be found at the v.1.0 of MERIT but only in v.2.2 and it can help the user to build a *".clm"* file from an external source, provided that the file to be converted is in a compatible form or *".csv"* file form.

Figure 3.9/ *CreateClimate.exe*

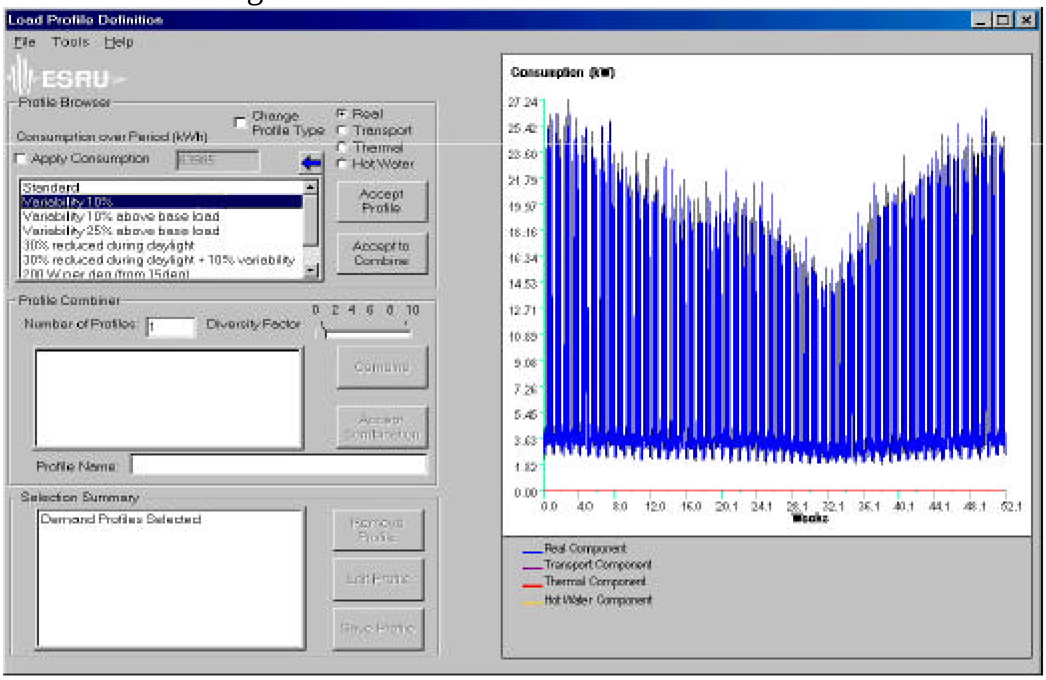


Specify Demand

After a satisfactory climatic model has been selected the user can delve into middle-phase control platform through the first of the two buttons corresponding to this phase. The main interaction feature that is allowing such a task is the **Demand Definition Window** (Figure 3.10) that contains the following main functions:

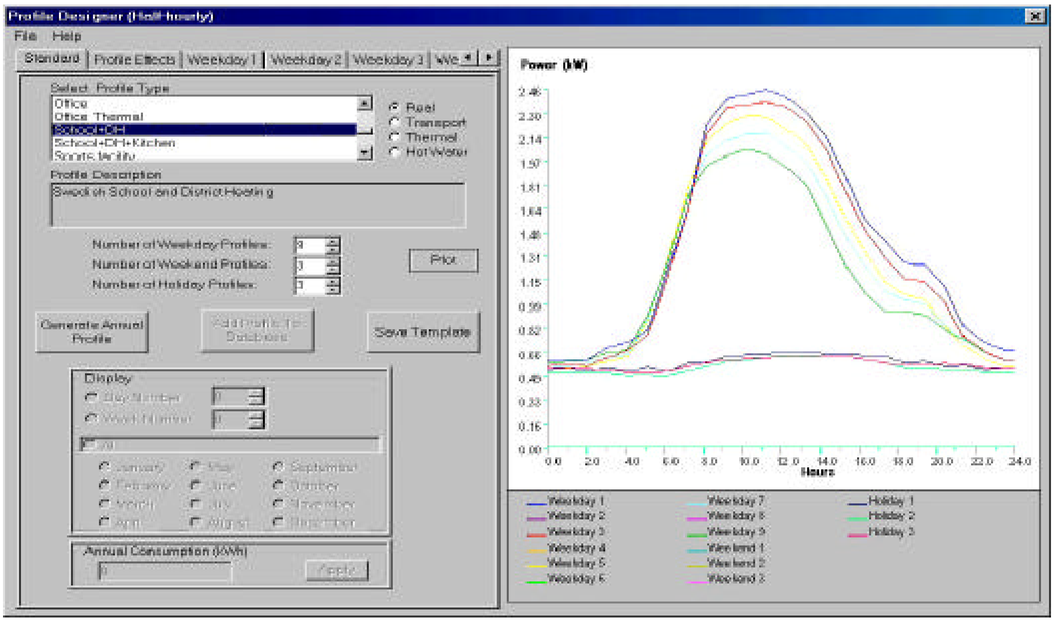
- "Load Database"
- "Import Profile"
- "Profile Designer"

Figure 3.10/ Demand Definition Window



On selection of the "Load Database" function-button brings up a variety of existing profiles which may be selected using the "Accept Profile" function-button, or chosen for combining with others using the "Accept to Combine" function-button. Up to nine profiles (single or combined) may be chosen. Another important component of this platform is the *"Profile Designer"*. Double clicking on "Profile Designer" function-button brings up the **Profile Designer Standard Window** (Figure 3.11), in which there are more existing profiles to be amended for a desired result.

Figure 3.11/ Profile Designer



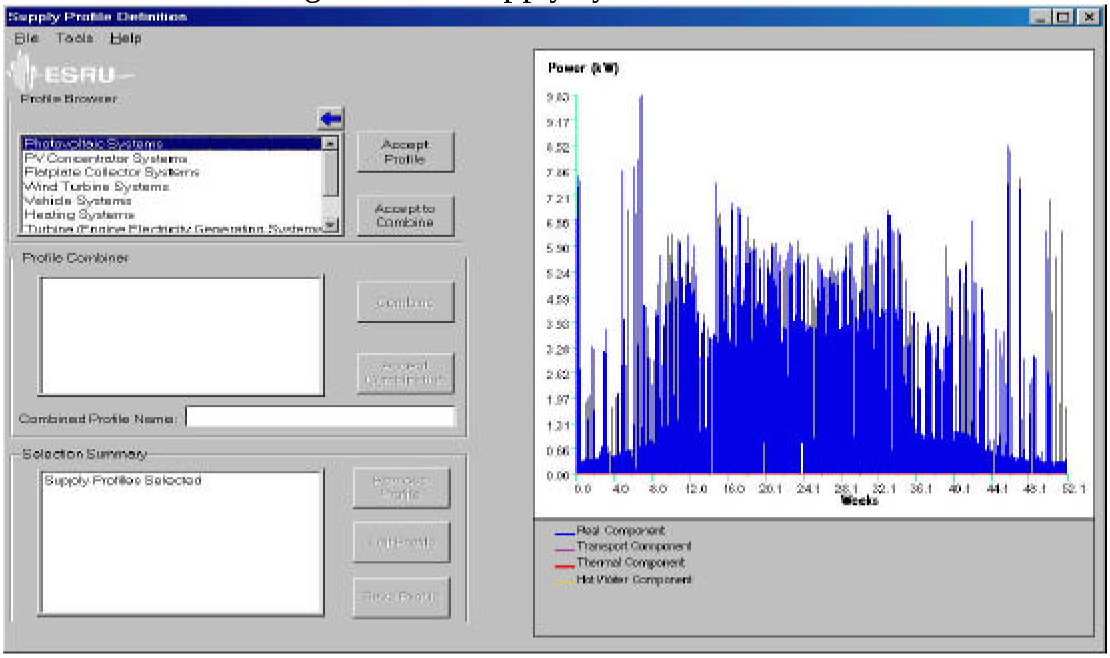
Clicking on the tabs at the top brings up details of these profiles on the **Profile Tab Window**. This half-hourly data can be amended manually, or the overall consumption can be changed. Someone can also change the specified time frame or days for which a profile is defined for. Going back to the *"Standard"* tab, an annual profile can be generated by pressing *"Generate Annual"*, and the radio buttons should be used to choose which type of profile is desired (real, thermal, hot water).

Specify Supply

This is the other middle-phase control platform where the supply profiles can be selected and that is possible in a two-part approach. The first part is by determining the *"Renewable Generating Systems"* and the second by the *"Auxiliary Systems"* specification. When the **Supply System Definition Window** (Figure 3.12) first appears, the list at the top contains the following functions-buttons:

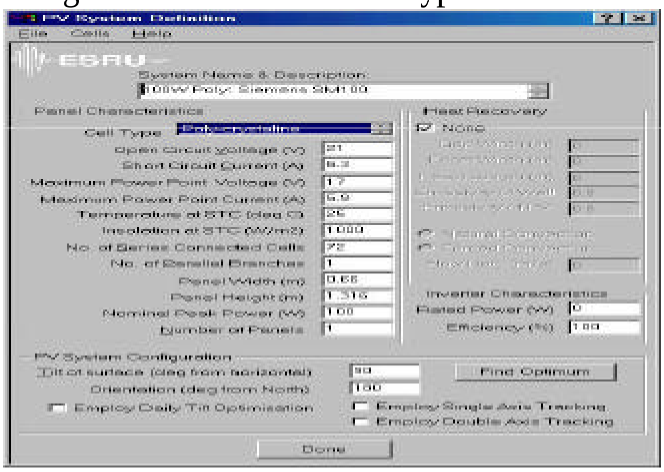
- "Simulated Supply Profiles"
- "Supply Database"
- "Import Profile"
- "Supply Profile Designer"

Figure 3.12/ Supply System Definition



Double clicking on "Simulated Supply Profiles" button brings up a variety of generation methods. Double clicking on each generation type brings up its **Generation Type Definition Window** (Figure 3.13), on which the user can input readily available manufacturers information. Also, "Open" on the "File" menu allows a variety of existing information to be accessed by double clicking on the desired profile on the window which appears. This information may be used or augmented as necessary.

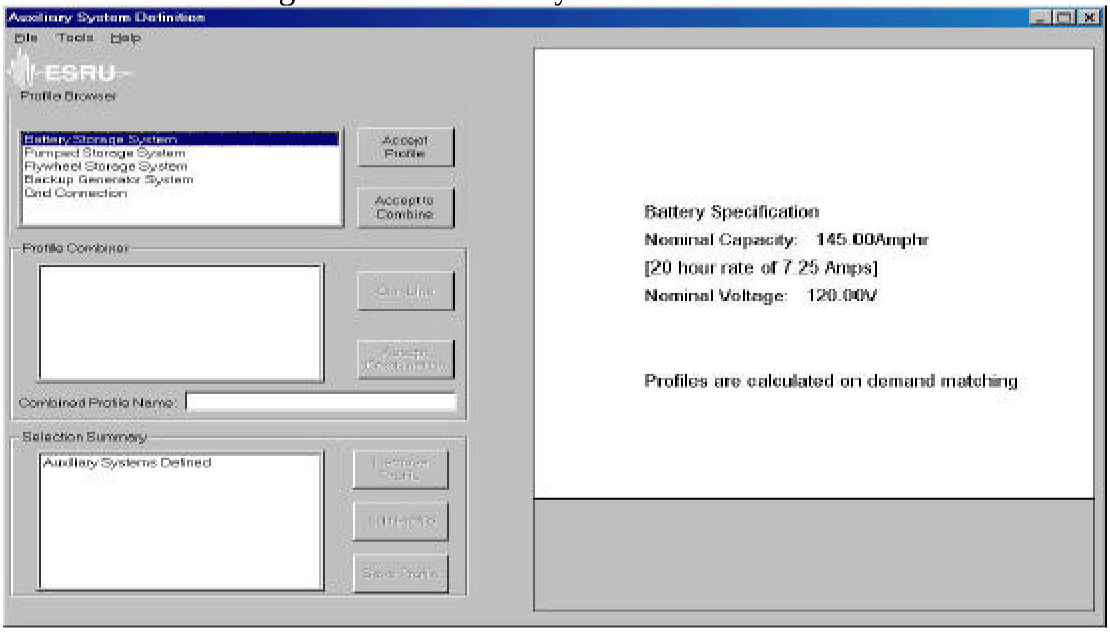
Figure 3.13/ Generation Type Definition



When the **"Auxiliary Definition Window"** (Figure 3.14) first appears, the list at the top contains a variety of auxiliary system types. Again, double clicking on one of these brings up the **"Relevant Definition Window"** which functions in the same way as the supply windows. As the performance of the auxiliary systems can not be calculated until the demand

and supply matching stage, a description of the system appears in the window when the definition windows are exited. If this is satisfactory, it may be accepted and combined in exactly the same way as for the demand profiles.

Figure 3.14/ Auxiliary Definition Window



Match & Dispatch

As the last stage of the phases this is the simulation-phase control platform with which the work is completed. When the "**Match and Dispatch Window**" (Figure 3.15) opens, the chosen demand, supply and auxiliary profiles will be seen as buttons at the top, in the middle. Any number of profiles may be chosen for matching. The **box** at the top **right** hand corner contains information about the match. There are 6 indicators which the user can consult to retrieve the best information about his/hers selections from the previous steps. Indicator *Inequality* refers to the difference in the phase for demand-supply profiles. If for example at summer a PV can offer more energy than that the EV requires and at winter can not reach the required values the match will have a large inequality. Indicator *Correlation* refers to the difference in the magnitude for demand-supply profiles. A small difference in magnitude will result in large correlation. There are also indicators *Deficit* and *Excess* which their difference can give the value of the magnitude for demand-supply profiles. This can be verified by the top **left** hand corner **box** indicators namely the *Selected Demand* and *Selected Supply* by the equation:

Selected Demand –Selected Supply = Deficit-Excess... (Equation 3.17)

So if *Deficit-Excess* < 0 then there is an excess amount of energy to be utilised and the closest this value is a zero the better Equation 3.17 is verified and the better are the matching results. Different combinations can be tried out, and it is possible, at any time, to go back to the earlier stages and amend demand, supply and auxiliary data to help improve the match. Three graphs are shown at the bottom:

- Demand and Supply
- Residual Power
- Auxiliary Performance

All potential matches can be assessed automatically against various criteria by using the "Auto Search" function-button. When this is pressed, a **"Criteria Definition Window"** (Figure 3.16) appears on which a variety of criteria may be selected for the match. Each possible match is then evaluated against these criteria, and results are suggested.

Figure 3.15/ Match and Dispatch

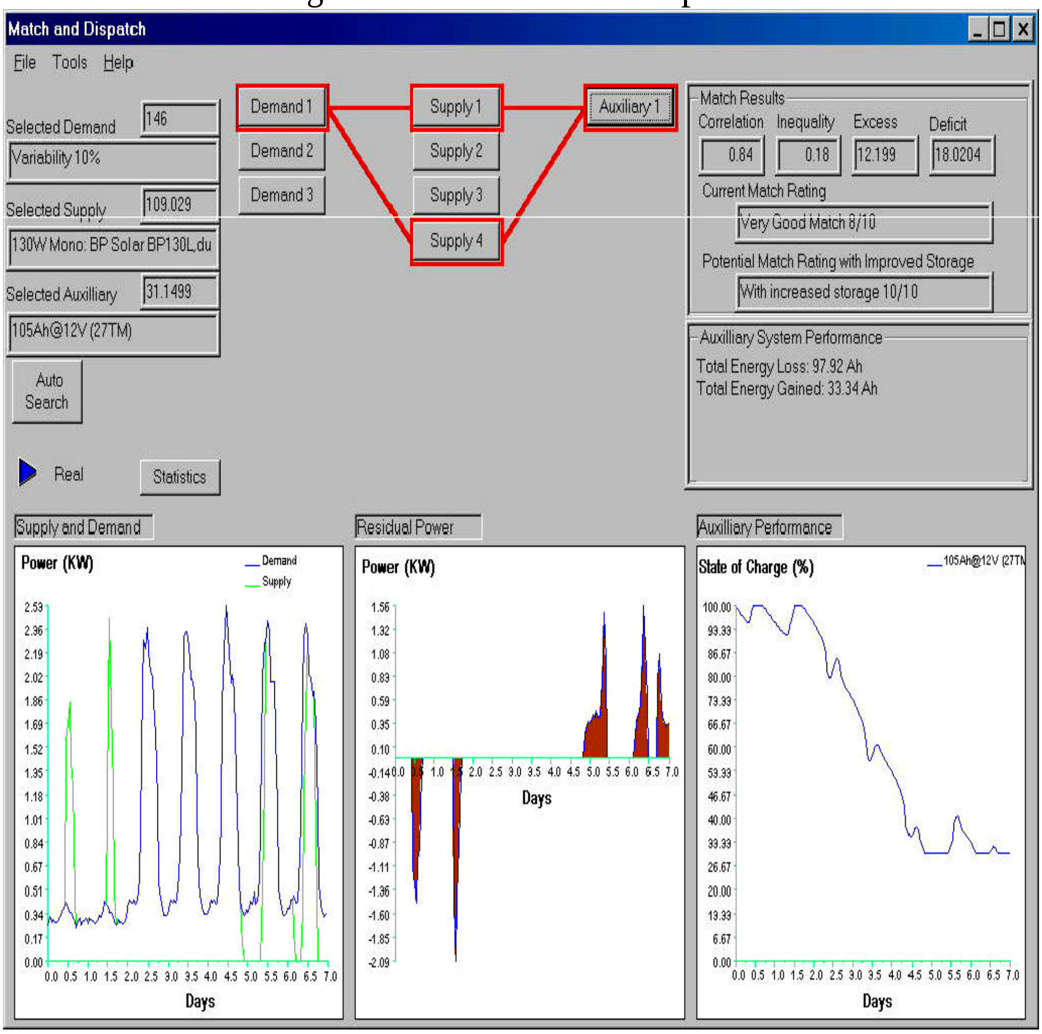
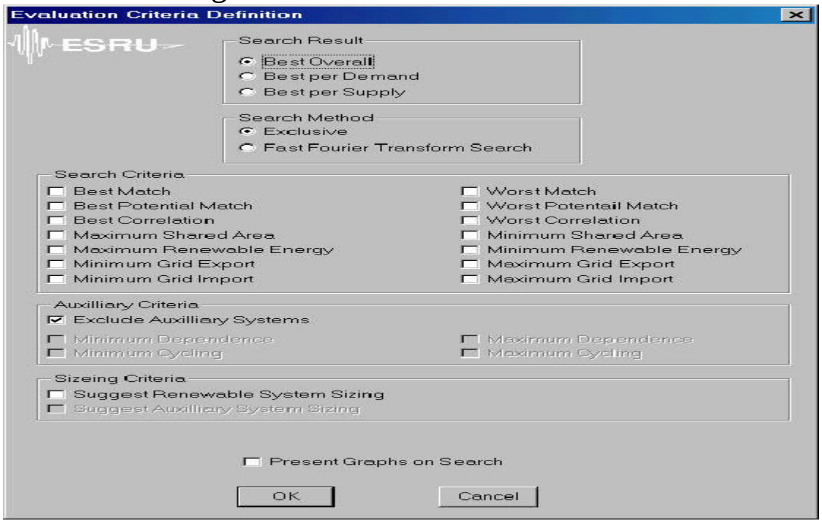


Figure 3.16/ Criteria Definition



3.3.2. Scenarios Design

There are two possible demand-supply relationships. A unipolar one where the objective is to explore the applicability of Wind Turbines and Photovoltaic systems into providing Electrical Energy (E_{El}) to the Eco-Village and a bipolar where the objective is to check the degree of matching Electrical Energy from PES with SES for providing Electrical and Thermal Energy (E_{El} and E_{Th}) to the Eco-Village. The first relationship is named as Scenario 1 and the second as Scenario 2. The importance of Scenario 1 is mainly due to the fact that we will realise the implementation possibility of two well known solutions for autonomous communities at the area of interest and that the deduced results from that study could be compared with those arising from the other project on this Eco-Village by Angelos Mandemlis [Reference: LE-36] which studies electrical coverage in a similar fashion. The importance of Scenario 2 is focusing on the possible implementation of a new way for establishing thermal and electrical coverage for a community i.e. the Fuel Cell modules.

3.3.2.1 Scenario 1

The beginning of the experiments (Attempts) for this scenario start with the appropriate selection of PES. Even before the choice of the Photovoltaic modules it is necessary to select a felicitous type of Wind Turbine (from MERIT's database) since its multiples will embrace the core of the electrical load E_{El}. That Wind Turbines are known for their large capacities in kW will readily make them the framework of PES. To succeed such a selection we need to know the daily power requirement of the village. As we saw from P3.2.2 the Electrical Energy the Eco-Village requires for 1 year is:

$$E_{El_V} = 68{,}000kWh,$$

Or in 1 day

$$E_{El_V^1} = 186.30\,kWh$$

So the theoretical power that is required by PES, in one day, will be:

$$^{*}P_{El^1} = 7.76kW$$

This critical number can help us determine the kind of turbine for the PES framework. MERIT has a number of turbines in its database in different sizes (power outputs) ranging from $1kW$ to $1.3MW$. We can choose a 3 kW turbine or a 10 kW one since both of them are close to the value of $^{*}P_{El^1}$. It was proved by a roughcast MERIT experiment that the actual power that a turbine can offer is much less than the nominal power for a given type of electrical demand and the corresponding climatic profile. So with this tolling observation in hand we decided that a 10 kW turbine will provide better results when multiples will be required for the simulation. Thus the turbine type that we selected was the **LMW-10KW** model from the LMW Company. In that case we might need to make a small farm at the top of Thornylee hill. There is not much information about the company or the turbine itself on the internet [Reference: IS-19] except that where we found from the **Generation Type Definition Window** in MERIT database about the technical parameters of that turbine (Table 3.13)

Table 3.13/ Technical Characteristics for LMW**-10KW** turbine

Turbine Type			
Stall Regulated			
Power Curve Parameters (Density of Air: 1.225*Kg/m³*)			
Cut In Speed (m/s)	3	Power (kW)	0.01
Nominal Speed (m/s)	12	Power (kW)	10
Peak (m/s)	16	Power (kW)	10
Cut Out (m/s)	22	Power (kW)	5
Positioning Parameters			
Height above ground (m)		18	

To start the simulation in the form of experiments (Attempts) we firstly require the climatic model of the area that is to be simulated (P.3.1) and then a demand profile that would set the electrical or thermal conditions for the supply (in this case just electrical conditions). In MERIT's database there are a lot of fixed profiles for a number of possible situations – domestic and industrial (P.3.3.1). Unfortunately v.1.0 did not contain a profile that could assimilate the value of E_{El_V} and thus we looked at the database of the newest version v.2.2 to find any particular profile of good approximation. Indeed that we found in the database *"UK"* under *"Load Factor 0-20%"*. There were again many profiles but only one could approximate the E_{El_V} value and that was "*Variability 25% above Base Load*". So by comparison:

$$E_{El_V} = 68{,}000kWh,$$

And

$$E_{El_M} = 66{,}015.2 \; kWh$$

This is really not too unseasonable for representing the default demand and thus we accepted it for the simulation. Now that demand profile was set we only had to experiment with the REST to find out what results would we get on the subject of electrical matching. The experimental phase itself was a mixture of two complimentary phases' i.e. a preliminary phase (PP) and a main phase (MP). The first would allow an insight into the associations of demand-supply selections and would provide sound candidates for the introduction of batteries, whereas the second would integrate the selected candidates into completed patterns for comparisons and analysis. The PP was a set of 9 Attempts and the MP a set of 6. Below Tables 3.14a and 3.14b have the details for the PP and Table 3.15a and 3.15b for the MP. A detailed analysis of the two phases can be found at P.4.3.2.1 and P.4.3.2.2 respectively.

Table 3.14a/ Match Results for Preliminary Phase -Scenario 1, PP

Name of Experiment	**1st Attempt - Scenario 1**	**2nd Attempt - Scenario 1**
Characterisation Code	**1 Turb-No Aux. Electr. Recovery**	**2 Turb-No Aux. Electr. Recovery**
Assessment Parameters:		
Inequality	0.5432	0.4564
Correlation	0.105	0.105
Excess (KWh)	8321.17	27791.5
Deficit (KWh)	43649.6	32433.1
Current Match	Very Poor Match 4/10	Poor Match 5/10
Potential Match Rating	No significant improvement	With moderate storage : 8/10
Auxiliary System Performance	-	-
Name of Experiment	**3rd Attempt - Scenario 1**	**4th Attempt - Scenario 1**
Characterisation Code	**3 Turb-No Aux. Electr. Recovery**	**2 Turb+19 BP130L-No Aux. Electr. Recovery**

Assessment Parameters:		
Inequality	0.4906	0.4482
Correlation	0.105	0.1268
Excess (KWh)	53392.8	28555.9
Deficit (KWh)	27347.5	31262.9
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	With moderate storage 6/10	With moderate storage 9/10
Auxiliary System Performance	-	-
Name of Experiment	**5th Attempt - Scenario 1**	**6th Attempt - Scenario 1**
Characterisation Code	**2 Turb+38 BP130L-No Aux. Electr. Recovery**	**2 Turb+76 BP130L-No Aux. Electr. Recovery**
Assessment Parameters:		
Inequality	0.441	0.4293
Correlation	0.1478	0.1867
Excess (KWh)	29408.4	31364.8
Deficit (KWh)	30180.8	28267.9
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	With moderate storage 9/10	With moderate storage 9/10
Auxiliary System Performance	-	-
Name of Experiment	**7th Attempt - Scenario 1**	**8th Attempt - Scenario 1**
Characterisation Code	**2 Turb+100 BP130L-No Aux. Electr. Recovery**	**2 Turb+100 SM110-No Aux. Electr. Recovery**
Assessment Parameters:		
Inequality	0.4239	0.4302
Correlation	0.209	0.185
Excess (KWh)	32739.6	31240
Deficit (KWh)	27198.9	28404.2
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	With moderate storage 8/10	With moderate storage 9/10
Auxiliary System Performance	-	-
Name of Experiment	**9th Attempt - Scenario 1**	
Characterisation Code	**2 Turb+150 SM110-No Aux. Electr. Recovery**	
Assessment Parameters:		
Inequality	0.4222	
Correlation	0.2191	
Excess (KWh)	33364	
Deficit (KWh)	26789.6	
Current Match	Poor Match 5/10	
Potential Match Rating	With moderate storage 8/10	
Auxiliary System Performance	-	

Table 3.14b/ Analytical Record of MERIT Selection Parameters for REST –Scenario 1, PP

Name of Experiment	**1st Attempt - Scenario 1**	**2nd Attempt - Scenario 1**
Characterisation Code	**1Turb-No Aux. Electr. Recovery**	**2 Turb-No Aux. Electr. Recovery**
Discription:		
Turbines	• 1 LMW Turbine • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"
Photovoltaic Modules	N / A	N / A
Name of Experiment	**3rd Attempt - Scenario 1**	**4th Attempt - Scenario 1**
Characterisation Code	**3 Turb-No Aux. Electr. Recovery**	**2 Turb+19 BP130L-No Aux. Electr. Recovery**
Discription:		
Turbines	• 3 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"
Photovoltaic Modules	N / A	• 19 Units - BP130L • "Employ Daily Tilt Optimisation"
Name of Experiment	**5th Attempt - Scenario 1**	**6th Attempt - Scenario 1**
Characterisation Code	**2 Turb+38 BP130L-No Aux. Electr . Recovery**	**2 Turb+76 BP130L-No Aux. Electr. Recovery**
Discription:		
Turbines	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"
Photovoltaic Modules	• 38 Units - BP130L • "Employ Daily Tilt Optimisation"	• 76 Units - BP130L • "Employ Daily Tilt Optimisation"
Name of Experiment	**7th Attempt - Scenario 1**	**8th Attempt - Scenario 1**
Characterisation Code	**2 Turb+100 BP130L-No Aux. Electr. Recovery**	**2 Turb+100 SM110-No Aux. Electr. Recovery**
Discription:		
Turbines	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"
Photovoltaic Modules	• 100 Units - BP130L • "Employ Daily Tilt Optimisation"	• 100 Units – SM 110 • "Employ Daily Tilt Optimisation"

Name of Experiment	9th Attempt - Scenario 1	
Characterisation Code	2 Turb+150 SM110-No Aux. Electr. Recovery	
Discription:		
Turbines	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	
Photovoltaic Modules	• 100 Units – SM 110 • "Employ Daily Tilt Optimisation"	

Table 3.15a/ Match Results for Main Phase -Scenario 1, MP

Name of Experiment	10th Attempt - Scenario 1	11th Attempt - Scenario 1
Characterisation Code	**3 Turb -BB with C=2365Ah**	**3 Turb-BB with C=3931.2Ah**
Parameters:		
Inequality	0.417	0.4062
Correlation	0.3086	0.3361
Excess	35081.9	33929.1
Deficit	13580.2	11560.1
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	With increased storage 8/10	With increased storage 8/10
Auxiliary System Performance	Total Energy Loss:77684.59Ah	Total Energy Loss:89190.27Ah
	Total Energy Gained:65751.95Ah	Total Energy Gained:69413.05Ah
Name of Experiment	**12th Attempt - Scenario 1**	**13th Attempt - Scenario 1**
Characterisation Code	**2 Turb+76 BP130L-BB with C=2365Ah**	**2 Turb+76 BP130L-BB with C=3931.2Ah**
Parameters:		
Inequality	0.3336	0.3116
Correlation	0.4906	0.5494
Excess	15373.8	13951.6
Deficit	15322.2	13183.5
Current Match	Reasonable Match 6/10	Reasonable Match 6/10
Potential Match Rating	With increased storage 10/10	With increased storage 10/10
Auxiliary System Performance	Total Energy Loss:71376.9Ah	Total Energy Loss:83792.12Ah
	Total Energy Gained:59190Ah	Total Energy Gained:64045.06Ah
Name of Experiment	**14th Attempt - Scenario 1**	**15th Attempt - Scenario 1**
Characterisation Code	**2 Turb+100 SM110-BB with C=2365Ah**	**2 Turb+100 SM110-BB with C=3931.2Ah**
Parameters:		
Inequality	0.3336	0.3108
Correlation	0.4904	0.5517
Excess	15151.4	13646.4

Deficit	15388.2	13196
Current Match	Reasonable Match 6/10	Reasonable Match 6/10
Potential Match Rating	With increased storage 10/10	With increased storage 10/10
Auxiliary System Performance	Total Energy Loss:71819.50Ah	Total Energy Loss:84624.26Ah
	Total Energy Gained:59569.09Ah	Total Energy Gained:64720.13Ah

Table 3.15b/ Analytical Record of MERIT Selection Parameters for REST –Scenario 1, MP

Name of Experiment	**10th Attempt - Scenario 1**	**11th Attempt - Scenario 1**
Characterisation Code	**3 Turb-BB with C=2365Ah**	**3 Turb-BB with C=3931.2Ah**
Description:		
Turbines	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"
Photovoltaic Modules	N/A	N/A
Battery Bank	• 215Ah@12V • 18 in Series • 191 in Parallel	• 215Ah@12V • 18 in Series • 330 in Parallel
Name of Experiment	**12th Attempt - Scenario 1**	**13th Attempt - Scenario 1**
Characterisation Code	**2 Turb+76 BP130L-BB with C=2365Ah**	**2 Turb+76 BP130L-BB with C=3931.2Ah**
Description:		
Turbines	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"
Photovoltaic Modules	• 76 Units - BP130L • "Employ Daily Tilt Optimisation"	• 76 Units - BP130L • "Employ Daily Tilt Optimisation"
Battery Bank	• 215Ah@12V • 18 in Series • 191 in Parallel	• 215Ah@12V • 18 in Series • 330 in Parallel
Name of Experiment	**14th Attempt - Scenario 1**	**15th Attempt - Scenario 1**
Characterisation Code	**2 Turb+100 SM110-BB with C=2365Ah**	**2 Turb+100 SM110-BB with C=3931.2Ah**
Description:		
Turbines	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"	• 2 LMW Turbines • Terrain: "Open Agricultural with little Shelter" • Wind Speed Measurements: "Standard Meteorological Observations"

Photovoltaic Modules	• 100 Units – SM 110 • "Employ Daily Tilt Optimisation"	• 100 Units – SM 110 • "Employ Daily Tilt Optimisation"
Battery Bank	• 215Ah@12V • 18 in Series • 191 in Parallel	• 215Ah@12V • 18 in Series • 330 in Parallel

3.3.2.2. Scenario 2

From the four consecutive stages in MERIT (see P.3.3.1) only the first one –the *"Specify Analysis Conditions"* can be used as a main part for the two scenarios. After that stage there is a bifurcation between Scenario 1 and 2. In Scenario 2 instead of using a default database for the demand of the Eco-Village we used the *"Demand Profile Designer"* tool that is offered at the *"Specify Demand"* middle-phase control platform to construct an electricity profile for SES and then use the selected ReST as we did with Scenario 1 to simulate that profile. So in Scenario 2 the simulation will not be on the energy demand of the Eco-Village directly but on that of the Fuel Cell plant and more specifically of the Electrolyser since this is the only component of the Fuel Cell plant that is electrically connected to PES. Thus the electrical and thermal demands of the Eco-Village (E_{El} and E_{Th}) will be translated into electrical demand for the Electrolyser, over one year of operation, to provide the necessary fuel for the Fuel Cell that in continuant operation mode will supply the Eco-Village with electrical and thermal loads. Obviously some of the hydrogen fuel will be provided to the tanks so that an uninterruptible flow of energy occurs to the houses.

3.3.2.2.1 Fuel Cell Operating Modes

To make a more realistic simulation for the Fuel Cell plant we have to consider the fact that the latter will confront different loads over different seasons, which will vary the demand for hydrogen fuel and likewise the corresponding electrical demand for PES. Obviously there will be a difference in the E_D of the Eco-Village during the summer against that during the winter and that would apparently affect the operation of the Fuel Cell components. The solution that we thought about this problem was to make up a profile for the operation of the Fuel Cell in accordance to the seasonal demand for the village, which would be comprised by 3 different operation modes (OM) for the days of operation. The "Profile Designer" that MERIT possess (see P.3.3.1) allows for a partial representation of any energy demand for different periods by configuring…So we represented the 4 seasons by 4 Weekdays and 4 Weekend days and then we integrated that energy profiles over the year to get the demand for the Electrolyser demand. The 4 Weekdays and 4 Weekend energy consumption was determined by the OM of the Fuel Cell for the 4 seasons and that can be seen in Tables 3.16a, 3.16b and 3.16c below. We already know from (Eq.1) and (Eq.3) that:

$$E_D = 132{,}000kWh$$

$$^{*}P_{D^1} = \frac{361.64}{24} = 15kW$$

This is power we will use for the base-load demand of the Fuel Cell. The question is what can we use as sub-base load and peak-load demands? To answer that question we have to consider what will be an ideal size for the Fuel Cell relative to its Operational Capacity Range (OCR). Say for example that we have a 15kW and a 25kW Fuel Cell for the needs of the Eco-Village both reaching these watts at maximum operation (100% of OCR). Then at peak-load demand the 25kW Fuel Cell will have to work at 90% of its OCR to give 22.5kW whereas the 15kW Fuel Cell will have to work at 112.5% of its OCR to succeed the same power. So the first will a Capacity Cushion (CC) of 10% and the second a negative CC of -12.5%. This is not a satisfactory operation activity for the 15kW Fuel Cell, as it will strain its performance and possibly damage the module after some time, and so we have to choose the 25kW Fuel Cell for the E_D for the village. Thus the Operation Modes (OM) will be:

- OM_3 =Sub-Base Load=30%*25kW =7.5 kW
- OM_1 =Base Load= 60%*25 kW=15 kW
- OM_2 =Peak-Load=90%*25 kW=22.5 kW

For the base load we know the Fuel Cell requirements in terms of hydrogen fuel and the corresponding electricity for the Electrolyser (see P.3.2.1.1). We follow the same theoretical calculations to get the values of the same parameters for the three modes:

- OM_3 =3.93Nm^3/h, Electrical Demand for Electrolyser =19.65kW
- OM_1 =7.87Nm^3/h, Electrical Demand for Electrolyser= 39.35kWh
- OM_2 =11.80 Nm^3/h, Electrical Demand for Electrolyser =59kWh

Key for Colours	
OM1	Base Load = 25kW * 60% of total power = 15KW
OM2	Peak Load = 25kW * 90% of total power = 22.5KW
OM3	Sub-Base Load = 25kW * 30% of total power = 7.5KW

Table 3.16a/ Operating Modes for the Seasonal Profile- 1 Year

	Winter		**Spring**		**Summer**		**Automn**	
Number of Hours/Day	**Weekday**	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**
0	OM3	OM3	OM3	OM3	OM3	OM3	OM3	OM3
1	OM3	OM3	OM3	OM3	OM3	OM3	OM3	OM3
2	OM3	OM3	OM3	OM3	OM3	OM3	OM3	OM3
3	OM3	OM3	OM3	OM3	OM3	OM3	OM3	OM3
4	OM3	OM3	OM3	OM3	OM3	OM3	OM3	OM3
5	OM3	OM3	OM3	OM3	OM3	OM3	OM3	OM3
6	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
7	OM2	OM1	OM2	OM1	OM1	OM1	OM2	OM1
8	OM2	OM2	OM1	OM2	OM1	OM1	OM2	OM2
9	OM1	OM2	OM1	OM2	OM1	OM1	OM1	OM2
10	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
11	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
12	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
13	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
14	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
15	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
16	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
17	OM2	OM1	OM2	OM2	OM1	OM1	OM2	OM2
18	OM2	OM2	OM1	OM1	OM1	OM1	OM1	OM1
19	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
20	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
21	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
22	OM1	OM1	OM1	OM1	OM1	OM1	OM1	OM1
23	OM3	OM3	OM3	OM3	OM1	OM1	OM1	OM1

Table 3.16b/Corresponding Seasonal Energy Demand for Electrolyser (*kWh*)

	Winter		**Spring**		**Summer**		**Automn**	
Number of Hours/Day	**Week day**	**Week end**	**Weekda y**	**Weeke nd**	**Weekd ay**	**Weeken d**	**Weekday**	**Weekend**
0	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65
1	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65
2	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65
3	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65
4	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65
5	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65

6	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
7	59	39.35	59	39.35	39.35	39.35	59	39.35
8	59	59	39.35	59	39.35	39.35	59	59
9	39.35	59	39.35	59	39.35	39.35	39.35	59
10	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
11	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
12	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
13	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
14	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
15	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
16	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
17	59	39.35	59	59	39.35	39.35	59	59
18	59	59	39.35	39.35	39.35	39.35	39.35	39.35
19	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
20	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
21	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
22	39.35	39.35	39.35	39.35	39.35	39.35	39.35	39.35
23	19.65	19.65	19.65	19.65	39.35	39.35	39.35	39.35

Table 3.16c/ Corresponding Seasonal Hydrogen Demand for Electrolyser (Nm^3/h)

	Winter		Spring		Summer		Automn	
Number of Hours/Day	**Weekday**	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**
0	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93
1	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93
2	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93
3	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93
4	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93
5	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93
6	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
7	11.8	7.87	11.8	7.87	7.87	7.87	11.8	7.87
8	11.8	11.8	7.87	11.8	7.87	7.87	11.8	11.8
9	7.87	11.8	7.87	11.8	7.87	7.87	7.87	11.8
10	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
11	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
12	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
13	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
14	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
15	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
16	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
17	11.8	7.87	11.8	11.8	7.87	7.87	11.8	11.8

18	11.8	11.8	7.87	7.87	7.87	7.87	7.87	7.87
19	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
20	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
21	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
22	7.87	7.87	7.87	7.87	7.87	7.87	7.87	7.87
23	3.93	3.93	3.93	3.93	7.87	7.87	7.87	7.87

3.3.2.2.2 "Demand Profile Designer" and "Specify Demand" Numerical Configurations

For *"Demand Profile Designer"* numerical configurations we need to look back at P.3.3.1 for a basic knowledge of the environment that the user will come across when trying to define a demand profile. In this case we firstly set the number of days for the demand profile by choosing the *"Standard Tab"* (See P.3.3.1). According to the requirements of the Fuel Cell operating modes these had to be Weekday 1-4 and Weekend 1-4 for the four seasons. The parameters were set as described below in Table 3.17. Then the *"Profile Effects Tab"* had to be structured and arranged.

Table 3.17/ Parameters for *"Demand Profile Designer"*

"Week Days"-Tabs Recordings				
Parameters	**Weekday 1**	**Weekday 2**	**Weekday 3**	**Weekday4**
"Daily Consumption" in KWh	885.1	845.8	752.325	870.375
"Apply Profile to Days"	M,T,W,T,F			
"Apply Profile to Period"	01/01-31/03	01/04-30/06	01/07-30/09	01/10-31/12
	Weekend1	**Weekend2**	**Weekend3**	**Weekday4**
"Daily Consumption" in KWh	865.45	865.45	747.4	885.15
"Apply Profile to Days"	M,T,W,T,F			
"Apply Profile to Period"	01/01-31/03	01/04-30/06	01/07-30/09	01/10-31/12
"Profile Effect" -Tab Recordings				
"Treatment of Undifined Periods"	1st Option: Interpolate between defined periods			
"%Variabilty"	2nd Option: Apply to whole profile			
"Temperature Effects"	N/A			
"Daylight Effects"	4th Option: Stretch profile with daylight hour			

For the *"Profile Effect"* tab we came across a difficulty to choose how much should we set the *"%Variability"* to produce a realistic profile. By inspection we had:

- *"%Variability"*=0% then Total Annual Consumption=296,926*kWh*
- *"%Variability"*=2.5% then Total Annual Consumption=306.432*kWh*
- *"%Variability"*=8% then Total Annual Consumption=421,976*kWh*

The second choice seemed the most appropriate. Then we saved the template and we generated an annual profile with the *"Generate Annual"* button to get the demand for the electrolyser. The total demand was 306,839*kWh* with all the effects of the *"Profile Effect"* tab on. This was a relatively large value (almost the double) compared with that of Equation 1 that specified E_D = 132,000 *kWh*. This indicated that the analysis on the OM was overestimated and it had to be scaled for a realist simulation. We modified this result by using the *"Annual Consumption"* feature in the **Demand Definition Window** (See Figure 3.10) to integrate the 306,839*kWh* to 132,000 *kWh* and that was the final value for the simulation.

After all the necessary numerical configurations for the *"Specify Demand"* stage of Scenario 2 were completed we began the selection of ReST for the electrical demand of the Eco-Village. As for Scenario 1 we used the **LMW-10KW** turbine model from MERIT's database and the **BP130L** and **SM110** photovoltaic modules for the experiments of Scenario 2. The only difference was the insertion of a 3 *kW* turbine to adjust the matching as a means of improvement measures. The phase was completed with 8 experiments (Attempts) which can be seen in Tables 3.18a and 3.18b below.

Table 3.18a/ Match Results for Scenario 2

Name of Experiment	**16th Attempt - Scenario 2**	**17th Attempt - Scenario 2**
Characterisation	2Turb-No Aux Electr Recovery	4Turb-No Aux Electr Recovery
	Parameters:	
Inequality	0.45	0.4066
Correlation	0.1182	0.1182
Excess	7800.07	49666.4
Deficit	78424.3	58917
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	No significant improvement	With moderate storage 8/10
Auxiliary System Performance		
Name of Experiment	**18th Attempt - Scenario 2**	**19th Attempt - Scenario 2**
Characterisation	5Turb-No Aux Electr Recovery	4 Turb+8 BP130L-No Aux Electr Rec
	Parameters:	
Inequality	0.4414	0.4059
Correlation	0.1182	0.1203
Excess	75668.1	50076.6
Deficit	54231.8	58512.7
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	With moderate storage 8/10	With moderate storage 8/10
Auxiliary System		

Performance		
Name of Experiment	**20th Attempt - Scenario 2**	**21st Attempt - Scenario 2**
Characterisation	4 Turb+15 BP130L-No Aux Electr Rec	4 Turb+40 BP130L-No Aux Electr Rec
Parameters:		
Inequality	0.4053	0.4035
Correlation	0.1221	0.1285
Excess	50439.1	51769.5
Deficit	58162.3	56947.1
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	With moderate storage 8/10	With moderate storage 9/10
Auxiliary System Performance		
Name of Experiment	**22nd Attempt - Scenario 2**	**23rd Attempt - Scenario 2**
Characterisation	4 Turb+40 BP130L+1Turb-No Aux Electr Rec	4 Turb+20 BP130L+1Turb-No Aux Electr Rec
Parameters:		
Inequality	0.4129	0.4138
Correlation	0.128	0.1233
Excess	59780.2	58672.5
Deficit	55097.6	56026.4
Current Match	Poor Match 5/10	Poor Match 5/10
Potential Match Rating	With moderate storage 9/10	With moderate storage 9/10
Auxiliary System Performance		

End of Chapter 3

Chapter 4-Discussion

It is necessary for the reader to understand the analysis of the experiments of the previous chapter in order to modulate a complete idea about their actual conductance. Any of the results taken throughout this project were assessed for their integrity and to specify if either their modulation was required or their status was rigid enough to provide a solution. That was the tactic overall.

4.1 Climatic Analysis

The choice of appropriate stations with the essential climatic information was not easy at all since most of them were not referring to the area of study (Thornylee Forest) or the year of examination. We had to improvise techniques to bypass these difficulties with reasonable assumptions that would lead to a compromise between the problems faced and the conductance of the simulation.

4.1.1 Evaluation Process Remarks

From the last chapter we met the evaluation process for screening a number of stations to a working level. Via this process we could actually find out the quality of weather data that the stations under examination were endowed with and to identify their potential for a prolific application concerning the construction of the climatic file. From this process we could distinguish the veins and impasses of the Domains of the File Formats to a practical extend that decisions could be made about the formation of the climatic file for MERIT. Some of the remarks in this section will be upon the results of Table 3.7 and some other will come from the generic contact that the author had with the Domains in the BADC databases for the qualified stations of the evaluation stage – these can be identified by the Association number as found in the before mentioned table.

Referring to Table 3.7, we can identify two stations with the highest total score (8) readily discerning amongst the other 9 stations. This is the result of two facts. Both of the stations have a complete observations record for the three File Formats that we were looking for (*.hwx*, *.radt* and *.wind)* and since the quality of these fomats is important as well both of them have the most appropriate type of data structures i.e. ***{1}, {5}, {6}, {7} {9}, {13}, {10,*** jointly. These structures are rendered with the highest Ordinance – Table 3.6. When Availability is concerned we can see again from Table 3.7 that Eskdalemuir and Drumalbin Saws have up-to-date weather records, another useful point when flexibility of utilization is regarded. Thus very rightfully these two stations can qualify for any use in the construction of the MERIT climatic file. The ReST of the 9 stations are deemed inadequate for this scope for low scoring or for small QPA. The only exception will be made for Chartehall Saws since it is the only station with a *.radt* file and that is very important since most of the *.radt* files that were examined had high inconsistencies and deficiencies in registering radiation data. Having said that, we can now present the problems of information flaws in registering radiation data and the dilemma of choosing stations for wind values (relative to their advantageous distance to the Thornylee Forest) or to their similitude with climatic measurements that MERIT requires i.e. on a 1h-basis measurement steps on 24h/daily cycles.

4.1.1.1 Radiation Problems

With the examination of 10 *Domains* for 11 stations we observed inconsistencies and deficiencies in registering radiation data. For the construction of MERIT climatic file we require 6 fields (see P.3.1.5). For radiation fields the file must be completed with diffuse solar intensity (I_d) on the horizontal and direct normal solar intensity (I_n) values in 1 hour steps. But the three stations with radiation records (***Rad1***, ***Rad2*** and ***Rad3*** – Association Numbers) can hardly provide these data since these values are not embodied into the BADC files. The value *-999* (BADC's way to declare a missing value) was stated under the diffuse solar intensity on the horizontal and direct normal solar intensity columns in the data records. Global radiation was recorded but unfortunately we could not exploit that as we need other factors to make up the other two parameters only from that radiation values. As a solution to this problem was to extend the search of radiation File Formats to even more remote counties from Peeblesshire with the hope of finding Domains with a better register on the I_d and I_n values. That searching process can be found in P.3.1.4. Unfortunately this had not the predictable outcome that we hoped for and so a third solution was to be given to the problem.

With the help of an academic staff within the department we managed to acquire a radiation file with vital information upon the crucial solar intensity values (I_d and I_n values). The station providing this information was Eskdalemuir for the year 1978, we could not find the same information at the BADC databases ourselves. The great thing about this climatic file was that since it was used by some other weather-data intensive software within the ESRU department (ESP-r) it was already modified in the required MERIT configuration since the two are using the same architecture of translating weather information into electronic climatic files. According to the objective of the project for a realistic simulation using a radiation file with meteorological observations from a different area (Dumfriesshire County) and from a different time scale (24 years before) are two discrepancies that we have to compromise effectively in order to stay on line with that objective. This compromise will be based on the two assumptions that state respectively:

A1: “When referring to solar insolation affecting a relatively small geographical area of a country we can assume that localised geographical radiation phenomena will fuse into solid irradiation behaviour within the boundaries of the enclosed area of study”.

A2: “When referring to solar insolation affecting a relatively small period of time we can assume that seasonally localised geographical radiation phenomena will stay unaffected within the boundaries of that time scale”.

These assumptions would simplify the problem of using a climatic file with meteorological observations from another area and another time, such as the ambiguous file of Eskdalemuir that we possessed. These assumptions are obviously not a robust scientific approach to the problem but they can help us bypass the latter without the risk of terminate the project. Thus they were a significant compromise to the issue of climatic information. What those assumptions simply state is that, for **A1**, the 19,800 Km^2 of the area of study (that is **Delimitation Plan-A** and **B** including Glasgow where we finally got the climatic file for the simulation- see P????) are really small compared to the 78,783 Km^2 of Scotland’s mainland and, for **A2**, a time scale of 30-50 years would be effectively small compared to 100 or 200 years of possible climatic change of a place.

4.1.1.2 Wind Speed Problems

The problem with the wind speed value is of a different nature to the radiation problem. In this case we could get valid measurements from the 11 stations of the Evaluation phase but stations close to the Thornylee Forest had recordings on a 24*h* steps for each day (***W1, W2, W3, W4, W5, W6, W7, and W8*** – Association Numbers) whereas the two stations on the more remote areas (***Rad1*** and ***Rad2*** – Association Numbers) were of the desired format, 1h steps for each day. The binding requirement for a realistic simulation is dictating for wind speed measurements at the area of Thornylee Forest but that it is not possible in our case. Thus like before a compromise but be established for allowing a safe conduct of the product. Assumption 3 below states the conditions for using the *.wind* data from stations ***Rad1*** and ***Rad2*** i.e. those with the most attractive parametrical format (Table 5 and 6 in Chapter 3).

A3: “If any sites have the same morphological and climatic characteristics with the site under climatic examination and belong to a homogeneous geographical area with that target area, they can be deemed as reasonably connatural to the natural weather behaviour of the critical area”.

In simpler words that assumption can allow for a more flexible approach to the selection of a station with the required wind parameters (speed and direction) remote from the area of study under the conditions that the remote area has more or less identical characteristics in its morphology with the target area and that its global and particular climatic demeanour is essentially streamlined to that of the target area (provided that the region for both of the stations is homogeneous). In our case the morphological problem would be translated in similarities in elevation between any areas of consideration and Thornylee Forest, the particular climatic demeanour in divergence of the annual values for average wind speed between any areas of consideration and Thornylee Forest, and the global climatic demeanour in comparison of two seasonal weather profiles for two random years. With this in hand we devised a CEACP approach described in P.3.1.4 for the two top stations ***Rad1*** and ***Rad2***, as these were the most effective stations wind-wise in order to select the most efficient for wind data.

As we can see from Table 3.8 it is clear that by Step 2 the comparison is very vague since the elevation and distance values are almost the same and so there are no clear judgment factors for a sound selection. At Step 3 though we have the necessary bias for a decision towards Eskdalemuir station since the average wind speed of the latter is closest to the value of $10m/s$ that the Thornylee Forest has. This reason is quite sufficient in justifying the use of this station since the process is made for obtaining wind data and such an inclination towards the critical value of $10m/s$ is a valid proof for such a decision. So since we have selected ESKDALEMUIR for wind data we need to test its climatic match with the weather at Thornylee Forest. But from P.3.1.4 we know that there is no such station in that area to give us meteorological observations and the closest is Bowhill station. Tables 3 and 4 in Appendix A have the details of the local meteorological measurements and from these tables we can make up graphs leading to tangible means of comparisons for the climatic behaviour of the areas around the stations. Below in Figures 4.1a, 4.1b, 4.2a, 4.2b, 4.3a and 4.3b we are presenting only six graphs out of the ten possible, for just three of the parameters namely wind speed, visibility and temperature, leaving the other two out of this text for reasons of convenience. A quick examination of the figures will show inconformity between the climatic parameters for the chosen years. Wind speed and dry bulb temperature are almost following the same pattern for the two stations, for both of the years and this is essentially the critical point of validating the choice of Eskdalemuir and verifying the assumption **A3**. Visibility's graphs are truly very different between the two stations but compared with the graphs of the other two parameters, which have identical pattern configurations and are not shown here (total cloud amount and wind speed direction), they can be overlooked in the greater vision. So to finalise, the important weather parameters have few discrepancies and that is acceptable for continuing the weather profile configuration with wind data coming from Eskdalemuir station.

Figure 4.1a/ Dry Bulb Temperature comparative chart for 1994

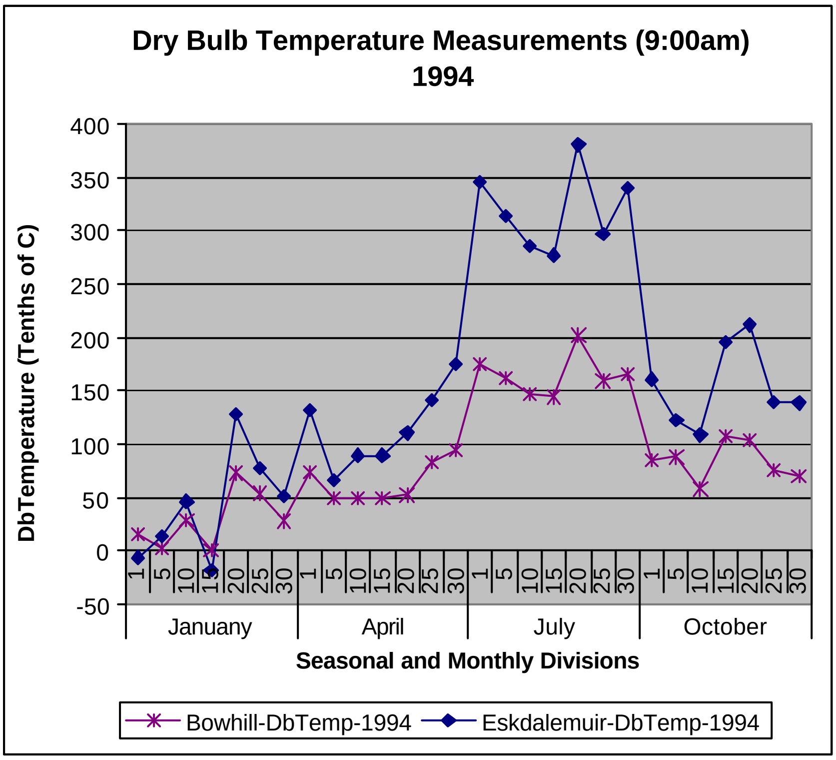


Figure 4.1b/ Dry Bulb Temperature comparative chart for 1997

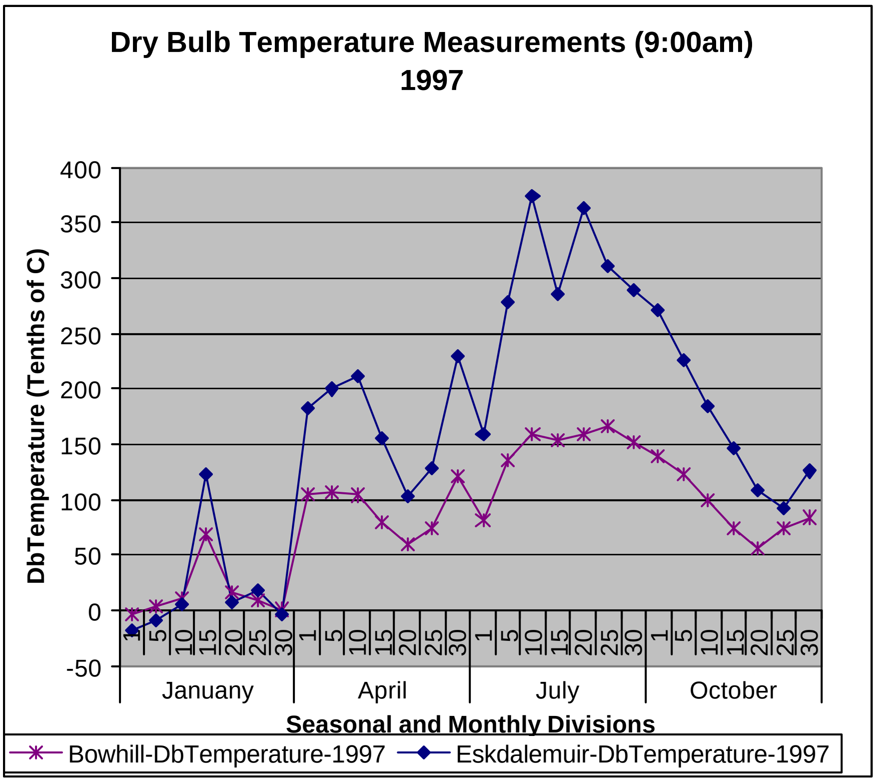


Figure 4.2a/ Visibility comparative chart for 1994

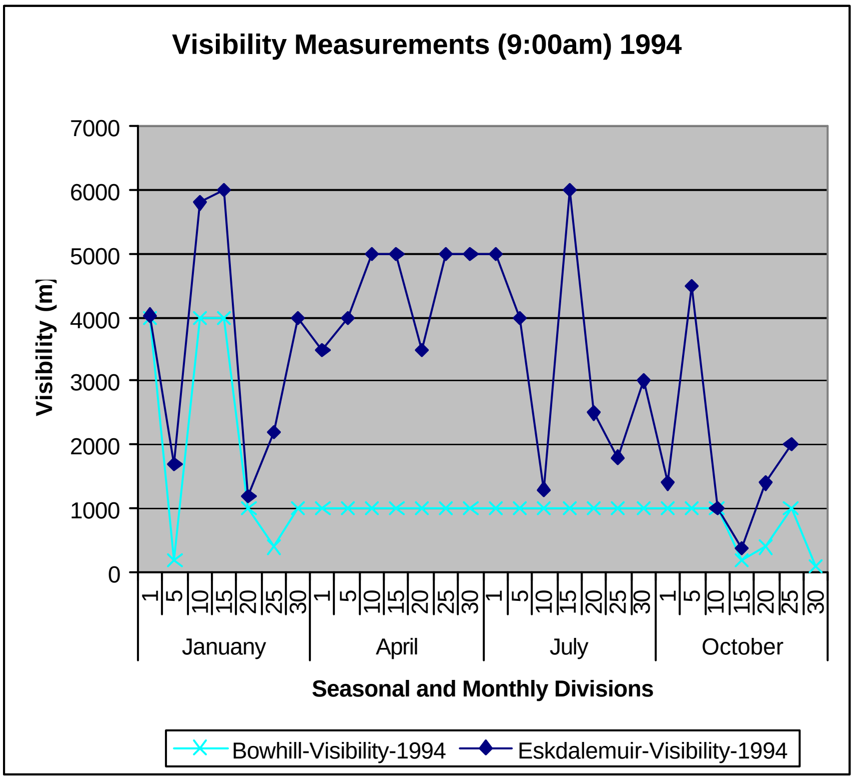


Figure 4.2b/ Visibility comparative chart for 1997

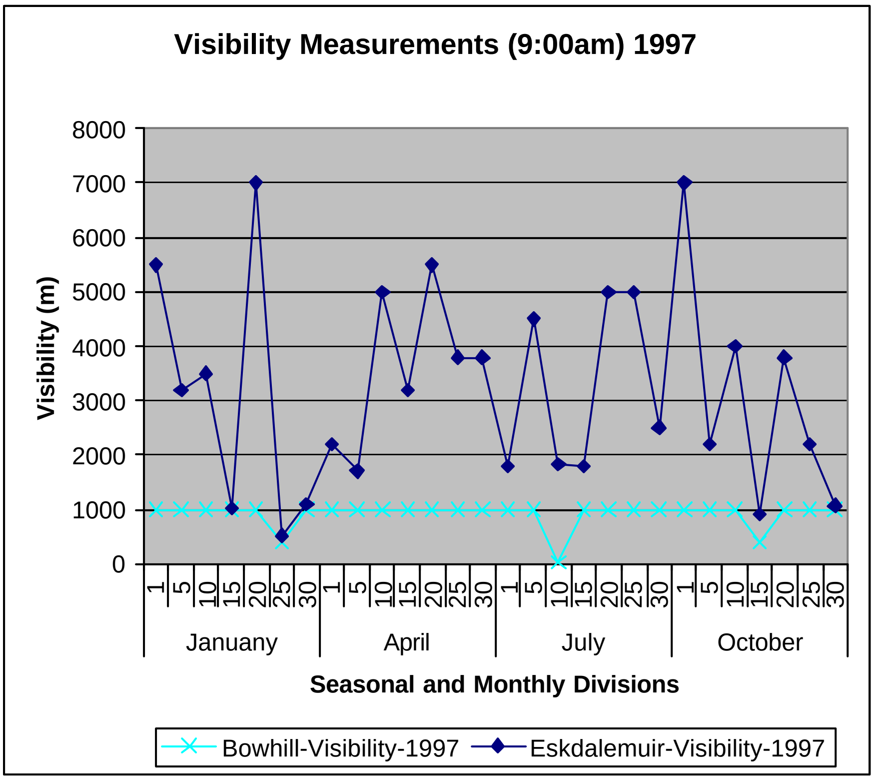


Figure 4.3a/ Wind Speed comparative chart for 1994

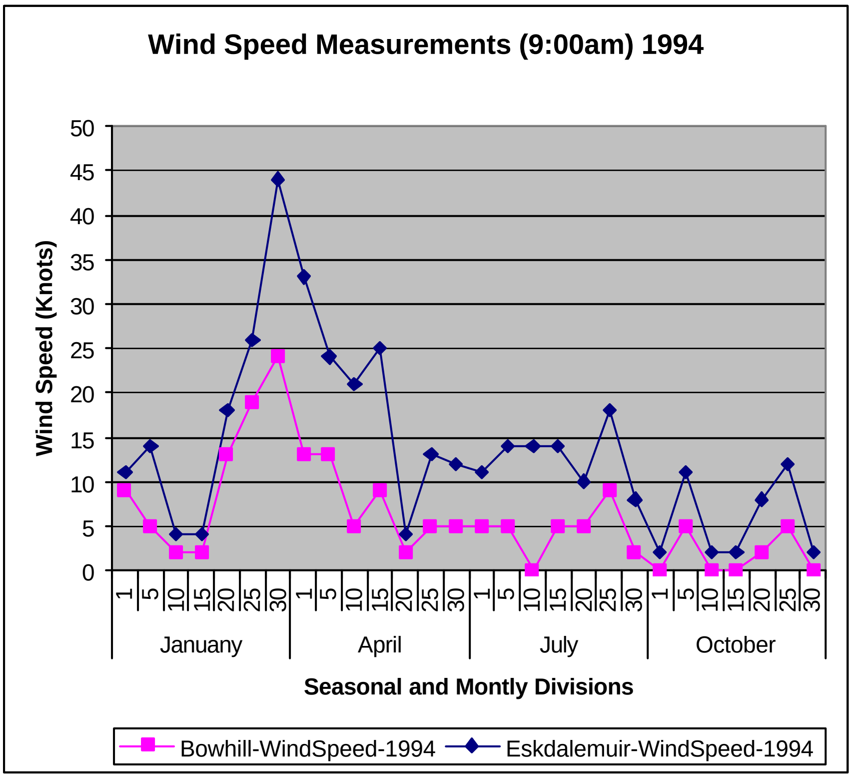
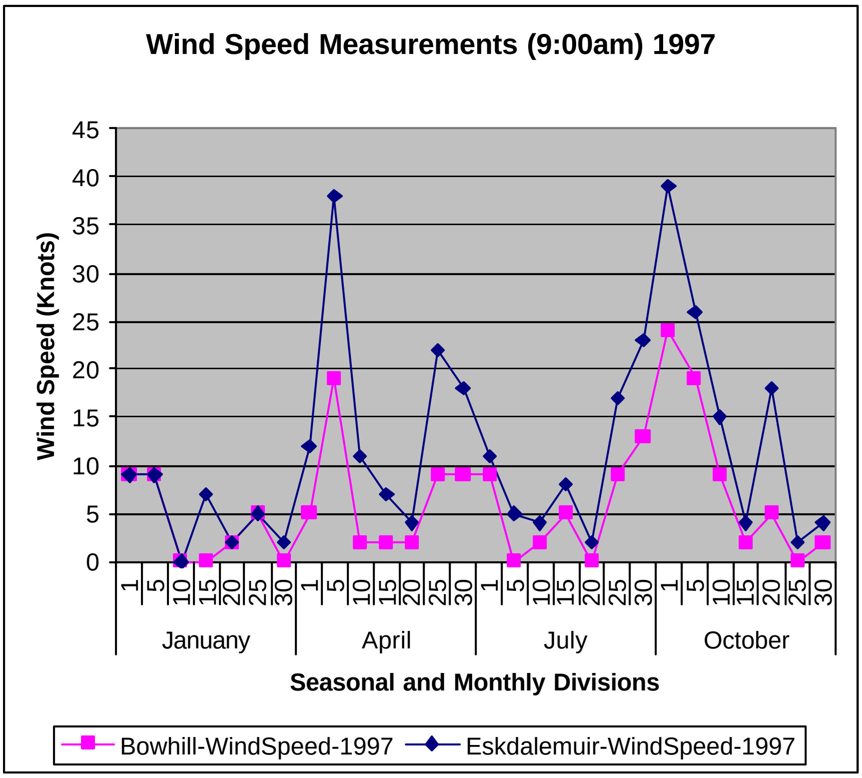


Figure 4.3b/ Wind Speed comparative chart for 1997



4.1.2 Formation Process Commentaries

From the last chapter in P.3.1.5 we saw the final phase of the meteorological methodology devised for the production of the climatic file that MERIT needs to integrate a simulation between renewable technologies and demand of the Eco-village but the reality was somewhat cruel with the outcome of such a process. On trying to use the *Esk(97).clm* file in trials to verify its successful conversion with the *CreateClimate.exe* module all of them where disappointing and none would prove that we could use this file for the simulation. Since this file was created after a long and arduous process we tried to identify the problem by making variations of the *Esk(97).clm* file and checking for mistakes on the creation and the conversion of the latter in different stages and the signs would prove that upon the *CreateClimate.exe* module was immolating the data from the *Eskdalemuir1997Final.csv* into the *Esk(97).clm* file. That was an imponderable and unexpected occurrence that left us no other choice that to drop the actual conversion and accept the build-in climate databases that MERIT occupied to run the simulation. Of the two possible choices for the final selection (*Kew.clm* and *Glasgow.clm*) there is none that can satisfy the requirement for a realistic simulation and there is no obvious way of making up assumptions this time to defend any of the two files. It is clear that this time a more important compromise would have to be made that would allow us to continue this project or to terminate it. Since the second choice is not acceptable we need to accept to run the simulation even with a climatic file from a totally different area and time and to try to derive technical results for the aims and objectives of the project following this critical compromise that they would not be based at all on the sensitivity of the weather. Paragraph 3.1.5.1 has the final details of the final selection between the two candidate files.

4.2 Scenarios- Results Analysis

The two scenarios devised were a mixture of knowledge, mathematical guidelines and intuition. Their technical shaping was progressively established to describe the two possible situations of energy distribution at the Eco-Village and by the energy demand and supply signatures their matching would prove their applicability. At the end it was MERIT that decided if our actions were valid by approving or disapproving their integrity.

4.2.1 Software Elucidations

Since the analysis of this project is based upon a software simulation processing, the problems of compatibility, between the operating system (OS) and the software version on one hand, and software vigorousness, in terms of "bugs" on the other, were to apply in this analysis to the extend of influencing some decisions and selections.

In more details the newest version 2.2 in the author's computer could not perform vital operations like the very important *"Saving Project"* represented by one of the right-hand-side-column buttons in the **Main Program Window** (See P.3.3.1). It would be really inapprehensible to try to move on any further since this very essential operation was not occurring. Had we moved on though, we would have fallen onto more of the aforementioned problems just enough to make our life even harder than what we already were experiencing. With some special arrangements we managed to save some files into the directories of MERIT but this time the *"Open"* operation in the *"File"* menu would not work. At this point we abandoned any more experimentation with the v.2.2 and we thought that if we could work the *"CreateClimate.exe"* component/program we might be able to use it with the v.1.1 of MERIT and proceed in this way. But things did not went as we hoped once more; the conversion of the created climatic file was not succeeding and that the reason to exclude it from the simulation. In spite of these algorithmic problems though, that prevented a thorough utilisation of that version, v.2.2 had a much better inventory for REST, updated and with more combinations available, so this is were we would get the electrical demand profile for the Scenario 1. Version v.1.1 may was much more stable but that did not mean that it was impeccable. In the *"Match and Dispatch"* platform (See P.3.3.1) for the main phase of Scenario 1 (see below P.4.2.2.1) it would not save any of the graph data that were produced during that experiments resulting in insufficient experiments exhibits for the readers to assess for themselves these experiments. Apart from that minor problem, there were no other serious problems on using the program except a few crashes and freezes throughout the experiments but nothing serious in the overall behaviour. But quite reasonably these crashes could be a part of an interrelated nature of incompatibility problems and not absolutely from MERIT part.

4.2.2 Scenarios Design- Result Analysis

For all the experiments (Attempts) of the two scenarios there was a Central Guidance Panel (CGP) with 5 indicators that helped us proceed with the experiments and reach the most appropriate results for an efficient integration of REST with the Eco-Village energy demands. These indicators are rendered in Merit's last processing component ("*Match and Dispatch*") as we presented in P.3.3.1 and their value is reflecting a holistic assistance by the software to the user to identify and scrutinize the selections of demand-supply variations-combinations according to their relative importance to the aims of the experiments. Had these indicators been inexistent there would be no way to pick the right variations-combinations. In our case we used these indicators differently for each one scenario. In Scenario 1 we gave a weighted ordinance to them according to the aims of designing that scenario, which was different from the ordinance that was assigned for Scenario 2. The reason for doing such discrimination was to ascertain that only justified trial and error variations-combinations were approved for the final assessments. So for Scenario 1 we determined CGP-1 and for Scenario 2 CGP-2 respectively.

Table 4.1/ Central Guidance Panel

CGP-1	Requirements	CGP-2	Requirements
1st. *"Current Match"*	As high as possible with minimum value of 5/10	1st. *"Current Match"*	As high as possible with minimum value of 5/10
2nd. *"Potential Match Rating"*	As high as possible with minimum value of 6/10	2nd. *"Deficit"-"Excess"*	→0
3rd. *"Deficit"-"Excess"*	<0	3rd. *"Inequality"*	As low as possible
4th. *"Inequality"*	As low as possible	4th. *"Correlation"*	As high as possible
5th. *"Correlation"*	As high as possible	5th. *"Potential Match Rating"*	As high as possible with minimum value of 6/10

4.2.2.1 Scenario 1

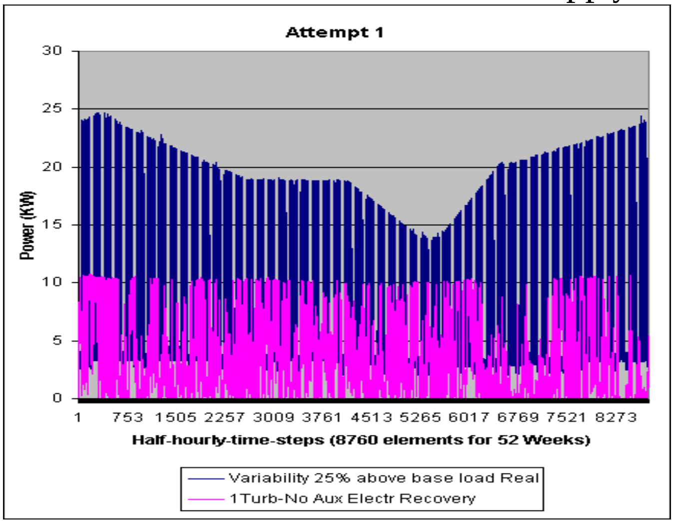
As we saw in P.3.3.2.1 Scenario 1 has two phases to completion. All the experiments (Attempts) are described at Tables 3.14a and 3.14b for the PP and Tables 15a and 15b for MP. In this paragraph we will explain all the background analysis that followed each Attempt for PP in order to reach the candidates for the MP and satisfy this design by another set of Attempts to the final selection of efficient ReST numbers and combinations for a satisfactory integration with the Eco-Village electricity demands. The PP has the role of manifesting Attempts with the best CGP-1 indicators but as well as the other will contribute to the best candidates the third one is the one of extreme importance since it will illuminate the Attempt with enough energy to charge the battery bank (BB) and is respected for that reason. Thus what we will expect from any Attempts performed is to find one with the biggest possible condition *Deficit-Excess* < 0 for all of the rest of indicators satisfied.

4.2.2.1.1 Preliminary Phase for Scenario 1

Attempt 1-PP

Beginning with Attempt 1 (experimental evidence can be found at Table 3.14a and 3.14b) we drew near the supply selection for Scenario 1 by following the ${}^{*}P_{El^1}$ value (P.3.3.2.1) and so selecting a single **LMW-10KW** turbine for the first experiment as the theoretical value of the turbine was close to the value of ${}^{*}P_{El^1}$. Following the ordinance for CGP-1 indicators and from Table 3.14a and 3.14b we can see that the *Current Match* indicator is really too low (4/10) and so since this is the first criterion in the CGP-1 we leave this Attempt. Moving on to the Attempt 2 the thought is that since from Attempt 1 there is *Deficit-Excess*=35,328.43*kWh*>0 amount of energy(See P.3.3.1) we should better increase the number of turbines to succeed negative value i.e. more of *Excess* energy. Thus in this case there were two **LMW-10KW** turbines for the supply.

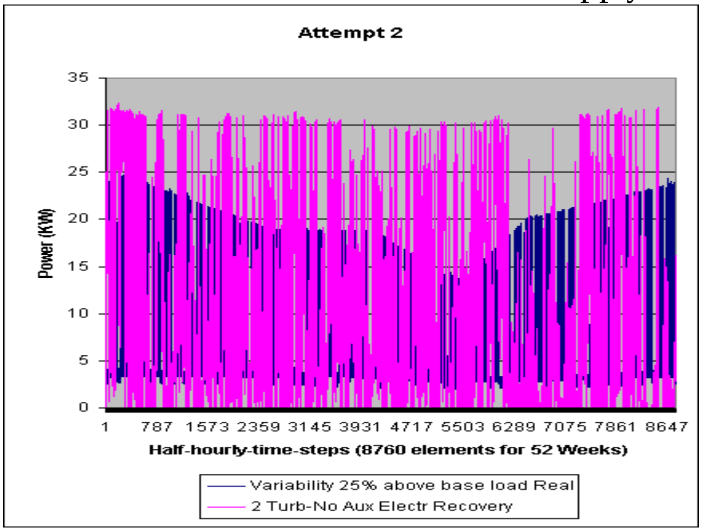
Figure 4.4/ Power curves for the Demand and Supply of Attempt 1



Attempt 2-PP

Here the *Current Match* indicator is improved to 5/10 and the *Potential Match Rating* is also improved to 8/10. Also the *Deficit-Excess*= 4,641.6*kWh* difference is still positive but it is significantly decreased from the last Attempt. As again as with the previous case we will perform Attempt 3 with a further increase in energy supply which will be coming from three **LMW-10KW** turbines.

Figure 4.5/ Power curves for the Demand and Supply of Attempt 2



Attempt 3-PP

The results in this case are in favour of an extremely large *Deficit-Excess* value (-26,045.3kWh) and more importantly of negative sign which means that the 3rd indicator is satisfied. The 1st indicator is also satisfied ($5/10$) and so is the 2nd ($6/10$). From the 4th and 5th indicator examination we can choose upon the next attempt. From CGP-1 we want 4th indicator to be as low as possible or between Attempt 2 and 3 to decrease, but it was not and also the 5th to be low as possible but this was kept invariable. From P.3.3.1 we know that the *Inequality* index symbolises the difference in the phase for demand-supply profiles and so we hope that by the introduction of Photovoltaic modules will be able to improve this difference. Another reason of why we were to choose to introduce Photovoltaic modules and not a smaller wind turbine for example is that the latter produces bigger vaults in the *Deficit-Excess* values (for Attempt 2 it was: 4,641.6kWh and for Attempt 3: -26,045.3kWh) and so with Photovoltaic units will help us to control better the 4th index. Apart from the experimental actuation for introduction of Photovoltaic units there are two other reasons for doing so. One is stemming from the objectives of the project (for a backup system that would secure PES from shutting down completely) and the other is simply technical orientated since PVs are a very mature technology to be overlooked. So how did we choose for any possible photovoltaic combinations? First of all if we look back at Attempt 2 we will see that it has a better 5th indicator according to that of Attempt 3. Thus we will use Attempt 2 as the building block for a possible combination dock for photovoltaic units. So

$$Deficit\text{-}Excess = 4{,}641.6\,KWh \text{ and since}$$

$$E_{El_M} = 66015.2\ KWh$$

We want photovoltaic modules to cover at least a quarter of that energy for a safe PES operation. Therefore:

$$E_{El_{Photovoltaics}} = \frac{E_{El_M}}{4} + Deficit\text{-}Excess$$

Or,

$$E_{El_{Photovoltaics}} = 21{,}145.75\ kWh$$

And so the theoretical expected power from the photovoltaic modules will be for one day:

$$^{*}P_{El^{1}_{PV-Sc.1}} = 2{,}413.8\,W$$

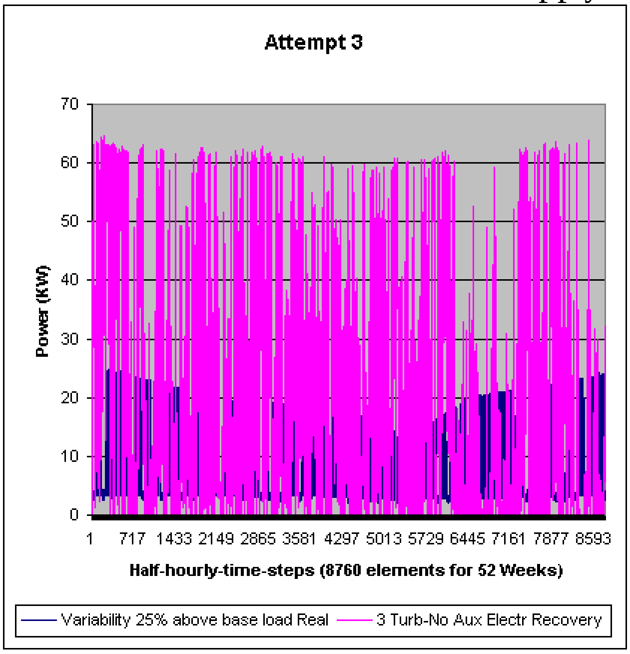
From MERIT database we can choose two possible models that are the **BP130L** and the **SM110**. These are the two top models in the range with the highest efficiencies and power outputs. Briefly we can see some of their characteristics in Table 4.2 below (more can be found in MERIT's database).

Table 4.2/ Technical Specifications for the PV modules

	BP130L	**SM110**
Nominal Efficiency	11.6%	12.66%
Open Circuit Voltage	36	21.7
Short Circuit Voltage	4.8	6.9
Number of Series Connected	72	72
Number of Parallel Connected	1	1
Power Output	130W	110W

So if we are to use these modules, and/or their multiples, then we need to know how many do we need theoretically to configure Attempt 4. Simply divide ${}^{*}P_{El^{1}_{PV-Sc.1}}$ by their power output and get: For **BP130L** =19 units and for the **SM110**=22 units.

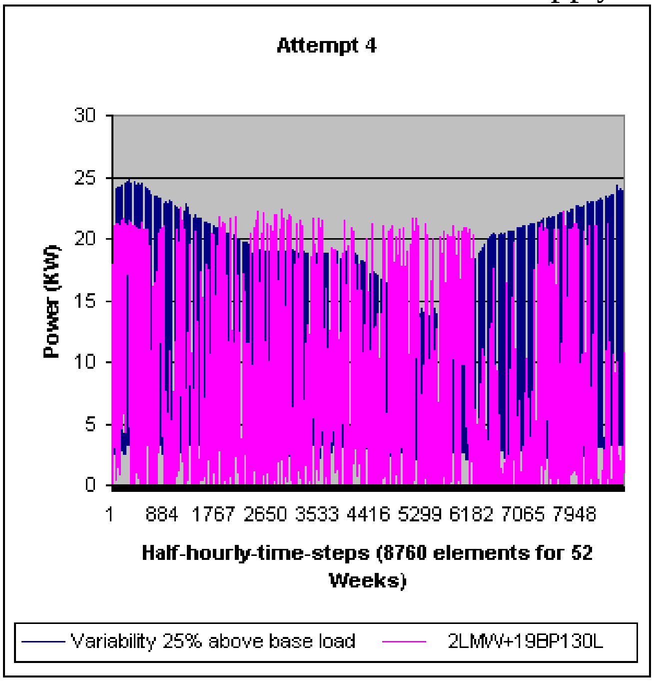
Figure 4.6/ Power curves for the Demand and Supply for Attempt 3



Attempt 4-PP

We initiated the combined PES experiments with **BP130L**, 19 from them, to see how the previous values for indicators for Attempt 2 would behave. Again Tables 13a and 13b have the details for selection parameters. The 1st indicator was unchanged; the 2nd had a marginal increase of 1 point (9/10) and the 4th and 5th were marginally improved according to the CGP-1 requirements. The 3rd indicator though had still not improved very much, as was expected, from Attempt 2 (*Deficit-Excess* = 4,641.6kWh before vs. 2,707kWh now). So in a similar action to the first three Attempts we will increase the number of photovoltaic modules until a dramatic, significant change happens to the indicators.

Figure 4.7/ Power curves for the Demand and Supply for Attempt 4



Attempts 5 6 and 7-PP

In Attempt 5 we doubled the number of **BP130L** to 38 but still the same trends were present for the 1st, 2nd 4th and 5th with an exception for the *Deficit-Excess* energy difference fluctuating at -772.8 kWh, which was too far away from the $E_{El_{Photovoltaics}}$ value that we had theoretically defined previously. So again for Attempt 6 we increased the number of **BP130L** to 76 and apart form a change in the third indicator (*Deficit-Excess* = -3,096.9kWh) again all other indicators were obeying a good potential swing but did not present a significant change. Especially for the 1st and 2nd indicators the results for Attempts 5 and 6 were static. Then in Attempt 7 it decreased to 8/10 and this were we stopped the augmentation of **BP130L** finalising with 100 units.

From the last three Attempts we realise that the $E_{El_{Photovoltaics}}$ as is required by the theoretical hypothesis for a secure backup supply (from the photovoltaic systems) will not be met unless we drop the 2nd indicator, which no such violation is allowed from CGP.

Figure 4.8/ Power curves for the Demand and Supply for Attempt 5

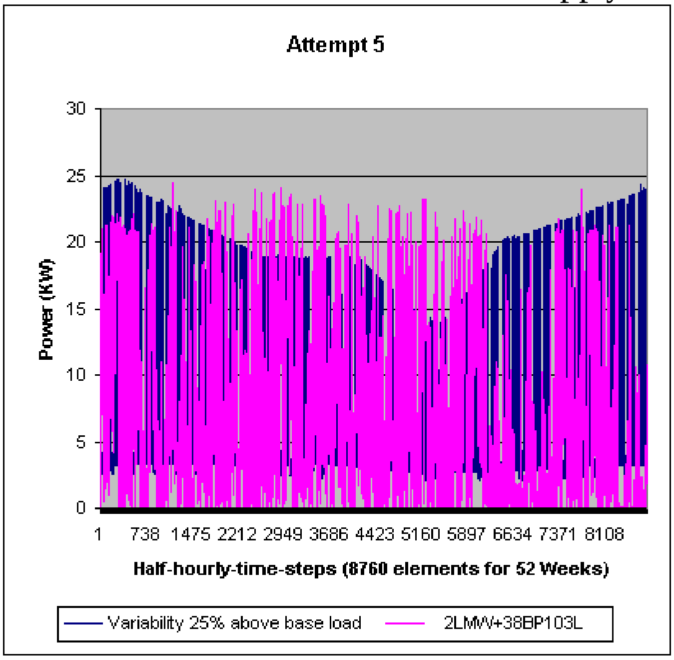


Figure 4.9/ Power curves for the Demand and Supply for Attempt 6

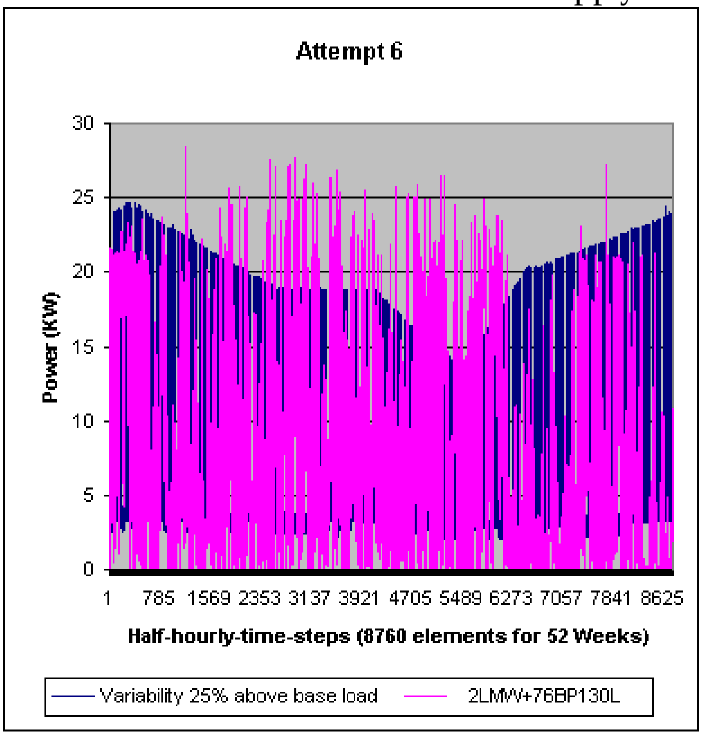
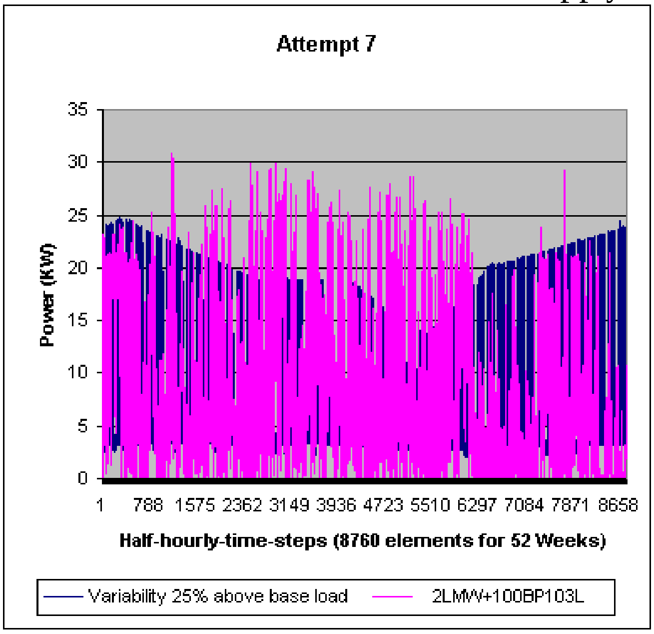


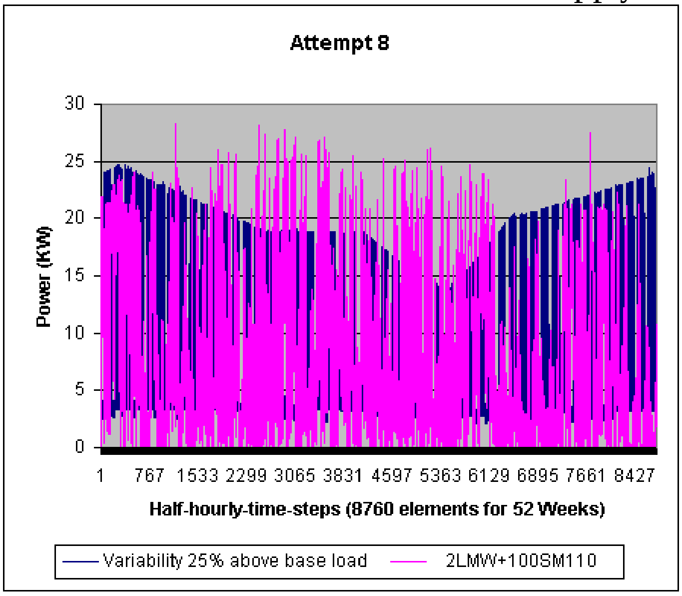
Figure 4.10/ Power curves for the Demand and Supply for Attempt 7



Attempt 8-PP

For the penultimate experiment of this phase we did not follow the augmentation procedure that we did in Attempts 5 to 7 and immediately we set the number of **SM110** models to 100 units. In this case the 1st and 2nd indicators remained unchanged, the 3rd indicator was decreased from the last attempt i.e. *Deficit-Excess*= -5,540.7*kWh* in Attempt 7 to *Deficit-Excess*= -2,835.8*kWh* in Attempt 8 and reversely according to the CGP requirements.

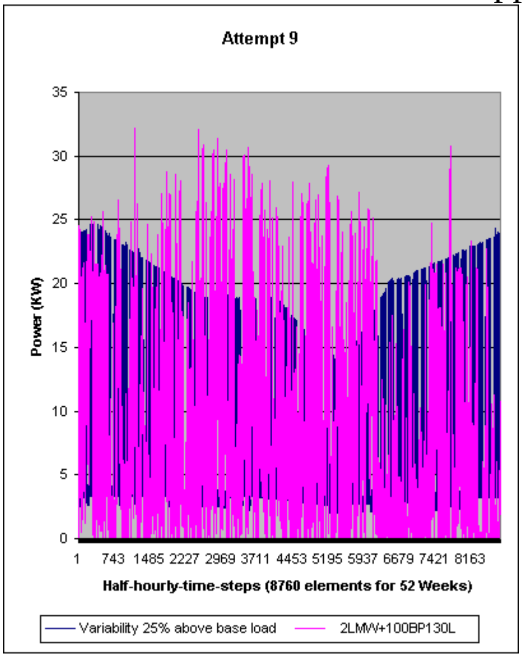
Figure 4.11/ Power curves for the Demand and Supply for Attempt 8



Attempt 9-PP

Finally we increased the number of **SM110** photovoltaic modules to 150 units to mainly check the response of the 1st and 2nd indicators to that action but although the 1st remained constant at 5/10 the 2nd dropped to 8/10 from 9/10 that Attempt 8 scored.

Figure 4.12/ Power curves for the Demand and Supply for Attempt 9



As a recapitulation of the 9 Attempts of the PP we must consider the CGP-1 so that we can select successfully the ones of relative importance to the aims and objectives of the Scenario 1. These are no other than a realistic operation of REST and a backup electrical system that will provide a safe coverage for the Eco-Village for the largest possible number of days. Since the best mark for 1st indicator has been 5 we can not sustain a choice for any of the experiments. The discrimination will be based on the 2nd and the 3rd indicators. So we can justify the following Attempts:

- Attempt 3: It has the best results on the 3rd indicator and a moderate result on the 2nd
- Attempt 6: It has a quite moderate result for the 3rd indicator and the best possible on the 2nd
- Attempt 8: Same characteristics as Attempt 6.

4.2.2.1.2 Main Phase for Scenario 1

Obviously from what has been mentioned above the MP we will deal with the introduction of batteries as an energy storage system to improve the match results of the previous Attempts. Since in this case we do not care so much about the *"Potential Match Rating"* of the experiments we will assess the results of the MP experiments with the help of CGP-2 since this time the

"Deficit"-"Excess" energy is a much more important indicator for the overall success of them.

The batteries that MERIT's database has are Lead-Acid type of batteries; the most commercially trusted and used cells for the last 30 years [Reference: IS-17]. These come with different voltages and currents specifications. Our aim is to find the best possible battery bank (BB) for the Eco-Village relative to the electrical energy requirements of the latter. This indicates the fact that since the capacity of the BB will remain constant over the MP experiments then for these experiments (modified experiments of the PP) there will be different charging times according to their energy potentials as described by the *Excess* indicator (Table 3.14a). The above argument is true since the capacity of a BB is proportional to the product of the current, which can provide to a load, to the time that it can do so ceaselessly and in this case the discharging time will be fixed as well [Reference: IS-18]. Let's have a look at some numerical specifications for the selection of the BB. The Electrical Energy for Scenario 1 (for the Eco-Village) is according to P.3.3.2.1:

$$E_{El_M} = 66{,}015.2\ kWh$$

For the UK, the standard mains voltage ($^*V_{UK}$) is fixed at $230\,Volts$ and so the current that the REST will have to provide to the 17 houses of the Eco-Village for 1 day (24h) will be:

$$I_{M^1} = \frac{^*P_{El^1_M}}{^*V_{UK}} = 32.76A\ldots \text{ (Equation 4.1)}$$

Where

$$^*P_{El^1_M} = \frac{E_{El_M}}{365*24} = 7{,}535.98W\ldots \text{ (Equation 4.2)}$$

So for the three attempts of the PP we can have, according to their *Excess* values (Table 3.14a):

$$I_{Att_3} = 26.3A\ldots \text{ (Equation 4.3a)}$$

$$I_{Att_6} = 15.56A\ldots \text{ (Equation 4.3b)}$$

$$I_{Att_8} = 15.50A\ldots \text{ (Equation 4.3c)}$$

The capacity of the BB will be determined according to the following relationship:

$$C=I*t\ Ah\ldots \text{ (Equation 4.4)}$$

We set a discharging span of 3 days or 72 hours. So in our case (Equation 4.4) will become:

$$C_{V^3} = I_{M^1} *72=2358.72Ah\ldots \text{ (Equation 4.5)}$$

So to find the charging time for the three cases we use (Equation 4.4), where

$$C=C_{V^3} \text{ and } I=I_{Att_3},\ I_{Att_6} \text{ and } I_{Att_8}$$

Therefore we have respectively:

$$t_{Att_3} = 3.75 \text{ days} \ldots \text{ (Equation 4.6a)}$$

$$t_{Att_6} = 6.25 \text{ days} \ldots \text{ (Equation 4.6b)}$$

$$t_{Att_8} = 6.25 \text{ days}\ldots \text{ (Equation 4.6b)}$$

As a verification of these results we will use the Current Ratio (CR) and Day Ratio (DR) concepts[Definiton]. These should come to equality if the time and currents are calculated correctly. So for Attempt 3 CR=DR=0.8, for Attempt 6 CR=DR=0.47 and for Attempt 8 CR=DR=0.48.

Now to define the size of the BB we need to incorporate a battery from MERIT's database to approximate the C_{V^3} by producing multiples of its capacity. We chose the **215*Ah*@12V** battery type and so the theoretical numbers for the BB will be:

- 20 in Series= $^{*}V_{UK} = 230\,V$
- 11 in Parallel = $C_{V^3} = 2358.72Ah$

<u>Attempt 10-MP</u>

This is the modified Attempt 3 from the previous phase. This time we introduce the application of batteries to relieve the *Excess* energy that was wasted in the previous experiment. So we choose **215*Ah*@12V** batteries with the theoretical combinations, as stated above, to see if there are any differences in the real values of voltage and capacity. And there were! From MERIT we get Nominal Capacity 1= 317.38Ah and Nominal Voltage

[Definiton] *CR*=Discharge Current/Charging Current, *DR*=Supply Days for BB/Charging Days for BB

1=252.00V (very different from C_{V^3} and $^*V_{UK}$). So again by iteration we approximated the theoretical values with the following combinations:

- 18 in Series ≈ $^*V_{UK}$
- 191 in Parallel ≈ C_{V^3}

For this analysis we must remember to use CGP-2 for the appellation of the indicators! As we can see in Tables 13a and 14a by inspection of the Attempt 3 and 10 results, the 1st indicator remained constant, the 3rd indicator was reduced and the 4th was increased in a manner as required by CGP-2. Also the 2nd indicator shows a decrease in its value from -26,051.3 to -21501.7 kWh respectively. MERIT suggests that with increased storage we can get an $8/10$ for the 5th indicator. We interpreted that as a prompt to increase the BB capacity. It is not really important according to the ordinance of CGP-2 to study the *"Potential Match Rating"* indicator any more but since the suggested value is really tempting we decided to go with a further increase in the BB capacity to find out if that hypothesis was true. So for this case, if t=5 days and I= I_{M^1} then C_{V^5} will be equal to 3931.2Ah, and so charging time for Attempt 10 will be $t_{Att_{10}}$ =6.25 days now. Again with iteration we approximated the theoretical value for C_{V^5} and we got the following combination:

- 18 in Series ≈ $^*V_{UK}$
- 330 in Parallel ≈ C_{V^5}

Attempt 11-MP

Here the 1st and 5th indicators remained unchanged, the 2nd indicator decreased to -22,359kWh something that implies that more energy was utilised from the BB and the 3rd and 4th indicators were following the required inclinations in the manner dictated by CGP-2. Still MERIT suggests an improvement for 2nd indicator with increased storage but we consider such an action an unnecessary experiment since Attempt 10 is already extended.

Attempt 12-MP

This is the modified Attempt 6 from the previous phase. Like before we have introduced the application of batteries to relieve the *Excess* energy that was wasted in the previous experiment. This is the first experiment for which we get for the 1st indicator a value 6/10, above the average. The 2nd indicator decreased from -3,096.9*kW*, in Attempt 6 to -51.6*kW*, in Attempt 12 which by far the best balance of Electrical Energy that we have seen so far from all the experiments. The 3rd and 4th indicators were following the required inclinations in the manner dictated by CGP-2. The 5th indicator suggests again a further improvement in the match results with an increased storage. So by following the same numbers for $^{*}V_{UK}$ and C_{V^5} as derived from before we moved on to Attempt 13.

Attempt 13-MP
Here the 1st indicator remained constant but the 2nd increased to -768.1*kWh*. Truly the 3rd and the 4th indicators did improve from Attempt 12.

Attempt 14-MP
This is the modified Attempt 8. This experiment showed that it exploited well the excess energy since the 2nd indicator fluctuated around -236.8*kWh* relative to the -2,835.8*kWh* of the previous experiment. Again the 3rd and 4th indicators were following the required inclinations in the manner dictated by CGP-2, and presented an improvement compared with the values of Attempt 8. Similarly to the previous Attempts we again increased the BB capacity since the 5th indicator was promising a further improvement in the matching of the demand-supply electrical profiles.

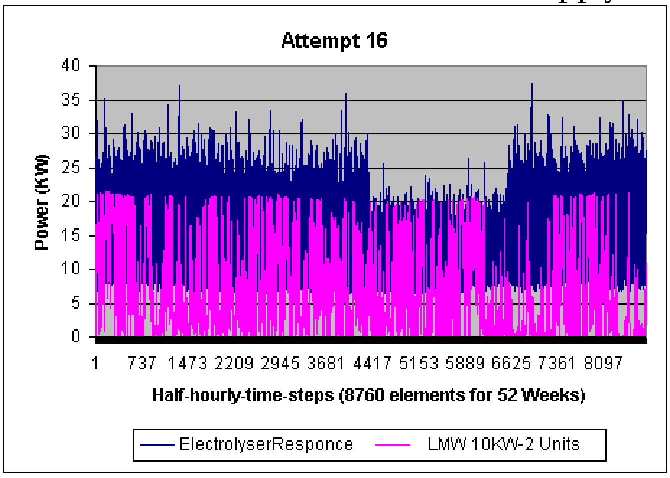
Attempt 15-MP
Here the 1st indicator remained, as expected, constant and the 2nd increased to -450.4*kWh*. Truly the 3rd and the 4th indicators did improve from Attempt 14.

4.2.2.2 Scenario 2
Contrary to Scenario 1 this one has only one phase since in this case we do not require the introduction of BB for the recovering any of the energy from REST. So we will use CGP-2 to assess the results for the experiments of this scenario. A complete record of the experiments (Attempts 16-23) can be found at Table 3.18.

Attempt 16
For the supply modules, as in Attempt 2, we implicitly used two **LMW-10KW** turbines for this experiment, since comparatively the precondition of using one turbine was proved (Attempt 1) that it was insufficient for the electrical supply of E_{El_V} never mind the E_D value that we have to cover here, which is double that value. So from Table 16/Chapter 3 we can see the

1st indicator is a moderate result (5/10) and the 2nd corresponds to a residual energy levelling (to the value of E_D) of -61,374.1kWh. Thus we increased the number of turbines to four.

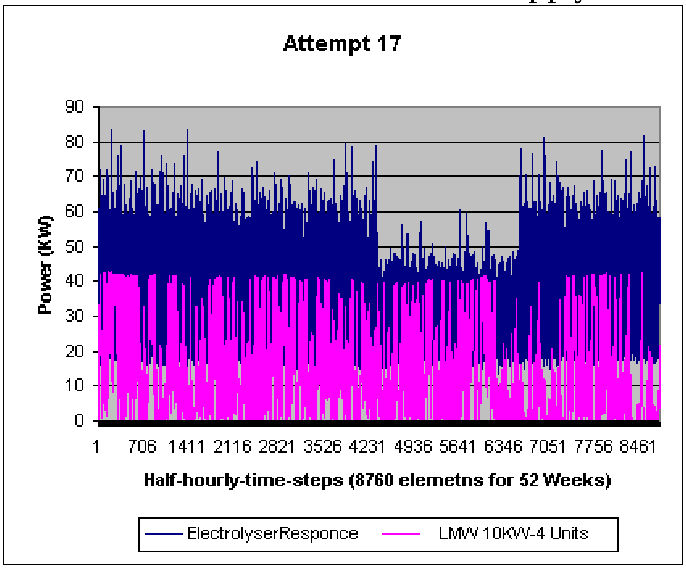
Figure 4.13/ Power curves for the Demand and Supply for Attempt 16



Attempt 17

In this case we got for the 1st indicator an unchanged results and for the 2nd a slightly improved number of -9,252kWh. The 3rd and 4th indicators were slightly changed and the 5th suggested a potential improvement to 8/10. Although we know from past experience (Attempt 3) that in order to control the value of the 2nd indicator effectively, for small fluctuations (<5,000kWh), the use of PV modules is suggested still in increased the electrical supply by raising the number of turbines to five.

Figure 4.14/ Power curves for the Demand and Supply for Attempt 17



Attempt 18

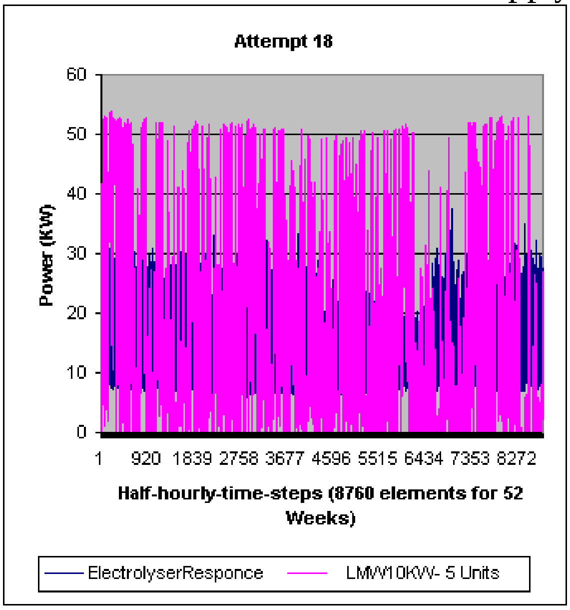
Here the 1st indicator was still constant and the 2nd was not satisfied at all since its value was greater than zero something that was against the requirements of the CGP-2. So as we did in Attempt 3 we will introduce photovoltaic modules for a possible combination with the four turbines from Attempt 17. Again as in Attempt 3 we start with the theoretical orientation for the numbers of photovoltaic units and through experiments-iterations we will try to find the best number according to the requirements from CGP-2. So from Attempt 17:

$$Deficit\text{-}Excess = 9{,}250.6kWh$$

$$^{*}P_{El^{1}_{PV-Sc.2}} = 1056kWh$$

The model this time will only be **BP130L** to stay in conformity with the previous actions and their theoretical numbers will be: For **BP130L** =8 units and for the **SM110** =10 units.

Figure 4.15/ Power curves for the Demand and Supply for Attempt 18



Attempts 19, 20, and 21

In these three experiments there was gradual increase in the 2nd indicator from 8,436.1 to 7,723.2 to 5,177.6 compared with the 9,250.6kWh of Attempt 17 and the 3rd and 4th indicators were following a gradual improvement according to the inclinations of CGP-2. But the most important indicator, 1st has not shown any improvement constantly set at 5/10 poor match result. At this point it was clear that to cover that 5,177.6kWh at the rate of 70kWh/Photovoltaic units we would need about 80 units eliminate that residual energy. In this case we know more or less from the previous attempts that nothing will change in the matching results and so it was verified by an unrecorded experiment. So if this was the case how could we check if there were any other modules that could have a different impact on the match results? The answer lies at the turbines power. There is no need to use a large turbine for such small energy spans but surely a smaller turbine could do the job. From MERIT's database we recalled the 3*kW* turbine and that is what we combined with the modules from the last attempt.

Figure 4.16/ Power curves for the Demand and Supply for Attempt 19

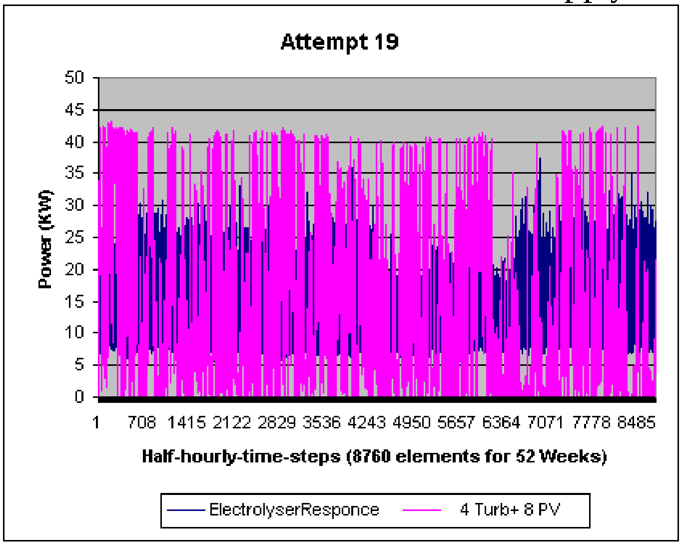


Figure 4.17/ Power curves for the Demand and Supply for Attempt 20

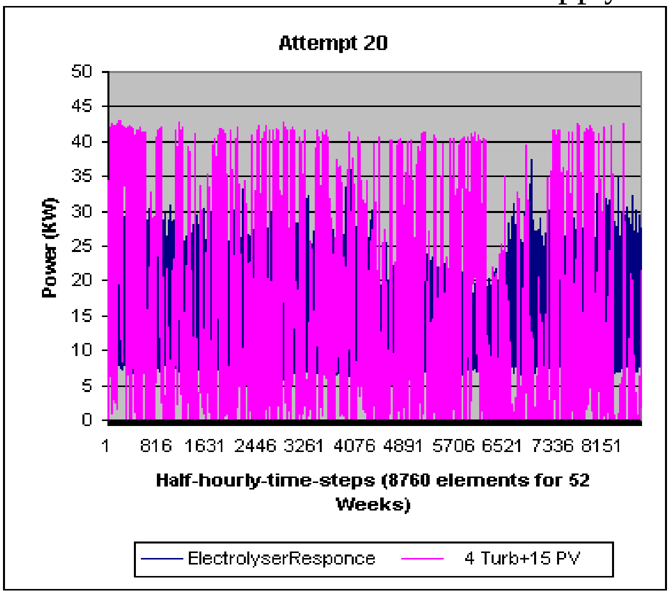
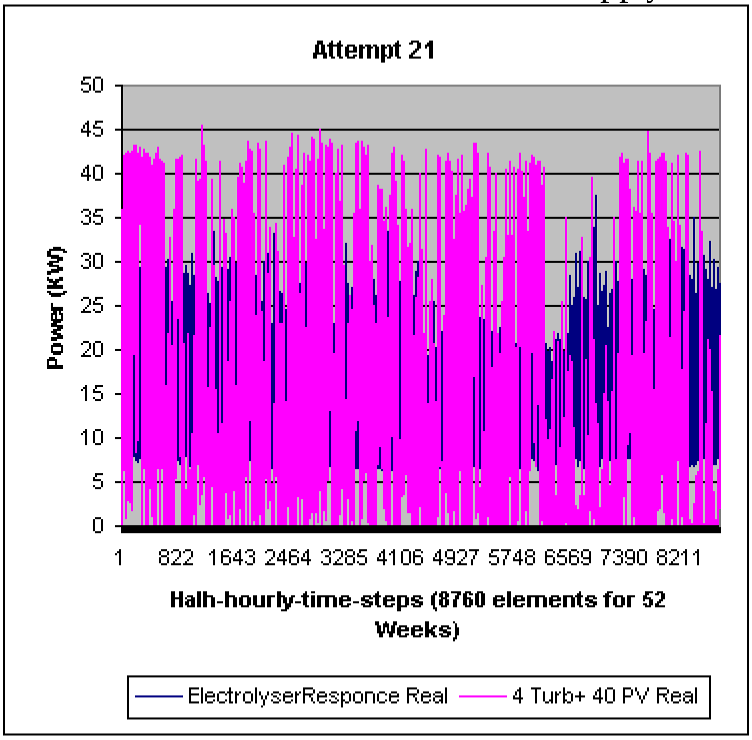


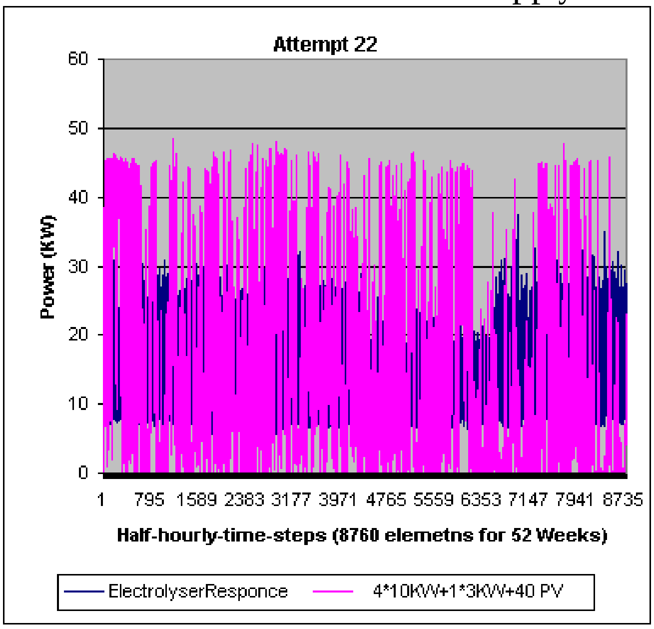
Figure 4.18/ Power curves for the Demand and Supply for Attempt 21



Attempt 22

The 1st indicator did not change but the 2nd became negative (-4,682.6*kWh*) to violate the requirement of the CGP-2 for that index. We can also see opposite fluctuations for the 3rd and 4th indicators according again according to the requirements of the CGP-2. This experiment did not live up to our expectations of a better matching result and so we would need to reduce the number of photovoltaic modules to 20 units to satisfy the 2nd indicator.

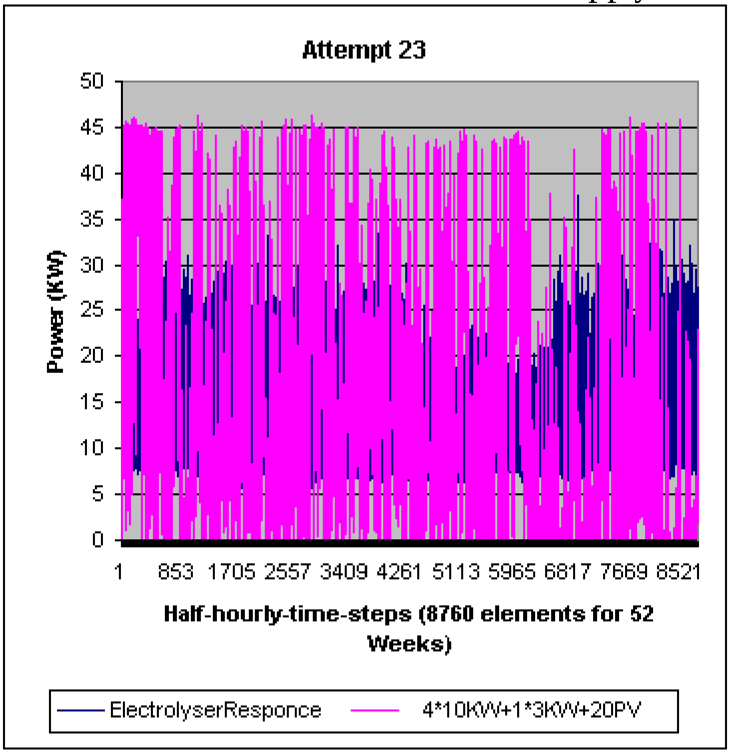
Figure 4.19/ Power curves for the Demand and Supply for Attempt 22



Attempt 23

Again the 1st indicator did not change from the last 6 attempts and the 2nd did fail to improve. The 3rd and 4th indicators also showed unfortunate results contoured reversibly from what the CGP-2 dictates.

Figure 4.20/ Power curves for the Demand and Supply for Attempt 23



End of Chapter 4

Chapter 5-Conclusions

The results of a project are to be digested after their analysis according to a pattern of accentuated fundaments. These fundaments are the true reason of contemplating and studying and the reason for researching a subject so vocaciously. All of the work must be imparted to the readers as practical upshots that can be used for discussion and further research.

5.1 Aims Attestation

In this project there is a slight difference between the aims and the objective of this study. We decided that it would be better if give to the aims a more generic character about the purpose of establishing this study and to the objectives a more specialised character. As we have mentioned before both of them are bonded to a certain type of Requirements/Guidelines, which are in mathematical words are the Boundary Conditions (BC) for the experiments:

R1: "The Eco-Village has to be energy-wise supported by sustainable technologies only".

R2: "The Eco-Village must be autonomous to any biological, physical and energy requirements".

R3: "The simulation must be a realistic model of the actual dynamic relationships of energy demands to the area of development and the community size and character".

5.1.1 Aim-I: Identify the Potential Use of MERIT in the Integration of REST for the Tweed Valley Eco-Village.

The first aim of this project is about the program itself which we had to use to succeed the study for the integration of REST for the Eco-Village. This software belongs to category of programs that the author refers to as $C_oS_iMR_eT_sI$ or Computer Simulation Methods for Renewable Technologies Integration and as the rest programs of its family their aim is to provide invaluable assistance when planning with renewable technologies for the provision of energy for a variety of applications (from a single house to a large community). All these programs facilitate the engineers with time effective dynamic simulations that would take otherwise, with conventional means of planning, multiples of the time scales that these programs can succeed.

We had the pleasure to work with one of these little "scouters" to help us complete this study for the Tweed Valley Eco-Village project and the only remarks that we can make are no other but admiration and support for this amazing concept. It would be really almost impossible to arrange hundreds of equations with several parameters in each one of them to produce realistic results about the use, flow, distribution and magnitude of energy requirements of a dynamic entity. Since the beginning of the project it was quite obvious that this program would be the best facilitator that we could ask for under the sun. One of the characteristics of MERIT is the very illustrative and concise environment-interface that the user navigates between the three-phase control platforms (preliminary, middle and simulation) and inside them once they are selected (See P.3.3.1). But where MERIT was really proved an excellent assistant was at the point when we had to simulate the Electrolyser demand in *kWh* according to the Fuel Cell seasonal Operational Modes (OM) and of course at the simulation part of the two scenarios (Scenario 1 and 2) where it was incredible the ease by which we could iterate between the experiments (Attempts) to approximate the required values.

As all computer programs MERIT did appear to have some shortcomings (these did not objectively verified by other sources to provide a complete assessment factor) that hindered the possibility of a greater success of the project; concerning Aim-II below. The version v.2.2 did not correspond well at the specific computer (OS and other applications) and did not rise to the full expectations of what we might have though that could offer in the opposite case. The newest version is clearly much more advanced than the first one including the all essential component-program *"CreateClimate.exe"* that would allow us to use the weather data, arduously searching for over two months, so that we could achieve a much feasible simulation for the Thornylee forest area. Unfortunately this component did not work successfully no matter how many different performances we applied on the critical file to be converted and how much advice we seek from academic staff of the University of Strathclyde. It also was superior to the less developed oldest version v.1.1 database-wise since it included energy carriers such as hydrogen, had much more up-to-date renewable technologies such as fuel cells and finally more realistic profiles for electricity and thermal energy demands in the UK (including the one that we used for the Scenario 1 experiments. Version v.1.1 was much more stable in terms of partial and greater vital operations such as *"saving"* and *"opening"* although it did present quite frequently a few crashes

5.1.2 Aim-II: Identify the Potential of Thornylee Forest as a Development site for the Eco-Village.

This aim was unfortunately not verified through the analysis of this project and maybe this could be the biggest loss amongst the ReST of the aims since it is considered to be by the author the backbone of the study. It is obvious that that if the critical conversion of the climatic file was successful

(See P.3.1.5.1 and P.4.3.1) then we would have a good reason to talk about a potential use of the Thornylee Forest although the simulation would refer to a weather profile for a slightly expanded and remote area than the forest itself (See P.3.1). In engineering intellection someone would rather have a rather good approximation of a field of study than none whatsoever, as in this case. We can not speak of the potential of the Thornylee Forest since the climatic profile is referring to Glasgow which is too far away from that area and has no conformity with the assimilation assumptions that we set in Chapter 4 (P.4.1.1.1 and P.4.1.1.2) but to approximate the energy simulation we tried to embrace a reasonable replica of the Thornylee Forest at the Eskdalemuir location. So it is a bit of a disappointment that this aim did not come to a conclusion as this could be possibly used as an extemporaneous planning for the villagers in case of considering the same PES and SES as this project did (sorry folks!).

5.1.3 Aim III: Identify the absolute Matching of Demand and Supply energy Requirements for the different Solutions examined under the Condition of an Autonomous Eco-Village.

If we detach the location, on which this project is readily applied (Glasgow), from the actual simulation then we can focalise on the numerical and statistical matching results of the Energy requirements for the Eco-Village rotating around the demands and supply methods of the two Scenarios. As a quick reminder Scenario 1 was an absolute Electrical study with Wind Turbines and Photovoltaic technologies as Primary Energy Supply (PES) and Batteries utilisation as a Secondary Energy Supply (SES) and Scenario 2 a combined Electrical and Thermal study (CHP study) with the same PES and a Fuel Cell module as SES comprising an Electrolyser, a Fuel Cell and a number of pressurised fuel Storage Tanks units (See P.3.2.1).

Scenario 1

For Scenario 1 only the Main Phase (MP) is of relative importance to the current aim examination; the Preliminary Phase is a selection stage for the candidates of the MP (See P.3.3.2.1 and P.4.2.2.1). Referring to P.4.2.2.1.2 for the MP we conducted 6 experiments (Attempts 10-15) which we are going to evaluate with the help of the Central Guidance Panel (CGP-See P.4.3.2). For the MP of Scenario 1 we will use the weighted evaluation ordinance as directed by the CGP-2. According to the requirements of that panel the 1st indicator must be satisfied before other indicators are examined. In that way Attempts 10 and 11 are disqualified since they are below the average score of the rest of the Attempts: 5/10<6/10 (See Tables 3.15a and 3.15b). So we are left with 4 Attempts. For these now we need to assess them according to the 2nd indicator of CGP-2, the requirement for a balanced energy flow to the Eco-Village or in simpler words the balance between electrical energy demand of the community (in a year of operation) and the electrical supply from Renewable Supply Technologies (ReST) for a normal and undisturbed electrical vitality. Again from Tables 3.15a and 3.15b we can see that the more successful experiment is Attempt 12 as this satisfies the condition of 2nd indicator (*"Deficit-Excess"*=-51.6*KWh*) with Attempt 14 following with a value of 236.6*KWh*. In the first case the difference is negative which shows a slight ascendancy of excess energy supply over the demand scale and corresponds to an implicit predominance over the second case in which the difference is positive. We are certainly in favour a positive stock of energy than any deficit amount that is against the 2nd indicator but the second case is closer to a more balanced value. So the choice will depend on the rest of the indicators for a final selection. So for Attempt 12 the 3rd and 4th indicators are 0.3336 and 0.4906 respectively and for Attempt 14 are 0.3336 and 0.4904 respectively. Thus a direct choice cannot be made from these conditions and neither can be form the last indicator (5th) since both experiments have a potential score of 10/10 with *"Increased Storage"* according to MERIT. It is thus a conclusion that both Attempts were successful according to the current specifications for the electrical coverage of the village. The SES in this case i.e. the Battery Bank (BB) will provide enough electrical energy for running any loads in the Eco-Village within 3 days, maximum charging-discharging cycle occurrence, after which it will be completely discharged.

Obviously a "Reasonable Match" of 6/10 is just satisfactory but we have to remember that this simulation really corresponds for Glasgow and not for Thornylee Forest where the winds would be expected to be much more stronger (according to the British Wind Energy Association Glasgow has an average wind speed of around 6-7*m/s* whereas the area around Thornylee Forest is 9-10*m/s*-See Figure 6/Chapter 3) and maybe the solar radiation would be likewise increased respectively. So such a result is not depressing at all and is considered a valid argument to say that if the autonomous Eco-Village where to be situated at Glasgow it would most likely support an electrically self-sustained community. MERIT suggests an even further improvement for a potential match between demand and supply but surely the experiments here (Attempts 13 and 15) showed an opposite case. We don't know exactly where this increased storage is referring to but we suspected that maybe it has a connection with other forms of storage for the village. It was made clear that this was true from an unofficial number of experiments upon these two Attempts that if combined with say with *"Grid Connection"* the matching results were rocketed to 8/10. Obviously in this case we cross the requirement for an autonomous village (R2) so this was the best compromise with BC of the project.

Scenario 2

For Scenario 2 we need to look at Attempts 16-23 to deduce any results for the satisfaction of Aim-III. Again we are assessing their results with weighted evaluation ordinance as directed by the CGP-2. In this scenario we have 8 potential experiments to choose from the best match results between the Electrical and Thermal demand of the Electrolyser and that arising from the PES. The difference between this scenario and the previous one is in terms of the actual demand quality for the simulation the latter being not directly the demand of the Eco-Village itself but its modified form translated for the needs of the Fuel Cell and its inherent component the Electrolyser (See P.4.2.2.2). Here all the Attempts exhibited a very modest match result of 5/10 for the 1st indicator of CGP-2. This is quite discouraging since the requirement of the 1st indicator is for a minimum value of 5/10 leaving all these attempts out of the game. Or is it not? A *"Poor Match"* is simply MERIT's user-software interaction method to warn the user for more energy storage in terms of auxiliary storage media that it possess. In our case we did not respect at this recommendation and so we got rather disappointing results. But if we compare the graphs of P.4.2.2.2 and the results of the Table 3.18 we will see that the 2nd indicator is well satisfied by most of them and that is a good identification element of the possible success amongst some of them. More specifically Attempt 23 was much more closer to a energy balance than any other experiment (-2,646.1*KWh*) and since these *kWh* are of a negative sign it simply means that the village will not utilise this energy by any other storage technology and this is why MERIT is rating it with a *"Poor Match"* indicator. But in real terms what would happen is that the Electrolyser would be fully run by PES and so would be the Fuel Cell. Thus the cycle of energy flow would be satisfied. The 3rd and 4th indicators are also very gentle with Attempt 23 as the latter has the best ratings for these two against all other Attempts. Finally the 5th indicator looks quite well since the potential of this Attempt could reach theoretically a 9/10 excellent match by capturing all the excess energy. All these facts testify that Scenario 2 was successful in matching the electrical demand of the Electrolyser.

5.2 Objectives Attestation

5.2.1 Objective I: Assess the Use of a Fuel Cell Module as a Provider and Storage Solution of Renewable energy for the Eco-Village with respect to Sustainability requirements.

It is really difficult to assess the Fuel Cell Module since it was not an experimental aim of this study to directly examine and talk about any tangible results so we can only talk about the actual selection of it as a CHP method to provide and store energy for the Eco-Village. There is a large antagonism out there for CHP solutions the more known being a CHP with diesel generator(s) to achieve the required power outcomes and a more synchronous choice would be micro-turbines not a bad solution for large energy projects such as this Eco-Village. But it would be really a violation of the very first of the BC of the project (R1), for R1 is requiring only sustainable solutions to any of the technologies selected for PES or SES. Thus the Fuel Cell Module would prove the only green and sustainable choice in our case.

The Electrolyser was a market model that could produce around $60\,Nm^3/h$ of hydrogen fuel at an energy feeding cost of $5kW/Nm^3$ and a rate of $1lt/Nm^3$ or $0.001m^3/Nm^3$. At this H_2 production rate it sufficiently connected in series with the Fuel Cell itself which required in the best of the cases $3.93\,Nm^3/h$ for OM_3 and in the worst $11.80\,Nm^3/h$ at OM_2. In any of the cases it seems that there is a large safety margin between these two values and the maximum fuel flow the Electrolyser can provide for the Fuel Cell. That brings us to the question of how we will exploit all the wasted hydrogen fuel. As we saw in P.3.2.2.2 this was going to be channelled to a number of low pressure tanks 5 for the small charging cycle (1 day) and 10 for the large one (2 days). To ensure that the hydrogen tanks are always charged the study was such that allowed this consideration by the application of larger PES units. For the practical case of installing such a module a Fuel Regulator (FR) device could be used that could control the flow of hydrogen gas to the storage vessels and stop the process by deactivating the Electrolyser from the village grid so that electricity from PES could be arranged and utilised in a different way. Instead of that and according to future changes in the structure of transportation the excess hydrogen could be even used, under specific modifications i.e. larger pressure and change of composition (liquid), for topping up hydrogen vehicles or just for selling purposes to a chemical company or a hospital, oxygen gas is also attractive in this case for its high purity.

Thus the Fuel Cell module would cover the electrical and heating demand of the Eco-Village very satisfactorily according to the theoretical numbers of this study and it is simply the most sustainable option that someone can select to grand these demands. In our case the Fuel Cell was to be chosen at $25kW$ power output at 100% of its operating range. This would allow an unstressed operation for any of the three operation modes (OM) on a continuous working pattern. For any future expansion of the Eco-Village since the fuel cells are modular devices we can simply add another module, of an appropriate power value, in series or in parallel to get the energy we need. The positioning of the Fuel Cell Module is thought to be at a central point in the community area with power lines and gas pipes stretching in a web-like form to all of the houses (17) to provide the necessary electrical and thermal energy. It is considered that to avoid the unnecessary cost and installation and maintenance operations on gas pumps and gas pipes for the hydrogen fuel the Electrolyser should be situated at the same control room as that of the rest of the units will be it, Fuel Cell and Storage Tanks. Finally in order to decrease the cost of the installations the FC plant could be connected to the grid for the time that produces excess electricity and so an appropriate selling or even exchanging of this extra power to the grid could be arranged that would economically boost the financing of the plant acquisition.

End of Chapter 5

Chapter 6-Limitations and Future Research

No project is conducted without problems, misadventures or misfortunes and this study is certainly one of these. There were many obstacles in trying to find the appropriate information and in trying to apply it in practice to get results. This would lead to incoherencies and discrepancies that need to be examined by future workers.

6.1 Climatic Limitations

- For retrieving the necessary weather parameters we had to look at a variety of databases over the internet until we finally spotted the most appropriate one (PWD). This was a time intensive process, approximately two months for the selection of a satisfactory database.
- The inexistence of a station at the area of study (Thornylee Forest) was a big obstacle to readily identify the critical weather parameters for the simulation and so approximations were followed to bypass that problem that disturbed the true values for that area. In future work someone would have to monitor the area for a minimum of two years for these weather parameters, especially for wind values since the radiation could be assimilated by nearby stations of the BADC database.
- The geographical examination of the weather stations was a very difficult process since their distances from the Thornylee Forest had to be calculated according to valid map scales and in the case of applying assumption three (**A3**) to some of them a further identification of morphological maps of Scotland had to be retrieved.
- The database files on which the Evaluation and Formation stages (P.3.1.4 and P.3.1.5) were conducted had a lot of missing values that hindered the process of a more robust analysis.

6.1 Technical Limitations

- It has been stated a number of times so far that the conversion of the climatic file was not possible since the *"CreateClimate.exe"* did not work. Had this conversion been successful we would have run the simulation on a truer and realistic basis and so the results produced would have been much more authentic. In future work it is necessary that a real climatic profile is made for the simulation as this enable the engineers to predict the behaviour of PES to a more realistic extend and thus the feasibility if the project will be much clearer.
- For the Selection of Power Plant (P.3.2) we had a numerous problems in identifying the most appropriate type of Electrolyser, Fuel Cell and Storage Hydrogen Media. For the Electrolyser we had to identify a model that not only could it provide the FC with the CFC but it would produce that hydrogen fuel at the necessary pressure conditions and it would only use fresh water as its fuel. The

electronic correspondence was not many times successful and so no technical specifications could be retrieved. The same problems we faced on trying to identify a proper FC and Storage Hydrogen Media modules. The theoretical approach was thus necessary to determine the numerical guidelines for assembling the FC plant.

- In Scenario 1 we had to approximate the annual demand of the Eco-Village with a profile from the MERIT's database. In version 1.0 this was not possible and only with an appropriate maneuver did we manage to overcome this problem.

End of Chapter 6

References

Literature Exhibits

LE-1. Marina Fischer-Kowalski (1997). *Gesellschaftlicher Stoffwechsel und Kolonisierung von Natur*. Amsterdam.

LE-2. I.G. Simmons (1989). *Changing the Face of the Earth. Culture, Environment, History.* Oxford 1989, 379.

LE-3. Marina Fischer-Kowalski and Helmut Haberl (1997). *Tons, Joules and Money: Modes of Production and Their Sustainability Problems In Society and Natural Resources.* 1997, 10, 70.

LE-4. Grove, Richard H (1995). *Green Imperialism: Colonial Expansion, Tropic Island Edens and the Origins of Environmentalism*. Cambridge 1995, UK: Cambridge University Press.

LE-5. R.P. Sieferle (1997). *Rückblick auf die Natur. München.* Database 1997, 155-158.

LE-6. *United Nations Environment Programme / Global Environment Outlook 2000*

LE-7. Brown Paul (1996). *Global Warming: Can a Civilization Survive?* Blandford, London.

LE-8. Kaufman, Donald G. and Cecilia M. Franz (2000). *Biosphere 2000: Protecting Our Global Environment.* Kendall/Hunt Publishing Co., Dubuque, Iowa.

LE-9. Wilson, Edward O. (1999). *The Diversity of Life*. W.W. Norton & Co., New York.

LE-10. Tilman, David (1999). *The ecological consequences of changes in biodiversity: a search for general principles*. Ecology 80(5):1455-1474.

LE-11. Goldsmith, Edward, R. Allen, M. Allaby, J. Davoll, and S. Lawrence (1972). *Blueprint for Survival.* Houghton Mifflin Co., Boston.

LE-12. Brown, Lester R. (1981). *Building a Sustainable Society.* W.W. Norton, New York.

LE-13. World Commission on Environment and Development (1987). *Our Common Future Oxford University Press*. Oxford 1987

LE-14. United Nations Conference on Environment and Development. (1992). *Agenda 21: Programme of Action for Sustainable Development*. United Nations Department of Public Information, New York.

LE-15. Robinson, John and Caroline Van Bers. (1996). *Living Within Our Means: The Foundations of Sustainability.* David Suzuki Foundation, Vancouver, BC.

LE-16. Costanza, Robert, R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G.

Raskin, P. Sutton, and M. van den Belt. (1997). *The value of the world's ecosystem services and natural capital*. Nature 387: 253-260.

LE-17. Francesca Jane Born (2001). *Aiding Renewable Energy Integration through Complimentary Demand-Supply Matching*. PhD Thesis. Strathclyde University.

LE-18. Osborne Dariane (2000). *The Relationship between the Increase in Computing Power and the Development and Adoption of Renewable Energy Technologies*.

LE-19. Clarke J.A. and Grant A. D. (1996). *Planning Support Tools for the Integration of Renewable Energy at the Regional Level.* WREC 1996.

LE-20. Jones P. J., Vaughan N. D., Sutcliffe A. and Lannon S. (1996). *An Environmental Prediction Tool for Planning Sustainability in Cities*. 4th European Conference on Architecture, 26-29 March 1996, Berlin Germany.

LE-21. Energy Efficiency and Renewable Energy Network (EREN-f), US Department of Energy, RETScreen, 2000,

LE-22. Castro M.A., Caprio J., Peire J. and Rodriguez J.A. (1996). *Renewable-Energy Integration Assessment Through a Dedicated Computer Program*,. Solar Energy Vol. 57, No.6, pp471-484, 1996

LE-23. Ramakumar R., Abouzahr I., Ashenayi K. (1992). *A Knowledge-Based Approach to the Design of Integrated Renewable Energy Systems*. IEE Transactions on Energy Conversion, Vol. 7, No. 4, December, 1992.

LE-24. Energy Efficiency and Renewable Energy Network (EREN-a), US Department of Energy, ASEAM, 2000.

LE-25. Energy Efficiency and Renewable Energy Network (EREN-b), US Department of Energy, Energy-10, 2000.

LE-26. Energy Efficiency and Renewable Energy Network (EREN-d), US Department of Energy, DOE-2, 2000.

LE-27. Energy Efficiency and Renewable Energy Network (EREN-c), US Department of Energy, ESP-r, 2000.

LE-28. Sir Julius Vogel (1889). *Anno Domini 2000 or Woman's destiny* (colonial edition) Hutchisons, London. 1889.

LE-29. Samuel Butler(1972). *Erewhon, or Over The Range* (rev. edition). Golden Press in association with Whitcombe & Tombs, Auckland 1927.

LE-30. Edward Bellamy (1960). *Looking Backward 2000-1887*. New American Library, New York. 1960

LE-31. William Morris (1995). *News from Nowhere*, or *an epoch of rest* (ed Krishan Kumar) Cambridge University Press, Cambridge and New York 1995.

LE-32. Context Institute (1991). *Ecovillages and sustainable communities: a report for the Gaia Trust Context Institute*. Bainbridge Island, Washington. USA. 1991

LE-33. Cuming P. & Francis R. (1999). *Design for Human Settlement-notes of an advanced designer course*. Permaculture Education Nimbin NSW 2480, Australia. 1999.
LE-34. Kathryn McCamant and Charles Durrett. The 3rd North American Cohousing Conference in Seattle, September, 1997
LE-35. Tweed Valley Ecovillage Project Overview. March 2002
LE-36. Angelos Mademlis. *Wind And Hydro Power System For The Tweed Valley Ecovillage*. September 2002. MSc Thesis. Strathclyde University.
LE-37. Dincer I. (1999). *Environmental impacts of energy*. Energy Policy, vol. 27, July.845-854.
LE-38. World Bank, *World Development Report* (1992)
LE-39. Markvatt (2001). *Solar Electricity*. John Willey and Sons, LTD.
LE-40. Godfrey Boyle (1996). *Renewable Energy- Power for Sustainable Future*. Oxford University Press.
LE-41. Zinger, D. S. and Muljadi, E. *Annualized Wind Energy Improvement Using Variable Speeds*. IEEE Transactions on Industry Applications. Vol. 33, no. 6. November-December 1997, pp. 1444-1447.
LE-42. Hoffmann, R. and Mutschler, P. *The Influence of Control Strategies on the Energy Capture of Wind Turbines.* 2000 IEEE Industry Applications Society Annual Meeting, Rome, 8-12 October, 2000.
LE-43. Slootweg, J. G., Polinder, H., and Kling, W. L. *Dynamic Modelling of a Wind Turbine with Direct Drive Synchronous Generator and Back to back Voltage Source Converter and its Controls*. 2001 European Wind Energy Conference and Exhibition. Copenhagen, Denmark. 2-6 July 2001.
LE-44. Slootweg, J. G., Polinder, H., and Kling, W. L. *Dynamic Modelling of a Wind Turbine with Doubly Fed Induction Generator*. 2001 IEEE Power Engineering Society Summer Meeting, Vancouver, Canada, 15-19 July 2001.
LE-45. *Fuel Cells for distributed generation: A technology and marketing summary*, USDOE 2000.
LE-46. A.J. Appleby, F.R. Foulkes. *Fuel Cell Handbook*, Van Nostrand Reinhold, New York, NY.1989.
LE-47. *Fuel Cell Handbook*, Fifth edition, USDOE, Office of Fossil Energy, 2000 and cogeneration”, USDOE 2000

Internet Sources

IS-1 http://www.runet.edu/~wkovarik/hist1/timeline.new.htmlgdfgfd
IS-2 http://www.eeexchange.org/sustainability/Intro/outline.htm
IS-3 http://library.thinkquest.org/26026/index.php3

IS-4 http://www.pbs.org/now/science/unenergy.html
IS-5 http://gen.ecovillage.org/index_body.html
IS-6 http://www.esru.strath.ac.uk/Courseware/Merit/index.htmgdfgd
IS-7 http://www.ecn.ac.uk/dfg
IS-8 http://badc.nerc.ac.uk/home/df
IS-9 http://www.eere.energy.gov/buildings/energy_tools/energyplus/cfm/weatherdata_int.cfmfddf
IS-10 http://www.metoffice.comfdg
IS-11 http://www.bwea.com
IS-12 http://www.fuelcelltoday.com/index/0,1967,,00.html
IS-13 http://www.hydrogenics.com/hypm.htm
IS-14 http://www.fuelcells.org/StationaryTechnical.pdf
IS-15 http://www.eere.energy.gov/consumerinfo/elecsource.html
IS-16 http://www.esru.strath.ac.uk/Courseware/Merit/index.htm
IS-17 http://www.automotive-technology.co.uk/support/batteries.htm
IS-18 http://www.wppltd.demon.co.uk/WPP/Batteries/Charging_Methods/charging_methods.html
IS-19 http://ovis.khv.ru/eng/wind.html

Appendix A

Table 1/ Record of the stations reviewed for the Peeblesshire County

County	Station Name	*.hwx*	*.radt*	*.wind*
PEEBLESHIRE	BADDINSGILL RESR	x	x	x
	BLYTH BRIDGE	x	x	x
	BONNYCRAIG FILTER STA.	x	x	x
	BRAWN S DOD	x	x	x
	COWDENBURN	x	x	x
	EDDLESTON	x	x	x
	FRUID DAM	x	x	x
	GLEN HOUSE, FETHAN VIEW COTTAGES	x	x	x
	GLENTRESS	•	x	x
	HALLMANOR HOUSE	x	x	x
	KINGLEDORES AUTO.STA.	x	x	x
	MENZION BURN	x	x	x
	NORTH ESK RESR	x	x	x
	PEEBLES	x	x	x
	PORTMORE RESR	x	x	x
	RACHAN	x	x	x
	SHIPLAW LOGGER STA.	x	x	x
	SKIRLING	x	x	x
	SKIRLING, HANNA HOUSE	x	x	x
	STANHOPE FARM	x	x	x
	STOBO CASTLE	x	x	x
	TALLA LINNS FOOT	x	x	x
	VICTORIA LODGE	x	x	x
	VICTORIA LODGE NO.2	x	x	x
	VICTORIA LODGE NO.2 LOGGER STA.	x	x	x
	WEST LINTON	x	x	x
	WEST LINTON, WOODLEA COTT.	x	x	x
	WEST WATER RESR	x	x	x
	WEST WATER RESR NO.2	x	x	x

Table 2/ Record of the stations reviewed at the neighbouring Counties of Peeblesshire

County	**Station Name**	*.hwx*	*.radt*	*.wind*
SELKIRKSHIRE	BOWHILL	•	x	•
	GALASHIELS	•	x	x
DUMFRIESSHIRE	AUCHEN CASTLE	•	x	x
	CHAPEL CROSS	x	x	•
	DUMFRIES	•	x	•
	ESKDALEMUIR	•	•	•
	MOFFAT, BRECONSIDE	•	x	x
LANARKSHIRE	ABINGTON	•	x	•
	CAMPS RESERVOIR	•	x	x
	CARNWATH	•	x	•
	COATBRIDGE	•	x	x
	CRAWFORDJOHN	•	x	x
	DRUMALBIN SAWS	•	•	•
	DRUMCLOG	•	x	•
	EAST KILBRIDE	•	x	•
	GLASGOW, SPRINGBURN	•	x	x
	GLASGOW WEATHER CENTRE	•	x	x
	LANARK	•	x	x
	LANARK, DRUMALBIN	•	x	x
	LEADHILLS NO.2	•	x	x
	MOTHERWELL, STRATHCLYDE PARK	•	x	x
MIDLOTHIAN IN BORDERS	-	-	-	-
MIDLOTHIAN IN LOTHIAN	BUSH HOUSE	•	x	•
	EDINBURGH, EAST CRAIGS	•	x	•
	EDINBURGH, ROYAL BOTANIC GARDEN	•	x	x
	EDINBURGH, BLACKFORD HILL	•	x	•
	FORTH ROAD BRIDGE	x	x	•
	LEITH HARBOUR	x	x	•
	PENICUIK	•	x	x
BERWICKSHIRE	CHARTERHALL SAWS	x	•	x

Table 3/ Local meteorological measurements for Bowhill and Eskdalemuir areas (1994)

		Bowhill-1994 (Dly3208.hwx)					Eskdalemuir-1994 (SYNOP.hwx)				
		Dir	Speed	TCA	Vis	TEMP	Dir	Speed	TCA	Vis	TEMP
Januany	1	250	9	5	4000	16	170	2	7	40	-22
	5	140	5	8	200	3	80	9	8	1500	11
	10	270	2	8	4000	29	310	2	7	1800	18
	15	270	2	1	4000	1	350	2	2	2000	-19
	20	290	13	8	1000	73	240	5	8	200	55
	25	290	19	5	400	54	190	7	7	1800	23
	30	290	24	6	1000	28	280	20	4	3000	23
April	1	230	13	6	1000	74	290	20	6	2500	58
	5	20	13	7	1000	49	180	11	7	3000	17
	10	230	5	8	1000	49	30	16	7	4000	41
	15	360	9	7	1000	49	30	16	7	4000	41
	20	230	2	7	1000	53	80	2	7	2500	58
	25	180	5	8	1000	84	170	8	8	4000	58
	30	230	5	8	1000	94	300	7	7	4000	81
July	1	230	5	4	1000	175	120	6	7	4000	170
	5	200	5	2	1000	162	270	9	1	3000	152
	10	0	0	8	1000	147	200	14	4	300	138
	15	230	5	2	1000	144	360	9	4	5000	133
	20	50	5	5	1000	202	210	5	3	1500	178
	25	100	9	8	1000	159	200	9	8	800	138
	30	180	2	4	1000	165	150	6	3	2000	175
October	1	0	0	8	1000	85	30	2	8	400	76
	5	270	5	3	1000	88	190	6	6	3500	34
	10	0	0	4	1000	58	170	2	3	10	51
	15	0	0	8	200	108	290	2	7	180	88
	20	180	2	8	400	104	120	6	8	1000	108
	25	200	5	0	1000	76	220	7	8	1000	64
	30	0	0	8	100	70	350	2	8	120	69

Table 4/ Local meteorological measurements for Bowhill and Eskdalemuir areas (1997)

		Bowhill-1997 (Dly3208.hwx)					**Eskdalemuir-1997 (SYNOP.hwx)**				
		Dir	Speed	TCA	Vis	TEMP	Dir	Speed	TCA	Vis	TEMP
Januany	1	20	9	6	1000	-4	0	0	7	4500	-14
	5	360	9	7	1000	4	0	0	6	2200	-12
	10	0	0	6	1000	11	0	0	7	2500	-5
	15	0	0	8	1000	69	170	7	8	10	54
	20	320	2	7	1000	16	0	0	7	6000	-8
	25	320	5	8	400	9	0	0	8	120	10
	30	230	0	0	1000	1	360	2	4	80	-4
April	1	140	5	7	1000	105	190	7	8	1200	78
	5	230	19	8	1000	107	280	19	8	700	93
	10	320	2	5	1000	104	310	9	3	4000	107
	15	320	2	3	1000	79	50	5	1	2200	77
	20	270	2	6	1000	60	240	2	7	4500	43
	25	160	9	7	1000	74	70	13	7	2800	55
	30	320	9	7	1000	121	240	9	7	2800	108
July	1	0	9	8	1000	82	340	2	8	800	78
	5	200	0	8	1000	136	120	5	4	3500	142
	10	230	2	9	20	159	180	2	1	1800	215
	15	0	5	8	1000	154	200	3	8	800	132
	20	290	0	0	1000	159	50	2	1	4000	204
	25	200	9	4	1000	166	290	8	5	4000	145
	30	270	13	7	1000	153	220	10	7	1500	137
October	1	230	24	6	1000	139	27	15	5	6000	132
	5	230	19	4	1000	123	190	7	5	1200	103
	10	230	9	8	1000	100	240	6	7	3000	85
	15	50	2	8	400	75	360	2	8	500	72
	20	50	5	7	1000	56	50	13	6	2800	53
	25	20	0	4	1000	75	350	2	6	1200	18
	30	230	2	8	1000	84	350	2	8	70	42