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Sustainable Energy for the Rural Village Environment

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On-site generation, load management and local grid for Eco-Village

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1 Introduction

Work package 7 within the SERVE Project focuses on specific research related to sustainable electricity supply. The main objective of this research is to investigate and make recommendations which will lead to the implementation of methods and technologies to achieve sustainable electricity supplies within the Eco-village, in particular, and also in the wider SERVE Region. The activities include:

a) Community Purchasing of Energy (SERVE Region)
b) Local grid development and control (Eco-Village)
c) Future on-site renewable electricity supply options (Eco-Village)

Further work has been completed on the last two objectives with the development of an assessment of the options for small and medium sized renewable generation to provide green electricity to the Eco-Village. This report has been produced by Senergy Econnect. The report outlines the key issues that require consideration in order to progress the development of a small or medium scheme at the site. The report also examines the option for the development of a local grid at the Eco-Village, and provides general background information about potential load management solutions to enable maximum use of the electricity generated within the site. The report has been prepared in time for submission to SPIL's board meeting in September 2009 so that they can consider their options regarding sustainable electricity for the Eco-Village.

The report on On-Site Generation and Local Grid for the Eco-Village is provided in Appendix 1 and forms part of Deliverable 7.2b.

2 Appendix 1: On-Site generation, load management and local grid for Eco-Village

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SERVE Project

Deliverable D7.2b

On-site generation, load management and local grid for the Eco-Village

Econnect Project No: 2061

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1 Introduction

1.1 Background

The "Village" is a new eco-village development currently under construction adjacent to the existing village of Cloughjordan, Co. Tipperary, Southern Ireland. It is designed to have a low environmental impact. Its heating needs will be met by a district heating scheme powered by a biomass / solar thermal boiler system. Other energy needs are likely to be met using electricity. The SERVE (Sustainable Energy for the Renewable Village Environment) project has specific targets for energy use within the Village. Many relate to heat demand and supply for the planned 132 dwellings and 3 community buildings, but the electricity-related objectives (taken from reference [1]) are as follows:

5. Using RES (renewable energy system) Heat supply via district heating and RES electricity purchase (initially) from a green supplier to approach 100% RES Supply in the Eco-village
6. To monitor and publish energy use and demand in all buildings to allow for demonstration of the cost-effectiveness of a holistic design approach and provide feedback to energy users
8. To investigate the potential for future polygeneration, by monitoring the actual electrical load of the Eco-Village and the scope for load management. Based on this data a RES electricity production facility will be developed to match Eco-Village demand by 2010, but funded outside of CONCERTO (EU funding mechanism).
9. Establishment of Energy Supply Company (ESCO) to operate and develop the energy supply systems in the Eco-Village by Month 12.

1.2 Site description

The Cloughjordan site is located in the county of Tipperary, approximately 10 km north east of Nenagh and 10 km west of Roscrea. Access to the site is provided via R490, R491, and local roads. Within the site boundary, residential dwellings are located to the south, east and west of the site. The site is characterised by arable land and trees interspersed with developed plots.

1.3 Estimated energy demand

The average electrical energy demand for the Village (132 energy efficient houses plus community buildings) has been estimated to be 375 MWh per year (2.5 MWh per house per year plus an allowance for the community buildings). As an example, this could be met on average by:

- a ~300kW wind turbine (i.e. about 30m diameter, 30m hub height) - this could not be fitted onto the Village site because it would be too close to houses and roads

or

- 15 or more 20kW wind turbines (about 11m diameter and hub height) - still difficult to fit onto the Village site

or

- 2500-7500m^2 of PV panels[1]

However it might be possible to site some renewable generation in the Village which could partially contribute toward its energy needs. The remaining electrical energy could be provided either by a larger renewable generator located outside the Village site, or by subscribing to a green electricity tariff from a supplier.

1.4 Senergy Econnect

Econnect was formed in 1995 and has build up a 500 strong client base including utilities, developers, manufacturers, banks, government and trade associations., By 2005, Econnect had been involved in over 50% of all wind projects constructed in the UK, and were also involved in 85% of all wind farms constructed in 2007. Econnect was purchased by the Senergy Group in 2008, becoming Senergy Econnect and continuing the activities of former Econnect.

Senergy Econnect's experience spans across 20GW of renewable projects in 32 countries including onshore and offshore wind, wave, tidal, hydro, landfill gas, CHP, photovoltaic, energy from waste, biomass and On-site Generation projects.

1.5 This report

Prior to this report, Senergy Econnect had already carried out a study to investigate the option for installing a large wind turbine on the Village site. That report was delivered in Month 12 of the SERVE project and was used as a first point of discussion with SPIL (Sustainable Projects Ireland Ltd), who are the partner representing the Village in the SERVE project.

This report takes the findings of the previous report and expands the scope further, based on the feedback obtained so far from SPIL. In the report, we identify practical options for renewable electricity generation and load management within the Eco-Village.

This report constitutes Deliverable 7.2b report, and is delivered in Month 18 of the project. It is planned that further consultation with SPIL will help to focus their requirements relating to the electrical energy supply for the Eco-Village, and allow more detailed proposals for a sustainable electrical energy supply to be developed. We will then be in a position to issue further reports for Deliverable 7.2.

Wind turbines are used as an example, because in general they represent the best value for money compared with other renewable generators, and they can be installed from sizes of 1kW to more than 1MW. Other possibilities include photovoltaic panels (PV) and biomass-based generation. Ideally, renewable generation in the Village would produce power which will be used immediately on-site (e.g. PV panels on a building which is used during the day).

[1] http://www.n-e-renewables.org.uk/page/technologies/photovoltaics/pv_variations.cfm - ~50-150 kWh/m^2 per year depending on panel type

2 Previous work – large-scale on-site wind turbine

2.1 Feasibility assessment

At the request of the Serve Project leader, Senergy Econnect OSG (On-Site Generation) team carried out an initial feasibility assessment for a large-scale wind energy scheme at the Cloughjordan site [2]. Wind turbines are a mature technology available in a wide range of sizes which, on sites with a good wind resource, can provide a very cost-effective form of renewable electrical energy. Such a scheme could provide a supply of green energy for the Village. A report was produced providing an indication of the key issues that required consideration in order to progress the development of a large-scale wind energy scheme at the site. The objectives of the assessment were as follows:

- To identify the key technical and environmental issues that need to be considered prior to the preparation of a planning application relating to the installation of a single large wind turbine;
- To identify an indicative turbine location and appropriate turbine specification;
- To provide indicative capital costs, operational costs, and potential revenue that a project of the proposed capacity could expect; and
- To provide relevant recommendations to progress the development to the planning phase.

A desktop study was undertaken to determine the technical, financial and environmental feasibility of a wind energy scheme at the Cloughjordan site. Initial assessments indicated that the site has reasonable wind speeds, favouring the development of a wind turbine. However, the turbine location is constrained by the proximity of dwellings. The Village itself is not suitable for a turbine installation of the proposed size because there is no area inside the Village which is far enough away from the Village and existing dwellings. Potentially suitable turbine locations were identified outside the Village itself, but these would be subject to arrangements with the landowner.

A suggested turbine location and specification were determined on the basis of an evaluation of a number of constraints and technical parameters. A preliminary assessment indicated that a 750kW turbine would be suitable to meet the demand from the Village, while providing a reasonable return on an initial investment of €1,133,000, with an indicative annual revenue of €152,000, a payback period of 9 years, and net lifetime profit in the order of €2.03M. The energy output from such a turbine was estimated at 1,942MWh per year, somewhat in excess of the estimated 375MWh annual electrical demand of the Village. Such a large turbine was recommended because the payback time and return on investment become disadvantageous for smaller turbines. The energy output decreases more rapidly than the capital outlay as turbine size falls.

During the evaluation, a number of issues were highlighted which may conflict with the development of a wind energy scheme and will require further assessment. Key issues include:

- Three aviation stations are located within 50 km of the development. Aviation and radar issues may require further assessment in conjunction with the relevant stakeholders.
- Sogaboy Hog Natural Heritage Area (NHA) is located within 5 km of the proposals, but is unlikely to be affected by a turbine development. An ornithological survey may be required to assess potential flight paths and collision risks associated with a wind energy scheme.

- The proposed development is located close to sites of cultural heritage and landscape interest. Impacts on these designations are likely to be minor, although assessment will be required.

The report recommended that a site visit be carried out, followed by an initial formal consultation with the Civil Aviation Authority, and a subsequent full consultation exercise to provide a realistic assessment of the feasibility of the proposals, and to identify the level of environmental assessment required, prior to a potential planning submission. Following the outcome of the project feasibility review, it was recommended that an anemometer (met mast) be installed to provide an accurate model of the site feasibility in terms of wind yield and turbulence effects.

Senergy Econnect OSG emphasised that this report represented an initial desktop assessment, and that issues not considered in this report may arise as the project progresses and such issues may impact on both the costs and/or the probability of the proposed project receiving planning approval.

2.2 Discussion of issues relating to the feasibility assessment

Average energy output

The energy balance calculated in the feasibility analysis is an average one. The wind turbine will over the course of a year produce the same amount of energy as the Village uses (or more, in the case of the turbine recommended in the feasibility study). However, sometimes it will produce less power than the Village is using at a given moment, and the Village's power needs will be met by other generators connected to the Irish grid. At other times, it will be producing more power than the Village needs, and it will be supplying other loads on the Irish grid.

In overall terms of carbon dioxide emissions, this averages out over the year. However electricity consumers who have local renewable generation often wish to match their power consumption more closely with their generator, for example, by switching on more loads when the generator's output power is high. This is one of the main applications of load management (discussed later).

Economic model and regulatory environment

The standard scenario employed using an on-site generation model is that of a single large electricity user (e.g. a manufacturing site owned by a single company), which installs a wind turbine on its own site. The site has a single electricity meter at the point of connection to the ESB (Electricity Supply Board) grid. The wind energy generated reduces the amount of electricity the site needs to import from the ESB grid, reducing the electricity bill. Sometimes the wind power exceeds the site power consumption, and the site exports energy to the ESB grid, with associated financial reward for that wind energy. The saving per kWh of energy which is made by avoiding importing energy to the site is usually more valuable than the energy which is exported, so it is beneficial to the company to use as much wind energy as possible, and avoid export. However it is not possible to ensure that the wind power matches the site power exactly at all times, so there will always be some energy imported and some exported, unless the wind turbine is so small compared to the on-site loads that there is never any electricity export.

The Village is slightly different from this scenario because it will comprise many separate buildings, each with their own electricity meter and supply agreement. A large wind turbine will therefore not be able to supply the site directly before the metering point - the wind energy will need to be supplied to the Village residents via the ESB network[2]. This means that the residents cannot

[2] Some developers of CHP and renewable installations have considered the possibility of installing a direct line (also known as a private wire network). A direct line is a piece of electrical infrastructure that is independent of the ESB system and whose purpose is to supply electricity directly to another party (e.g. an industrial estate) from the generator. Direct line installations are not uncommon in other jurisdictions, however they are, effectively, currently prohibited under Irish

reduce the total amount of electrical energy they import by using wind energy, and it means that the energy from the wind turbine will only be worth the value per kWh of the export rate its owners can obtain. Although the Village will be reducing its carbon footprint by having its own wind turbine, the economic value of the wind energy to its residents will be reduced. The financial analysis in the feasibility report therefore requires adaptation for it to be applicable to the Village.

The main point is that a large wind turbine may not be a very effective investment, if that is one of the drivers for the Village community. However if the Village wants to it have its own renewable electrical generation which will ensure that it is carbon neutral overall, then a large wind turbine can offer a relatively straightforward approach which could (pending further investigation) be no more expensive than individuals opting for a green electricity supplier.

Grid connection constraints

In global terms, Ireland is at the forefront of wind integration into electricity networks. There are many prospective wind farms seeking permission to connect to the ESB network, to the extent that the Commission for Energy Regulation (CER) placed a temporary moratorium on the acceptance of any further connection applications in 2003. Although this was lifted shortly afterwards, the process for obtaining a grid connection agreement for large wind turbine installations in Ireland is formal and very slow (possibly taking years), as connection applications are processed in groups[3]. Generators smaller than 500kW may be able to obtain a dispensation to be processed outside the Group process, and generators smaller than 11kW (three-phase) or 6kW (single phase) qualify as microgenerators, which benefit from a much more straightforward connection process. There is therefore a benefit in terms of timescales as well as initial investment in considering smaller renewable generators.

3 Possible renewable energy supplies for the Village

3.1 Large wind turbine

The initial study described above recommends a 750kW wind turbine to meet the Village's electrical energy needs. It will not be possible to site such a large turbine in the Village, and its exact location is not critical in technical terms (although there may be a desire for it to be nearby or visible locally). Such an installation would easily ensure that the Village is carbon-neutral on average.

The turbine would need to be owned and operated by a single organisation. Such an organisation could be SPIL or a separate community co-operative or company. Following installation, management activities will include monitoring energy production; organising insurance, maintenance and repair; arranging and administering sale of the energy produced; setting up loan repayments; and distributing any income / dividends. Necessary decisions would include how to operate the organisation, how to fund the capital investment required; how to manage the ongoing management tasks; and how to distribute the revenue from operating the turbine over its lifetime once any external loans have been paid off.

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legislation. A generator connected via a 'direct line' differs from a generator connected directly to the ESB network or an onsite generator. In a private wire network or direct line, the generator supplies loads that are on a different 'single premise' (as defined in the legislation). These loads are supplied without using the ESB system.

[3] This process is explained at
http://www.esb.ie/esbnetworks/generator_connections/gen_connection_export.jsp

A large machine such as this would require a significant initial investment. A proportion of this could be raised from community investors, but it is likely that additional loan funding could be required.

The 750kW machine suggested will fall into the Group process for obtaining a connection to the Irish grid, being larger than 500kW. This could delay a connection agreement until 2011. Since a machine nearer 300kW should be able to ensure the Village is carbon neutral electrically, it may be advantageous to the project to consider a reduction in turbine size.

The two main disadvantages of wind turbines smaller than the 750kW machine suggested are that:

1. there are fewer machines available on the market;
2. the overall project become less cost-effective as the size reduces.

One way to improve the financial balance is to opt for a second-hand machine. This will require a smaller initial investment for a given power output capacity. However, it will have a shorter operating life than a new machine. Maintenance and technical support may also be more difficult to obtain, depending on the age and type of machine.

3.2 Medium-sized wind turbines / large PV array

The next most cost-effective option for renewable generation for the Village is likely to be one or more installations below 50kW but above domestic-scale. Depending on the Village site layout, this could also allow an installation within the Village itself, if there is a preference for renewable generation on-site. It is unlikely that sufficient renewable generation could be installed within the Village to offset its total electrical energy demand.

Examples of grid-connected wind turbines in this range are listed Table 1 below, and others are also available.

Manufacturer	Rating	Rotor diameter	Hub height	Comment
Union Co. U54	*750kW*	*46m*	*45m*	*for comparison*
Proven Scotland	6kW	5.5m	9m / 15m	
Proven Scotland	15kW	9m	15m	New to the market
Westwind Northern Ireland	10kW	6.2m	15m / 18m	
Westwind Northern Ireland	20kW	10.4m	15m / 18m	
Gaia Wind Scotland	11kW	13m	18m	

Table 1: Examples of medium size wind turbines

PV arrays are very flexible in terms of sizing, from a few watts up to 20kW or more. Typically, 1kWp of PV requires a surface area of approximately 6.4m^2, 8m^2, or 16m^2, depending on the type of technology used.

3.3 Microgeneration

In addition to on-site generation options that feed the Village community, there is also the option of individual properties having their own microgeneration.

Roof mounted photovoltaic (PV) panels

The building plan for the Village has been made such that a maximum number of houses have a roof that faces south, encouraging exploitation of solar energy by the individual properties.

In general, solar thermal systems which provide hot water offer better value for money than PV systems because they are significantly cheaper and the energy they provide can easily be stored in a hot water tank, for use later. However the fact that the Village has a district heating scheme may mean that individual solar thermal installations are not required.

A typical capacity factor for a PV installation in Ireland could be expected to be around 8-9% (depending on prevailing weather conditions and installation details) i.e. an annual output of 700-800kWh. The advantages of PV arrays are their minimal maintenance requirements compared with rotating machines like wind turbines, and their long operating life (20+ years). Because electrical energy is generally not stored, the most benefit will be achieved if PV is installed on buildings which are in use during the day, so that the solar energy can be used directly within the building.

Roof mounted wind turbines

Recent studies[4] indicate that roof-mounted and other small wind turbines in built environments have very low efficiencies and thus do not offer very good value for money. Although such wind turbines may be useful to make a public statement in support of wind energy, a more effective ground-mounted machine would perhaps provide more value to the Village.

3.4 Alternative to on-site generation

The Eco Village has limited space available, and is therefore fairly constrained regarding what kind of on-site generation can be installed. An alternative option to on-site generation is therefore outlined below.

Shares in an off-site renewable generation scheme

As discussed above, an onsite generation scheme sufficient to supply the Eco Village with renewable electricity may be hard to realise in an efficient way. An alternative approach is to invest in an off-site renewable generation scheme, with the idea that the scale of the investment would correspond to an average generation that matches the Eco Village electricity demand, effectively making the Village carbon neutral.

In the UK and other countries there are several examples[5] of community owned wind farms ideal for this sort of investment. In Ireland there is presently no community shareholding in wind farms. However, this may change. Plans by what would have been the first community operated wind farm in Ireland, *Killala Community Wind Farm* in County Mayo, were refused in July 2008.

Some advantages of investing in a large off-site scheme rather than a modest on-site scheme include

- Off-site scheme is not bound by local constraints
- Larger schemes are typically more effective (better return for the money)

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[4] See e.g. Warwick Microwind Trial project, http://www.warwickwindtrials.org.uk/
[5] See e.g. Energy4All, http://www.energy4all.co.uk .

- No need or less need to get involved in planning process and technical details
- Partial ownership would be possible (i.e. no need for the Village to fund a complete scheme)

Some disadvantages are

- The relationship between the Village and the renewable generation is less direct, both in terms of energy usage and visible connection between the two
- The financial benefits may be lower than those from on-site generation.

4 Local grid

One idea that may appear attractive is to disconnect from the national electricity network and operate the Village as an off-grid system. Such an arrangement would require renewable generation capacity significantly larger than the average demand of the Eco-Village to be installed, to allow the system to cope with periods of low renewable resource. Even with sufficient capacity installed, operating off-grid is difficult to achieve with variable renewable generators, because it is necessary to match the consumer power demand with the available power supply second-by-second, otherwise the voltage and frequency of the supply will fall outside permitted limits. In an islanded system, any discrepancy between demand and supply is usually managed using some form of energy storage, either (in a conventional system) by using a diesel generator (where diesel fuel contains the stored energy), or by making use of batteries or other energy storage technologies.

At the scale of the Eco-Village, this is likely to be technically challenging, space-consuming, and expensive.

Such an arrangement also puts the responsibility for providing a safe and reliable electricity supply onto the organisation which operates the system, rather than ESB.

For these reasons it is usually recommended that a grid connection is maintained.

5 Load management

The term “Load Management” describes the process whereby power systems operators ensure that their generation capacity matches their predicted load demand. Historically, on conventional power systems, this has usually meant increasing generation capacity as load demand grows. However it can also refer to measures to reduce load, for example, to avoid having to increase generator capacity, or to reduce operating costs. Occasionally, measures are taken to increase load, for example, to optimise generator operating conditions. Demand side management (DSM) refers to techniques used specifically to manage demand by controlling consumption patterns.

This section gives a high level discussion of the potential for load management at the Eco Village. It intends to give a broad overview of how it might work and to point out issues that need further investigation.

Senergy Econnect’s load management experience

Senergy Econnect has extensive experience in load management with consultancy work and research and development projects including:

- Design and installation of several island grid systems with integrated load management to avoid overload. Two examples are the Scottish islands of Foula and Eigg.

- Powaplug™ products – a range of off the shelf products used for load shedding through automatic frequency response.
- 'Demand for Wind' project – a research project that developed a pilot system for electricity monitoring and automatic load management which was subsequently tested out in small scale household trials.

The Demand for Wind project, completed in March 2009, included automatic control of hot water heating and 'semi-automatic' control (requiring *some* interaction by the user) of dishwashers and washing machines. The trial system had a central processor which determined control signals based on the availability of surplus wind energy, and communicated these as well as monitoring data from each household via the Internet. A website interface gave users easy access to their electricity consumption (and microgeneration) data.

5.1 General considerations

The phrase "load management" can cover a wide range of activities. Some options include:

- making consumers aware of how much power they are using, to encourage them to reduce their consumption;
- making consumers aware when extra renewable energy is available (e.g. when it is windy), to allow them to increase their consumption (e.g. running a washing machine) and make sure they use as much "green" energy as possible;
- automatically switching on some loads (e.g. water heaters) when extra renewable energy is available (e.g. when it is windy), to make sure that "green" energy is used locally when it is available;
- automatically switching off some less-essential loads when power supplies are limited, to ensure that the power supply can meet the total power demand - at present this is most valuable on off-grid systems.

Load management *can* help to:

- reduce electricity bills, if renewable generation is installed locally;
- reduce the net CO_2 produced by a property or community;
- ensure a reliable power supply (on off-grid or unreliable systems).

In all cases, load management requires some knowledge of power consumption to be available, as well as information on the output of any relevant (e.g. local) renewable generation. The information acquired from the energy monitoring work package of the SERVE project may help to provide this information.

The exact way in which load management is used will depend on:

- what is the aim for using it (e.g. saving money; using more renewable energy);
- where and how much renewable generation is installed;
- what the commercial arrangements are for buying and selling electricity;
- what communications options are available for providing information to consumers or controlling loads remotely (e.g. control wiring; radio transmitters; broadband);
- what budget is available.

One example of how load management could be used is within the Utilities Area. If a small wind turbine were to be installed, then sometimes it would generate more power than is needed within the Utilities Area, and sometimes less. If operating some of the equipment within the Utilities Area could be delayed for a short while to wait for windy periods, then the wind energy would save 16.4c/kWh of electricity import rather than possibly being exported to the grid at 9c/kWh.

5.1.1 Motivations

As mentioned above, there are several possible motivations for considering load management. Some of these are:

System balancing – On a system-wide level, it is important to maintain the balance between supply and demand on a second to second basis in order to keep frequencies and voltages within allowed limits. For national girds this is usually achieved by controlling the generation of big power plants, but for islanded smaller grids, load management can be of crucial importance. In the latter case, load management could involve both load shedding to avoid overload, and dumping of surplus generation (load adding).

On-site generation – With on-site renewable generation, load management can help maximise the value of this generation by increasing the on-site use of generated electricity. For an off-grid system, this can be essential to reduce waste, while for an on-grid system, it has financial benefits due to the fact that the electricity import price (retail tariff) is higher than the export price (feed-in tariff). In this sense it helps with obtaining maximum value out of local generation. It also contributes towards self-sufficiency, and by increasing the use of renewable energy, load management can reduce CO_2 emissions.

Time differentiated tariffs – If the electricity price varies with time of day, load management can be used to reduce costs for the customer by having loads come on when the price is favourable (as far as possible). In Ireland, such night-saver tariffs already exist. The introduction of smart meters in the future may introduce more time differentiated tariffs.

5.1.2 Economics

How the economics work out with a load management scheme depends on the type of scheme and other details that are not known at present in the SERVE project. Some general remarks are made in this section.

In short, there are four questions that determine the financial benefit of a load management scheme

- How much of the load is controllable, i.e. *can* be shifted to some degree?
- How much load *will* be shifted, given control system design and constraints and other conditions like the climate?
- How much of the shifted load is able to exploit on-site generation / cheaper tariff? (Depends on the characteristics of the controllable loads.)
- What is the cost of the load management equipment and its maintenance?

<u>On-site generation</u>

When load management is used in conjunction with on-site generation, a financial benefit may be derived due to the difference in the electricity export price (feed-in tariff) and the electricity import price (retail tariff). Currently, the import price for residential customers is 16.4 c/kWh and an export price (feed-in tariff) for renewable microgeneration has recently been introduced at 9 c/kWh (with a limited offer of 19 c/kWh[6]). In this case, load shifting that results in exploitation of on-site generation (that would otherwise be exported) instead of imported electricity reduces the cost by (16.4-9.0) c/kWh = 5.4 c/kWh. For larger scale on-site generation, the export price is less (around 6 c/kWh), increasing the potential benefit of load management.

In the absence of a feed-in tariff, i.e. if the alternative of using generated electricity on-site is to let it go to waste, the cost reduction is 16.4 c/kWh.

How the feed-in tariff will develop in the future is an open question. If it remains relatively low, there is an incentive to use load management to maximise on-site use of on-site generation. A high feed-in tariff, on the other hand, will make export of on-site generation to the grid more attractive, thereby reducing the desire for load management.

Time-differentiated tariffs

If load management is based on time-of-day variations in the electricity price (a future scenario) then the financial benefit will come from the price difference, and the ability to exploit the cheaper price. It is impossible to quantify this at the moment.

This is similar to the idea of night-saver tariffs. The Rural Nightsaver tariff from ESB is currently[7] 17.52 c/kWh at daytime and 8.67 c/kWh at night-time. With this tariff, shifting load from daytime to night-time reduces costs by 8.85 c/kWh.

Example

To see how load management could be beneficial, it may be useful to look at a simple test case. Figure 1 shows an example with demand and generation for two different times, labelled simply 1 and 2. Demand and generation are split in three: 1) demand met by onsite generation; 2) demand met by import from the grid; and 3) generation exported to the grid. At time 1 there is little on-site generation, making import of electricity necessary, whilst at time 2 there is surplus on-site generation which is exported to the grid. Figure 1 shows two scenarios: 'Base' represents a scenario without any load management, and 'Managed' represents a scenario where load is shifted to times with surplus generation.

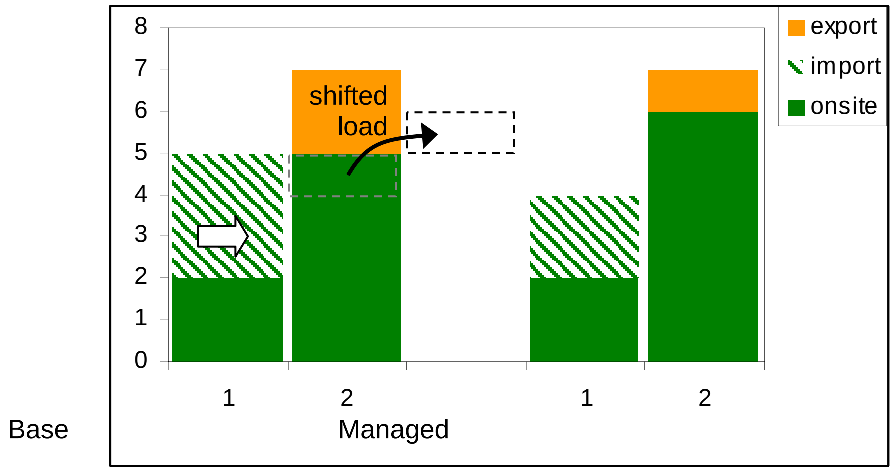

Figure 1: Load shifting principle.

[6]An initiative to support microgeneration whereby ESB will provide an extra support payment of 10 cents per kWh for the first 3,000kWh exported annually. This payment will be made to the first 4,000 microgenerators connected in the next 3 years and will be paid over a 5 year period.
Source: http://www.esb.ie/esbnetworks/generator_connections/micro_gen_connections.jsp
[7] Retrieved from the ESB Customer Supply website, 27 March 2009

Figure 1 shows that total demand (onsite + import) for the two times is 10 units and total generation (onsite + export) is 9 units in both cases. There is no overall change in demand or generation between the base case and the managed case. The difference is that the managed case has shifted one unit of demand from time 1 to time 2, exploiting more of the generation which is available at time 2, and thereby reducing import at time 1 and export at time 2 by one unit each. This amounts to a 10% reduction in import/export. In financial terms, assuming that the ratio between the import price and the export price is 16.4/5.7, this would give a relative cost reduction of 28.3%.

In this example, all shifted load is able to exploit on-site generation, reducing import by a maximum amount. This is too optimistic for realistic cases. Since wind generation fluctuates a lot on a short timescale, it is inevitable that there will be some electricity flow to or from the grid.

5.1.3 Load management and CO_2

Does load management affect CO_2 emissions? This question can be seen from different perspectives:

- It increases on-site use of renewable energy, reducing the need to import brown electricity from the grid. This brown energy therefore does not need to be produced, hence less carbon is emitted.
- If the alternative to using the renewable energy on-site is to export it to the grid, then it will replace brown electricity in any case, giving reduction in carbon emissions elsewhere. The main difference is *where* the renewable energy is used. From this point of view, there are carbon savings associated with load management only if it enables use of *otherwise wasted* renewable energy, i.e. in situations where the energy cannot be exported.

The second point does not take into account losses during transportation of energy. Use of electricity close to where it is being generated reduces these losses, and as such load management may, to some extent, help reducing carbon emissions by reducing energy losses in the electricity distribution system.

As discussed previously, the visibility and awareness of electricity consumption that a load management scheme provides is likely to increase energy efficiency i.e. reduce electricity consumption and carbon emissions.

5.1.4 Load management techniques

From a basic technical point of view, the primary objective of load management is either to reduce electricity demand or to increase it – load shedding or load adding.

- **Load shedding** – A reduction of the demand for electricity which helps avoiding overload on the system, or the need to import electricity from the grid. For island systems, load shedding is essential to avoid overload.
- **Load adding** – An increase in the demand for electricity which can be useful for exploiting available renewable energy that would otherwise be wasted or exported at a low price.

If the load management is designed to change the time when the loads are used (and not affect the overall electricity consumption), it can be referred to as *load shifting*. However, there may also be designs which do lead to overall changes, e.g. by switching to or from alternative fuels like gas or diesel, or by turning on or off loads that are not essential like e.g. extra heating.

A load management scheme can be implemented with varying degrees of complexity and automation. A fundamental distinction is whether it works by providing visibility or by some form of automatic control:

- **Visibility** – Electricity consumption and generation is measured and made visible to people in the community, increasing their awareness and leading to voluntary control. For example, if people are made aware that the on-site generation is currently higher than the demand, they may decide it's a good time to turn on the washing machine. Visibility is also helpful to increase energy efficiency.
- **Automatic control** – Suitable loads are controlled automatically, and are made to respond when there is a need or desire to shed and/or add load. How the automatic control is implemented depends on the nature and requirements of the controllable loads, and the objectives of the load management scheme.

Another distinction which can be made relates to whether the load management scheme operates on a community level or on an individual level.

Community-based load management

This means load management including a number of properties where the aim is to benefit the community as a whole. Such a load management scheme may be useful if it links in with community on-site generation or potentially a community electricity purchasing scheme. Islanded grids where load management is used to maintain grid stability would also fall within this category.

An advantage of a community load management is that the aggregation of electricity consumption from several properties makes the demand profile smoother and more predictable, making it easier to design control algorithms that work efficiently.

Section 5.3.3 contains further discussion of a community-based load management option.

Individual-based load management

This relates to load management at one single property. It may be designed to exploit microgeneration (e.g. rooftop PV panels) or based on time-differentiated tariffs.

As individual load management misses the opportunities and flexibility associated with having a pool of loads, automatic load management is likely to be less efficient both financially and environmentally than it would be for a community scheme.

However, load management through increased visibility and manual actions by the individual residents can be a good alternative to automatic load control, leaving it to the users to decide how involved they want to be, whilst keeping costs at a minimum. On the other hand, individual-based load management is simpler than community-based load management particularly with regards to metering and communications issues.

Sections 5.3.1and 5.3.2 contain further discussions of load management options within the Village's common utilities area and for individual properties respectively.

5.1.5 Loads suitable for automated control

For an electric load to be suitable for automated control, there will either be a degree of flexibility in the timing of when the load comes on, or the load is used for a purpose that has an alternative energy source i.e. its function is not crucial. The first situation (flexible timing) is generally the case with loads associated with some form of energy storage (batteries, thermal stores). An example of the second situation (alternative energy source) is a heating element that is constantly on, but can switch fuel between electricity and gas.

Some suitable loads are given in Table 2 below.

Load	Principle	Comment
Hot water heating	Energy storage	District heating. Loads in utilities area
Space heating	Energy storage	District heating. Loads in utilities area
Fridge/freezer cooling	Energy storage	
Dishwasher	Timing flexibility	More suitable if using cold water feed
Washing machine	Timing flexibility	More suitable if using cold water feed
Electric car battery charging	Energy storage	Currently not common
Community utilities area loads		See section 5.3.1.

Table 2: Controllable loads in the Village

For the Eco Village, hot water heating and space heating requirements are met by an obligatory district heating system which uses a combination of solar and biomass as energy source. Since these are already exploiting renewable energy, there is no environmental reason for considering a load management scheme aimed at linking on-site electric generation with the heating system. However, depending on prices, there may be a financial incentive for dumping electric generation produced from a fuel-free source into the heat storage rather than exporting it to the grid.

Automatic control of the utilities area loads are an interesting option which is further discussed in section 5.3.1.

The charging of electric car batteries provides a good option for load management, since it is both highly power consuming and time flexible, especially for overnight charging. The main problems are that electric cars are not common, and that they are less likely to be available as controllable loads during daytime.

5.1.6 Equipment

What sort of equipment will best achieve the load management goals depends on the objective and design of the system. The list below gives a flavour of what exists on the market:

Powaplug

The Powaplug is Senergy Econnect's own load management product. In its current form it is only available for use on island (off-grid power systems) where it has been used successfully both for load adding and load shedding for many years. We are however in the process of investigating grid connected versions, which could become available within the timescales of the SERVE project and be deployed as part of a load management solution for the Village.

EMMA

Cool Power's EMMA system[8]

EMMA (Energy and Microgenerator Manager) is an "intelligent energy management controller". A small unit that sits alongside your existing ESB meter, EMMA controls electrical power consumption in the home by adjusting the amount of energy stored in heating and cooling devices and EV battery packs

[8] Website: http://www.coolpower.ie/energycontrol/index.html

By doing this, EMMA maximizes the value of electricity generated on site and minimizes the cost of electricity imported from the grid.

Other equipment

There are several easily available devices that can be used for measurements and monitoring of electricity usage. Some examples are

- RFXCOM (www.rfxcom.com)
- Wattson (http://www.diykyoto.com/uk)
- Owl Electricity Monitor (http://www.theowl.com/)

Equipment for automatic control of appliances range from grocery shop available products like the Bye Bye Standby remote switch (http://www.byebyestandby.com/indexwed.html) to very advanced (and costly) industrial installations.

5.2 Energy aspirations of the Village community

Electricity demand

Expected household electric load (lights and appliances including cooking) has been estimated by SPIL as 14 kWh/m^2/year. The SERVE project aim is to build 13,200 m^2 of dwellings and 1,113 m^2 of community buildings, so if we assume that the community buildings have the same electricity demand per area as dwellings, the total demand for electricity by village buildings will be 200,382 kWh/year. In addition to this comes electricity consumption in the utilities area, which has been estimated as 23 kW i.e. 201,480 kWh/year. So in total:

- Estimated total Eco Village electricity demand: 402 MWh/year

This annual consumption equates to an average power of 56 kW.

Requirements

Initial consultation has taken place with SPIL with regard to their aspirations and plans for the electrical supply for the Eco Village. However this is at an early stage, and to achieve further work in this area, we need detailed feedback to be supplied by SPIL in order to focus efforts on solutions which are appropriate for SPIL's requirements. This includes the relative importance of different drivers, for example: funds available for investment, operating costs, the desire to achieve CO_2 savings, the required payback from investment in renewable generation, and the availability of personnel to implement and maintain any kind of load management system. Possibilities may also be constrained by the commercial and regulatory environment for electricity supply and generation in Ireland, which is continuously evolving.

5.3 Load management options

5.3.1 Option 1: Utilities area load management

The Village is considering the installation of a 50 kW wind turbine connected to the utilities area. Although the capacity of the generator is chosen to fit to the demand, there will be times when generation is larger than the demand and other times when it is less. This could allow some load management to be usefully implemented to optimise the use of the available wind energy.

The electric loads within the utilities area are summarised in Table 3 below[9]

Load	Demand [kW]
Boiler 1	9
Boiler 2	9
Pump 1	7.5 (estimated)
Pump 2	7.5 (estimated)
Solar park	2.5
Waste water treatment	7.5
Discharge pump	1.5
Extra lighting	2

Table 3: Electric loads in the utility area

The peak load has been estimated as about 33 kW, while the annual average has been estimated as 23 kW.

It has been suggested by SPIL that due to the thermal storage within each individual property, the district heating could operate on an interval basis – a few hours in the morning and a few hours in the evening. In this case, load management could be used to modify the timing within set limits. E.g. if the district heating normally comes on between 4am and 10am, but there is a large surplus of on-site generation at 2am, the system could make the district heating come on then instead, either running at reduced power for a longer time, or just moving it forward in time.

Design

If there is some flexibility in *when* the electric loads are turned on, the Village community could benefit from a load management scheme that sought to shift the load to maximise on-site use of generation. Figure 2 gives a schematic view of a load management system that measures generation, g, and utilities area demand, d, sends this information to a control device. This device then decides whether controllable loads should be switched on or off and sends the appropriate signal to a remote switch at the controllable loads.

[9] Information from SPIL

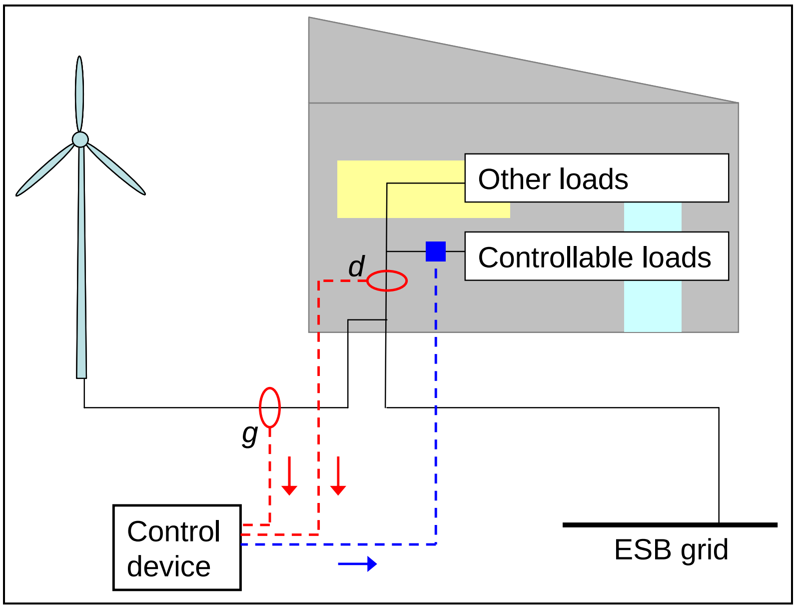

Figure 2: Outline of measurement and control points for utility area.

The detailed design of the load management scheme and the logic of the control device depend on the nature of the controllable loads. At the very basic level, the logic for maximising the value of on-site generation would be:

- If $g > d$ then turn load on.
- If $g < d$ then turn load off.

However, this would have to be accompanied by additional rules to take into account all constraints and to ensure the automatic control does not lead to undesired effects of any sort. How to achieve this can only be determined after a good understanding of the utilities area loads has been gained, e.g. of their demand profile and to what extent they can be shifted in time.

The extent to which shifted loads are able to exploit (otherwise) surplus onsite generation depends on factors such as:

- Can loads be shifted in a step-wise manner, e.g. 1 kW at a time, or only in bigger jumps ('all or nothing')?
- What is the response time when turning on and turning off?
- What are the load control constraints?

If the distances between measurement and control points are small, communication could probably be done most easily through wires. Radio signals, LAN network communication or power line carrier could also be considered.

<u>Economics</u>

Whether there are financial benefits, and if so, what these might be depends on how the load management is set to work and the details about the generator and the loads being controlled. The answers to these questions are not clear the current stage of the project.

5.3.2 Option 2: Individual property load management

This load management scheme option considers properties independently of each other, and may be relevant for properties with their own microgeneration, or more widely in the future if time differentiated electricity tariffs are introduced.

In the case of microgeneration, the objective is to match household demand as much as possible to the microgeneration, thereby reducing import and export. For tariff-based control, the objective would be to maximise the advantage of cheaper electricity price at certain times.

<u>Design</u>

Figure 3 shows a possible basic design for a household load management setup. Microgeneration, *g*, and household demand, *d*, are measured and compared. Based on the details of how the controllable loads are allowed to be controlled, and whether there is a surplus of wind ($g > d$) or not, the *control device* generates signals that control the controllable loads. The *control device* would be a dedicated low-power device, or it could be software running on a computer.

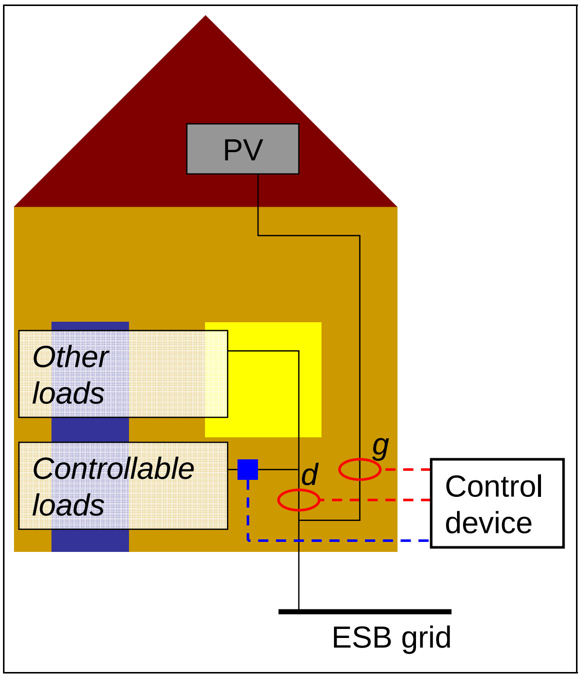

Figure 3: Measurement and control points for individual properties

In the case of photo-voltaic (PV) panels, the generation is fairly predictable with a maximum at noon (see Figure 4), so a simplified control mechanism could consist of simply a time trigger that would turn on e.g. a dishwasher at 12 noon to take advantage of likely maximum PV generation at mid-day. This would ignore the important effect of clouds, but would nevertheless be better than simply turning the dishwasher on at e.g. 8am before going to work.

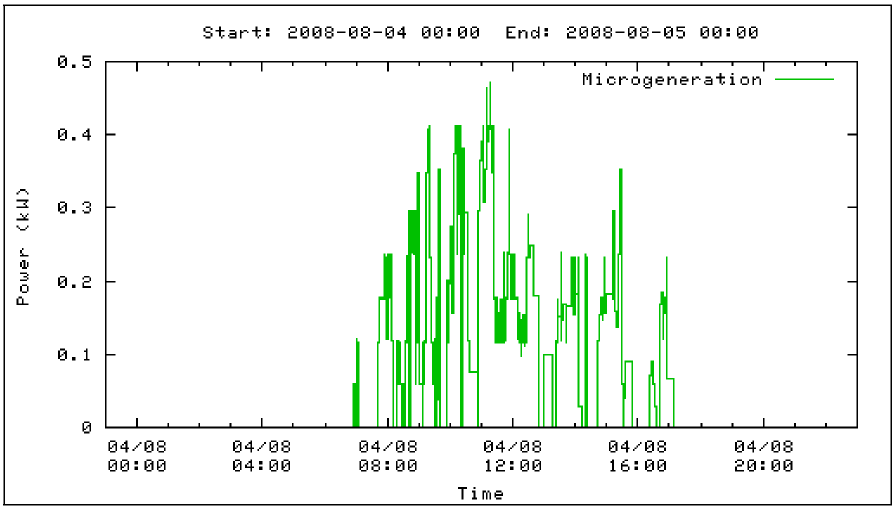

Figure 4: Example of PV generation during a late summer day.

Electric loads that could be automatically controlled via this scheme include dishwasher, washing machine, fridge / freezer and battery chargers.

Concerning electricity monitoring, the Village could coordinate this task and have measurements recorded and stored in a common database, allowing visibility for the entire Village and making it possible e.g. to have friendly energy efficiency "competitions" between Village properties, further encouraging energy efficiency.

Economics

A dishwasher uses about 1.2 kWh per cycle. If it is used once per day, the annual consumption is 440 kWh. Cost savings can arise from the fact that the feed-in tariff (9.0c/kWh) is less than the normal "buy" tariff (16.4c/kWh). If half of the total dishwasher use is controlled such that it uses microgeneration instead of imported electricity, the annual cost saving is € 16. Control of a washing machine will have a similar impact.

The financial benefit of automatic load control based on individual household generation and demand is therefore limited. However, increased visibility and awareness from detailed electricity monitoring is likely to have a significant additional impact.

Some possible obstacles to a beneficial use of load management based on PV generation include

- There are few suitable electric loads
- Electricity usage of washing machines and dishwashers when active is high (about 2.5 kW) compared to typical PV output, but relatively short lasting (30 minutes – most of the energy is used to heat up water at the beginning of the cycle), meaning that only *some* microgeneration can be absorbed.
- It is difficult to avoid export, as daytime demand while people are away is typically very low, at the same time as PV generation is at its maximum.

5.3.3 Option 3: Community load management

A more ambitious load management scheme could involve the entire Village community, by managing household loads in a synchronised way. The objective of such a scheme could be:

- Change Village demand to maximise value of large scale on-site generation (e.g. a 300 kW wind turbine).
- Manage demand to take advantage of time-of-day price variations for electricity. Currently, suppliers in Ireland offer night-saver tariffs, but the future introduction of smart meters may open up for more advanced price differentiation in electricity tariffs.
- Raise awareness and increase energy efficiency through detailed monitoring.

Issues that are particularly relevant when considering community load management are

- On-site generation: Load management is only really relevant if generation capacity is similar to community load size. If community load is much higher, all generated electricity will be absorbed anyway, and if the load is much smaller than typical generation capacity, shifting the load will not result in a reduction of export.
- Community purchasing: Are there any financial benefits if load is constrained?
- Metering: For load management to have any financial benefit to the community it is necessary that electricity generation and consumption is adequately metered.
    - If the electricity from the generator to the controllable load(s) flows via the ESB Network, both the exported electricity (from the generator) and the imported electricity (houses with controllable loads) need to have certified half hour meters.
    - Half hour meters are expensive. And even with such meters in place, a deal has to be made with the supplier to provide a financial incentive to use electricity when the on-site generator produces it.
- Monitoring and visibility: Should monitoring of individual consumption be part of the scheme? If so, how should it be visualised? Could heat be included? Could information be displayed in community buildings?
- Communications: How to communicate monitoring information and load control signals to/from the control centre? Is Internet/LAN available? Power line carrier?
- District heating: Load management could be used to direct surplus microgeneration to supplement the district heating. This could save fuel (wood pellets), but it may be more financially attractive to export the surplus electricity to the grid.

Design

Compared to a single property load management scheme, as discussed above, a community based load management scheme introduces additional challenges with regards to communication and complexity of the control algorithm. An outline of the system is shown in Figure 5. Measurements are taken at household level and sent to a central control device which contains the control algorithms operating each controllable load. Control signals are sent from the central device out to each controllable load.

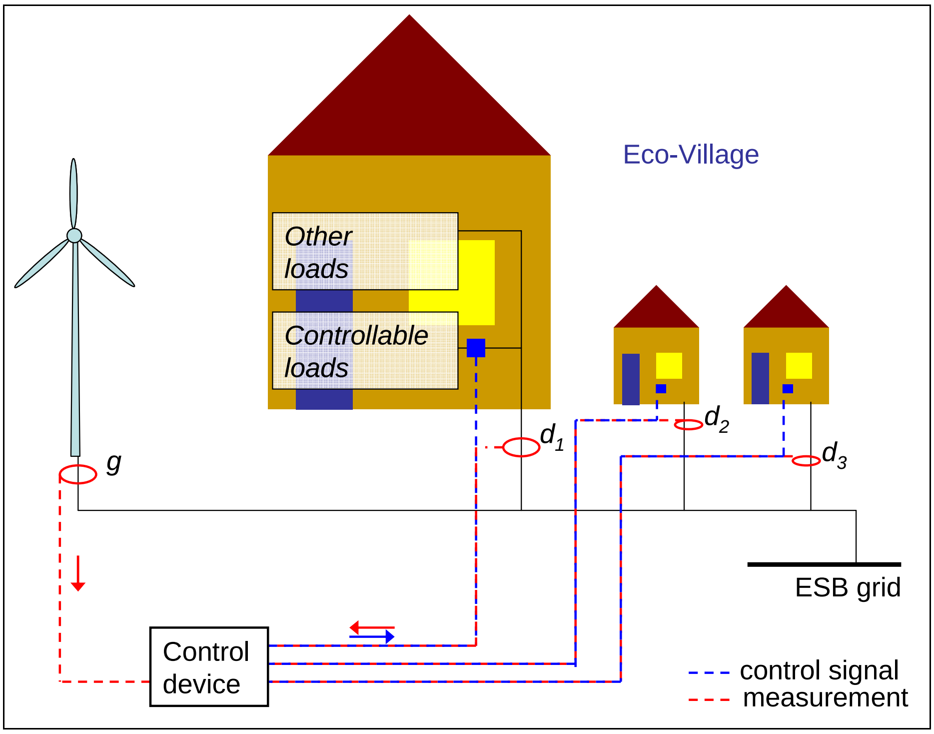

Figure 5: Basic design for community load management scheme.

Communications

Some options for the communication between dwellings/loads and the central control device are:

- Internet or local area network (LAN) – This infrastructure may already be available and easy to adapt.
- Power line carrier signals
- SMS messages
- Radio frequency signals – The required range (size of the Village) is larger than what cheap domestic equipment can deliver.
- Dedicated wires – likely to be expensive and work intensive due to the total distances involved

Monitoring and control equipment

The monitoring and control equipment required within each property will be the same for this scheme as described for individual-based load management in section 5.3.2. What equipment can be used for monitoring the wind generation depends on how it is connected to the grid.

Economics

There are currently some obstacles to achieving a financial reward from this type of load management scheme:

- The cables connecting on-site generation to Village houses is part of the ESB grid, so all on-site generation has to go via the grid, i.e. first exported and then imported ('bought back').

- Village properties could have different electricity suppliers, making it more complicated to negotiate discounts

6 Conclusions and recommendations

Senergy Econnect has carried out a study to inform the objective 8. of the SERVE project, which forms part of the EU-supported CONCERTO scheme, namely “To investigate the potential for future polygeneration, by monitoring the actual electrical load of the Eco-Village and the scope for load management. Based on this data a RES electricity production facility will be developed to match Eco-Village demand by 2010, but funded outside of CONCERTO.”

In this report, options for on-site and off-site renewable electrical generation have been considered. The main technologies under consideration were wind turbines and PV generation. The pros and cons of installing large off-site wind turbines, medium-sized on-site wind turbines, domestic-scale wind turbines and PV arrays have been discussed. Possibilities for incorporating load management into the Eco-Village to optimise use of renewable electricity have been presented, along with the practical implications and associated issues.

This report is in initial study intended to present a range of options. The most attractive options (in terms of sustainability, CO_2 reduction, and/or financial benefit) appear to be a) investment in a large off-site wind turbine, b) installation of a medium-sized on-site wind turbine in the Utilities Area, c) installation of one or more PV arrays on buildings which are used during the day.

For Senergy Econnect to complete this study and present detailed cost benefit analysis as well as a tailored solution, SPIL will need to provide a clear direction on their priorities and decide what the most appropriate choice is for sustainable electrical generation for the Eco-Village.

7 References

[1] Periodic Activity Report Year 1, CONCERTO INITIATIVE: SERVE (Sustainable Energy for the Rural Village Environment), Seamus Hoyne, Tipperary Rural and Business Development Institute, November 2008

[2] Deliverable 7.2a, Large Wind Option for Eco-Village, Pre-Planning Feasibility Study and Business Case for On-Site Wind Generation at the Cloughjordan Site, Senergy Econnect OSG, Issue 2, December 2009