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THE ASSESSMENT OF RENEWABLE ENERGY PROJECTS FOR COMMUNITY BENEFIT IN WEST HARRIS

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FINAL REPORT

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1 Introduction

The Isle of Harris is part of the Scottish Outer Hebrides islands[1] with great potential for renewable energy. Exploiting this potential could trigger economic growth within the communities in the islands. Therefore, the community energy projects initiate a different approach towards the energy issue fostering a new perception and understanding of the energy resources. These type of initiatives link the local energy demand with a locally generated supply thereby boosting the local economy and empowering the community.

The use of wind, hydro and tidal technologies for electricity generation can resolve some of the challenges related to energy access in West Harris. Consequently, the use of domestic energy resources reduces the length of the supply chain, decreasing the dependency on the supply from the mainland while retaining the income in the local economy. Generating energy from renewable sources reduces the environmental harm caused by fossil fuel technologies, leading to a local low carbon development.

A major challenge when using the energy produced locally is the limited grid capacity in rural areas. An innovative way to tackle this problem is by developing energy systems solutions such as storage technologies that match the community's energy needs.

Organizations such as Community Energy Scotland (CES) and the West Harris Trust (WHT) encourage the development of renewable energies aiming to provide long term income for communities. In turn, issues such as energy poverty and energy security can also be addressed while building resilience and capacity.

A five-week field research was carried out by 14 students undertaking the Master of Engineering in Energy and Environmental Management programme at the University of Flensburg in Germany in close collaboration with CES, the WHT and the West Harris community.

The mission of this research is to contribute to the achievement of sustainable development through independent and sustainable energy systems as a means of generating income for the revitalization of West Harris. Specific sites were assessed to propose sustainable energy solutions based on the potential of renewable energy resources in order to evaluate the possible benefits that could be derived by the community upon exploitation.

In order to achieve the objective three possibilities have been explored: Options for complementing the electricity generation of the hydropower scheme in Gleann Dubhlinn with wind generation; Further options for micro hydropower developments (Luskentyre & Seilebost) and a wind scheme

[1] The Outer Hebrides are also known as the Western Isles in the UK.

in Laxdale are also analysed. Alternatives for the use of the excess energy from the aforementioned projects are considered.

This report presents the main findings organized as follows: Chapter 2 includes a general background. Chapter 3 explains the methodology applied in this research. Chapter 4 establish the assumptions made in the economic analysis of the projects, while Chapter 5 presents the main findings on the household survey. In Chapter 6 the environmental impact considerations are clarified. Chapters 7 to 10 include a multi-approach assessment carried out at the Gleann Dubhlinn, Laxdale, Luskentyre and Seilebost sites. Chapter 11 analyses different alternatives to use locally the possible surplus of energy generated at the sites described previously. Based on the preceding sections, Chapter 12 describes how the arrangement of renewable resources, when innovatively combined with energy storage, could lead to a dynamic local renewable energy development. Finally Chapter 13 presents the conclusions and recommendations from the assessment, visits, interviews and discussions with the community of West Harris, WHT and CES.

2 Background

Islands in the Outer Hebrides have been suffering from depopulation in the past decades. Between 1981 and 2011, Harris has seen its population decreased by 23 per cent (Comhairle nan Eilean Siar, 2015). The decline can be attributed to an aging population, migration, lack of job opportunities and housing for young families within the islands.

Furthermore, according to the Scottish Government (2012) almost a third of the Scottish households are estimated to experience fuel poverty[2]. In 2012 a national survey identified that 58 per cent of households in the Outer Hebrides were fuel poor, another survey suggests fuel poverty encounters more than 70 per cent of the Western Islands population (Comhairle nan Eilean Siar, 2014). *The Outer Hebrides Fuel Poverty Action Plan* (2014) describes the three main causes for this predicament, as summarized below:

a) **Poor energy efficiency:** the age and characteristics of the buildings (solid stone or poured concrete walls) make it difficult to apply energy efficiency measures.
b) **High fuel costs:** due its location, the Western Isles rely on a long supply chain in which *at the last mile* prices are 49 per cent above national average.
c) **Low incomes:** compared to the Scottish income level; income in Western Isles is the second lowest.

A holistic and integrated approach to address this problem has been considered in the *Outer Hebrides Fuel Poverty Strategy 2015-2025* which complements the *Outer Hebrides Energy Strategy.* The latter provides a framework to work together with implementation partners *"to maximize the economic benefits of renewable energy generation, increase self-sufficiency meeting the energy demand and address the levels of fuel poverty in the islands.*"

One of these partners is Community Energy Scotland, whose role is to build local energy economies. Its objectives are linked towards empowering "*communities to become stronger, self-reliant and resilient by generating their own energy and using it efficiently"* by providing education, finance and support (Community Energy Scotland, 2016). This principle resonates with the West Harris Trust (WHT), a community organisation that owns and manages 7,225 ha[3] of land on the west side of Harris. Among the plans and key objectives that the WHT have for this land is the development of sustainable small scale renewable energy projects. The overall goal is to revitalize the community by attracting new residents, developing affordable housing and creating

[2] Fuel poverty applies when a household spends more than 10 per cent of its income on fuel for heating.

[3] In 2010 the WHT acquired the crofting townships of Losgaintir, Seilebost, Horgabost, Na Buirgh and Sgarasta Mhor, from the Scottish Government (West Harris Trust, 2016).

employment opportunities, while preserving the natural heritage of West Harris (West Harris Trust, 2016).

For WHT, the renewable energy projects present a means of generating and also retaining income within the local economy. A major constraint that hinders the development of these projects is the limited grid capacity. This is attributed to the limitations of the existing interconnector to the mainland; however an upgrade of the grid is foreseen by the year 2022.

Renewable energy projects that have already been implemented or planned by WHT include: a wind turbine in Scarista (60 kW); planned wave energy (45-75 kW) combined with wind energy (70 or 100 kW) in the new Community Center in Horgabost that will include storage and a planned hydro scheme (100 kW) on the Abhainn Gil an Tailleir River (Gleann Duhblinn).

During discussions with the WHT, other options to develop renewable energy on the trust's land arose, such as: a) A wind turbine to complement the 100 kW hydro scheme along the Abhainn Gil an Tailleir River to maximize on the 200 kW grid access that has been granted; b) small -hydro plant or / and wind turbines close to the townships of Luskentyre and Seilebost; c) a 1MW wind project in the Laxdale area.

Renewable energy community schemes have the potential to transform and create inclusive benefits that could trigger development in West Harris. To access these benefits, the community needs to adopt new and innovative solutions to start up, scale up and roll-out renewable energy projects within its boundaries.

3 Methodology

The methodology employed to achieve the objective set out for this study included several stages. The initial step taken was to carry out a survey among the households under jurisdiction of the West Harris Trust. By use of questionnaires, interviews were conducted with the various home owners. The data collected in the survey was used to facilitate to assess the energy consumption, the existing and potential business opportunities and also to gauge the acceptance level of renewable energy technologies in the community.

The following step was the assessment of the potential of the identified hydroelectric projects. The key resource needed to evaluate the hydro potential of any micro hydro power plant is determined by the flow available in the identified rivers or streams. However, determining flow in each potential site is both laborious and cost intensive. In this study, long term flow data was not available for any of the identified sites. The Gleann Dubhlinn site had a limited number of stage and flow measurements available from previous studies. The only river in close proximity to the potential sites with recorded long term flow data was Laxdale River. Long term flow data of Laxdale River was used to correlate and compute the long term flow data of Gleann Dubhlinn. The catchment areas of all the potential micro hydro sites were calculated using ArcGIS ®, the Hydrology tool for spatial analyst extension was used for this purpose. A digital elevation model for West Harris based on ASTER Global Digital Elevation Model (GDEM) Version 2 developed by NASA was used to generate the local watershed for the intake points (Aster, 2016). The conversion tool was then used to transform the watersheds into catchment polygons. The assumption made is that the topographic condition as well as the precipitation received in Luskentyre and Seilebost sites are similar to Gleann Dubhlinn .The area ratio method was used to correlate the long term flow data of Gleann Dubhlinn to the flow data of all the potential sites. Site visits were undertaken to determine the location and elevation of the possible intakes by handheld GPS. Using the flow and the head available, the energy profile of the potential hydro sites was generated. For this purpose various parameters such as environmental regulations, demand profile, turbine efficiency, generator efficiency, and penstock efficiency were taken into consideration.

The steps undertaken to evaluate the wind potential of the proposed sites in West Harris were carried out in two separate procedures using the software WindPRO® by EMD International (EMD, 2016). This software is suited for project design and planning of both single wind turbines and large wind farms, it consists of several modules; each one with its own purpose. To assess the wind potential in the different sites, three sets of wind data were used: a one year measured data from the Horgabost meteorological tower (met mast) and two long term MERRA data sets, one from a nearby node and the second from an offshore node. For every scenario, the energy output was calculated, as well as an environmental impact assessment that will be further elaborated in the subsequent sections of this report. WindPRO® was used as the base to import all data into the program while the software WAsP® is used as an internal calculation engine to perform energy prognosis and generation of the resource map using the wind atlas method developed by Risø National Energy Lab, Denmark (WAsP, 2016). Furthermore, to carry out the turbulence intensity calculation, the software Windographer® was used.

Financial and economic analyses were carried out for project evaluation in each scenario. This necessitated the development of an Excel® tool for analyzing the main financial and economic indicators used to measure the viability and profitability of the projects. The most relevant ones include the net present value of the project (NPV project), internal rate of return (IRR), levelized cost of electricity (LCOE), payback period and average debt service coverage ratio (ADSCR[4]). While the NPV and IRR are specifically used to determine the profitability of a project based on the cash flows, the ADSCR is specific to the financing aspect of the project investments. The latter is essentially a ratio which indicates whether the cash flow (after taxes) is sufficient for debt service. Debt service refers to the sum of interest and loan principal payments. An ADSCR above 1.0 indicates that on average annual cash flows exceed the debt repayments and therefore the loan payments can be comfortably met. Any value below 1.0 means that the amount of cash required for loan payments cannot be sufficiently met by cash flows. ADSCR can be improved by imploring different loan conditions including alternatively opting for an annuity loan payment and modifying loan maturity period. In some cases a project may be deemed viable if it yields a positive NPV and a satisfactory IRR but still have an ADSCR a little lower than 1.0, in which case modification to financing terms can be made. Feed in Tariffs (FIT) are a crucial parameter for the economic viability of the projects. Future FITs are impossible to predict but generally a decrease can be assumed. To account for this uncertainty, in all scenarios, the effect of different FITs on the NPV of the projects is analysed, thus determining a range of FIT's for which the projects are viable. Positive NPVs are taken as an indication of profitability for each project. Downward trend of wind FIT scheme is presented in Annex 15.2 which is a good representative for the whole FIT scheme.

In addition, by calculating the IRR of the projects, it is also possible to assess the financial viability in each analysed scenario. The IRR is analysed based on a comparison with the discount rate. Thus, an IRR greater than the discount rate indicates that the project is profitable. The payback period, although not the most reliable method of project investment evaluation, is used in addition to the NPV and IRR. The method of calculation adopted in this economic analysis employs the discounted cumulative cash flows as uneven cash flows resulting in each year.

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[4] Average debt service coverage ratio (ADSCR): The ratio between operating cash flow and debt service during any one-year period. This ratio is used to determine a project´s debt capacity.

The main inputs for each scenario are investment cost, operation and maintenance (O&M) costs and annual energy generation. Other fixed inputs common to each scenario are summarized in Table 4.1.1. The calculations carried out for investment costs and O&M costs are described for each site under the specific methodology sections in each chapter. The analysis is being carried out for the individual wind and hydro scenarios in order to illustrate the viability and overall returns for the West Harris Trust (WHT) as a key stakeholder of these projects.

4 Assumptions for the Financial Analysis

To calculate revenue, grids constraints are considered for each site to determine the amount of energy available for export tariff; because in some cases energy production is higher than what is permitted under the grid constraints. The last FIT generation rate published on 12th February 2016 by OFGEM was considered as part of sensitivity analyses in the financial calculations. One exception is the loch project in the Gleann Dubhlinn site which will be described later. For hydro-power with a total installed capacity of less than 100 kW, the feed-in tariff assumed is 8.54 p/kWh. For wind power with a total installed capacity greater than 50 kW but not exceeding 100kW, the feed-in tariff is 8.53 pence/kWh and for wind power with a total installed capacity greater than 100 kW but not exceeding 1.5MW, the feed-in tariff is 5.46 p/kWh. Moreover, the export tariff is 4.85 p/kWh for all projects (ofgem, 2016). One exception is the loch project in the Gleann Dubhlinn site which will be described in section 7.6.3.1.

The following table consolidates the main assumptions for the financial analysis:

Table.4.1.1: Main assumption for financial analysis

Parameter	Value	Source
Degradation factor	0.05	(Iain Staffell, Richard Green, 2014)
Debt	100%	WHT
Interest rate	5%	WHT
Inflation	2%	Assumed by WHT
Tax	20%	UK Government (gov.uk, 2015)
Repayment	Straight	WHT
Discount rate	3.5%	UK Government (gov.uk, 2015)
Lifetime	20 years	Assumed
Maturity	15 years	Assumed

5 Survey Findings (Summary)

5.1 Introduction

A questionnaire survey was conducted by pairs of students between the 22nd February and the 1st March 2016. The survey had three main objectives:

- To assess the current energy status of dwellings/buildings in West Harris
- To assess the current and potential developments related to the local economy of West Harris
- To ascertain the levels of acceptance of renewable energy in the West Harris community

There are 54 residential dwellings in the West Harris community with approximately 130 residents. The survey was carried out in the Luskentyre, Borve, Scarista and Seilebost areas. A total of 32 households completed the survey, resulting to a response rate of 59% and 76 persons.

On this section some of the most important results of the survey are discussed; the complete results of the survey can be found on Annex 15.1.

5.2 Energy Status of Dwellings

5.2.1 Predominant Heating Technology Used in Dwellings

The results of the survey as depicted in Figure 5.2.1 shows that among the respondents there are only three types of heating technologies. By far the predominant heating technology is the central oil boiler with a share of 75%, followed by the electric heating technology (22%) and finally the air source heat pump (3%).

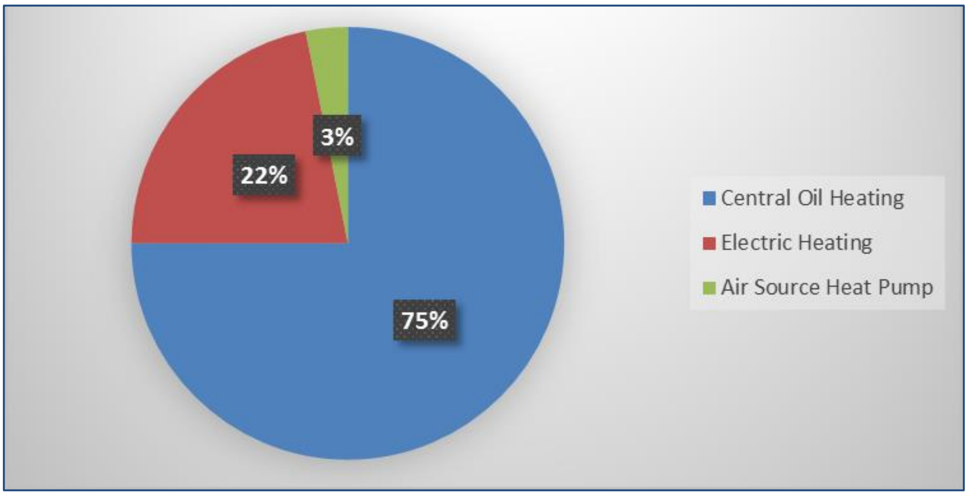

Figure 5.2.1: Predominant Heating Technology

5.2.2 Annual Heating Fuel Expenditure and Heating Demand Computation

Information regarding the expenditure on fuels for heating was also retrieved. From the total expenditure, in combination with additional data, the total energy consumption for heating was calculated for the surveyed dwellings. Excluding 7 respondents who use predominantly electrical heaters, 25 households use a range of 647,660 - 816,197 kWh aggregated heating demand based on the lower and higher efficiencies (mainly for central oil heater boiler) assumed in the computation. This yields approximately 25,906 – 32,645 kWh annual heating demand per household in West Harris. The total expenditure which flows out annually for the heating fuels amounts to £ 35,374 for 25 respondents. From the 25 respondents, 18 respondents provided the living space area of their dwellings. Based on these 18 respondents (only considering the heating demand of the 18 respondents) a heating demand per square meter in the range of 160 – 202 kWh/m^2 was computed.

5.2.3 Suitability of Heating System

When asked about the suitability of the heating in the household, the vast majority of the interviewees ranked their systems positively. The results are depicted in the Figure 5.2.2: **Suitability of Current Heating System**

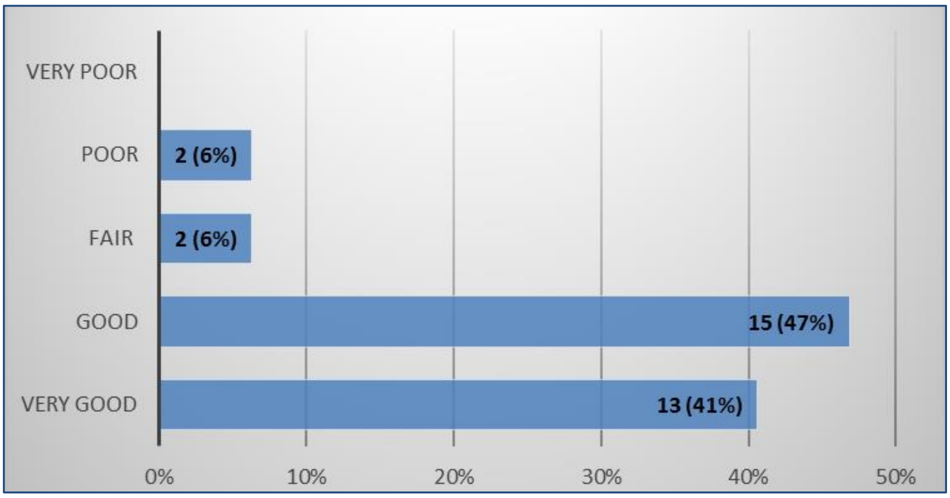

Figure 5.2.2: Suitability of Current Heating System

5.2.4 Total Annual Electricity Consumption and Demand

The electricity demand of the community and an indicator of consumption per household were calculated based on the annual expenditure from the households. The aggregated electricity expenditure amounts to **£35,438**. Using a standard electricity rate of **£0.1561/kWh** (SSE, 2016), an electricity demand of **227,022KWh** was obtained.

Due to the significant difference in electricity consumption between households using electric heating and other technologies, a different calculation was made to obtain the energy indicator.

Table 5.2.1: Annual Electricity Consumption: Dwellings with Predominant Central Oil Heating System

Indicators	Expenditure		Electricity consumption	
Central Oil Heating System	754	£/household	4,830	kWh/household
Predominant Electric Heating System	1,992	£/household	12,763	kWh/household

5.3 Income Generation in West Harris

5.3.1 Promising Businesses ideas in West Harris

The survey gave the opportunity to the respondents to give business ideas that they consider could be successful in West Harris. In the following list, the most suggested ideas are presented:

- Bed & Breakfast, Guest houses, hotels
- Eating places (Restaurants, tea rooms, etc.)
- Passenger ferries, boat excursions, sailing
- Nurseries, child care, etc.
- Information technology businesses
- Laundry
- Massage, acupuncture, reflexology, natural medicine

5.4 Renewable Energy Perception and Acceptance Level

In the survey there was also a statement to assess the level of agreement to the following statement: "**Community Based Renewable Energy Projects is one of the best ways to contribute to income generation in West Harris".**

The level of agreement of respondents was evaluated on a 5 point scale. Table 5.4.1 summarizes the results from these 2 questions.

Table 5.4.1: Agreement Level on RE Community Projects as One of the Best Ways to Contribute to Income Generation in WH

Agreement Level	Respondents	Reasons for the agreements or disagreements
Strongly Agree	9 (28%)	· Availability of abundant resources of Wind, Hydro and Tidal/Wave · High potential of Renewable Resources · Seen as only viable option to generate income and provide sustainable community · RE Projects generate excess electricity and can be used to generate income · Large land area can be used for Solar PV installations
Agree	15 (47%)	· Abundant RE resources as mentioned above · Based on previous experience with 53KW wind turbine, it has generated much revenue · Noble Hydro schemes would provide funds for investment which would give profits · Grants are available for Community RE projects · Seen as better option than generation of income from crofting
Uncertain	7(22%)	· Community not well informed · Lack of knowledge to give a sound answer
Disagree	1 (3%)	· No interest in RE technologies
Strongly Disagree	No respondents strongly disagreed	

5.5 Open Comments and Suggestions

The final part of the questionnaire was left open for respondents to provide feedbacks and suggestions which were not explicitly captured in the questionnaire. The suggestions are arranged in the following sub sections:

- **Comments by respondents on Renewable Energy**
  - There is a need to change the perspective of the community on Renewable Energy
  - Explore options on ‘smart grid’ and exporting electricity to mainland
  - Uncertain on how RE community projects can attract young people
  - Feels that large scale RE community projects is the future/way forward
  - With the use of RE storage systems, density of houses around the storage systems can be increased
  - There is a need to find other alternatives besides RE projects to generate income
  - Feels that the trust is doing a great job in carrying out community based RE projects
- **Comments by respondents on needs/facilities in West Harris**
  - Child care/nursery
  - Day care center for the elderly
  - Sports facilities
  - Horticulture
- **Comments by respondents on Improvement in infrastructure**
  - Better broadband connections

6 Environmental Impact Assessment

6.1 Hydro Projects

An assessment of the potential environmental effects of hydro schemes in the Western Isles was conducted by W.A. Fairhurst & Partners (2009). These potential environmental effects are summarized as follows:

Noise and vibration	Potential negative impact on sensitive receptors near the turbine hosue during construction.
	Noise of turbine in operation shall be considered to avoid negative impact on nearby housing.
	Sensitive ecological receptors such as riparian species may be affected during the construction phase.
	Temporary impacts during construction need to be minimized

Air quality	During construction displacement of dust and exhaust emissions from contractor vehicles travelling to and from the site. The temporary impact can be mitigated by dmping dOwn elaboration stockpiles of construction materials and installing wheel washes on site.
	Means of construction need to consider no significant impacts on sensitive ecological receptors.

Landscape and visual impact	Landscape is predominantly uninhabited, only few croft houses are found.
	Overhead power lines and infraestructure may have an impact on the openess and remoteness of the landscape.
	Closed spaces whitin the landscape shall be used to minimise impacts on the landscape.
	Tree planting can be used to screen intake location and minimise the visual impact.

It is unlikely that the sites for the different hydro schemes are significant fish habitat and that the flow abstraction would be a threat. According to SEPA (2005) predominantly bedrock streambeds areas with continuous rock surface provide poor habitat for fish.

According to the assessment previously done there is no requirement to submit an Environmental Statement for the Gleann Dubhlinn site. Nevertheless a detailed ecological assessment and habitat survey in all sites shall identify species that could be affected by the hydro scheme. It should consider all implementation phases and locations, including lochs along the water courses.

A next step would imply mitigation measures to minimise any negative impact. Specially considering the close boundary with areas hosting different terrestrial and aquatic species.

6.2 Wind Projects

Implementation of wind energy projects has the potential to impact the environment negatively; therefore it is crucial to carry out an environmental analysis. DECIBEL, SHADOW, PHOTOMONTAGE and Zones of Visual Impact (ZVI) Modules in WindPRO® were used to assess the noise, shadow and visibility of wind turbines of the Gleann Dubhlinn and Laxdale Wind Projects. Additionally, the adverse effects that the Golden Eagle population of West Harris could face are included in this section.

6.2.1.1 Noise

To identify the noise assessment criteria for Gleann Dubhlinn and Laxdale wind projects, ETSU-R-97 "The Assessment and Rating of Noise from Wind Farms" report is used as reference. According to the report, the noise limit during day-time is within the range of 35-40 dB (A) and during the night time the level is 43 dB (A). For the calculations, a noise limit of 43 dB (A) was used. According to the results obtained, the two houses located in the surroundings of the Gleann Dubhlinn project site will not be affected by the noise from the turbine(s). To see the detailed map of the noise impact in this area, refer to Annex 15.3.2 and 15.4.1.

Since there is no housing around the proposed Laxdale project site, the wind turbine(s) will not have any noise effects to any residential area. The noise map that is shown in Annex 15.3.2 and 15.4.1 can be used for future settlement planning.

6.2.1.2 Shadow

To determine the flicker effect caused by the rotation of the turbine blades, shadow assessment is carried out in WindPRO®. Since there is no Scottish shadow standard, the values of the German shadow standard are considered. For the worst case scenario, this standard establishes that the sun shines from sunrise to sunset on a cloudless sky and only 30 hours/year of shadow cast is allowed. Additionally these standards, a more realistic climatic scenario states that only 8 hours/year of shadow is allowed (Green Rhino Energy, 2016). The results obtained show that the two houses located in the vicinity of the Gleann Dubhlinn project site are slightly affected by the shadow from the turbine(s), at an extent much lower than the stipulated limit. To see the detailed map, refer to Annex 15.3.2.

Since there is no housing around the proposed Laxdale project site, there will be no effect on any residential area. The detailed map is shown in Annex 15.4.1.

6.2.1.3 Visualization of Turbine

Scotland is renowned for the diversity and quality of its landscapes and scenery. Wind turbines are large structures with the potential to have significant landscape and visual impacts. Therefore visual impacts of a wind project have to be considered before implementation and have to be designed to minimize impacts. To assess the visualization of the proposed wind turbine(s), PHOTOMONTAGE and ZVI Modules in WindPRO® are used.

Four viewpoints were proposed by the WHT for the visualization of the wind turbine(s) at Gleann Dubhlinn site. From Viewpoint 3, the wind turbine(s) is not visible at all, thus it is not included in the results as shown in Annex 15.3.2. Similarly, visualization of the wind turbine(s) at Laxdale site was carried out. The results are depicted in Annex 15.4.1.

Table 6.2.1: Coordinates of the view points

	Gleann Dubhlinn				Laxdale
	Viewpoint 1	Viewpoint 2	Viewpoint 3	Viewpoint 4	Viewpoint 5
Longitude	6°55′54.99″	6°55′26.92″	6°53′57.79″	6°55′26.85″	6°51′43.33
Latitude	57°52′7.99″	57°51′59.91″	57°52′5.38″	57°52′33.58″	57°51′32.88

6.2.1.4 Impact on Golden Eagles

All wild birds in Scotland are given protection under the Wildlife and Countryside Act of 1981. The isle of Harris is a natural habitat for the golden eagles which are of special interest in this study. These birds are included in this act as one of the species that are protected from harassment and whose nests are conserved (Scottish Natural Heritage, 2014).

When siting wind turbines in bird protection territories it is of great importance to consider their nesting areas, migratory and flight paths. The major concern is collision of the birds with turbine blades. The bigger the rotor blades and the more the number of wind turbines located in an area, the higher the chances of bird death due to collision and displacement of the birds from the golden eagles habitat areas.

Predators such as golden eagles are much more sensitive to bird strike because the size of the population is small.

The wind turbines selected for the proposed projects are of low capacity hence the rotor swept area is not highly significant and neither is the hub height. Additionally only a maximum of two turbines are proposed in each site therefore the risk of displacing the birds is quite low.

The golden eagles prefer to fly and nest in windy and mountainous regions. As seen on the Figure 5.2.1 the Gleann Dubhlinn site is nearer to the coast region, in relatively low altitude and at a considerable distance from the nearest nesting area, highlighted in green on the map. The feeding areas and flight paths of golden eagles are away from the coast and are concentrated more on the highest parts of the mountains. Nevertheless a detailed environmental assessment on the impacts of the wind turbines to the golden eagles may be required by the Royal Society of the Protection of Birds (RSPB).

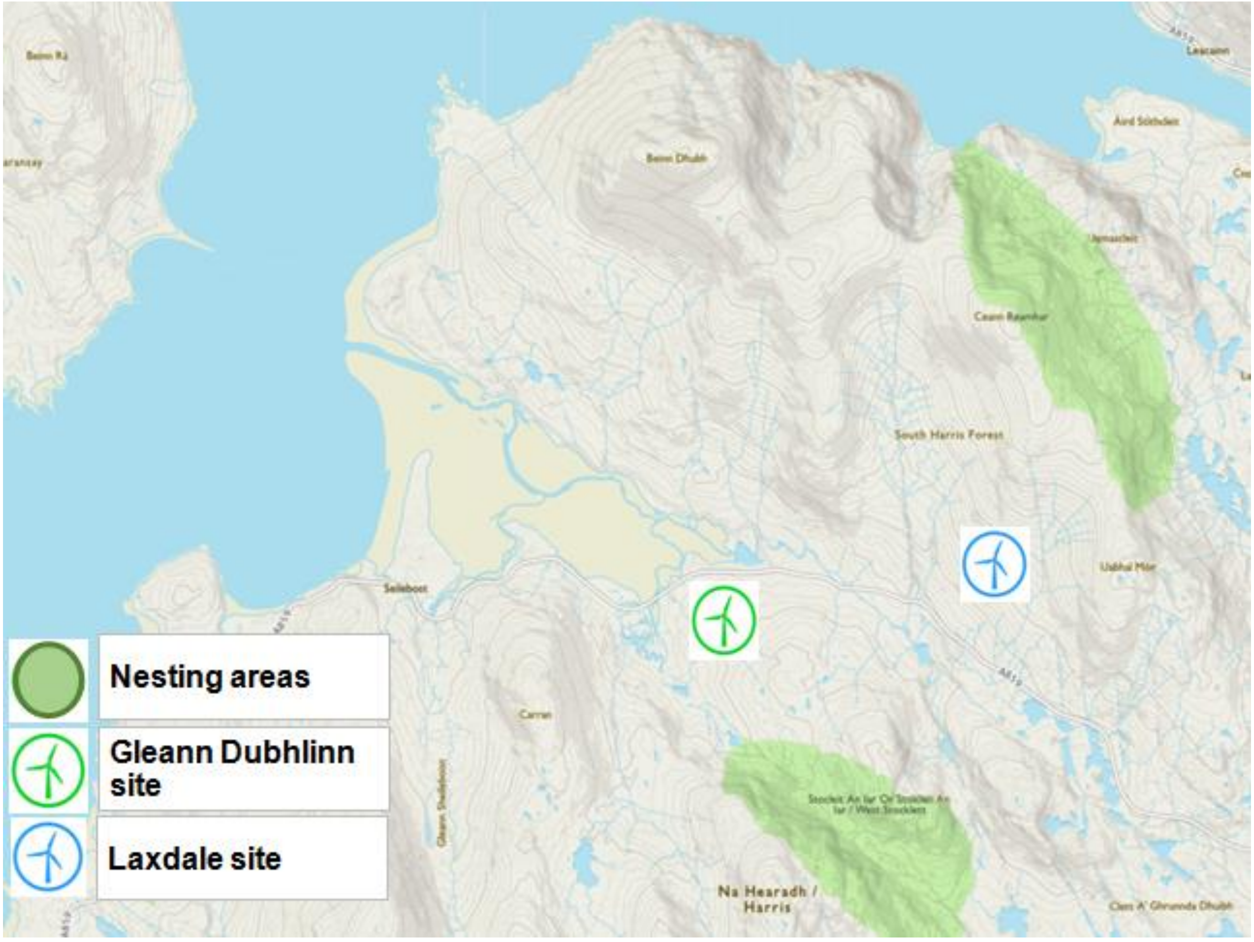

Figure 6.2.1 : Golden Eagle nesting areas
Source: Interview with Robin Reid, Conservation Officer for the Western Isles RSPB

On the other hand, Laxdale site is more significant in terms of the size of the turbines. The site is located in the middle of the mountain where golden eagles could be affected, although the nearest nesting area is located on the other side of the mountain.

From the aspects mentioned in this section, although a great risk for golden eagles is not anticipated, a detailed environmental assessment on the impacts of the wind turbines to the golden eagles may be required by the Royal Society of the Protection of Birds (RSPB).

7 Gleann Dubhlinn Hydro and Wind Project

7.1 Background

Among the proposed micro hydro projects, Gleann Dubhlinn is the one which has already been planned and is expected to start in the summer of 2016. The catchment area of this scheme is around 5 km^2 in size and is located to east of Seilebost. There is an existing intake on the Abhainn Gil an Tailleir River which has been used for supplying drinking water to settlements in the west of Harris. According to W.A. Fairhurst & Partners (2009), the watercourse flows from south to north discharging into the Luskentyre Banks and Saltings a Site of Special Scientific Interest (SSSI).

The capacity of the hydro plant planned for this site is 100 kW. Previous studies conducted on this site indicate a low base flow index with variable flow. To contribute to the stability of the system, one of the scenarios developed in this report is the storage option. A significant lake (loch) around 850 m upstream of the intake has been considered as a storage option which will be discussed further.

Presently, 200 kW of grid access has been granted, thus it is of great interest for the WHT to assess the possibility of implementing a complementary 100 kW wind scheme to maximize the export of energy to the grid. The wind turbine was sited approximately 1.4 km (57°51'55.03"N, 6°54'42.66"W) North-East from the proposed power house location of the 100 kW hydro project, this was site was identified on the initial site visits with Directors of the West Harris Trust.

Furthermore for this purpose, three scenarios were assessed in this site as follows:

- Scenario 1: 100kW hydro and 100kW wind turbine
- Scenario 2: 100kW hydro with storage and 100kW wind turbine
- Scenario 3: 100kW hydro with storage and a larger wind scheme to determine if there is any surplus than can utilized economically.

The locations of the schemes are as shown in Figure 7.1.1

Figure 7.1.1 : Wind and Hydro sites in Gleann Dubhlinn

7.2 Specific Methodology

7.2.1 Hydro

For the power profile generation of the Gleann Dubhlinn hydro project, the following parameters were assessed:

1. Long term flow data
2. Flow duration curve
3. Catchment area, head and penstock length

7.2.1.1 Long term flow data

Stage and flow measurements of the Abhainn Gil an Tailleir River were obtained from the feasibility study (W.A. Fairhurst & Partners, 2010). However these measurements corresponded to only few months of a specific year, thus not enough to perform the system analysis of combining both wind and hydro generation. Recorded flow data of a nearby river, Laxdale[5] was used to generate the required flow of Gleann Dubhlinn micro hydro site. To correlate the flow data of

[5] The Laxdale River flows three and a half miles north-west from its source in Loch Bearasta Mor to Loch Fincastle. It is described as a narrow burn that one mile from its source enters Loch Laxdale from which a mile further reaches sea across the sands of Luskentyre (Sandison, 2013).

Laxdale and the available data of Gleann Dubhlinn, corresponding flow data in the same year, month, day and time from both sites were selected. Both the flows were plotted against each other to get the correlation equation with corresponding correlation coefficient. With this equation, long term flow data of Gleann Dubhlinn was calculated.

7.2.1.2 Flow Duration Curve

After the generation of long term flow data, these data were then used to generate a flow duration curve. Long term flow data of Gleann Dubhlinn sorted in chronological order was plotted against *Exceedance Probability*. Exceedance probability is the percent of time that each discharge is exceeded. The base flow of the stream or river was calculated from the curve.

7.2.1.3 Catchment area, head and penstock length

For Gleann Dubhlinn, the catchment area, head and penstock length was already determined. However, it was possible to replicate almost exactly the watershed using ArcGIS.

7.2.2 Wind

As introduced in Chapter 3, three sets of data were considered. First the one year measured data and the onshore MERRA data were analysed to obtain a long term corrected data set. In the Figure 7.2.1 : **The comparison of the wind direction of the different data sets** the comparison of the wind conditions of the different data sets used in the calculations.

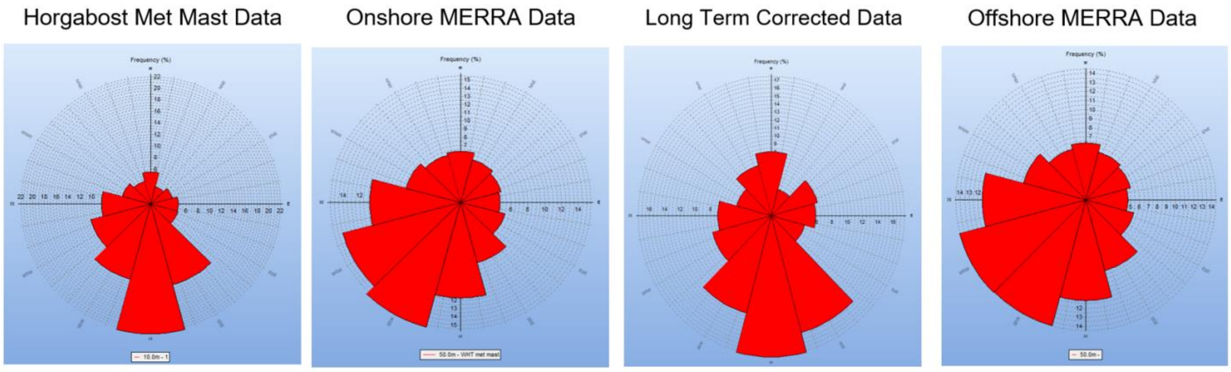

Figure 7.2.1 : The comparison of the wind direction of the different data sets
(Source: WindPRO®)

The results obtained showed that the predominant wind direction from the met mast was south, while the MERRA long term data was South-West. The difference in the predominant direction suggests that the met mast is positioned in the location where the wind is deflected. In light of this, it was concluded that the measured wind data of the met mast is not representative of the actual wind direction of the proposed wind locations.

Regarding the wind speed, the average value from the met mast was 9.33 m/s taken at a height of 10 m while the average wind speed from the offshore MERRA node presents an average wind speed of 9.45 m/s at 50m height. Taking into consideration that MERRA data is based on a MESOSCALE[6] model to interpolate the wind data it provides a better representation of the wind speed comparing to onshore MERRA data. Additionally, as can be seen in Figure 7.2.1 the results of the wind direction of the two MERRA data sets are consistent with each other.

Considering all mentioned aspects, the use of offshore MERRA data was deemed most appropriate to compute the energy prognosis. Since the MERRA node uses a Mesoscale model to interpolate the wind data, uncertainties exist. Therefore it is recommended to build a new met mast in the proposed site.

For the energy output of the different scenarios the wind data selected was simulated in the software. The specific topographic conditions of each site and the different proposed turbines were also factored in the simulation.

An environmental analysis was also carried out including noise of the wind generators and the shadow flicker. Additionally, visualization of the wind turbines from various points is done and possible repercussions on the golden eagle population are discussed.

7.2.3 Considerations for Economy

All main economic assumptions mentioned in Chapter 4 of this report also apply to the case of the Gleann Dubhlinn wind projects. However, specific considerations include road access costs which have been assumed to be negligible because of the location of the site near existing roads and other specific investment costs as listed in Table 7.2.1. Operation and maintenance costs were assumed to be 5% because of the small scale of the turbines considered for that site. The total energy generation and energy exported to the grid have been calculated using the Homer® Energy software. This was done for each scenario to ascertain how much revenue can be attained based on the 200 kW grid constraint. Revenues in this section are therefore considered by applying the FIT to the total amount of useful energy generated and the export tariff specifically on the amount of energy exported to the grid.

[6] Mesoscale Model simulates weather and wind conditions throughout the area at all levels of the atmosphere for 366 days randomly sampled from a 15 year period.

Table 7.2.1: Cost break-down for total investment cost of 1 Xant turbine

Break-down	Cost (£)	Source
Turbine purchase price	235,000	WHT
Foundation	31,000	WHT
Turbine installation	19,000	WHT
Grid connection costs	0	Payment assumed completed
Grid cable costs	117,000	Estimated based on previous projects
Consultancy	6,000	Estimated based on previous projects
Land	0	WHT
Road access	0	WHT
Total investment cost	**408,000**	

Source: Own elaboration (Compiled from various sources)

7.3 Technology Review

7.3.1 Hydro

7.3.1.1 Turgo Turbine

A Turgo turbine manufactured by Gilkes has been selected as the type of turbine in this site (Annex 15.3.1). The Turgo turbine is a type of impulse turbine which is specifically designed for medium head hydro projects. These turbines have an overall operational efficiency up to 83.69% (Gilkes, 2010). This turbine normally operates in a head range between Pelton and Francis (about 9 m and 300 m) and a minimum design flow of 0.045 m^3/s (Annex 15.3.1). The runner of the Turgo turbine is able to handle a greater quantum of flow along with higher specific speed.

7.3.2 Wind

In this section, technical specifications of the proposed wind turbines for different scenarios are briefly described. For the first and second scenarios of the Gleann Dubhlinn project, installation of a 100 kW XANT M-21 wind turbine was taken into consideration (Xant, 2016). For the third scenario, two 100 kW XANT M-21wind turbines are proposed. For the fourth scenario, three 60 kW HWT60 wind turbines were considered (Harbon, 2016). The turbine selection was based on the wind characteristics of the site, preferences of the West Harris Trust, existing installations in the Western Isles, availability in the market, the current tariff and financial schemes.

In the Table 7.3.1, the different classes of turbines are specified, based on the wind regimes according to the IEC standards. Following this criteria the turbines selected are in Class IA, this is in accordance to the results obtained in the resource assessment section that will further be discussed in the subsequent sub-chapters.

Table 7.3.1: Basic parameters for small wind turbine classes

Turbine Class	IEC I High Wind	IEC II Medium Wind	IEC III Low Wind
Annual average wind speed	10 m/s	8.5 m/s	7.5 m/s
Turbulence classes	A 18% B 16%	A 18% B 16%	A 18% B 16%

Source: (Vestas, 2015)

7.3.2.1 HWT60 Wind Turbine

HWT60 is a 3-bladed Class IA turbine model manufactured by H S Harbon & Sons Limited, an England based designer and manufacturer. The installed capacity of the turbine is 60 kW, hub height of 18.6m and rotor diameter of 16 m. This turbine model adapts to the conditions of the site since it does not require a crane for erection (Harbon, 2016). The price of the turbine is £209,000.

Additionally, a 60 kW Harbon turbine was installed in Scarista in 2014 March, therefore WHT is already familiar with the turbine.

7.3.2.2 XANT M-21 Wind Turbine

Xant M-21 is a 3-bladed Class IA turbine model manufactured by Xant, a Belgium based designer and manufacturer. The installed capacity of the turbine is 100 kW, hub height of 38 m and rotor diameter of 21 m. The turbine has a permanent-magnet synchronous generator. It has no gear box, which makes operation and maintenance easy. Considering the topography of the site, a convenient characteristic of this model is that it does not require heavy machinery to be erected (Xant, 2016).

The turbine is £235,000 (2,350 £/kW) which makes is more attractive compared to a 60 kW Harbon turbine with a price of £209,000 (3,483 £/kW). The price information for both turbines was given by the WHT.

Additionally, an identical turbine was selected to be used at the West Harris Community Center. Inevitably the installation and use of this turbine will provide the WHT valuable first-hand experience on the quality, operation and maintenance of this model and breed familiarity to the technology. Consequently, this conveniently allows WHT gauge the suitability of this turbine, creating a good rapport with the supplier and ultimately easing the administration of the projects.

7.4 Resource Assessment

7.4.1 Hydro assessment

7.4.1.1 Hydro without water storage

7.4.1.1.1 Long-term flow data

An average profile for the years 2008 to 2015 would neglect peak flows after strong rainfalls and very low flows after longer periods without rain. Therefore a representative year had to be selected to generate a generation profile. The values for the year 2008 were used as a reference as these are close to the average of the last eight years.

Table 7.4.1: Gleann Dubhlinn yearly average flows

	2008	2009	2010	2011	2012	2013	2014	2015	Average
Average values	0,123	0,109	0,095	0,138	0,107	0,114	0,131	0,147	0,120
	Closest to average year		MIN year					MAX year	

Source: Own elaboration based on correlation calculation

A flow hydrograph in Figure 7.4.1 was constructed using the 15-minutes data of the characteristic year (2008). The results were compared with those reported by Wallingford HydroSolutions (2010)

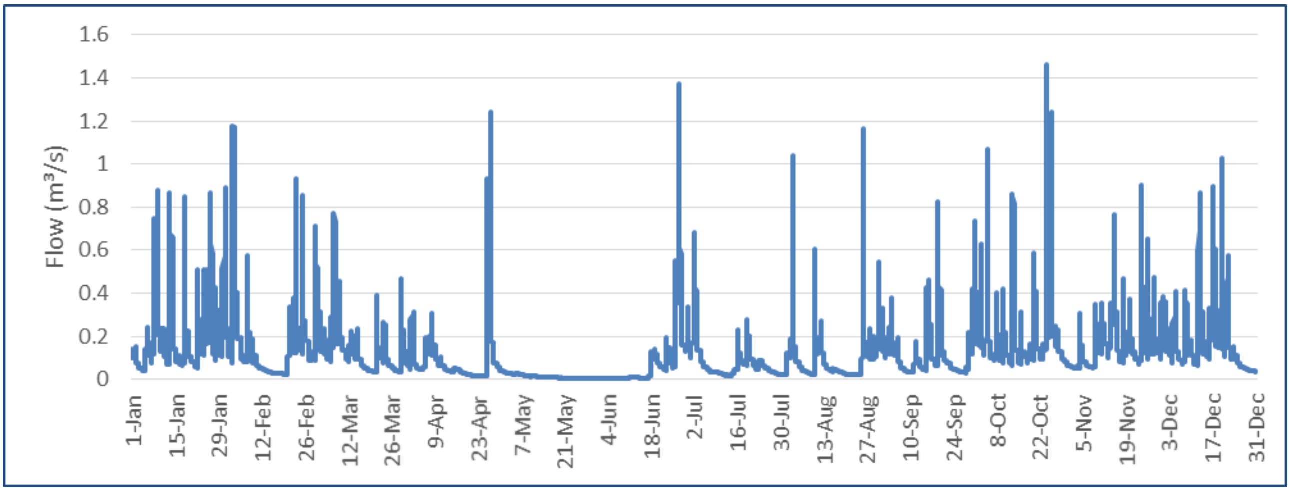

Figure 7.4.1: Gleann Dubhlinn hydrograph (m³/s) based on characteristic year (2008)
Source: Own elaboration

The flow levels across the year are expressed as exceedance percentiles Table 7.4.2. For the Gleann Dubhlinn scheme it is expected the use of Q90 as SEPA stipulates for compensation flows for hydro projects with a catchment area under 10 km² (SEPA, 2015).

Table 7.4.2: Flow statistics for the correlated long-term data FDC Gleann Dubhlinn

Flow Percentile (%)	Flow (m^3/s)
95	0.0053
90	0.0128
80	0.0284
70	0.0428
60	0.0607
50	0.0833
40	0.1060
30	0.1322
20	0.1727
10	0.2625
5	0.3774

Source: Own elaboration

The Q90 is the flow level that is exceeded 90 per cent of the year (for 90 per cent of the year the flow is above 0.12 m^3/s in Gleann Dubhlinn). Over the course of a year it will be expected to have at least this flow 328 days. This flow has to be left in the river at all times; it cannot be subtracted for electricity generation purposes.

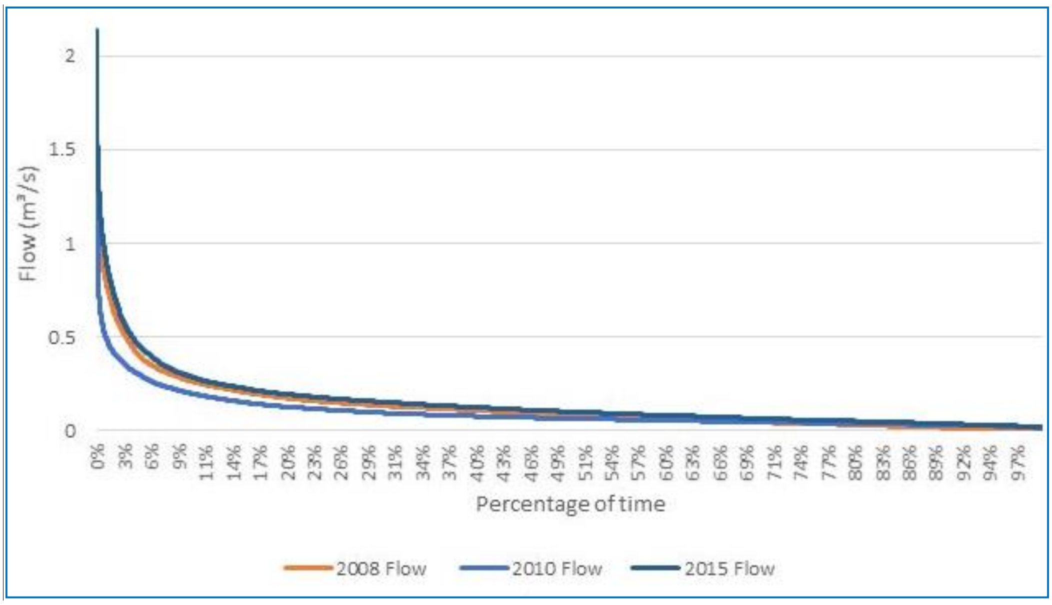

Figure 7.4.2: Gleann Dubhlinn Flow Duration Curve (FDC)
Source: Own elaboration

7.4.1.1.2 Catchment area

The catchment area for Gleann Dubhlinn was calculated (using ArcGIS) to replicate the catchment area already defined by Wallingford (2010). The catchment area extends roughly over five square kilometers as shown in Figure 7.4.3.

The head for this project site is located 81m above descending from smooth slopes combining rocky convexities in the relative low steep hillside.

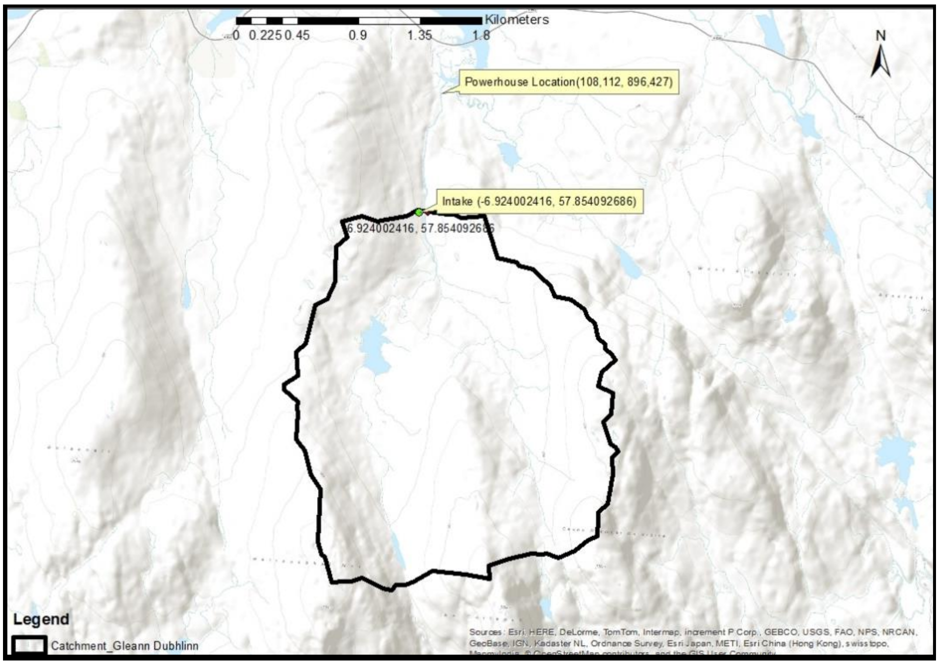

Figure 7.4.3 Gleann Dubhlinn catchment area
Source: Own elaboration using ArcGIS®

7.4.2 Wind assessment

Once the preliminary wind data assessment was finalized in the resource assessment chapter it was necessary to prepare the data for further stages of the calculation in WindPro®. To do so, a frequency analysis was performed to calculate the distribution of the wind speeds.

The Weibull distribution showed in Figure 7.4.4 represents how frequent a particular wind speed occurs. In this site, the most prevalent wind speeds are between 8 -10m/s at 50m height. The predicted wind direction is represented graphically by the energy rose as shown in Figure 7.4.4.

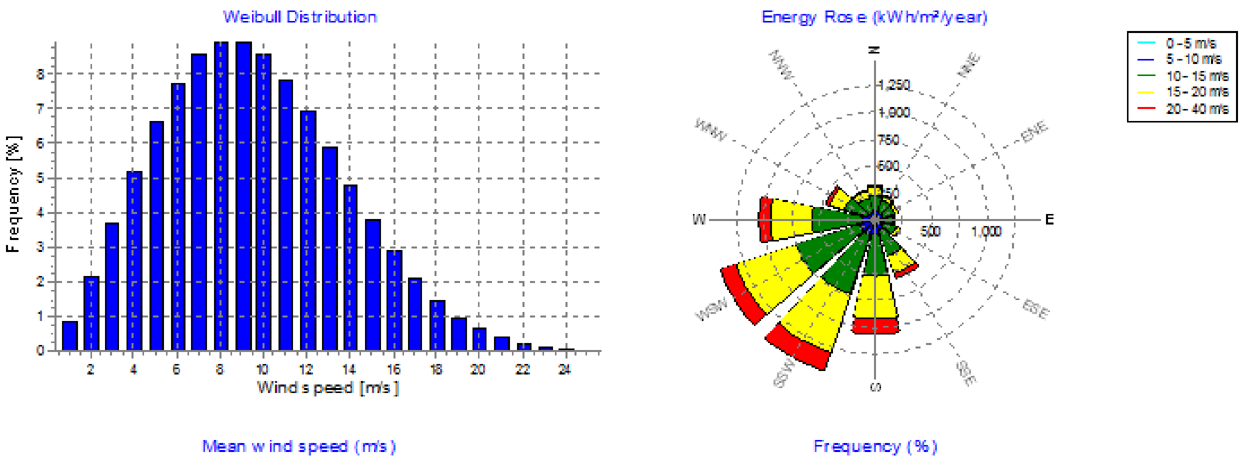

Figure 7.4.4: Weibull distribution and Energy rose
(Source: WindPRO®)

7.4.3 Turbulence

Wind turbulence is the rapid disturbance or irregularity in wind speed and direction. High turbulence levels decrease power output and cause extreme loading[7]. The Figure 7.4.5 illustrates the turbulence intensity (TI) at 10m height. TI is the ratio of the standard deviation to the main wind speed. Since MERRA data does not have standard deviation and the data on sites are limited, TI is calculated using the data retrieved from the met mast in Horgabost.

In the Figure 7.4.5 the TI calculated is represented with blue curve, which lies slightly above the IEC-B curve and below IEC-A curve, therefore the most suitable turbine under this conditions has to be IEC-A.

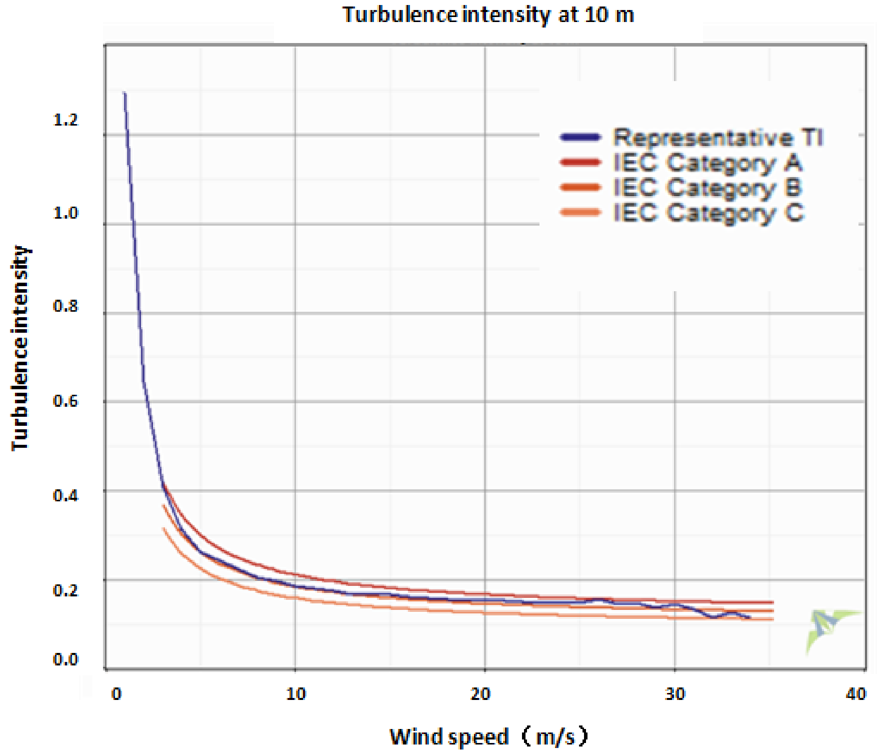

Figure 7.4.5: Turbulence intensity curve
(Source: Windographer®)

7.4.4 Wind Resource Map

The wind resource map is an analytical tool to represent the wind resources available in a geographical area. It is essential for wind energy planning and it is useful to map a smaller space within a region in order to optimize the positioning of a wind turbine. The parameters required to compute this include the wind data, turbulence and the topography of the area under analysis.

[7]Extreme loading refers to the high wind speeds that subject the wind turbine to a massive amount of stress.

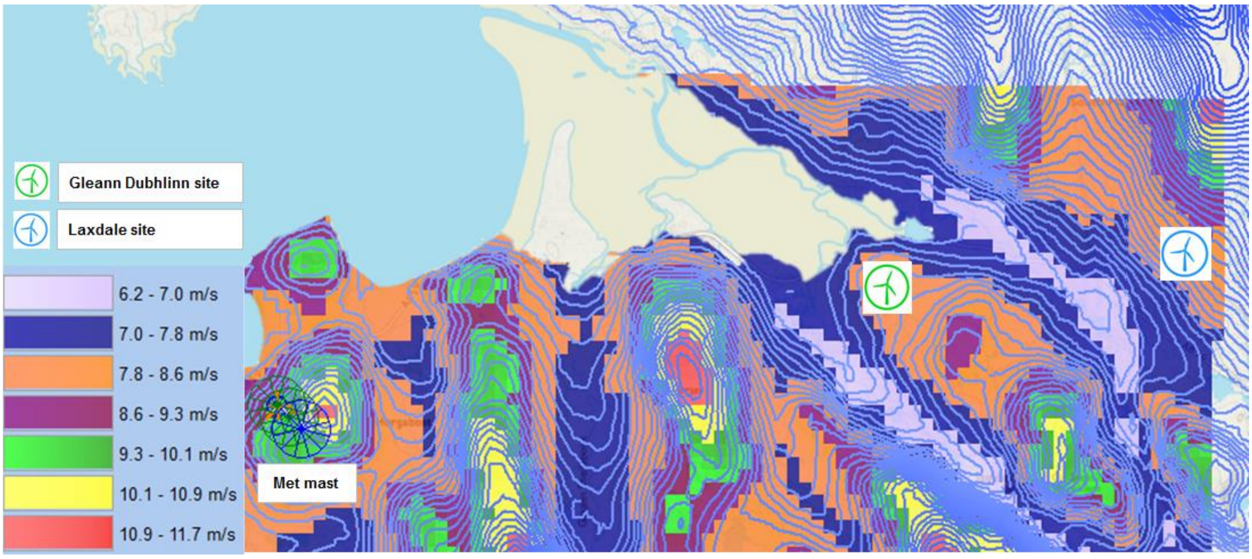

Figure 7.4.6: Wind resource map
(Source: WindPRO®)

The Figure 7.4.6 shows the resource map of the area of interest. According to the results obtained, the range of wind speeds expected on the proposed project sites is between 7.8 m/s and 8.6 m/s.

7.5 Scenario I: 100 kW Hydro + 100 kW Wind

7.5.1 Hydro Energy Assessment

7.5.1.1 Hydro without water storage

To simulate the combined generation profile of the hydro scheme and a wind turbine at Gleann Dubhlinn a generation profile for the hydro scheme had to be generated. The calculation was made to guide further calculations regarding the energy profile and the use of water storage explained later.

7.5.1.1.1 Generation profile

Variation in flow affects the overall efficiency. Therefore using the every 15 minutes flow values and the efficiencies provided by the supplier (Gilkes, 2010) result in a total generation of 389.83 MWh as shown in Table 7.5.1.

Table 7.5.1: Power generation Gleann Dubhlinn scheme

Gross head (m)	Turbine rated flow (m^3/s)	Turbine capacity (kW)	Capacity factor	Annual energy generation (MWh)
81	0.168	100	0.450	389.83

Source: Own elaboration

As expected, the water flow is not constant along the year; there will be periods where generation will stop completely. From the long term data as per Figure 5.2.1, it can be deducted that this is most likely to happen between May and June, as these seem to be the driest months in the year. According to the flow data of 2008 (characteristic year), the turbine does not have enough flow to operate for about 40 per cent of the year.

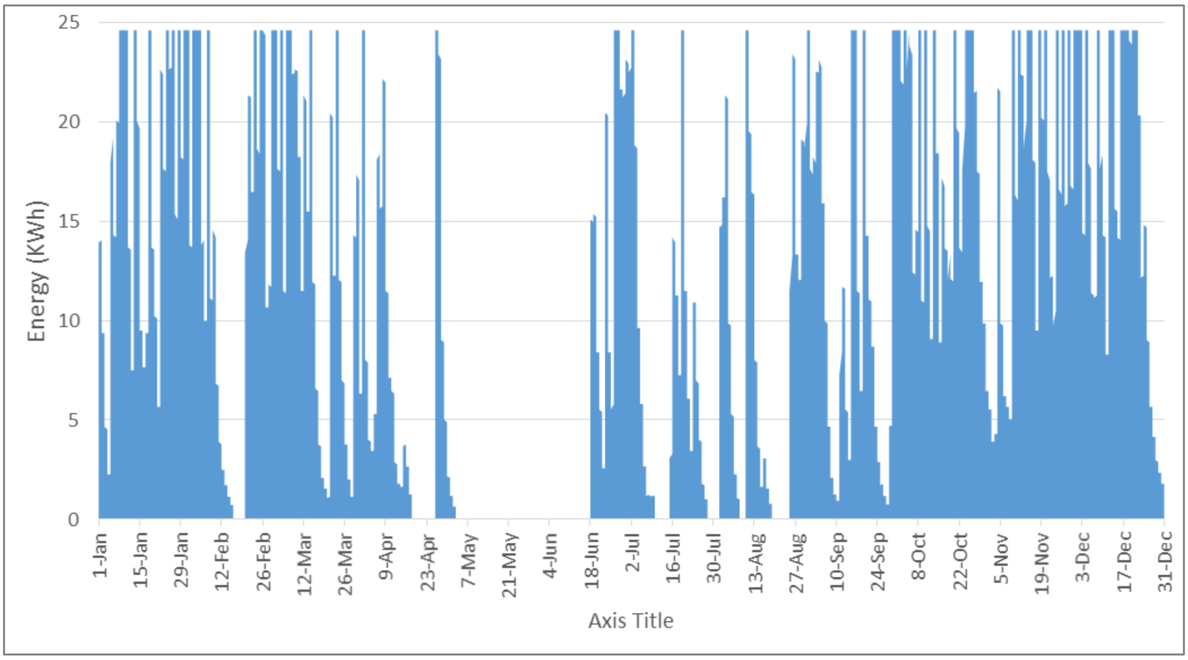

Figure 7.5.1 Gleann Dubhlinn 15-minute energy generation (kWh)
Source: Own elaboration (Annex 15.3.1)

7.5.2 Wind Energy Assessment

The softwares WindPRO® and WAsP® used the parameters mentioned in the preceding sections to calculate the expected annual energy output from the wind turbine. The results are summarized in the Table 7.5.2. The annual energy output using the Xant M 21 wind turbine was 380 MWh and as expected, the WSW-W sectors contribute to the highest share of the energy produced.

In this particular case the number of full load hours is 3800 per year. To encapsulate additional losses such as turbine performance losses and electrical efficiency that could not be computed a reduction factor of 10% is applied and subtracted from the total, obtaining a final net energy output of 342 MWh.

Table 7.5.2: Annual Wind Energy Output in Gleann Dubhlinn (Scenario I**)**

Sector	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	TOTAL
Resulting Energy (MWh)	16.4	11.6	11.7	12.8	19.7	35.7	47.1	55.2	60.3	56.0	34.1	19.3	380.0
Full Load Equivalent (Hours/year)	164.0	116.0	117.0	128.0	197.0	357.0	471.0	552.0	603.0	560.0	341.0	193.0	3800.0

Source: WindPRO®

The resource map in as per the Figure 7.4.6 shows the location that is proposed by WHT for the Gleann Dubhlinn wind project. The purple regions represent the regions with the highest wind speeds. The turbine was placed in this region and the energy output calculated was 35% higher than the output at the proposed site. Nevertheless factors such as road access and cable costs, would considerably raise the investment costs.

7.5.3 Economic Analysis

1 Xant turbine (100 kW) installed to produce energy in addition to the 100 kW hydro, proves to be profitable only if a minimum FIT of 8 p/kWh is applied, when the base energy output according to the wind energy assessment is considered. If 20% less energy is generated, a minimum of 12 p/kWh would be required to break even. In the event that 20% more energy is generated, the minimum required FIT decreases to approximately 6 p/kWh. Figure 7.5.2 shows how the NPV varies with varying FIT's for each bandwidth of energy generation.

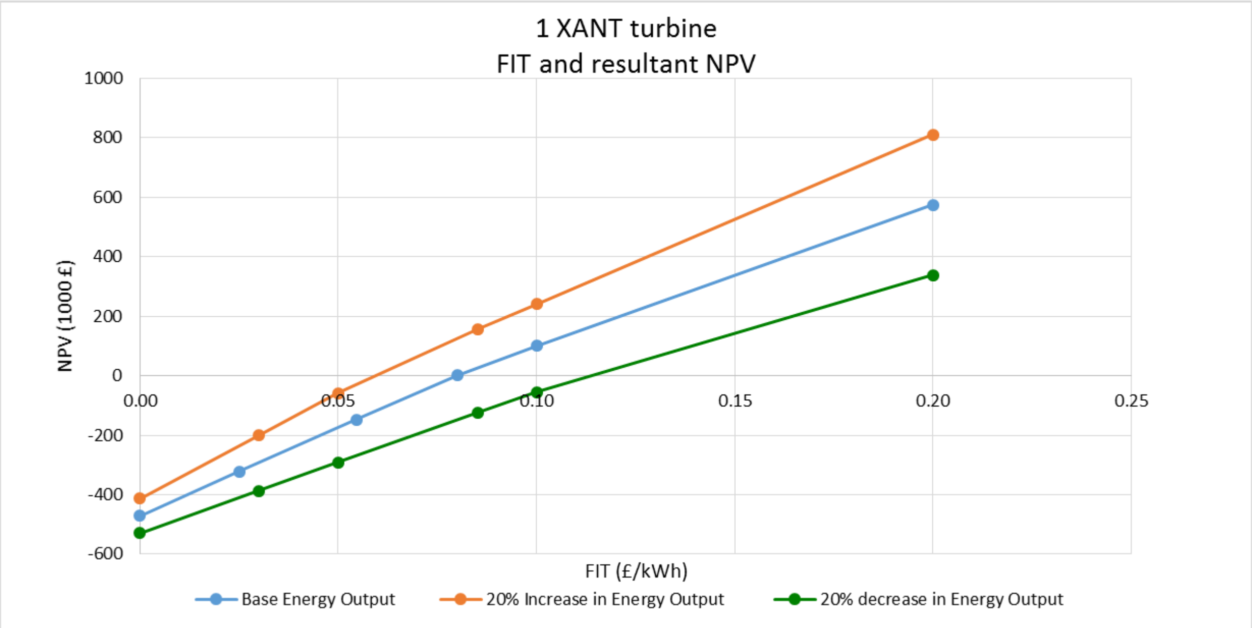

Figure 7.5.2: FIT and resultant NPV for 1 Xant turbine
Source: Economic model results

7.5.3.1 Example Case: FIT (8.53 p/kWh)

The example case assumes the current FIT of 8.53 p/kWh and with this FIT it results in a positive NPV and IRR which is comparable to the discount rate. An ADSCR of 0.83 suggests the need for further investigation into financing options to ensure that with the aforementioned FIT, the loan can be adequately serviced. Table 7.5.3 summarizes these results. The full cash flow is shown in the Annex 15.3.3

Table 7.5.3: Economic results for 1 Xant turbine

PARAMETER	RESULT
$NPV_{project}$ (£)	27,635.6
IRR (%)	4.2%
LCOE (£)	0.155
Payback Period (years)	19.00
ADSCR	0.830

Source: Economic model results

7.6 Scenario II: 100 kW Hydro + 100 kW Wind + Storage

7.6.1 Resource Assessment

7.6.1.1 Hydro

Wallingford HydroSolutions' findings (2010) established a low base flow index for the Gleann Dubhlinn catchment area, mentioning that highly variable flows are therefore expected in this site. For this scenario of hydro storage option, Loch Heilasbhal has been taken into consideration to serve as a natural storage option. This loch is located at a height of 157meters with an area of 59000 m^2. This loch is the biggest storage option available for this site of Gleann Dubhlinn. It is located at a distance of around 850 meters from the intake.

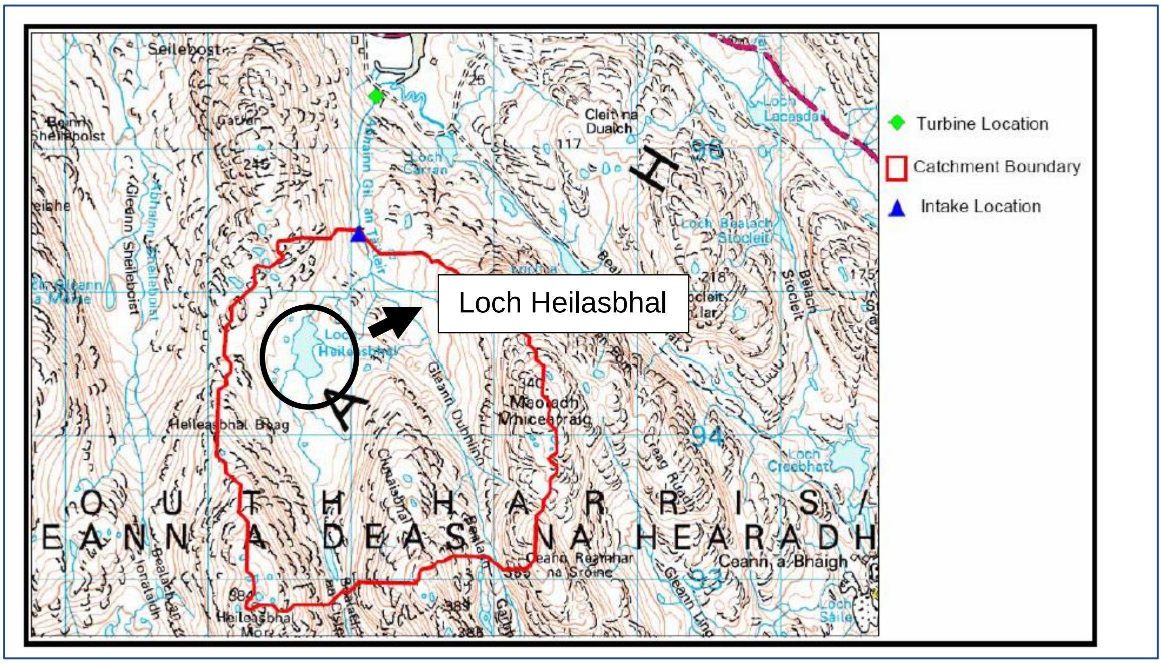

Figure 7.6.1: Location of Loch Heilasbhal
Source: W.A. Fairhurst & Partners (2009)

7.6.2 Energy Assessment

7.6.2.1 Hydro Energy Assessment

To carry out the energy assessment of Loch Heilasbhal as a storage option, volume of water that can be contained for the storage above the minimum water level in the lake was looked into. From site inspection, it was realized that constructing a dam of height less than 1 meter would not affect the natural loch storage. For further increase in height, the effect on the surface area of the water body needs to be studied. Furthermore, increasing the height also results in much more significant investment costs. Therefore, only an increase of water level between 0.5 to 2.5 meters was considered to calculate the excess energy. The additional energy generated from storage with the corresponding height is elaborated in Figure 7.6.2.

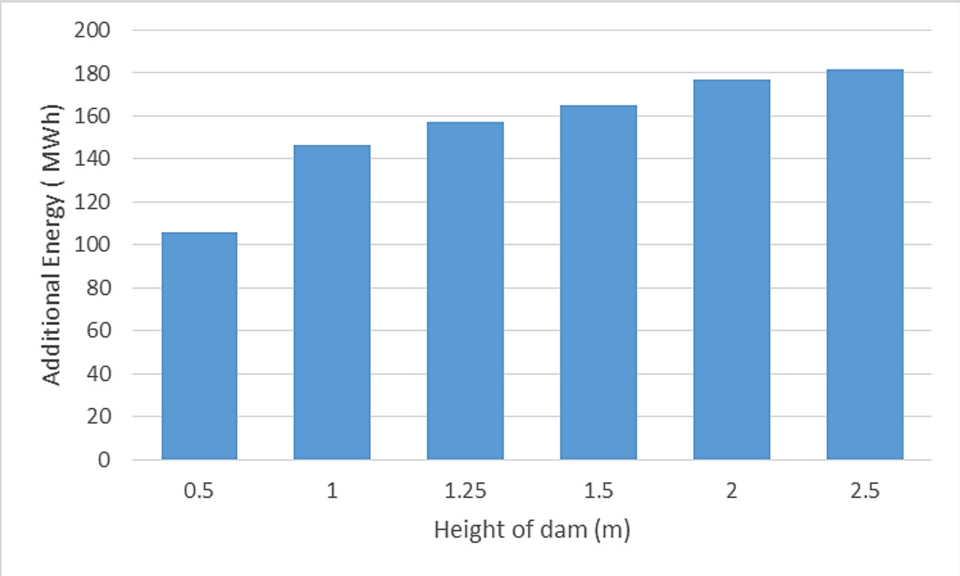

Figure 7.6.2: Gleann Dubhlinn excess energy generated with storage option[8]
Source: Own elaboration Analysis

We can see from the Figure 7.6.2 that additional 181 MWh of energy can be generated with 2.5 meters dam height. We can establish from the same figure that the most significant amount of additional energy can be achieved with an increase of height from 0 to 0.5 meters. Height of dam till 2 meters can be seen as a viable option for this scenario as there is no significant increase in energy after this increase. As increase in height also refers to a much higher investment with potential environmental impacts, dam height of anything between 0.5 to 2 meters is recommended for this scenario.

[8] These figures do not consider the time lag between the water being released by the storage and reaching the turbine intake. A rough estimation shows that this time lag can be in the range of 10-20 minutes. It can be avoided by installing a valve pipeline between the loch and turbine intake

7.6.2.2 Wind Energy Assessment

The wind energy output results for this scenario are identical as the ones presented in the preceding section 7.5.2 for Scenario 1.

7.6.3 Economic Analysis

The economic analysis specific to the wind turbine in this scenario is identical to the one presented in section 7.5.3. This is due to the fact that even with the additional energy generated from the proposed Loch, the 200 kW grid constraint is never exceeded when one Xant turbine is added.

7.6.3.1 Loch Economic Analysis

Based on excess energy generation calculated in previous section for the Loch, following economic analysis was employed. Total additional energy output for Loch with 1 meter and 2 meters storage height is 146,430 kWh and 176,850 kWh respectively. Based on data provided by WHT if the installation of the Loch storage option happens before 23rd September 2016, 20.28 p/kWh as the FIT rate would apply for 20 years and be updated by the retail Price index (RPI) increase each year. Moreover, from 1st April 2016 the sale price of electricity (Export Tariff) will increase to 4.91p/kWh. As WHT has already started ordering parts with lead-in time, we assumed that the scheme will be installed by 23rd September and mentioned tariffs will apply for this scheme, not the prevailing FIT rate which are much lower.

Trial and error method was used for investment cost to determine a range of investment cost for which $NPV_{project}$ is positive and IRR is greater than the discount rate (3.5%). O&M cost is assumed as 1% of the investment cost. Figure 7.6.3 presented the NPV vs investment cost for the loch with 1 meter height. As shown in Figure 7.6.3 , at 2.0% inflation rate the project is viable if the investment cost is less £500,000. In other words, based on our calculation £500,000 is the maximum investment lead to a viable project, with IRR equal to 4.27% which is slightly higher than the discount rate.

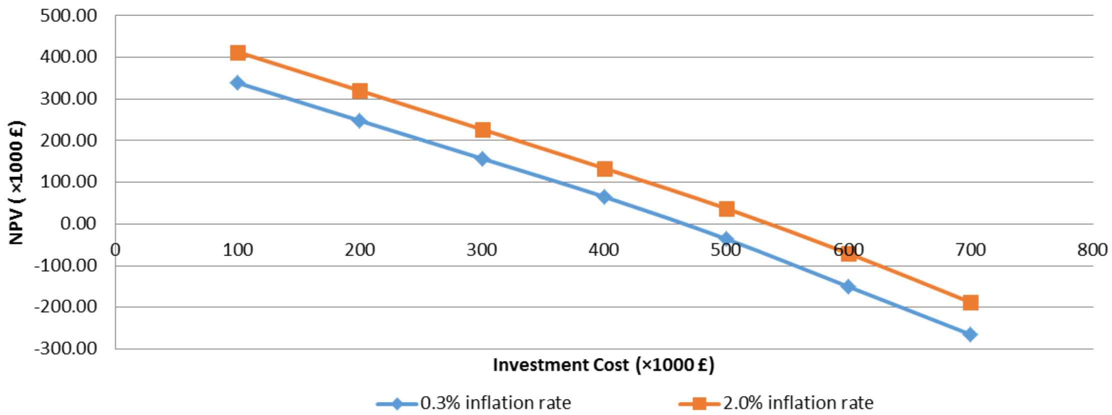

Figure 7.6.3: NPV vs investment cost for loch with 1 meter height (Source: **Economic model result)**

However, based on the main assumption for financing method, in this case ADSCR is lower than 1 so our cash flow is not enough for covering the debt service each year. As shown in **Table 7.6.1** in order to reach the ADSCR greater than 1 our investment should be less than £400,000 so WHT can cover the annual debt service. The Financial result of different investment costs at 2% inflation rate is summarized in **Table 7.6.1**.

Table 7.6.1: Economic results for loch (height: 1m), 2.0% inflation rate

NPVproject (£)	413,123	320,194	227,265	133,926	37,330	-70,746	-187,965
IRR (%)	32.77%	16.62%	10.40%	6.80%	4.27%	2.24%	0.46%
LCOE (£/kWh)	0.0566	0.1132	0.1698	0.2264	0.2829	0.3395	0.3961
Payback Period (years)	4	7	11	15	19	21	21
ADSCR	3.91	1.98	1.34	1.02	0.83	0.67	0.56
Total Investment Cost (£)	100,000	200,000	300,000	400,000	500,000	600,000	700,000

Source: Economic model result

Regarding 2 meters height for the loch, Figure 7.6.4 presented the investment cost vs NPV. As shown in Figure 7.6.4, at 2.0% inflation rate the project is viable if the investment cost is less than £600,000. In other words, based on our calculation £600,000 is the break-even point lead to IRR equal to 4.34% which is slightly higher than our discount rate.

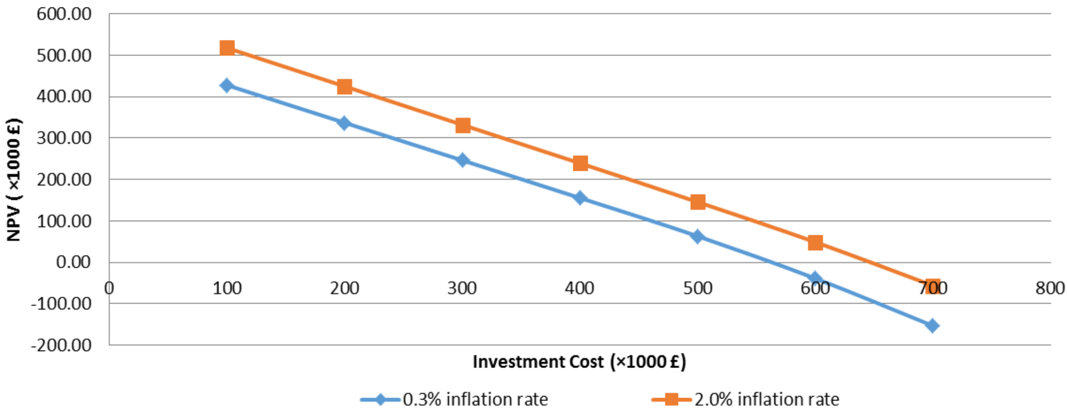

Figure 7.6.4: NPV vs investment cost for loch with 2 meters height

Source: Economic model result

However, based on our main assumption for financing method, in this case our ADSCR is lower than 1 so our cash flow is not enough for covering the debt service each year. As shown in Table 7.6.2 in order to reach the ADSCR greater than 1 our investment should be less than £500,000 so WHT can cover the annual debt service. The Financial result of different investment costs at 2% inflation rate is summarized in Table 7.6.2.

Table 7.6.2: Economic results – loch (height: 2m) – 2.0% inflation rate

NPVproject (£)	518,252	425,323	332,394	239,465	145,720	48,897	-56,553
IRR (%)	39.15%	20.16%	13.10%	9.11%	6.39%	4.34%	2.64%
LCOE (£/kWh)	0.0469	0.0937	0.1406	0.1874	0.2343	0.2811	0.3280
Payback Period (years)	3	6	9	12	15	19	21
ADSCR	4.71	2.38	1.61	1.22	0.99	0.84	0.70
Total Investment Cost (£)	100,000	200,000	300,000	400,000	500,000	600,000	700,000

Source: Economic model result

As it is clear in both figures, the break-even point for investment cost is decreased regarding the inflation rate of 0.3%. The cash flow diagrams of the two presented cases are shown in Annex 15.3. In conclusion, considering the 2.0% inflation rate, the loch project with 1 meter height will require less investment to reach the specific NPV compare to loch with 2 meters height.

7.7 Scenario III: 100 kW Hydro + 200 kW Wind (2 x 100 kW Xant M-21)

7.7.1 Energy Assessment

Under the current FIT scheme the same electricity price is paid for projects between 100kW to 1500kW. A third scenario was created to first maximize on the 200kW access granted. Furthermore in this section a production surplus is considered by studying the energy output of more than one turbine in the Gleann Dubhlinn scheme. This was based on the fact that there was no energy surplus in the two previous scenarios, which can be used to meet part of the local energy demands while stimulating the economy.

Prior to the detailed economic analysis, a preliminary comparative economic and technical analysis was done in the software Homer® to evaluate the optimal number of wind turbines. There were considered two, three and four 100kW Xant turbines while maintaining the same generation profile of the 100kW hydro scheme. The preliminary results indicate that two 100kW Xant turbines in combination with 100kW hydro is the most viable option that can be analysed further in details.

The results obtained from the energy assessment from both turbines are summarized in the Table 7.7.1. The annual energy output is 735.5 MWh which is lower than expected from the two turbines due to the wake losses which is the effect of one turbine on another. Turbines are positioned in reference to the IEC standards. According to the standards, turbines in a row have to be positioned at a distance of 5 times the rotor diameter. The full load hours calculated for these turbines is 3677 hours per year. On application of a 10% reduction factor for energy losses, the final net energy output of 661.86 MWh is obtained.

Table 7.7.1: Annual Wind Energy Output in Gleann Dubhlinn (Scenario III**)**

Sector	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	TOTAL
Resulting Energy (MWh)	29.2	22.6	22.4	24.5	38.5	71.8	86.6	108.1	116.2	108.4	68.0	39.0	735.4
Full Load Equivalent (Hours/year)	146.0	113.0	112.0	123.0	192.0	359.0	433.0	541.0	581.0	542.0	340.0	195.0	3677.0

Source: WindPRO®

The Figure 7.7.1 clearly shows the expected energy generation from the 100kW hydro turbine and two Xant 100kW wind turbines. Additionally the blue graph represents the total combined energy from both resources.

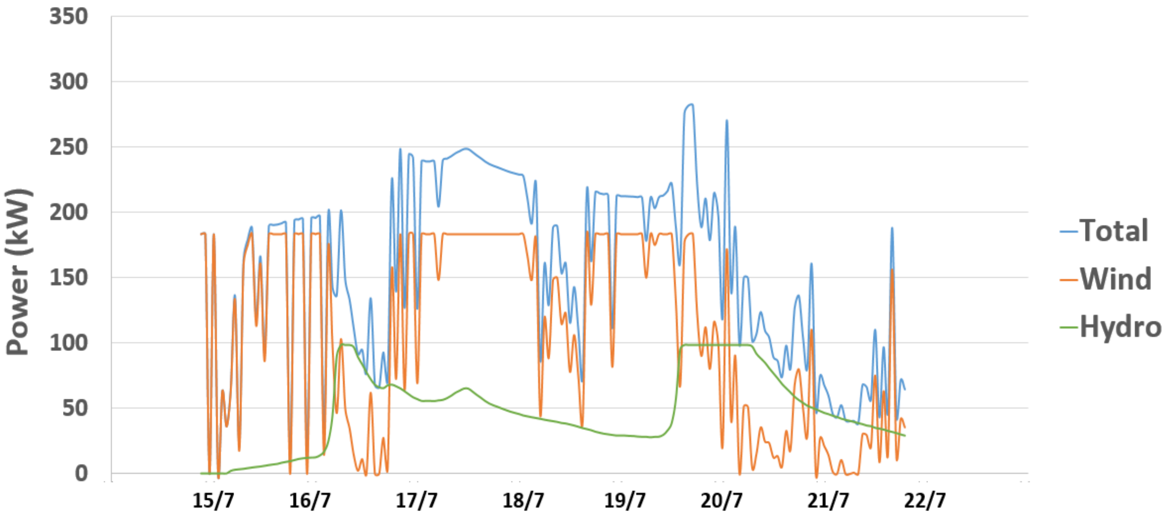

Figure 7.7.1: Wind, hydro and total generation for Scenario III
Source: HOMER®

In Figure 7.7.2 the energy generation under the 200 kW export constraint can be observed. The blue curve below the orange line shows the amount of energy that can be exported to the grid. While the green curve represents the energy surplus production. The time window portrayed in the “x” axis represents a week in July.

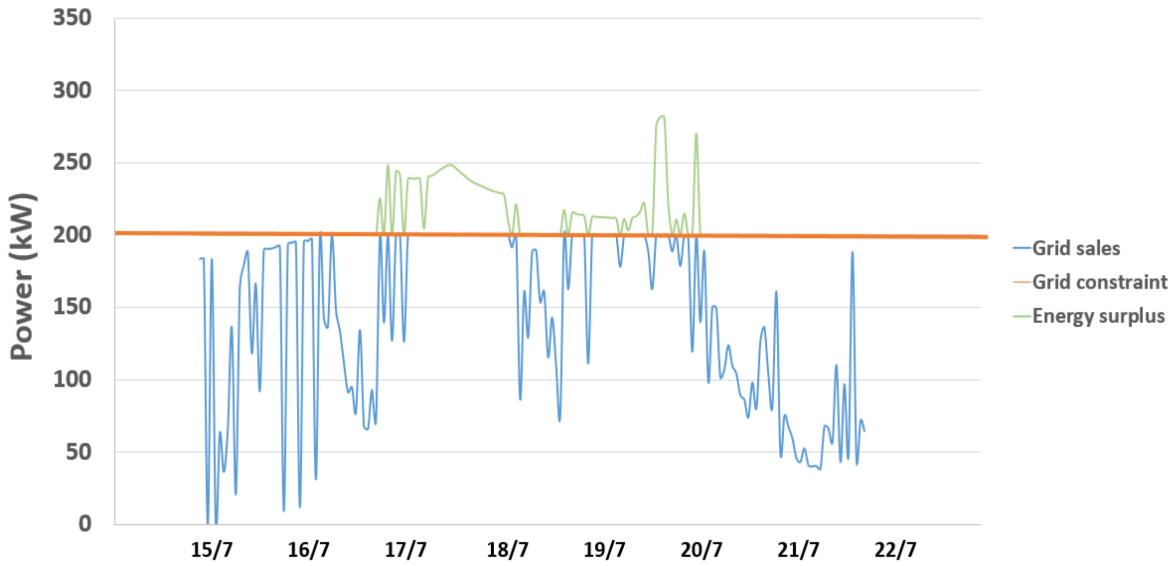

Figure 7.7.2: Surplus of energy, grid sales and grid constraints for Scenario III (Source: HOMER®)

The total energy production surplus calculated is 135,226 kWh/year, which represents around 10.2% of the total energy produced.

7.7.2 Economic Analysis

In this scenario, approximately 96% of the total energy generated is exported to the grid and is eligible for the export tariff. The remaining 4% is considered as excess energy which is not predicted to be used for any meaningful purposes. Therefore the FIT is also applied 96% of the total energy which could possibly be generated in the base energy case as indicated in the wind energy assessment. Under these conditions the investment on the two Xant turbines, breaks even only if a minimum FIT of approximately 7 p/kWh is applied, when the base energy output is considered. Figure 7.7.3 shows how the NPV varies with varying FITs for each bandwidth of energy generation.

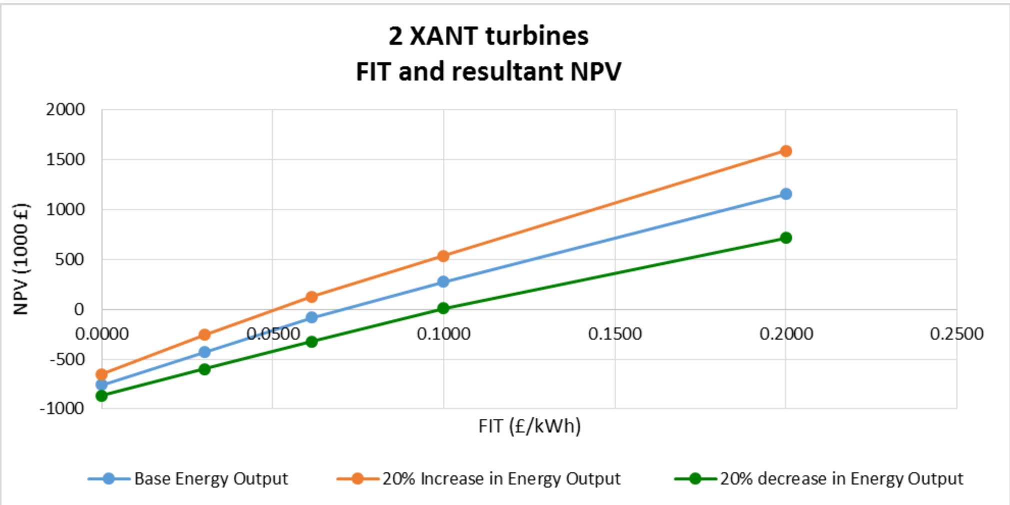

Figure 7.7.3: FIT and resultant NPV for 2 Xant turbine
Source: Economic model results

7.7.2.1 Example Case: FIT: (8.00 p/kWh)

In this example case a FIT of 8.00 p/kWh was considered and this results in a positive NPV and an IRR greater than the discount rate. An ADSCR of 0.88 suggests the need for further investigation into financing options to ensure that with the aforementioned FIT, the loan can be adequately serviced. Table 7.7.2 summarizes these results. The full cash flow is shown in the Annex 15.3.

Table 7.7.2: Economic results for 2 Xant turbines

PARAMETER	RESULT
$NPV_{project}$ (£)	£97,326
IRR (%)	4.9%
LCOE (£/kWh)	£0.142
Payback Period (years)	17
ADSCR	0.88

Source: Economic model results

7.8 Scenario IV: 100 kW Hydro + 180 kW Wind (3 x 60 kW HWT60)

7.8.1 Energy Assessment

Due to a previous project implemented by the WHT, it was in their interest to analyse the energy output when using three 60 kW Harbon wind turbines in comparison with two Xant turbines from Scenario 3.

The results obtained from the energy assessment for the Harbon turbines are summarized in the Table 7.8.1. The annual energy output is 458.3 MWh. The full load hours calculated for these turbines are 2546 hours per year. On application of a 10% reduction factor, the final net energy output is 415.47 MWh.

Table 7.8.1: Annual Wind Energy Output in Gleann Dubhlinn (Scenario IV)

Sector	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	TOTAL
Resulting Energy (MWh)	17.5	12.5	12	13.7	23.4	47.7	55.3	64.8	69.9	69.8	45.7	26	458.3
Full Load Equivalent (Hours/year)	97	70	67	76	130	265	307	360	389	388	254	144	2546

Source: WindPRO®

Despite the similar installed capacity, when comparing the result of Scenarios III and IV, the energy output of the three Harbon turbines (415.47 MWh/year) is considerably lower than the one obtained from two Xant turbines from Scenario III (661.86 MWh/year). Even if the rotor swept area per kW installed for both Harbon and Xant turbines are close to each other, lower energy output of Harbon turbine is attributed to the lower hub height.

8 Laxdale Wind Project

8.1 Background

A relatively large wind turbine or a combination of turbines totaling a power capacity of 1 MW is proposed for installation in the Laxdale area. The area for the location of the turbine can be specified by the following coordinates 57°52'01.06"N, 6°52'00.59"W,which is south of the South Harris forest ,approximately 840m off the road.

Presently, one of the main limitations of installing wind turbines in West Harris is the constraints of the existing grid. These constraints are for the most part, due to the limitations of the interconnector to the mainland, however an upgrade of the grid is expected by the year 2022. This upgrade to the interconnector promises an allowance of 1 MW feed-in capacity to the grid and was a major consideration in the modeling of wind turbines for the Laxdale area. Additionally, the other constraint to be considered is the proximity of the golden eagle nesting area to the turbines.

In addition, site access considerations were made in tandem with technical considerations for the final determination of suitable wind turbine technologies.

8.2 Specific Methodology

8.2.1 Considerations for economic analysis

All main economic assumptions mentioned in Chapter 4 also apply to the scenarios under this project. Other specific considerations include specific investment costs and operation and maintenance costs. A percentage of 3.7% of investment costs was considered to calculate operation and maintenance costs. This percentage resulted from calculations based on investment and O&M costs for a previous project in which Windflow® turbines were used. This percentage is applied based on the larger scale of these specific turbines for this site. Table 8.2.1 and Table 8.2.2 show the cost break down as considered for input into the economic model. The total energy generated in both scenarios linked to this site, is all exported to the grid. In both cases the capacities are below the grid connection of 1 MW which has been indicated by SSE as a future possibility, provided that the planned interconnector materializes. Revenues in this section are therefore considered by applying both the FIT and export tariff to the total energy generated.

Table 8.2.1 Cost break-down for total investment cost of 1 Enercon 900 kW turbine

Break-down	Cost (£)	Source
Turbine purchase price	840,000	Based on quotations of manufacturers for other projects in the Highlands of Scotland
Foundation	90,000	Based on quotations of manufacturers for other projects in the Highlands of Scotland
Grid connection costs	100,000	Assumed based on consultation with WHT
Grid cable costs	70,000	Estimated based on cost of other projects in the Highlands of Scotland
CARES loan to planning	200,000	Based on literature
Further Professional Fees	268,500	Based on cost of other projects in the Highlands of Scotland
Road access	420,000	Based on consultations with WHT
Total investment cost	**1,988,500**	

Source: Compiled from various sources

Table 8.2.2 Cost break-down for total investment cost of 1-2 Windflow turbines

Break-down	1 turbine	2 turbines	Source
Turbine purchase price	500	1,000,000	Windflow®
Foundation	30	60,00	Windflow®
Turbine installation	35	70,00	Windflow®
Grid connection costs	100, 000	100,00	Estimated based on consultations with WHT
Grid connection cable	70	70,00	Based on cost of other projects in the Highlands of Scotland
CARES loan to planning	200	200,00	Assumed based on literature
Further Professional Fees	269	268,50	Based on cost of other projects in the Highlands of Scotland
Road access	420	630,00	Based on consultation with WHT
Transportation	8	15,00	Windflow®
Sub-Total investment cost	1,461,000	2,412,000	-
Contingency costs (15%)	229	361,90	Assumed
Total investment cost	**1,750,000**	**2,774,000**	**-**

Source: Compiled from various sources

8.3 Technology Review

In this section, technical specifications of the proposed wind turbines for different scenarios are briefly described. For the first scenario of Laxdale Wind Project, installation of a 900 kW Enercon E-44 wind turbine is considered; while for the second scenario, installation of two 500 kW Windflow 33/500 wind turbine is proposed.

The turbine selection was based on the existing installations in the Western Isles, availability in the market, the current tariff and financial schemes.

8.3.1 Enercon E-44

The Enercon E-44 is a 3-bladed Class IA turbine model manufactured by the German manufacturer Enercon. The installed capacity of the turbine is 900 kW, hub height of 55 m and rotor diameter of 44 m.

Worthy to note, Enercon Gmbh UK is a business member of Community Energy Scotland, one of the major stakeholders as concerns community energy projects. Therefore, it is one of the few companies that have proven their willingness to supply their technology for this kind of projects. (CES, 2016)

The proposed turbine E-44 has been installed by several communities, especially in Western Isles. In Isle of Lewis, The Horshader Community Turbine and The Tolsta Community Turbine have been generating since 2012 and 2013 respectively. There are also other examples from the Isle of Barra and Vatersayand the Galson Estate where the same Enercon E-44 turbine is installed (CES, 2014).

Therefore this poses as an advantage since the manufacturer has produced and supplied this turbine to communities near West Harris. Furthermore, it creates a sense of confidence in the wind turbine due to its popularity of use in this region.

8.3.2 Windflow 33/500

Windflow 33/500 is a 2-bladed Class IA turbine model manufactured by Windflow Technology Limited which is a New Zealand based designer and manufacturer of wind turbines. The installed capacity of the turbine is 500 kW, hub height of 30 m and rotor diameter of 33.2 m. Windflow turbines are mainly optimized for high wind speed sites. Load-avoiding design of the turbine copes with strong, turbulent and high shear winds.

Given the wind speed regime of the project site, this turbine model was taken into account for Scenario 2. The 2-blade design of the turbine helps to reduce both transport and construction costs. It has a grid-friendly generator that simplifies connection, especially into weak grids.

Windflow has been installing turbines in Scotland since early 2013 (Windflow, 2016). Presently, 3 Windflow 33/500 IA turbines have been installed by North Harris Trust at Monan in 2014 (NHT, 2016).

8.4 Resource Assessment

The resource assessment results for this project are identical as the ones presented in the Chapter 6 Scenario 1.

8.5 Scenario I: Enercon E-44 900 kW

8.5.1 Energy Assessment

The softwares WindPRO® and WAsP® used the parameters mentioned in the preceding sections to calculate the expected annual energy output from the wind turbine. The results are summarized in the Table 8.5.1. The annual energy output is 3012.4 MWh.

In this particular case the number of full load hours is 3347 per year. To encapsulate additional losses that could not be computed a reduction factor of 10% is applied and subtracted from the total, obtaining a final net energy output of 2,711MWh.

Table 8.5.1: Annual Wind Energy Output in Laxdale (Scenario I)

Sector	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	TOTAL
Resulting Energy (MWh)	125.2	107.7	119.9	112.4	144.8	241.1	360.5	497.3	544.6	436.5	196.3	126.1	3012.4
Full Load Equivalent(Hours/year)	139	120	133	125	161	268	401	553	605	485	218	140	3347

Source: WindPRO®

8.5.2 Economic Analysis

With a 2% inflation rate and a FIT equal to 0 the Enercon 900kW turbine, remains non profitable at energy outputs varying between 20% increase and 20% decrease of the resulting energy output from WindPro®. The NPV remains negative in all these cases. Further sensitivity analyses confirm that the FIT has a significant effect on the NPV, resulting in an increase in NPV with increasing FIT. The energy output greatly affects the profitability of the project. In this scenario the project breaks even with a minimum FIT of approximately 0.5 pence/kWh when a 20% increase in energy output is considered. When a 20% decrease in energy output is considered, the project breaks even with a minimum FIT of 3 pence/kWh. Figure 8.5.1 below shows the project evaluation using NPV at varying FITs and energy outputs.

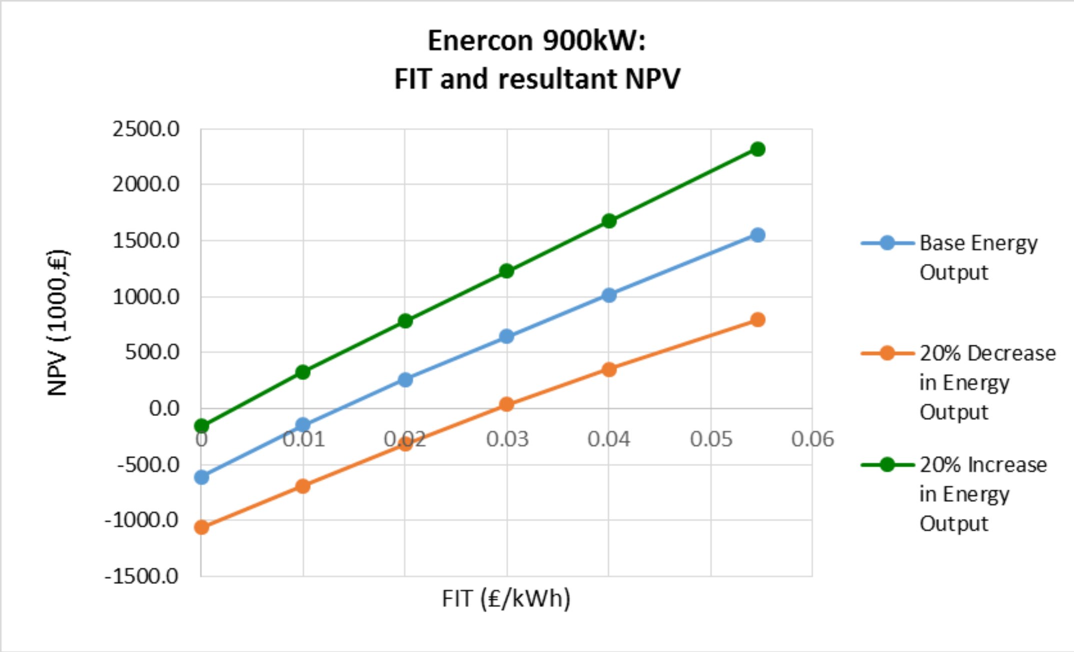

Figure 8.5.1: FIT and Resultant NPV for Enercon 900kW

Source: Economic model results

8.5.2.1 Example Case: FIT =2.73 p/kWh

Emanating from sensitivity analyses, one case in point shows the viability of the project under select conditions. When the FIT is half (2.73 pence per kWh) of the current tariff (5.46 pence per kWh) and is applied to the base energy generation, a positive NPV and an IRR almost doubled the discount rate results. This is an indication of the minimum FIT that should be applied for the project to be feasible. Additionally, a payback period of 15 years is required. Under the specific financing conditions presented, in section 4, an ADCSR of 0.99 over the 15 years maturity of the loan indicates that on average, each year there is just about enough cash flow to service the loan. **Table 8.5.2** summarizes these results.

Table 8.5.2: Economic results for example case: 1 Enercon 900 kW turbine

PARAMETER	RESULT
$NPV_{project}$ (£)	£539.071
IRR (%)	6.34%
LCOE (£/kWh)	0.0746
Payback Period (years)	15.0
ADSCR	0.99

Source: Economic model results

8.6 Scenario II: Two Windflow turbines of 500 kW

8.6.1 Energy Assessment

The annual energy output calculated was 2214 MWh while the full load equivalent hours were 2215 hours per year. A final net energy output of 1993.2MWh on application of the 10% reduction factor. The results are summarized in the **Table 8.6.1**.

Table 8.6.1: Annual Wind Energy Output in Laxdale (Scenario II)

Sector	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	TOTAL
Resulting Energy (MWh)	70.3	68.2	80.3	78.4	104.1	172.4	239.1	368	439.4	365.5	146.9	82.1	2214.7
Full Load Equivalent (Hours/year)	70	68	80	78	104	172	239	368	439	365	147	82.1	2215

Source: WindPRO®

8.6.2 Economic Analysis

8.6.2.1 Main Results

Similarly to the scenario of the Enercon 900 kW turbine, the installation of two 500 kW Windflow® turbines proves feasible only when a particular minimum FIT is applied. With no FIT applied, this project proves to be unprofitable at the three chosen energy outputs. With the base energy output, a minimum FIT of approximately 9 to 10 p/kWh is required to make this project economically viable. At the lower and upper values of energy output, as presented in Figure 9.4.1 **Catchment Area** the minimum FIT to make this project viable is roughly 7 and 13 p/kWh, respectively.

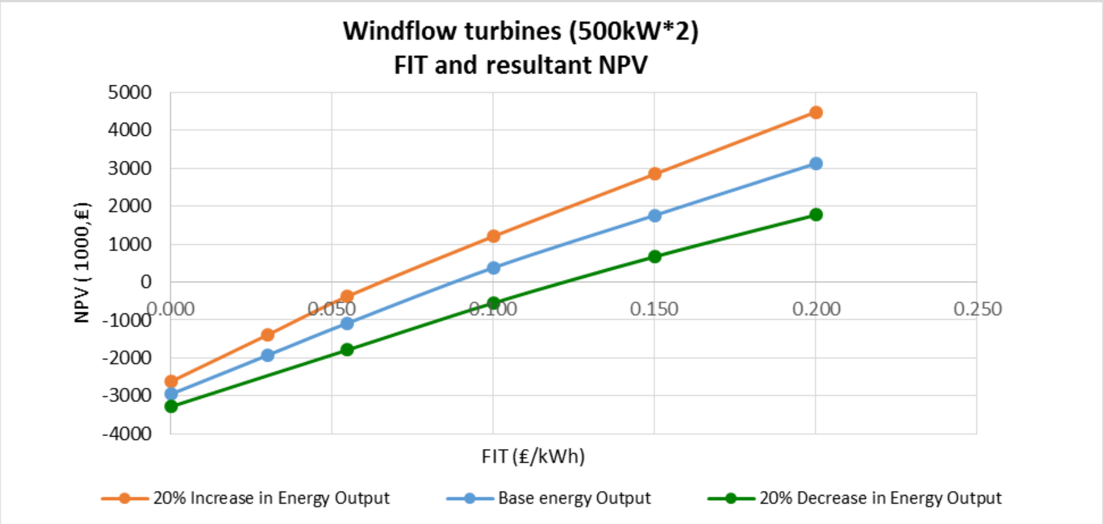

Figure 8.6.1: FIT and Resultant NPV for two Xant turbines
Source: Economic model results

Example Case: FIT = 11 p/kWh

In the example case the project is analysed with the base energy output, and all the main conditions previously described. The FIT which yields these results is 11 p/kWh. Under the specific financing conditions the ADSCR which is slightly lower than 1.0 suggests that on average each year the cash flow available for debt service cannot adequately service the loan. However with a FIT of 12 p/kWh, the ADSCR is just exceeds 1. This analysis confirms the integral role of the FIT in the profitability of these projects. A general comparison of the Enercon 900 kW turbine and the two 500 kW Windflow® turbines suggest that the latter are less profitable. While a FIT of 2.73 p/kWh results in an economically viable project when the Enercon turbine installed, a much higher FIT of approximately 11 p/kWh is required to make the installation of the Windflow® turbines economically feasible. The results of the example case is shown in Table 8.6.2.

Table 8.6.2: Economic results for example case: Two 500 kW Windflow turbines

PARAMETER	RESULT
$NPV_{project}$ (£)	£659,950
IRR (%)	5.85%
LCOE (£/kWh)	£0.163
Payback Period (years)	16
ADSCR	0.95

Source: Economic model results

9 Luskentyre Micro Hydro

9.1 Background

The source for the Luskentyre Micro hydro site is the Gleann Beinn Dhuibh River. The objective of the assessment of the hydropower potential from this site is to investigate the possibility of supplying electricity to the planned housing demand in this area. The housing plan is that of the WHT and currently it is limited to supply 5-7 houses. Throughout the extent of this report the possibility of this Luskentyre scheme and the number of houses that it can support will be discussed in detail. However, the scope of this chapter is only limited to resource assessment.

9.2 Specific Methodology

9.2.1 Hydro

For the purpose of resource assessment of the Luskentyre Micro Hydro Scheme the following parameters were assessed:

1. Catchment area, head and penstock length
2. Long Term Flow
3. Annual Energy Generation Profile

9.2.1.1 Catchment Area, Power House location, Head and penstock length

For the purpose of assessing the resource, the potential intake locations, their elevations and a suitable location for situating the powerhouse was identified during a site visit. The different locations identified are shown in the following. These potential locations were then keyed in to ArcGIS to obtain the catchment area, head and penstock length for each site. The Figure 9.2.1 shows an overview of the site.

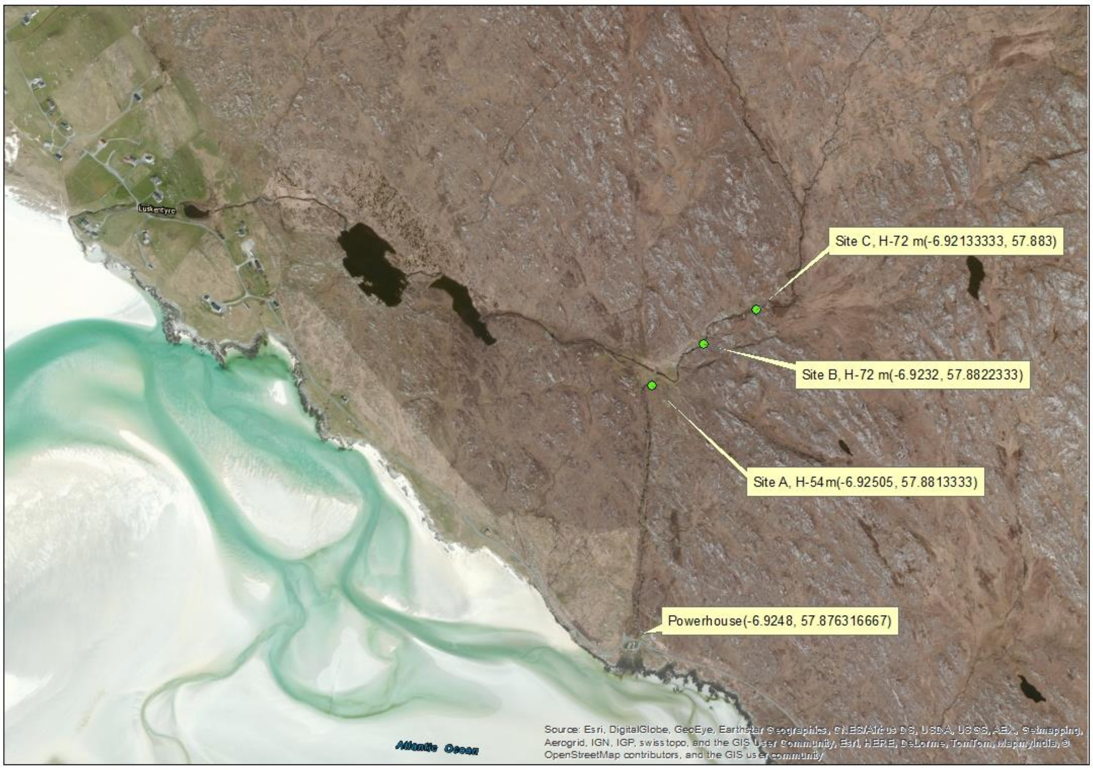

Figure 9.2.1: Birds Eye View of the Site
Source: Own Elaboration using ArcGIS

9.2.1.2 Long term Flow

The catchment area and long term flow data for Gleann Beinn Dhuibh River was obtained as mentioned in Chapter 4. Year 2008 was selected for correlating the flows of Gleann Dubhlinn and Gleann Beinn Dhuibh River as it was the year which is closest to the average of the 8 years available data of Gleann Dubhlinn. A sample of the flow calculation sheet is presented in the Annex 15.3.3

9.2.1.3 Annual Energy Generation profile

The Annual Energy generation profile for the Luskentyre Micro hydro scheme was generated for each of the possible intake sites and for different variations of design flow. Hand off flow, overall system efficiency, head, and design flow were considered to get the annual generation profile of the system.

9.2.2 Economic Specific Methodology for Luskentyre

The same economic methodology is used for the Luskentyre and Seilebost hydro projects. The economic model used requires various inputs including investment and O&M costs among others.

9.2.2.1 Investment costs

For these sites, 4 methods of calculating investment costs of the hydro schemes were considered. These are discussed below as they each yielded different economic outcomes.

Method 1

This method was adapted from the financial breakdown of a 200kW hydro plant in Gleann Dubhlinn (Gleann Dubhlinn financial assessment, 2000). The method was guided by the breakdown of the investment costs into civil as well as mechanical and electrical components. The key civil components are the intake structure as well as the intake pipeline. The intake structure and pipeline costs were taken as £1,007/kW and £115/m based on a past project quotation in the western Isles (Applecross , 2015). The turbine and generator costs were calculated using the following formula:

$$Cost_{(turbine\ and\ generator)} = b\ x\ kW^{n}\ x\ H^{r}\ (£\ 2000)$$

Where b, n and r are constants (Aggidis, et al., 2010, p. 2634).
Contractor's preliminary costs are assumed at 35% and detailed design cost as 10% of the total costs.

Method 2

The second method used an average per kW cost of 3 past hydro projects quotations in the western Isles i.e. Glean Dubhlinn, Apple cross as well as Achiltibuie (Green Highland Renewables Ltd). This yielded a unit cost of £5,328/kW.

Method 3

This method considered the following formula for heads of 30 – 200 m to calculate total investment costs (Aggidis, et al., 2010, p. 2634):

$$C = 45{,}500\ x\ (kW/H^{0,3})^{0,6}\ (£\ 2008)$$

Method 4

The last method that is considered to give costs per kW of typical hydro power plants is based on their capacities (Renewables First, 2016) as per Figure 9.2.2. It can be seen that the bigger the plant capacity, the cheaper the investment costs, but after a certain threshold, smaller plants rapidly become too expensive.

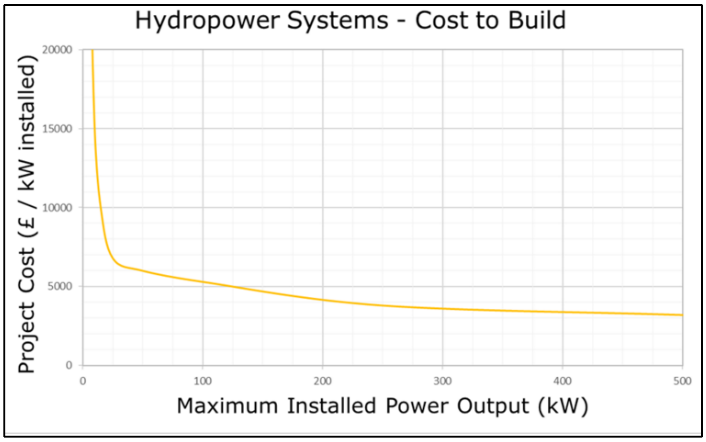

Figure 9.2.2: Hydropower system cost
Source: (Renewables First, 2016)

9.2.2.2 Other Inputs

IRENA reports small hydro schemes as having a typical O&M cost of 1-4% of the total investment cost. For this case study an O&M cost of 2.5% of the total investment cost is assumed. (IRENA, 2012, p. i). A degradation factor of 0.5% is also assumed which reduces the energy production annually.

9.2.2.3 Energy tariff

For the Luskentyre hydro projects, it is assumed that all the electricity generated would be sold to households. This is an optimistic scenario that may not be the reality. In the systems chapter, 11 the exact amount of energy to be sold to households will be determined.

An energy tariff is applied and varied for sensitivity analyses of economic calculations. This may be seen to comprise of a feed in tariff and a household tariff which is the price consumers would pay for energy they buy. The currently available Feed in Tariff for hydro projects of less than 100 kW capacity is 8.54 pence (ofgem, 2016).

4 energy tariffs are applied in the sensitivity analysis:

- **5.92p/kWh** (equivalent to cost of heating using oil at current prices)
- **10 p/kWh** (equivalent to current cost of storage heaters tariff or alternatively heating using oil at 76pence per liter of oil).
- **14.46 p/kWh** (equivalent to a FIT of 8.54 pence combined with a household tariff of 5.94 pence. 5.94 pence/kWh is the cost of heating using oil at current prices)
- **18.54 p/kwh** (equivalent to a FIT of 8.54 pence combined with a household tariff of 10 pence/kWh. 10pence/ kWh is the current storage heaters tariff or alternatively heating using oil at an assumed cost of 76pence per liter of oil).

For the cost of heating using oil , 1 liter of diesel is equal to 10 kWh using the lower calorific value (Packer, 2011).With the assumption of an average oil boiler efficiency of 76%% (Energy saving Trust, 2008). Thus this results in 1 liter of diesel producing 7.6 kWh of heat. The price of oil has been declining for the past 3 years. However, the oil price is volatile; which means it might increase in the future. An average of the oil price for the past 2 years specifically for Scotland was calculated using the average price for every 3 months (UK Heating Oil Market, 2015). The average price was calculated to be 45 pence/liter at current oil prices. Hence, 5.92pence/1kwh resulted from 45 pence/7.6kWh.

The storage heating tariff is taken as 10 pence/kWh (SSE, 2016).

9.2.2.4 Sensitivity analysis

Based on the above mentioned inputs and the sensitivities to be carried out, the resulting NPV for each of the possible investment costs is investigated for each scenario and illustrated graphically. 5 scenarios will be analysed; 2 from Seilebost and 3 from Luskentyre.

One case example is picked from each scenario where the various inputs and resultant key indicators, NPV of the project, IRR, the levelized cost of electricity and the payback period are analysed as the key indicators of the project soundness. Additionally, the (Average Debt Service Cover Ratio (ADSCR) is evaluated to assess the capability of each to meet the debt obligations. The case examples are all selected from the 14.46 p/kWh energy tariff band. They should at least have a positive NPV and an IRR greater than the discount rate. It will be seen that they don't always perform well in all the other key indicators. Detailed results of the different sensitivity analyses cases as well as cash flows for the specific case example can be found in the Annex 15.5.4.

9.3 Technology Review

Based on the flow and head characteristics of Luskentyre Micro Hydro Scheme, Pelton and Turgo turbines could be used. This selection is based on two parameters. The optimum flow for all three intake sites discussed above are 0.09m^3/s while the head ranges from 54 m to 94 m. As per the specifications mentioned in chapter 7.3.1.1

Table 9.3.1: Turbine, Generator and Penstock

Head (m)	Flow(m^3/s)	Turbine and Generator		Penstock
	Optimum flow(m^3/s)	Optimum turbine capacity(kW)	Optimum Generator capacity (kVA)	Penstock Length(m)
54	0.090	35	40	550
72	0.090	50	55	740
94	0.090	60	70	840

Source: Own Elaboration

For the maximum power output that could be generated from this scheme, a 60kW Turgo turbine could be used to generate the maximum power. The choice of the Turgo type is also because it is a matured technology for micro hydro schemes in Scotland

9.4 Resource Assessment

Three potential locations for intake were identified based on the site visit of the Luskentyre site. The river Gleann Beinn Dhuibh under assessment for supplying electricity to the planned housing project is at a distance of around 500 meters from the proposed power house site. For each of these intake locations catchment area was calculated using the Hydrology toolbox of the Spatial Analyst extension in ArcGIS 10.2.2.The location coordinates and elevation of the sites as recorded by the GPS monitor along with the catchment areas that were obtained from ArcGIS are shown in the Table 9.4.1. The head available was then calculated as a difference in the elevation of the power house location and elevation of the intake sites.

Table 9.4.1 Possible intake locations

Intake	Longitude (decimal degrees)	Latitude	Head (m)	Catchment Area (km^2)
Site A	-6.925050	57.88133	54	2.335
Site B	-6.923200	57.88223	72	2.114
Site C	-6.921333	57.88300	94	2.017

Source: Own elaboration

The different catchment areas generated by GIS are presented below in Figure 9.4.1:

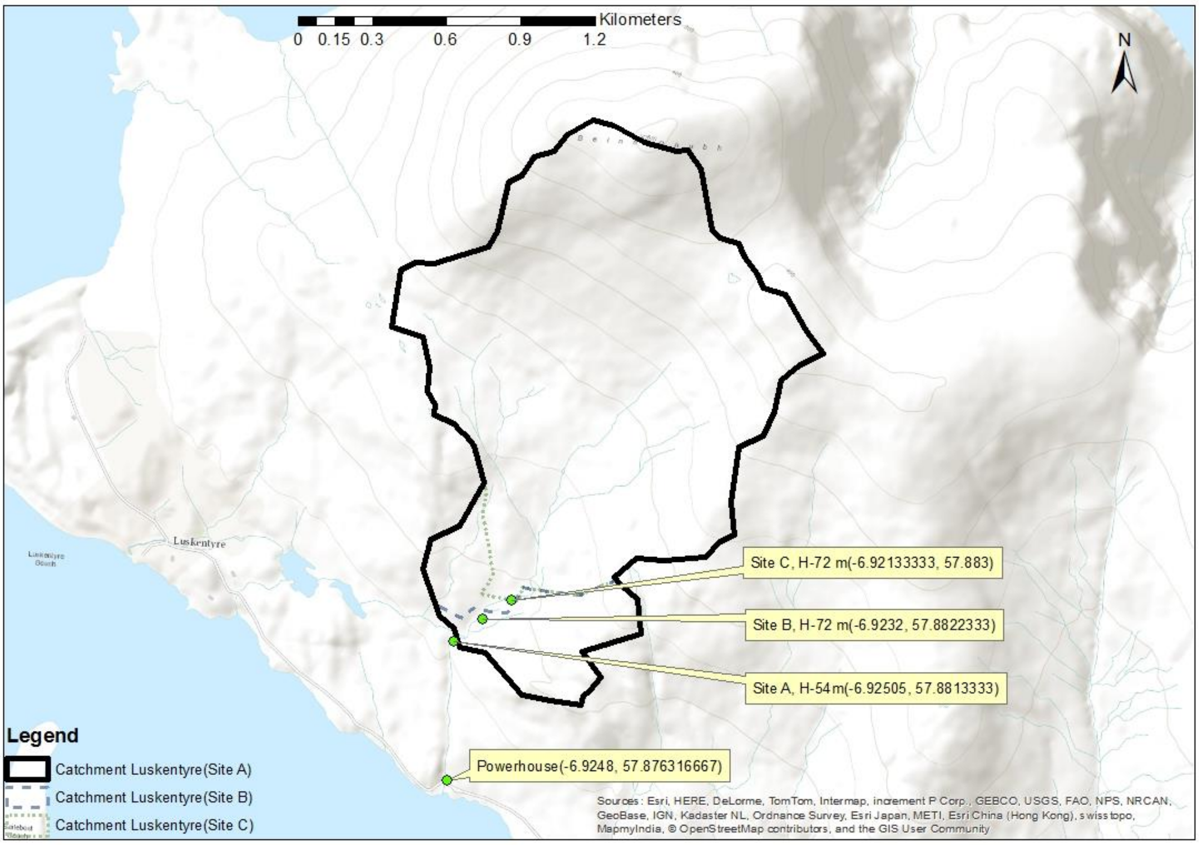

Figure 9.4.1 Catchment Area
Source: Own elaboration using ArcGIS

To estimate the available flow for the Luskentyre Scheme the flow available in the Gleann Beinn Dhuibh River was also correlated with the average year flow data of Gleann Dubhlinn River using the area ratio method. This available flow in combination with the elevation of the identified three intake sites was used to assess the energy generation and the capacity of power-plant that could be installed in the site. The base-flow for each site was identified as Q90 as all the three sites had a catchment area of less than 10 km^2 (SEPA, 2015) upstream of the tailrace. The annual generated energy and installed capacity for each site versus different flows are presented respectively in the following figures. The detailed flow calculations and the flow duration data are presented in the Annex 15.5.1.

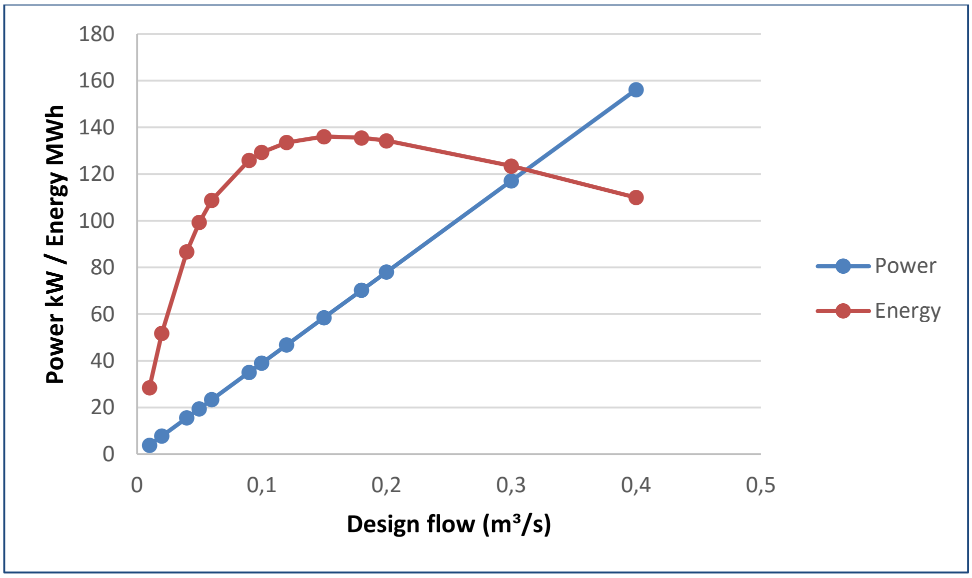

Figure 9.4.2: Luskentyre-Site A (Head 54m)
Source: Own elaboration

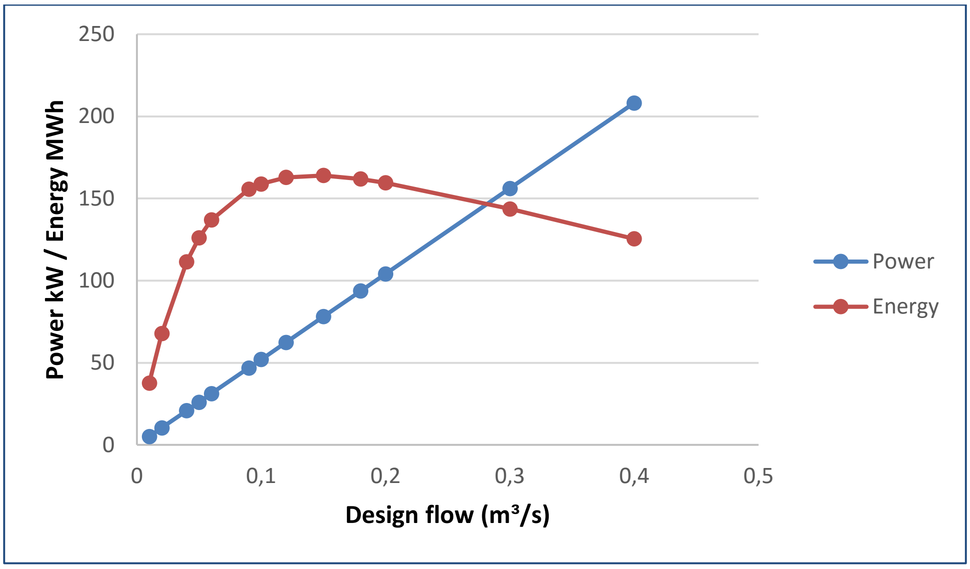

Figure 9.4.3: Luskentyre-Site B (Head-72m)
Source: Own elaboration

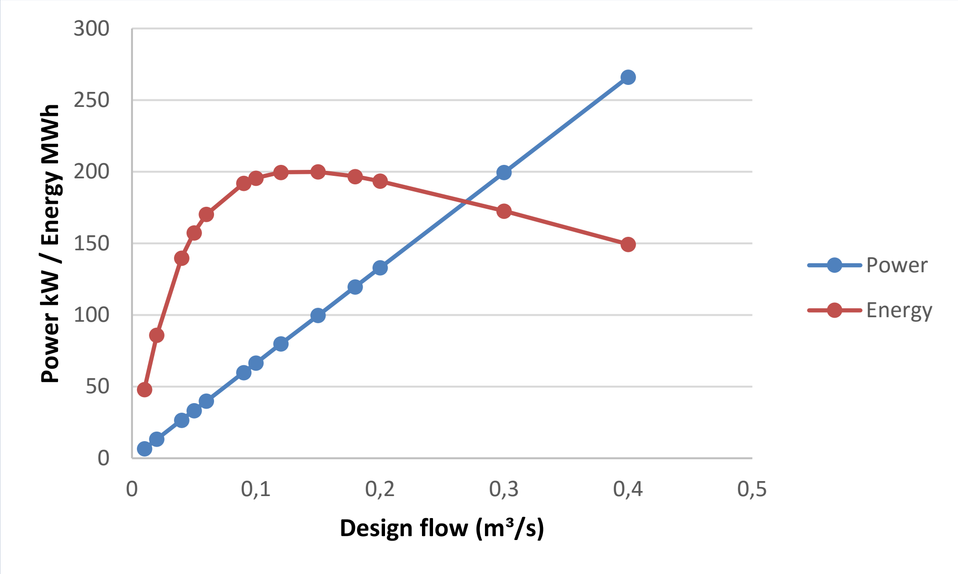

Figure 9.4.4: Luskentyre-Site C (Head-92m)
Source: Own elaboration

From the results of the analysis two different options for design flow and the annual energy yield with these flows were identified. The first option for flow is in which the annual energy generations are the highest and the second option for flow is up to which investment in additional plant capacity would yield significant additional annual energy yield. They are named as maximum annual generation and Optimum flow in the Table 9.4.2. The detailed calculations of the resource assessment for these three possible intake sites are presented in the Annex 15.5.1.

Table 9.4.2: Flow vs annual generation vs capacity

Intake	Head (m)	Maximum capacity			Optimum capacity		
		Maximum Flow(m^3/s)	Maximum Annual energy generation (MWh)	Maximum Plant Capacity(kW)	Optimum flow(m^3/s)	Optimum annual energy generation (MWh)	Optimum plant capacity (kW)
1	54	0.15	136.080	59	0.09	125.922	35
2	72	0.15	163.979	78	0.09	155.656	46
3	94	0.15	199.915	100	0.09	191.898	59

Source: Own elaboration

9.5 Energy Assessment

The energy generation potential from the three sites for various flows leads to a wide range of energy profile. Since the generation from the Luskentyre Scheme depends mainly on the demand from the households, it will be discussed in further detail in the Chapter 11. The power profile for all three sites at the optimum design flow as per Table 9.4.2 are shown in the following figures.

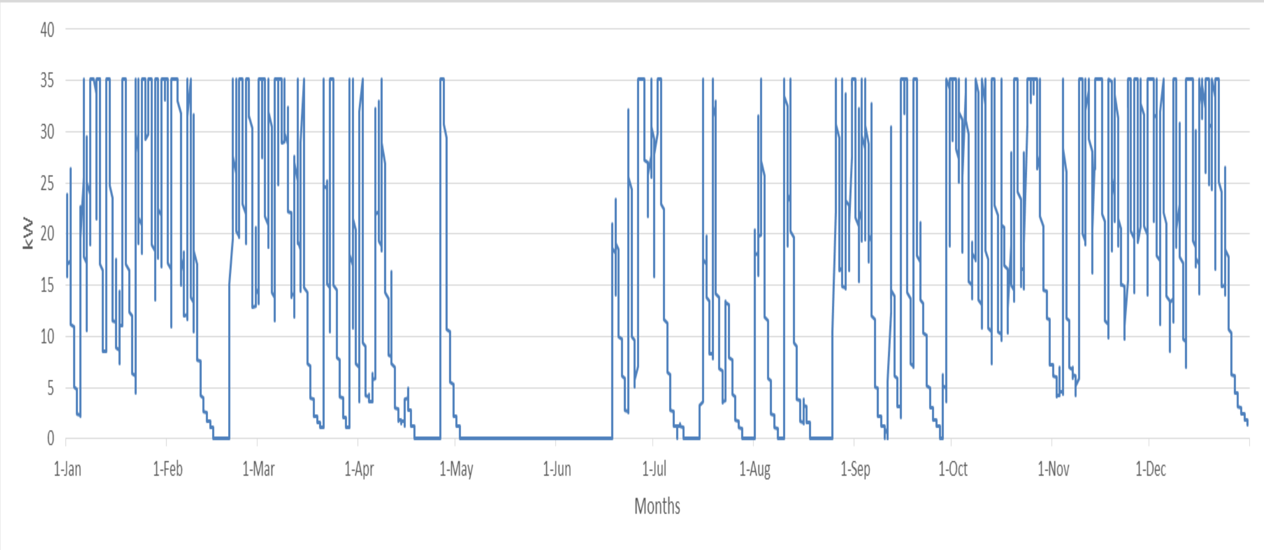

Figure 9.5.1: Luskentyre-Annual Power Profile- Site A
Source: Own Elaboration

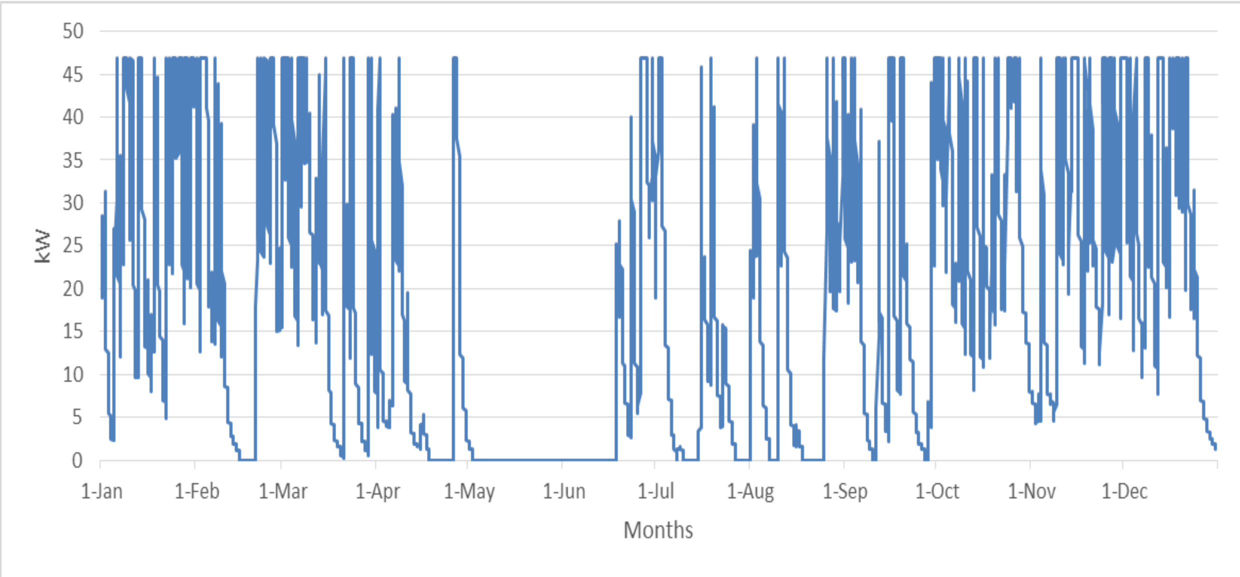

Figure 9.5.2 Luskentyre**-**Annual Power Profile-Site B
Source: Own Elaboration

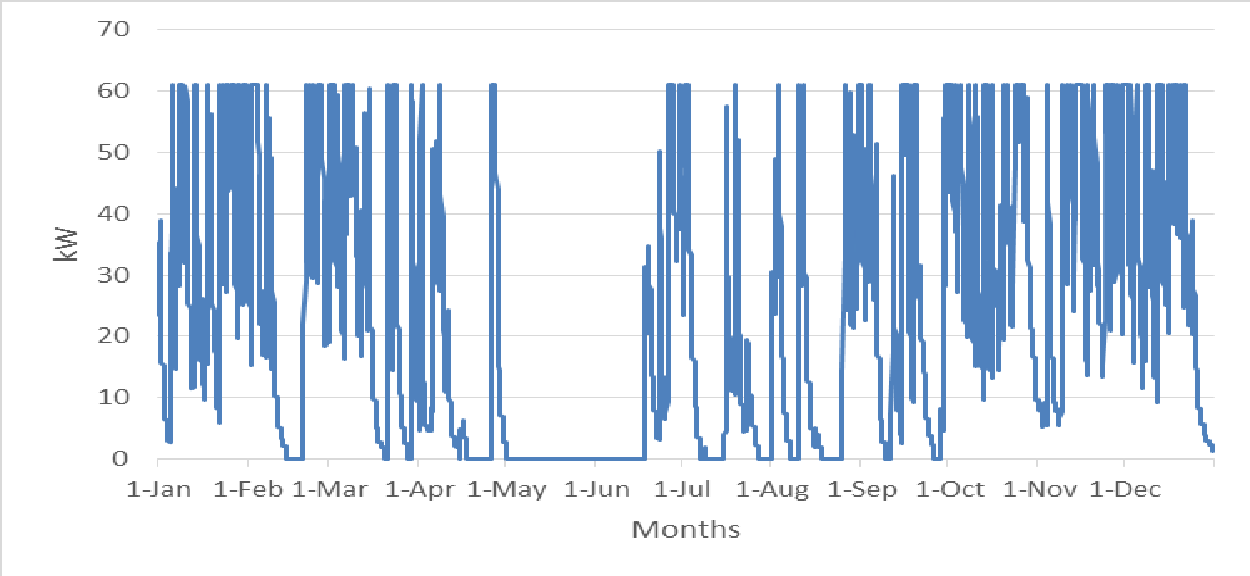

Figure 9.5.3: Luskentyre-Annual Power Profile-Site C
Source: Own Elaboration

From the profiles above it is seen that for all three sites from the May to mid-June the power output is nil. This is because of the flow characteristics of the typical year of Gleann Dubhlinn chosen to obtain the long term flow data of Gleann Beinn Dhuibh. The annual generation for each of the profiles presented above have already been presented in Table 9.4.2.

9.6 Economic Analysis

9.6.1 Economic Analysis of Luskentyre 3, 5 and 7 Households

Initially, 3 scenarios were considered in Luskentyre that would limit hydro generation capacity to the household demands of the new housing scheme. This yielded installed capacities of 4kW, 6kW and 8kW for 3, 5 and 7 Households respectively. A preliminary economic evaluation using the investment costs calculation method 1 yielded costs above £30,000/kW which is quite high. Consequently a further economic analysis was not carried out on these scenarios.

9.6.2 Economic Analysis of Luskentyre 94 m head, 60kW

A maximum of 191,898kwh is generated annually. For the economic calculations, it is assumed that all the energy generated is used up. For the 4 investment cost calculation methods, this scenario has a range of costs of £3905/kW to £8,996/kW. Evaluating how they relate to NPV yields **Figure 9.6.1**. The detailed results of each are found in the Annex 15.5.2. A lower investment cost or a higher energy tariff displays a better NPV.

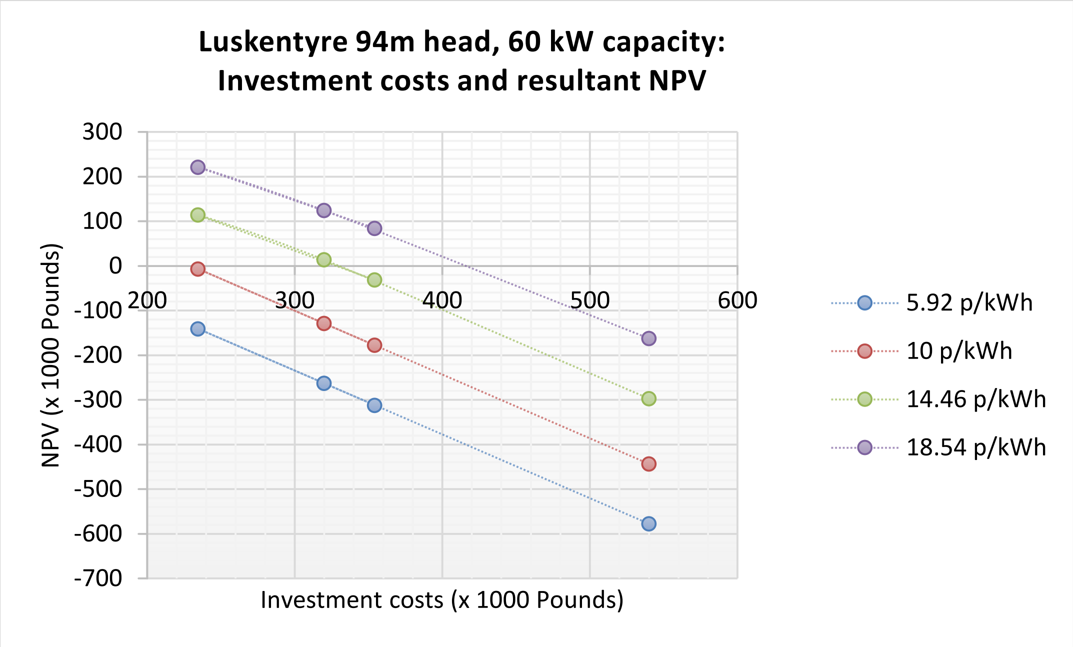

Figure 9.6.1: Investment Costs and Resultant NPV

Source: Economic model results

9.6.2.1 Example case: Investment (£5,328/kW), Energy tariff = 14.46 p/kWh)

The example for further analysis is drawn from the 14.46 p/kWh bandwidth. It has an investment cost of £319,656 (method 2) whilst generating 191,898kWh annually. Its performance is documented in Table 9.6.1.

Table 9.6.1 Economic Results for example case: Luskentyre 94m head, 60kW

PARAMETER	RESULT
$NPV_{project}$ (£)	£14,156
IRR (%)	3.96%
LCOE (£/kWh)	£0.168
Payback Period (years)	19
ADSCR	0.80

Source: Economic model results

The payback period seems to be long at 19 years. It can also be seen that the NPV and IRR are good, but, the ADSCR is quite low at 0.80. As such a grant or higher energy tariffs would be required to meet the loan payments. Considering the results from the 18.54p/kWh sensitivity analyses, shows that higher energy tariffs yield better results.

9.6.3 Economic Analysis of Luskentyre 54m head, 35kW Capacity

This scenario generates a maximum of 125,922 kWh annually which assumed as all sold. The calculated investment costs for this scenario range between £5328/kW and £11992/kW with the performance illustrated in **Figure 9.6.2**. Generally most times the NPVs are negative for the different calculation methods though higher energy tariffs and lower investment costs yield better NPVs.

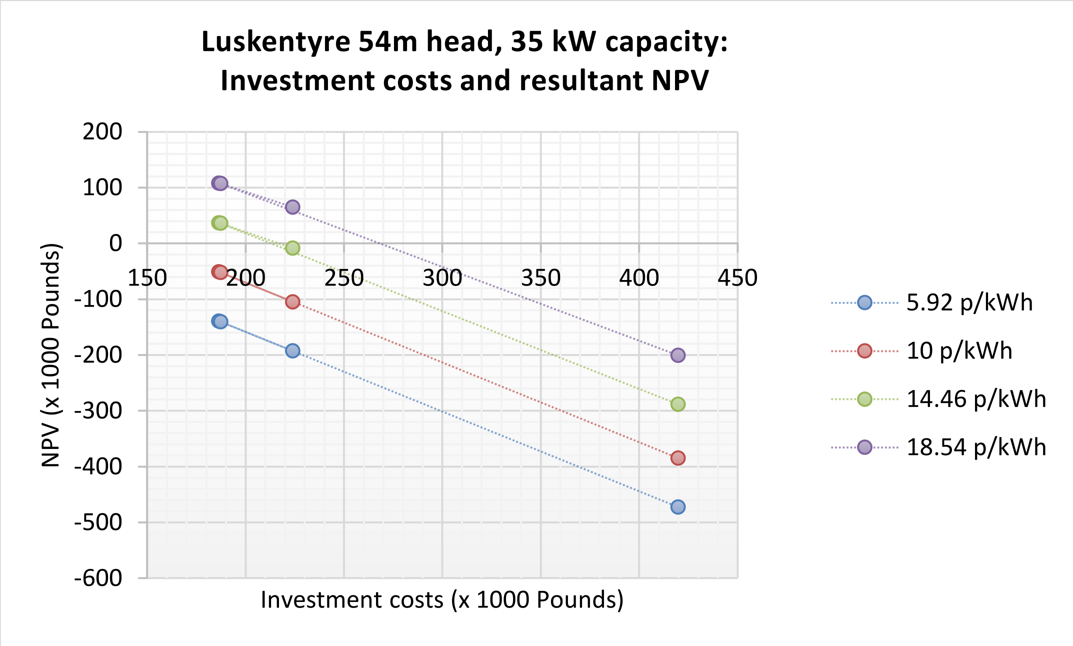

Figure 9.6.2: Investment Costs and Resultant NPV

Source: Economic model results

9.6.3.1 Example case: Investment (£5352/kW), Energy tariff = 14.46 p/kWh)

The performance of a case example with an investment cost of £187,336 (method 3) is evaluated as shown in Table 9.6.2. It is seen that the NPV is positive, the IRR higher than the discount rate, whilst the payback period is 17 years. Again, for this case the ADSCR performs poorly for a 100% debt scenario requiring higher revenues or loan subsidies to perform better.

Table 9.6.2: Economic Results for example case: 54m head 35kW

PARAMETER	RESULT
$NPV_{project}$ (£)	£36,059
IRR (%)	5,44%
LCOE (£/kWh)	£0.1504
Payback Period (years)	17
ADSCR	0.92

Source: Economic model results

9.6.4 Economic analysis of Luskentyre 72m head, 50kW capacity

The last case considered in Luskentyre requires a capacity of 46.8kW which is assumed to be 50kW. It generates 155,656 kWh of energy annually and has investment costs of £4407/kW to

£9787/kW. The performance of investment costs and resulting NPVs is shown in Figure 9.6.3 and the detailed results are in the Annex 15.5.2. Just as in the foregoing hydro cases, higher NPVs result from lower investment costs and higher energy tariffs.

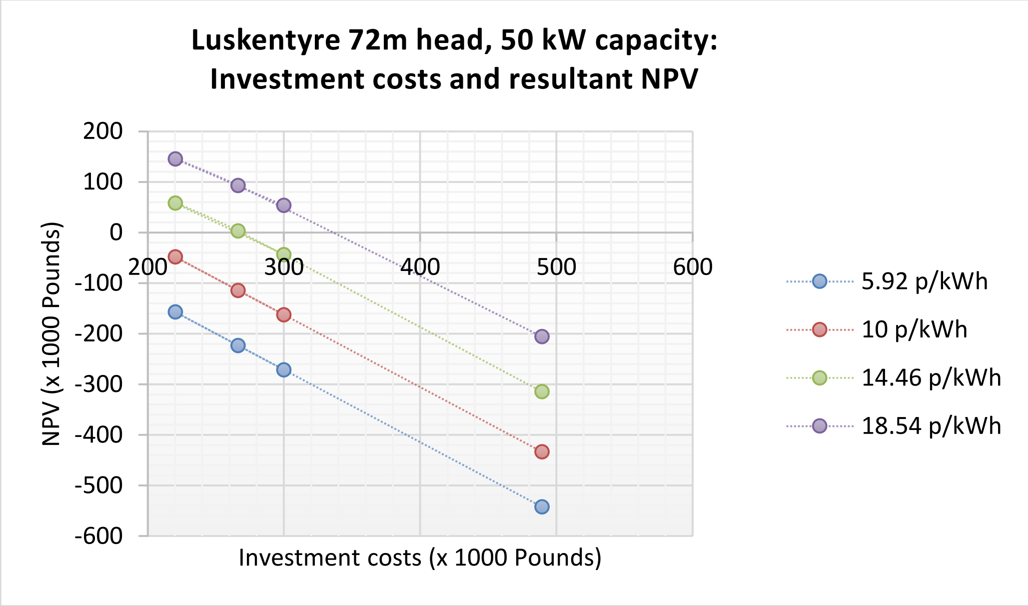

Figure 9.6.3: Investment Costs and Resultant NPV
Source: Economic model results

9.6.4.1 Example case: Investment (£5328/kW), Energy tariff = 14.46 p/kWh)

A case in point is considered within the 14.46 p/kWh energy tariff bandwidth. It has an investment cost of £266,380 (method 2). The NPV and IRR meet the threshold requirement. However, the ADSCR performs poorly for this case at 0.77 as shown in Table 9.6.3.

Table 9.6.3: Economic Results for example case: 72m head 50kW

PARAMETER	RESULT
$NPV_{project}$ (£)	£2,864
IRR (%)	3.61%
LCOE (£/kWh)	£0.1731
Payback Period (years)	20
ADSCR	0.77

Source: Economic model results

The payback period does not perform too well, with the investment being recuperated only on the last year of the project lifetime. Additionally the ADSCR is less than 1 for the cash flows which are illustrated in the Annex 15.5.2. At lower costs of £4407/kW, the ADSCR greatly improves. The best results come with the energy tariff of 18.54p/kWh. It is to be noted that the economic calculations for Luskentyre assume all the energy is sold; this may not be the case as will be discussed in the system chapter.

10 Seilebost Micro Hydro

10.1 Background

The Seilebost stream has been identified by the West Harris Trust as a potential Micro Hydro Scheme. It is located approximately 600m from the old school which serves as an office for West Harris Trust (WHT). WHT intends to convert the building into a business hub, once they have moved to the Horgabost centre.

Figure 10.1.1 Seilebost
Source: Own elaboration using Google Maps

Moreover, the site can supply power for a possible housing development site in Seilebost which needs to be looked at. Seilebost stream looks promising for a Micro Hydro Scheme.

10.2 Specific Methodology

10.2.1 Hydro

In order to calculate power and energy profiles, the following steps are taken.

1- Possible intakes and the powerhouse determination.
2- The catchment area and head determination.
3- Hydrograph and Flow Duration Curve generation.

The first step to asses a potential micro-hydro scheme is to determine possible intakes on the stream. For this purpose, a site visit has been done during which two possible intakes have been determined to be feasible.

Generally, long-term flow data is desirable for resource assessment and energy calculation of a micro-hydro scheme. In this case, the flow and catchment area of the 100 kW Glean Dubhlinn micro-hydro scheme is correlated with the catchment area of the Seilebost stream in order to obtain its hydrograph. As for the hydro/wind project at Gleann Dubhlinn the 2008 flow data has been used as a representative year to determine a typical Hydrograph and Flow Duration Curve.

10.2.1.1 Economic Specific Methodology of Seilebost

The methodology used in the Luskentyre economic calculations is the same one employed in Seilebost. This includes the 4 methods of calculating investment costs.

10.2.2 Technology Review

Based on the gross head and design flow range Turgo and Pelton turbines are good choices for both sites. Turgo has a higher efficiency for a lower flow percentage, and works with a lower head. Based on the Turbine Selection Chart of Gilkes Turgo turbines, both intakes' head and flow are inside the Turgo turbine's limits. Therefore, it has been chosen for this micro-hydro scheme. The Flow, Power and Annual Energy relation charts in Annex 15.6.1, shows the following sizes are optimum.

Table 10.2.1 Capacity of the Seilebost stream sites

Site	Head (m)	Flow (m^3/s)	Capacity (kW)
A	21	0.169	25
B	42	0.166	50

The efficiency curve of the turbine, synchronous generator and penstock are included into the overall efficiency curve. The overall efficiency curve is shown in Annex 15.6.1.

10.2.3 Resource Assessment

The first possible intake's (Site A) coordinates are -6.9533 North, 57.8637 East. For the second intake (Site B) they are -6.95256 North, 57.86068 East. The powerhouse could be located close the road (-6.95222 North, 57.86441 East).

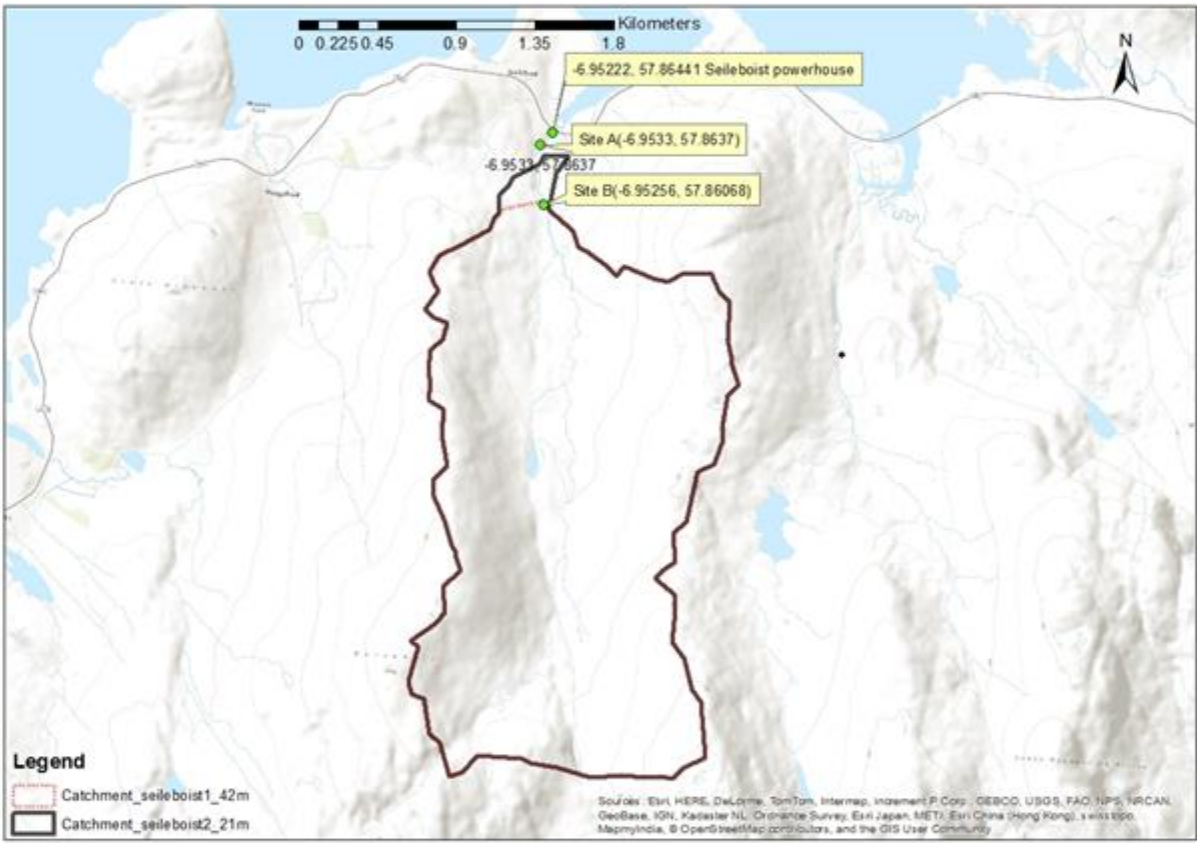

Figure 10.2.1 : Seilebost catchment area and coordinates of the intakes and the power house
Source: Own elaboration using ArcGIS®

For Site A and Site B, the catchment areas are calculated as 4.60 km², 4.54 km² respectively. Furthermore, the Gross Head is calculated to be 21 meters for Site A, and 42 meters for Site B. Once the catchment areas and Gross Head for both intakes are determined, the next step is to calculate 15 minutes flow data. The flow of the stream is shown in the Hydrograph of Figure 10.2.2.

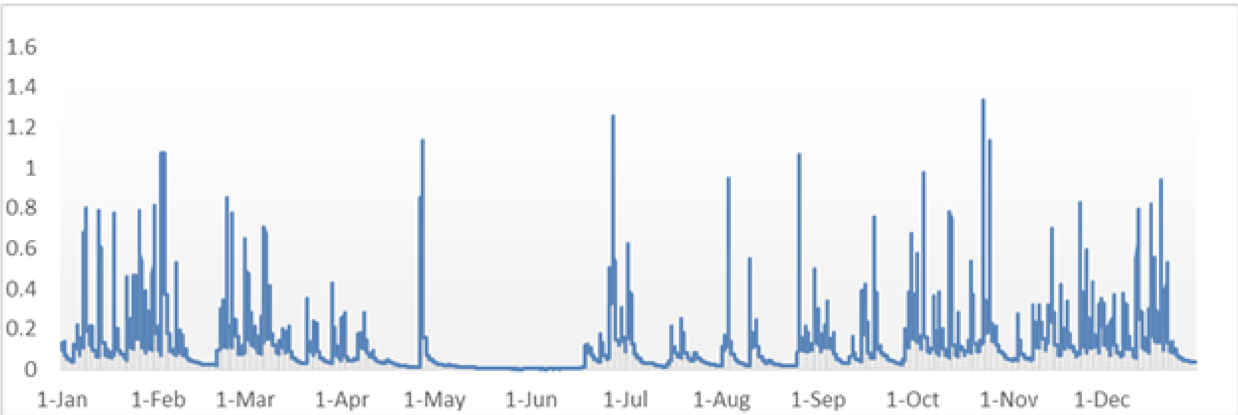

Figure 10.2.2 : Hydrograph of Site A (21m)
Source: Own elaboration

Once the Hydrograph is obtained, the next step is to illustrate the Flow Duration Curve (FDC) in order to calculate the percentage of time during a year for each flow value, and to determine the Base Flow or Hand-off Flow. It is the minimum flow which is not allowed to be diverted into the intake, and it must flow into its original path (the stream path). It is obligated by the environmental regulations. In order to obtain the Flow Duration Curve for the sites, 15 minutes based hydrograph is sorted in a descendent order. Figure 10.2.3 show FDC of the sites.

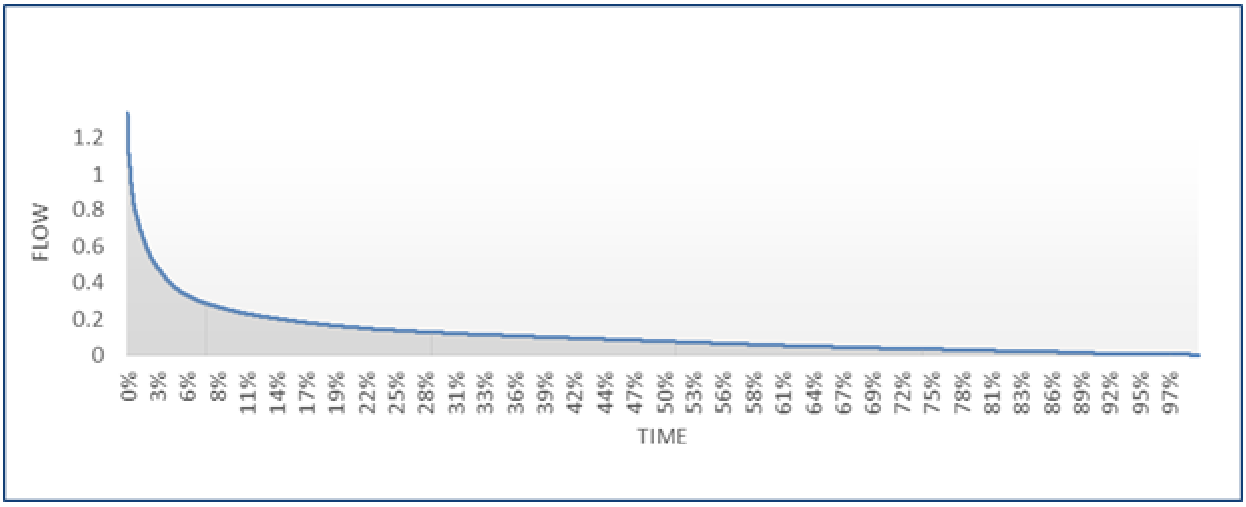

Figure 10.2.3 : Flow Duration Curve for Site A (21m)
Source: Own elaboration

From the FDC, the peak and average flows are calculated to be 1.337 and 0.112 m^3/s respectively. The base-flow (Hand-off Flow) at Q90, which is specified by Scottish Environmental Protection Agency (SEPA), is approximately 0.0114 m^3/s.

The flow of Site B is slightly lower than Site A, however, the FDC and hydrograph follow the same pattern. From the FDC of site B, the peak and average flows are calculated to be 1.318 and 0.111 m^3/s. The base-flow (Hand-off Flow) at Q90 is approximately 0.0113 m^3/s.

In order to calculate power or energy profiles, base-flow must be deducted from the flow of the stream which gives the amount of water that can be diverted into the intake. After including efficiency curve into the calculations, the power and energy profiles are illustrated. As shown in the Figure 10.2.4 and Figure 10.2.5, there is water shortage which consequently leads to lack of power generation in April and May, and there is more energy yield in winter season.

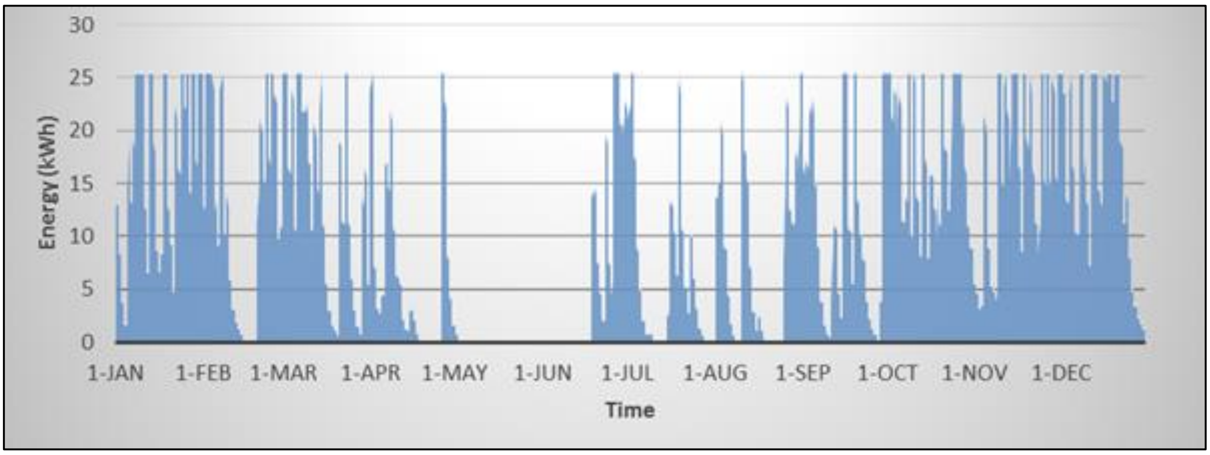

Figure 10.2.4 : Hourly energy profile of Site A (21m)
Source: Own elaboration

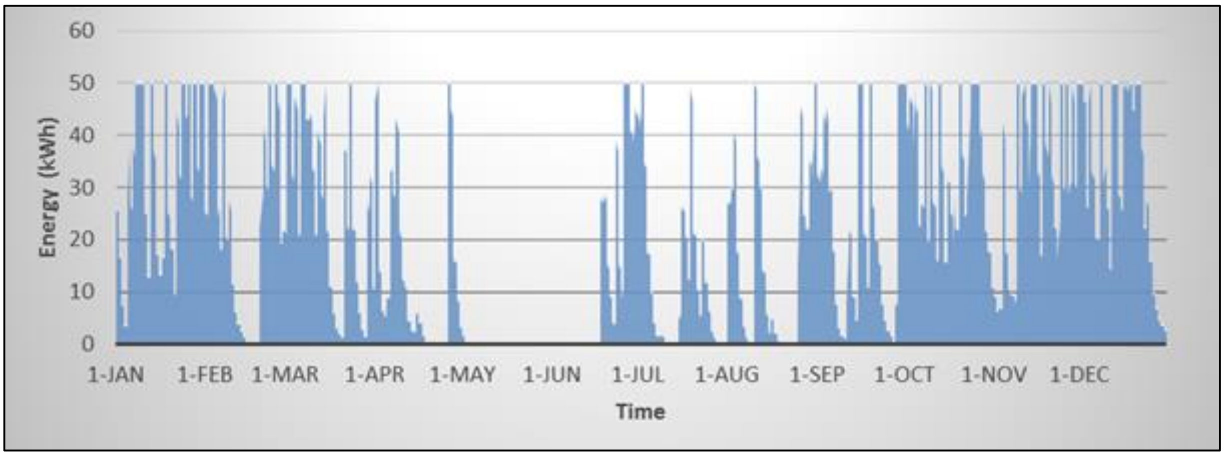

Figure 10.2.5 : Hourly energy profile of Site B (42m)
Source: Own elaboration

The maximum achievable annual energy form Site A and Site B are about 100 and 200 MWh respectively which can be seen in the Annex 15.6.1. For the design flows of 0.169 and 0.166m^3/s for the Site A and Site B the annual energy yield is about 95.2 and 187.6 MWh respectively. In order to evaluate that how many households can be connected to the hydro scheme, it is essential to look closer at the demand curve. Possible demand curve and storage options are discussed further in Chapter 11.

10.2.4 Economic Analysis

10.2.4.1 Economic Analysis of Seilebost 42m head 50kW Capacity

For Seilebost 42m head, 50kW capacity scenario, the investment costs calculated using the various methods result in a unit rate of between £4,856/kW and £9,068/kW. This case yield 187,600kWh annually which we assume is all sold to the households. Sensitivity analyses are run for the four test scenarios described before based on the different energy tariffs yielding the results shown in Figure 10.2.6.

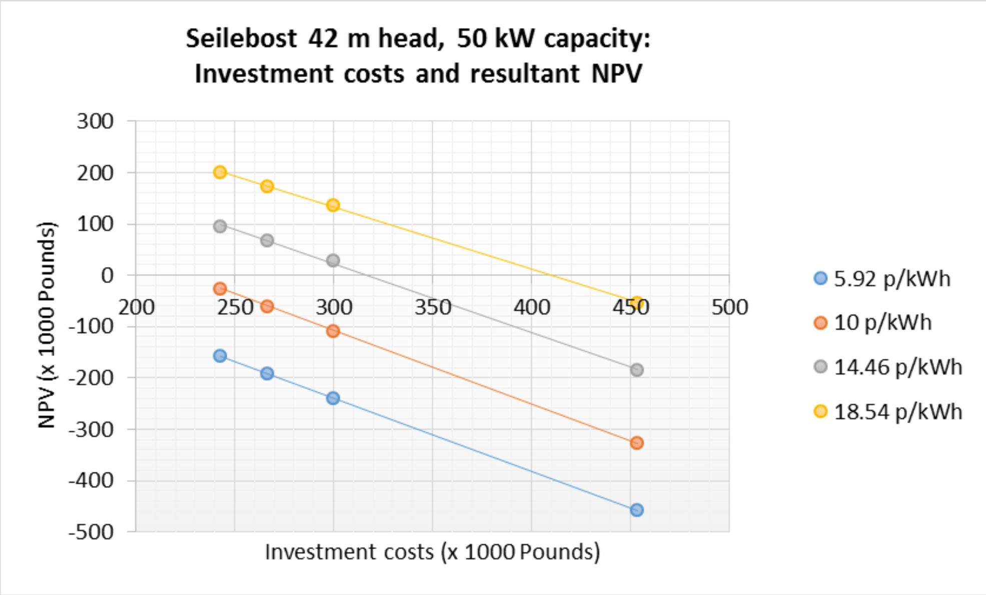

Figure 10.2.6: Investment Costs and Resultant NPV
Source: Economic model results

It is seen that the higher the investment cost, the lower is the resultant NPV. Particularly, method 1 and 2 only yield negative NPVs which is not economically feasible. The detailed results of each are found in the Annex 15.6.2. To improve on this, grants may be sought that cover part of the investment costs.

Additionally, the higher the energy tariff, the higher the NPV due to the increase in revenues. Thus the best cases are the ones with the energy tariff of 18.54p/kWh. Thus, one may conclude that this scenario is worth considering if an FIT is in place and as high as can be. Alternatively if the energy tariff charged to Households is high, then better NPVs may be realized.

10.2.4.1.1 Example case: Investment (£4,856/kW), Energy tariff = 14.46 p/kWh)

As a case in point, we analyse one instance with an energy tariff of 14.46p/kWh that may be composed of the current FIT of 8.54p/kWh and a HHT equivalent to the current oil prices for heat generation of 5.92p/kWh. The investment cost chosen is the one calculated from method 3 as £242,778 (£4,856/kW). This yields the results in Table 10.2.2.

Table 10.2.2: Economic Results for example case: Seilebost 42 m 50kW

PARAMETER	RESULT
$NPV_{project}$ (£)	£95,922
IRR (%)	7.35%
LCOE (£/kWh)	£0.1309
Payback Period (years)	14
ADSCR	1.07

Source: Economic model results

Analyzing the resultant key indicators shows that the NPV is positive, while the IRR of 7.35% is higher than the discount rate of 3.5% used in the model. This indicates that the project is economically feasible. Furthermore, the discounted payback period is 14 years, which is within the lifetime of the project. The calculated levelized cost of electricity is 13.09p/kWh.

Moreover, this case yields an average Debt Service Cover Ratio (ADSCR) of 1.07. Since this is greater than 1, it indicates that the project would be able to meet its debt obligations to the financing institution which is significant especially since a 100% loan financing is assumed in the model. The cash flows over the years are attached in the Annex 15.6.2.

10.2.4.2 Economic Analysis of Seilebost 21m head, 25kW capacity

The Seilebost 21m head scenario requires a calculated installed capacity of 25kW and yields 95,200kWh of energy annually. The 4 methods of calculating the investment requirement yield costs ranging from £5,328/kWh to £12,651/kWh. Assuming all the energy generated is sold to households, the NPVs shown in Figure 10.2.7 result for the various investment costs. It is seen that most of the resultant NPVs are negative.

Again just as in the aforementioned case the lower investment costs and higher energy tariffs may lead to improvement of the key indicators.

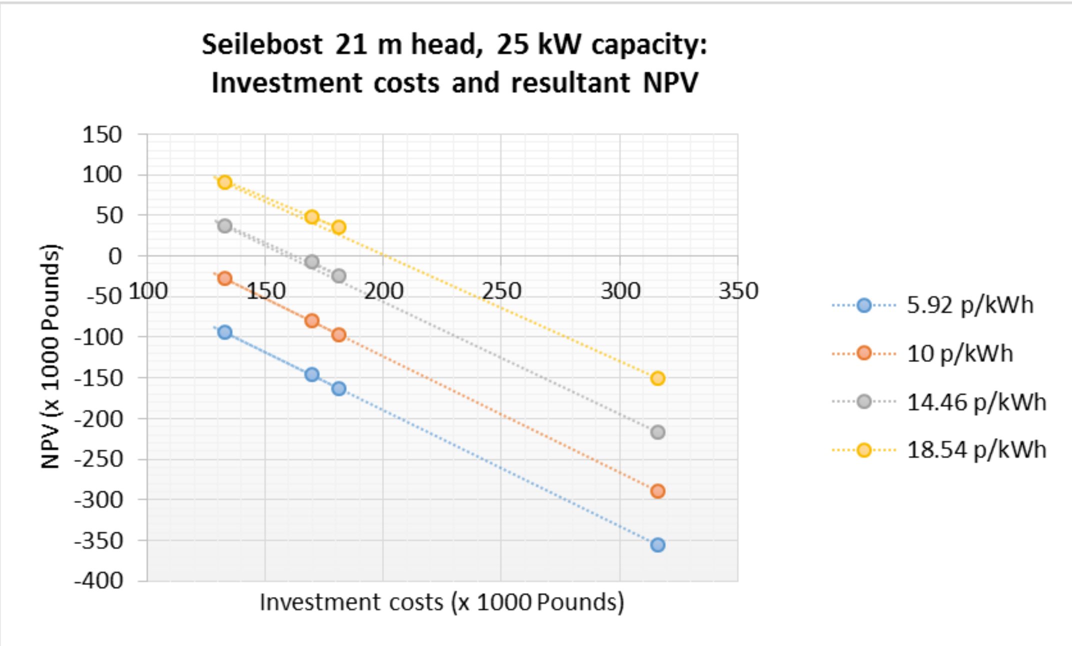

Figure 10.2.7: Investment Costs and Resultant NPV
Source: Economic model results

10.2.4.2.1 Example case: Investment (£5,328/kW), Energy tariff = 14.46 p/kWh)

The considered case study with an investment cost of £133,190 (method 2) yields the results in Table 10.2.3.

Table 10.2.3: Economic Results for example case: Seilebost 21 m 25 kW

PARAMETER	RESULT
$NPV_{project}$ (£)	£37,142
IRR (%)	6.27%
LCOE (£/kWh)	£0.1415
Payback Period (years)	15
ADSCR	0.98

Source: Economic model results

Whilst the NPV is positive and the IRR of 6.27% is greater than the discount rate of 3.5%, which are positive project indicators, as well as a discounted payback period of 15 years. The ADSCR is less than 1. This indicates that the project cash flows would not be able to fully meet the financing of a loan facility with this particular investment cost and tariff. As such, a lower investment cost or one subsidized through a grant would make the project feasible.

Alternatively, a higher energy tariff could be set. For instance, with the higher tariff of 18.54p/kWh that could be composed of an FIT of 8.54 p/kWh and a HHT of 10p/kWh yields much better results with ADSCR values of greater than 1. Of the 2 Seilebost scenarios, the 42m 50kW capacity scenario seems to perform slightly better. It is to be noted that the economic calculations for Seilebost assume all the energy is sold, this may not be the case as will be discussed in chapter 11 System Analysis.

11 System Analysis

11.1 Background

The system analysis chapter aims at analyzing four separate sites from earlier assessed scenarios which produce excess energy. Table 11.1.1 highlights the selected scenarios to be analysed further in the systems section. Here, the electricity produced in Laxdale site is used for onsite Hydrogen production assessment in the case that grid connection for the Laxdale wind site cannot be established. In Gleann Dubhlinn, the combinations comprise both hydro and wind generation. The scenarios chosen in systems from Gleann Dubhlinn are made up of 3 x 100kW Wind Turbines and 100kW Hydro (both with and without storage volume of the loch). The storage height at the loch considered for assessment in systems analysis is 2 meters. For the Wind and Hydro scenarios, the typical average year for Wind and Hydro was selected as 2008 and 2011 respectively for simulations in the systems section.

Table 11.1.1: Scenarios Assessed in System Analysis

Location	Scenarios Assessed
Luskentyre - Hydro	Electricity for Local Heat Demand and Electric Transportation in Luskentyre
Seilebost - Hydro	Electricity for Local Heat Demand and Electric Transportation in Seilebost
Gleann Dubhlinn - Hydro/Wind	On site Hydrogen production in Gleann Dubhlinn
Laxdale - Wind	On site Hydrogen production in Laxdale
All Locations in West Harris	Integrated scenario to meet the local demand

11.2 Electricity for Local Heat Demand and Electric Transportation

11.2.1 Household Demand

The household electricity demand in West Harris consists mainly of the demand for household appliances, space heating demand and the hot water demand. The demand for household appliances was estimated using the Electricity Demand Profile Generator[9] based on an occupancy of

[9]The electricity demand profile generator was created for estimating the Electricity demand for a community in UK(University of Strathclyde)

3 person per household. The parameters used to calculate the hourly space heating demand are presented in Table 11.2.1: **Space Heating Parameters**:

Table 11.2.1: Space Heating Parameters

Parameter	Values
Comfortable room temperature (˚C) [10]	18
Heat demand (kWh/m²) per annum [11]	40
Annual Heating degree days	3050
Building area (m^2)	120
Heat electricity demand (kWh/annum)	4800

Source: Own Elaboration

Hourly temperature distribution averaged over the period of eight years was obtained from the Meteonorm software. Assuming a comfortable room temperature of 18 ˚ C, the heating degree days were calculated. The annual heating demand was then distributed over this heating degree distribution to obtain the heating demand distribution.

The hot water demand was estimated based on a survey done by the UK government to assess the consumption of hot water in a typical UK household(Energy Saving Trust, 2008). The details of the demand calculations are presented in the Annex 15.7.1. The graph in Figure 11.2.1 shows the hourly energy demand of a typical household on an average day[10].

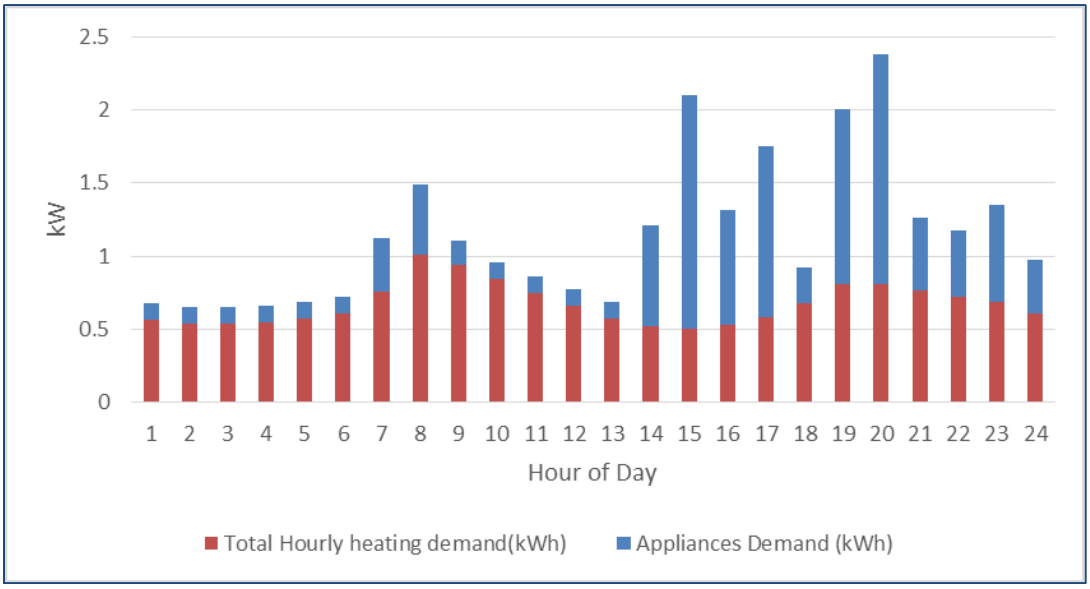

Figure 11.2.1: Average Day Demand Profile
Source: Own elaboration

[10]Average day is the day in which the total daily demand in closest to the annual average demand.

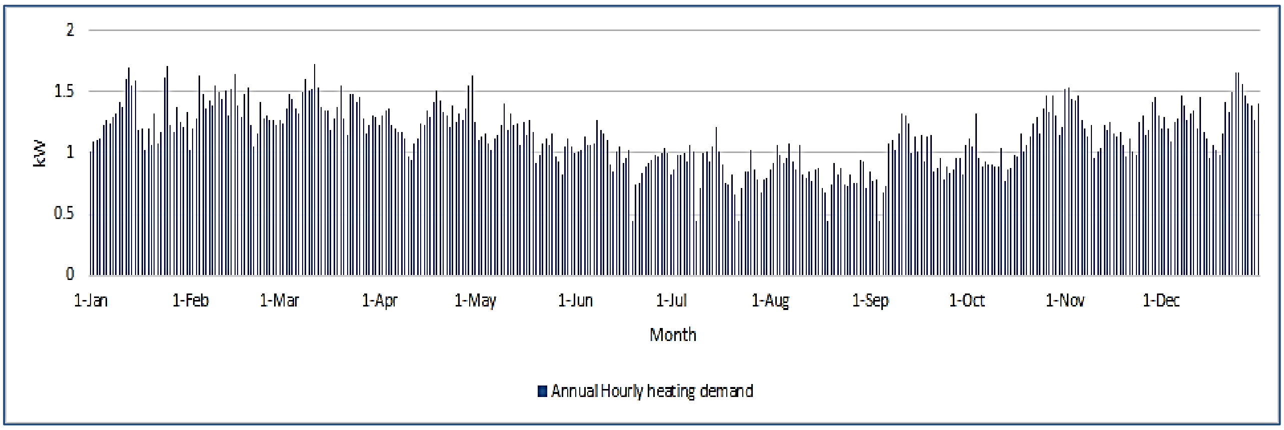

Figure 11.2.2: Annual heating demand profile
Source: Own elaboration

Table 11.2.2: Household Energy Demand Summary

Demand categories	Annual demand (kWh)
Appliance	4,146.40
Space heating	4,800.00
Water heating	1,711.04
Total demand	**10,657.44**

Source: Own elaboration

The peak demand can be seen to be around 2.5 kW at 8 pm which is justifiable as the energy intensive kitchen appliances come into operation mostly at this time. Also it can be seen that the appliances cause fluctuations in the demand while the heating demand makes up the base load. As seen in Table 11.2.2 the heating demand constitutes a major portion of the overall demand. Thus, for the purpose of assessment only heating demand is considered.

11.2.2 Electric Transportation

Scotland's Electric Vehicle Roadmap is developed by Transport Scotland which sets a vision for Scotland's electric vehicle future. The target is 2050 in which Scotland will be free from damaging effects of oil fueled vehicles. It is aimed by the Scottish Government to increase the penetration of electric vehicles that can help to reduce emissions, improve the air quality and public wellbeing.

11.2.2.1 Methodology

An alternative that is proposed to the West Harris Community is to utilize excess energy for electric vehicles, such as cars, community bus and school bus, which could cut fuel costs, vehicle tax and carbon emissions. In this section, the steps undertaken to assess the electricity demand for electric vehicles is explained. To evaluate whether demand can be fulfilled or not, survey results are taken into consideration.

For the electric cars, the main assumption is made that one household owns one electric car. Based on the generation profile of each project, the maximum number of households that can benefit from the generation, as well as the community and school bus are calculated. Since the generation in May is very low, it is excluded from the calculation. For the demand calculation of the community bus, an assumption is made that the community bus provides service to Stornoway once a weekday, whereas for the demand calculation of the school bus it is assumed that it goes to Tarbert twice a weekday. School holiday schedules are also taken into consideration. The methodology that is adopted for the selection of the electric vehicles is also based on the survey outcomes. Specifications of the electric vehicles and charging conditions are important to encourage residents to prefer to use electric vehicles. In the following sections, specifications are explained in details.

11.2.2.2 Specifications of Electric Vehicles

One of the most important specifications is the mileage range. The usage of air conditioning, heating, driving style and speed also affect the range. For the particular scenarios, electric vehicles with a mileage range of approximately 100 miles are selected that can fulfill most of the demand to make a round trip to Stornoway and Tarbert.

Based on the survey results, another important criterion is the price of the electric vehicles. Compared to the conventional cars, electric vehicles are expensive to buy due to the batteries. However, high prices can be acceptable taking running costs into account, which are lower than petrol/diesel equivalents. A rough comparison of the investment and driving cost of an electric car to a petrol and diesel cars is done. To carry out the calculation, fuel costs, price of the cars, factors and components such as maintenance and battery are taken into account. The results obtained shows that electric cars are not far from being competitive to the conventional cars. Additionally Scottish Government is encouraging citizens to use electric vehicles, offering funding and Plug-in Grants to reduce the cost. From 1st of March 2016, government is changing the grant levels based on the environmental performance of the vehicles. The rate of £4,500 applies for the proposed electric car which is taken into account in the following calculations.

Charging time is also mentioned in the survey as an issue for the preference of electric cars, which depends on the size of the car and the battery size. Electric cars can be charged at charging points or at home as one of the major benefits. Additionally for home charging, there is a funding provided to cover part of the cost of installing a home charge point with Electric Vehicle Home-charge Scheme (Greener Scotland, Scottish Government, 2016). Either a grant of up to 75% of the installation cost or £700 are provided, whichever is less, including taxes (Energy Saving Trust UK, 2016).

11.2.2.2.1 Electric Car

To carry out the demand calculations, Renault Zoe, a supermini electric car produced by the French manufacturer Renault is considered here and specifications are shown here:

Table 11.2.3 : Specifications of the Electric Car

Type	Brand	Charging time (hours)	Power (kW)	Range (miles)	kWh/miles
Super min	Renault Zoe	4.00	7.00	130.00	0.22

(Source: (Renault, 2016))

As it is given in the Table 11.2.3 above, it can be fully charged in four hours with 7kW power and has a mileage range of 130 miles. Therefore it consumes 0.22 kWh per mile. For the assumption of an existing electric car that makes a round trip to Stornoway once a week, the consumption is 103.4 kWh per month. In the case of twice of week round trip, the consumption figure is doubled to 206.8 kWh per month.

11.2.2.2.2 Community Bus

Stornoway being the furthest is used for the computation, another way to utilize excess energy is proposed for an electric community bus that provides service to Stornoway once a weekday, which can be practical for the community to use public transport. For this option, electric minibus model Edison by Smith Electric Vehicles is considered. The minibus is available in different seat configurations that range between 12 to17.

Table 11.2.4: Specifications of the Electric Minibus

Brand	Charging time (hours)	Power (kW)	Range (miles)	kWh/mile
Smith EV – Edison Minibus	8	18	100	1.44

Source: (Smith Electric Vehicles, 2016)

As can be seen from the Table 11.2.4 above, it features the longest drive range of 100 miles on one single charge and requires 8 hours with a power of 18 kW for full charge. Therefore it consumes 1.44 kWh per mile. For the assumption that a community bus makes a round trip to Stornoway once a weekday, the total consumption is 3456 kWh per month.

The same minibus is considered for the option of electric school bus that provides service to the children that are living in West Harris and studying in Tarbert, in Sir E Scott School. The assumption made is that the school bus makes a round trip to Tarbert twice a weekday. Additionally, Government has a Plug-In Van Grant of £8,000.

11.2.3 Scenario Analysis - Luskentyre

The main purpose behind the investigation of the feasibility of Luskentyre Micro Hydro Scheme was to supply electricity to the housing development planned by the West Harris Trust in the vicinity of the project Site. We assumed 5-7 Houses as the beneficiaries of this scheme at the present. But economic analysis showed that developing the scheme only for this number of houses was not economical. Also three different optimum flows and Micro hydro capacity were identified in the Chapter 3. Then in the chapter 3 these different options of 35, 50 and 60 kW were analysed and were found to be economically feasible assuming that all generated electricity will be sold. Now the purpose of this demand assessment is to estimate the number of houses the Luskentyre Micro Hydro Scheme can supply with electricity. For the purpose of simplicity only intake site A with 35 kW installed capacity and intake site B with 60 kW installed capacity are presented here.

11.2.3.1 Generation and heating demand analysis

From chapter 7 Luskentyre, three different optimum options were identified for generating electricity from the Gleann Beinn Dhuibh River. However in this chapter only the minimum and maximum generating options are analysed to see the range of possible households that could be connected.

Table 11.2.5: Site Specification- Luskentyre

Intake Site	Head (m)	Flow (m^3/s)	Energy generation (MWh/year)	Capacity (kW)
A	54	0.09	125.92	35
B	94	0.09	191.90	60

Source: Own Elaboration

A reverse calculation was then performed to obtain the number of houses that each of these settings would be able to supply[11]. A comparison of the unmet demand and surplus with varying number of households as in Figure 11.2.3 and Figure 11.2.4 give the following results.

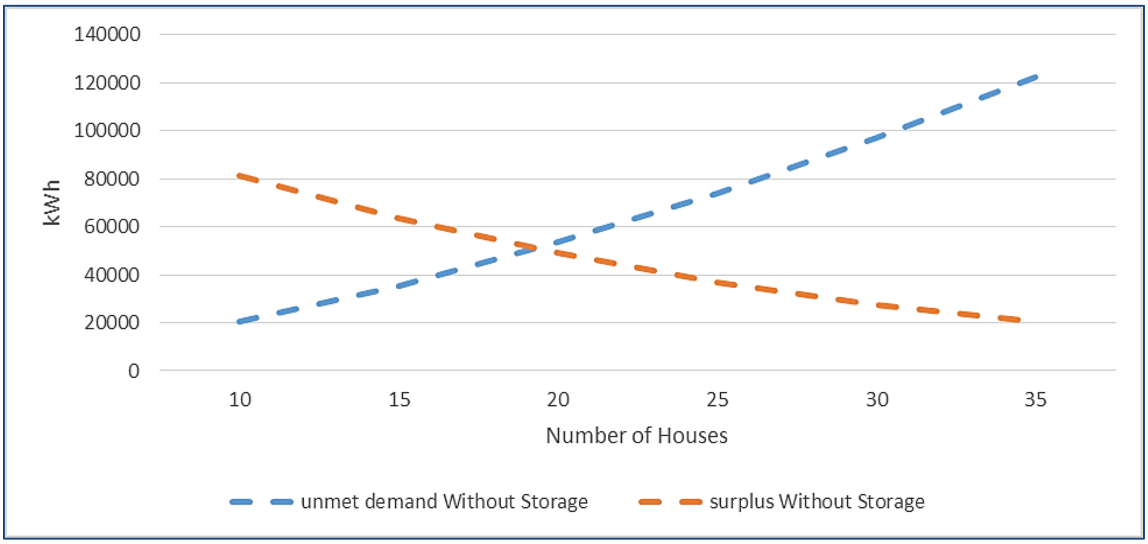

Figure 11.2.3: Surplus and Unmet demand-Luskentyre (Intake Site A) without heat storage
Source: Own Elaboration

[11]Assumption: Demand profile for each house is the same and that the demand profile of x number of houses is just a multiple of the demand profile of one house.

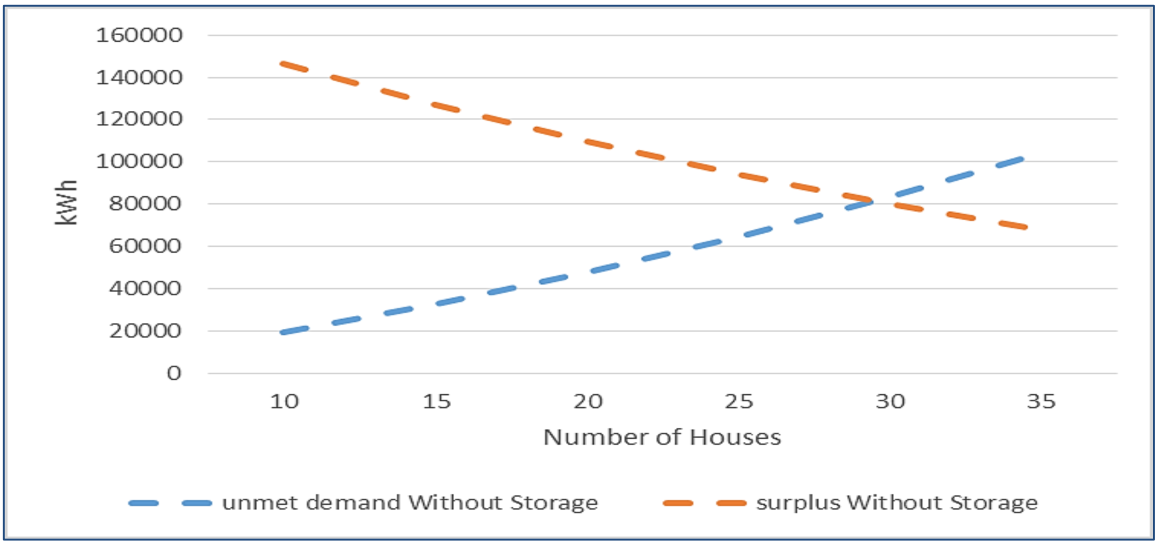

Figure 11.2.4: Surplus and Unmet Demand-Luskentyre (Intake Site B) without heat storage
Source: Own Elaboration

The demand and generation analysis shows that for Site A and Site B the optimum number of houses to be connected to the scheme would be 20 and 30 respectively. Table 11.2.6 summarizes the annual generation and demand for each intake site.

Table 11.2.6: Annual Generation and Demand- Luskentyre

Intake Site	Site characteristics	Capacity (kW)	Energy generation (MWh/year)	Optimum number of houses	Heating demand (MWh/year)
A	Q0.09,H-54m	35	125.92	20	130.22
B	Q0.09,H-94m	60	191.90	30	195.33

Source: Own Elaboration

The demand vs generation profile for both the sites are presented in Figure 11.2.5 and Figure 11.2.6

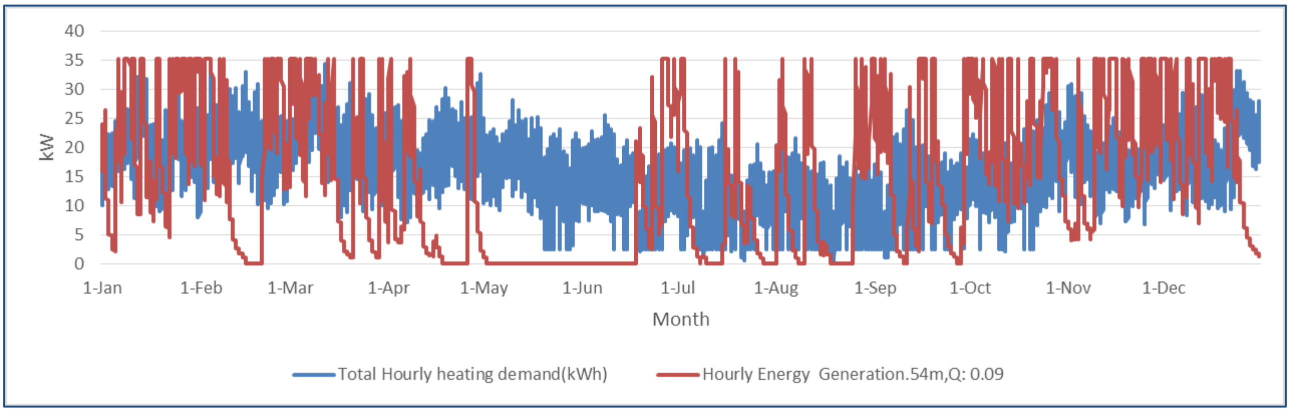

Figure 11.2.5: Annual Demand vs Generation Profile-Luskentyre (Intake Site A)
Source: Own Elaboration

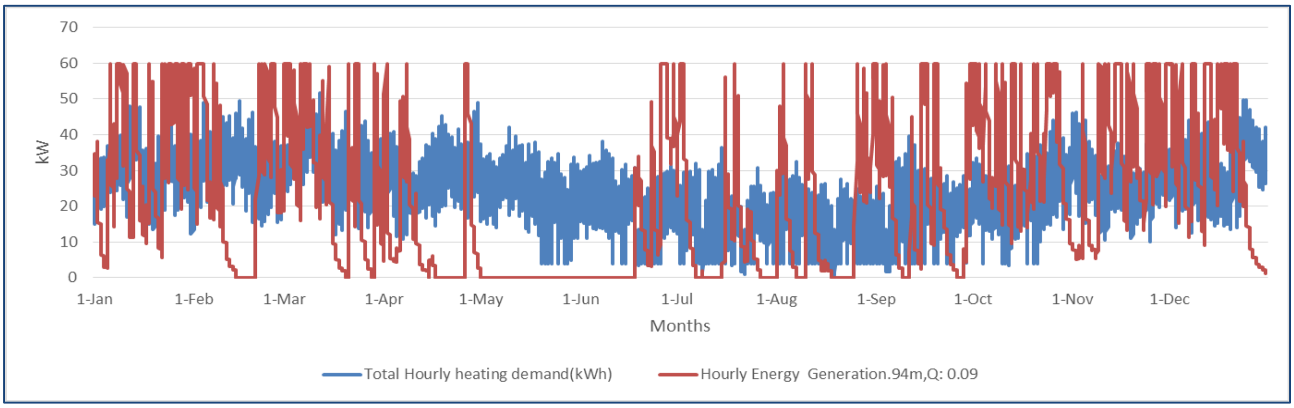

Figure 11.2.6: Annual Demand vs Generation Profile-Luskentyre (Intake Site B)
Source: Own Elaboration

The demand vs generation profiles shows that there is a mismatch between the generation profile and the demand profile. There are several cases of excess generation and of unmet demands throughout the year. But in cases where there is a long term reduction in the river flow (e.g. May-June), there is no production at all. So for these times the total demand could be covered by the main grid or other backup systems. But for other short term generation deficits, a heat storage system is proposed to reduce the unmet demand.

11.2.3.2 Heating System

Excess energy generated from the Micro Hydro Scheme will be used to heat and store the water in an insulated tank. A volume of approximately 1000 liters per household has been assumed for storing the excess energy. However, further study would be required to determine the optimum storage volume to utilize the surplus energy (Annex 15.7.2). This heat will then be used for space heating and for domestic water heating in the households. For both sites depending on the distances between the houses, a community heating system could be an option. Depending on the distance of the houses from each other and the related cost for district heating pipes the costs and heat losses of common heat storage can be comparatively lesser than when using individual storage tanks. The Summary of Storage analysis is presented in the Table 11.2.7. The assumptions made and a sample of the calculation sheet is presented in the Annex 15.7.2.

Table 11.2.7: Storage Analysis Summary

Site	Number of Households	Unmet Demand with storage (MWh)	Unmet Demand without storage (MWh)	Total Demand Covered From Storage (MWh)	Original Surplus (MWh)	Modified Surplus (MWh)
Site A	20	32.32	53.41	21.09	49.11	28.02
Site B	30	46.83	83.49	36.66	80.06	43.55

Source: Own Elaboration

A comparison of the unmet demand and surplus energy is shown in Figure 11.2.7 and Figure 11.2.8. It shows that with the incorporation of community heating system the unmet demand decreases significantly.

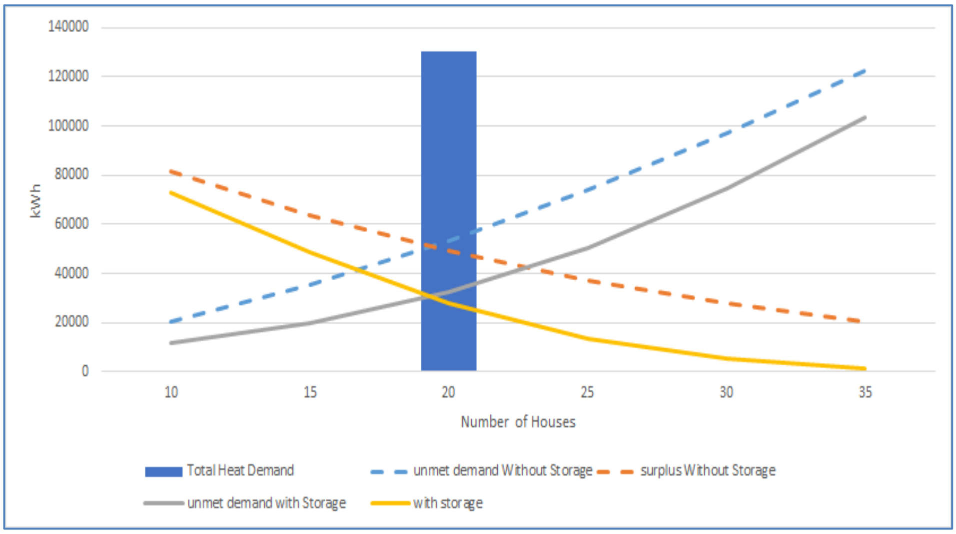

Figure 11.2.7: With Storage and without Storage-Luskentyre (Intake Site A)
Source: Own Elaboration

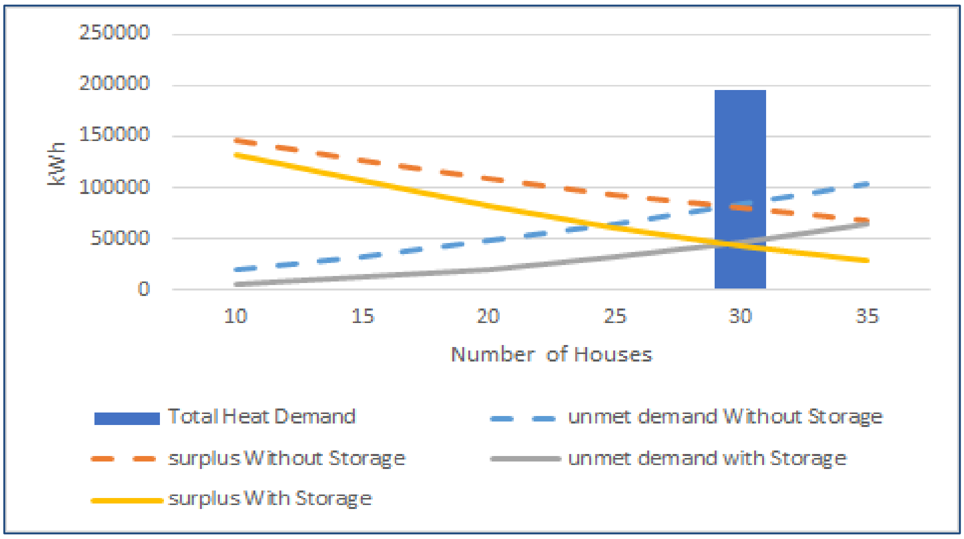

Figure 11.2.8: With Storage and Without Storage-Luskentyre (Intake Site B)
Source: Own Elaboration

Thus from this analysis we can recommend that for the intake sites A and B the optimum number of household connections should be around 20 and 30 respectively. Luskentyre Village which is around 1500 m from the power house site could also be connected to the Micro Hydro Scheme. A heat storage system is an option for the Micro Hydro Scheme to utilize the excess energy. It reduces the unmet demand which otherwise would have to be fulfilled by other sources.

11.2.3.3 Combined Heating and Electric Transportation

Considering the demand of school bus and community bus and assuming that each household owns an electric car, the maximum number of households that can benefit from the total generation of 35 kW is estimated. In addition to the community and school bus, the demand for 2 houses that have an electric car can be met by the total generation, excluding the month of May. The case of low hydro electricity generation in May occurs in the reference year of 2008 chosen for calculation. However, the flow conditions might be different in other years. Table 11.2.8 shows the monthly heating and transportation demand. The annual generation is 125.92 MWh and the annual total demand 71.56 MWh.

Table 11.2.8: Monthly Heating and Transportation Demand

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Generation (kWh)	16,019	11,198	13,346	5,891	45	6,054	6,171	8,605	9,841	18,208	15,628	14,916
School bus demand (kWh)	1,037	1,382	1,382	691	1,382	1,037	0	691	1,382	691	1,382	1,037
Community bus demand (kWh)	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
2 cars demand (kWh)	414	414	414	414	414	414	414	414	414	414	414	414
2 houses heating demand (kWh)	1,411	1,322	1,432	1,260	1,077	851	689	631	745	1,002	1,214	1,390
Total demand (kWh)	6,318	6,574	6,684	5,821	6,329	5,758	4,559	5,192	5,997	5,563	6,466	6,296
Surplus electricity (kWh)	9,701	4,624	6,662	70	-6,284	295	1,613	3,412	3,844	12,645	9,162	8,620

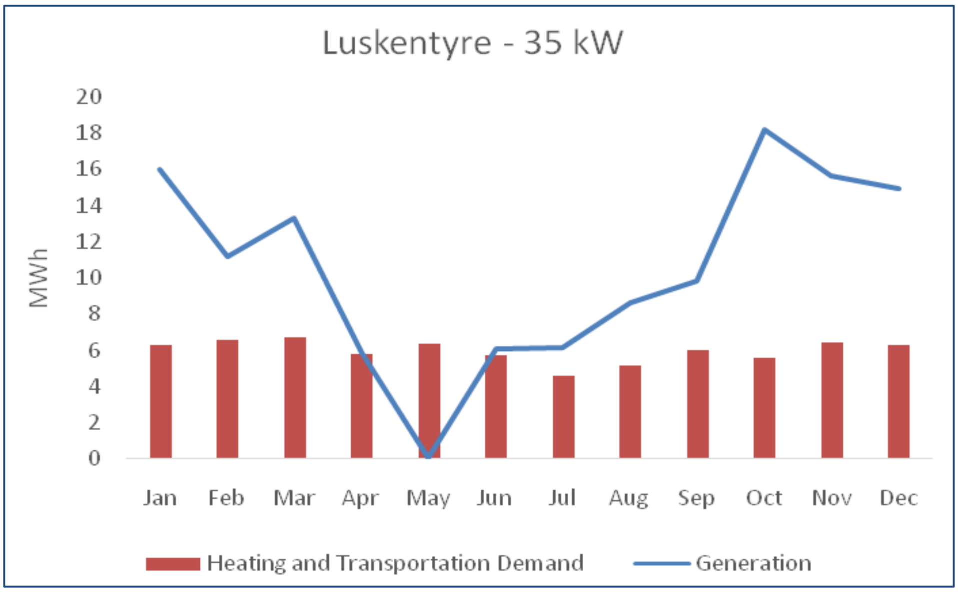

Figure 11.2.9: Monthly Heating and Transportation Demand and Generation Profile

As can be seen from the Figure 11.2.9 above, there is still a big surplus from October to March. This is due to the fact that the minimum generation is considered to fulfill the monthly demand to make sure that the transportation system work properly.

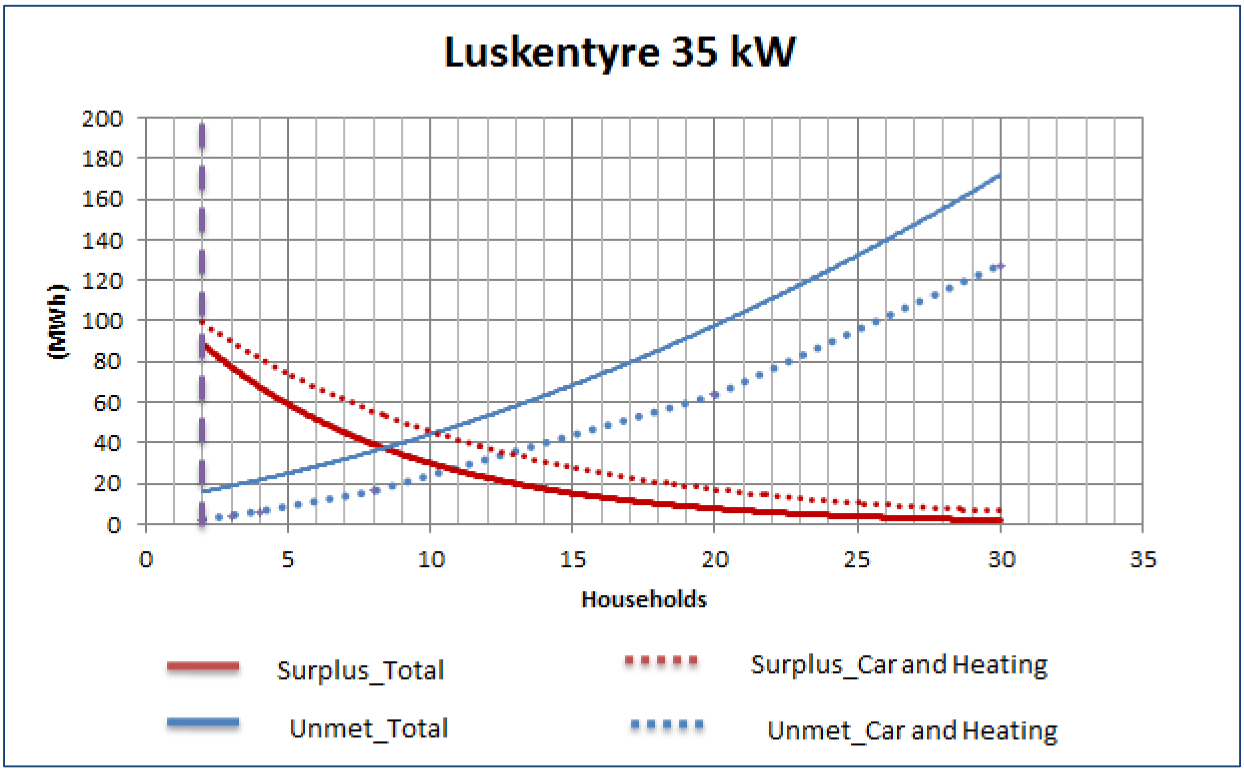

Figure 11.2.10: Comparison between unmet demand and surplus

The red solid line represents the total supply for households including heating, community bus, school bus and electric cars, whereas the red dashed line represents supply including electric cars and heating. Similarly, the blue solid line represents the total unmet demand for heating, electric cars, community and school bus. Blue dashed line represents unmet demand excluding busses.

Figure 11.2.10 above shows the comparison between unmet demand and surplus for households, with and without school and community bus. As can be seen from the Figure 11.2.10, for 2 households, all demand can be fulfilled, except the month of May, but the surplus is too big. Although the surplus of 8 households can be matched up with unmet demand, the time tables of the community and school bus cannot be changed. Therefore the 2 households is the optimal solution. If community and school bus are not taken into account, 14 households is the optimal solution.

In the case of 60 kW total generation, the same methodology is used. Considering the demand of school bus and community bus and assuming that each household owns an electric car, the maximum number of households that can benefit from the total generation of 60 kW is estimated. In addition to the community and school bus, the demand for 5 houses that have an electric car can be met by the total generation, excluding May. The annual generation is 191.898 MWh, the annual total demand 98.543 MWh and the monthly demand is shown in the Table 11.2.9 below.

Table 11.2.9: Monthly Demand for Community Bus, School Bus and Electric Cars

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Generation (kWh)	24,587	17,304	20,133	8,584	26	9,261	8,980	13,021	14,671	28,359	24,073	22,90
School bus demand (kWh)	1,037	1,382	1,382	691	1,382	1,037	0	691	1,382	691	1,382	1,037
Community bus demand (kWh)	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
5 cars demand (kWh)	1,035	1,035	1,035	1,035	1,035	1,035	1,035	1,035	1,035	1,035	1,035	1,035
5 houses heating demand (kWh)	3,528	3,305	3,579	3,149	2,691	2,128	1,721	1,578	1,861	2,505	3,034	3,474
Total demand (kWh)	9,056	9,178	9,452	8,331	8,565	7,656	6,212	6,760	7,735	7,688	8,908	9,002
Surplus electricity (kWh)	15,531	8,126	10,681	252	-8,538	1,605	2,768	6,260	6,936	20,671	15,165	13,898

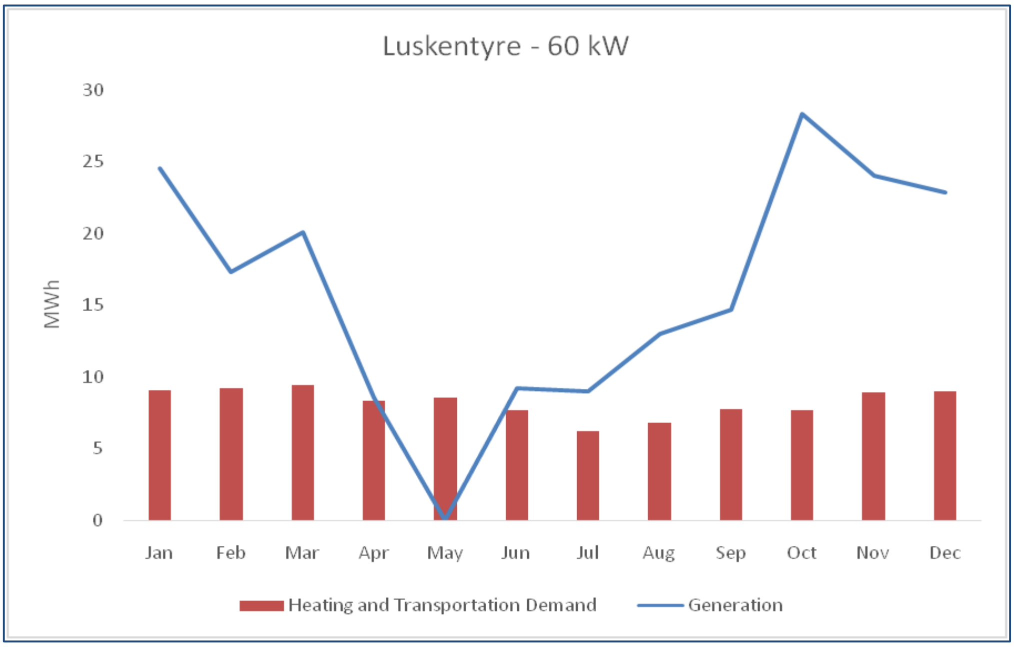

Figure 11.2.11: Monthly Heating and Transportation Demand and Generation Profile

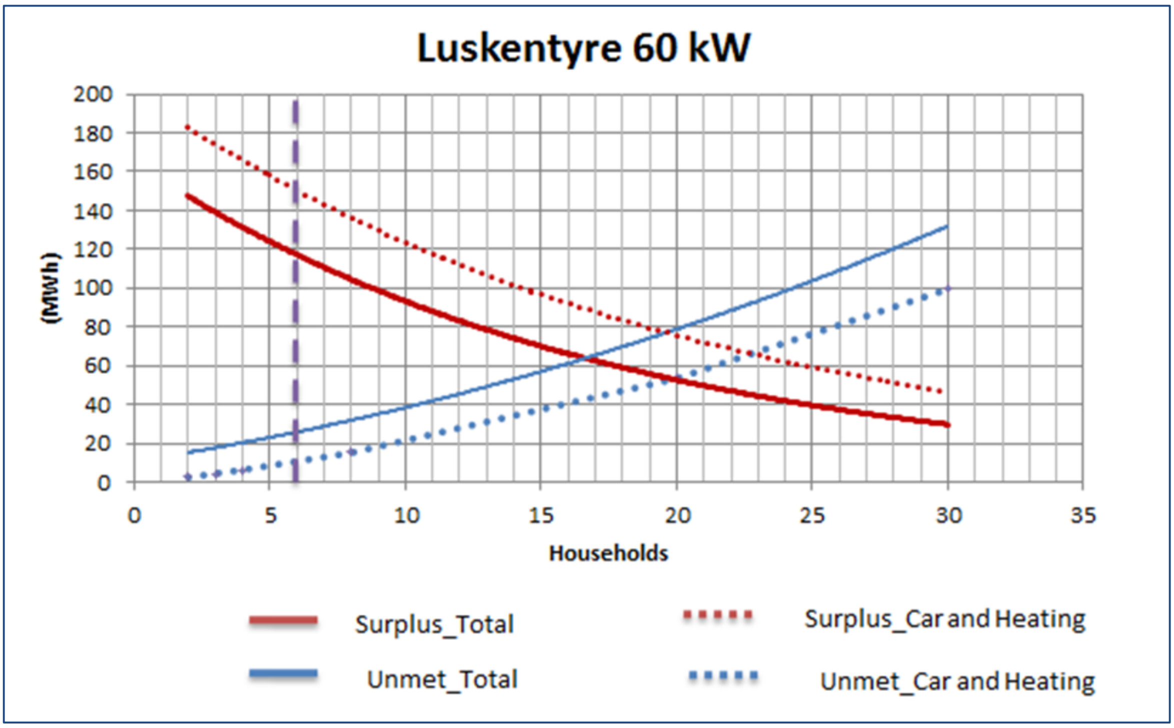

Figure 11.2.12: Comparison between unmet demand and surplus

The red solid line represents the total supply for households including heating, community bus, school bus and electric cars, whereas the red dashed line represents supply including electric cars and heating. Similarly, the blue solid line represents the total unmet demand for heating, electric cars, community and school bus. Blue dashed line represents unmet demand excluding busses.

As can be seen from the Figure 11.2.12 for 6 households, all demand can be fulfilled, except the month of May, but the surplus is still big. Although the surplus of 17 households can be matched up with unmet demand, the time tables of the community and school bus cannot be changed. Thus, the 6 households is the optimal solution. In the case of excluding community and school bus, 23 households is the optimal solution.

11.2.4 Scenario Analysis - Seilebost

There are currently around 5 to 6 houses around the vicinity of the scheme. There is an old school close to the area which can be a major demand for the scheme as it is planned to be converted to a business hub. The distance from the school to the scheme is around 600 meters. For the purpose of this study this site is considered as a potential site for housing development. The optimum number of households that can be connected from its maximum energy generation will be analysed in this chapter.

11.2.4.1 Generation and heating demand analysis

The maximum annual energy that can be achieved from this site can be summarized in Table 11.2.10

Table 11.2.10: Site specification- Seilebost

Intake	Head (m)	Flow (m^3/s)	Annual energy (MWh)	Capacity (kW)
1	42	0.166	187.60	50

Source: Own Elaboration

The optimum number of households that can be connected to this site was calculated using the similar method as in section 11.2.3.1.

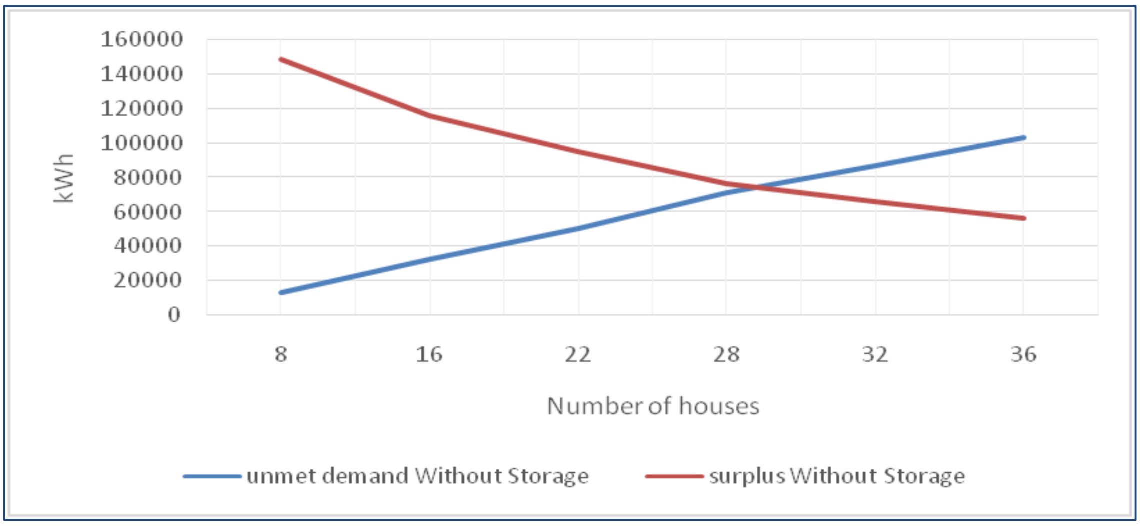

Figure 11.2.13: Surplus and unmet demand- Seilebost
Source: Own Elaboration

The demand and generation analysis shows that optimally 28 houses could be connected to the Micro Hydro Scheme, resp. 25 houses and the old school building once it has undergone an energy retrofit.. This would result in an annual heating demand of 182.309 MWh. The heating demand of 28 household vs generation profile of the site is shown in Figure 11.2.14

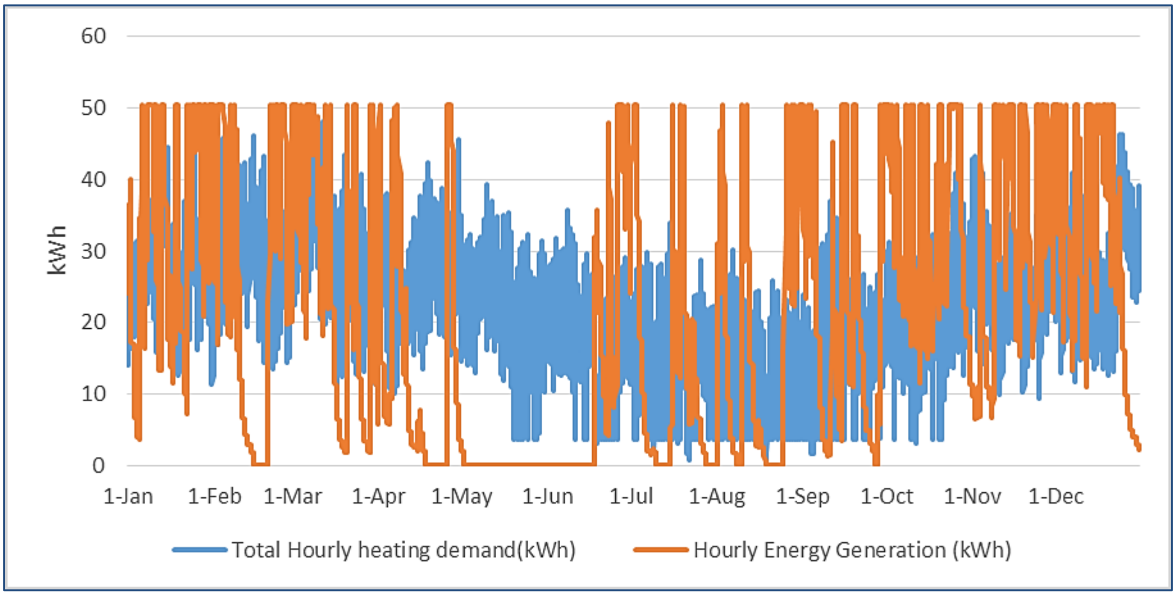

Figure 11.2.14: Annual Demand vs Generation Profile- Seilebost (Source**:** Own Elaboration)

From the results, we can see that there are periods when there may be no production at all and periods when there is excess generation. May and June can be seen in the Figure 11.2.14 as the driest months of the reference year when there is no flow in the river to operate the turbine. Similar to Luskentyre, a heat storage system is proposed to minimize the unmet demand during short term deficits.

11.2.4.2 Heating system

As in Luskentyre, it is considered that the Seilebost Micro Hydro Scheme produces electricity for heating systems. The Summary of the storage analysis is presented in the Table 11.2.11. The assumptions made and a sample of the calculation sheet is presented in the Annex 15.7.1.

Table 11.2.11: Storage Analysis Summary- Seilebost

Site	Number of Households	Modified Unmet Demand (MWh)	Original Unmet Demand (MWh)	Total Demand Covered From Storage (MWh)	Original Surplus (MWh)	Modified Surplus (MWh)
Seilebost	28	42.47	71.48	29.01	49.11	76.75

Source: Own Elaboration

A comparison of unmet demand and surplus with and without storage was conducted as represented in Figure 11.2.15.

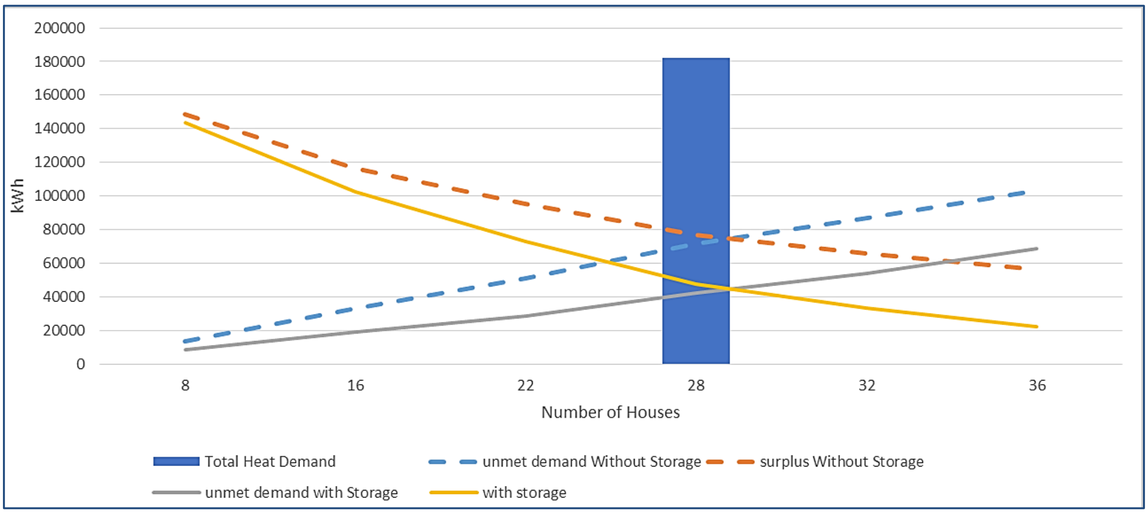

Figure 11.2.15: with Storage and without Storage- Seilebost
Source: Own Elaboration

We can see from Figure 11.2.15 that unmet demand and excess energy can be reduced with the inclusion of heat storage option. For this Micro Hydro Scheme many other business options can also be considered as it holds the potential to fulfil the demand of a significant number of households. Business options such as laundry business and day care centres can be further realized as a potential demand for this site.

11.2.4.3 Combined Heating and Electric Transportation

The same methodology is used and in this case, addition to the community and school bus, the demand for 6 houses that have an electric car can be met by the total generation, excluding May. The annual generation is 187.59 MWh and the annual total demand is 107.54MWh.

Table 11.2.12: Monthly Demand for Community Bus, School Bus and Electric Cars

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Generation (kWh)	23,795	16,599	19,915	8,928	80	9,011	9,353	12,870	14,790	26,894	23,187	22,163
School bus demand (kWh)	1,037	1,382	1,382	691	1,382	1,037	0	691	1,382	691	1,382	1,037
Community bus demand (kWh)	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
6 cars demand (kWh)	1,42	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242
6 houses heating demand (kWh)	4,234	3,966	4,295	3,779	3,230	2,554	2,066	1,894	2,234	3,006	3,641	4,169
Total demand (kWh)	9,969	10,046	10,375	9,168	9,310	8,289	6,764	7,283	8,314	8,396	9,722	9,904
Surplus electricity (kWh)	13,826	6,553	9,540	-240	-9,230	723	2,589	5,587	6,476	18,498	13,465	12,259

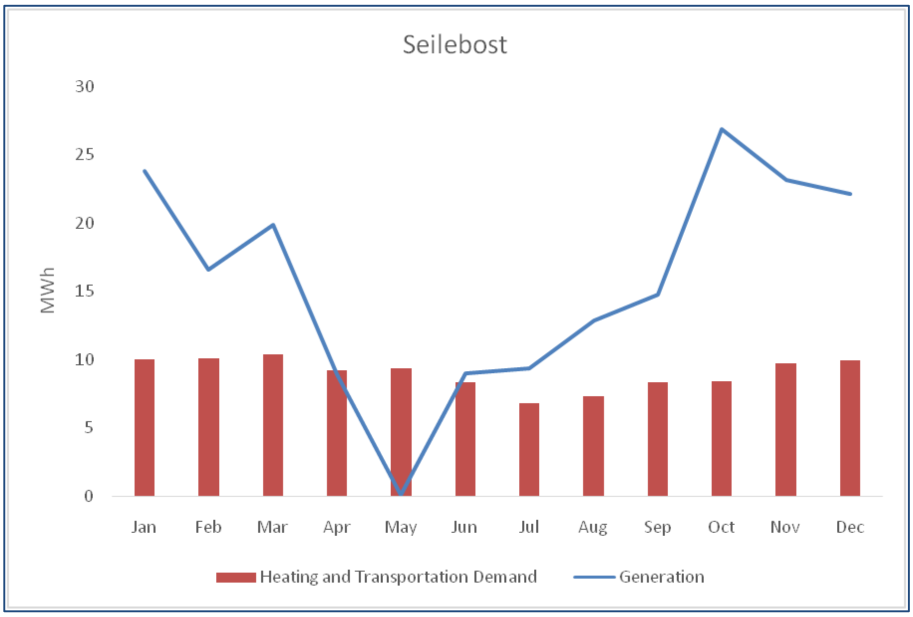

Figure 11.2.16: Monthly Heating and Transportation Demand and Generation Profile

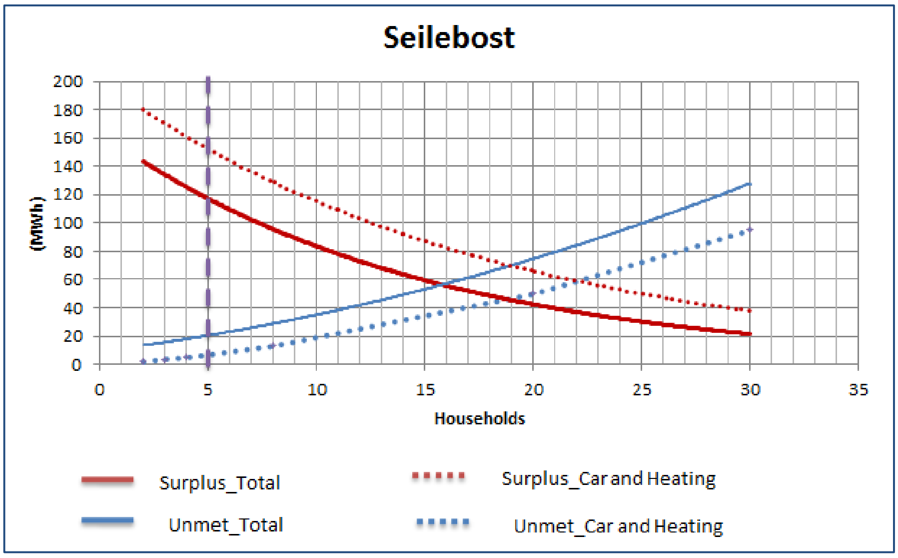

Figure 11.2.17: Comparison between unmet demand and surplus

The red solid line represents the total supply for households including heating, community bus, school bus and electric cars, whereas the red dashed line represents supply including electric cars and heating. Similarly, the blue solid line represents the total unmet demand for heating, electric cars, community and school bus. Blue dashed line represents unmet demand excluding busses. As can be seen from the Figure 11.2.17, for 5 households, all demand can be fulfilled, except the month of May, but the surplus is too big. Although the surplus of 15 households can be matched up with unmet demand, the time tables of the community and school bus cannot be changed. Therefore the 5 households is the optimal solution. If community and school bus are excluded, the optimal solution refers to 23 households.

11.3 On site Hydrogen production in Gleann Dubhlinn and Laxdale

11.3.1 Overview

Hydro and wind production depend heavily on weather. There are occasions when the electricity production by the renewable technologies far exceeds the demand and in some of the sites the grid is constrained to be able to export all the electricity produced. Hydrogen production from the excess electricity (Gleann Dubhlinn) and the generation from Laxdale Wind Site using electrolysis process is seen as a possible option to be proposed in this section. The idea of producing Hydrogen from excess electricity was inspired from the 'Surf n Turf' concept adopted in Orkney by CES to harness locally sourced energy without the dependence on Fossil Fuel Imports (Community Energy Scotland(CES), n.d.). Hydrogen can in return be converted into electricity using fuel cells or internal combustion engines.

11.3.2 Specific Methodology

The production of hydrogen was simulated using Homer Software. Each scenario considered in the system analysis was simulated with electrolysers for Hydrogen production. The scenarios in Gleann Dubhlinn and Laxdale were assessed differently. In Gleann Dubhlinn, the first method adopted was to convert all the excess electricity which could not be fed to the grid (200kW constraint) to Hydrogen. The second method in Gleann Dubhlinn was to prioritize the production of Hydrogen first and then feed the rest into the grid given the high investment cost of Hydrogen. The aim here was also to compare between the scenarios on which option could potentially give better returns between grid sales and potential Hydrogen sales. In Laxdale all the electricity produced from the Wind Turbines were assessed for Hydrogen production.

The basis behind the selection of different electrolyser capacities in each scenario was the attempt to fully utilize the excess electricity produced optimized by running sensitivity analyses. An efficiency of 70% was first used to simulate each scenario to gauge the required electrolyser capacity. Upon carrying out the first simulation, the required capacity of electrolysers in each scenario was computed. To select a suitable technology based on the computation above, a similar electrolyser technology as used in Orkney, Scotland (Surf 'n' Turf project) was chosen for simulation for West Harris with the brand name 'ITM Power'. (Community Energy Scotland(CES), n.d.).Based on the excess production for electricity of the different sites, a range of electrolyser capacity between 113kW and 635 kW was necessary and it well fitted the range of products offered by ITM Power.

Upon choosing all the electrolyser models for each scenario, a new simulation was carried out with the product specification of each model that was chosen. A stack efficiency of 77% was used for the calculations retrieved from ITM Power website.(ITM Power) The input parameters and results for each scenario are described in more detail under the heading of each scenario in section 11.3.3 for scenario analysis.

11.3.2.1 Technology Review

Electrolyser technology from ITM Power was used in the calculation of hydrogen production. The type of technology chosen is self pressurizing polymer electrolyte membrane electrolyser (PEM).The technical specifications of the HGas technologies chosen are summarized in the table below:

Table 11.3.1: HGas ITM Power Electrolysers Specification

Product Specification	HGas60		HGas180		HGas360		HGas1000	
	Nom	Max	Nom	Max	Nom	Max	Nom	Max
Number of stacks	1		3		6		10	
Hydrogen production (kg/day)	28	42	80	125	170	255	283	425
System Power (kW)	73	113	200	320	400	635	668	1,060
System Efficiency (kWh/kg)	62	64	57	60	56	60	57	53
Power Requirement (kW)	70		190		360		1,030	
Hydrogen Pressure (bar)	20 – 80							

Source: (ITM Power(b))(ITM - Power(C))

A recent document was sourced which published investments costs associated with selected electrolyser technology to compute the specific production cost of Hydrogen in each scenario.(T.Smolinka, 2016, p. 6).The published cost used Euro currency and a conversion rate of 0.78 (Euro to Pound) was used for calculation as of 11th March 2016. Table 11.3.2 shows the Capital and Operational cost which is used to compute the Hydrogen Production Cost in the economic analysis under each scenario.

Table 11.3.2: Investment Costs for PEM Electrolyser

Year		2015	2020
Investment Cost	Central, £/kW	1224	780
	Range, £/kW	936 - 1513	546 - 1014
Annual Operational and Maintenance (O&M) Cost	Chosen as 17% of Capital Investment Cost (Chosen for aggressive conditions)		

Sources: (T.Smolinka, 2016, p. 6), (High Efficiency Electrolysers Hannover Messe, slide 23)

11.3.2.2 Market Price of Hydrogen

Based on a published report in the UK by 'Element Energy UK', hydrogen as transport fuel has much higher value of up to £7/kg as compared to hydrogen for chemical industry of £1.50/kg.(E4tech, p. Slide 7) Two other online sources were also used to verify transport fuel price of £/7kg published by Element Energy UK. One source mentioned a pump price of £4/kg (S.Errity, 2015) and another source has used a range of £5/kg - £6/kg for their computation.(J.Crosse, 2014).It was deemed that the market hydrogen as a transport fuel ranges between £4/kg to £7/kg.

11.3.2.3 Storage and Distribution of Hydrogen

Hydrogen can be stored in gas, liquid and solid phases. Gaseous phase is by far the most employed method for small and large scale productions.(Institute of Gas Engineers and Managers (IGEM), 2012, p. 18)Technology selected from ITM Power is able to provide pressure up to 80 Bar. Pressure requirements vary based on markets of hydrogen. However, the storage and distribution of the hydrogen production in the context of West Harris is not further analysed as a further in depth analysis is required to assess the possible utilization of hydrogen Produced in West Harris. Table below gives an idea of the different pressure requirements for different applications of hydrogen.

Table 11.3.3: Hydrogen Application Pressure Requirements

Hydrogen Application	Pressure Requirement	Required Compression
Refueling Station	750-950 bar	Mechanical
Underground Storage	200-300 bar	Mechanical
Pipelines (transportation)	60-80 bar	Electrochemical
Methanisation	30 bar	Electrochemical
Chemical Industry	10-60 bar	Electrochemical
Pipelines (local distribution)	1-4 bar	Electrochemical

Source: (Smolinka, 2014)

11.3.2.4 Hydrogen Market in West Harris

There are many opportunities to use locally produced hydrogen within the West Harris community and maintain a local energy economy. The dependency on fossil fuels can be reduced and clean hydrogen production can be produced from renewable. The survey conducted in West Harris had asked the potential promising businesses which could be developed in West Harris. Some of the 'potential promising business ideas' suggested by the respondents were analysed and the ideas which could potentially use locally produced hydrogen are depicted in Figure 11.3.1.

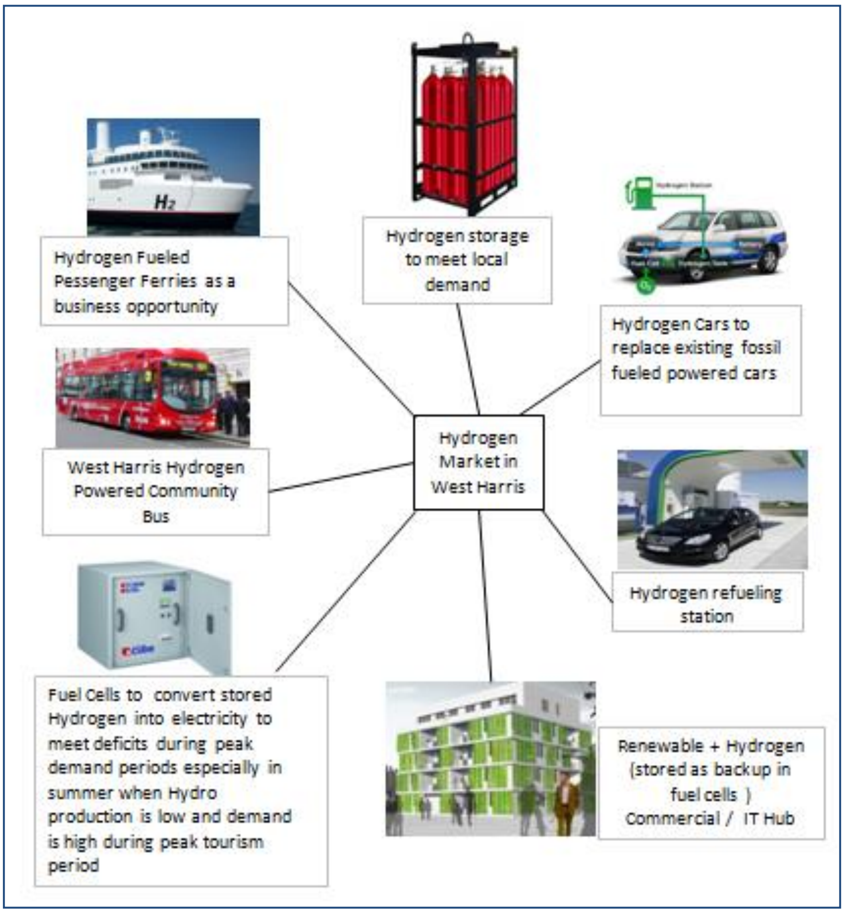

Figure 11.3.1: Potential Hydrogen Market in West Harris

11.3.3 Scenario Analysis

11.3.3.1 On site Hydrogen production in Gleann Dubhlinn

In this site, two analyses are done. One analysis is to evaluate the excess electricity after feeding it to the grid which is constrained at 200 kW. The second scenario analyses the option of first producing Hydrogen with a 113 kW sized electrolyser and then feeding the excess remaining after hydrogen production to the grid. Both the scenarios are referred to as Case 1 and Case 2 respectively. The scenarios are then compared in the economic analysis to compare which option is better economically.

Figure 11.3.2 shows the scenario for case 1 whereby the grid sales is treated as priority 1 and then the excess electricity is used to produce electricity.

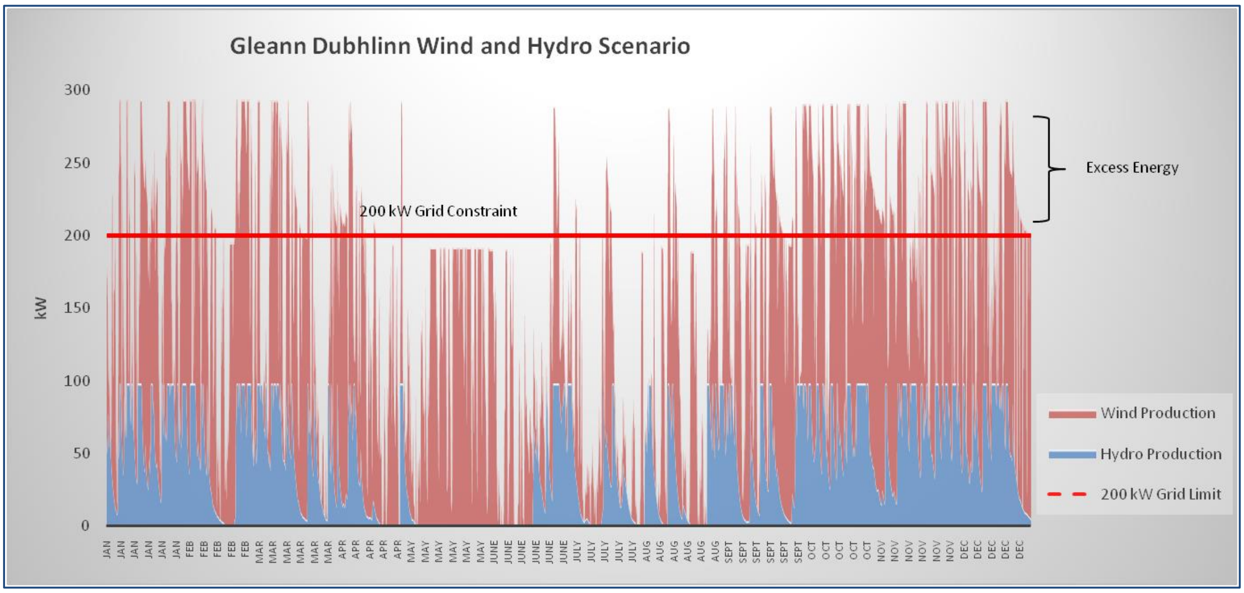

Figure 11.3.2: Depiction of Gleann Dubhlinn Wind and Hydro Scenario (H2 Production after Grid Sales)

Figure 11.3.3 shows the scenario whereby the Hydrogen Production was treated as priority 1 (with 113 kW electrolyser running at high capacity factor) and then the excess electricity after hydrogen production was exported to the grid. The purple lines in the graph show that all the residual electricity after Hydrogen production falls below the export constraint of the grid at 200kW and can be all exported to the grid.

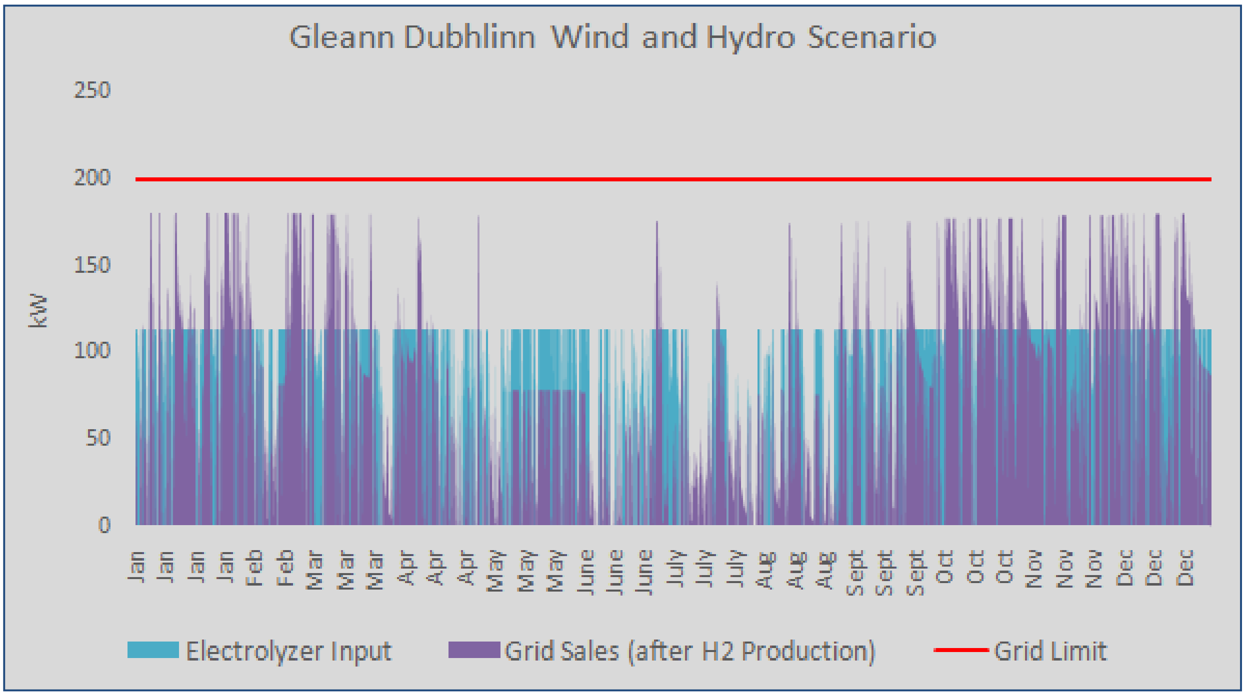

Figure 11.3.3: Depiction of Gleann Dubhlinn Wind and Hydro Scenario (Hydrogen Production before Grid Sales)

11.3.3.1.1 Hydrogen Production System Schematic Diagram

Figure 11.3.4 shows the schematic diagram whereby the grid sales are treated as priority and the excess curtailed electricity is used for Hydrogen Production. From this schematic, it is visible that there is unused energy which is wasted as the electrolyser is unable to produce Hydrogen when the excess electricity channeled into the electrolyser is below the minimum power requirements.

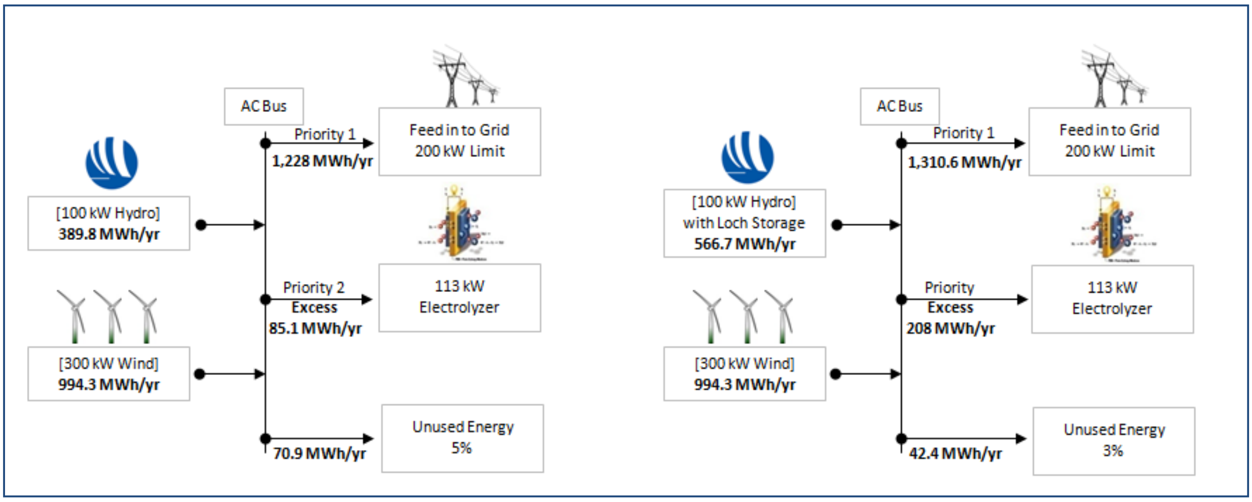

Figure 11.3.4: Gleann Dubhlinn Hydrogen Production Schematic Diagram (Case 1)
[Priority 1: Grid Sales, Priority 2: H2 Production]

Figure 11.3.5 shows the schematic diagram whereby the Hydrogen Production is treated as priority and the excess after Hydrogen Production using an 113kW electrolyser is exported to the grid. From this schematic, it is visible that there is no 'unused electricity' which is wasted and all the excess electricity is fully used to either produce Hydrogen or feed in to the grid.

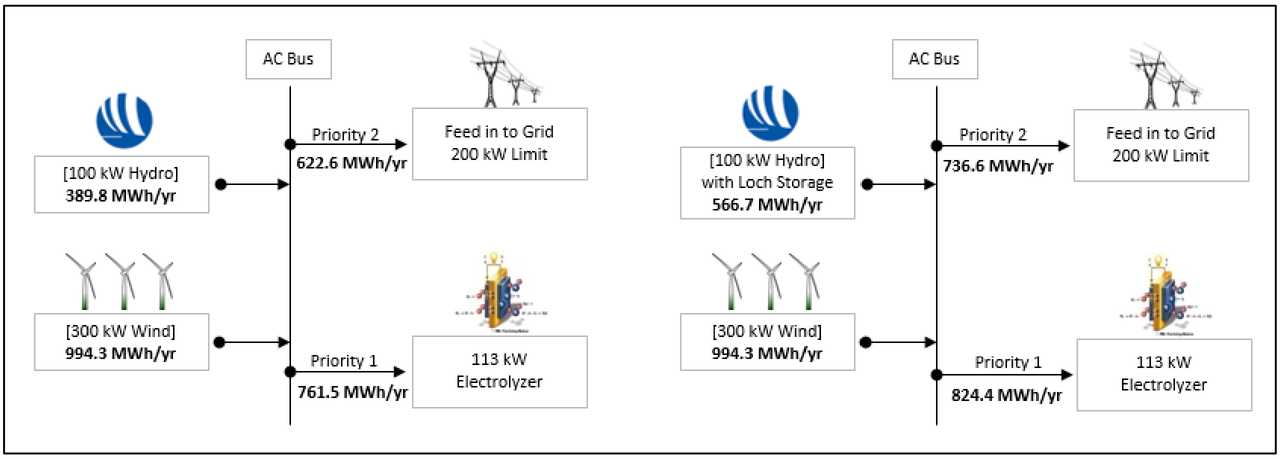

Figure 11.3.5: Gleann Dubhlinn Hydrogen Production Schematic Diagram (Case 2)
[Priority 1: H_2 Production, Priority 2: Grid Sales]

11.3.3.1.2 Technical Analysis

Case 1: Priority 1: Grid Sales, Priority 2: H_2 Production

In this scenario, HGAS 60 was chosen as the electrolyser model. Table below summarizes both the summary of the input and output parameters for the Hydrogen Production. The specific consumption of the electrolyser was calculated to be 51.23 kWh/kg which reflects the efficiency of 77% which was used for the electrolysers. In this scenario, the annual utilization rate (capacity factor) is relatively low operating at an average of 11-26% and there is also significant unused electricity ranging from 70.9 to 42.4 MWh amounting to 17 - 45.4% of total input to electrolysers.

Table 11.3.4: Gleann Dubhlinn - Hydrogen Production Input and Output Parameters

Scenarios	Excess Electricity (After Grid Sales) (MWh)	Electrolyzer Input (MWh)	Electrolyzer Input Power (kW)	Power required (kW)	Min. Load Factor	Annual Utilization Hours (%)	Annual H2 Production (kg)	Unused Electricity from Electrolyzer (MWh)
Gleann Dubhlinn 100 kW Hydro + Wind (3x100 kW)	156.1	85.2	113	70	62%	11%	1,664	70.9
Gleann Dubhlinn 100 kW Hydro + Loch + Wind (3x100 kW)	250.4	208.0	113	70	62%	26%	4,030	42.4

(Note: Unused electricity here refers to energy below the minimum power requirements of the electrolysers which could not have been used)

Case 2: Priority 1: H_2 Production, Priority 2: Grid Sales

In this scenario, HGAS60 was chosen as the electrolyser model reflecting a higher capacity. The specific consumption of the electrolyser was calculated to be 51.23 kWh/kg which reflects the efficiency of 77% which was used for the electrolysers. In this scenario, the annual utilization rate is relatively high operating at an average of 80-85% with no unused electricity. All the electricity produced is effectively used to produce Hydrogen and for grid export. Table 11.3.5 summarizes both the summary of the input and output parameters for the Hydrogen Production.

Table 11.3.5: Gleann Dubhlinn - Hydrogen Production Input and Output Parameters

Scenarios	Assesed Electricity (total generation) (MWh)	Electrolyzer Input (MWh)	Grid sales (MWh)	Electrolyzer input power (kW)	Power requirement (kW)	Annual Utilization Hours (%)	Min. Load Factor	Annual H2 Production (kg)
Gleann Dubhlinn 100kW Hydro + Wind (3x100kW)	1,384	761.5	622.6	113	70	80	62%	14,892
Gleann Dubhlinn 100kW Hydro + Loch + Wind (3x100kW)	1,561	824.4	736.6	113	70	85	62%	16,118

11.3.3.1.3 Economic Analysis

The aim here is to calculate the production cost of Hydrogen in both case 1 and case 2. The investment and operational cost has been quoted under technology review. In the calculations here, the electricity for the input of electrolyser was assumed to be purchased at a rate of 7p/kWh from the Wind/Hydro generating plants and was included in the annual operational costs. The first two calculations use the central investment costs of year 2015 and lower range of projected year 2020 cost which reflects the price for larger systems (economies of scale). Table 11.3.6 below shows that using case 1 (exporting to grid as priority), the unit cost calculated is relatively high ranging between £12.2/Kg - £24.4/Kg. If compared to the case two whereby Hydrogen Production is treated as priority, the production costs calculated return lower values between £5.7/Kg - £5.9/Kg.

Table 11.3.6: Gleann Dubhlinn - Hydrogen Production Cost Calculation with Investment Cost £ 1,224/kW

Case	Site	Electrolyzer Size (kW)	Investment Cost £/kW	Total Investment Cost £	Annual Operational Cost £	H2 Produced (kg / year)	Unit Cost (£/kg)
Priority 1: Grid Sales, Priority 2: H2 Production	100 kW Hydro + 300 kW Wind	113	1,224	138,312	40,576	1,664	24.4
	100 kW Hydro + 300 kW Wind + loch storage	113	1,224	138,312	49,168	4,030	12.2
Priority 1: H2 Production Priority 2: Grid Sales	100 kW Hydro + 300 kW Wind	113	1,224	138,312	87,917	14,892	5.9
	100 kW Hydro + 300 kW Wind + loch storage	113	1,224	138,312	92,320	16,118	5.7

(Note: An interest rate of 5% was assumed over the 20 years lifetime of electrolyser)
(Note: Cost does not include the grid connection, external compression (>80 Bar) and hydrogen storage)

Using an investment cost of £ 546/kW (lower range for year 2020), case two (hydrogen production as priority) returned a production price of £4.53/Kg - £4.62/kg.

Table 11.3.7: Gleann Dubhlinn - Hydrogen Production Cost Calculation with Investment Cost £546/kW

Case	Site	Electrolyzer Size (kW)	Investment Cost £/kW	Total Investment Cost £	Annual Operational Cost £	H2 Produced (kg / year)	Unit Cost (£/kg)
Priority 1: Grid Sales, Priority 2: H2 Production	100 kW Hydro + 300 kW Wind	113	546	61,698	21,403	1,664	12.9
	100 kW Hydro + 300 kW Wind + loch storage	113	546	61,698	29,996	4,030	7.4
Priority 1: H2 Production Priority 2: Grid Sales	100 kW Hydro + 300 kW Wind	113	546	61,698	68,744	14,892	4.6
	100 kW Hydro + 300 kW Wind + loch storage	113	546	61,698	73,147	16,118	4.5

(Note: An interest rate of 5% was assumed over the 20 years lifetime of electrolyser)
(Note: Cost does not include the grid connection, external compression (>80 Bar) and hydrogen storage)

The local energy challenge fund in Scotland awards grants to projects that demonstrate the value and benefit of local low carbon energy economies. In the past, two projects similar to the one proposed here were awarded grants by the local energy challenge fund. One being implemented by Community Energy Scotland for Orkney Surf 'n' Turf and second Bright Green Hydrogen for 'Levenmouth Community Energy Project' whereby both were aimed at producing Hydrogen from curtailed energy generation to produce Hydrogen. (Local Energy Scotland) The funding amount differs based on projects. A sensitivity analysis was carried out using grant percentages between 10-30% of the Capital Investment Cost (Capital investment cost used was £546/kW for Year 2020). The Operational annual cost was maintained at 17% of the actual investment cots assumed earlier for harsh site conditions. The calculations were carried out mainly for case 2(Hydrogen production as priority) which could potentially be a better option than case 1. Results are summarized in tables below:

Table 11.3.8 shows that with possible grant funding, the price of Hydrogen Production in Gleann Dubhlinn could be significantly reduced for case 2 whereby the Hydrogen production is given a priority than grid sales.

Table 11.3.8: Gleann Dubhlinn - Hydrogen Production Cost Calculation with Different Funding Amount

Sites	Electrolyzer Capacity	Funding Amount Local Energy Scotland (Investment Cost = £546/kW)				Hydrogen Production Cost (£/kg) with different funding amount			
		None	10%	20%	30%	None	10%	20%	30%
100 kW Hydro + 300 kW Wind	113	61,698	55,528	49,358	43,188	4.62	4.51	4.41	4.30
100 kW Hydro + 300 kW Wind + loch storage	113	61,698	55,528	49,358	43,188	4.53	4.44	4.35	4.25

[Case 2: Priority 1: Hydrogen Production, Priority 2: Grid Sales]

Considering the analysis which is carried out above, case two has seemed to be a better option than case 1. Producing Hydrogen as the first priority (operating at a minimum of 113kW and high annual utilization rate) yields better production costs as both the export feed in tariff of £ 4.85/kWh and the high profit margin of producing Hydrogen could be realized as opposed to case 1 whereby very little excess electricity after grid curtailment is used to produce Hydrogen decreasing the annual utilization rate of the electrolysers and increasing the Hydrogen production cost drastically. In case 2, there is no unused electricity as all the electricity generated from Gleann Dubhlinn site is used to produce Hydrogen and harness the export tariffs. Adding on, it would also be worthwhile to mention that the feed in tariffs in the UK has experienced a decreasing trend. It would be interesting to consider further the option of producing Hydrogen and assess further the possibility of using Hydrogen within West Harris.

11.3.3.2 On site Hydrogen production in Laxdale

11.3.3.2.1 Hydrogen Production System Schematic Diagram

Figure 11.3.6 shows the schematic diagrams of onsite Hydrogen Production in Laxdale Wind Site.

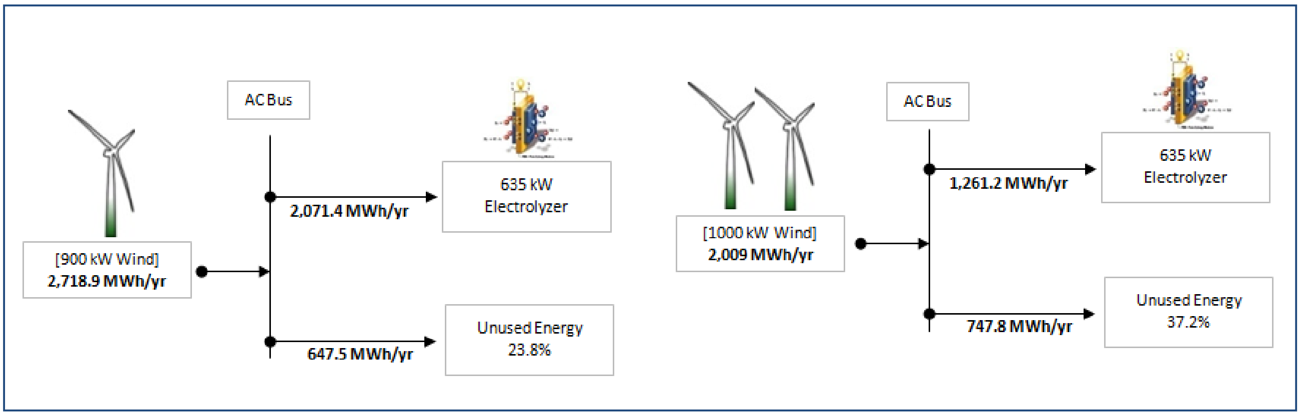

Figure 11.3.6: Laxdale Hydrogen Production Schematic Diagram

11.3.3.2.2 Technical Analysis

In this scenario, HGAS 360 was chosen as the electrolyser model. Table 11.2.10 summarizes both the summary of the input and output parameters for the Hydrogen Production. The specific consumption of the electrolyser was calculated to be 51.23 kWh/kg which reflects the efficiency of 77% which was used for the electrolysers. In these scenarios, the annual utilization rate (capacity factor) in the range of 28-43% was calculated and there is also significant unused electricity ranging from 648 to 748 MWh amounting to 27 - 32% of total input to electrolysers.

Table 11.3.9: Laxdale - Hydrogen Production Input and Output Parameters

Scenarios	Electrolyzer Input (MWh)	Electrolyzer Input Power (kW)	Power Required (kW)	Min. Load Factor	Annual Utilization Hours (%)	Annual H2 Production (kg)	Unused Electricity from Electrolyzer (MWh)
Laxdale 900 kW	2,719	635	360	57%	28%	24,616	747.9
Laxdale 1000 kW	2,009	635	360	57%	43%	40,471	647.6

11.3.3.2.3 Economic Analysis

The calculations here were carried out based on the investment and operational cost quoted in under technology review. The first two calculations use the central investment costs of year 2015 and lower range of projected year 2020 cost which reflects the price for larger systems (economies of scale). Here the electricity tariff for the inputs to the electrolyser was assumed similar to Gleann Dubhlinn at a rate of 7p/kWh. Table below shows that using Enercon E44 900kW wind turbine, the unit production cost calculated is £8.3/Kg and £15.6/Kg. The Hydrogen production using Enercon E44 turbine yields high output and hence the higher production of Hydrogen with high utilization rate.

Table 11.3.10: Laxdale - Hydrogen Cost Calculation with Investment Cost £ 1224/kW

Site	Electrolyzer Size (kW)	Investment Cost £/kW	Total Investment Cost £	Annual Operational Cost £	Annual H2 Production (kg)	Unit Cost £/Kg
Laxdale 900kW	635	1,224	774,240	384,829	40,471	15.6
Laxdale 1000kW	635	1,224	774,240	384,829	24,616	8.3

Using an investment cost of £ 546/kW, the case two returned a production price of £5.6/Kg and £11.3/Kg which could potentially be sold in the market of Hydrogen and Table 11.3.11 summarizes the results.

Table 11.3.11: Laxdale - Hydrogen Cost Calculation with Investment Cost £ 564/kW

Site	Electrolyzer Size (kW)	Investment Cost £/kW	Total Investment Cost £	Annual Operational Cost £	Annual H2 Production (kg)	Unit Cost £/Kg
Laxdale 900kW	635	564	346,710	277,092	40,471	11.3
Laxdale 1000kW	635	564	346,710	277,092	24,616	5.6

Reiterating, the local energy challenge fund in Scotland awards grants to projects that demonstrate the value and benefit of local low carbon energy economies. Hence using the same funding percentages similar to the ones used in the Gleann Dubhlinn scenario, production costs of Hydrogen were calculated and are summarized here in Table 11.3.12

Table 11.3.12 here shows with possible grant funding, the price of Hydrogen Production in Glean Dubhlinn could be reduced for both options of wind turbines considered.

Table 11.3.12: Laxdale - Hydrogen Production Cost Calculation with Different Funding Amount

Sites	Electrolyzer Capacity	Funding Amount Local Energy Scotland (Investment Cost = £546/kW)				Hydrogen Production Cost (£/kg) with different funding amount			
		None	10%	20%	30%	None	10%	20%	30%
100 kW Hydro + 300 kW Wind	635	346,710	312,039	277,368	242,697	11.30	11.14	11.00	10.92
100 kW Hydro + 300 kW Wind + loch storage	635	346,710	312,039	277,368	242,697	5.60	5.55	5.48	5.41

Considering the Laxdale case which is seen as a future possible project, the 900kW Enercon E44 turbine is expected to produce high amount of electricity which could potentially yield attractive Hydrogen prices. The Laxdale site will require a grid connection for the excitation of the turbines and has not been given detailed consideration in the calculations.

For the Gleann Dubhlinn site, from the analysis which was carried out earlier, the lower range of investment cost for Year 2020 (£546/kW) has shown to give attractive Hydrogen production costs. The annual Operation and Maintenance costs were maintained at 17% of the total investment cost. It would be worthwhile to explore the option of producing and selling Hydrogen and then selling the excess electricity to the grid which has been analysed to be within the 200 kW grid limits for the whole year (see Figure 11.3.3).

For Laxdale scenario, a similar trend was seen using the lower range of investment cost for Year 2020 (£546/kW). The Hydrogen production from electricity produced from a 900kW Enercon Turbine was seen as better option than a 1000kW Wind Flow Turbine because firstly the higher electricity generation and secondly the lower Hydrogen production cost calculated for case 2 (Hydrogen Production given priority. Exclusively for Laxdale site, it would also be worthwhile to evaluate the plans for the interconnector in year 2022 mainly to assess again the Hydrogen Production and grid sales similar to what was done for Gleann Dubhlinn. The possibility of having a weak grid to excite the motors of the wind turbines could also be seen as an option to realize the plans of installing Wind Turbine(s) in this site to start the production of Hydrogen before the planned interconnector in year 2022. The unused energy after the Hydrogen Production for Laxdale could potentially be sold for local demand lower than standard tariffs and higher than the levelized cost of electricity.

11.4 Integrated Scenario

In the integrated scenario, all the maximum generation capacities and productions from all different sites was considered and was computed to give an annual generation of 4,910 MWh. A demand load assessment for West Harris was carried out using a number of 60 Households having also in light future developments of 6 additional houses. The household occupants mix for West Harris was gathered from the survey data. For the local demand computation, a figure of 85% of total household houses was assumed to use electrical heaters in light of future excess electricity production which could be used to meet local demand encouraging the community to use electrical heaters. The demand included an assumption of 17 holiday homes with an average 3-4 occupants per holiday home to be fully occupied in the months between May to August. Based on this inputs, an annual demand of 570 MWh was computed for West Harris.

The vision seen after analyzing the systems chapter is encapsulated in Figure 11.4.1. Figure 11.4.1 depicts an idea of having a common grid connecting all generation sites to balance and optimize the residual electricity similar to 'ACCESS Project' carried out in the Isle of Mull.(ACCESS Project) It is recommended to mimic a 'Mull model' by first working out a solution with the local grid operator to be able to use the local grid to fully supply the local demand in West Harris. The local demand of 570 MWh can be fulfilled by the assessed sites with the maximum production of 4,910 MWh. The remaining 4,340 MWh of electricity could be then exported to the grid to harness the export feed in tariffs and simultaneously produce Hydrogen depending on the financial returns of both the options. The large amount of excess electricity could also be used to create local demand from promising businesses which could be realized in West Harris. Hydrogen assessment in the earlier analysis has shown to be financially viable in Laxdale Scenarios whereby the utilization factor of the electrolysers are high which drastically decreases the production cost of Hydrogen making it a valuable product obtained from the excess electricity (with no cost). Having a common grid in mind also mean channeling all the excess electricity from all sites into common electrolyser(s) which will allow the increased utilization hours and further reduction of Hydrogen production costs compared to earlier assessed scenarios done separately.

Using the 'Mull' Model, the local demand could potentially be supplied first using the local SSE grid and even possibly with lower electricity tariffs than the tariffs offered by SSE. This could potentially reduce the outflow of cash about approximately £ 57,000 annually from West Harris (computed from data collected in survey for 54 households) spent on electricity bills. Based on the calculated local demand of 570 MWh and annual generation (all sites) of 4,910 MWh, there were 570 hours (6.5%) whereby the demand was not met mainly because of low generation from both Hydro and Wind resources equivalent to about 21.6 MWh with the highest unmet demand peak registering at 134 kW. Hence with the possibility of storage options possibly from Locally Hydrogen produced storage, the deficits during these periods could be met by Fuel Cells converting stored Hydrogen into electricity (1st priority) or even buying from local grid operator (SSE) as a second priority.

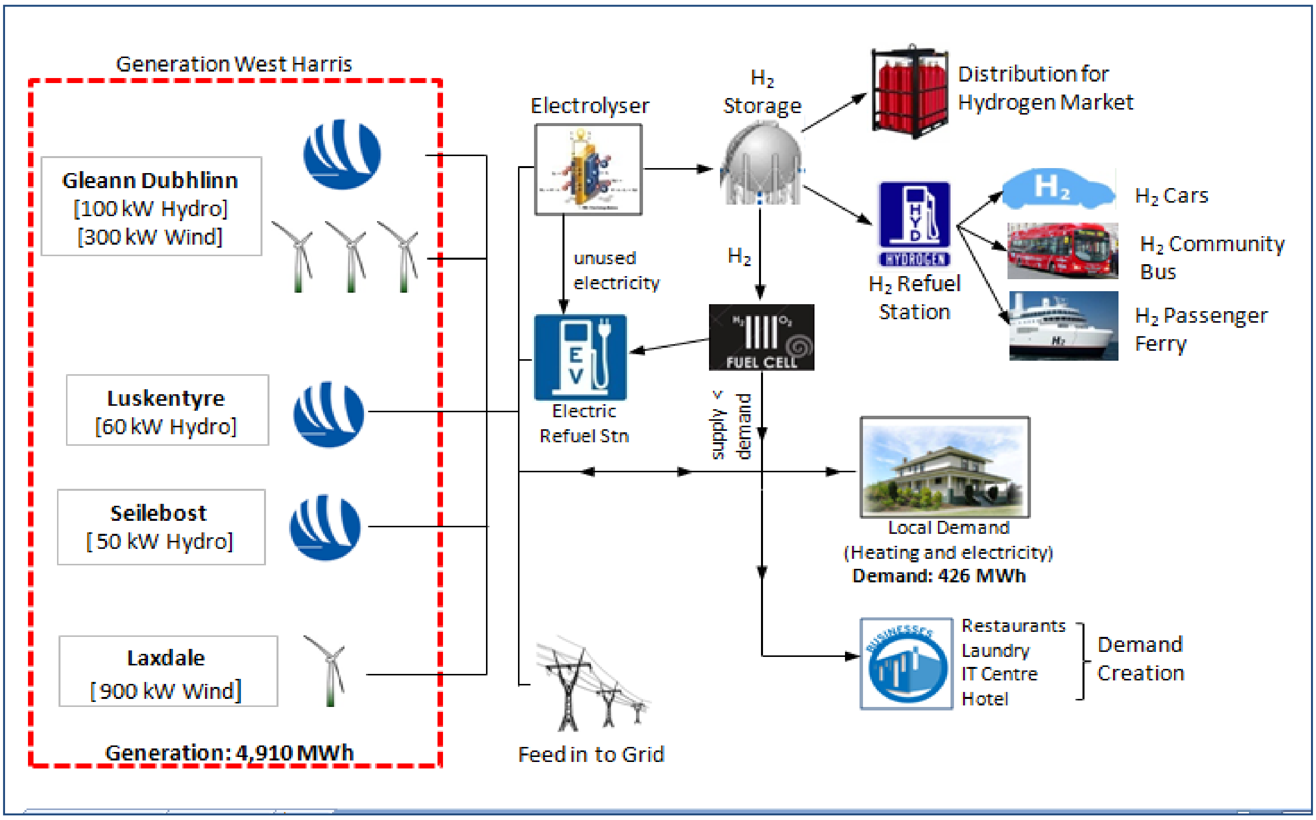

Figure 11.4.1: Proposed West Harris Integrated System Model

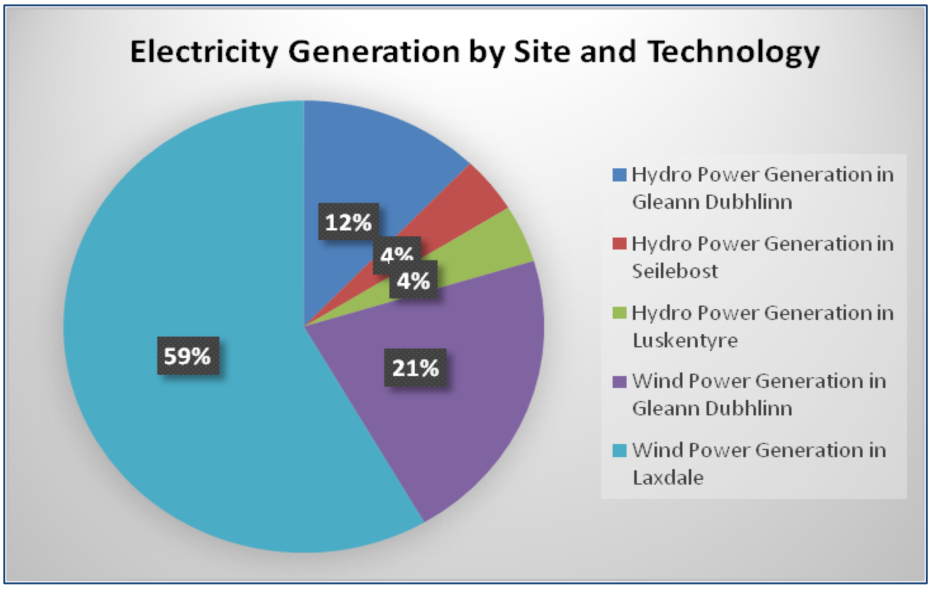

Figure 11.4.2: Electricity Generation by Site and Technology

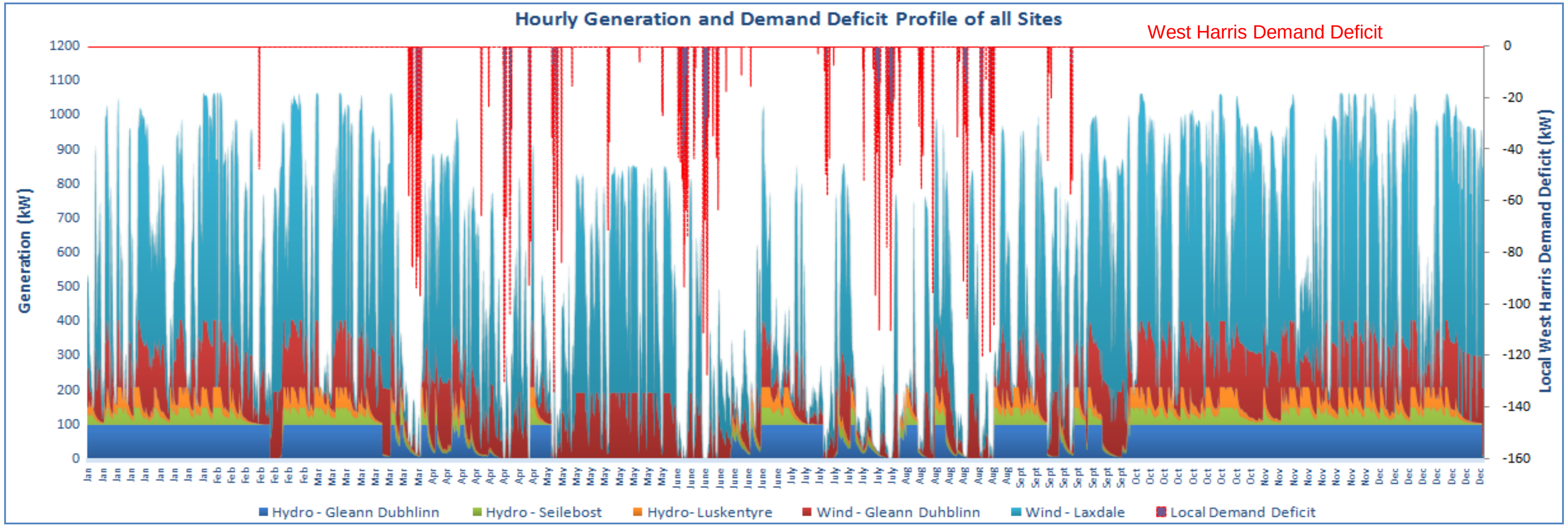

Figure 11.4.3: Hourly Generation Profile from All Sites (Left Axis) and West Harris Demand Hourly Deficit (Right Axis: Negative Scale)

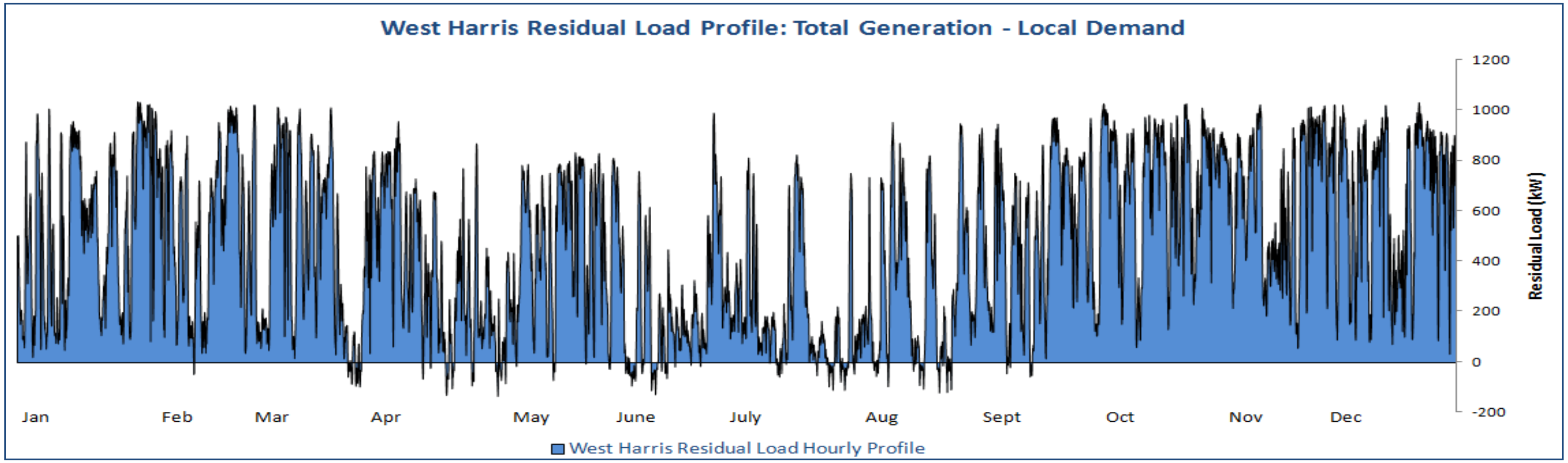

Figure 11.4.4: Hourly Residual Load (Total Generation minus Local West Harris Demand) Profile from All Sites (Right Axis)

Having analysed the vision of a common grid with the maximum generation of all the scenarios above, about 11.6% (570 MWh) of total production of 4,910 MWh was calculated to be enough to meet the local demand. Hence, it was also deemed necessary to carry out an additional analysis to compare the local demand with the generation from only Gleann Dubhlinn, Luskentyre and Seilebost sites. (Excluding Laxdale).The generation from all sites excluding Laxdale is 1,370MWh and is able to provide about 42% of the local demand. Approximately 39.3MWh of deficit is calculated as seen in Figure 11.4.5 with highest peak registering at 134kW. Hence similar to above stated suggestion for all sites, with the possibility of storage options possibly from Locally Hydrogen produced storage, the deficits during these periods could be met by Fuel Cells converting stored Hydrogen into electricity (1st priority) or even buying from local grid operator (SSE) as a second priority. This analysis was aimed to show that the all sites excluding Laxdale are enough to meet the local demand of West Harris. Laxdale Wind Project would be feasible when the new interconnector is planned to allow the export of electricity to mainland instead of having huge generation of electricity but with grid constraints.

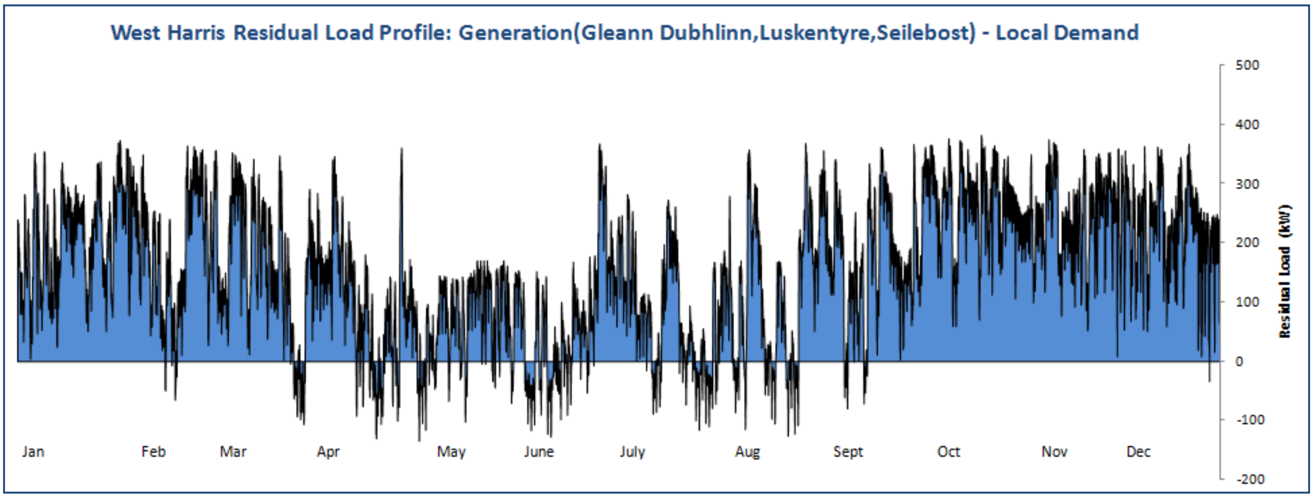

Figure 11.4.5: Hourly Residual Load (Total Generation excluding Laxdale minus Local West Harris Demand) Profile from All Sites (Right Axis)

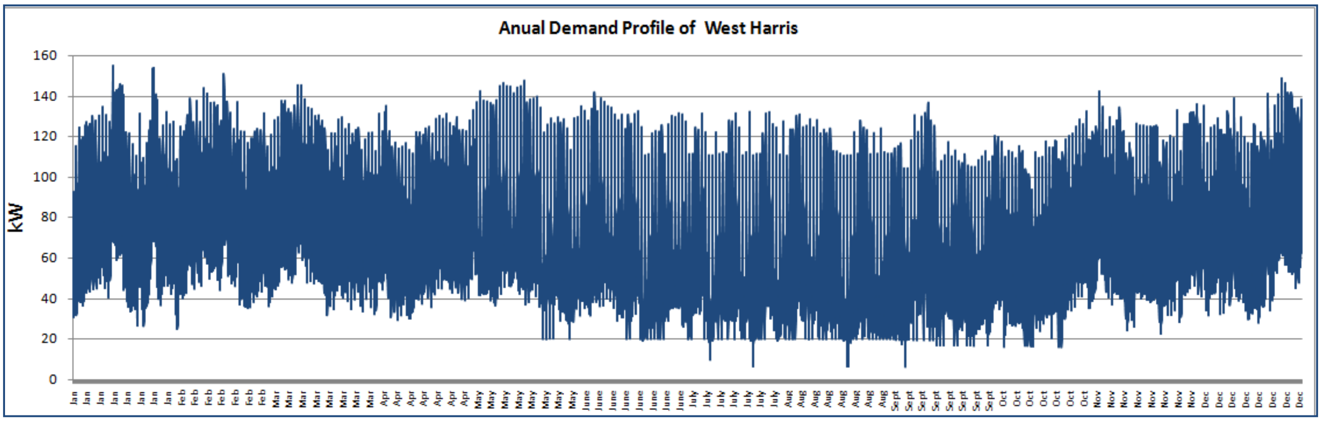

Figure 11.4.6: Annual Demand Profile of West Harris

12 Synthesis

The inputs and outcomes of the present study are being presented in an overall scheme to better understand their interactions. The diagram illustrates how in a cyclical process driven by innovation, a community can look beyond the wind and hydro schemes to reach sustainability through a local energy economy.

Community energy projects can deliver a wide range of benefits and impacts. To unlock this potential, innovation needs to play an important role, not only concerning the use of new technologies, but also in the development of new concepts for sustainable energy systems. New approaches to start-up, scale up and spin out new products and services for the community and the region are an opportunity to rupture the current energy paradigm; changing the way West Harris perceives, relates and understands energy.

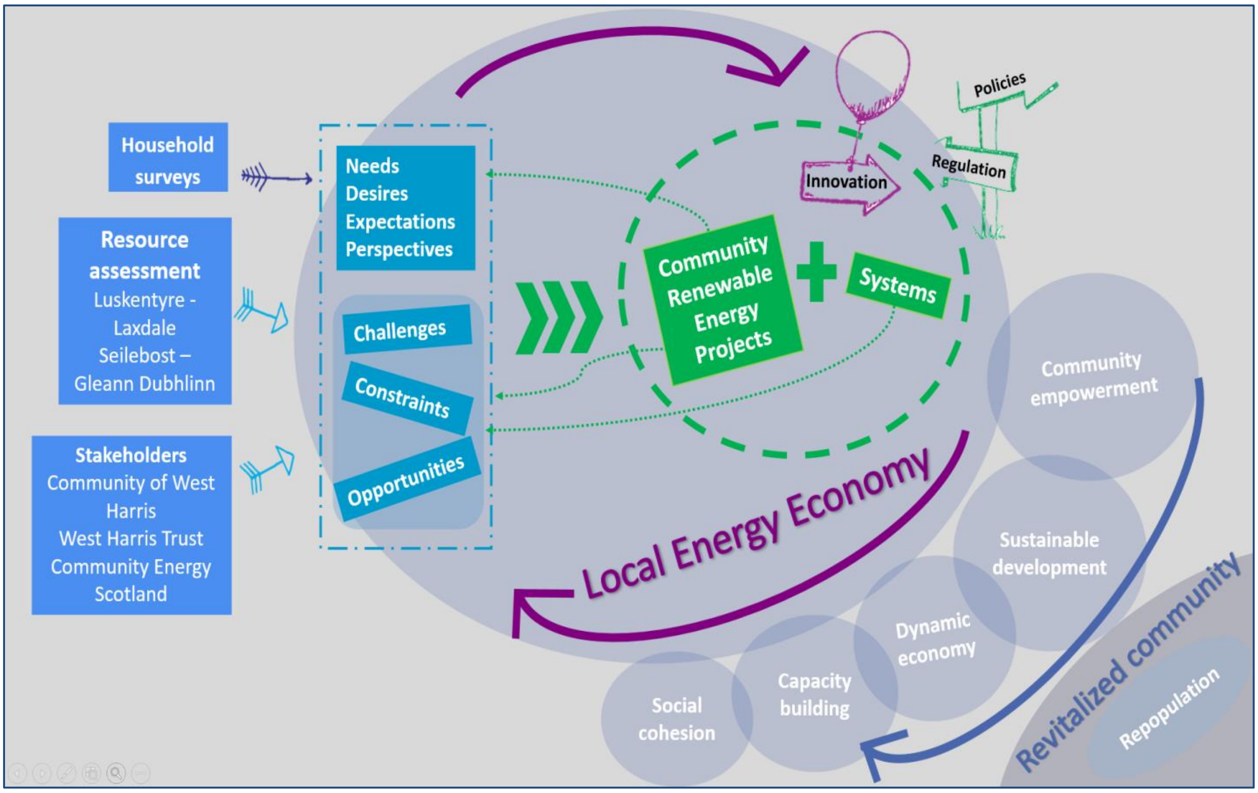

Figure. 12.1 From renewable energy potential towards a local energy economy
Source: Own elaboration

The methodology used for synthesis was to consider the appraisal of the household survey to better understand the needs, desires, expectations and perspectives regarding energy and renewables was possible. Afterwards, this information was analysed in conjunction with the material received from the West Harris Trust and Community Energy Scotland related to the current situation for renewable energy in the regional and national context. Simultaneously, different reports and studies related to the sites of study were considered to have a broad overview of the challenges, constraints and opportunities for renewable energy projects in West Harris.

On the basis that the community of West Harris undertakes new community energy projects, it is necessary to consider systems to store, distribute and use the energy locally. Under the current context, the development of local energy systems is driven mainly by two factors, the grid constraint and the funding schemes reduction alongside with the fast rate of regression of the feed-in tariff scheme.

In many rural areas of Scotland the grid capacity is limited. This situation is even more critical in the Outer Hebrides, where the majority of the electricity consumed is imported from the Mainland in a limited grid connection.

On the other hand, the fast decline of the FiT and the extensive cuts in funding forces to identify the most suitable energy system solution according to its reliability, profitability, environment, cost, among other reasons.

Furthermore, the fast decline of the FiT and the extensive cuts in funding forces to identify the most suitable energy system solution according to its reliability, profitability, environment, cost, among other reasons.

Systems are key especially in a framework of decreasing feed in tariffs. Their application can make projects to be more appealing for financing. When planned ahead, systems could also assist to overcome the challenges and constraints to produce renewable energy. Its applicability should be also considered as a parameter to (re -)design renewable energy projects to run sustainably.

When generation from renewable sources is complemented with smart systems, projects take a new direction in building *local energy economies*. Local energy economy refers to a system where energy is generated, distributed and used locally, with the cost of energy infrastructure supported through local finance (CES, 2015).

The most important characteristic of a local energy economy is that the resources, both financial and human, flows within the community rather than in an out. In the context of West Harris, new local financing schemes could be developed while capacity and knowledge in the development of renewable energy projects could be built. This model guarantees that the benefits of the local resources stay in the local economy, empowering as the returns of the energy projects convert into visible impacts.

The result of reliable, profitable and sustainable energy systems is the key for long-term success (Amstrong, 2015), as it can later lead to a revitalized West Harris community. In this sense, affordable housing, electricity and heating, as well as job creation can attract people to settle in West Harris, resulting in an increase of population. However this transformation does not come from technological innovation alone, it also depends on the community adopting new and innovative approaches to make renewable energy systems sustainable to keep the revenue in the local economy.

Moreover the impacts of the local energy economies go beyond energy itself, an example of these are presented in Figure 12.2

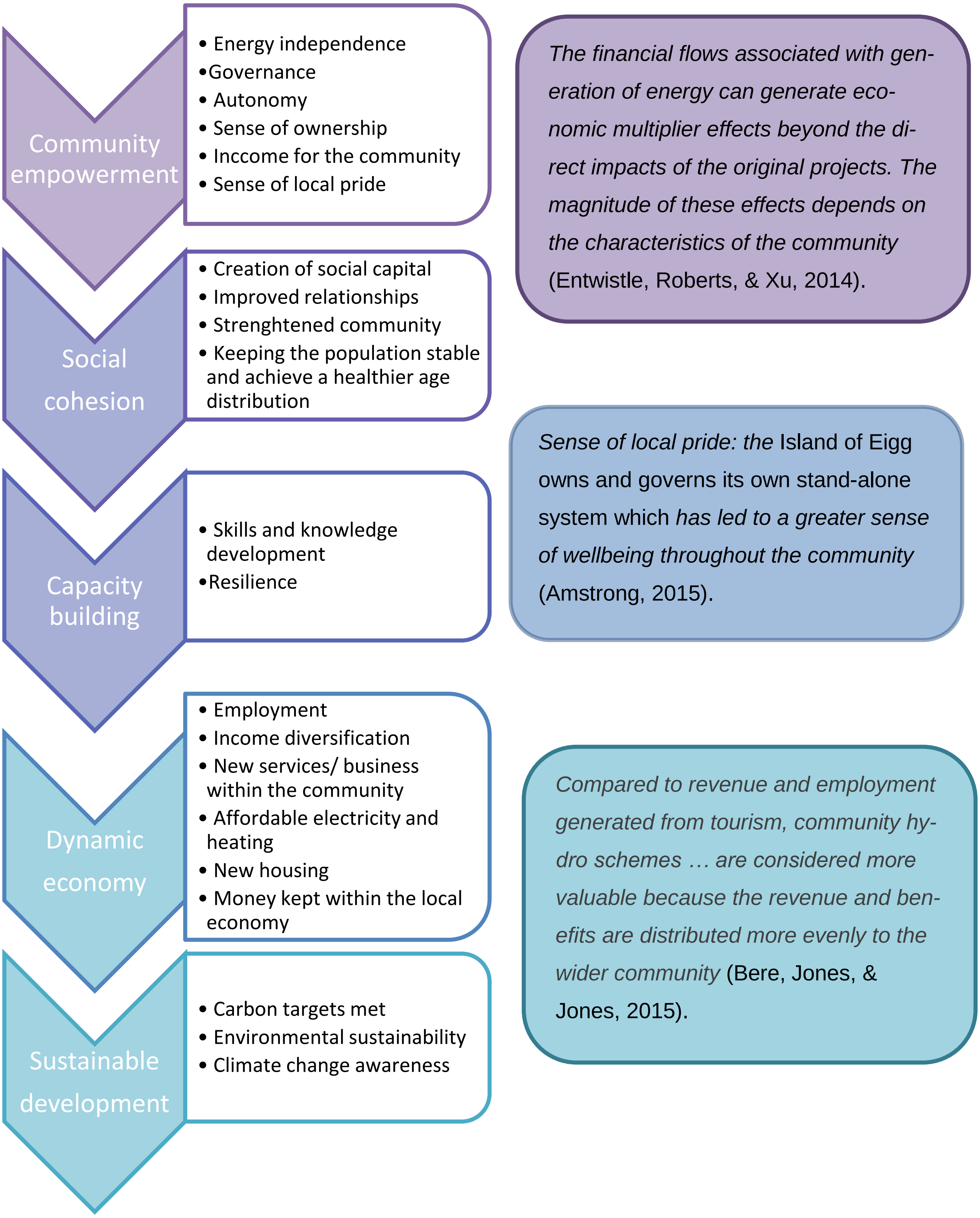

Figure. 12.2 Possible impacts of local energy economies

Source: Own elaboration based on Creamer (2016), Bere, Jones, & Jones (2015), Amstrong (2015) and Entwistle, Roberts, & Xu (2014)

Going forward in the direction of local energy economies requires addressing certain local pre-conditions for it to happen. For example it cannot be achieved without the community's ability to raise funds. West Harris has a choice, either to actively shape their energy needs and impacts as a sustainable local energy economy or to be formed / marked by fuel poverty, high energy prices and depopulation.

Based on the results of this research and after its completion, there are some questions to keep the discussion between the different stakeholders (Community of West Harris, WHT and CES):

- *With cuts in funding and loss of renewable subsidies, could West Harris locally finance smart energy systems?*
- *How to foster participation to create local support and appreciation for renewable infrastructure in West Harris?*
- *How can the WHT create long-term local energy strategies, participation and forward-thinking among the community?*
- *Which are the partnerships that can facilitate planning, design, operation and administration of smart systems within West Harris?*
- *Are there options to create public, private and community partnerships in West Harris?*
- *Policies, regulations, initiatives help access the benefits of local energy economies, but how to proceed when these are not convenient anymore?*

13 Conclusions

The Isle of Harris is a privileged place, not only because of its people and staggering beautiful landscapes, but also for the abundant natural resources that make it suitable for the development of renewable energy projects.

As in many communities in the Outer Hebrides, West Harris faces many challenges, such as aging population, unemployment, high energy prices, grid constraints and fuel poverty. Instead of burdens, these challenges must be considered drivers and motivators to shape a new reality for the community.

The exploitation of renewable energies as the driver of socio-economic development can be the great opportunity of the West Harris Community to attract people and boost the economy in a sustainable way to become an autonomous, empowered and self-dependant community.

To become a local energy community is a choice that the West Harris Community must take. It is not an easy or short path; there are many obstacles in the way such as the declining incentives for the development of community energy projects. To overcome this obstacles new and innovative model for local financing and energy systems are required as well as the joint and committed effort of the community to reach the vision of a prosperous and vibrant West Harris.

The underline of this choice is whether the community converts itself from a receiver of grants from the Mainland to a self-funding, empowered, independent community. Grants are a political decision for which the communities in the Western Isles have little or no power of decision, but what can be done inside the community, their resources and how to administer the benefits to propel the community's vision is on the hands of the West Harris Community.

Considering the results of the study, the sentiments of the population and the current economic and political scenario, we firmly believe that the West Harris Community has the potential to develop a local energy community if together they decide to make the journey.

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15 Annex

15.1 Survey

Introduction

A questionnaire survey was conducted by 14 students from the '*Department of Energy and Environmental Management, University of Flensburg, Germany'* in pairs of two in West Harris between 22nd February and 1st March 2016. The survey had three main objectives:

- To assess the current energy status of dwellings/buildings in West Harris
- To assess the current and potential economic related developments in West Harris
- To ascertain the levels of acceptance of West Harris community in Renewable Energy

There are 54 residential dwellings (households) under the scope of West Harris Trust land with approximately 130 residents as of year 2015. The survey was carried out in Luskentyre, Borve, Scarista and Seilebost.32 households (59%) completed the survey and the rest were either away or were not interested to participate in the survey. The 32 households amounted to 76 occupants in the interviewed households. Figure 15.1.1 and Figure 15.1.2 shows the respondents interviewed from each area and total interviewed respondents by location:

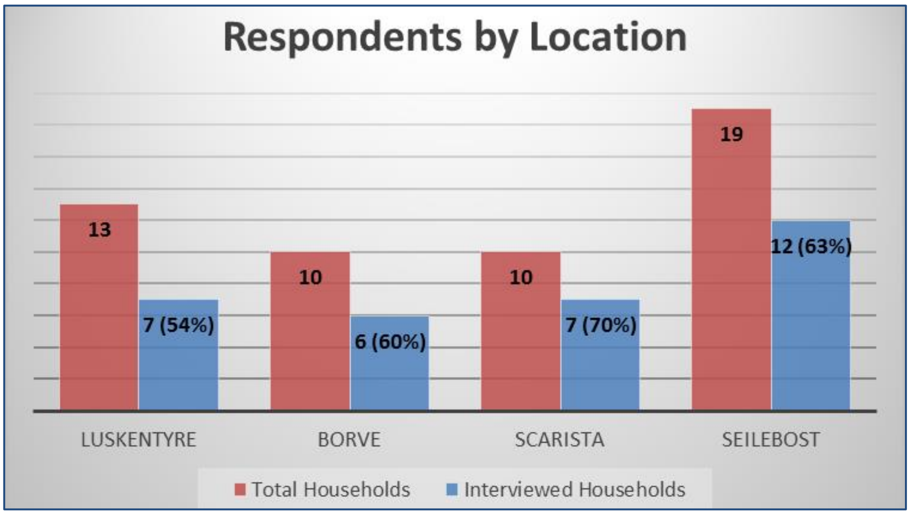


Figure 15.1.1: Respondents from Each Area Interviewed

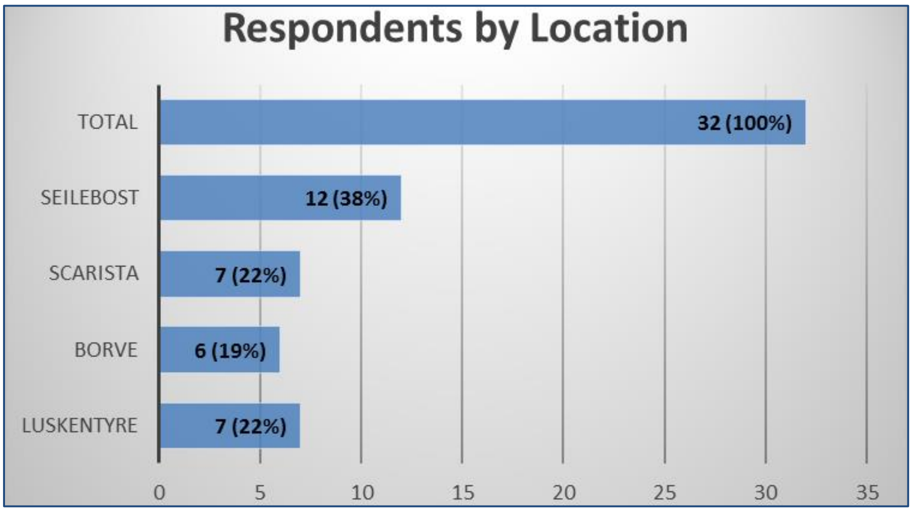


Figure 15.1.2: Total Respondents by Area Interviewed

Demographics

Distribution of Households by size

Most of the households in West Harris have a household size of 2 (62%) followed by household size 4 (17%).

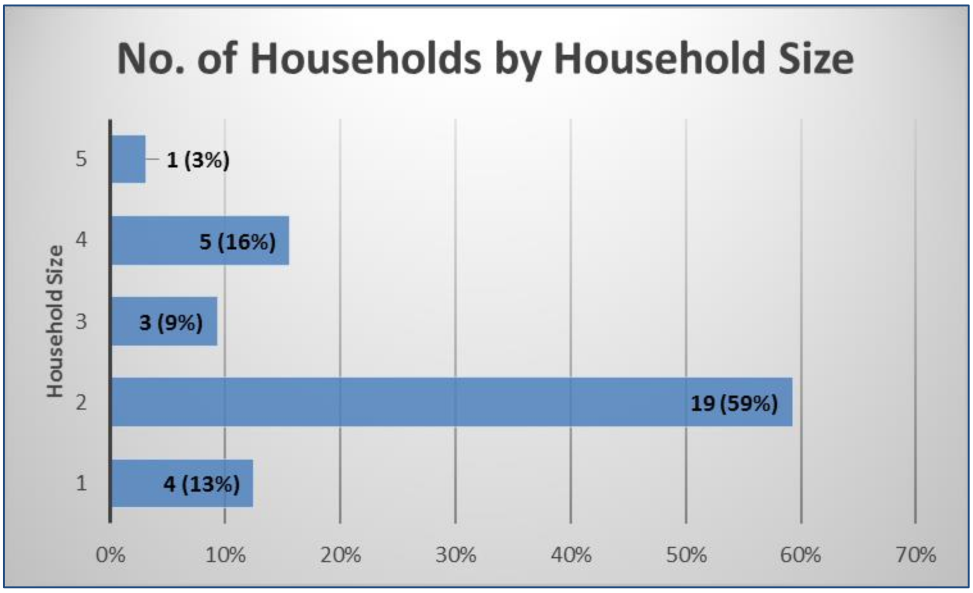


Figure 15.1.3: No. of Households by Household Size

Age of groups of Occupants in Respondent's Households

The occupants in the interviewed households in West Harris mainly comprised of 'Non Pensioners' and 'Pensioners' amounting to (65)86% from total 76 occupants in all 32 households. Teenagers and young children make up (11)14% from the total occupants in households interviewed.

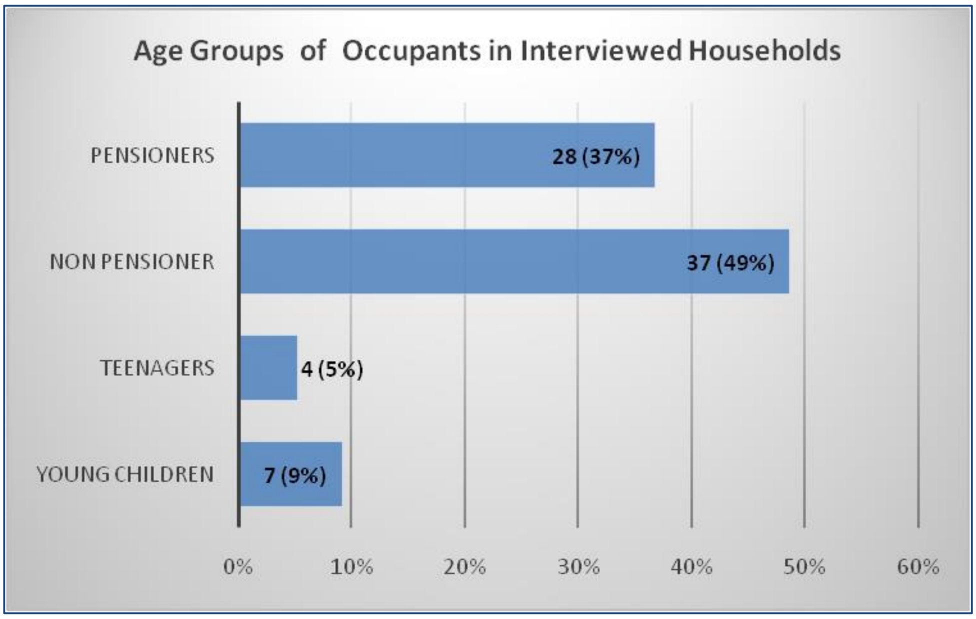


Figure 15.1.4: Age group distribution of occupants in interviewed household

Ownership Status of Dwellings

Most of the dwellings are personal owned croft tenancies 24(75%) followed by personally owned 7(22%). One of the respondents stays in a 'state owned' dwelling as the respondent works for the government and the dwelling is provided by the government.

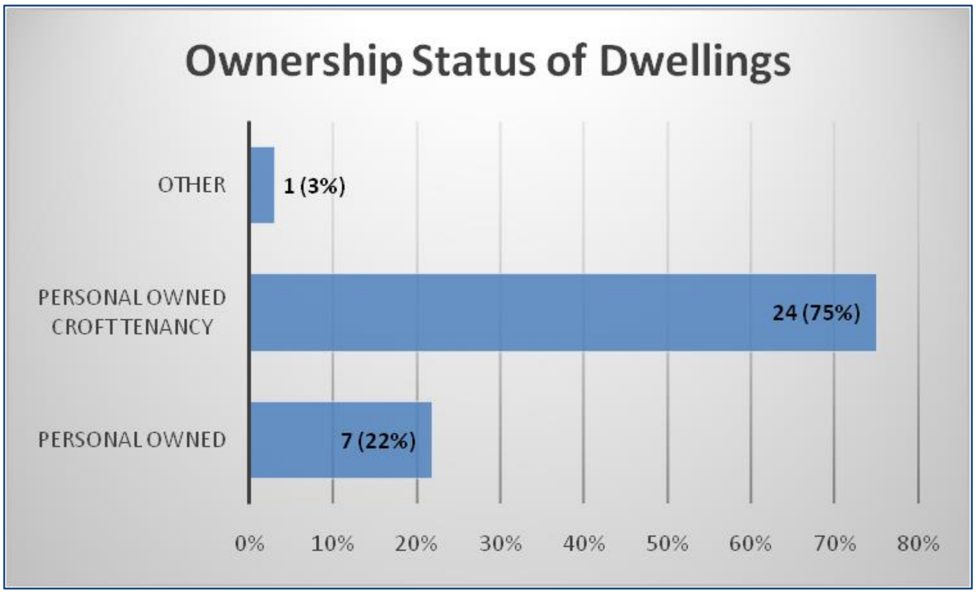


Figure 15.1.5: Ownership status of dwellings

Dwelling/ Building Information

Dwelling/Building Construction Period

22 dwellings were constructed before year 1983 (70%) while 7(23%) dwellings were constructed after Year 1998. The rest 2(6%) were constructed in the period 1984 and 1997. One of the respondents did not know about the building construction date.

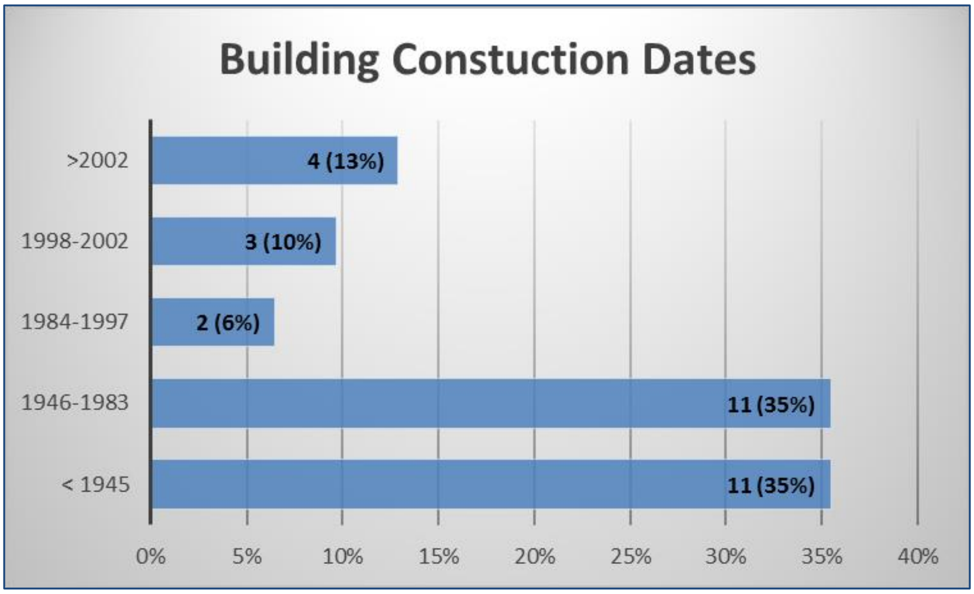


Figure 15.1.6: Dwelling construction period

Dwelling Type and Number of Bedrooms per Household

All the 32 surveyed residential dwellings were of detached build type. A question was also asked on the number of bedrooms contained in the dwellings. 25 (78%) of the dwellings contain between 3-4 bedrooms.

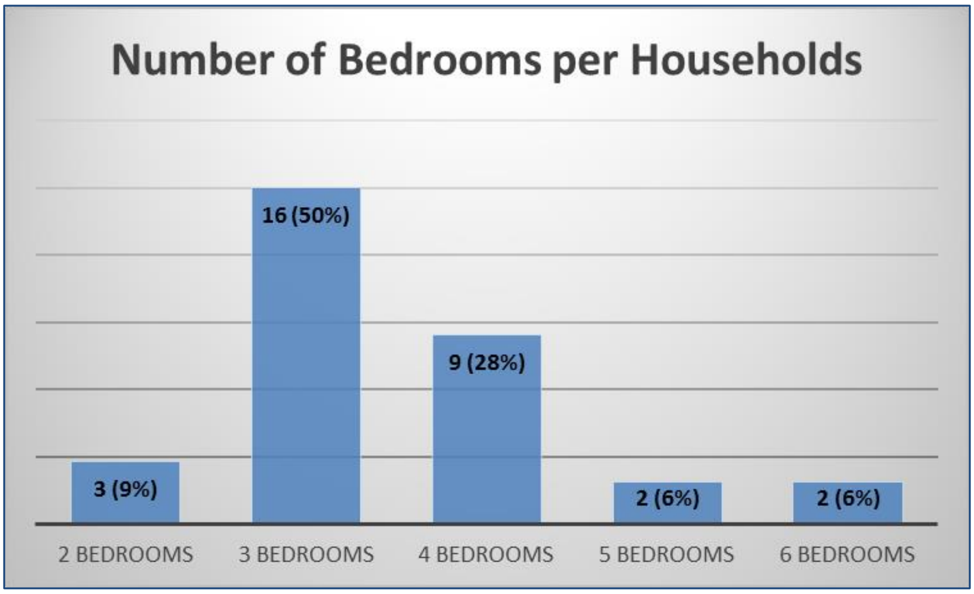


Figure 15.1.7: No. of bedrooms contained in households

Energy Status of Dwellings

Energy Efficiency Related Retrofits (Past)

26 of the 32 respondents (81%) had energy efficiency related retrofits carried out in the past. Figure 15.1.8 shows the type of retrofits carried out by the 26 residents.6 (19%) respondents had no retrofits installed in the past. 4 of the 6 respondents who had no retrofits carried out in the past live in dwellings which were constructed after year 1998 and are relatively new.

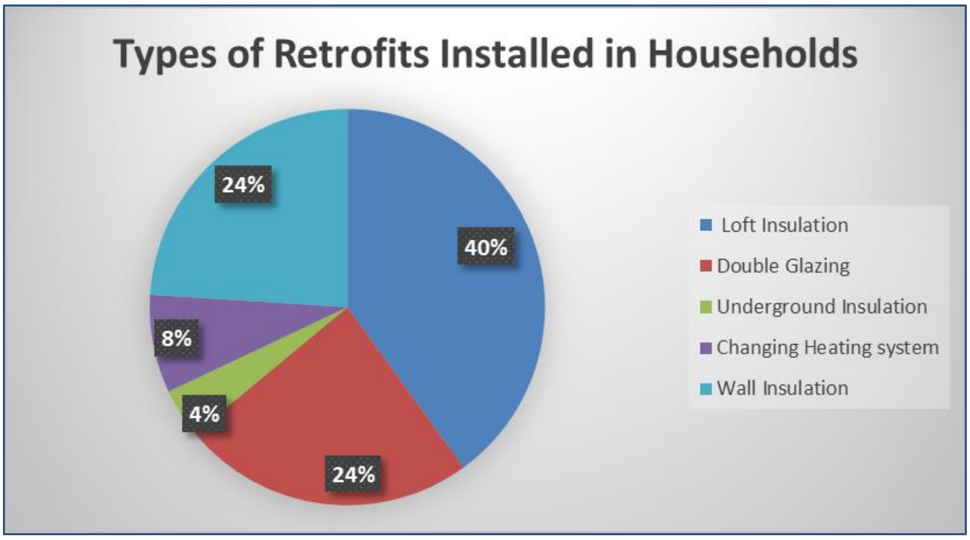


Figure 15.1.8: Type of retrofits carried out in households

Cost of Past Retrofits Carried out

Most of the respondents who carried out past retrofits could not remember the exact expenditure involved in carrying out the retrofits due to the use of different grants and schemes. 7 of the respondents remembered the approximate expenditure involved in carrying out the retrofits by types. Table 15.1.1 shows the approximate expenditure involved in carrying out the aforementioned energy retrofits summarized together with the built year of the dwelling and approximate area and bedrooms contained in the dwelling.

Table 15.1.1:Cost of past retrofits

Dwelling Built Year	Bedrooms contained	Approximate Living Area (sqm)	Retrofits Carried Out	Expenditure, £
1946-1983	4	Uncertain	Double Glazing windows	5000
1946-1983	3	140	Double Glazing windows	8000
Before 1945	3	Uncertain	Double Glazing windows + Loft	8000
1946-1983	3	80	Loft Insulation (2012)	800
1946-1983	3	80	Double Glazing Windows (2012)	7000
1946-1983	3	120	Multi Stove Boiler	700
1998-2002	3	280	Double Glazing Windows (<10 yrs ago)	24,000
1984-1997	4	70	New Central Oil Boiler (2012)	7000
1984-1997	4	70	Loft Insulation (2012)	2000

Planned Energy Efficiency Related Retrofits

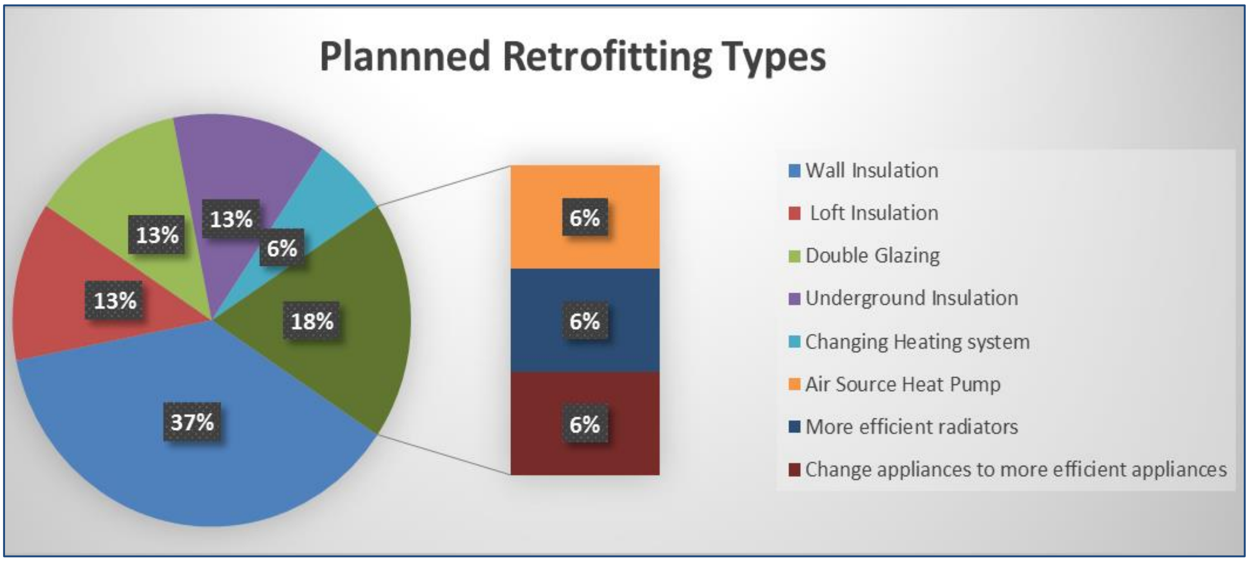


Figure 15.1.9: Type of planned retrofits

12(38%) respondents have future plans to conduct energy related retrofits while 20(62%) have no future plans. 11 out of the 12 respondents (92%) had retrofits carried out in the past while the remaining 1 respondent (8%) had no retrofits done in the past. Figure 15.1.9 summarizes the type of retrofits planned by the 11 respondents.

Follow up question was asked to the 20 respondents on the reasons why the respondents have no future plans to carry out energy retrofits. 16 respondents gave reasons while 4 did not provide any reason. Figure 15.1.10 below summarizes all the reasons given by 16 respondents for no planned retrofits.

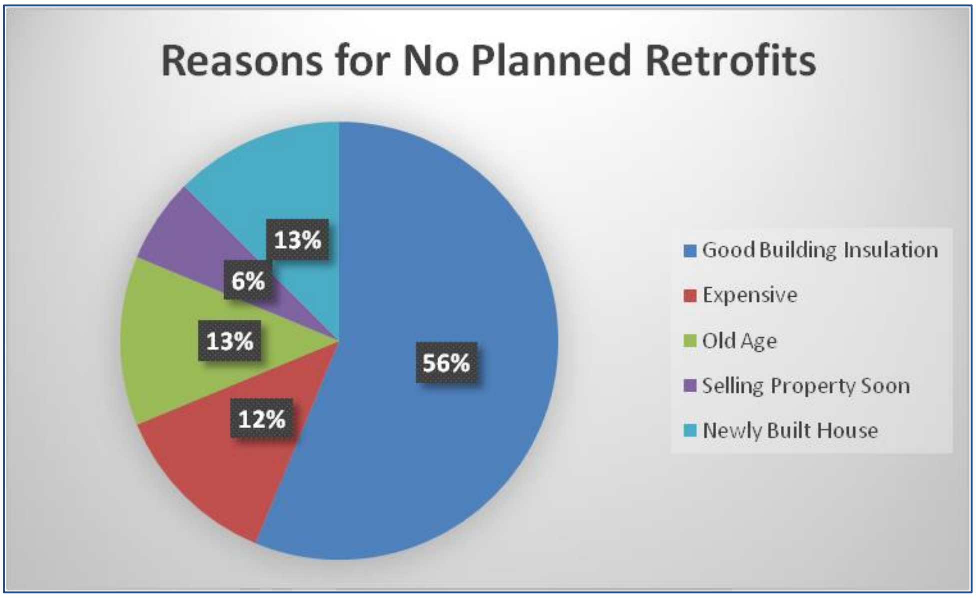


Figure 15.1.10: Reasons for No Planned Retrofits

Energy Consumption Information of Dwellings

Predominant Heating Technology Used in Dwellings

24 of the 32 interviewed respondents (75%) use Central Oil Heating as their predominant source of heating. 7 respondents (22%) use purely electrical heaters namely electric panel and electric storage heaters. 1 respondent (3%) uses an air source heat pump as the predominant heating technology.

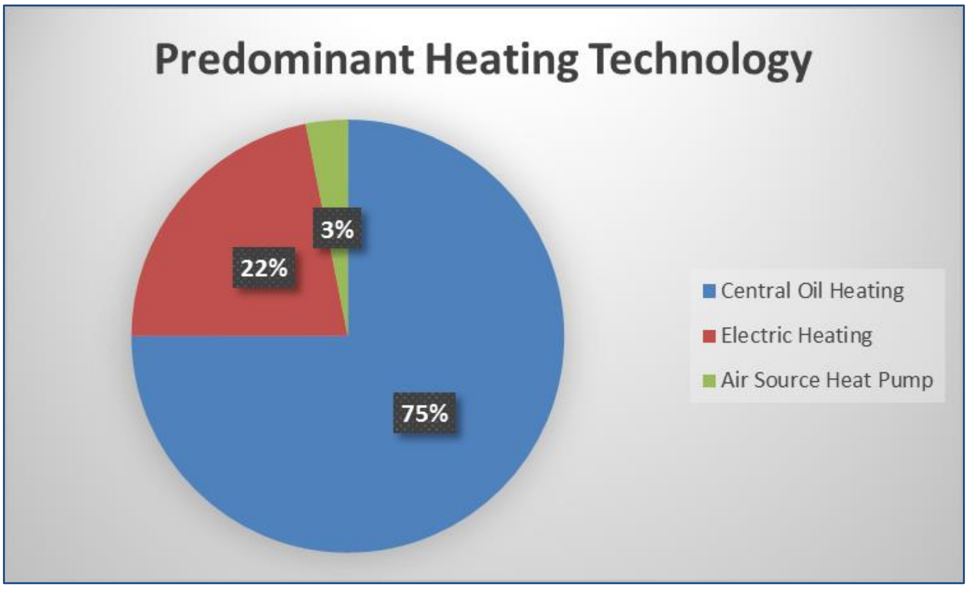


Figure 15.1.11: Predominant Heating Technology

Following points gives an overview of respondents who use an additional second source of heating besides the aforementioned predominant source of heating:

- 3 respondents use electrical heaters in addition to central oil heaters
- 1 Respondent uses solid fuel heaters in addition to electrical heater.
- 8 respondents use Solid Fuel Heaters in addition to central oil heaters. Most of the solid fuel heaters used are multi-fuel solid fuel boilers and are able to use peat, coal and wood as fuel. Solid fuel in form of coal and peat are more commonly used in West Harris.

Annual Heating Fuel Expenditure and Heating Demand Computation

The residents were also asked on their annual expenditure (Year 2015) on heating fuels mainly to assess firstly the heating demand and secondly the outflow of local money to pay for heating fuels. None of the 32 respondents mentioned the use of gas heaters. Based on the figures collected, Table 15.1.2 summarizes the aggregated annual fuel heat demand for all residents and annual expenditure for the heating fuels.

Table 15.1.2: Annual Heating Fuel Expenditure and Calculated Heating Demand

Heating Fuel	Annual Expenditure, £	Fuel Energy Content (Biomass Energy Center UK)		Fuel Energy Price		Calculated Fuel Annual Usage	Assumed System Efficiency, % (Lower - Higher)	Calculated Heat Demand, kWh
Oil	29,494	10	kWh/litre	0.35	£/litre	84,269	70% - 82% (Energy Saving Trust, p. 31)	589,880 - 758,417
Coal	5,680	8	kWh/kg	0.46 (Ace Energy(a))	£/kg	12,348	60 % (Energy Saving Trust UK(a), p. 22)	55,565
Wood	200	4.8	kWh/kg	0.26 (Ace Energy)	£/kg	769	60 % (Energy Saving Trust UK(a), p. 22)	2,215
Total Computed Heat Demand Range								647,660 - 816,197

(Note: The information on specification of type of coal, oil and wood used by the respondents was not explicitly enquired in the surveys. The fuel energy content information is based on lower heating value (LHV) taken from an online source (Biomass Energy Center UK. The fuel content of fuels differs based on the specification (grades) of fuel used. The price of fuels for oil was given by some respondents while the price for coal and wood was sourced from online supplier (Ace Energy) who supplies coal and wood in Harris)

Excluding 7 respondents who use predominantly electrical heaters, 25 households use a range of **647,660 - 816,197 kWh** aggregated heating demand based on the lower and higher efficiencies (mainly for central oil heater boiler) assumed in the computation. This yields approximately **25,906 – 32,645 kWh annual heating demand per household** in West Harris. The total expenditure which flows out annually for the heating fuels amounts to **£ 35,374** for 25 respondents. From the 25 respondents, 18 respondents provided the living space area of their dwellings. Based on these 18 respondents (only considering the heating demand of the 18 respondents) a heating demand per square meter in the range of **160 – 202 kWh/sqm** was computed.

Suitability of Heating System

Most of the respondents 28 (88%) rated the suitability of their heating system as at least 'Good'.

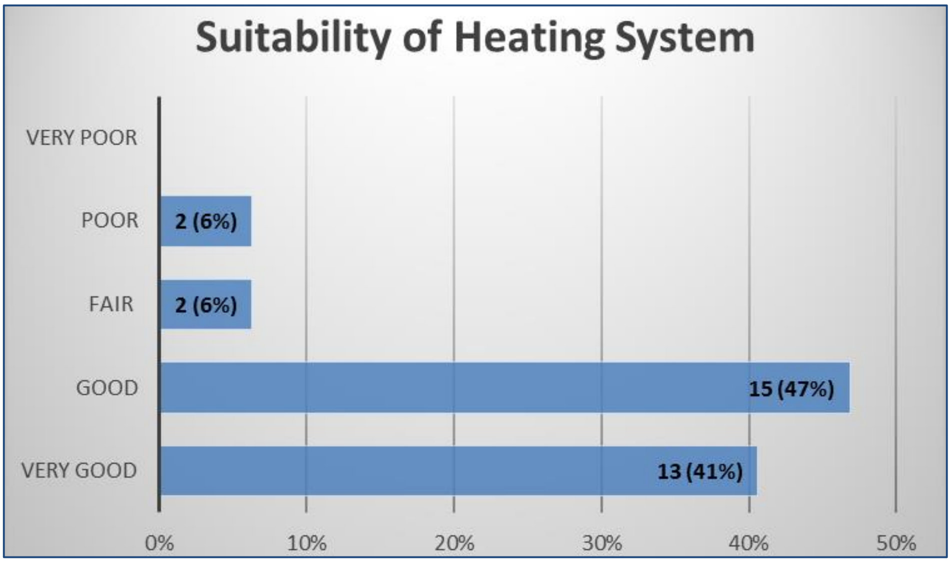


Figure 15.1.12: Suitability of Current Heating System

Improvement of Heating System

When asked on how the heating system can be further improved, 18 respondents gave answers. From the 18 respondents, most respondents 12(66%) answered by 'improvement of current insulation system' and 'Heaters/Boilers Upgrade to more efficient heaters'. Suggestions from respondents are summarized in the following figure:

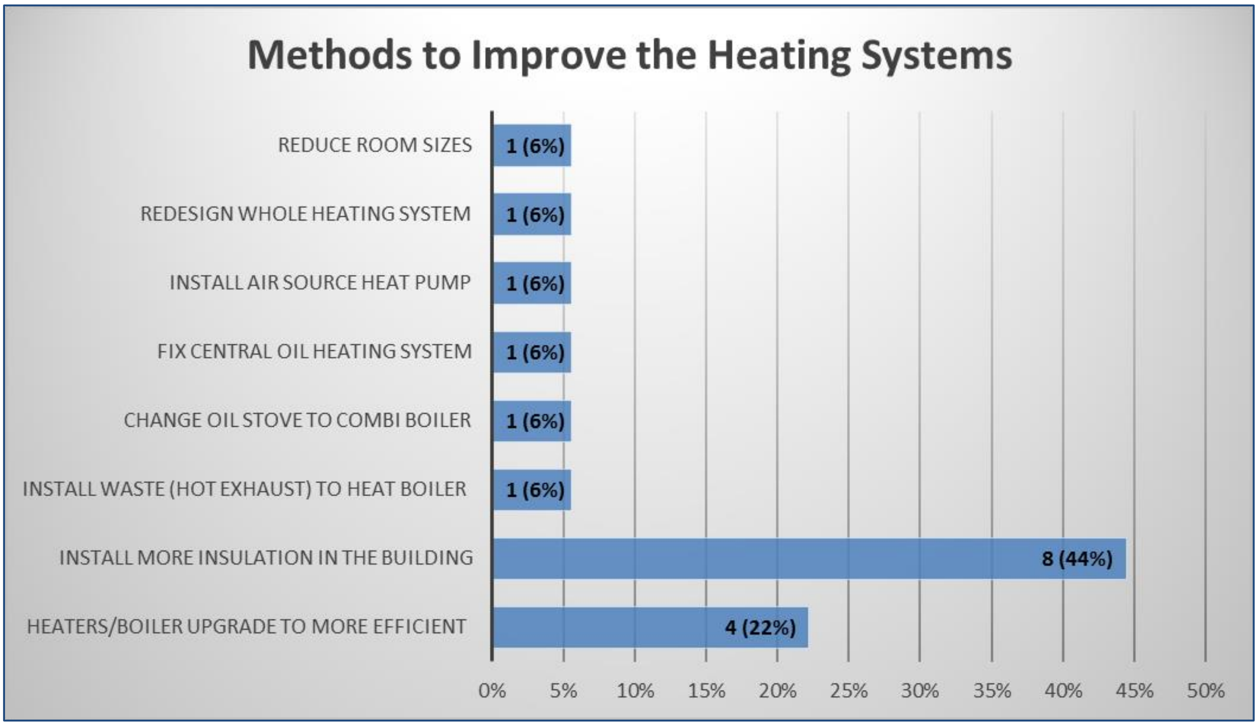


Figure 15.1.13: Suggested Methods to Improve Heating System

Total Annual Electricity Consumption and Demand

The respondents were also asked on their annual expenditure on electricity mainly to compute the electricity demand for the 32 interviewed respondents and establish an indicator for electricity consumption which could be applied within West Harris. The aggregated electricity expenditure sum of interviewed 32 respondent's amounts to **£35,438**. Using a standard electricity rate of **£0.1561/KWh** sourced from Scottish and Southern Energy Power Distribution (Scottish and Southern Energy (SSE), n.d.), an electricity demand of **227,022KWh** was computed for 32 respondents.

Due to the significant difference in electricity consumption between households using predominantly electrical heaters and non-electrical heaters, further computation was done to differentiate the consumption by household, by person and by area for residents using predominantly central oil heaters and electrical heaters. Computed results are summarized in tables below:

Table 15.1.3: Annual Electricity Consumption: Dwellings with Predominant Central Oil Heating System

Predominantly Central Oil Heating System					Comments
Indicators	**Expenditure**		**Electricity consumption**		
Average per Household	754	£/household	4,830	kWh/house-hold	Based on 22 households which provided information on cash spent on heating oil
Average per person	313	£/person	2,005	kWh/person	Based on 53 occupants in 22 interviewed households
Average per area	4	£/sqm	25	kWh/sqm	Based on 17 households which provided information on living space areas (sum = 2,930 sqm)

Table 15.1.4: Annual Electricity Consumption: Dwellings with Predominant Electrical Heating System

Predominantly Electric Heating System					Comments
Indicators	**Expenditure**		**Electricity consumption**		
Average per Household	1,992	£/household	12,763	kWh/household	Based on 8 households which provided information on cash spent for electricity
Average per person	759	£/person	4,862	kWh/person	Based on 21 occupants in 8 interviewed households
Average per area	16.2	£/sqm	104	kWh/sqm	Based on 4 households which provided information on living space areas (sum = 570 sqm)

Predominant Water Heating Technologies Used

Most respondents amounting to 14(56%) use water heating technologies via central oil heating followed by the use of electrical immersion heaters by 7 respondents (28%).

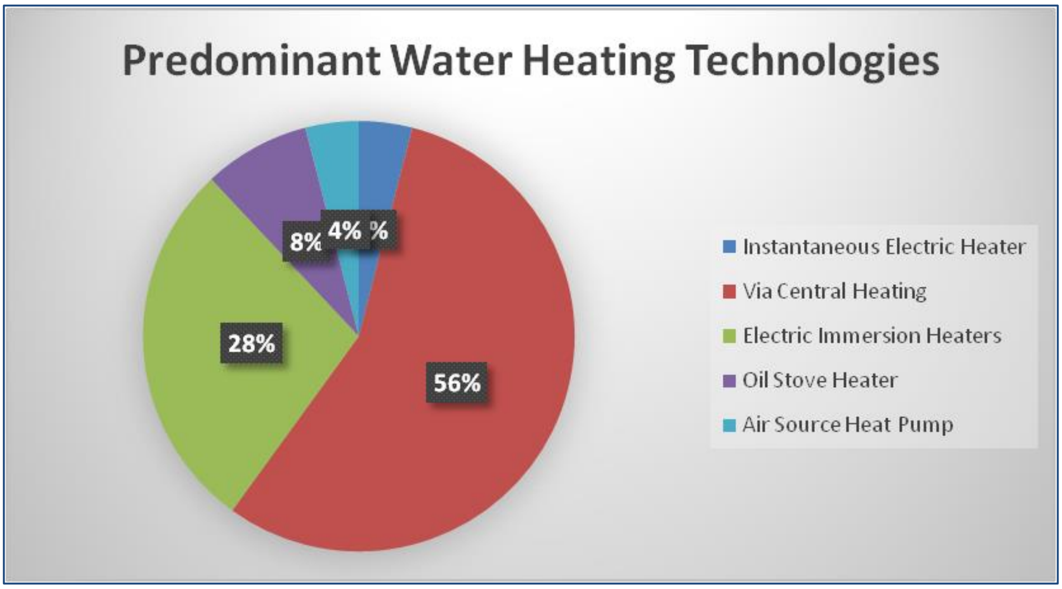


Figure 15.1.14: Predominant Water Heating Technologies

Predominant Lighting Technologies Used

Figure 15.1.15 summarizes the mix of lighting technologies used by respondents.

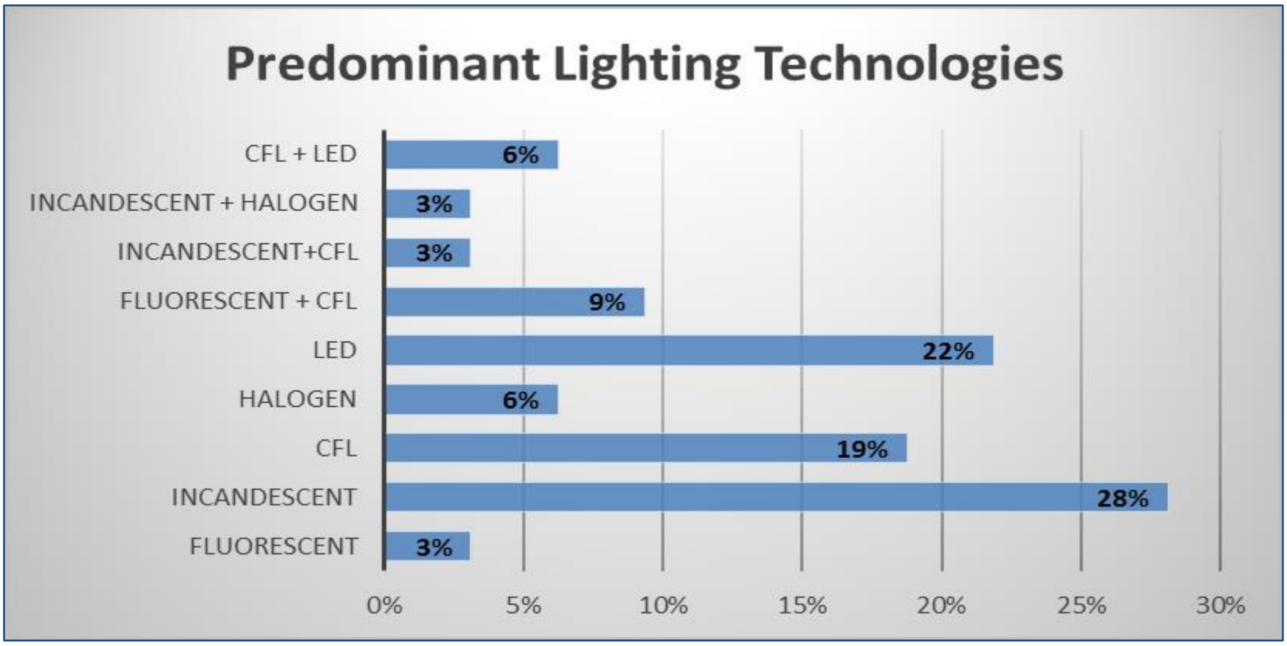


Figure 15.1.15: Predominant Lighting Technologies

Predominant Cooking Technologies Used

The main objective of this question was to assess the demand of electrical cooking technologies in West Harris.13(41%) of respondents use purely electrical cooking technologies. 8 (25%) respondents use a combination of gas and electrical cooking technologies. 7(22%) respondents use purely gas for cooking. The rest 4 (12%) respondents use a mix of electricity, gas and other (presumably oil stoves) for cooking.

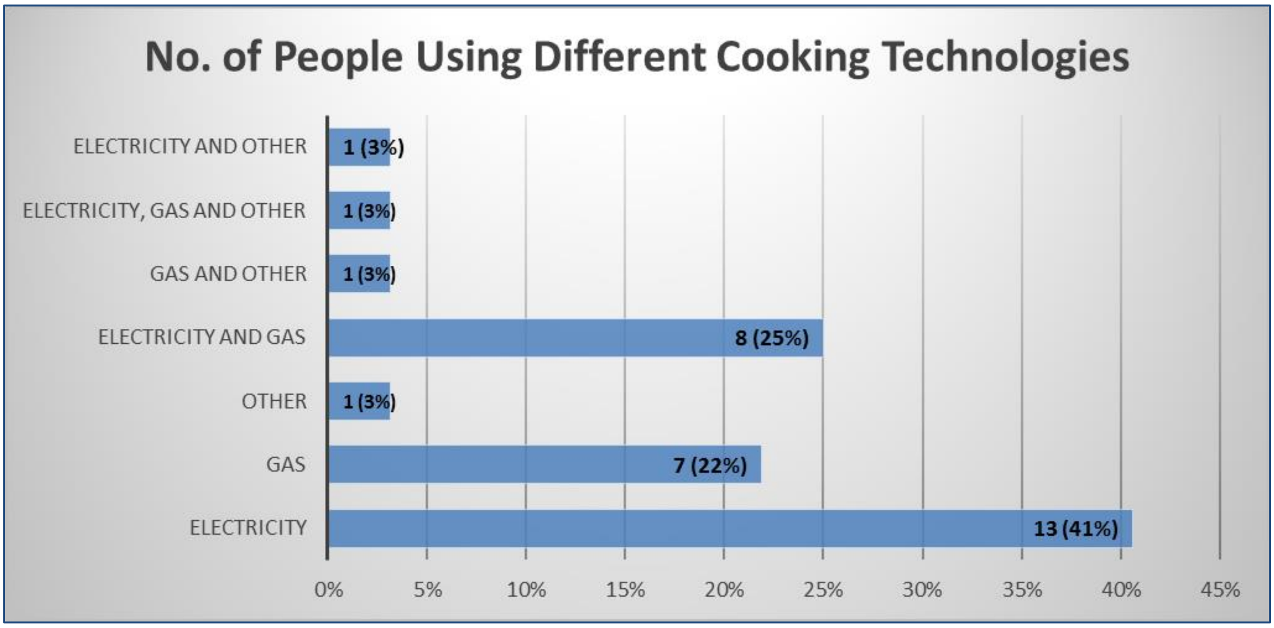


Figure 15.1.16: Cooking Technology Used by Residents

Income Generation in West Harris

Commercial Activity carried out in dwellings

7 (22%) of the interviewed households run commercial activities in their dwellings. The following points summarize the type of commercial activity carried out:

- 5 respondents run a Bed and Breakfast/Guest House business
- 1 respondent has a coffee shop and a small café
- 1 Respondent has a small leather craft workshop

Other Businesses owned by respondents in West Harris

11 (34%) of the 32 of the respondents own other businesses in West Harris. The following points summarize the type of other businesses owned by the 11 respondents:

- 6 respondents own Self Catering Holiday Cottages
- 2 Respondents own Caravans
- 1 Respondent owns Crofting, cattle, sheep and a camping site
- 1 Respondents have a weaving business
- 1 Respondent has a quarry business

Businesses Plans of respondents

4(13%) of the respondents have future plans to start a new business namely sand business, leather craft shop and weaving business while remaining 28(87%) have no future plans to start a new business.

Reasons for No Future Business Plans of respondents

Figure 15.1.17 shows the reasons given by the 28 respondents for not having plans to start a new business.

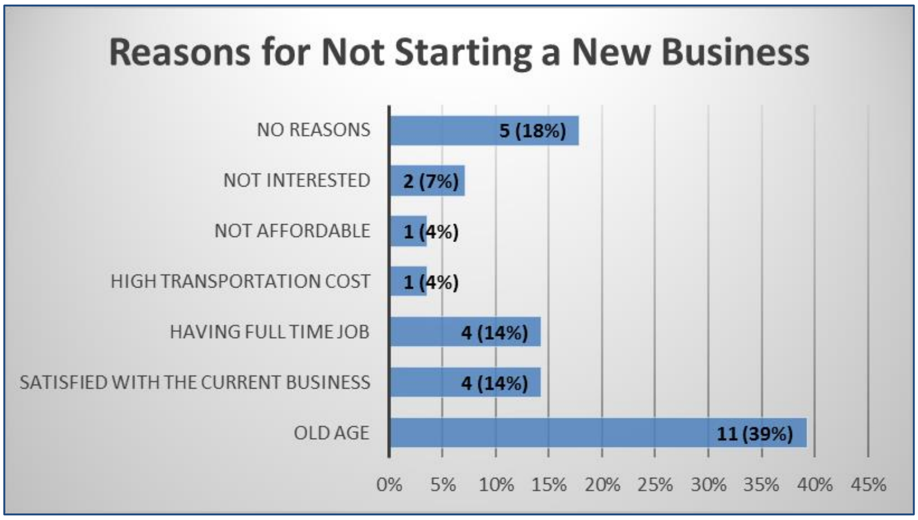


Figure 15.1.17: Reasons for Not Starting a New Business

In addition, 15 (47%) of the 32 respondents own at least one business either in their dwellings or in other places within West Harris. 12 of these 15 respondents do not wish to start a new business and it would be worthwhile to differentiate the reasons provided by these 12 respondents.

- 4 respondents are satisfied with their current business
- 3 respondents mentioned the 'age factor' as to not start a new business
- 2 respondents generally said they are not interested
- 2 respondents mentioned reasons - 'High transport cost' and 'Available full time job'
- 1 respondent did not provide a reason

Figure 15.1.18 summarizes the aforementioned reasons summarized in a chart:

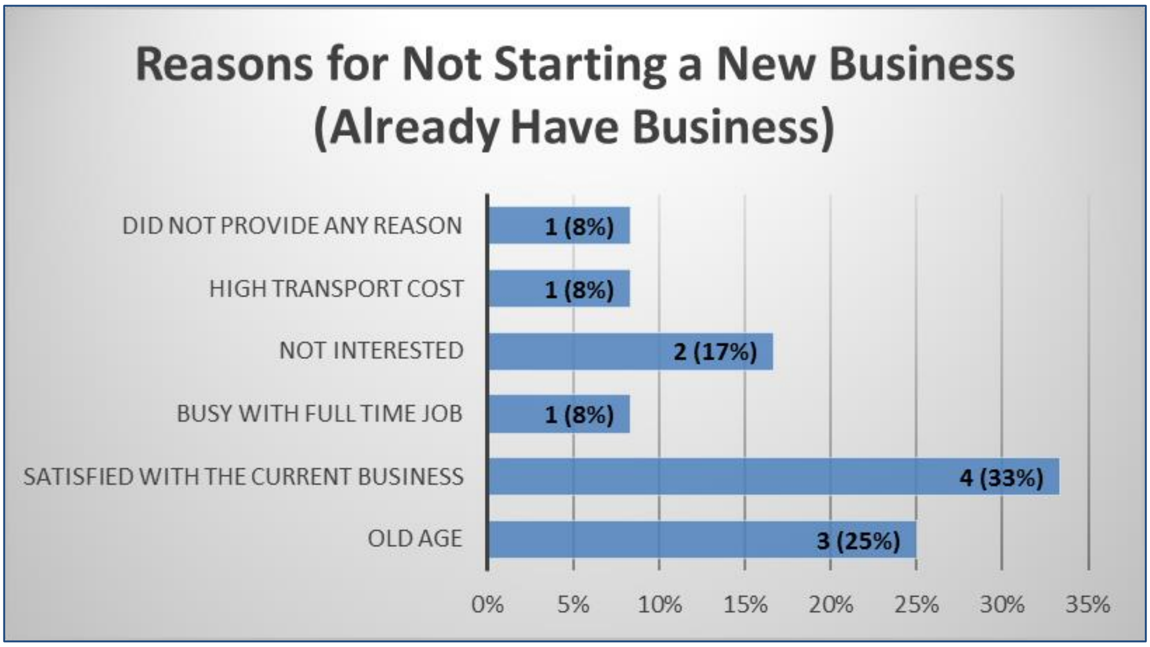


Figure 15.1.18: Reasons for Not Starting a New Business by Residents Already Owning a Business

Promising Businesses Ideas in West Harris

When asked about the promising business ideas which specifically can be realized in West Harris, many responses were received and are arranged in the following points arranged in descending order from the most suggested ideas from respondents to least suggested ideas:

Table 15.1.5: Promising Businesses Idea Suggestions

Businesses Ideas Suggestions	Number of Suggestions from Respondents
Bed Breakfast + Guest House	11(34% of respondents)
Restaurants (I.e.- at gold course center) / Café's /Tea rooms/Eateries	11 (34% of respondents)
Passenger Ferries/Boat Excursions/Sailing	8 (25% of respondents)
Hotels	3 (9% of respondents)
Nursery/Child care/Children park	3 (9% of respondents)
Commercial offices/Internet Works/Wi-Fi company/ Web Design Company/Internet Based Businesses	3 (9% of respondents)
Shops/Grocery Shops	3 (9% of respondents)
Massage + acupuncture + alternative medicine + reflexology	3 (9% of respondents)
Laundry	2
Bookshop	1
Black Pudding Business	1
Dog Care Centre	1
Small scale products manufacturing in WH	1
Fishing trips / Fish Farming	1
Wedding halls (Closest in Stornoway)	1
Exhibition Centre of specialized items in Harris	1
Weaving/Textile - Harris Tweed	1
Car Garage	1
Horticulture	1

Constraints to Realization of Businesses Ideas in West Harris

The constraints to the realization of business activities received from all the respondents are summarized in Table 15.1.6. The two main constrains highlighted by most of the respondents were the 'transport factor' being either expensive of difficulty in assessing the mainland and the second main reason the 'unreliable/slow' broadband connection in West Harris.

Table 15.1.6: Constraints to Realization of Business Ideas

Businesses Ideas Constraints	Respondents
Transport - Access to mainland different/High transportation cost	11 (34% of respondents)
Unreliable/Slow Broadband Internet Connection	9 (28% of respondents)
Lack of Labor to operate businesses	2 (6% of respondents)
Short tourism Season	2 (6% of respondents)
Harsh/unpredictable weather conditions	2 (6% of respondents)
Lack of full/part time job opportunities	2 (6% of respondents)
Lack of labor required due to the employment of advanced technologies	2 (6% of respondents)
Difficulty in acquiring land - don't want to interfere with current setup of crofting	1
Access to grants difficult	1
No support for local business ideas	1
Difficulty in getting into crofting business given high cost for farming equipment. Upfront cash needed first to pay and only then grant can be applied	1
Difficulty for young people to raise capital to start business	1
Lack of new people with new business ideas/continuation with local businesses	1
Lack of housing opportunities for young people	1
Goods limitation	1

Renewable Energy Perception and Acceptance Level

Renewable Energy Knowledge Level of Respondents

When asked on the respondent's level of knowledge in Renewable Technologies, Next Figure summarizes the responses received. 15(47%) of the respondents have at least an average level of knowledge in renewable energy technologies and the rest 17(53%) said they have a low level of knowledge in renewables.

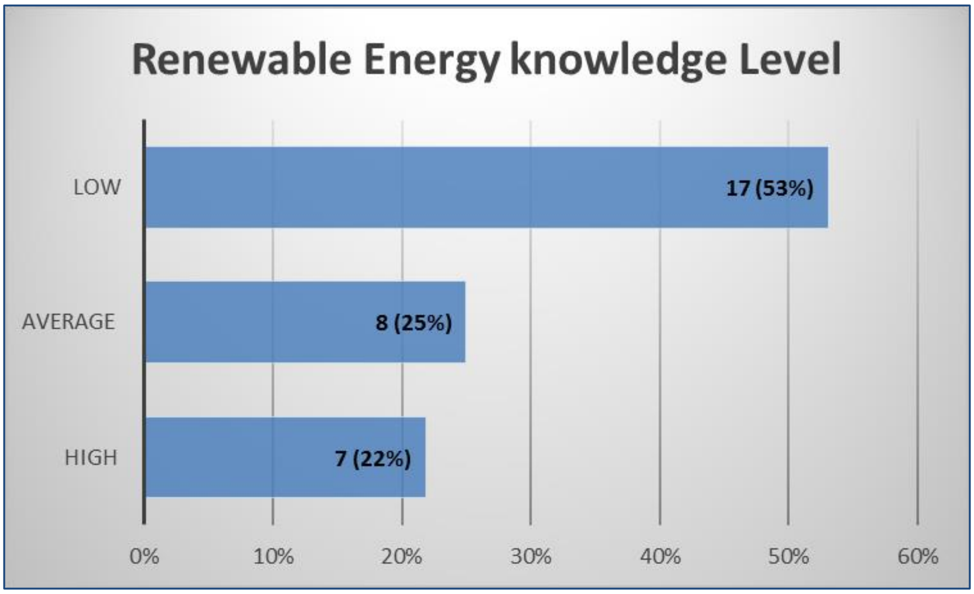


Figure 15.1.19: Level of Knowledge in Renewable Energy

Interest of respondents to receive more information on Renewable Energy

When asked if the respondents are interested in receiving more information on Renewables, 14(44%) were positive while 7(22%) said maybe and 11(34%) were not interested to receive more information.

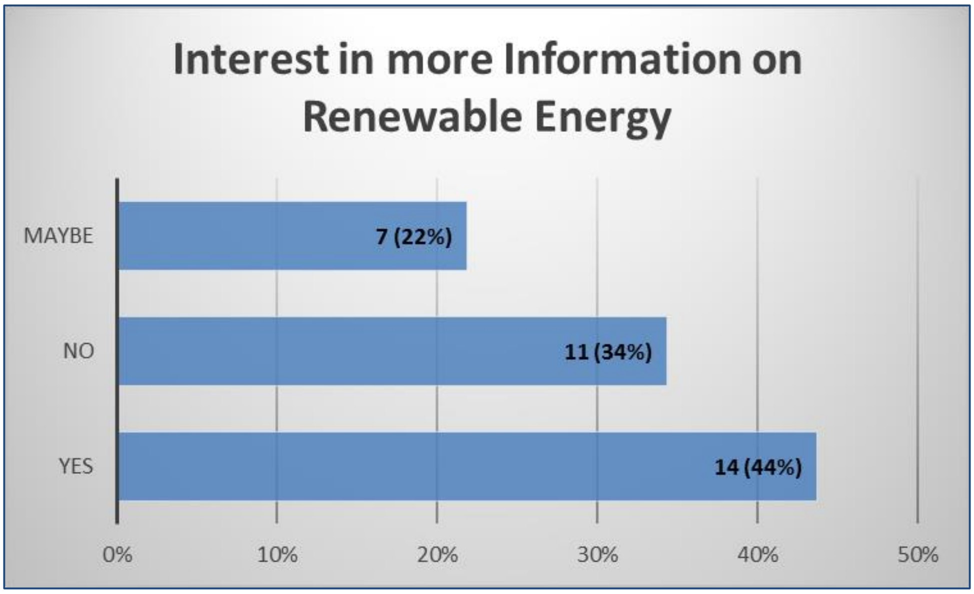


Figure 15.1.20: Interest in Receiving More Information on Renewable Energy

Future Plans of Respondents to Install Renewable Energy Technologies

When asked on the future plans of respondents to install renewable energy technologies, only 5(16%) said they were interested while the most amounting to 24(75%) respondents said ‘No’ to future plans.3(9%) said that ‘maybe’ will consider future plans to install RE technologies

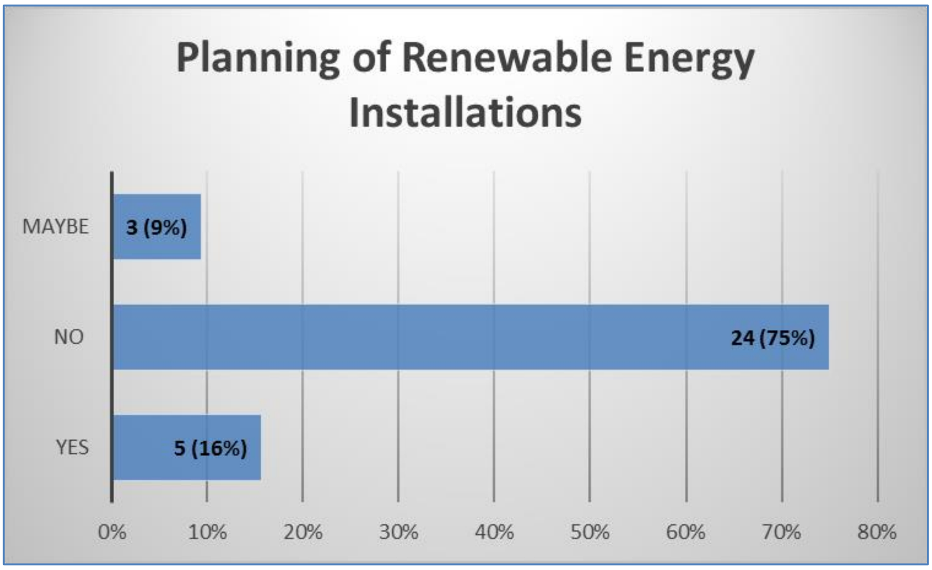


Figure 15.1.21: Residents Planning for Renewable Energy Technology Installations

Reasons for ‘No’ or ‘Maybe’ for future installations of Renewable Energy Technologies

A follow up question was asked to the respondents who answered either ‘No’ or ‘Maybe’ to future plans of Renewable technologies to analyse the reasons for not having planned installations of renewable technology. Figure 15.1.22 shows the reasons given by different respondents with mostly skewed towards the ‘low returns’ of installing such a technology mainly because of the revised Feed in Tariff which is deemed low and do not encourage the use of Renewable Energy Technologies. There was a mention on ‘Air Source heat Pump’ as a preferred technology but due to lack of maintenance support in the island, some respondents chose not to install the technology.

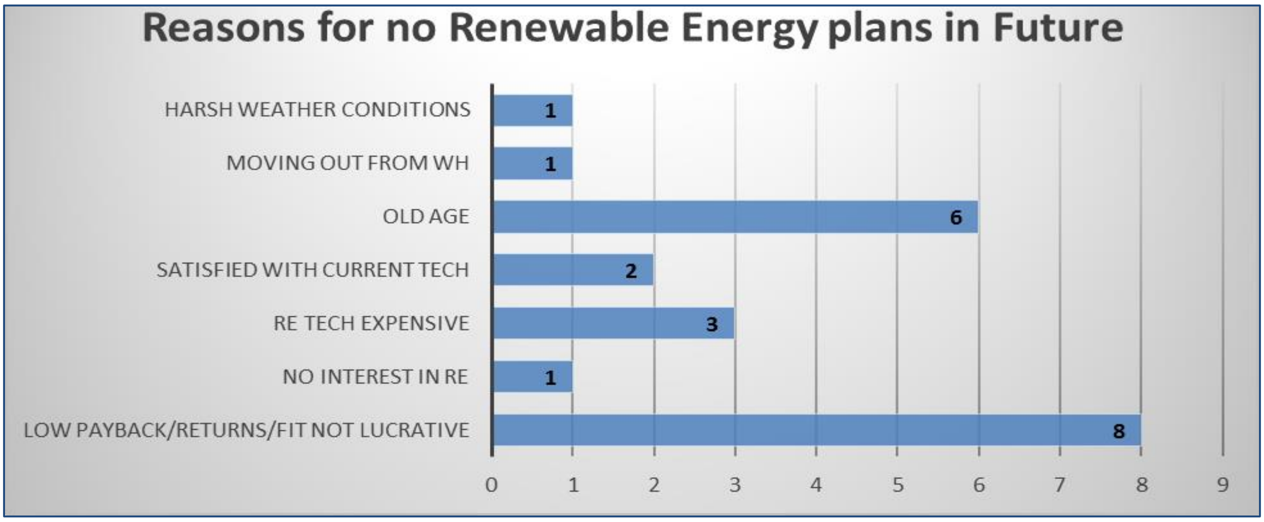


Figure 15.1.22: Reasons for Not Having Any Plans to Install Renewable Energy Technologies

Preferred type of renewable energy technologies installation in the future

As mentioned from earlier section, 5(16%) respondents were interested in installing renewable energy technologies in their dwellings. A follow up question was asked to these 5 respondents on the preferred type of technology they plan to install and is summarized here:

- All 5 respondents mentioned Photovoltaic(PV) Panels
- 3 from 5 respondents mentioned Solar Water Heaters
- 3 from 5 respondents mentioned Small Wind Turbine
- 1 respondents mentioned 'low head hydro technology' to be installed in the backyard
- 1 respondent mentioned the installation Air Source Heat Pump

Figure 15.1.23 summarizes the type of renewable technology planned for the buildings:

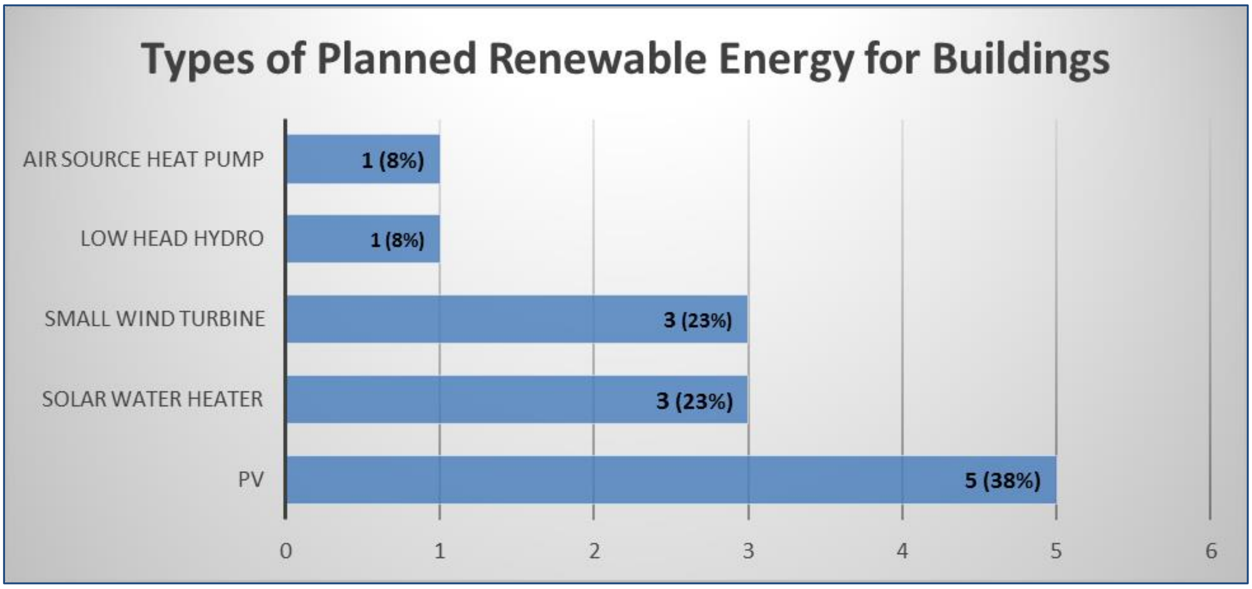


Figure 15.1.23: Type of Planned Renewable Energy Technology Installations

Perception of 'RE Community Projects' as one of the best ways to contribute to income generation in West Harris

The respondents were also given a statement to assess their level of agreement on 'community based renewable energy projects being one of the best ways to contribute to income generation in West Harris'. The level of agreement of respondents was evaluated on a 5 point scale. A follow up question was asked on the reasons they for their chosen level of agreement. Table 15.1.7 summarizes the results from these 2 questions:

Table 15.1.7: Agreement Level on RE Community Projects as One of the Best Ways to Contribute to Income Generation in WH

Agreement Level	Respondents	Reasons for the agreements
Strongly Agree	9 (28%)	• Availability of abundant resources of Wind, Hydro and Tidal/Wave • High potential of Renewable Resources • Seen as only viable option to generate income and provide sustainable community • RE Projects generate excess electricity and can be used to generate income • Large land area can be used for Solar PV installations
Agree	15 (47%)	• Abundant RE resources as mentioned above • Based on previous experience with 53KW wind turbine, it has generated much revenue • Noble Hydro schemes would provide funds for investment which would give profits • Grants are available for Community RE projects • Seen as better option than generation of income from crofting
Uncertain	7(22%)	• Community not well informed • Lack of knowledge to give a sound answer
Disagree	1 (3%)	• No interest in RE technologies
Strongly Disagree	No respondents strongly disagreed	

Priority for Reinvestments from Community Renewable Energy Projects Income Generation

Respondents were asked on the priority preference for reinvestments if the renewable energy community projects generated income. Table 15.1.8 summarizes the responses received:

Table 15.1.8: Priority for Reinvestments from Community RE Projects Income Generation

Respondents	Priority for Reinvestments
7(22%)	Affordable Housing especially for young people
6 (19%)	Renewable Projects Expansion
5 (16%)	Initiatives to create employment opportunities in WH
2 (6%)	Café/Eateries to bring community together
2 (6%)	High speed broadband services
1 (3%)	Coastal Protection
1	Crofting
1	Retention of community officers to bring projects into West Harris
1	Provision of small grants and loans for small businesses
1	Schemes that benefit each household to be efficient by improving insulation
1	Provision of grants and loans for small RE projects
1	Invest in Roads
1	Investment into Tidal and Wave technologies (New Technologies)
1	Use income for the Operation and Maintenance of Renewable Technologies
1	Passenger ferries with water jet engines
1	Preservation of old buildings
1	Workshops to teach children about renewable energy
1	Youth Activities
1	Tourism
1	Improve common facilities in West Harris
1	Invest in Western Isles energy company which could provide cheaper electricity tariffs

Interest in Investing in Community Renewable Energy Projects

A question was asked to evaluate the interest of respondents to invest in community based renewable energy projects (buying shares in RE community projects was quoted as an example) in West Harris. Figure 15.1.24 summarizes the responses received with 21(66%) of respondents saying ‘Yes’ (13 respondents) and ‘Maybe’ (8 respondents) while 11(34%) saying ‘No’ to investing.

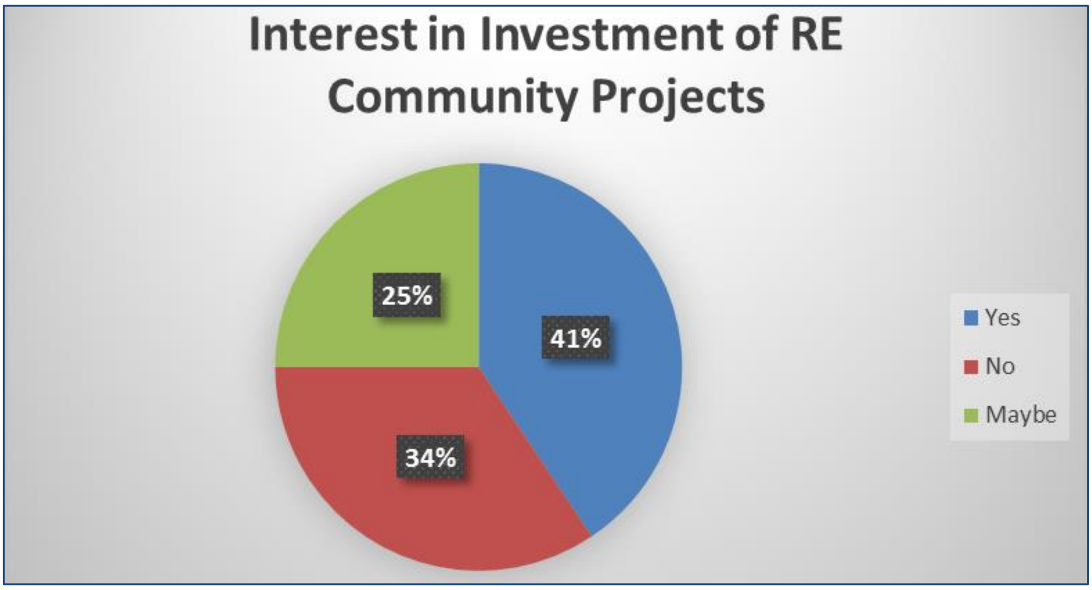


Figure 15.1.24: Interest of Residents in Investing in Community Based RE Projects

Expected positive impacts from community based renewable projects

Table 15.1.9 summarizes the responses received when asked on the expected positive impacts from community based renewable energy projects in West Harris.

Table 15.1.9: Expected Positive Impacts from Community Based RE Projects

Respondents	Expected Positive Impacts
8(25%)	Employment Generation/Retention
7 (22%)	More business/Sustainable income generation
6 (19%)	Cheap electricity
6 (19%)	Clean Energy Source
4 (13%)	Repopulation of WH by attracting people back
2 (6%)	Maintain local income within West Harris
1 (3%)	Income from RE Projects can be reinvested into WH community
1	With reinvestment into high speed broadband from RE income, more businesses such as IT hubs can be set up in West Harris
1	Revenue can be used by West Harris Trust to invest in other projects without relying on Grants
1	Green tourism business schemes

Perceived negative impacts from community based renewable projects

18(56%) respondents did not perceive any negative impacts from renewable energy community projects in West Harris while 12(38%) said they perceived negative impacts. 2(6%) respondents did not know.

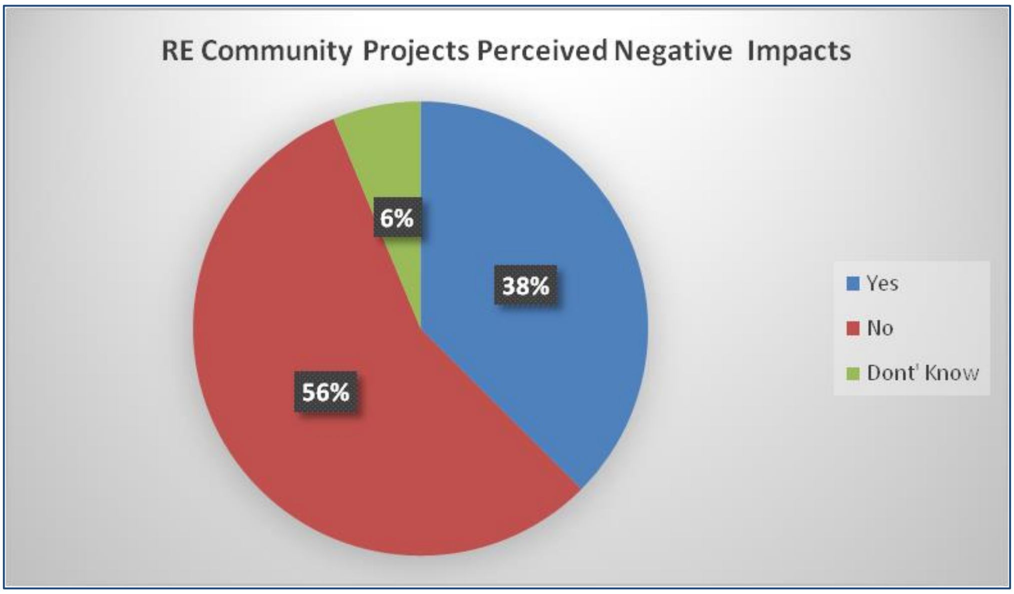


Figure 15.1.25: Perceived Negative Impacts from Community Based RE Projects

A follow up question was asked to the 12 respondents who perceived negative impacts from such projects and are summarized by technology in table below:

Table 15.1.10: Type of Perceived Negative Impacts from Community Based RE Projects

Technology	Respondents	Perceived Negative Impacts
Hydro	1 (8%)	Less water availability in Summer season Advantages negligible compared to advantages, scenic view will be disturbed
Wind	2 (16%)	Noise Pollution
	7 (58%)	Visual impact from large and many turbines
Tidal and Wave	1 (8%)	Interference with fishing activities
	2 (16%)	Visual Impact / Disturbance of landscape

Transportation in West Harris

Types of Vehicles Owned by Residents

31 (97%) of the 32 residents own a normal petrol/diesel run car. 1 resident (3%) owns a hybrid electric/petrol car. There is a fleet of 44 cars in West Harris among the 32 residents interviewed.

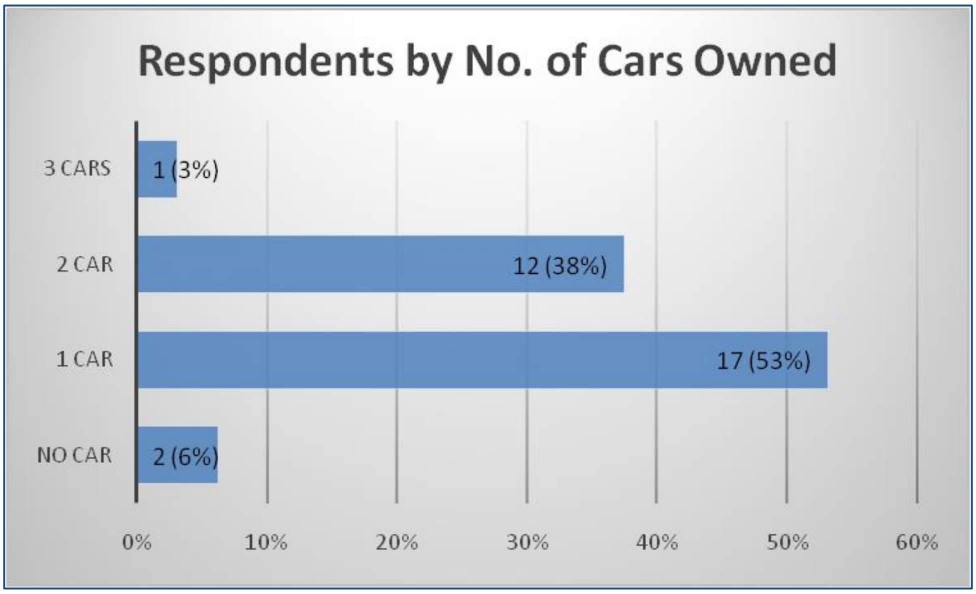


Figure 15.1.26: No. of Cars Owned by Respondents

Mileage of Car Fleet in West Harris

The residents were also asked on their annual mileage driven within the Western Isles. The total mileage of all 30 respondents (who own cars) amounted to **341,603 miles**. The main reason for this question was mainly to gauge the fuel consumption and secondly to gauge the possible demand creation for electricity in the event of increased usage of hybrid/electric cars.

Further analysis was also done to separate the mileage into 3 scales to give a better view on number of households in each category and per household average mileage driven in each category. Table 15.1.11 summarizes the results.

Table 15.1.11: Mileage of Car Fleet in West Harris

Mileage (miles)	No. of Households	% Respondents	Average miles/Household
< 10,000	13	50%	4,564
10,001 - 20,000	8	31%	15,284
>20,000	5	19%	24,000

Interest of Residents to buy electric cars

22(69%) of respondents were not interested to buy an electric car while 7 (22%) said that they were interested. 3(9%) of respondents did not know.

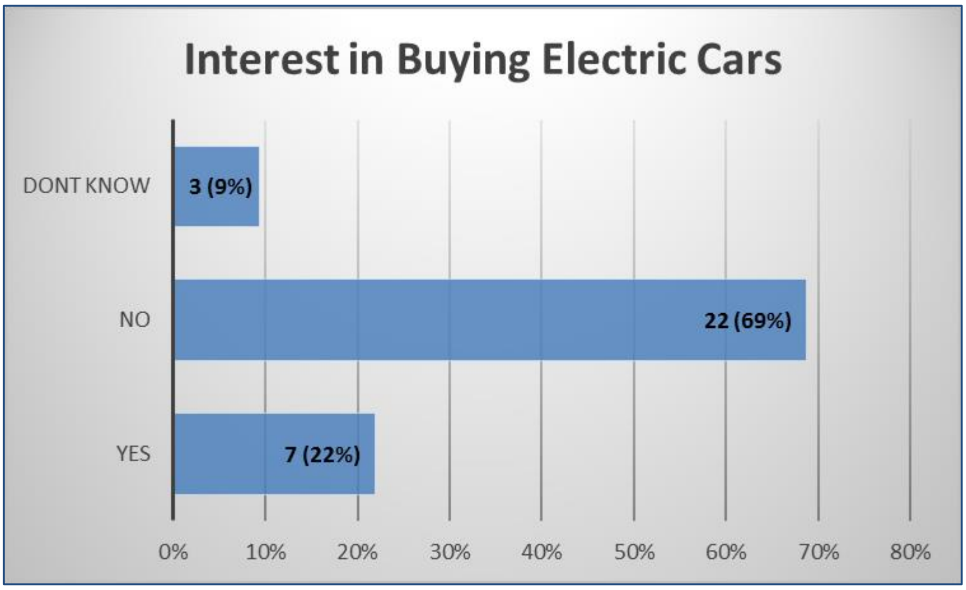


Figure 15.1.27: Interest in Buying Electric Cars

Conditions under which residents would interest themselves to buy electric cars

A follow up question was asked on the conditions which would encourage them to buy electric cars. Most 11(34%) said 'more mileage' would be preferred and most have the impression an electric car could only give a mileage range of only about 100-120 miles and would be not sufficient for them to make two way trip to and from Stornoway. 11(34%) mentioned they would buy an electric car if the 'economics' of it was good translated into cheaper conditions. Respondents have an impression that electric cars are generally expensive. 9(28%) of the respondents mentioned they would interest themselves if they were more filling stations. Based on information received from respondents, there are 2 charging stations currently available in Harris. Another respondent mentioned that if the charging time was shorter, that would encourage the respondent to buy an electric car as the charging time can be a hassle due to long waiting time. Figure 15.1.28 summarizes the aforementioned conditions under which respondents would interest themselves to buy an electric car.

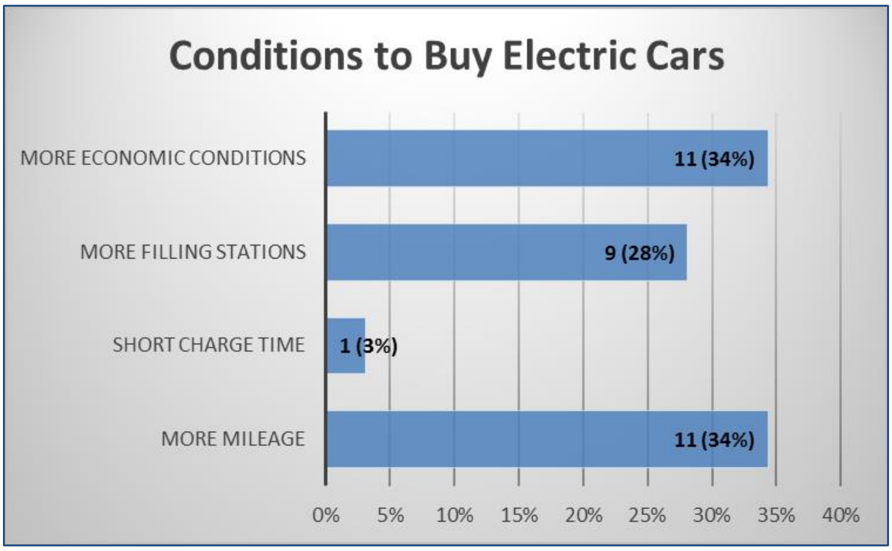


Figure 15.1.28: Conditions under Which Respondents will buy electric cars

Community Bus Provision in West Harris

A question was asked if the respondents would be interested in using a community bus if it was provided by the trust. 23(72%) said they will be interested to use a community bus while the remaining 9(28%) of respondents said that they will not be interested. A follow up question was asked to the 23 respondents who said they will be interested to use a community bus on what routes and schedules would be of preference. Table 15.1.12 below summarizes the preferred routes and schedules suggestions:

Table 15.1.12: Community Bus Route Suggestions

Routes Suggestions	No. of respondents
West Harris to Tarbert, Stornoway, Leversborough (Shopping areas)	15
Luskentyre village to Luskentyre road end	1
Rodel to Tarbert	1
West Harris to Lewis (and back)	1
Within West Harris to New Community Centre	1

The following are the schedules suggested by the respondents:

- Daily Midday / Daily Every 2 hours
- From 9am onwards, every 3-4 hours
- Time suggestion: 10am,2pm,6pm
- 3 times daily at 10am, 2pm. 4pm / 2 times daily at 10am, 4pm
- 2 times daily at 9am, 2pm
- Weekly but increase frequency in summer
- 2-3 times per week
- Try to fit outside of current bus schedules especially in the evenings / Evenings
- To New Community Centre - Mid Morning, Mid Afternoon
- To Shopping areas : Late Afternoon

Open Comments and Suggestions

The final part of the questionnaire was left open for respondents to provide feedbacks and suggestions which were not explicitly captured in the questionnaire. The suggestions are arranged in the following sub sections:

- **Comments by respondents on Renewable Energy**
  - There is a need to change the perspective of the community on Renewable Energy
  - Explore options on 'smart grid' and exporting electricity to mainland
  - Uncertain on how RE community projects can attract young people
  - Feels that large scale RE community projects is the future/way forward
  - With the use of RE storage systems, density of houses around the storage systems can be increased
  - There is a need to find other alternatives besides RE projects to generate income
  - Feels that the trust is doing a great job in carrying out community based RE projects

- **Comments by respondents on needs/facilities in West Harris**
  - Child care/nursery
  - Day care center for the elderly
  - Sports facilities
  - Horticulture

- **Comments by respondents on Improvement in infrastructure**
  - Better broadband connections

- **Other General Comments by respondents**
  - Promotion of cultural festivals in West Harris
  - Archeology can be promoted in West Harris – more research or archeology based tourism can be realized
  - There is also a need to maintain the local culture like Highland sheep and cattle, stone hedge houses and other local cultures

Holiday Homes Energy Consumption

A short separate questionnaire was used to evaluate the energy consumption information of holiday cottages/holiday homes (HH) mainly to assess the additional demand for electricity which is created. The information on the number of holiday cottages in each areas in West Harris were obtained from the 'pilot phase' of questionnaire survey by asking the first few respondents involved in the pilot study to point out holiday homes on the maps provided. No differentiation were made between holiday homes used as second home by families and holiday homes which are commercially rented out due to lack of information. No information was obtained on holiday homes in Horgabost as no surveys were carried out in Horgabost. Only 3 additional questionnaires for holiday homes were filled completely and one questionnaire was incomplete (filled up for 6 cottages aggregated into one questionnaire). The following sections aims to provide information based on the limited responses received for the questionnaires.

Table 15.1.13: No. of Approximate Holiday Homes by Area

Areas in West Harris	No. of Holiday Homes
Luskentyre	9
Borve	5
Seilebost	12
Scarista	3
TOTAL	**29**

Information on Holiday Cottages

Holiday Home Buildings Construction Period

For this section, only three questionnaires were completely filled up.

Table 15.1.14: Construction Period of Holiday Homes

Holiday Homes (HH)	Construction Period
HH 1	1946 - 1983
HH 2	1984 - 1997
HH 3	After 2002

Holiday Homes Build Type

Based on the 4 questionnaires (total of 9 Holiday homes), 2 (22%) holiday homes were semi detached and 7(78%) others were of detached build type.

Holiday Homes Energy Efficiency Related Retrofits (Past)

- Double glazing for windows were carried out for 8 of the 9 holiday homes
- Loft Insulation was carried out for 7 of the 9 holiday homes
- Underground insulation was carried out for 6 of the 9 holiday homes
- Wall Insulation was carried out for 1 of the 9 holiday homes

Energy Status of Holiday Homes

Planned Energy Efficiency Related Retrofits in Holiday Homes

There are planned retrofits for 2 out 9 holiday homes mainly for loft insulation. The remaining 7 holiday homes are not planning for retrofits mainly for the reasons given as ‘not required’ interpreted by the authors as insulation is sufficient.

Predominant Heating Technology Used in Holiday Homes

The following points summarize the use of predominant heating technologies:

- 1 of the 9 holiday homes use Central oil heating
- Remaining 8 holiday homes use electrical heaters (1 use only storage heaters, 1 use a mix of electrical panel and electrical storage heater, 6 use only electrical panel heaters)

Improvement of Heating System in Holiday Homes

The following points were proposed for the improvement of heating system in Holiday Homes (HH):

- 1 HH - Change from electrical heating system to central oil heating system
- 1 HH – Better insulation
- 1 HH – Install more efficient central oil boiler

Suitability of Heating System in Holiday Homes

Figure 15.1.29 summarizes the information on suitability of heating system provided by the owners of holiday homes:

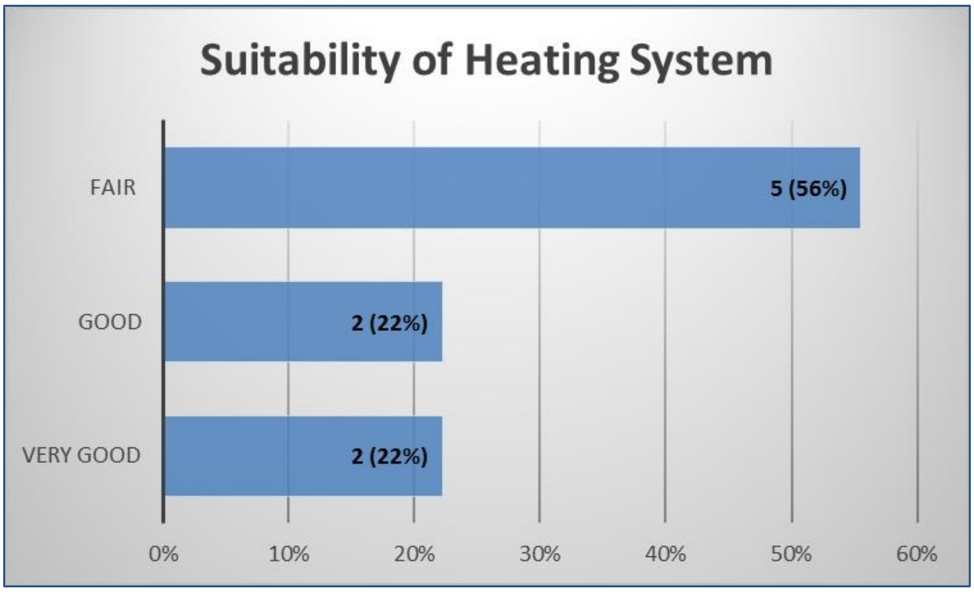


Figure 15.1.29: Suitability of Heating System in Holiday Homes

Holiday Homes: Total Annual Electricity Consumption and Demand

Similar to the analysis done in the household section, computation was done to differentiate the consumption by holiday home and by area for residents using predominantly central oil heaters and electrical heaters. The electricity consumption by person were not carried out due to uncertainty of occupancy in the holiday homes. Computed results are summarized in tables below:

Table 15.1.15: Annual Electricity Consumption: HH with Predominant Central Oil Heating System

Predominantly Central Oil Heating System (Only 1 Holiday Home)					Comments
Expense Indicators	Expenditure		Electricity consumption		
Average per Holiday Home	240	£/holiday home	1,537	kWh/holiday home	Based on 1 holiday home
Average per area	4	£/sqm	25.6	kWh/sqm	Area of Holiday Home = 60 sqm

Table 15.1.16: Annual Electricity Consumption: HH with Predominant Electrical Heating System

Predominantly Electric Heating System					Comments
Consumption Indicators	Expenditure		Electricity consumption		
Average per Holiday Home	1,029	£/ holiday home	6,589	kWh/holiday home	Based on 7 holiday homes which provided information on cash spent for electricity
Average per area	14.7	£/sqm	94	kWh/sqm	Based on 2 holiday homes which provided information on living space areas (sum = 150 sqm)

Predominant Water Heating Technologies Used

Most (67%) of holiday homes use instantaneous electrical and immersion water heaters.

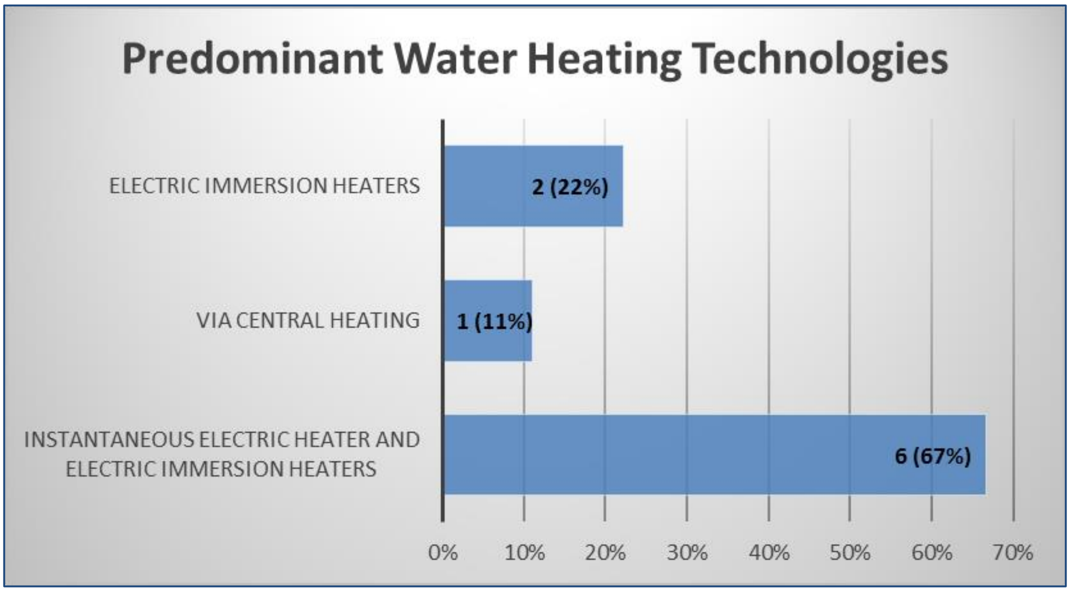


Figure 15.1.30: Predominant Water heating Technologies use in Holiday Homes

Predominant Lighting Technologies Used

Most (67%) of holiday homes use halogen lighting technologies.

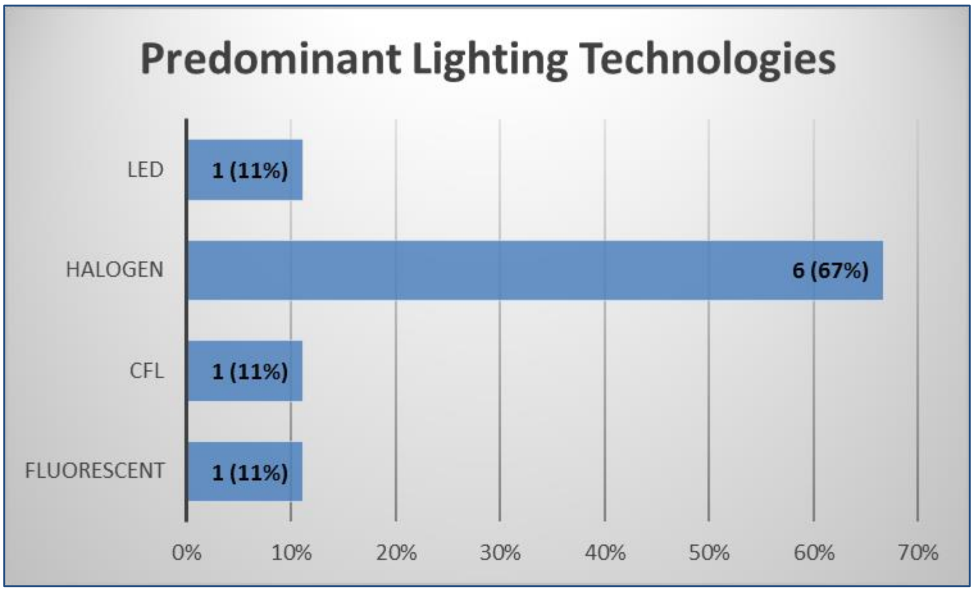


Figure 15.1.31: Predominant Lighting Technologies used in Holiday Homes

Predominant Cooking Technologies Used

All 9 holiday homes use electrical cooking. One of the 9 holiday homes use gas cooking stove in addition to the electrical cooking.

15.2 Annex for Economic Methodology

Feed-in Tariff Generation & Export Payment Rate Table– 08 February – 31 March 2016

The tariff rates in the below table apply in respect of electricity generated in the Relevant Period in FIT Year 6 by installations with a Tariff Date between 8th February 2016 and 31st March 2016.

Description	*Tariff*
Anaerobic digestion with total installed capacity of 250kW or less	9.12
Anaerobic digestion with total installed capacity greater than 250kW but not exceeding 500kW	8.42
Anaerobic digestion with total installed capacity greater than 500kW	8.68
Combined Heat and Power with total installed capacity of 2kW or less	13.45
Hydro generating station with total installed capacity of less than 100kW	8.54
Hydro generating station with total installed capacity greater than 100kW but not exceeding 500kW	6.14
Hydro generating station with total installed capacity greater than 500kW but not exceeding 2 MW	6.14
Hydro generating station with total installed capacity greater than 2 MW	4.43
Solar photovoltaic (other than stand-alone) with total installed capacity of 10 kW or less	Higher rate 4.39
	Middle rate 3.95
	Lower rate 0.87
Solar photovoltaic (other than stand-alone) with total installed capacity greater than 10 kW but not exceeding 50kW	Higher rate 4.59
	Middle rate 4.13
	Lower rate 0.87
Solar photovoltaic (other than stand-alone) with total installed capacity greater than 50 kW but not exceeding 250kW	Higher rate 2.70
	Middle rate 2.43
	Lower rate 0.87
Solar photovoltaic (other than stand-alone) with total installed capacity greater than 250 kW but not exceeding 1 MW	2.27
Solar photovoltaic (other than stand-alone) with total installed capacity greater than 1 MW	0.87
Stand-alone solar photovoltaic	0.87
Wind with total installed capacity of 50kW or less	8.53
Wind with total installed capacity greater than 50kW but not exceeding 100 kW	8.53
Wind with total installed capacity greater than 100 kW but not exceeding 1.5 MW	5.46
Wind with total installed capacity exceeding 1.5MW	0.86
EXPORT TARIFF	4.85

Figure 15.2.1 Current FIT (Date of publication: 12 February 2016)

Source: (ofgem, 2016)

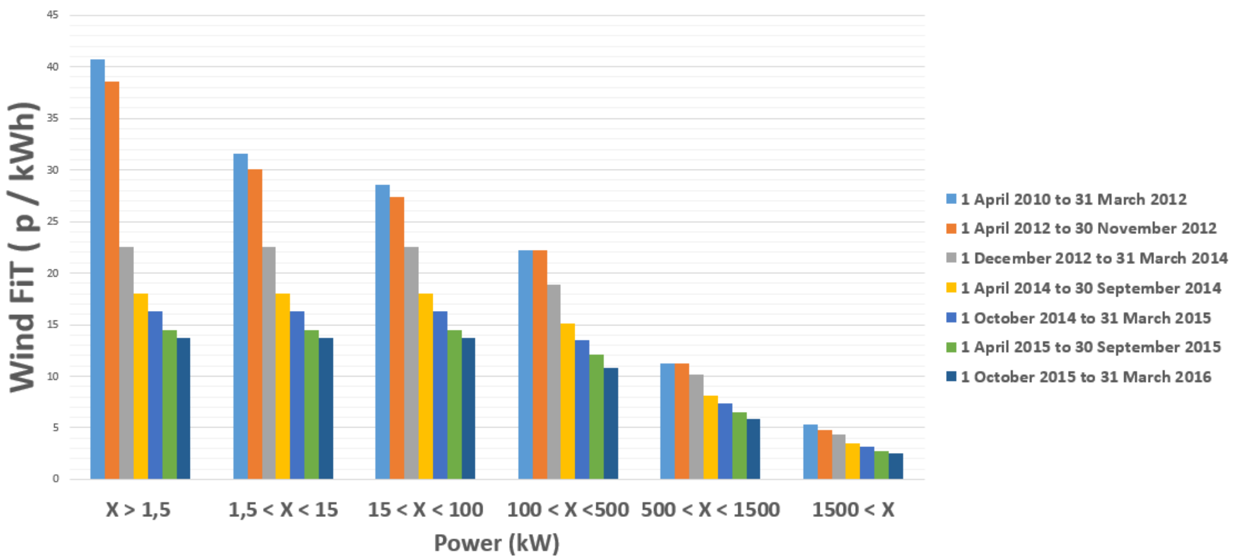


Figure 15.2.2 Feed-in Tariffs Scheme – Degression Trends

Source: (ofgem, 2016)

15.3 Gleann Dubhlinn project

15.3.1 Gleann Dubhlinn project: Hydro

Table 15.3.1 Laxdale river flow measurements (sample data)

No	Date	Time	River Discharge [m³/s]
1	24.10.2007	09:15:00	0,452
2	24.10.2007	09:30:00	0,461
3	24.10.2007	09:45:00	0,447
4	24.10.2007	10:00:00	0,447
5	24.10.2007	10:15:00	0,438
6	24.10.2007	10:30:00	0,433
7	24.10.2007	10:45:00	0,424
8	24.10.2007	11:00:00	0,424
9	24.10.2007	11:15:00	0,424
10	24.10.2007	11:30:00	0,419
11	24.10.2007	11:45:00	0,415
12	24.10.2007	12:00:00	0,406
13	24.10.2007	12:15:00	0,401
14	24.10.2007	12:30:00	0,397
15	24.10.2007	12:45:00	0,392
16	24.10.2007	13:00:00	0,392
17	24.10.2007	13:15:00	0,388
18	24.10.2007	13:30:00	0,383
19	24.10.2007	13:45:00	0,383
20	24.10.2007	14:00:00	0,379
21	24.10.2007	14:15:00	0,371
22	24.10.2007	14:30:00	0,371
23	24.10.2007	14:45:00	0,371
24	24.10.2007	15:00:00	0,362
25	24.10.2007	15:15:00	0,358
26	24.10.2007	15:30:00	0,362
27	24.10.2007	15:45:00	0,354
28	24.10.2007	16:00:00	0,354
29	24.10.2007	16:15:00	0,358

30	24.10.2007	16:30:00	0,35
31	24.10.2007	16:45:00	0,35
32	24.10.2007	17:00:00	0,35

Source: SEPA (2016)

Luskentyre Banks and Saltings

The documented area of this Site of Special Scientific Interest is about 1060 ha. According to the Site Management Statement (Scottish Natural Heritage, 2011) this site on the west coast of South Harris is an example of *transition from open sea, through sand flats, marsh, sand dunes and machair to acid peat moorland.* The characteristics of the dune ridges are unique to Harris. The breeding bird assemblage includes species normal to coastal habitats.

Currently there are several common grazing areas and Horgabost is a recreational area. The beach is highly visited specially during summer. The scientific interest has been threatened by the recreational use of the machair. The objectives included in the management statement include:

- *Maintain the extent of saltmarsh habitats by appropriate management of brazing, enable plants to set seed and minimize poaching.*
- *Maintain breeding bird populations by avoiding significant disturbance and maintaining habitats.*

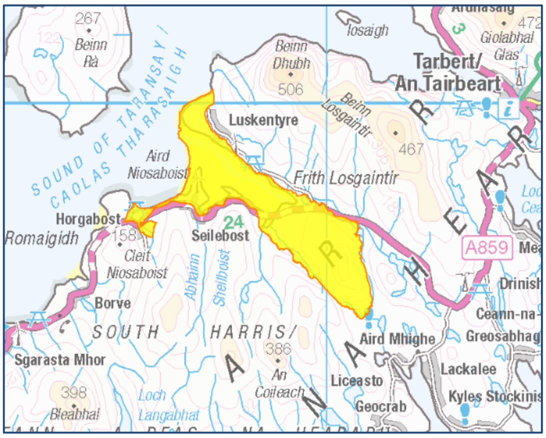


Figure 15.3.1 Map extract showing the location of the Luskentyre Banks and Saltings
Source: Scottish Natural Heritage (2016)

As the future implementation of the Gleann Dubhlinn hydro scheme is located in close proximity of the SSSI, it is important for it to consider (if applicable) the site management objectives to contribute to maintain the site's scientific value.

Correlation calculations

Based on available data for the Abhainn Gil an Tailleir River provided by WHT a correlation was made using data of the Gleann Dubhlinn site and the Laxdale river.

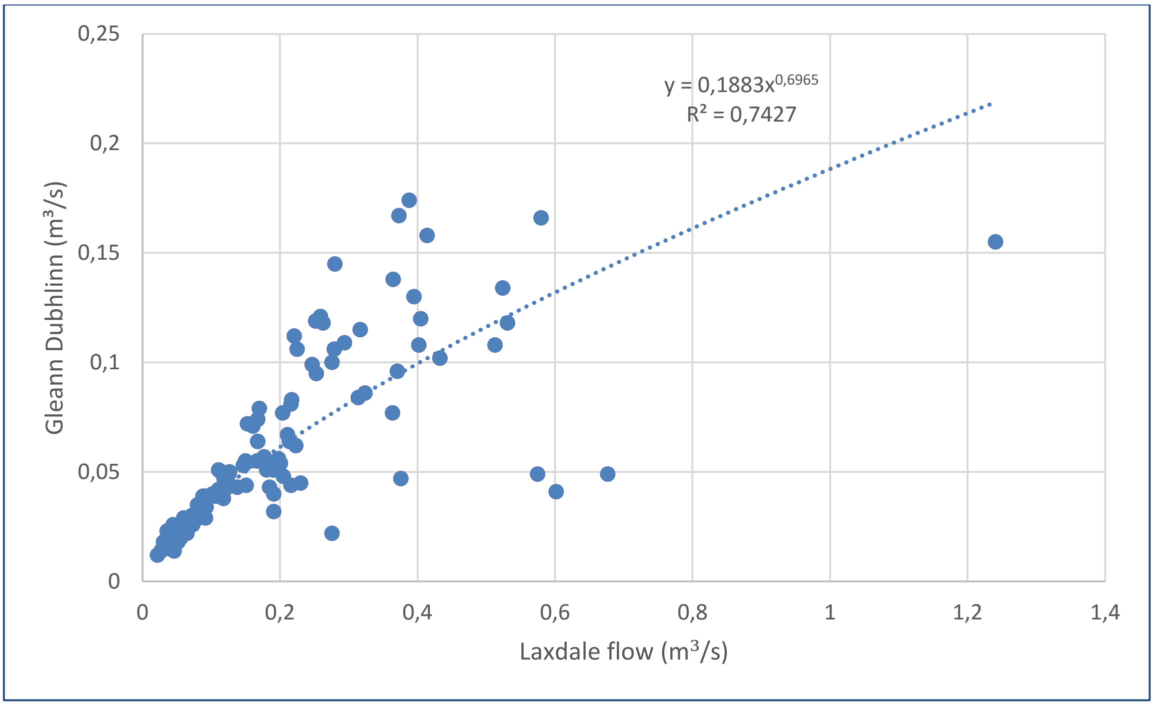


Figure 15.3.2 Gleann Dubhlinn correlation calculation using flow (m³/s) measurements
Source: Own elaboration based on data provided by SEPA

The equation was later used to correlate the long-term flow data (eight years) of the Laxdale River to estimate the flow for the Gleann Dubhlinn site.

Gilkes Turgo Turbine

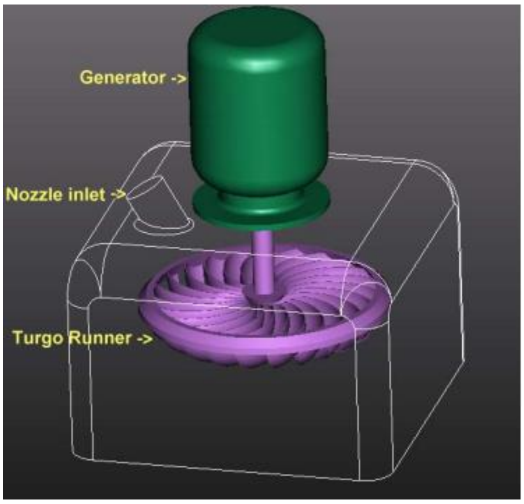


Figure 15.3.3 Gilkes Turgo Turbine
Source: Singh, (2009)

Efficiency calculations for Gleann Dubhlinn

Table 15.3.2 Efficiencies from turbine supplier's specifications (Turgo Turbine)

Flow (%)	Pipeline + Intake Efficiency	Turbine Efficiency	Generator Efficiency	Overall Efficiency
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
100%	95.00%	83.69%	92.95%	73.90%
89%	96.00%	83.74%	92.87%	74.66%
71%	97.40%	83.50%	92.60%	75.31%
60%	98.20%	82.85%	92.25%	75.05%
48%	98.90%	81.28%	91.63%	73.66%
42%	99.10%	79.41%	91.10%	71.69%
30%	99.60%	72.62%	89.02%	64.39%
18%	99.80%	51.83%	80.55%	41.67%
18%	99.80%	51.83%	80.55%	41.67%
12%	99.90%	36.11%	63.18%	22.79%
0%	0.00%	0.00%	0.00%	0.00%
0%	0.00%	0.00%	0.00%	0.00%
0%	0.00%	0.00%	0.00%	0.00%
0%	0.00%	0.00%	0.00%	0.00%
AVERAGE	**79.94%**	**63.48%**	**74.05%**	**67.36%**

Source: Gilkes (2010)

Comparison between hydrograph from literature and Own elaboration results

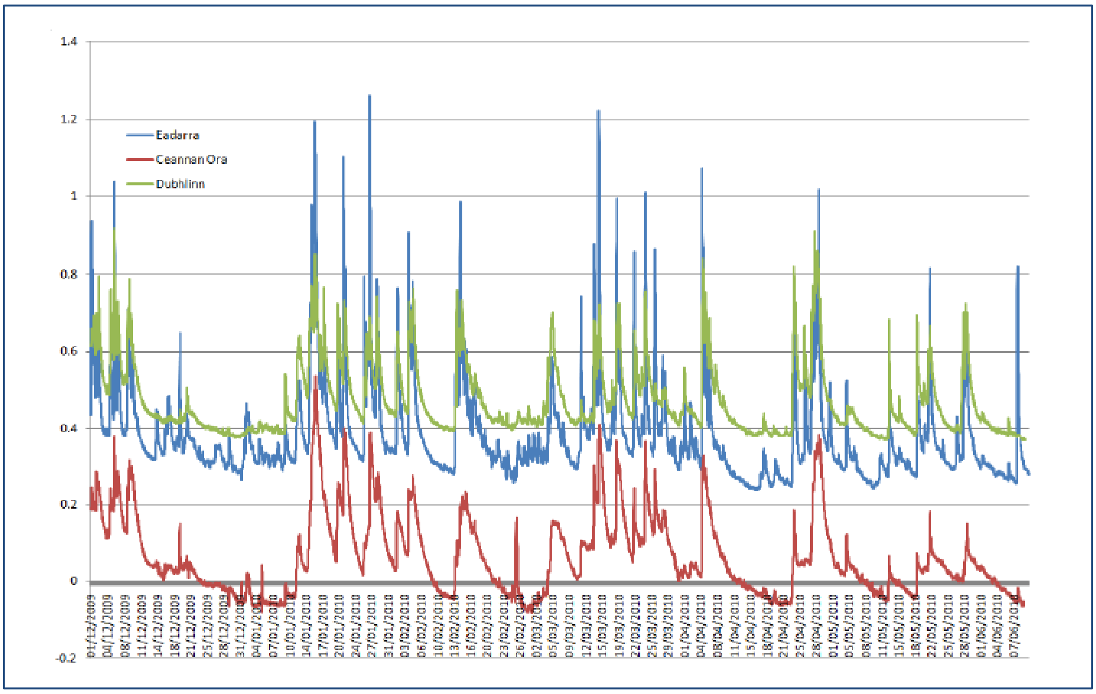


Figure 15.3.4 Observed water levels between Nov 2009 and June 2010
Source: Wallingford HydroSolutions (2010)

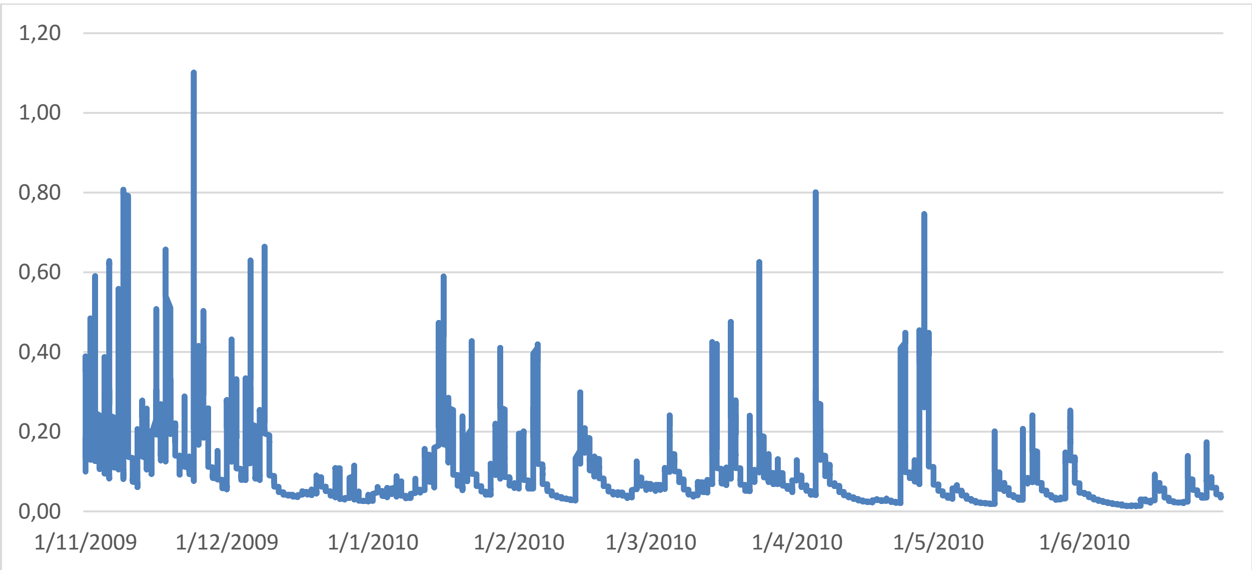


Figure 15.3.5 Gleann Dubhlinn hydrograph for the same time period reported in Wallingdford (2010)
Source: Own elaboration

Gleann Dubhlinn calculation sample data

Table 15.3.3 Gleann Dubhlinn calculation sample data

No	Date	Time	Flow (m3/s)	Average flow-base flow (m³/s)	Operational flow (m³/s)	Intake Flow (m³/s)	Intake Flow (%)	Overall Efficiency	Energy (KWh)	Annual Energy (MWh)
1	01. Jan	00:00:00	0,117163181	0,10468137	0,10468137	0,1046814	62%	74,45%	15,48306391	389,8350126
2	01. Jan	00:15:00	0,116355602	0,10387379	0,10387379	0,1038738	62%	74,38%	15,34827852	
3	01. Jan	00:30:00	0,116355602	0,10387379	0,10387379	0,1038738	62%	74,38%	15,34827852	
4	01. Jan	00:45:00	0,114733061	0,102251249	0,102251249	0,1022512	61%	74,24%	15,07984997	
5	01. Jan	01:00:00	0,113918034	0,101436223	0,101436223	0,1014362	60%	74,17%	14,9462401	
6	01. Jan	01:15:00	0,113100459	0,100618647	0,100618647	0,1006186	60%	74,11%	14,81304693	
7	01. Jan	01:30:00	0,1122803	0,099798488	0,099798488	0,0997985	59%	74,05%	14,68027435	
8	01. Jan	01:45:00	0,111457522	0,09897571	0,09897571	0,0989757	59%	73,99%	14,54792094	
9	01. Jan	02:00:00	0,111457522	0,09897571	0,09897571	0,0989757	59%	73,99%	14,54792094	
10	01. Jan	02:15:00	0,109803963	0,097322152	0,097322152	0,0973222	58%	73,89%	14,28443946	
11	01. Jan	02:30:00	0,110632088	0,098150277	0,098150277	0,0981503	58%	73,94%	14,41598001	
12	01. Jan	02:45:00	0,10830643	0,095824618	0,095824618	0,0958246	57%	73,80%	14,0486161	
13	01. Jan	03:00:00	0,10747056	0,094988748	0,094988748	0,0949887	57%	73,76%	13,91808615	
14	01. Jan	03:15:00	0,106631847	0,094150035	0,094150035	0,09415	56%	73,72%	13,78786113	
15	01. Jan	03:30:00	0,106631847	0,094150035	0,094150035	0,09415	56%	73,72%	13,78786113	
16	01. Jan	03:45:00	0,105958802	0,09347699	0,09347699	0,093477	56%	73,69%	13,68387518	

Source: Own elaboration

Energy generation with different storage volumes Gleann Dubhlinn

Table 15.3.4 Energy generation with different storage volumes Gleann Dubhlinn

Height of Dam(m)	Volume of Storage (m³/s)	Annual Energy Generation (MWh)	Additional energy generated from Storage (MWh)
0.5	56000	495.6646	105.8295874
1	56000	536.2617059	146.4266933
1.25	70000	547.0502991	157.2152865
1.5	84000	554.677136	164.8421234
2	112000	566.6846571	176.8496445
2.5	140000	571.7454796	181.910467

Source: Own elaboration

15.3.2 Gleann Dubhlinn project: Wind

Gleann Dubhlinn: Noise Map

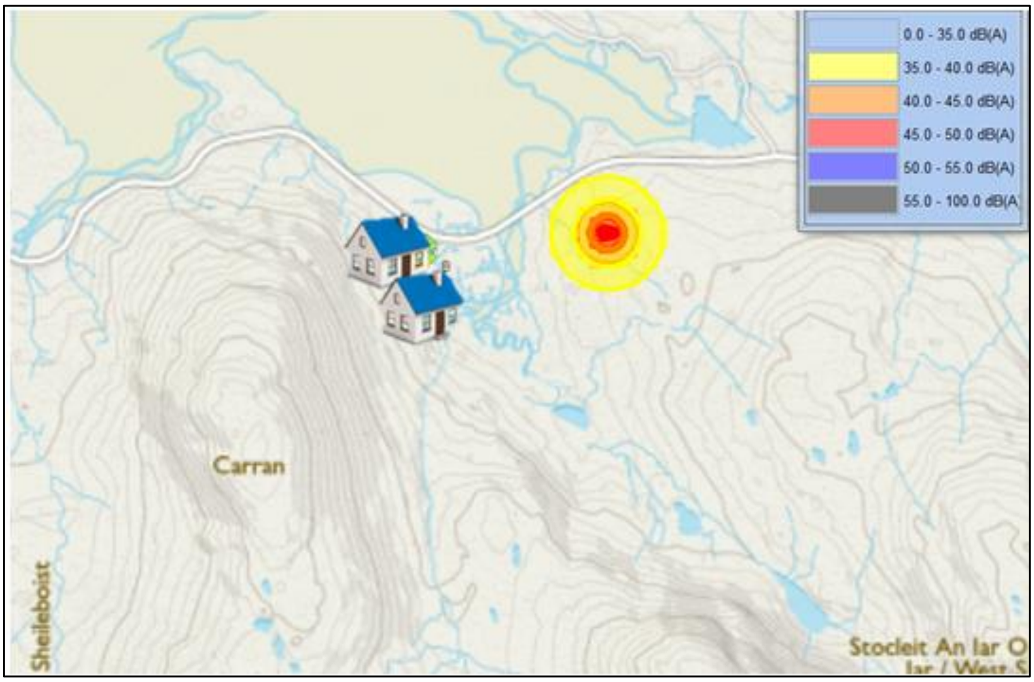


Figure 15.3.6. Gleann Dubhlinn Scenario I and II: Noise map (Source: WindPRO®)

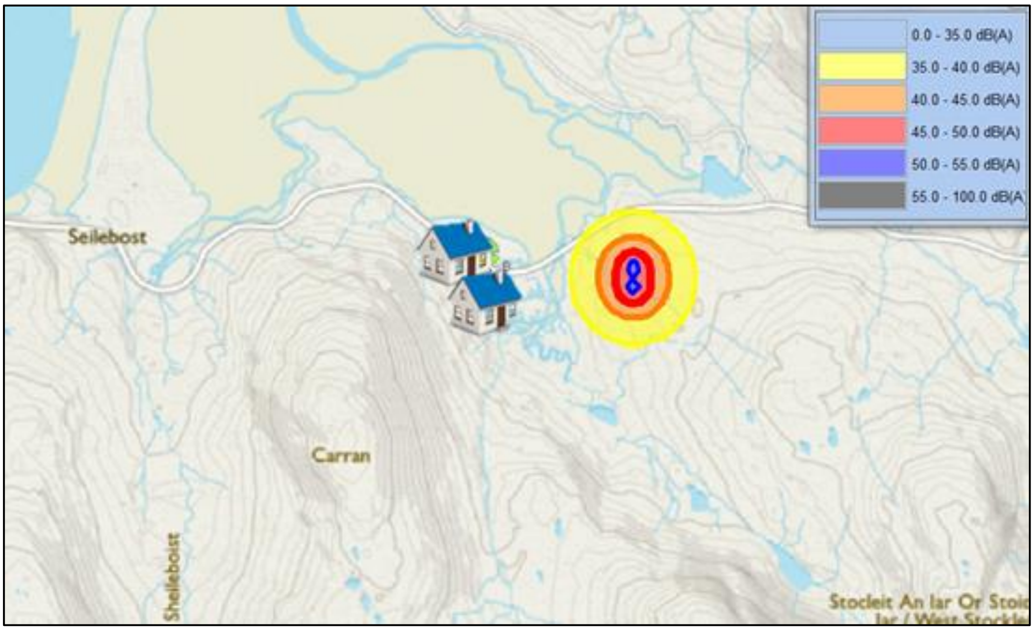


Figure 15.3.7 Gleann Dubhlinn Scenario III: Noise map (Source: WindPRO®)

Gleann Dubhlinn: Shadow Map

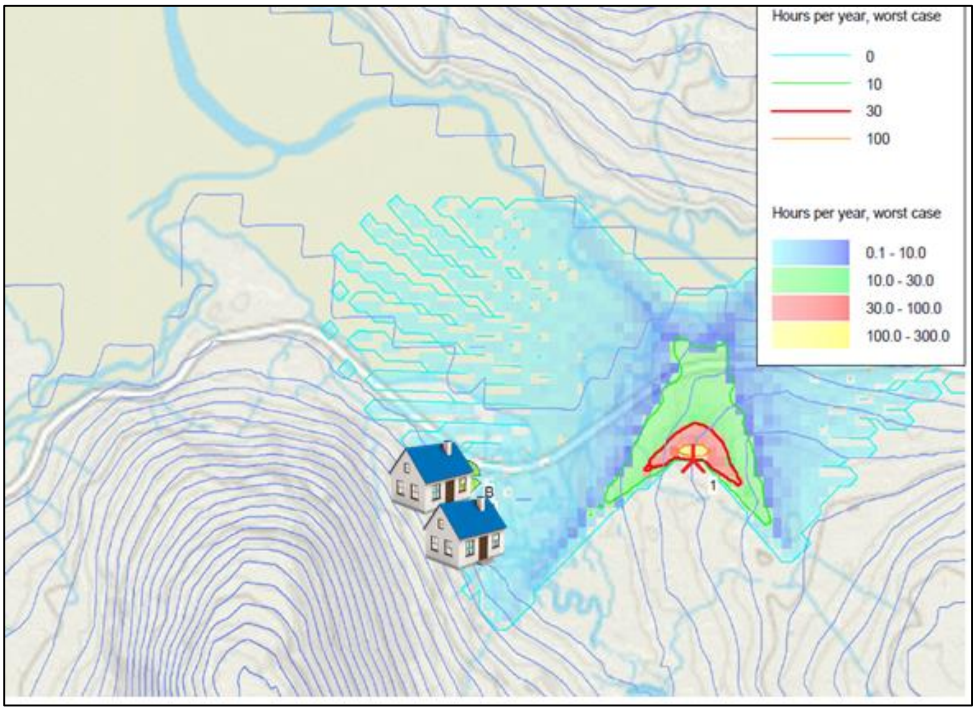


Figure 15.3.8 Glean Dubhlinn Scenario I and II: Shadow map (Source: WindPRO®)

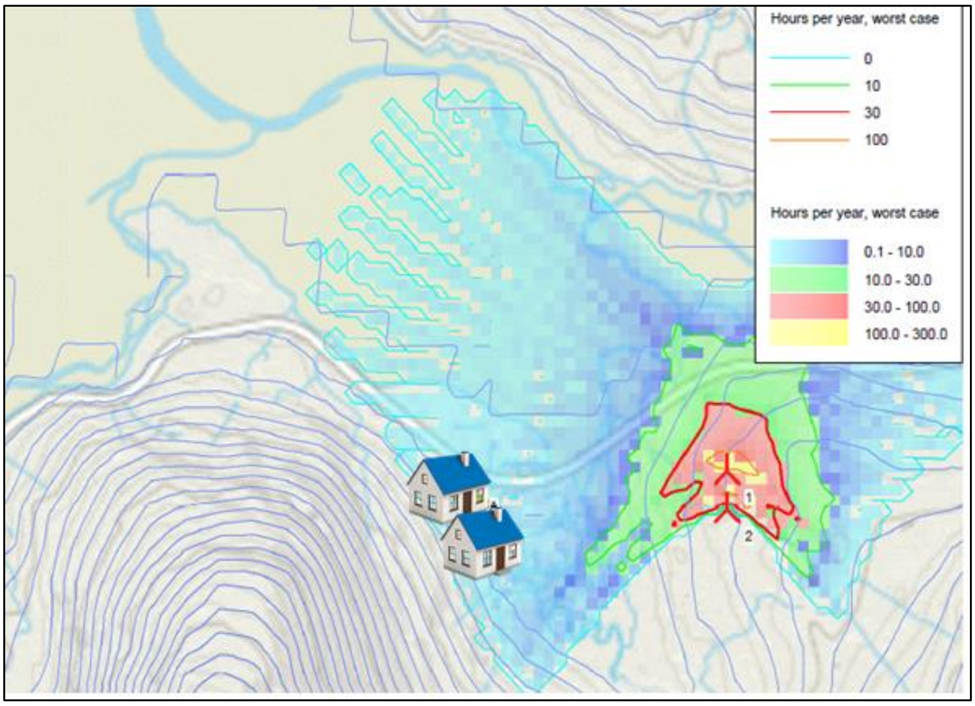


Figure 15.3.9 Gleann Dubhlinn Scenario III: Shadow map (Source: WindPRO®)

Gleann Dubhlinn Scenario I and II Visualization: Xant 100 kW

Figure 15.3.10 Visualization of Gleann Dubhlinn Scenario I and II - Viewpoint 1 (Source: WindPRO®)

Figure 15.3.11 Visualization of Gleann Dubhlinn Scenario I and II - Viewpoint 2 (Source: WindPRO®)

Figure 15.3.12 Visualization of Gleann Dubhlinn Scenario I and II - Viewpoint 4 (Source: WindPRO®)

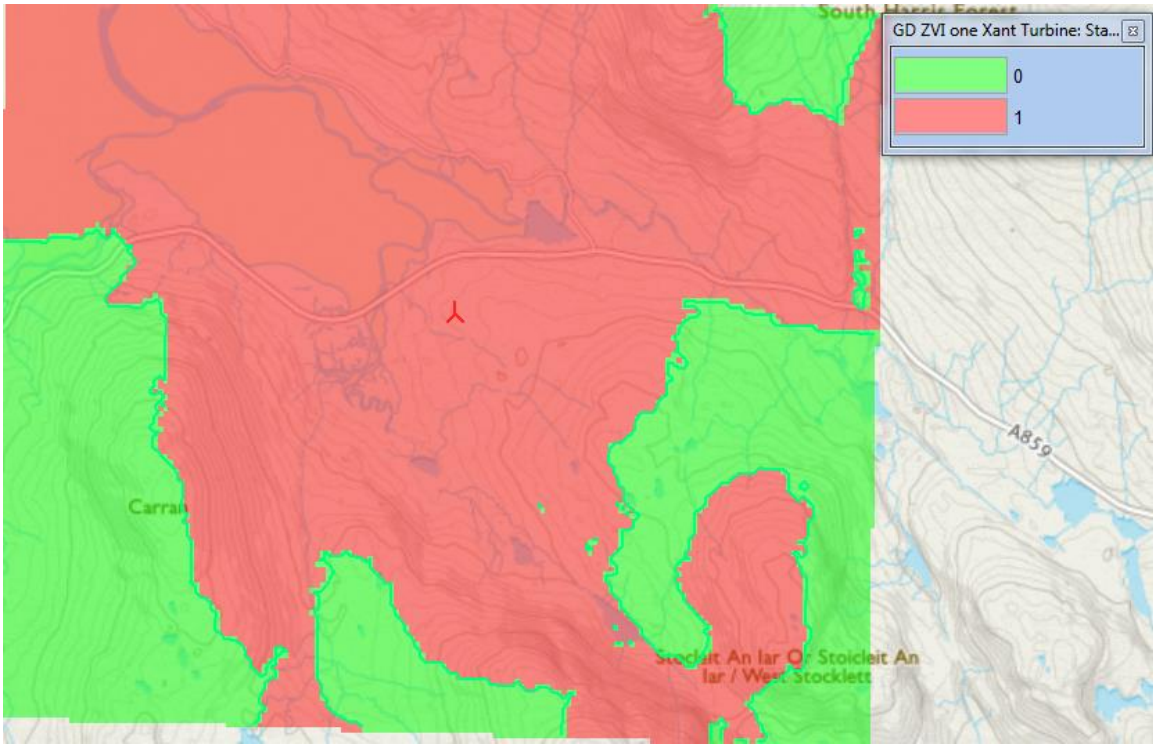


Figure 15.3.13 Zones of Visual Impact for Gleann Dubhlinn 100kW Xant M 21 Turbine

Gleann Dubhlinn Scenario III Visualization: 2 x Xant 100 kW

Figure 15.3.14 Visualization of Gleann Dubhlinn Scenario III- Viewpoint 1 (Source: WindPRO®)

Figure 15.3.15 Visualization of Gleann Dubhlinn Scenario III - Viewpoint 2 (Source: WindPRO®)

Figure 15.3.16 Visualization of Gleann Dubhlinn Scenario III- Viewpoint 4 (Source: WindPRO®)

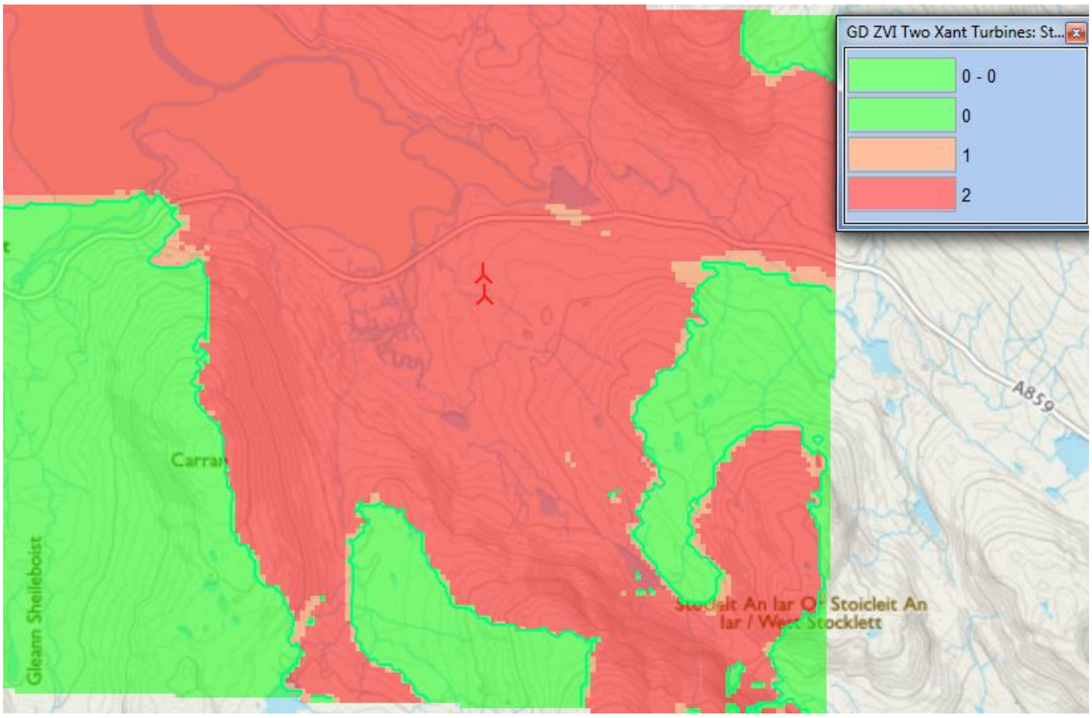
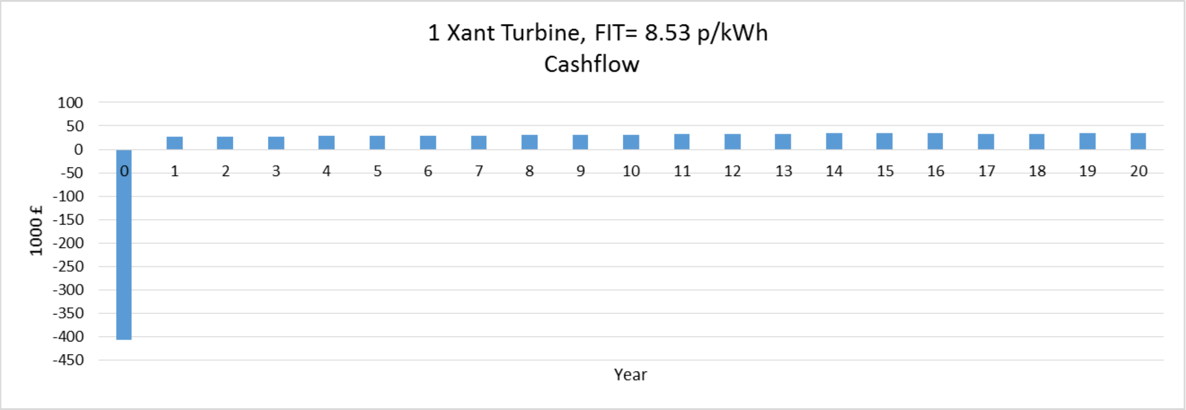


Figure 15.3.17 Zones of Visual Impact for Gleann Dubhlinn2 x 100kW Xant M 21 Turbine

15.3.3 Gleann Dubhlinn project: Economic Analysis Results

Gleann Dubhlinn Scenario 1

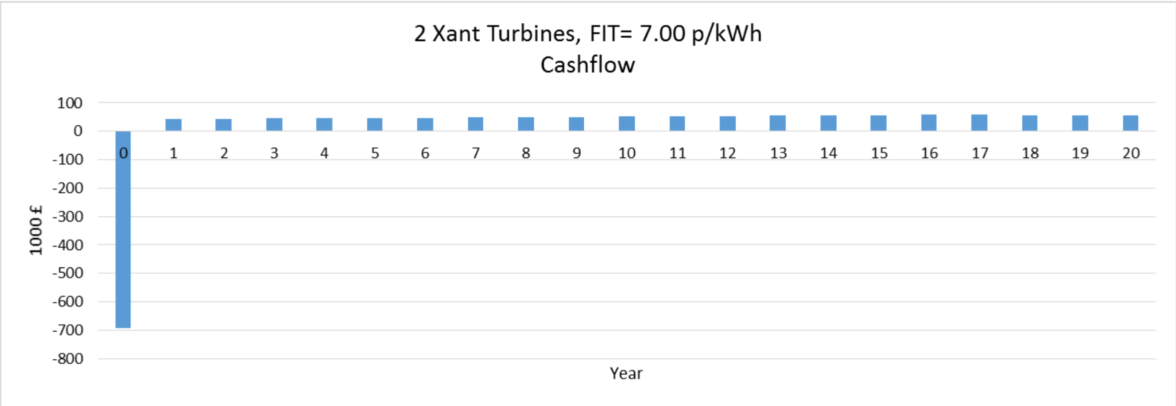
Xant 1	**% Increase in gen**	**0%**	0%	0%	0%	0%	0%
	NPVproject (£)	-471136	-322939	-147475	1079	99764	574998
	IRR (%)	NA	-9.17%	-0.76%	3.53%	5.95%	15.30%
	LCOE (£)	0.1550	0.1550	0.1550	0.1550	0.1550	0.1550
	Payback Period (years)	> 20	> 20	> 20	20	16	8
	ADSCR	-0.12	0.16	0.49	0.77	0.96	1.84
	FIT £/kwh	0.0000	0.0250	0.0546	0.0800	0.1000	0.2000
	% Increase in gen	20%	20%	20%	20%	20%	20%
	NPVproject (£)	-413636	-200233	-57964	157761	241615	810690
	IRR (%)	NA	-2.67%	1.96%	7.28%	9.06%	19.26%
	LCOE (£)	0.129	0.129	0.129	0.129	0.129	0.129
	Payback Period (years)	> 20	> 20	> 20	14.00	12.00	6.00
	ADSCR	-0.0108	0.3873	0.6526	1.0605	1.2163	2.2778
	FIT £/kwh	0.000	0.030	0.050	0.085	0.100	0.200
	% Increase in gen	-20%	-20%	-20%	-20%	-20%	-20%
	NPVproject (£)	-528636	-386368	-291522	-124119	-54407	339306
	IRR (%)	NA	-17.34%	-7.03%	0.00%	2.06%	11.00%
	LCOE (£)	0.1937	0.1937	0.1937	0.1937	0.1937	0.1937
	Payback Period (years)	> 20	> 20	> 20	> 20	> 20	10
	ADSCR	-0.2253	0.0400	0.2170	0.5292	0.6593	1.3985
	FIT £/kwh	**0.000**	0.030	0.050	0.085	0.100	0.200

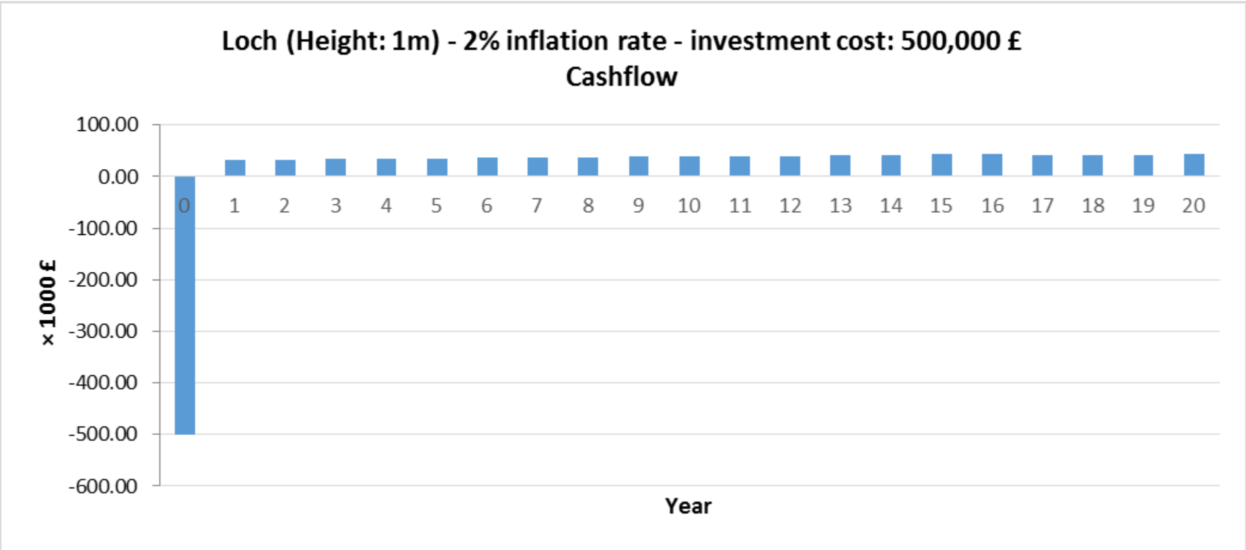


Gleann Dubhlinn Scenario 2

Gleann Dubhlin: 2 Xant

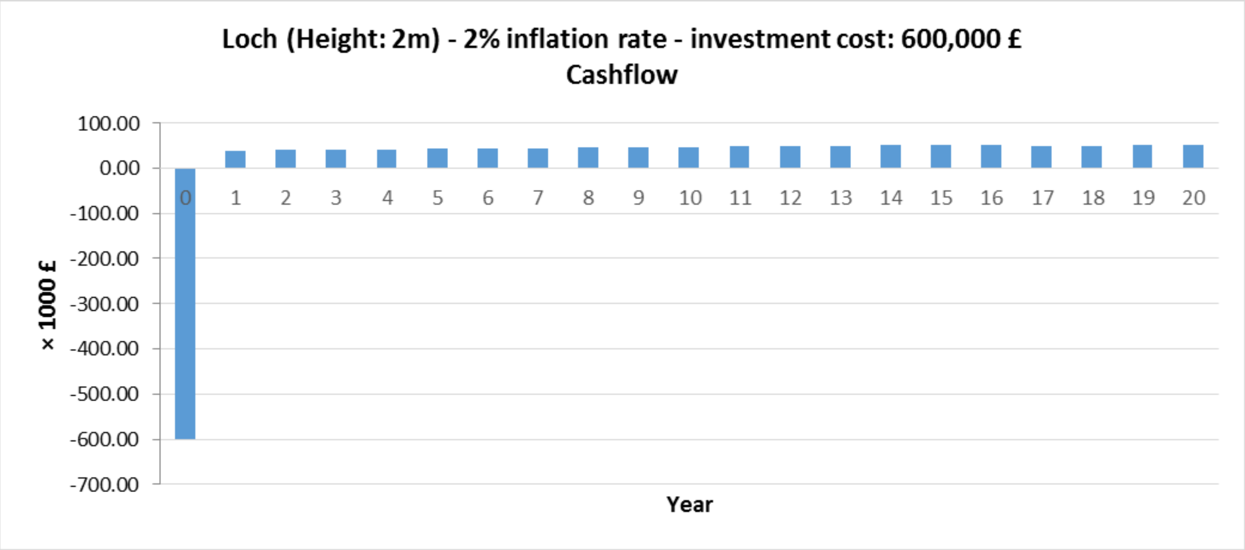
% Increase in gen	**0%**	0%	0%	0%	0%
NPVproject (£)	-757570	-417317	-61186	307022	1214484
IRR (%)	NA	-4.61%	2.56%	7.78%	17.68%
LCOE (£)	0.1376	0.1376	0.1376	0.1376	0.1376
Payback Period (years)	> 20	> 20	> 20	13	7
ADSCR	-0.070937283	0.302609637	0.693588746	1.102872681	2.098897629
FIT £/kwh	0.0000	0.0300	0.0614	0.1000	0.2000
% Increase in gen	20%	20%	20%	20%	20%
NPVproject (£)	-651284	-242980	151238	573641	1662450
IRR (%)	-16.60%	-0.61%	5.70%	10.97%	21.97%
LCOE (£)	0.115	0.115	0.115	0.115	0.115
Payback Period (years)	> 20	> 20	16	10	6
ADSCR	0.046	0.494	0.936	1.395	2.591
FIT £/kwh	0.0000	0.0300	0.0614	0.1000	0.2000
% Increase in gen	-20%	-20%	-20%	-20%	-20%
NPVproject (£)	-863856	-591654	-306749	34203	766519
IRR (%)	#NUM!	-11.42%	-1.92%	4.01%	13.10%
LCOE (£)	0.1721	0.1721	0.1721	0.1721	0.1721
Payback Period (years)	> 20	> 20	> 20	19	9
ADSCR	-0.19	0.11	0.42	0.81	1.61
FIT £/kwh	0.0000	0.0300	0.0614	0.1000	0.2000





Loch with 1 m height - 2.0% inflation rate - Energy Generation: 146.43 MWh							
NPVproject	413122.95	320194.04	227265.13	133926.03	37329.73	-70746.30	-187964.82
IRR	32.77%	16.62%	10.40%	6.80%	4.27%	2.24%	0.46%
LCOE	0.0566	0.1132	0.1698	0.2264	0.2829	0.3395	0.3961
Payback Period	4	7	11	15	19	21	21
ADSCR	3.9066	1.9826	1.3413	1.0214	0.8311	0.6708	0.5562
Total Investment Cost	100000	200000	300000	400000	500000	600000	700000

Loch with 1 m height - 0.3% inflation rate - Energy Generation: 146.43 MWh							
NPVproject	338894.96	248045.76	157196.56	65488.47	-35914.22	-150533.11	-265151.99
IRR	30.66%	14.84%	8.77%	5.26%	2.70%	0.53%	-1.21%
LCOE	0.0553	0.1107	0.1660	0.2213	0.2767	0.3320	0.3873
Payback Period	4	8	12	17	21	21	21
ADSCR	3.3875	1.7304	1.1780	0.9035	0.7159	0.5778	0.4791
Total Investment Cost	100000	200000	300000	400000	500000	600000	700000



Loch with 2 m height - 2.0 % inflation rate - Energy Generation: 176.85 MWh							
NPVproject	518252.34	425323.43	332394.52	239465.61	145720.03	48897.13	-56553.08
IRR	39.15%	20.16%	13.10%	9.11%	6.39%	4.34%	2.64%
LCOE	0.0469	0.0937	0.1406	0.1874	0.2343	0.2811	0.3280
Payback Period	3	6	9	12	15	19	21
ADSCR	4.706	2.38	1.61	1.22	0.989325721	0.837304763	0.698993504
Total Investment Cost	100000	200000	300000	400000	500000	600000	700000

Loch with 2 m height - 0.3 % inflation rate - Energy Generation: 176.85 MWh							
NPVproject	428171.87	337322.66	246473.46	155624.26	63129.03	-38936.98	-153555.86
IRR	36.93%	18.31%	11.40%	7.51%	4.87%	2.78%	0.93%
LCOE	0.0458	0.0916	0.1374	0.1833	0.2291	0.2749	0.3207
Payback Period	3	6	10	13	17	21	21
ADSCR	4.0760	2.0746	1.4075	1.0739	0.8767	0.7212	0.6021
Total Investment Cost	100000	200000	300000	400000	500000	600000	700000

15.4 Laxdale project

15.4.1 Laxdale Project: Wind

Laxdale Noise Maps

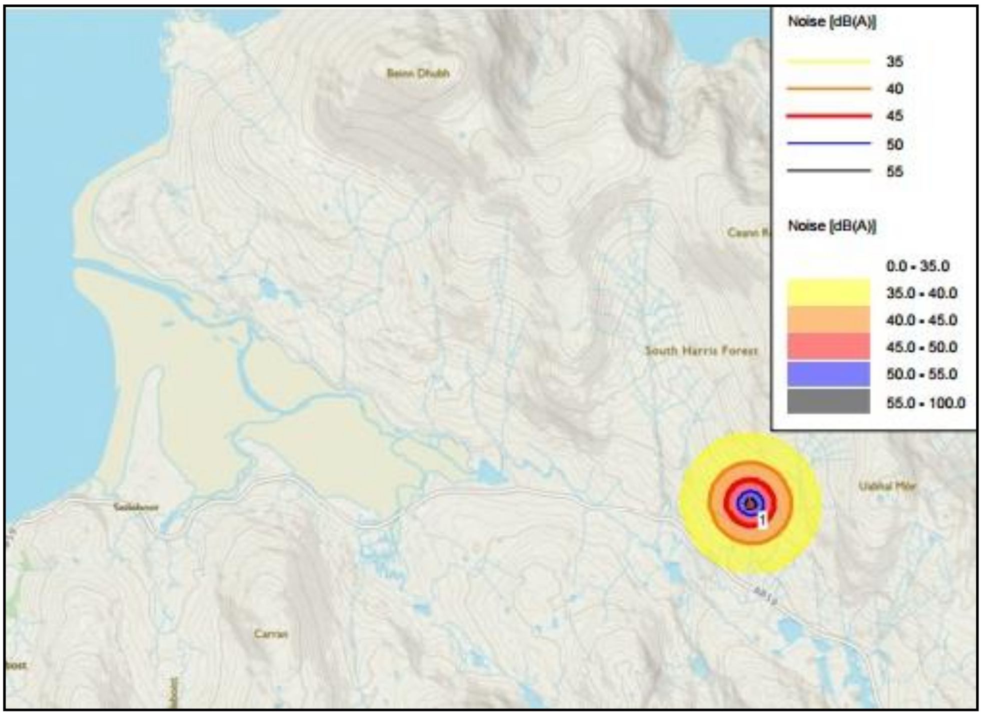


Figure 15.4.1 Laxdale Scenario I: Noise map (Source: WindPRO®)

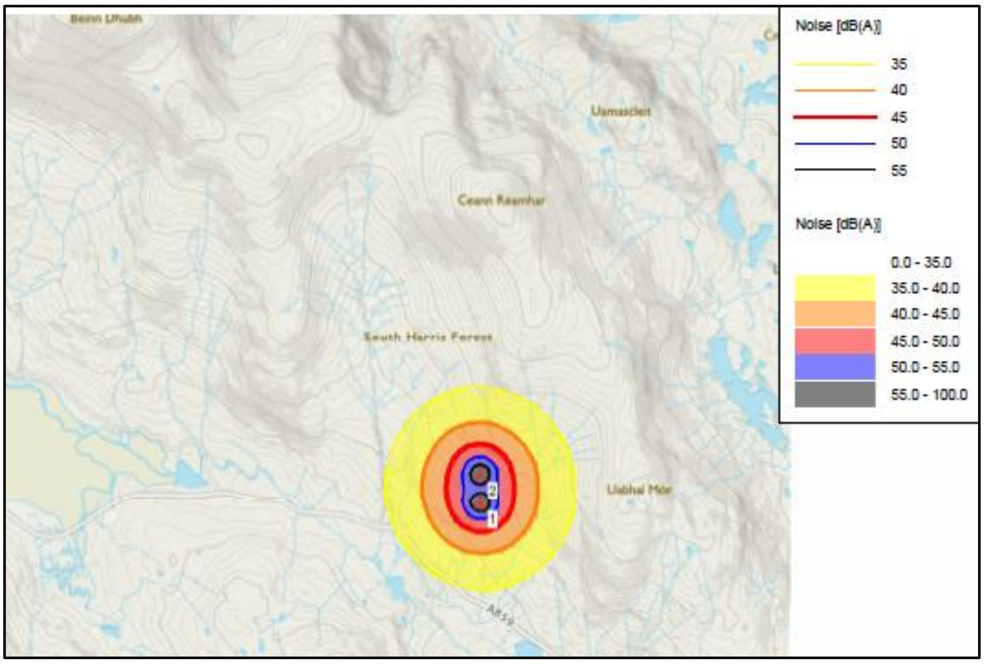


Figure 15.4.2 Laxdale Scenario II: Noise map (Source: WindPRO®)

Laxdale Shadow Maps

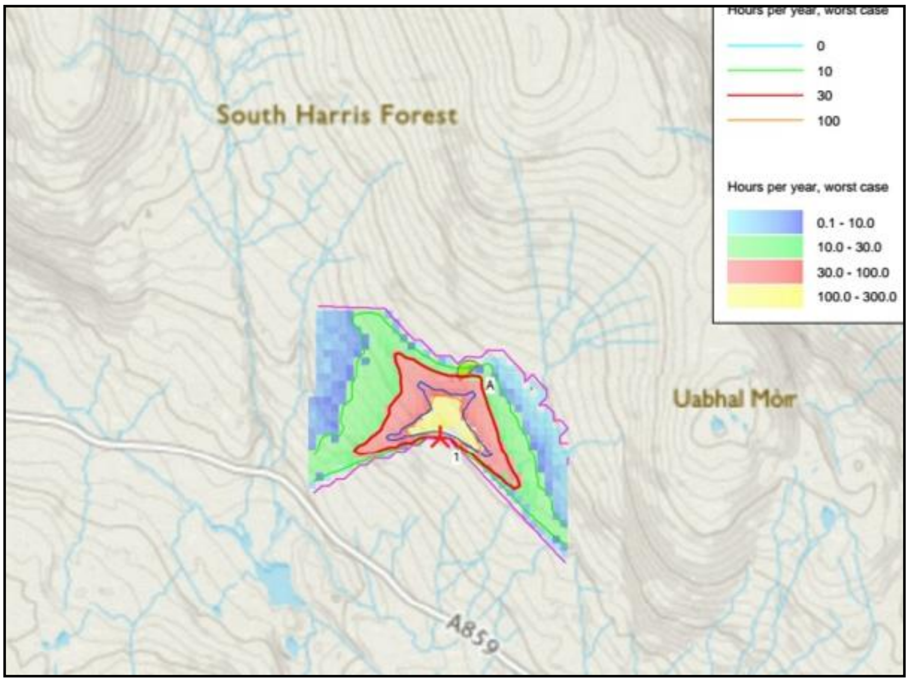


Figure 15.4.3 Laxdale Scenario I: Shadow map (Source: WindPRO®)

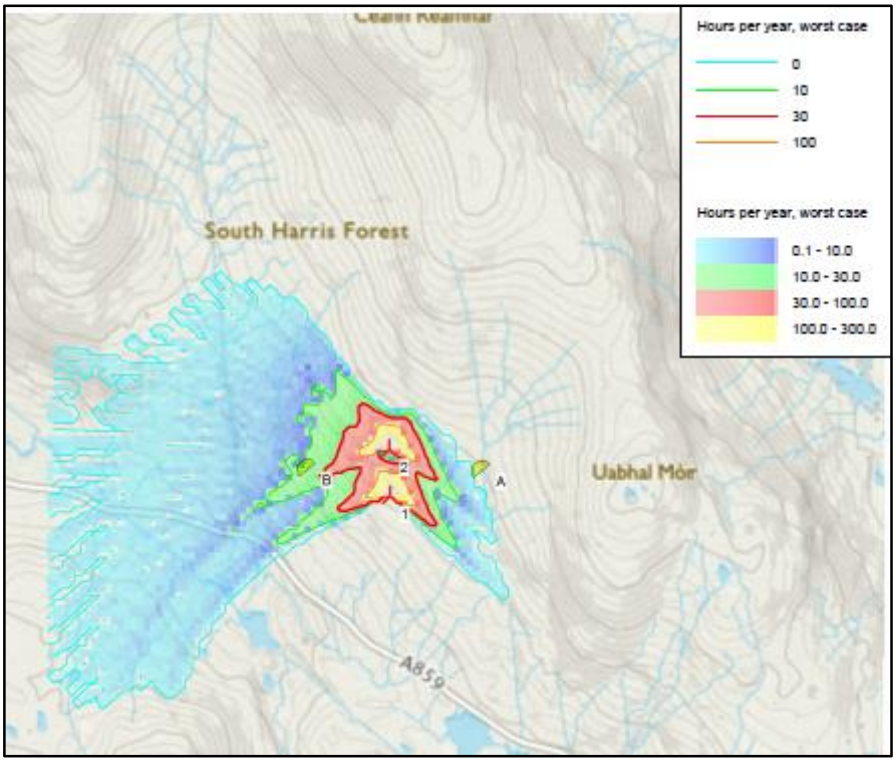


Figure 15.4.4 Laxdale Scenario II: Shadow map (Source: WindPRO®)

Laxdale Scenario I Visualization

The coordinates of the viewpoint for Laxdale are **6°51′43.33″W, 57°51′32.88″N.**

Figure 15.4.5 Visualization of Laxdale Scenario I- ENERCON E-44 (Source: WindPRO®)

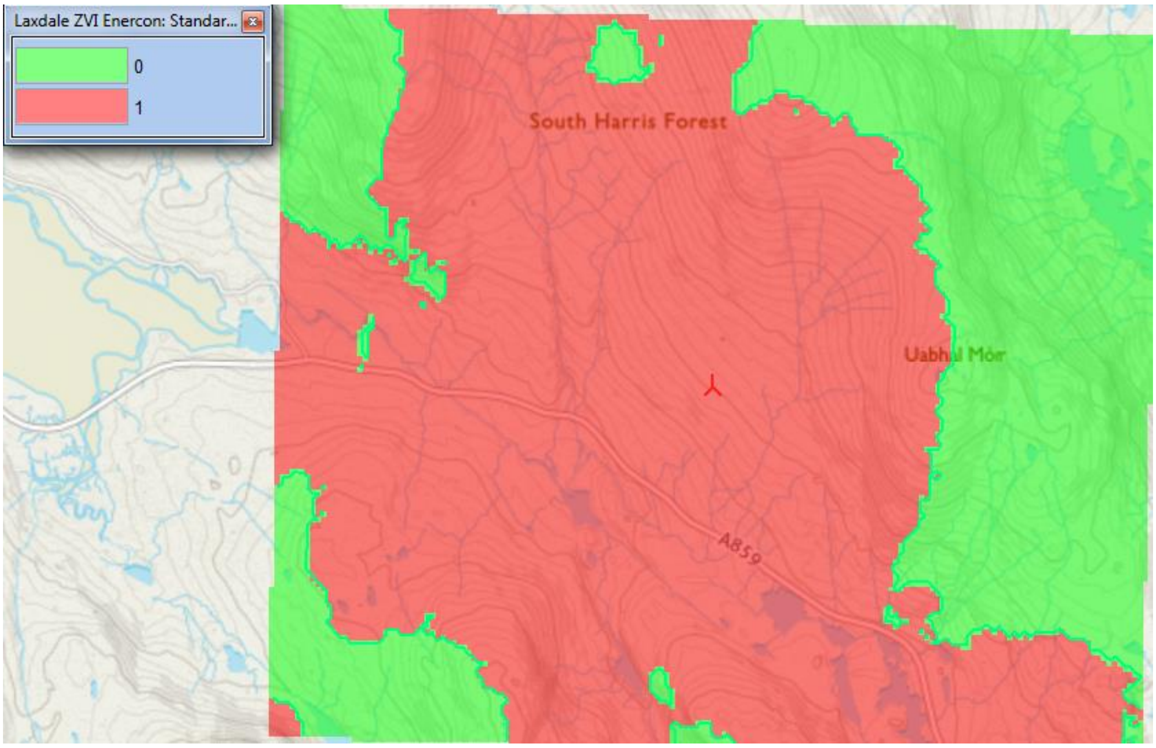


Figure 15.4.6 Zones of Visual Impact Laxdale Scenario I Enercon E44

Laxdale Scenario II Visualization: 2 x Windflow 500 kW

The visual impact assessment for two Windflow turbines is carried out from the same Viewpoint of the Scenario I. Although our Windflow turbines are two-bladed, the PHOTOMONTAGE module in WindPRO® only uses a generic three-bladed wind turbine for visualization.
The same viewpoint is used for this scenario. The coordinates are **6°51′43.33″W, 57°51′32.88″N.**

Figure 15.4.7 Visualization of Laxdale Scenario II- Windflow 500 kW turbines (Source: WindPRO®)

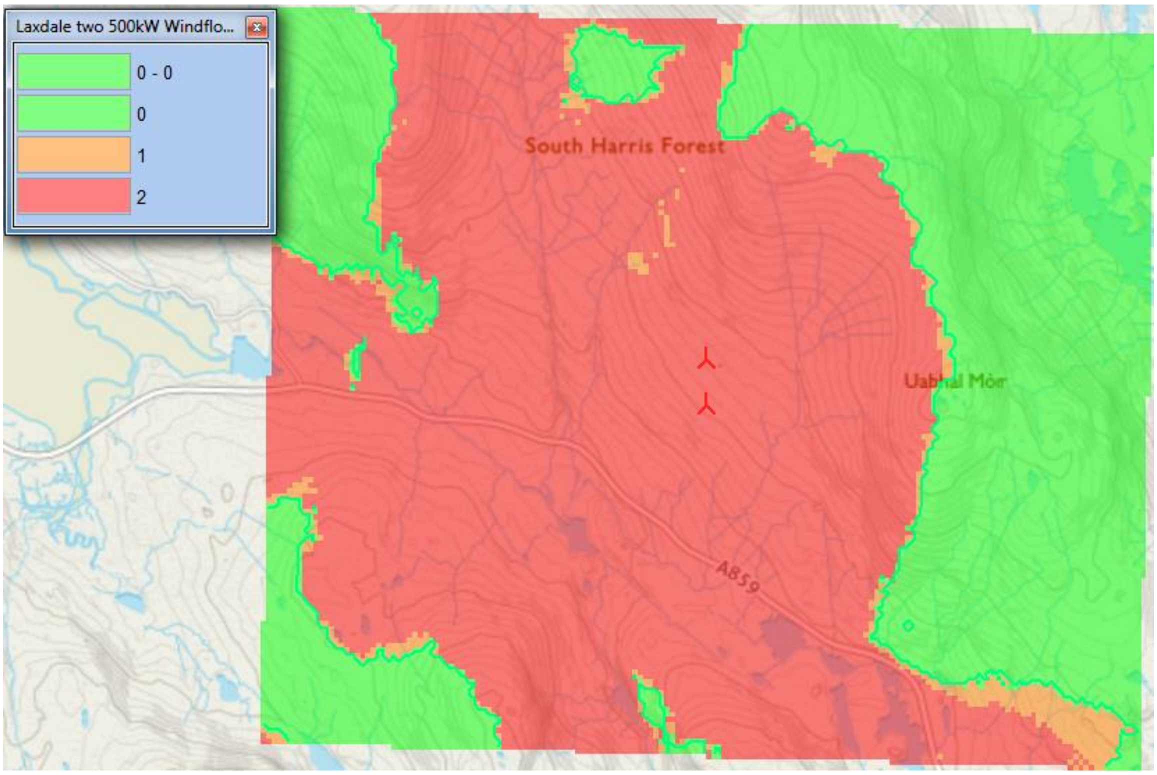
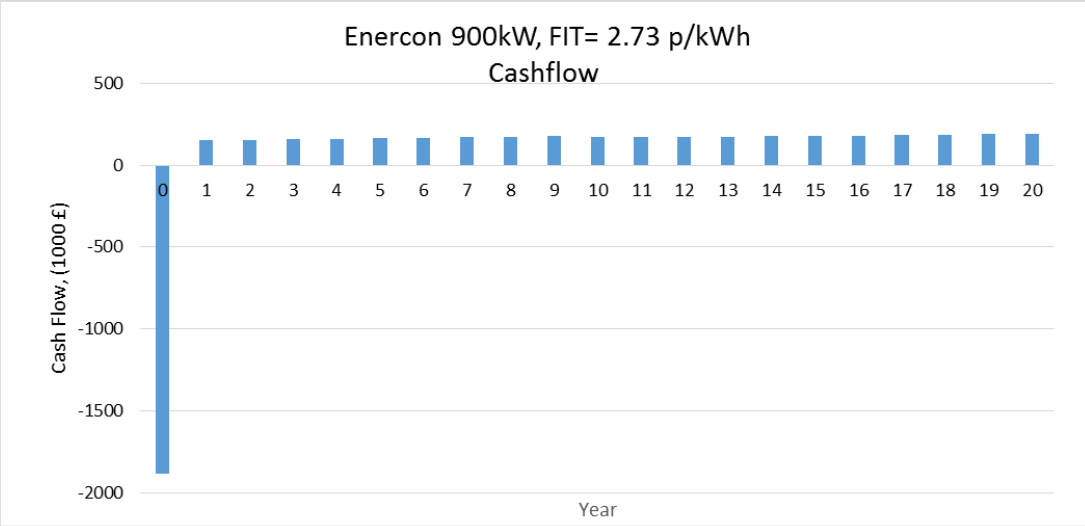


Figure 15.4.8 Zones of Visual Impact of Laxdale Scenario II- Windflow 500 kW turbines (Source: WindPRO®)

15.4.2 Laxdale project: Economic Analysis Results

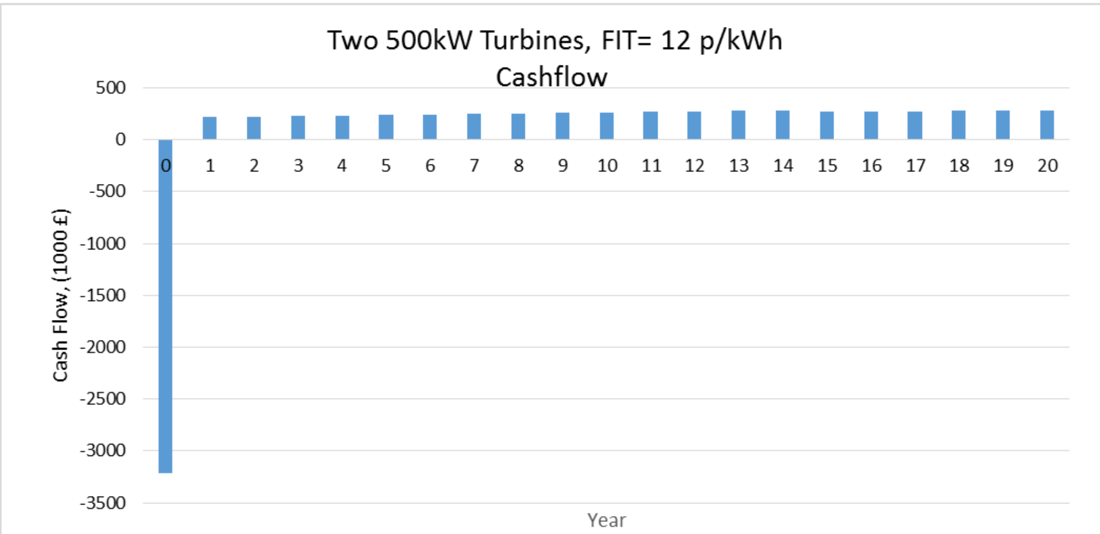
Laxdale Scenario 1

ENERCON 900 Kw: 2.0% inflation	% Increase in gen	**0%**	0%	0%	0%	0%	0%
	NPVproject (£)	-610102	-145639	260604	640812	1014157	1556664
	IRR (%)	-0.24%	2.68%	4.91%	6.84%	8.59%	10.94%
	LCOE (£)	0.0746	0.0746	0.0746	0.0746	0.0746	0.0746
	Payback Period (years)	20	20	18	14	12	10
	ADSCR	0.51	0.70	0.88	1.02	1.17	1.39
	FIT £/kwh	0.0000	0.0100	0.0200	0.0300	0.0400	0.0546
	% Increase in gen	-20%	-20%	-20%	-20%	-20%	**-20%**
	NPVproject (£)	-1060632	-689061	-317490	38727	348954	789927
	IRR (%)	-3.85%	-0.81%	1.66%	3.71%	5.37%	7.56%
	LCOE (£)	0.0933	0.0933	0.0933	0.0933	0.0933	0.0933
	Payback Period (years)	> 20	> 20	> 20	20	17	14
	ADSCR	0.33	0.48	0.63	0.78	0.91	1.08
	FIT £/kwh	0.0000	0.0100	0.0200	0.0300	0.0400	0.0546
		0					
	% Increase in gen	20%	20%	20%	20%	20%	20%
	NPVproject (£)	-159573	325952	779473	1225965	1671851	2322843
	IRR (%)	2.60%	5.25%	7.51%	9.53%	11.42%	14.00%
	LCOE (£)	0.0622	0.0622	0.0622	0.0622	0.0622	0.0622
	Payback Period (years)	> 20	17	14	12	10	8
	ADSCR	0.70	0.90	1.08	1.26	1.44	1.70
	FIT £/kwh	0.0000	0.0100	0.0200	0.0300	0.0400	0.0546



Laxdale Scenario 2

2*Windflow 100kW	% Increase in gen	**0%**	0%	0%	0%	0%	0%
	NPVproject (£)	-3605877	-2581522	-1741550	-191358	1238281	2605718
	IRR (%)	NA	-9.51%	-3.51%	2.87%	7.26%	10.83%
	LCOE (£)	0.1866	0.1866	0.1866	0.1866	0.1866	0.1866
	Payback Period (years)	> 20	> 20	> 20	> 20	14	10
	ADSCR	-0.09	0.15	0.35	0.72	1.06	1.38
	FIT £/kwh	0.0000	0.0300	0.0546	0.1000	0.1500	0.2000
	% Increase in gen	20%	20%	20%	20%	20%	**20%**
	NPVproject (£)	-3274669	-2045442	-1037476	674783	2324362	3963331
	IRR (%)	NA	-5.27%	-0.24%	5.62%	10.13%	14.02%
	LCOE (£)	0.1555	0.1555	0.1555	0.1555	0.1555	0.1555
	Payback Period (years)	> 20	> 20	> 20	16	11	8
	ADSCR	-0.01	0.28	0.52	0.93	1.32	1.70
	FIT £/kwh	0.0000	0.0300	0.0546	0.1000	0.1500	0.2000
	% Increase in gen	-20%	-20%	-20%	-20%	-20%	-20%
	NPVproject (£)	-3937085.9	-2445623.8	-1205470.3	123717.9	1246531.6	2340751.5
	IRR (%)	NA	-8.22%	-0.94%	3.90%	7.28%	10.17%
	LCOE (£)	0.2333	0.2333	0.2333	0.2333	0.2333	0.2333
	Payback Period (years)	> 20	> 20	> 20	20	14	11
	ADSCR	-0.17	0.18	0.48	0.80	1.06	1.32
	FIT £/kwh	0.0000	0.0546	0.1000	0.1500	0.2000	0.2500



15.5 Luskentyre project

15.5.1 Luskentyre project: Hydro

Area Ratio method, flow calculation sheet (sample) of Luskentyre

Site	Head(m)	Catchment Area(km2)
Gleann Beinn Dhuibh Site A	54	2.335042
Gleann Beinn Dhuibh Site B	72	2.110049
Gleann Beinn Dhuibh Site C	94	2.017277
Glean Dubhlinn (Km2)		5.032774

$$\frac{flow(B)}{Catchment\ Area(B)} = \frac{flow(A)}{Catchment\ Area(A)}$$

Date	Time	15 mins Flow (Glean Dubhlin	Hourly Flow Gleann Dubhlinn	15 mins Flow Site A	Hourly flow Site A	15 mins Flow Site B	Hourly flow Site B	15 mins Flow Site	Hourly flow Site
1-Jan	12:45:00 PM	0.139938544	0.14083225	0.064926893	0.065341542	0.058670861	0.059045557	0.0560913	0.0564495
1-Jan	1:45:00 PM	0.134822649	0.13693557	0.062553285	0.063533609	0.056525963	0.057411828	0.0540407	0.0548876
1-Jan	2:45:00 PM	0.129620705	0.13176953	0.060139754	0.061136737	0.054344987	0.055245906	0.0519556	0.0528169
1-Jan	3:45:00 PM	0.124640268	0.12627957	0.057828995	0.058589577	0.052256881	0.052944178	0.0499593	0.0506164
1-Jan	4:45:00 PM	0.12036962	0.12227299	0.055847554	0.056730658	0.050466363	0.051264374	0.0482475	0.0490104
1-Jan	5:45:00 PM	0.116355602	0.11816665	0.053985181	0.054825447	0.048783438	0.049542741	0.0466386	0.0473645
1-Jan	6:45:00 PM	0.1122803	0.11411924	0.052094375	0.052947584	0.047074821	0.047845819	0.0450051	0.0457422
1-Jan	7:45:00 PM	0.110632088	0.1112505	0.051329659	0.051616581	0.046383789	0.046643065	0.0443444	0.0445923
1-Jan	8:45:00 PM	0.10830643	0.10926346	0.05025063	0.050694662	0.04540873	0.045809977	0.0434123	0.0437959
1-Jan	9:45:00 PM	0.10747056	0.10767953	0.049862813	0.049959767	0.045058281	0.045145893	0.0430772	0.043161
1-Jan	10:45:00 PM	0.106631847	0.10663185	0.049473678	0.049473678	0.044706641	0.044706641	0.042741	0.042741
1-Jan	11:45:00 PM	0.10747056	0.1070512	0.049862813	0.049668246	0.045058281	0.044882461	0.0430772	0.0429091
2-Jan	12:45:00 AM	0.109803963	0.10926223	0.050945436	0.050694089	0.046036588	0.045809459	0.0440125	0.0437954
2-Jan	1:45:00 AM	0.113100459	0.11186759	0.052474902	0.051902892	0.047418682	0.046901788	0.0453338	0.0448397
2-Jan	2:45:00 AM	0.127141114	0.121696	0.058989305	0.056462953	0.05330539	0.051022464	0.0509617	0.0487792
2-Jan	3:45:00 AM	0.142614129	0.1380091	0.066168277	0.064031694	0.059792632	0.05786192	0.0571637	0.0553179
2-Jan	4:45:00 AM	0.153250136	0.15035951	0.071103035	0.069761881	0.064251901	0.063039974	0.061427	0.0602683

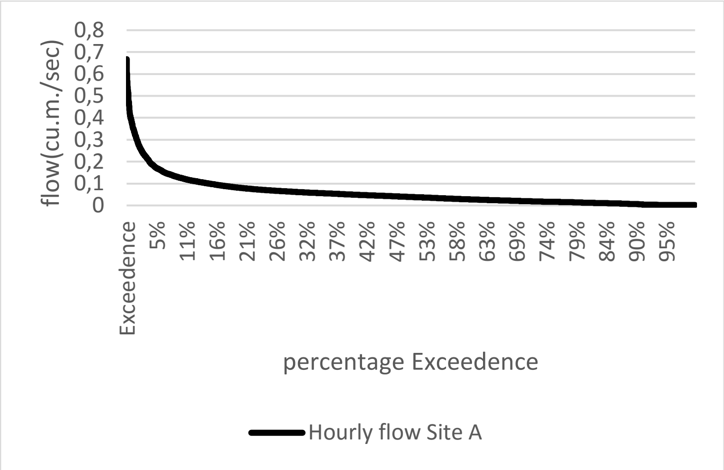
Source: Own Elaboration

Flow Duration Curves- Luskentyre

The flow duration curves for each of the identified locations are presented below.

Site A

The Hands off Flow for site A at Q90:0.005791151 m³/sec

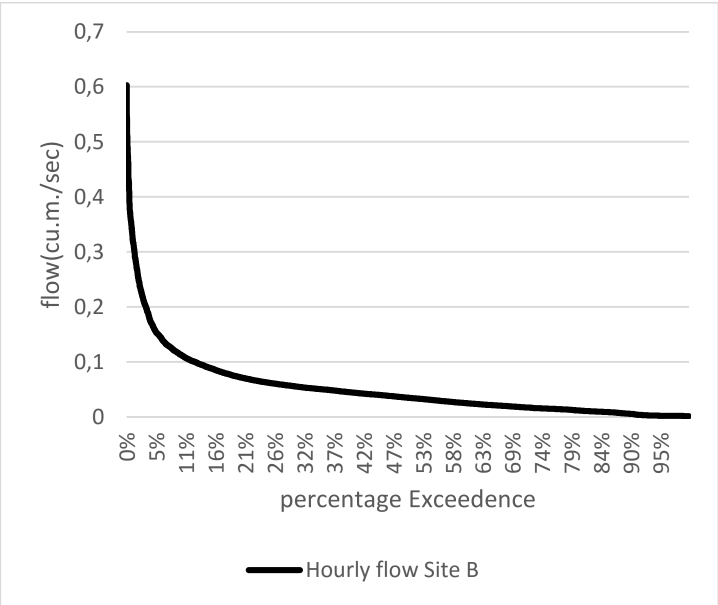


Date	Flow Ex-ceedence	Flow(m³/s)
19-Apr	5%	0.175932661
06-Apr	10%	0.122488702
12-Nov	20%	0.08033078
08-Nov	30%	0.061375929
11-May	40%	0.049265529
18-Nov	50%	0.038581194
13-Feb	60%	0.028103537
06-Apr	70%	0.019807139
16-Jul	80%	0.013308053
06-Oct	90%	0.005798621
24-Apr	100%	0.001528103

Figure 15.5.1 Flow Duration Curve
Source: Own Elaboration

Site B

The Hands off Flow for site B at Q90:0.005233145m³/sec

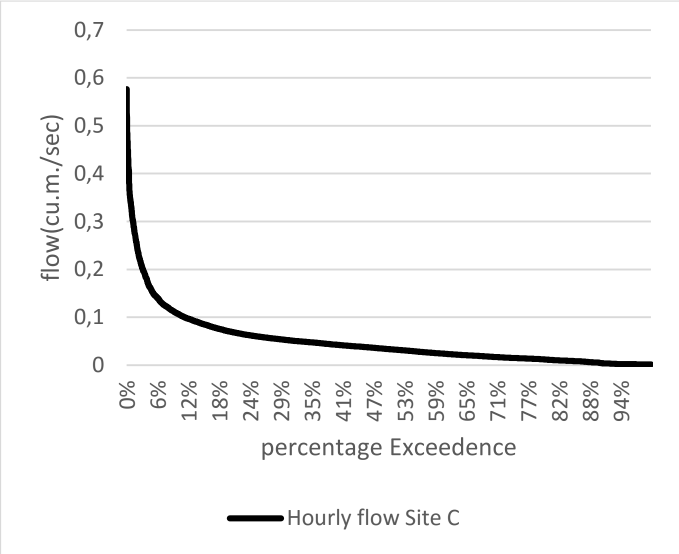


Date	Flow Ex-ceedence	Flow(m³/s)
02-Jul	0%	0.526121
19-Apr	5%	0.175933
06-Apr	10%	0.122489
12-Nov	20%	0.080331
08-Nov	30%	0.061376
11-May	40%	0.049266
18-Nov	50%	0.038581
13-Feb	60%	0.028104
06-Apr	70%	0.019807
16-Jul	80%	0.013308
06-Oct	90%	0.005799
24-Apr	100%	0.001528

Figure 15.5.2 Flow Duration Curve
Source: Own Elaboration

Site C

The Hands off Flow for site C at Q90: 0.00500306 m^3/sec.



Date	Flow Ex-ceedence	Flow(m^3/s)
24-Oct	0%	0.454909
05-Dec	5%	0.152224
12-Nov	10%	0.10537
07-Feb	20%	0.069413
10-Jan	30%	0.05306
26-Nov	40%	0.042541
06-Feb	50%	0.033283
23-Jul	60%	0.024264
29-Dec	70%	0.017094
17-Feb	80%	0.011493
13-May	90%	0.005003
10-Jun	100%	0.00132

Figure 15.5.3 Flow Duration Curve
Source: Own Elaboration

Flow and energy relation-Luskentyre

The Table 15.5.1 shows the relation between the flow and annual energy generation for each site. The rows highlighted in green are the ones up to which the differential[12] is high. I.e. for additional flow and plant capacity the annual energy yields will increase significantly.

Table 15.5.1 Flow vs Energy

Site A (54)				
No	Flow	Power(kW)	Energy(MWh)	Differ-ential
1	0.01	3.9	28.528	
2	0.02	7.8	51.867	5.97
3	0.04	15.6	86.798	4.474
4	0.05	19.5	99.295	3.201
5	0.06	23.4	108.807	2.436
6	0.09	35.1	125.922	1.461
7	0.1	39.0	129.314	0.868
8	0.12	46.8	133.555	0.543
9	0.15	58.5	136.08	0.215
10	0.18	70.2	135.546	-0.04
11	0.2	78.0	134.276	-0.16
12	0.3	117.1	123.511	-0.27
13	0.4	156.1	109.982	-0.34

Site B (72)				
No	Flow	Power(kW)	Energy(MWh)	Differen-tial
1	0.01	5.2	37.672	
2	0.02	10.4	67.798	5.79
3	0.04	20.8	111.455	4.19
4	0.05	26.0	126.106	2.81
5	0.06	31.2	136.918	2.08
6	0.09	46.8	155.656	1.20
7	0.1	52.0	158.907	0.62
8	0.12	62.5	162.814	0.38
9	0.15	78.1	163.979	0.07
10	0.18	93.7	161.837	-0.14
11	0.2	104.1	159.577	-0.22
12	0.3	156.1	143.690	-0.31
13	0.4	208.2	125.459	-0.35

[12] Differential :rate of change of energy with respect to the rate of change of power

Site C (92)				
No	Flow	Power(kW)	Energy(MWh)	Differen-tial
1	0.01	6.7	47.912	
2	0.02	13.3	85.822	5.70
3	0.04	26.6	139.848	4.06
4	0.05	33.3	157.482	2.65
5	0.06	39.9	170.270	1.92
6	0.09	59.9	191.898	1.08
7	0.1	66.5	195.570	0.55
8	0.12	79.8	199.587	0.30
9	0.15	99.8	199.915	0.02
10	0.18	119.7	196.678	-0.16
11	0.2	133.0	193.471	-0.24
12	0.3	199.5	172.605	-0.31
13	0.4	266.0	149.445	-0.35

15.5.2 Luskentyre project: Economic Analysis Results

Figure 15.5.4 Investment Costs and Resultant NPV for Luskentyre 94m head 60kW

Luskentyre 94m head, 60kW						
	Investment cost	Energy Tariff = 0.0592	Energy Tariff = 0.1	Energy Tariff = 0.1446	Energy Tariff = 0.1854	Cost/kW for this investment cost
NPV Inv method 1	*539,771*	-577490	-443352	-296720	-162582	*8,996*
NPV Inv method 2	*319,656*	-262623	-128485	14156	124377	*5,328*
NPV Inv method 3	*234,282*	-140500	-6361	114184	221509	*3,905*
NPV Inv method 4	*354,000*	-311752	-177613	-30982	84593	*5,900*

Source: Economic model results

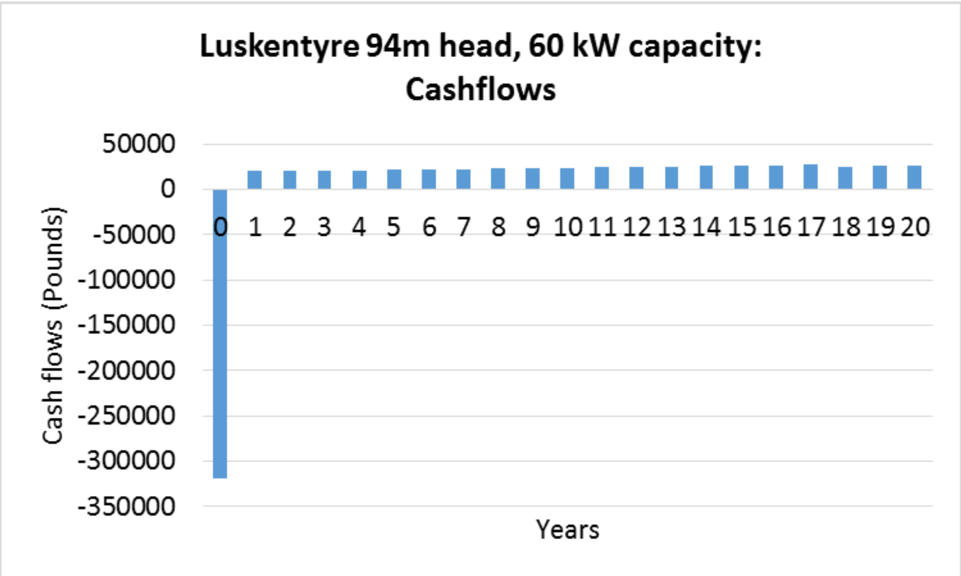


Figure 15.5.5 Cash flows for Luskentyre 94m head 60kW

Source: Economic model results

Table 15.5.2 Investment Costs and Resultant NPV for Luskentyre 54m head 35kW

Luskentyre 54m head, 35kW	Investment cost	Energy Tariff = 0.0592	Energy Tariff = 0.1	Energy Tariff = 0.1446	Energy Tariff = 0.1854	Cost/kW for this investment cost
NPV Inv method 1	*419,716*	-472672	-384651	-288433	-200412	*11,992*
NPV Inv method 2	***186,466***	-139016	-50996	37083	108172	***5,328***
NPV Inv method 3	***187,336***	-140261	-52241	36059	107183	***5,352***
NPV Inv method 4	***224,000***	-192708	-104687	-8469	65174	***6,400***

Source: Economic model results

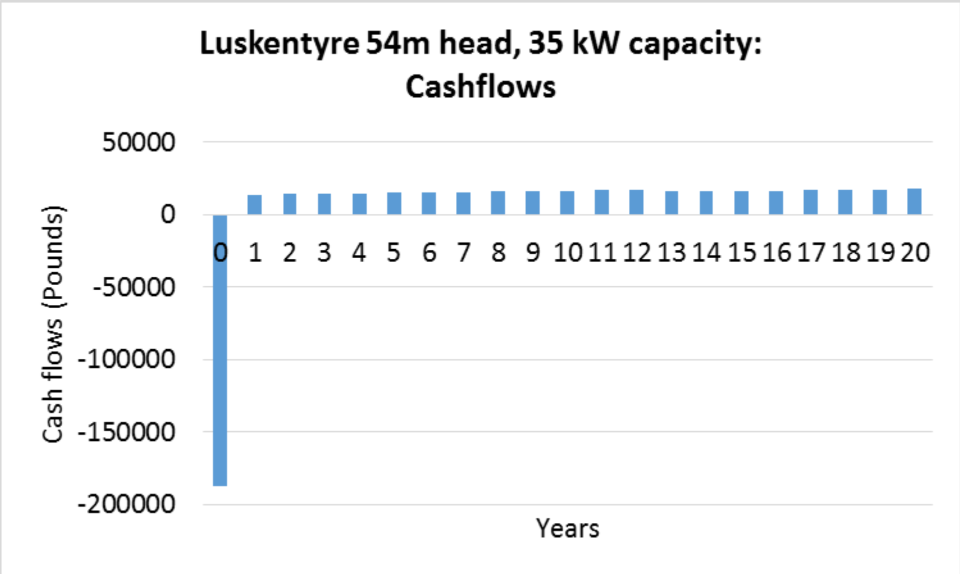


Figure 15.5.6 Cash flows for Luskentyre 54m head 35kW

Source: Economic model results

Table 15.5.3 Investment Costs and Resultant NPV for Luskentyre 72m head 50kW

Luskentyre 72 m head, 50kW	Investment cost	Energy Tariff = 0.0592	Energy Tariff = 0.1	Energy Tariff = 0.1446	Energy Tariff = 0.1854	Cost/kW for this investment cost
NPV Inv method 1	*489,358*	-542135	-433330	-314391	-205587	*9,787*
NPV Inv method 2	***266,380***	-223172	-114368	2864	92729	***5,328***
NPV Inv method 3	***220,330***	-157300	-48495	57748	145262	***4,407***
NPV Inv method 4	***300,000***	-271265	-162460	-43522	53505	***6,000***

Source: Economic model results

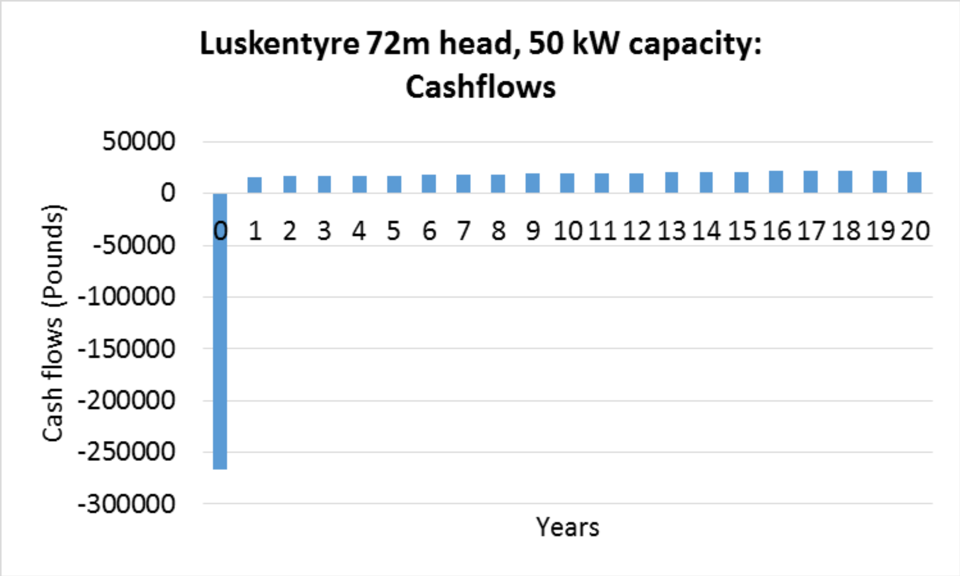


Figure 15.5.7 Cash flows for Luskentyre 72m head 50kW
Source: Economic model results

15.6 Seilebost project

15.6.1 Seilebost project: Hydro

Flow and energy relation-Luskentyre

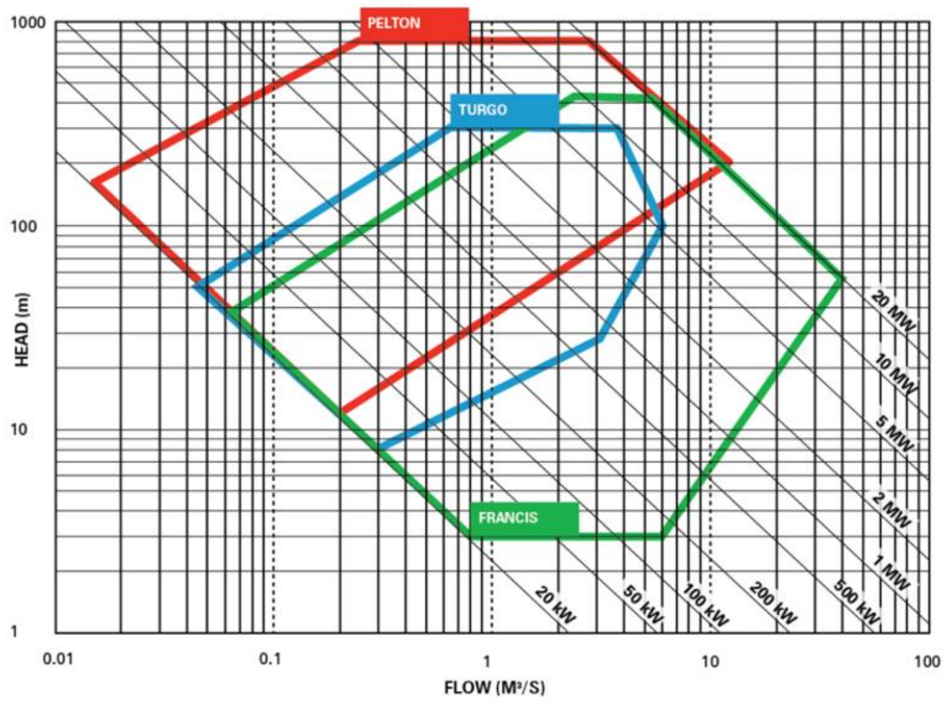


Figure 15.6.1 Turbine Selection Chart
Source: Gilkes (2016)

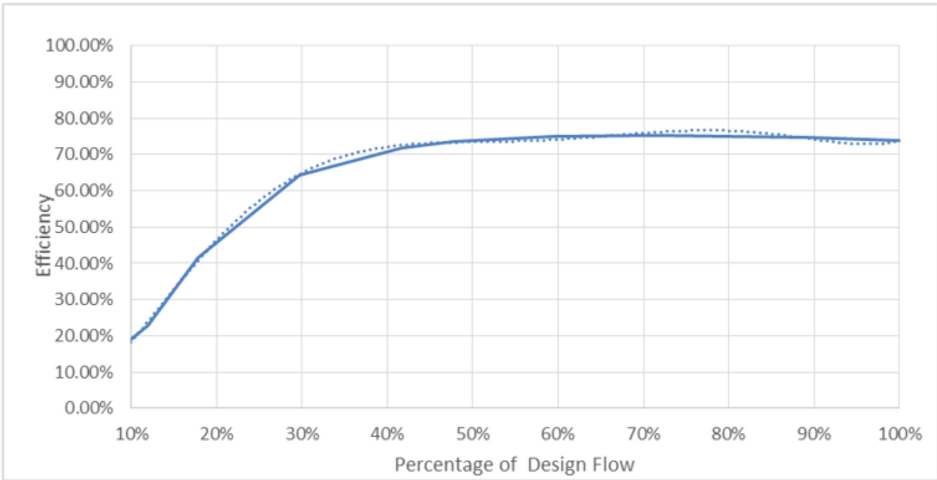


Figure 15.6.2 Overall Efficiency Curve (Penstock, Turbine and Generator)
Source: Own elaboration using efficiency chart from (Gilkes 2016)

Seilebost: Flow, Power and Energy Curves

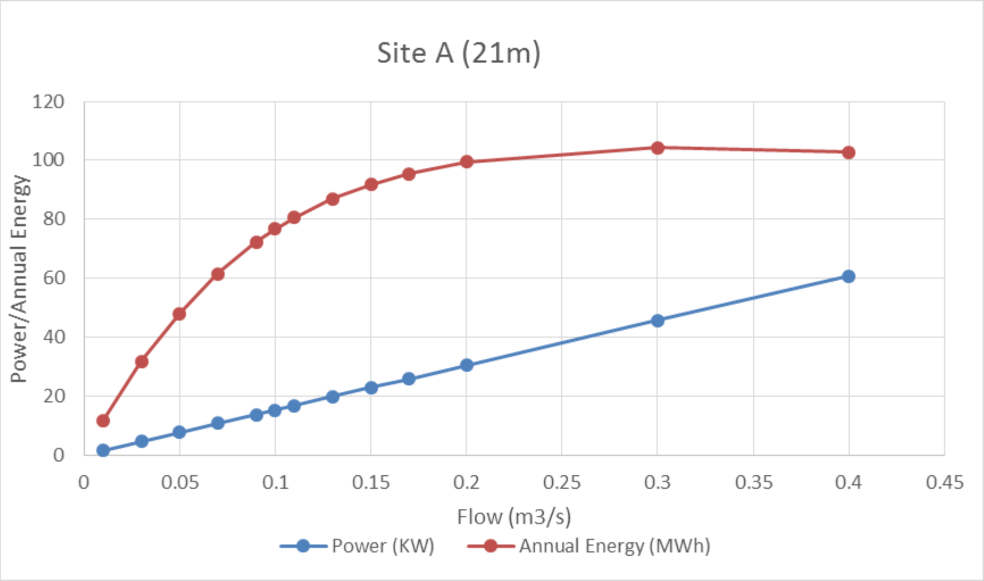


Figure 15.6.3: Seilebost-Flow, Power and Energy Relation Curve- Site A (21m)
Source: Own Elaboration

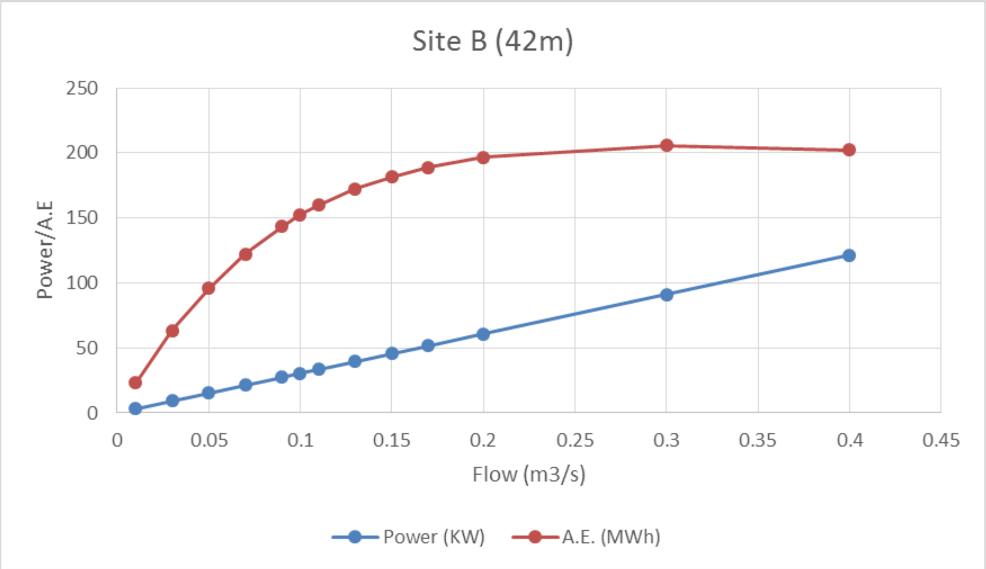


Figure 15.6.4 Seilebost-Flow, Power and Energy Relation Curve- Site B (42m)
Source: Own Elaboration

15.6.2 Seilebost project: Economic Analysis Results

Table 15.6.1 Investment Costs and Resultant NPV forSeilebost 42 m head 50kW

Seilebost 42 m head, 50kW capacity	Investment cost	Energy Tariff = 0.0592	Energy Tariff = 0.1	Energy Tariff = 0.1446	Energy Tariff = 0.1854	Cost/kW for this investment cost
NPV Inv method 1	453,393	-458289	-327155	-183808	-52674	9,068
NPV Inv method 2	266,380	-190773	-59639	68629	174127	5,328
NPV Inv method 3	242,778	-157011	-25877	95922	200937	4,856
NPV Inv method 4	300,000	-238866	-107732	28884	135893	6,000

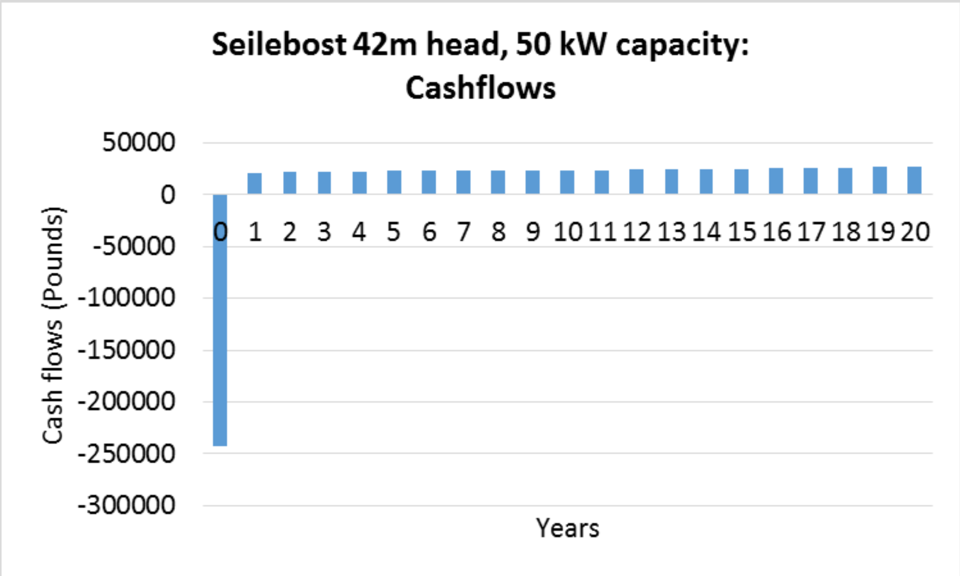


Figure 15.6.5 Cash flows for Seilebost 42 m head 50kW

Source: Economic model results

Table 15.6.2 Investment Costs and Resultant NPV forSeilebost 21 m head 25kW

Seilebost 21 m head	Investment cost	Energy Tariff = 0.0592	Energy Tariff = 0.1	Energy Tariff = 0.1446	Energy Tariff = 0.1854	Cost/kW for this investment cost
NPV Inv method 1	316,267	-355852	-289306	-216563	-150017	12,651
NPV Inv method 2	133,190	-93967	-27421	37142	90621	5,328
NPV Inv method 3	181,458	-163012	-96467	-23723	35112	7,258
NPV Inv method 4	170,000	-146622	-80077	-7333	48518	6,800

Source: Economic model results

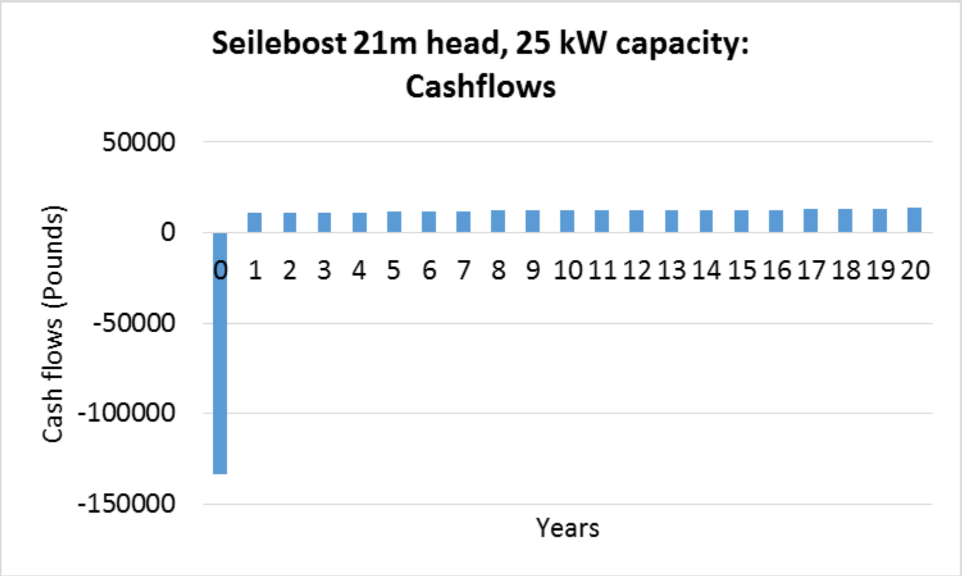


Figure 15.6.6 Cash flows for Seilebost 21 m head 25kW

Source: Economic model results

15.7 System Analysis

15.7.1 Demand analysis

Demand Profile Sheet (Sample)

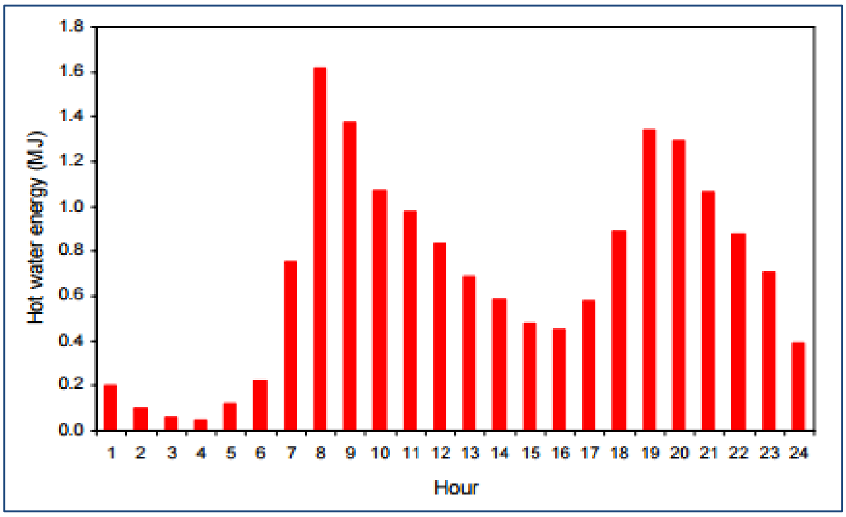


Figure 15.7.1: Hourly Domestic Hot water Energy Consumption
(Source**:** Energy Saving Trust, (2008))

Table 15.7.1: Annual Demand calculation for a Single Household (Sample)

S.No	Month	hour of day	Ambient Temperature(°C)	Kelvin hours (Kh)	Space heating demand (kWh)	Water heating demand(kWh)	Total Hourly heating demand(kWh)
1	1-Jan	1	10.3	7.7	0.504	0.0568	0.5616
2	1-Jan	2	10.2	7.8	0.511	0.0293	0.5407
3	1-Jan	3	10	8	0.524	0.0179	0.5424
4	1-Jan	4	9.8	8.2	0.537	0.0134	0.5510
5	1-Jan	5	9.7	8.3	0.544	0.0342	0.5784
6	1-Jan	6	9.6	8.4	0.550	0.0620	0.6127
7	1-Jan	7	9.6	8.4	0.550	0.2103	0.7610
8	1-Jan	8	9.5	8.5	0.557	0.4493	1.0066
9	1-Jan	9	9.5	8.5	0.557	0.3826	0.9398
10	1-Jan	10	9.7	8.3	0.544	0.2974	0.8416
11	1-Jan	11	10.7	7.3	0.478	0.2722	0.7508
12	1-Jan	12	11.5	6.5	0.426	0.2324	0.6585
13	1-Jan	13	12.1	5.9	0.386	0.1918	0.5786
14	1-Jan	14	12.5	5.5	0.3605	0.1642	0.5248
15	1-Jan	15	12.4	5.6	0.3671	0.1344	0.5015
16	1-Jan	16	11.8	6.2	0.4064	0.1276	0.5341

(**Source**: Own Elaboration)

15.7.2 Storage analysis

Table 15.7.2: Storage Capacity Calculation Table for 1 household (Sample)

Number of House	1
Mass of water(kg)	1000
Specific heat of water(KJ/kg˚C)	4.2
heated water temperature (˚C)	90
Average feedback temperature(˚C)	30
Conversion unit(joules to kWh)	0.0002777
Energy stored in the tank(kWh)	69
Assumption: 1000 liters of storage per household	

(Source: Own Elaboration)

Table 15.7.3: With Storage and Without Storage Comparison- Luskentyre (Intake Site A)

Houses	10	15	20	25	30	35
unmet demand Without Storage(MWh)	20.593	35.528	53.407	73.927	97.003	122.452
surplus Without Storage(MWh)	81.405	63.785	49.109	37.074	27.595	20.488
Met demand without storage (%)	68%	64%	59%	55%	50%	46%
unmet demand with Storage(MWh)	11.980	20.011	32.316	50.472	74.846	103.635
surplus With Storage(MWh)	72.828	48.351	28.016	13.462	5.290	1.518
Met demand with storage (%)	82%	80%	75%	69%	62%	55%

(Source: Own Elaboration)

Table 15.7.4: With Storage and Without Storage Comparison for- Luskentyre (Intake Site B)

Houses	10	15	20	25	30	35
unmet demand Without Storage(MWh)	19.544	32.784	47.716	64.726	83.494	103.936
surplus Without Storage(MWh)	146.332	126.981	109.394	93.848	80.062	67.949
Met demand without storage (%)	70%	66%	63%	60%	57%	54%
unmet demand with Storage(MWh)	6.456	13.286	20.918	31.923	46.831	65.147
surplus With Storage(MWh)	131.514	106.655	82.670	61.076	43.553	29.210
Met demand with storage (%)	90%	86%	84%	80%	76%	71%

(Source: Own Elaboration)

Table 15.7.5: With and without storage option for Seilobost micro hydro

Houses	8	16	22	28	32	36
unmet demand Without Storage(MWh)	13.315	32.953	50.748	71.477	86.733	103.147
surplus Without Storage(MWh)	14.881	116.362	95.090	76.753	65.965	56.335
Met demand without storage (%)	74%	68%	65%	61%	58%	56%
unmet demand with Storage(MWh)	83.05	19.101	28.516	42.466	54.029	68.932
surplus With Storage(MWh)	14.3746	102.699	73.025	47.812	33.311	22.064
Met demand with storage (%)	84%	82%	80%	77%	74%	71%

(Source: Own Elaboration)