MERIT – AN EVALUATION TOOL FOR 100% RENEWABLE ENERGY PROVISION

F.J. Born, J.A. Clarke, C.M. Johnstone & N.A.V. Smith*
Energy Systems Research Unit, Department of Mechanical Engineering, University of Strathclyde
James Weir Building, Glasgow G1 1XJ, UK.
www.esru.strath.ac.uk
*** Principal Author**

ABSTRACT: Islands represent an interesting challenge in terms of energy supply. A great deal of work has been carried out to look at specific aspects of this issue on different islands. Unfortunately, results from one study cannot be easily applied to other islands due to island-specific resources and energy-use profiles. A quantitative evaluation tool (MERIT) is presented here, which is able to match half-hourly energy demands (heat, electricity, hot water and transport) with local supplies. The program examines the energy balance on any scale, from an individual building through to an entire country, thereby providing a powerful and generic aid to decision making. This paper demonstrates the generality and usefulness of MERIT by using it to analyse the options for creating an energy-autonomous community on a typical, small island off the west coast of Scotland. Results are presented showing the feasibility of accomplishing 100% renewable provision on this island using available local resources.

1. INTRODUCTION

There are many small islands and remote communities around Scotland that are grid-isolated and have no other piped energy supply. These communities rely on expensive and difficult imports of fuel (usually diesel) to meet their energy needs. If local resources could be used to meet local energy needs, the cost of living would be reduced, the reliability of supply increased and local employment created. These factors would help boost the local economy and may help stem the de-population of these areas. Also, the use of renewable and sustainable methods of energy conversion benefits the local environment and helps preserve natural resources.

To evaluate the potential of creating a 100% renewable energy supply from local resources, a program (MERIT) has been developed at the University of Strathclyde [1]. MERIT has been designed to be as flexible and generic as possible, so that it can be easily applied to areas of varying size and local energy resources throughout the world (providing climate data is available). It is purely a quantitative evaluation tool, which allows the user to look at the half-hourly match between supply and demand in order to make informed decisions about the suitability of certain supply mixes for particular applications. Factors such as power quality and cost are not considered at this stage in the process, and once suitable mixes have been found, these should be looked at in more detail. Other simulation packages (ESP-r, EMTP) exist within the University of Strathclyde to enable this [2].

Within the program there are various methods for generating half-hourly demand profiles (electricity, heat, hot water and transport) based on existing data for different building types. Real or simulated data may also be easily input. While it has a database of various renewable energy supplies and storage devices, users can also input the specifications from manufacturers' data using the graphical user interface. The program then uses statistical methods to look at how closely the half-hourly demand and supply profiles can be matched. Finally, the output data is presented graphically with supporting statistics to aid quick analysis. This process can then be repeated to examine the effects of changing seasons or supplies, and simulations can be run for any time period from a day to a year, or representative seasonal days, weeks or months may be chosen.

A range of PV, solar concentrator, flat plate collector and wind technologies are held in a database, along with various auxiliary systems such as batteries, pumped storage and flywheels. Diesel generators and grid connection with various tariffs are also available for inclusion. Other energy carriers such as hydrogen, biogas, ethanol, methanol and biodiesel are available and a variety of methods for producing these energy carriers are currently being added. These include gasification, pyrolysis, anaerobic digestion and combustion of waste, biomass and energy crops, and electrolyser technologies. These fuels may then be used to meet base or peak loads for the various energy demands. A variety of turbine and engine electricity or combined heat and power (CHP) generating systems, air and water heating systems, fuel cells and vehicles will be available to accomplish this. Various different scenarios may be easily and quickly tried, and MERIT has proved to be a useful tool for decision-making.

2. ISLAND CASE STUDY

2.1 Demand Profile Definition

A hypothetical small island, typical of a number of communities to be found in Scotland, has been conceived for the purposes of this case study. The population, building use and industry have been based on that of the island of Muck, off the west coast of Scotland [3]. Forty people live on the island, supported mainly by a 1000-acre farm, and tourism. There are fifteen, three-bedroom houses, a school for six pupils, two workshops and a craft and grocery store all of which require heat and electricity all year round. There are also two, three-bedroom holiday cottages, a ten-bedroom hotel and a teashop, which require heat and electricity during the tourist season (April to October). Vehicles on the island include five tractors and one combine harvester with 170hp engines, and three general-purpose 4x4 vehicles, which all run on diesel fuel.

Annual consumption figures were estimated for the different building types using the good practice figures detailed in the relevant Good Practice Guides, published by the Energy Efficiency Office [4]. This electrical consumption was then applied to annual, half-hourly demand profiles that have been defined for various building types with non-electrical heating [5,6]. Thermal demand profiles for each building type were derived by estimating occupancy hours, assigning appropriate heating loads, correlating these with ambient temperatures given by local climate statistics, and applying annual consumption figures. These annual figures were derived using the figures for fossil fuel use given in the Good Practice Guides [4], estimating heating use and applying a conversion efficiency of 70%. Table I provides information about the annual consumption figures used.

Table I: Annual Consumption Figures

Building Type	No. of Units	Thermal Demand per Unit (kWh/year)	Electrical Demand per Unit (kWh/year)
3 Bedroom House*	15	14000	2000
School **	1	3500	1000
Workshop (50m2) *	2	2500	3000
Store *	1	2500	10000
3 Bedroom Holiday Cottage ***	2	2000	900
Hotel ***	1	15000	22000
Teashop***	1	2500	10000

* All year
** Except School Holidays
*** Tourist Season (1st April – 20th October)

Figure 1 shows the overall energy demands for the island for three representative days (summer, transitional and winter). This graph represents the overall demands if all the buildings on the island were supplied by a district-heating scheme. Figure 2 represents the same area, with five of the residential heat demands being met by off-peak electrical storage heating. Varying the demands in this way allows more favourable profiles to be created for different possible supply scenarios. The use of some off-peak electrical heating increases night-time electricity demand, giving a more constant electrical load, and decreases the heat demand. In this way, the annual balance and shape of the predicted electrical and heat demands can be studied to optimise the use of available local resources, CHP and other renewable technologies.

Transport fuel demand was estimated by assuming the six farm vehicles work 8 hours per day from February to mid July, and 15 hours per day from mid July to mid October, at 11.5 litres of biodiesel per hour. The 4x4 vehicles were assumed to travel 40 km per day, all year round, with a fuel efficiency of 16 litres of biodiesel per 100km. The estimated overall annual biodiesel consumption for the vehicles would therefore be 33200 litres, which would require 38 acres of land for growing rapeseed [7].

Figure 1: Overall energy demands for three representative days (all district heating)

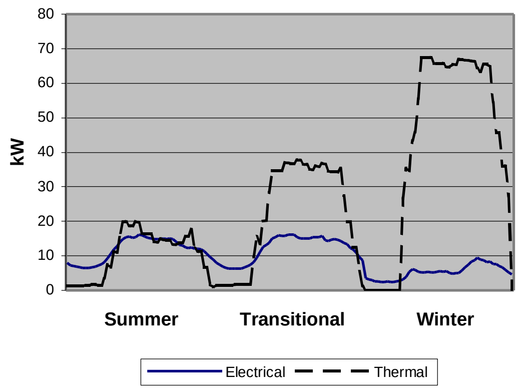
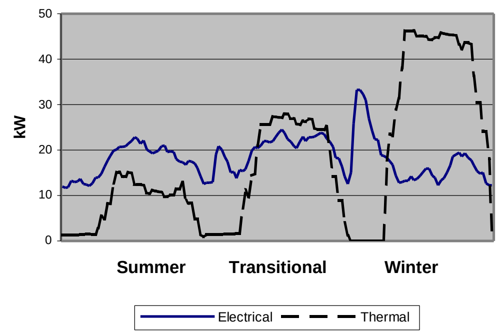


Figure 2: Overall energy demands for three representative days (all district heating except 5 residential)



2.2 Supply Profile Definition

Communities of this type typically use diesel generators for electricity generation, for which diesel needs to be imported, and a number of small local electricity distribution networks already exist. This study, therefore, concentrated on the feasibility of local production of biodiesel from crops for use in the existing plant. As diesel generators produce a substantial amount of waste heat (typical electricity to heat ratio is 1:1.8), various options were also considered for the use of CHP in a district-heating scheme.

Other possible supplies include wind and solar technologies. The use of wave power is another obvious consideration on an island, though most existing schemes would be too large for the size of community being considered here, and there is not currently provision for this in the program. As the demands being considered are relatively small, the use of battery storage may also be appropriate.

2.3 Biodiesel Production

The production of biodiesel (or methyl esters) is a well-known process that requires little specialised equipment. The most common method is base catalyst transesterification of 10 parts oil with one part methanol and a catalyst (either potassium hydroxide or sodium hydroxide). This produces 10 parts methyl ester and 1 part glycerine, which can be sold to the pharmaceutical industry or used for making cosmetics, soap or explosives. The only other by-product of this process are salts which, if potassium hydroxide is used, can be used as a fertiliser. In the UK, if rapeseed is grown, one acre of land can produce 875 litres of rape methyl ester (biodiesel) [7].

Although the island would still require to import methanol (or produce it themselves), this would be one tenth of the amount of diesel they would need to import. Also, glycerine is a valuable by-product, which may be exported or used on the island to produce toiletries and cosmetics that may be exported or sold alongside the local craftwork. Biodiesel and diesel can be mixed in an engine with no ill effects, so excess diesel may be imported and used in the same plant if necessary.

3. CASE STUDY RESULTS

3.1 The Role of MERIT

MERIT has been used to study a variety of different demand scenarios, to ascertain the best use of the available local supplies. When considering intermittent supplies such as wind and solar power, which are highly dependant on local weather conditions, it is necessary to consider the half-hourly demand and supply profiles over a year (or representative seasonal periods). This allows the performance of load following supplies (diesel engines, storage devices) to be analysed to ascertain the required plant size and profile of use, gives an accurate estimate of fuel consumption, and ensures that potential demand is always met. The results of these investigations are summarised in Table II.

3.2 Scenario 1: All District Heating

As seen previously, the demand profiles for the island where all heat is supplied by a district heating scheme gives a higher electricity demand in summer, mainly due to tourism, and demands for heat in winter and transitional times which are much greater than the electricity demand. The higher summer electrical demand could be reduced using PV technologies, but the limited available area and insolation limits the amount of electricity that can be generated. To meet these heat demands using biodiesel generator CHP, there would be an excess of electricity in winter and transitional times, and of heat in summer. Addition of a wind turbine reduces the biodiesel consumption a little, but does not change the required generator size. Increasing the size of the wind turbines being used makes little difference, as the main load in this scenario is thermal. Introduction of a supplementary heater, which would use excess electricity to boost heat production for the district-heating scheme, does make a significant difference to the overall annual fuel consumption, and increasing the wind turbine size makes a reasonable difference if supplementary heating is being used. Only one 25 kW generator would be needed in the summer, with another being needed during winter and transitional months. These profiles would not benefit from storage technologies unless they were interseasonal.

Table II: Demand and Supply Scenarios

Scenario	Diesel Engine	Wind Turbine	PV Cell	Electric Heater	Biodiesel Used	Land Used
	kW	kW	kW	kW	litres/year	acres
1	25 +25				47200	54
	25 +25		7.8*		46700	53
	25 +25	20			41500	47
	25 +25	50			40200	46
	25 +25	90			39500	45
	25 +25	50		50	29500	34
	25 +25	90		60	22600	26
2	70 + 30				91500	105
	70 + 30	50			51400	59
	70 + 30	50	7.8*		51000	58
	50 + 50	90			40300	46
	50 + 50	150			31700	36
	50 + 50	400			25500	29
		150	(1000 x	215Ah,	12V Batt	eries)
3	50 + 50				86000	98
	50 + 50	20			66500	76
	50 + 50	50			48300	55
4	35 + 35				65100	74
	35 + 35	50			37800	43
	35 + 35	50		25	33600	38
5	30 + 20				48900	56
	30 + 20	20			38800	44
	30 + 20	50			34600	40
	30 + 20	90			32500	37
	30 + 20	50		40	27100	31
	30 + 20	90		40	20800	24
6	25 + 25				47300	54
	25 + 25	50			36100	41
	25 + 25	50		40	27400	31

* 60 x 130W monocrystaline pv cells (1 m2)

3.3 Scenario 2: All Electrical Heating

If all buildings were to be heated by off-peak electrical heating, and no district heating scheme built, the demand profile produced would be fairly even with a higher demand in winter. A 70kW and a 30kW generator could meet this demand with only the former being needed in the summer. The annual fuel consumption, however, is double the amount of that with a district-heating scheme. The introduction of wind initially makes a substantial difference to this figure, but increasing the amount has less of an effect due to the relationship of output with climate. A bank of more than 1000, 215 Ah, 12V batteries would be needed along with a 150kW wind turbine to satisfy the electrical demand, and there is still a substantial amount of waste electricity at times when it cannot be stored.

3.4 Scenario 3: District Heating Except Residential

To make the demand profiles more favourable for CHP, the heat demand needs to be reduced. As the residential demands are by far the greatest for both electricity and heat, the effect of using electrical heating rather than district heating in some or all of these properties will be investigated. If all fifteen residential houses were supplied by off-peak electrical storage heating, this gives a larger electricity demand, and a heat demand that is, comparatively, very small (around one seventh of the electricity demand). Larger generator size and fuel consumption are required here to meet the increased electricity demand, and there is substantial heat loss throughout the year. The heat demand in this case is not significant enough to justify a district heating system or supplementary heating.

3.5 Scenario 4: District heating except 10 residential

The heat demand is increased again by having ten of the houses electrically heated. This does not make this scenario favourable for CHP alone, but the introduction of wind turbines makes this a more attractive proposition than scenario 1 due to the increased electrical demand. Introduction of supplementary heating makes a small but not significant difference.

3.6 Scenario 5:District Heating Except 5 Residential

With only five houses electrically heated, a further increase in the heat demand makes the use of wind turbines even more viable. The use of CHP alone, however, is still less viable than in scenario 1, as the engine produces more heat than electricity, and this scenario has a greater electricity demand.

3.7 Scenario 6:District Heating Except 3 Residential

With three of the houses electrically heated, the fuel consumption with the wind turbines has increased compared to scenario 5, as the engine is again needed to supply a greater heat demand, giving excess electricity. This shows that there is a balance that needs to be achieved between the electrical and thermal demand profiles to find the optimum demand mix for a given set of supplies.

4. CASE STUDY CONCLUSIONS

It can be seen that, **in this case**, if biodiesel generated CHP alone is to be used, then it is best for all the buildings to be supplied by the district heating system. As more heat is produced than electricity, it is not beneficial to increase the electricity demands above a certain level. Although this produces excess heat in the summer and excess electricity during the rest of the year, varying the existing demand profiles creates no better balance due to the limited number and shape of the demand profiles. This, however, would not always be the case with other demand mixes. It would be worthwhile to look for a local use for this excess energy.

If wind turbines are to be used a slight decrease in the heat demand and increase in the electricity demand are desirable here. It has been shown that having around five of the residential demands met by electrical heating provides the optimum balance in this case. Utilising increased amounts of wind power is not always beneficial due its intermittent nature and link with climate conditions, and MERIT can be used to find the optimum amount of wind power. The use of supplementary electrical heating can make a reasonable difference to the annual fuel consumption where there is an excess of electricity. This can also make the use of a larger wind power contribution more valuable. In this climate, with the area available, photovoltaic panels do not contribute significantly to electricity production.

This study has concentrated on the use of biodiesel in diesel generators as a large number of these are already in use in remote areas of Scotland. Current EU policy requires that between 10% and 15% of arable land must be set aside each year, but may be used for non-food production. It has been shown here that the energy needs of this size of community (for electricity, heat and transport) can be easily met by using under 10% of the available farmland for growing energy crops. It would also be interesting to investigate use of the various waste streams on the island for energy generation.

5. CONCLUSIONS

To evaluate the potential of creating a 100% renewable energy supply from local resources, the evaluation tool MERIT has been developed. The applicability and validity of this program have been highlighted using a small island case study. This simple study has highlighted some important balances that need to be considered in the design of energy systems supplied by renewable sources, especially if CHP is being considered. For all the possible supply combinations, it can be seen that there is an optimum balance to be found in the relative shape and magnitude of the heat and electricity demand profiles. MERIT has been designed to help the user find this balance with their available demands and supplies. The best options for a variety of different supply mixes have been highlighted, and the final solution would depend on other factors such as available land, local geography, positioning of buildings, existing plant and cost of equipment.

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