# AFFORDABLE HEATING FROM WIND AND HYDRO RESOURCES IN DURNESS

## An Assessment of a Community Owned Project

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The cover picture: Authors

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## List of Abbreviations

| | |
|---|---|
| AC | Alternating Current |
| ADSCR | Average Debt Service Cover Ratio |
| AEP | Annual energy production |
| BM | Business Model |
| BNG | British National Grid |
| CARES | Community and Renewable Energy Scheme |
| CFADS | Cash Flow Available for Debt Service |
| dB | decibel |
| DC | Direct Current |
| DDG | Durness Development Group |
| DEM | Digital Elevation Model |
| DH | District heating |
| DHW | District hot water |
| EIA | Environmental Impact Assessment |
| FDC | Flow Duration Curve |
| FIT | Feed-in-Tariff |
| £ | Great Britain Pound |
| GIS | Geographical Information System |
| GW | Gigawatt |
| GWh | Gigawatt-hour |
| HHD | Heating degree days |
| Hz | Hertz |
| IEC | International Electrotechnical Commission |
| IIF | Infrastructure and Innovation Fund |
| IRR | Internal Rate of Return |
| kV | Kilovolt |
| kW | Kilowatt |
| kWh | Kilowatt-hour |
| LCITP | Low Carbon Infrastructure Transition Programme |

| | |
|---|---|
| LCOE | Levelized Cost of Electricity |
| LECF | Local Energy Challenge Fund |
| MHP | Micro Hydro Power Plant |
| MSC | Mirogeneration Certification Scheme |
| MW | Megawatt |
| MWh | Megawatt-hour |
| NPV | Net Present Value |
| O&M | Operation and Maintenance |
| OFGEM | Office of Gas and Electricity Market |
| ONS | Office of National Statistics |
| OS | Ordinance Survey |
| PA | Preliminary Accreditation |
| REIF | Renewable Energy Investment Fund |
| ROO | Renewable Obligation Order |
| RPI | Retail Price Index |
| rpm | revolutions per minute |
| RSPB | Royal Society for the Protection of Birds |
| SAC | Special Areas of Conservation |
| SEGEC | Scottish European Green Energy Center |
| SEPA | Scottish Environmental Protection Agency |
| SNH | Scottish National Heritage |
| SSE | Scottish and Southern Energy |
| SSSI | Sites of Special Scientific Interest |
| THTC | Total heating and total control |
| TIC | Total Installed Capacity |
| TP | Tariff Period |
| VAT | Value added tax |
| VPW | Virtual Private Wire |
| WHS | Wallingford Hydro Solutions |
| WRF | Weather Research and Forecasting |
| WSW | West South West |

WTG Wind turbine generator

ZVI Zone of visual influence

# 1 Introduction & Background

Sutherland is one of the most sparsely populated area in Europe and the parish of Durness is one of the most remote communities in Sutherland (Durness Development Group, 2017). Durness is a small village with 400 inhabitants, located on the Northwest tip of the Scottish Coastline. The most north-westerly village on mainland Britain Durness consists of 8,000 acres of coastal and upland area (RD Energy Solutions Ltd., 2009).

Durness Development Group (DDG) is a limited company which was established as a community charity for Durness in 2005. DDG works in cooperation with the community to make the Parish of Durness a sustainable place for living. DDG believes that even the smallest contribution can have a major impact on economic challenges which are faced by communities in the Highland area. In this regard, it supports economic growth by working in cooperation with the residents, businesses and enterprises within the Parish of Durness. One of the key objectives of the group is the development of renewable energy sources[1]. A number of projects have been planned to create a sustainable source of internal revenue for the community and make Durness a net energy exporter. By establishing renewable energy projects, it may be possible to save Durness from dependence on grants and ensure a sustainable economic development in the Parish (DDG Ltd. , 2016).

DDG has made an attempt to implement two renewable energy projects which were a 40-kW micro hydro scheme in 2010 and a 500-600 kW wind turbine in 2006 (Grangeston, 2010) (RDES Ltd, 2006). However, due to grid constraint and high cost of infrastructure development, DDG has not taken these projects any further. Nevertheless, the DDG has not given up. A recent project on the Island of Mull has provided new impetus to the idea of local renewable electricity generation in Durness. In cooperation with the grid operator SSE and Community Energy Scotland the community of the Isle of Mull is currently implementing a system that uses locally generated hydroelectricity to heat local houses through the public electricity network.

Therefore, in close collaboration with Community Energy Scotland and the Durness Development Group, a five-week field research was carried out by 15 students of the Master of Engineering program in Energy and Environmental Management from the University of Flensburg, Germany. The mission of this research is to assess the potential of renewable energy sources, specifically from wind and hydro resources to provide affordable heating for Durness community. This is conceived in form of a community owned project as existing in other parts of the Scottish Highlands.

[1] DDG webte (2017), http://www.developingdurness.org/

This report presents the main findings which are organized as follows: Chapter 2 explains the methodology applied in this research. Chapter 3 presents the main findings of a household survey while chapter 4 analyses heating demand and technologies in Durness. The potentials of renewable energy resources, wind and micro hydro are discussed in chapter 5 and 6 respectively. Chapter 7 presents the overview of the system which considers a promising way to match energy demand with supply. It considers grid constraints as well as possible options of heating systems for Durness. An analysis of the project economics is presented in chapter 8. Lastly, conclusions and recommendations are given in chapter 9.

# 2 Methodology

## 2.1 Objective of the Study

The overall objective of this study is to assess a community owned project to meet local heat demand from locally available wind and hydro resources in an affordable way. This includes following specific objectives:

- To assess local heat demand and analyse the possible demand of a small-scale enterprise.
- To quantify the potential of wind and hydro resources for power generation to meet the heat demand.
- To suggest a system configuration that maximizes the use of locally produced energy.
- To analyse the cost and benefit of implementing such system in the community of Durness.

## 2.2 Research Questions

To address the above objectives the following questions needed to be answered.

- What are the present heat demand and the heat installations in Durness?
- What are the potentials of wind and hydro resources for generating electricity to meet heat demand?
- Which system configuration is suitable to match the demand with supply?
- How could such system be implemented in order to generate benefits?

## 2.3 Methodology Overview

The following methodology was deployed to achieve the objective of this study.

A structured questionnaire was designed to collect baseline data which were required to address the research questions. The questionnaire was a combination of multiple choice, fill in the blanks and Likert questions which enabled respondents to answer the questions within a predefined framework.

The data was collected by deploying the questionnaire through a survey consisting of face to face interviews with the occupants of different entities such as residential and business. To maximize the sample size, the whole community was approached for interview. However, whoever (permanent occupant/owner) was available at home or at their business and agreed to participate in the survey, was counted.

Apart from the surveyed data, several sources and literatures have been used in this study for data triangulation. The Scottish household survey, the Scottish heat map and, the Scottish neighbourhood statistics are the major sources of data which were used to compare the surveyed data.

The data from the survey and other sources were analysed through a methodological triangulation to determine a comparable heat energy demand in the study area of Durness.

Specific tasks and analysis such as assessments of wind resource, hydro resource, demand, and economic aspects were carried out in this project. For these analyses, several tools have been used throughout the study period such as, MS Excel models have been developed to investigate and match generation resources with demand and economic analysis which are described in the respective chapters.

# 3 Questionnaire Results

## 3.1 Introduction

A structured questionnaire (see the questionnaire in Appendix A) based field survey has been used for this study from 25th February – 1st March 2017. The questionnaire was prepared by the students to gather following information which are required for this study:

- Present condition of housing stock in Durness.
- Technology used for space and water heating and determine the satisfaction level corresponding to the heating system.
- Household expenditure on heating.
- Acceptance of implementing a community based renewable energy generation and consumption system in Durness.

### 3.1.1 Survey zones and respondents

In order to conduct the field survey, the area surrounding central Durness has been divided into 6 zones targeting around 230 (Gubbins, 2016) respondents of different entities in buildings (residential and business). In addition to the reference, this number of buildings was validated using satellite image of 2005 from Google Earth (Google Earth V.7.1.8.3036, 2016). However, according to Google Earth 187 building footprints have been found. One reason could be the difference between the time span of google image and survey date. During the survey, it was noticed that there are some cases such as two households in one building footprint which could not be differentiated from the Google Earth analysis and it was counted as one. Based on the above, it was found that the 230 numbers of building suggested by Nicholas Gubbins is acceptable. Therefore, this number was used for further extrapolations of survey information.

| **Zone** | **Physical Name of the Zone** | **Number of Properties** |
|---|---|---|
| Zone 1 | Central Durness | 55 |
| Zone 2 | Craft Village | 22 |
| Zone 3 | Sangomore | 38 |
| Zone 4 | Leirinmore | 45 |
| Zone 5 | Rispond | 3 |
| Zone 6 | Laid | 24 |
| Total | | 187 |

*Table 1. Survey Zones containing number of properties*

In this survey, a group of 14 students have participated as interviewers forming 7 sub-groups. During the survey period, a total of 172 properties were approached by the interviewers in all 7 survey zones. Nevertheless, among them only 34% approaches were successful to conduct interview while 17% of the people refused to participate to the interview and 48% household found empty during the survey (see Figure 1).

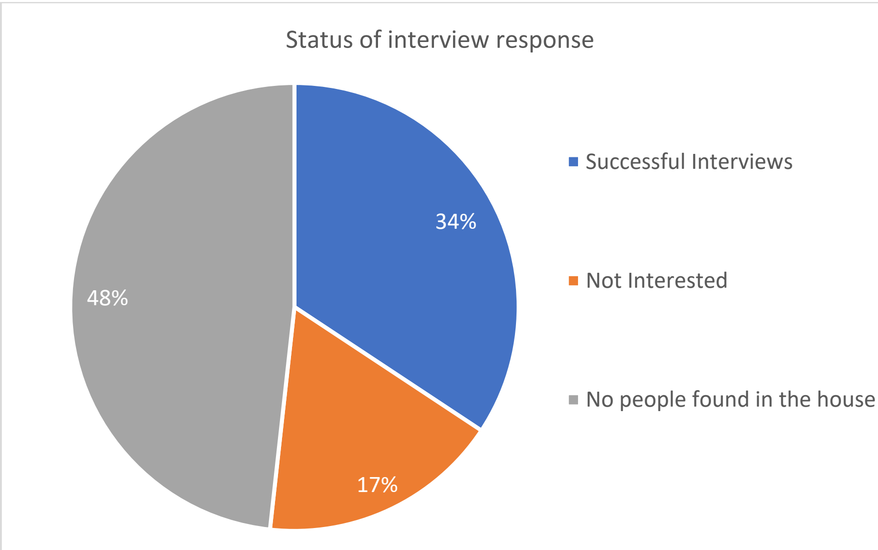



*Figure 1. Status interview response*

Among successful interviews, 58% response received from residential property and rest of them were from commercial and semi-commercial entities. Semi-commercial entity includes, bed and breakfast which are shared with a residential property (see Figure 2).

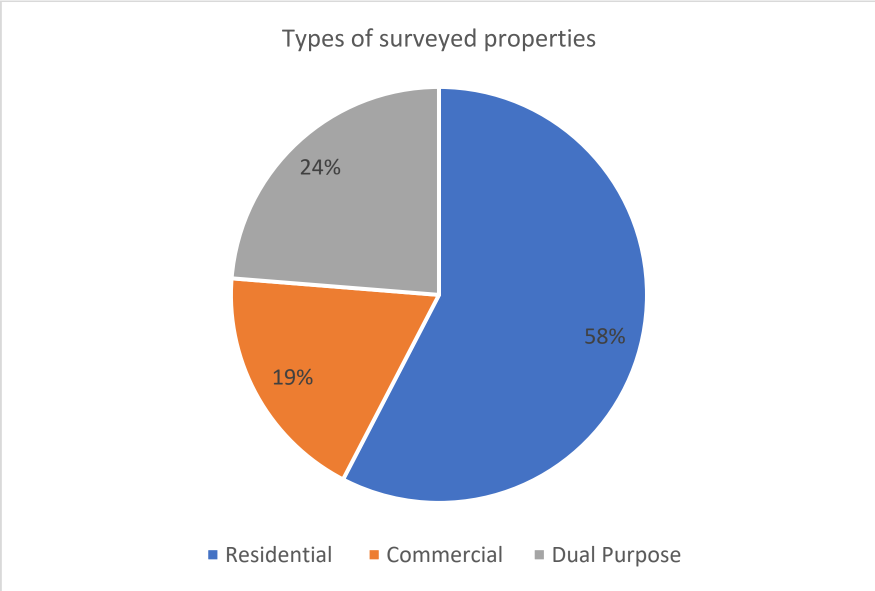



*Figure 2. Type of surveyed property by purpose of the building*

Zone-wise distribution shows (Figure 3), from Central Durness and Craft Village, the rate of participation to the interviews were much higher in comparison to other 4 Zones, and the figures are 42% and 24% respectively and there was no interview conducted from Rispond Zone.

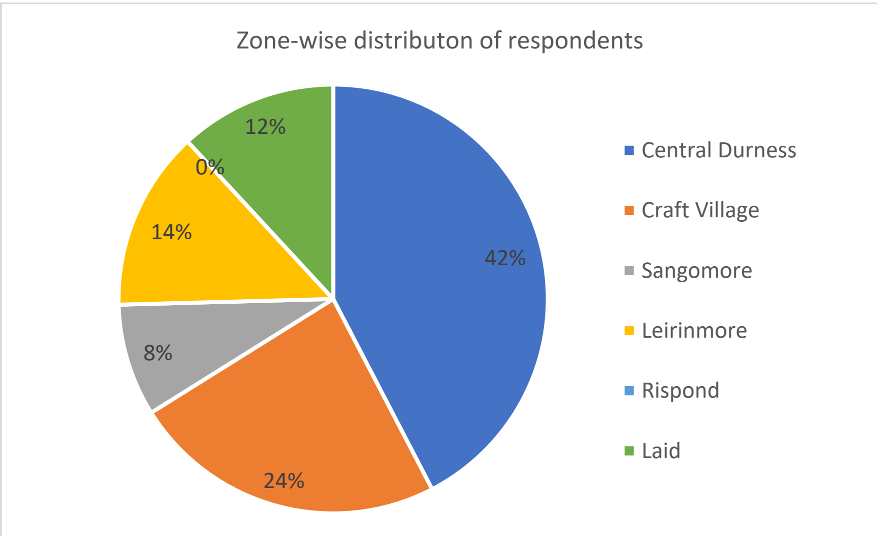



*Figure 3. Zone-wise distribution of respondents*

## 3.2 Survey Findings

### 3.2.1 Population

A total number of 88 persons of different age groups have been identified in 34 household and 14 semi-commercial property interviews. The distribution of the population is as follows.

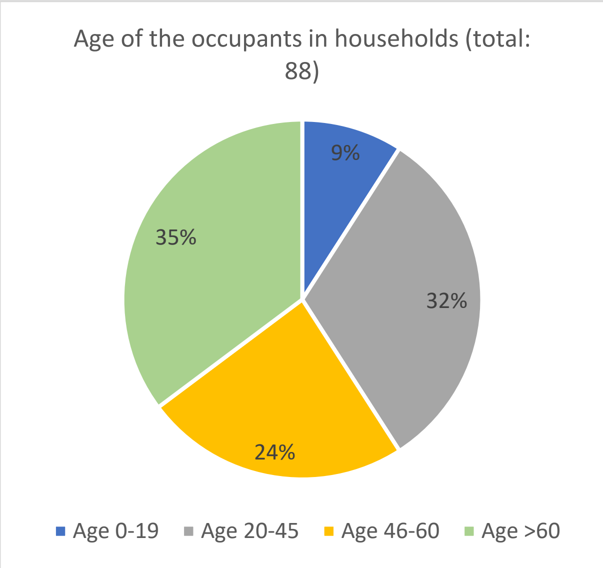



*Figure 5. Population at interviewed households*

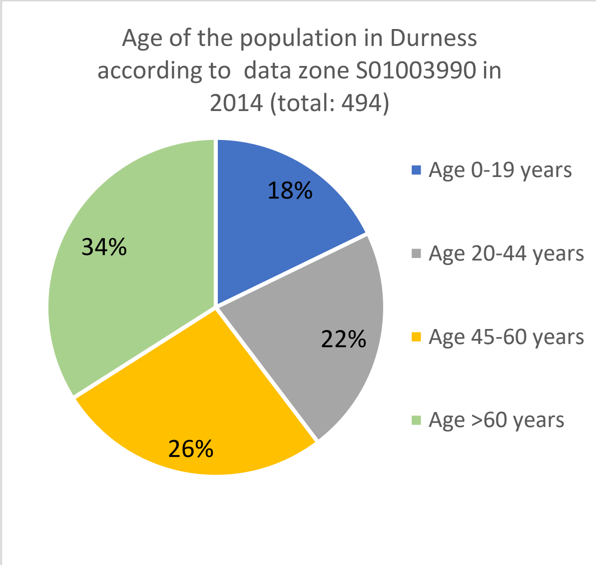



*Figure 4. Population according to SNS data zone*

Figure 5 shows that majority of the population belong to working age, accounting 56% of total. While, a significant portion of the chart is occupied by the people who are above 60 years. However, the data has been compared with Scottish neighbourhood statistics for the population of data zone S01003990 which represents Durness. The data zone information (Figure 4) shows nearly the similar percentage for the people of working age and who belong the age group over 60 years. Nevertheless, the percentage of young population is underrepresented in surveyed data compared to the information of data zone.

### 3.2.2 Housing stock

#### 3.2.2.1 Age of the property

Among 59 surveyed properties, those built after 1982 are the dominant accounting 39% of total. On the other hand, there are considerable numbers of properties which are more than 100 years old (see Figure 7). However, to get an overall picture of the ages of the properties a visual inspection was also conducted on 10$^{th}$ of March 2017 and the observation is illustrated in the graph below (Figure 6).

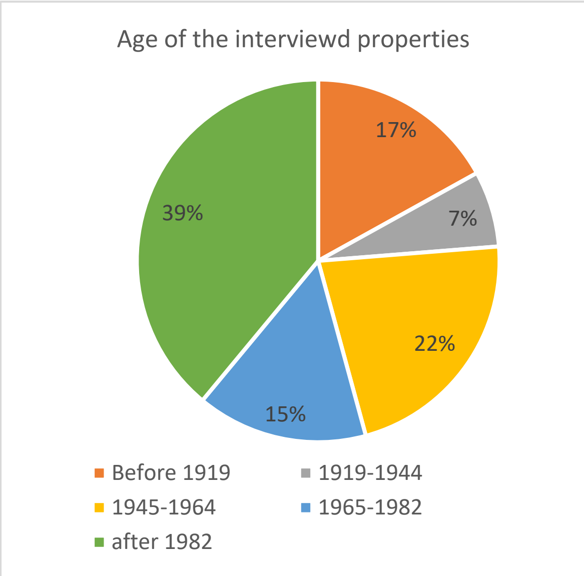



*Figure 7. Age of interviewed property*

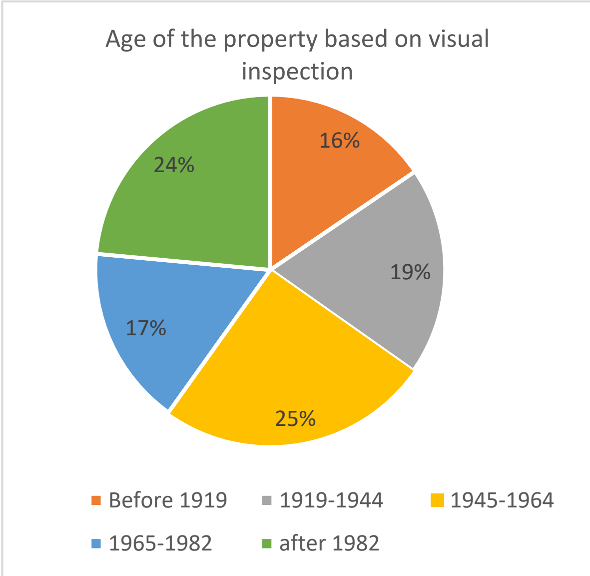



*Figure 6. Age of the properties based on visual inspection*

### 3.2.2.2 Building area

During interview, 28 respondents could not provide information on the size of their building area. Therefore, an aerial photo based analysis has also been conducted by drawing polygons on the buildings using GIS software to determine the building footprint area. Applying a correction factor to account for areas occupied by walls and roof forms as well as information on the number of storeys from visual inspection the total floor areas were estimated. Analysing the results of both the methodologies, it has been found that the area of the residential buildings varies from 45m$^2$ to 558m$^2$. The footprint area of the buildings also includes extensions of the properties, as 15 out of 59 respondents said that they have extended their property area from the original size in different years. The aggregated total of the all building footprint area found approximately 32,500m$^2$.

### 3.2.2.3 Type of buildings

Three categories of building types have been identified from the survey and visual inspection, which are, detached, semi-detached, and terraced. Among these categories, 76% of buildings are identified as detached while, semi-detached and terraced make up 20% and 4% respectively. In addition, in terms of property ownership, 45 out of 59 respondents have replied that the property is owned by them, while other replied that they rented.

### 3.2.2.4 Retrofits

To find energy efficiency measures in buildings, respondents were asked about retrofits related to energy efficiency in their building in the past 15 years. From respondents replies, 56% of the buildings have been retrofitted to improve energy performance. These retrofits have been performed to improve insulation (e.g. roof, wall, floor, window, and door) and heating systems of the buildings. 17 out of 33 respondents mentioned single retrofits while other said they had performed multiple retrofits.

Respondents were also asked about their future retrofit plans for building energy efficiency improvement. As a reply to this question, 12 respondents, who had already performed retrofit(s) in the past 15 years, shared their further plan for additional retrofits. On the other hand, 14 respondents, who had not implemented any retrofits in the past 15 years, were found to be not interested in any future retrofit.

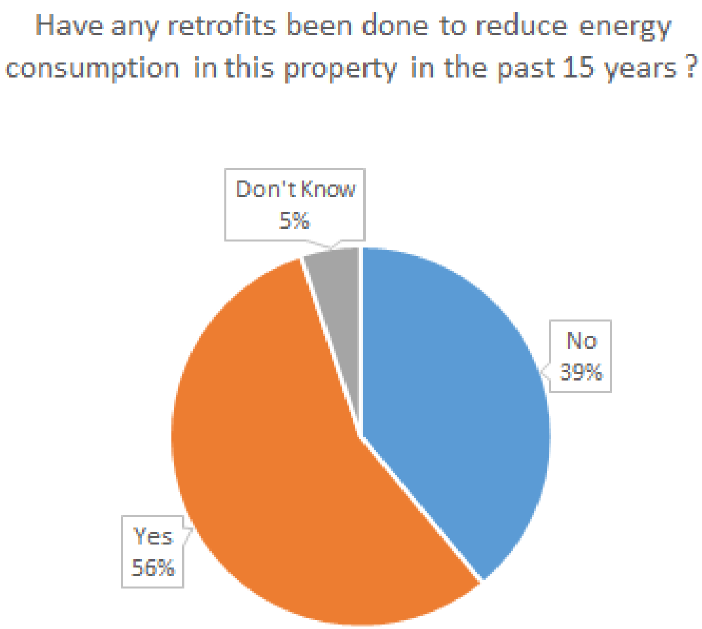



*Figure 8. Retrofits information within past 15 years*

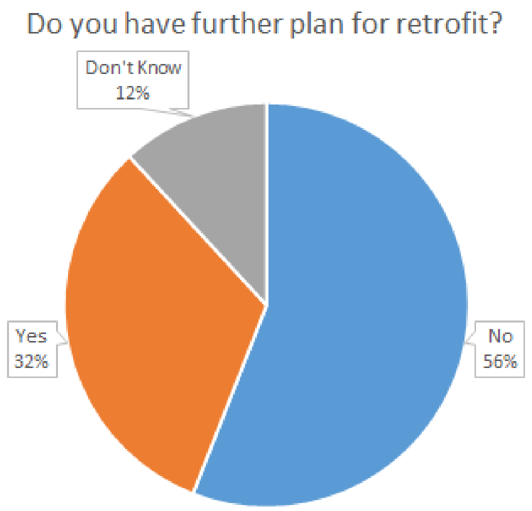



*Figure 9. Future plan for retrofit*

### 3.2.3 Heating technologies in buildings

Questions related to energy consumption were dominant in the questionnaire of this study. The questions were predominantly asked to study the status of space and water heating technology at user end and expenditure on energy.

#### 3.2.3.1 Space heating

Survey findings show that the following technologies (see Figure 10) are being used for space heating in Durness:

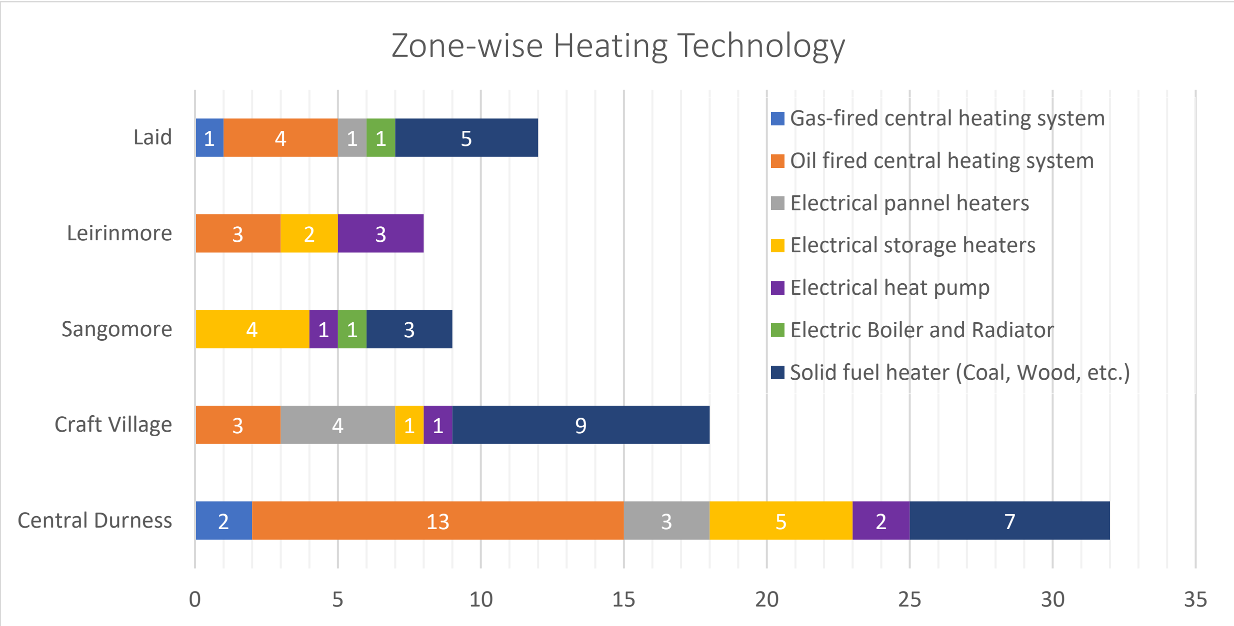



*Figure 10. Zone-wise heating technology in Durness*

Among these technologies, oil-fired and solid fuel heating systems appeared in a higher number during the interview and some households use more than one heating system. Therefore, to find the primary and secondary heating system among these technologies, further analysis has been done based on the responses of interviewees. From the analysis, it has been found that, out of 59, 37 buildings rely on a single heating system while 19 buildings use double heating systems and one respondent does not use any heating system (see Figure 11). Furthermore, among all the respondents, 28 buildings use central heating system (gas-fired, oil fired and electric boiler heating systems), where oil fired central heating system were found in a higher number than other technologies. These central heating systems also serve the purpose of water heating in respective buildings (see Figure 12).

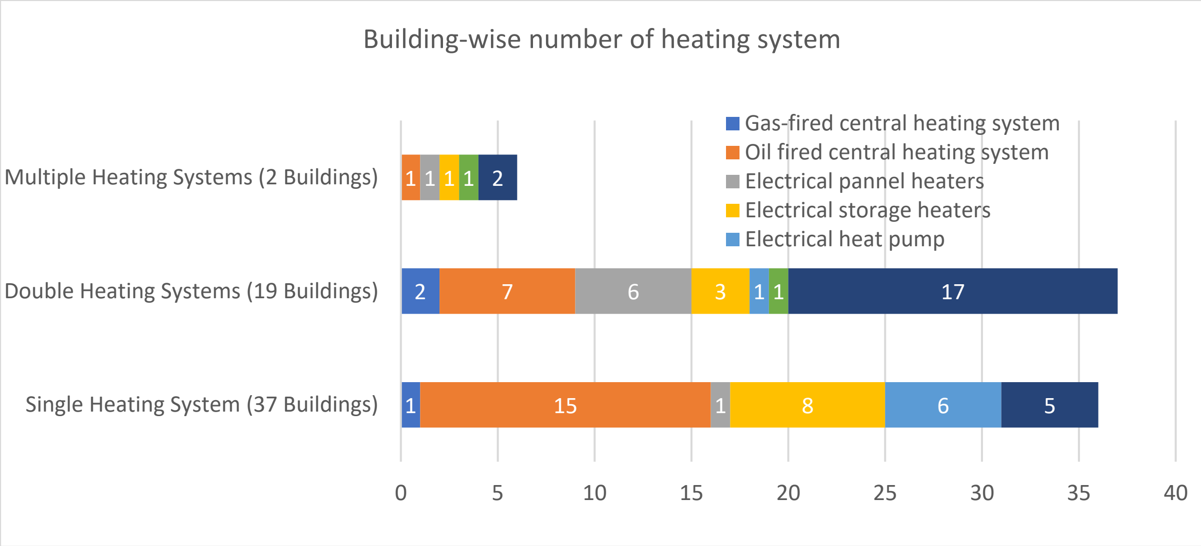



*Figure 11. Building--wise number of heating system*

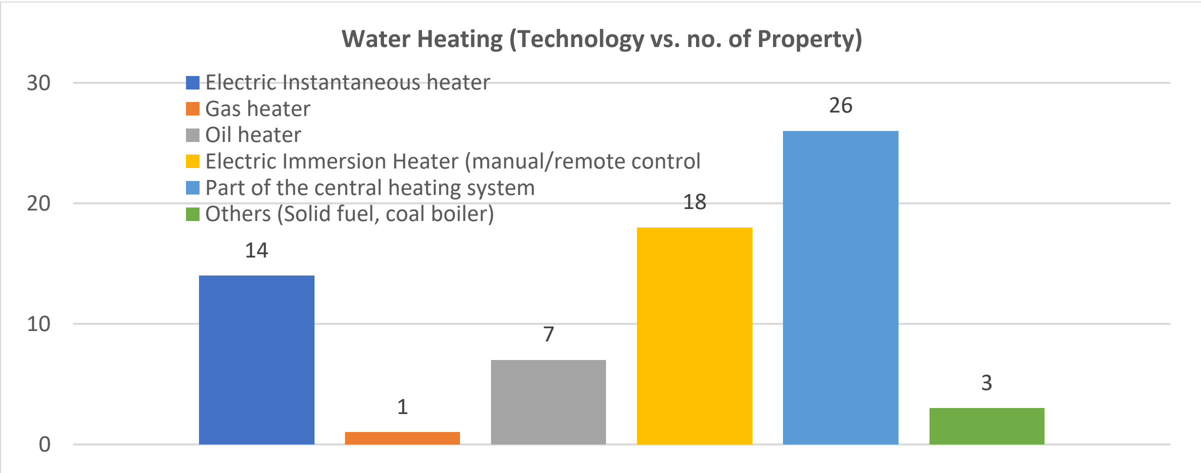



*Figure 12. Water heating technology*

#### 3.2.3.2 Expenditure on heat energy

To find the demand of energy, especially heat demand, interviewees were asked about their energy consumption in the form of electricity either in energy units (kWh/month) or in terms of expenditure (£/month). 8 respondents out of 59 did not provide this information. Furthermore, information on heating fuels, other than electricity, has been collected during the interview. The findings are discussed in detail in the Heating Chapter.

#### 3.2.3.3 Heating system satisfaction level

A question was placed in the questionnaire to gather information on overall satisfaction level with the heating system at the property. Figure 13 shows, 68% of the respondents are in the sector of satisfaction including 22% very satisfied, while 19% are dissatisfied with their heating system used at home including 7% very dissatisfied interviewees. However, 12% of the respondent could not rate their heating system in terms of satisfaction. Among 59 respondents, 2 respondents did not provide any satisfaction information as they do not use heating system in their working premises.

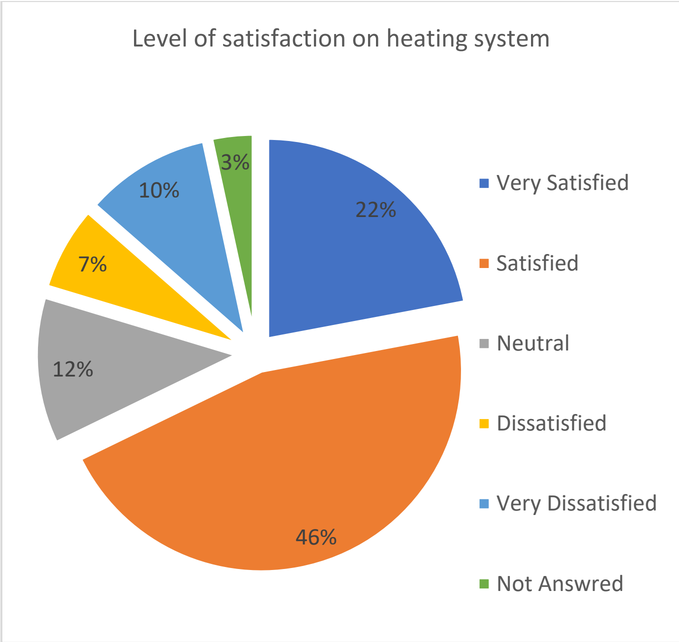



*Figure 13. Heating system satisfaction level*

### 3.2.4 Acceptance of renewable energy technology

This study is aimed to analyse the feasibility of a community owned renewable energy system. Therefore, by placing some Likert questions in the questionnaire, the respondents were asked for their opinion on implementation of wind and hydro projects, possibility of becoming customer of the scheme, and possibility of becoming an investor of the project as shareholder. Further, they were also asked for the replication of a project known as "Isle of Mull Project" in Durness (the model is attached in Appendix B). The Figure 14 below summarizes the opinion of the respondents. To summarize a significant majority of respondents are in favour of community owned renewable energy systems. In case of installing a wind turbine near Loch Meadaidh 7% of the respondents strongly disagreed. To the question "Would you like to become a shareholder of this project?", 24% of the respondents chose to answer as "I don't know" and 14% percent of the respondents did not agree, which includes 2% of strong disagreement.

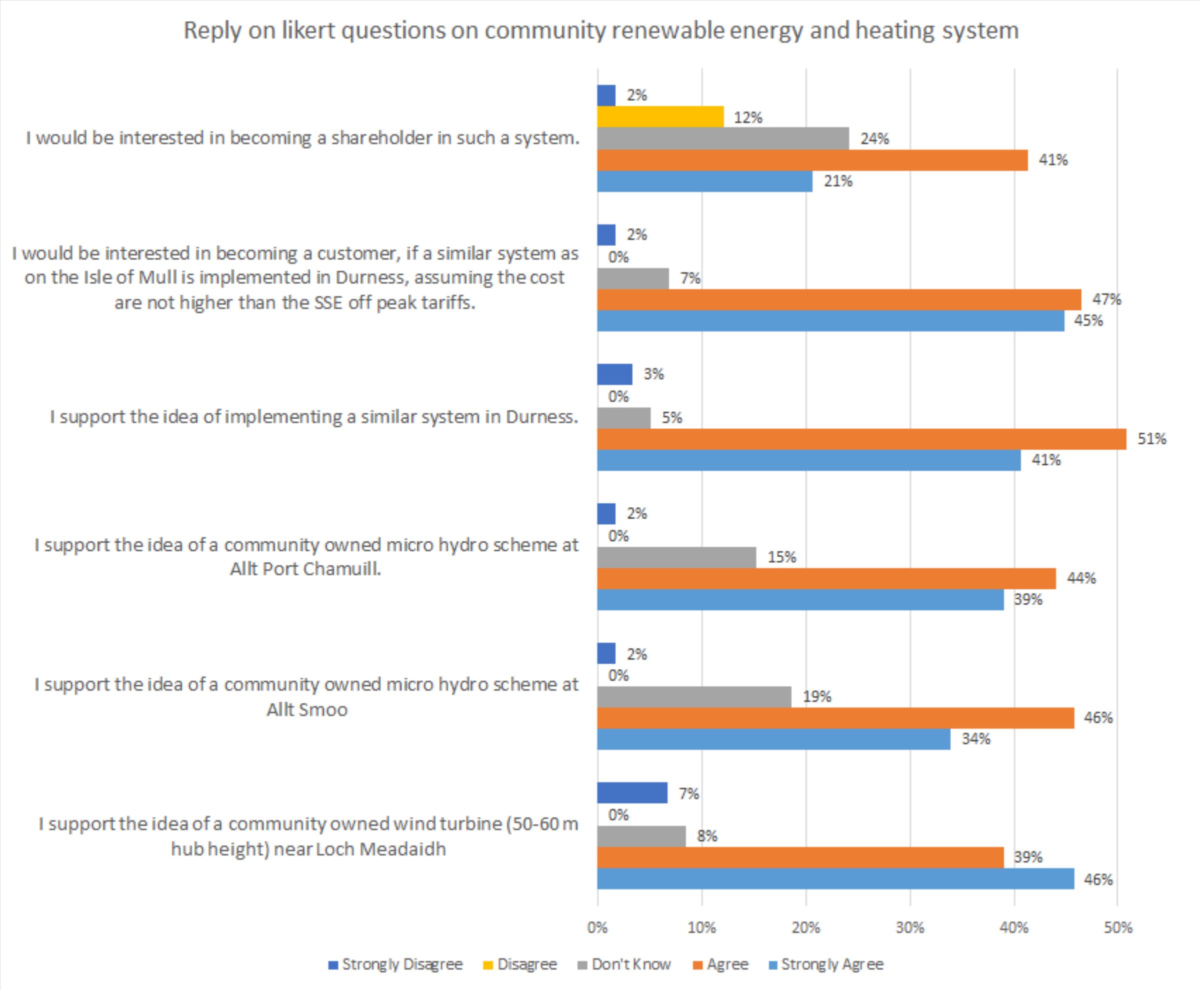



*Figure 14. Reply of respondents on Likert questions*

### 3.2.5 Additional Comments

Apart from structured questions, interviewees were requested to make an open comment on the topic of the questionnaire. Out of 59, 10 interviewees made comments expressing their views on the topic of the questionnaire. These comments can be summarized as bellow.

Interviewees expressed their supportive opinion to cooperate in the study project in different ways. Some interviewees are found as supportive to renewable energy project especially the approach of this study project. However, a positive study result might strengthen the support of these people to become an active part of the project. On the other hand, strong disagreement and doubt have also found from 2 respondents for implementation of renewable energy system Durness.

Interviewees have also made suggestions through their comments to include topics in the study such as solar thermal for water heating, choosing the old school (58°34'02.99" N, 4°46'04.76" W) water stream for the feasibility of a micro-hydro scheme, and the improvement of building insulation through community support. Further, it has also come out from the comments that implementation of wind project at Loch Meadaidh may be a divisive issue in the community which shows a link to the

7% strong disagreement of the related Likert question. However, though these suggestions are valuable but these were not considered to include in the scope of this study which was defined earlier.

# 4 Energy Demand Assessment

## 4.1 Methodology and Data Collection

To calculate the current heat demand for Durness, various methodologies have been adopted so that the approximate value of demand can be obtained. The following three methods were used.

1. A model-based approach combining behaviour, occupancy and building types from the heating Demand Profile Generator developed by ESRU, Strathclyde University.
2. Heating demand estimation based on the baseline of Scottish House Condition Survey, combined with area calculation using geographical information.
3. A conversion of fuel to heat consumption, derived from the questionnaire extrapolated to the community.

The Heating Demand Profile Generator and fuel consumption method consider user behaviour (for example occupancy and fuel usage). While Scottish Housing Condition Survey baseline is an estimate of the theoretical heat demand of the building shell. Both methods of heating demand estimation were based on area calculation of every property using a Geographical Information System (GIS) and aerial photographs. In addition, the Scottish heat map (http://heatmap.scotland.gov.uk/) was used for comparison purposes as it is a generic and authoritative tool.

### 4.1.1 Heating demand profile generator (Strathclyde model)

One of the methods used to estimate the heat demand for Durness is by using a Microsoft Excel® model called "Heat Demand Profile Generator" from the University of Strathclyde (ESRU, 2007) and the data collected from the surveyed properties (the interfaces of the model can be found in Appendix C). The model considers demographic information of the population to generate an occupancy pattern, and the main characteristics of the properties such as type, construction period and size to estimate a heat demand. Based on the above, it generates an hourly heat demand profile for each season. A flow diagram of the model can be seen in Figure 15.

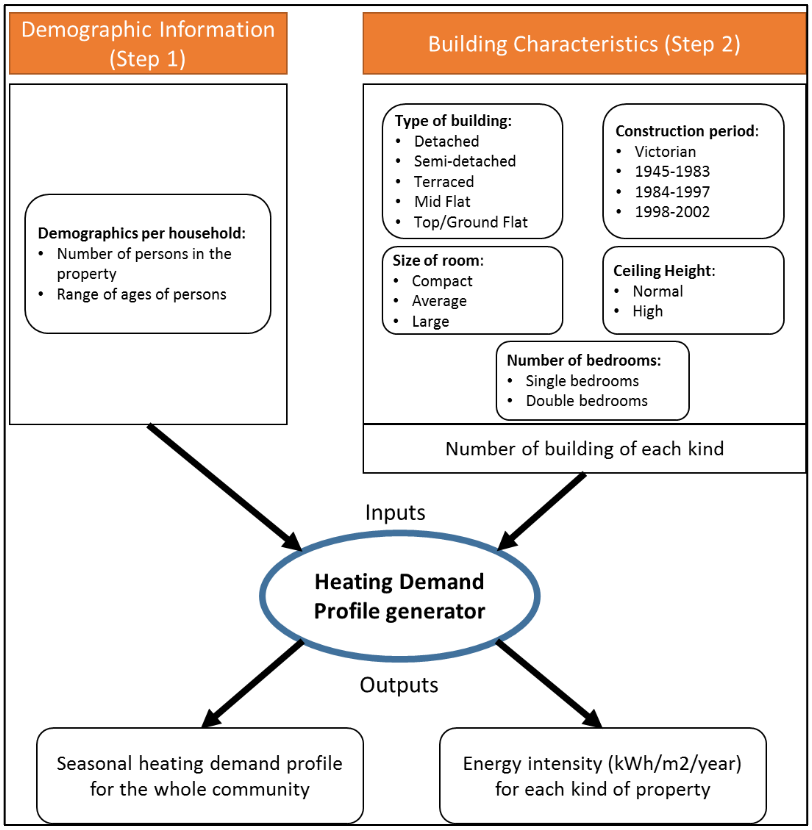



*Figure 15. Flow diagram of the "Heating Demand Profile Generator"*

To estimate the average occupancy pattern for Durness, demographic information obtained from the survey and the occupancy type definition from the Strathclyde model was used. 50 interviews provided useful information about the number of persons in the property and their ages. Based on those results, the classification shown in Table 2 was made.

| Type of household | Percentage Share | No. of household |
|---|---|---|
| Single adult | 22% | 11 |
| Single Pensioner Adult | 18% | 9 |
| Two adults | 20% | 10 |
| Two adults with children | 10% | 5 |
| Two pensioners | 20% | 10 |
| Two adults and at least 1 pensioner | 8% | 4 |
| Three adults | 2% | 1 |
| **Total** | **100%** | **50** |

*Table 2: Demographic distribution of Durness population based on survey information (ESRU, 2007)*

Afterwards, based on the classification from Table 2, three different Occupancy Types were defined according to the Strathclyde model. See Figure 16. Occupancy Type 1 comprises the categories of "Two adults with children", "Two adults and at least 1 pensioner" and "Three adults". These reflect the consumption of a property which is unoccupied between 09:00 and 13:00. Occupancy Type 2 comprises the categories of “single adult” and “two adults”, which represent a property which is unoccupied between 09:00 and 18:00. Lastly, Occupancy Type 3 comprises the categories of “Single Pensioner Adult” and “Two pensioners”, which represent a property occupied the whole day. Based on the above, the average occupancy pattern for Durness was obtained.

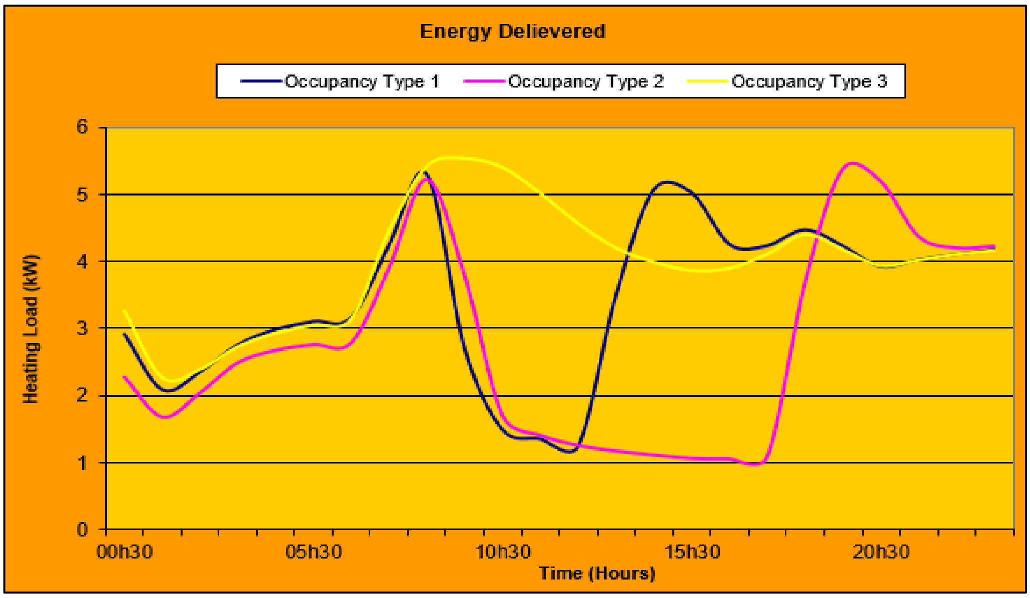



*Figure 16: Type of occupancy (ESRU, 2007)*

After that, the main characteristics of the properties such as type, construction period and number of rooms were entered in the Strathclyde model to estimate the heat demand in Durness. This information was obtained using 53 out of the 59 surveys performed. The remaining six surveys corresponded to commercial or public properties, which were not suitable for the model. Based on this, it was found that 73% of the properties were detached, 23% semi-detached and 4% of terrace type. No mid flats or top/ground flats were identified in Durness.

In terms of construction period, four categories were available in the model. The first category was “Victorian”. Although none of the properties in Durness was identified as Victorian, properties constructed before 1945 were modelled as such, due to the high infiltration and low insulation values. Therefore, categories “Pre-1919” and “1919-1944” from the survey, were modelled as “Victorian”. The second category in the model was “1945-1984”, which comprises the categories “1945-1964” and “1965-1982” from the survey. Category “1984-1997” from the model was not used because the correspondence in the survey was “post-1982”, and that category was assigned to the period “1998-2002” in the model which also fits. The properties which were constructed after 2002, were also modelled in the period “1998-2002”. Refer to Appendix C for more details.

For the parameter “size of room”, properties from the periods “Victorian” and ““1945-1964” were classified as “compact”, and properties from the period “1998-2002” were classified as “average”. For the parameter "ceiling height", all properties were classified as "normal". In terms of "number of bedrooms", all bedrooms were assumed to be double. Offices and additional kitchens in the properties were also modelled as double bedrooms. Refer to Appendix C for more detail. Afterwards, the number of houses of each kind (combination of type, age of construction and number of bedrooms) were entered in the model to obtain the hourly heat demand profile per season for Durness. (Refer to Appendix B to see the covered area).

The heat demand estimation for Craft Village and Central Durness was performed using the same methodology (refer to Appendix B to see the corresponding covered areas). The hourly demand profile per season based on the occupancy type, was assumed to be the same than in the previous case. For the building characteristics in Craft Village, the information from 11 surveys was extrapolated to the 22 properties existing in that area. For Central Durness, information from 25 surveys were used and extrapolated to 55 properties. It is important to highlight that in Craft Village, buildings have flat roofs and therefore have lower total building area per footprint area, and as former military barracks they belong to different type of buildings all together.

Additionally, each type of property (combination of type and year of construction) was entered individually in the model to estimate its energy intensity (kWh/m$^2$/year). To achieve this, the daily demand obtained from the hourly profile was multiplied by the number of days of each season. Afterwards, the total yearly demand of the property was divided by its area. Refer to Appendix C, to see the area of rooms assumed in the model.

### 4.1.2 Hourly profile generation based of heating degree days and Strathclyde model

In the Strathclyde Model, the hourly demand obtained is the same for every day within a season, which does not represent reality. Therefore, heating degree days (HDD) have been introduced to the seasonal demand. Thus, a daily demand profile incorporating within season variation was obtained for Durness. The HDD data has been collected from the website www.degreedays.net which collects information from the station located in Aultbea (5.63W, 57.86N), 100km southwest from Durness. The collected information corresponds to the year 2015 and considers a base temperature of 15.5°C. This information was later transformed to per unit by dividing each daily value by the total HDD of the season. Thereafter, per unit values were multiplied by 80% of the demand obtained from the Strathclyde model to obtain the daily space heat demand profile, based on the assumption that 80% of the demand corresponds to space heating and 20% to water heating.

Similarly, the hourly heat demand per season obtain in the Strathclyde model was transformed to per unit, by dividing the demand of each hour by the total demand of the day. Then, this per unit values were multiplied by the daily space heat demand profile obtained previously. Additionally, the 20% of the total demand obtained from the Strathclyde model (assumed for water heating) was multiplied by the hourly per unit values. This allowed to obtain a constant daily demand of water heating throughout the year, but including variations within the day. Finally, the space and water demand were added together to obtain the total heat hourly heat profile for the year 2015.

### 4.1.3 Heating demand estimation based on Scottish House Condition Survey and an area calculation using aerial photographs

In this method, the heating demand was estimated by using specific heat demand values (kWh/$m^2$/year) and mapping the area in a Geographical Information System (GIS). The software ArcGIS 10.3 was used. The idea was to assess the building footprint area of every household to calculate their heating energy requirement using specific heat demand values per square meter per year. First, a satellite image was imported to see every building in Durness (Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community) and next a polygon was drawn on each one to calculate their area. Empty and non-heated houses were excluded. In the meantime, with the help of Google Street View, the number of storeys and the type of property (detached, semi-detached or terrace) of those that were not interviewed were defined.

After drawing polygons on the satellite image, one team travelled around Durness to estimate the year of construction of the buildings that were not interviewed through a visual inspection, complemented by a visual estimation on Google Street View. These methods were also used to determine whether the purpose of the properties (those that were not interviewed) is residential, holiday houses (including bed & breakfast and home rental) or commercial (including institutions and organizations). Also, the contribution of Neil and Sarah Fuller (directors of the Durness Development Group) was important to cross check that the assumptions of the number of properties belonging to each category were accurate.

Construction year, type and purpose of the property were coded with numbers to make further analysis easier. In Figure 17, an image of the model can be seen that has been created in ArcGIS showing the polygons and the attribute table generated including all the features important for this research (zone, number of storeys, construction year, area, type and purpose of the property).

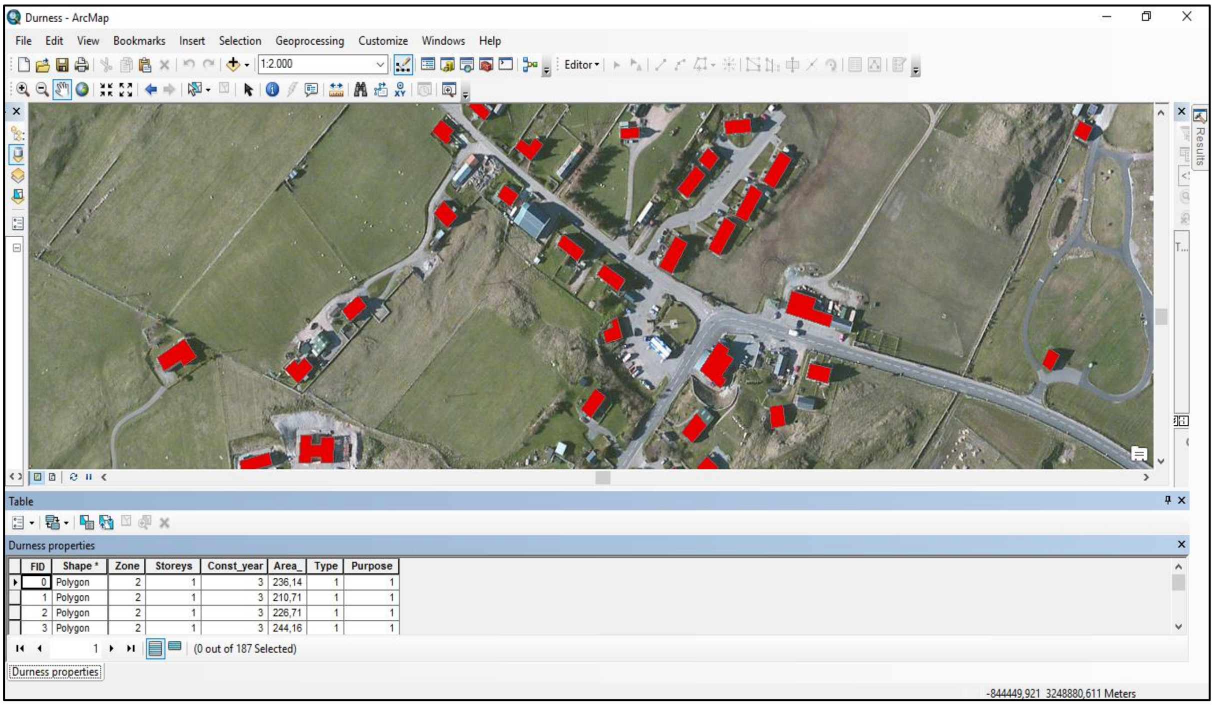



*Figure 17: Polygons and attribute table generated with ArcGIS*

A total of 187 polygons were drawn and classified. A summary of type and purpose of the property can be seen in following tables (Table 3 and Table 4). For summary on construction year of the properties, refer to the chapter 3, "Questionnaire Results" of the report.

| **Type of property** | **Number** |
|---|---|
| Detached | 158 |
| Semi-detached | 25 |
| Terrace | 4 |

*Table 3: Number of properties according to their type*

| **Purpose of the property** | **Number** |
|---|---|
| Residential | 109 |
| Holiday house | 67 |
| Commercial | 11 |

*Table 4: Number of properties according to their purpose*

Table 5 shows the sum of the areas of properties that were classified as residential, according to their type and construction year.

| | Total Area ($m^2$) | | | | | |
|---|---|---|---|---|---|---|
| **Type of Property** | **Pre 1919** | **1919-1944** | **1945-1964** | **1965-1982** | **Post 1983** | ***Total*** |
| **Detached** | 1924 | 3600 | 5340 | 2234 | 1296 | *14394* |
| **Semi-detached** | 423 | 382 | 787 | 1083 | 614 | *3289* |
| **Terrace** | 0 | 0 | 404 | 399 | 0 | *803* |
| ***Total*** | *2346* | *3982* | *6531* | *3716* | *1910* | *18486* |

*Table 5: Total area of residential properties calculated in ArcGIS per type and year of construction*

Two different calculations to estimate the annual heat energy demand of residential properties were made using the total footprint area obtained in the GIS model. The first was based on the figures obtained in the "Scottish House Condition Survey" made by the Scottish Government in 2010, which estimates the heat demand of households per square meter depending on their year of construction and type of property (see Table 6). The second was based on the values of heat energy consumption per square meter obtained from the Strathclyde model, which also depends on year of construction and type of property (see Table 7). For the second model the values of heat demand intensity of terrace-type properties for the periods pre-1919, 1919-1944 and post 1983 were not calculated because no properties of this type for this periods were found in Durness.

### 4.1.4 Fuel consumption method

This method of heat demand estimation is entirely based on the results from the conducted surveys. Though the information provided by the interviewed buildings was limited and incomplete in many aspects, however the annual heat demand for Durness has been computed after making informed estimates. Firstly, the heat energy cost (see Table 8) for different heating fuels used has been deduced on the basis of several factors such as standard rates of fuels in Durness (information collected while interviewing), average net calorific values of fuels (Department of Business, Energy & Industrial Strategy, 2015), and the system technological efficiency for the heating fuels (assuming 70% for liquid & gaseous fuels, 50% for solid fuels, and 100% for electrical heating). Using this information, a conversion of fuel consumption to heat consumption (or met heat demand) has been derived. The results obtained from the 59 surveys have then been extrapolated to the total community of Durness comprising 230 buildings.

The main source of data for this method of heat demand estimation are the questionnaires which are filled by the households of Durness. The information on the households' monthly consumed fuel quantities and their respective expenses have been analysed from the surveys too. The heating fuels being used by the households of Durness are mainly LPG delivered to home tanks, oil, coal, wood, butane cylinders, and peat. The quantities as well as the expenses on peat have not been provided by the households, using peat as a heating fuel, because of its free availability. Thus, for the calculations, heat consumption through peat has been assumed to be zero. In addition to above, many households also use electricity for heating (both space and water) in one or other form of various electrical heating technologies that has been already described in chapter 3. The fuels mentioned above are always used in conjunction with each other, except in a handful of cases.

Presently, the standard electricity tariff rate for Durness is 18.64 pence per kWh (SSE(SSE Energy Supply Limited), 2017). Furthermore, while analysing the survey results, it has been noticed that few households (that use the electrical storage heating technology) make use of another sub-meter called as “White Meter”, for measuring the electricity usage at off-peak hours. The “Economy 7” tariff rate has been taken as 9.81 pence per kWh (learned from one of the interviewees).

## 4.2 Heat Demand in Buildings

### 4.2.1 Heating demand profile generator (Strathclyde model)

According to the methodology described previously, an average hourly profile curve for each season was obtained using the Strathclyde model. (See Figure 18). (The definition of the seasons can be found in Appendix C). In the graph, can be seen that in every season there is a peak in the demand around 8:30am. That peak corresponds to the increase in the space heating when people wake up and get ready to leave the house. Additionally, this includes a peak in water heating demand required for showering. In the evening, around 7:30pm, a smaller peak can be evidenced. This correspond to the increase in space heating required when people arrive home after work.

From other perspective, it was found that for winter, the heat demand is high in the period from 10:30am to 17:30pm. An explanation for this, is that according to the demographic analysis, 38% of the properties follow an occupancy pattern type 3. This means that the property is occupied the whole day and therefore space heating is constantly required.

Based on this method, the annual demand for Durness was found to be 3.34GWh/year. Similar graphs were obtained for the areas of Central Durness and Craft Village. In that case the annual demand was found to be 875MWh/year and 290MWh/year respectively. (Refer to Appendix C for the detailed information).

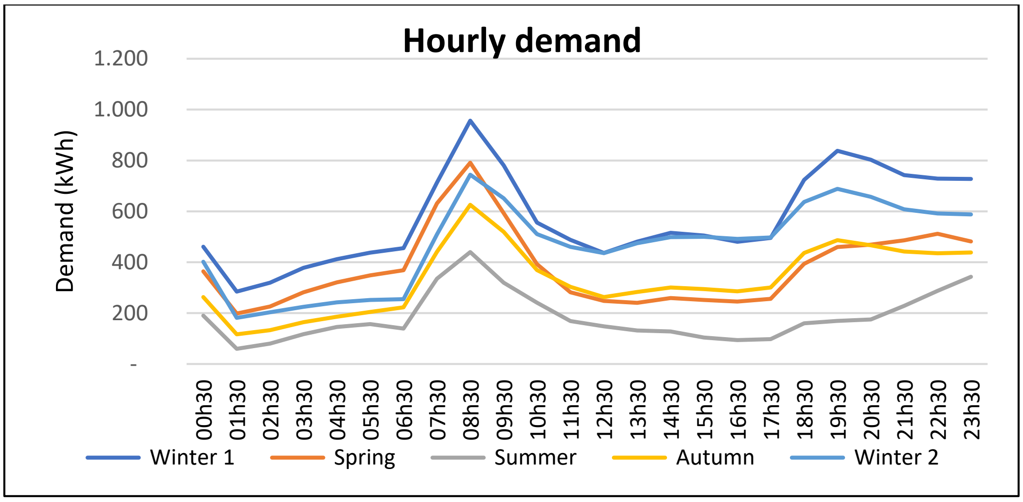



*Figure 18. Hourly demand per season from Strathclyde model*

### 4.2.2 Hourly profile generation based of heating degree days and Strathclyde model

The daily heat demand based on the HDD profile of 2015 is shown in Figure 19. In it, it can be evidenced that the maximum heat demand requirement is in December and January, while the minimum is in July and August. Additionally, during winter the variability of the heat demand is greater than in summer.

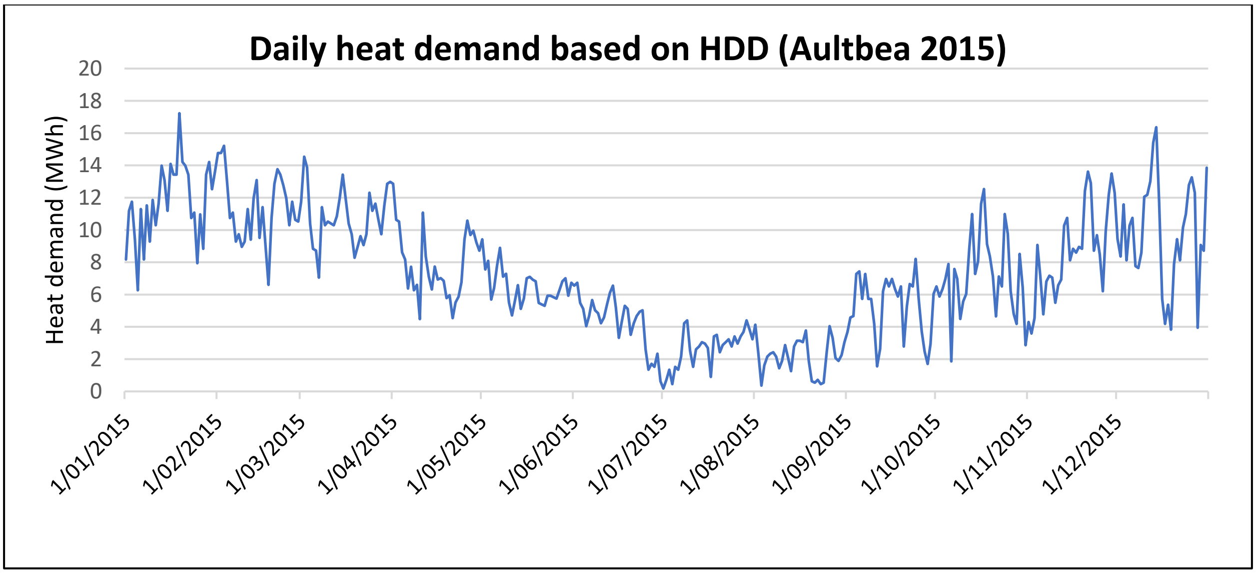



*Figure 19. Daily demand based on HDD*

The hourly heat demand for Durness can be seen in Figure 20. In the graph, it can be evidenced that it follows a similar pattern as that in the daily profile, with the difference in the minimum levels. The reason is that the hourly profile includes the water demand that is constant throughout the year. While, the daily demand with the degree days only considers space heating. Therefore, for the case of a warm summer days, the daily demand is low because no space heating is required, but in the hourly profile, the demand will be higher since water heating is still required.

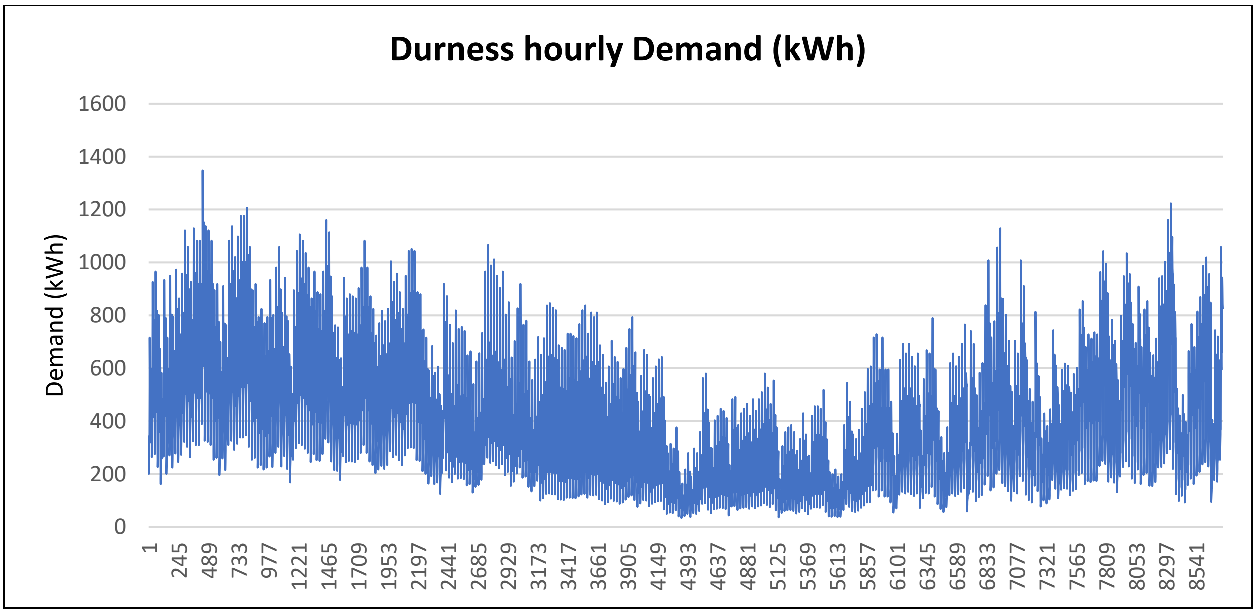



*Figure 20: Hourly heat demand for Durness*

Refer to Appendix C for the hourly heat demand graphs for Central Durness and Craft Village.

### 4.2.3 Scottish House Condition Survey baseline and energy intensities from Strathclyde model

As mentioned in chapter 1.1.1, heat demand intensities from the Scottish House Condition Survey (Table 6) and the Strathclyde model (Table 7) were used in combination with the areas calculated in the GIS model (Table 5) to obtain the total annual heat energy demand.

| | Heat Demand Intensities (kWh/m²/year) | | | | |
|---|---|---|---|---|---|
| **Type of Property** | **Pre-1919** | **1919-1944** | **1945-1964** | **1965-1982** | **Post 1983** |
| **Detached** | 594 | 627 | 505 | 404 | 276 |
| **Semi-detached** | 456 | 350 | 305 | 249 | 181 |
| **Terrace** | 349 | 251 | 249 | 204 | 149 |

*Table 6: Heat energy predictions for different types and ages of property (Scottish Government, 2010)*

| | Heat Demand Intensities (kWh/m²/year) | | | | |
|---|---|---|---|---|---|
| **Type of Property** | **Pre-1919** | **1919-1944** | **1945-1964** | **1965-1982** | **Post 1983** |
| **Detached** | 336 | 336 | 195 | 195 | 139 |
| **Semi-detached** | 336 | 336 | 251 | 251 | 135 |
| **Terrace** | | | 161 | 161 | |

*Table 7: Heat energy predictions for different types and ages of property (ESRU, 2007)*

Looking at Table 6 and Table 7, it can be clearly seen that the heat demand intensities according to the Scottish Government are always higher than the Strathclyde model values, except for semi-detached properties built during the period 1965-1982, which value is slightly higher for the second method. For detached properties, the difference in heat demand intensities is very high in every period, ranging from 76% to 158% higher for the first method. For semi-detached properties, the difference ranges from 4% to 35%, while for terrace properties the difference ranges from 26% to 54%.

The total heat energy demand per year of properties considered as residential using the first method of calculation is 7.32 GWh. According to the second method, the total heat energy demand per year of residential properties is 3.68 GWh.

### 4.2.4 Fuel consumption method

After making suitable assumptions (described in the methodology section) while calculating everything, the estimated annual fuel consumption for the Durness (refer to Appendix B to see the area covered) turns out to be 8726.44 MWh. Generally, 80% of the total energy use of a household in UK is primarily for heating purposes (62% for space heating and 18% for water heating), hence the annual heat consumption (or met heat demand) for Durness has been reckoned to be 5352.52 MWh **(5.35 GWh)** (Jason Palmer, 2013, pp. 35-36). The fuel-wise distribution of the heat consumption as well as their respective expenditure has been briefed in Table 8.

| Energy Source (Fuel) | Annual Fuel Consumption (MWh) | Fuel Cost (Pence/kWh) | Share of Heating (%) | Annual Heat Consumption (MWh) | Annual Expenditure (£) | Heat Energy Cost (Pence/kWh) |
|---|---|---|---|---|---|---|
| LPG | 780.01 | 4.76 | 100% | 546.01 | £ 37,135 | 6.80 |
| Oil | 4358.96 | 3.89 | 100% | 3051.27 | £ 169,439 | 5.55 |
| Coal | 895.48 | 4.28 | 100% | 447.74 | £ 38,317 | 8.56 |
| Wood | 147.06 | 11.02 | 100% | 102.94 | £ 22,680 | 22.03 |
| Butane | 7.46 | 18.81 | 100% | 5.22 | £ 1,403 | 26.86 |
| Electricity | 2537.47 | 18.64 for normal std. meter<br>9.81 for white meter | 47% | 1199.34 | £ 209,079 | 18.64 for normal std. meter<br>9.81 for white meter |
| Total | 8726.44 | | | 5352.52 | £ 478,054 | |

*Table 8: Fuel-wise distribution for annual heat consumption and their expenditure*

The drawback of this methodology of determining the final heat demand is that it only provides the final value, but not the hourly or daily profiles for the heating load. Therefore, the above used methods "Heating Degree Days" and "Heating Demand Profile Generator (Strathclyde model)" have been employed.

### 4.2.5 Comparison with Scottish Heat Map

The use of different methods has resulted in different results, which reflects the uncertainties of different approaches. The annual heating demand obtained from different methods can be seen as below (Table 9).

| Methods | Annual Heating Demand (GWh) |
|---|---|
| Heating Demand Profile Estimator | 3.34 |
| Heating Demand Estimation using Scottish Household Condition Survey | 7.32 |
| Fuel Consumption | 5.35 |
| Scottish Heat Map | 3.80 (see Appendix D) |

*Table 9. Annual demand estimate using different methods*

In general, heat demand from the Scottish heat map provided a baseline for our study. With the use of different methods, it can be seen that the demand is varying from 3.34 GWh to 7.32 GWh. All the methods that were used have their own advantages and disadvantages. The survey data reflect the actual, local behaviour that may be different from the Scottish average. The GIS method gives the realistic picture of housing stocks that might not be present in the Scottish heat map. While, in the other hand, the Scottish heat map is an authoritative tool. In selecting a method to proceed, following criteria were considered:

1. The users' behavioural aspects in the findings of household survey
2. Local data that is more specific
3. The value that is closer to the authoritative tool (Scottish heat map)

Encompassing the above-mentioned criteria, the team decided to build the study on the basis of heating demand (3.34 GWh) estimated from Heat Demand Profile Estimator.

## 4.3 Energy Demand Estimation for Small Scale Enterprise (Case Study: Microbrewery)

Before the arrival of the students to Durness, there was a positive plan to install a microbrewery complex in Durness. However, after the arrival of students, it has been learned that the same has been postponed due to some community's internal reasons. Therefore, in order to conduct the already planned research, the students proceeded while taking microbrewery project as a case study for small scale enterprises in Durness and calculated the energy demand accordingly.

As per the received sketch plan (Fraser Stewart Architect RIAS RIBA Chartered Architect, 2016), the whole microbrewery premises can be divided into two main areas: Residential area and Bistro/brewery area (refer Appendix E). The reason of this division is that the standard energy consumption requirements of a residential and a commercial area are different according to the Scottish building regulations. The residential area would comprise housing mix with semi-detached family houses & bed flats, and the bistro/brewery area would consist of brewery building, bistro with 68 covers, and other ancillary services like WCs, office, stores, kitchen, etc. Both the areas would be physically separated as realised from a sketch plan of the proposed microbrewery complex meant to be built in Durness.

### 4.3.1 Energy consumption of the residential area

This area can be divided into two sub-areas according to the type of housing (refer Appendix E): flats and semi-detached houses. There would be two semi-detached houses of 100m$^2$ each and four flats of 50m$^2$ each. The standard annual energy consumption per square meters is different for both types of housing (Department for Communities and Local Government, 2013, pp. 12-13). Therefore, after calculating the energy consumption for space heating, auxiliary services, lighting, and district hot water (DHW) respectively for both housing types, the total annual energy consumption for the residential area has been computed to be 28.6 MWh (15.8+12.8).

### 4.3.2 Energy consumption of the bistro/brewery area

The total gross internal area of the bistro/brewery is 340m$^2$ with bistro alone having an area of 75m$^2$ (Fraser Stewart Architect RIAS RIBA Chartered Architect, 2016). Generally, bistros are restaurants with bar facility; for calculating the annual energy consumption in the bistro (coming out to be 54.75 MWh), a typical practice value of 730 kWh/m$^2$/year has been considered (S. A. Hearnshaw, 2011, p. 2). For the rest of the area in bistro/brewery (265m$^2$), after considering the standard values of energy consumption for non-domestic buildings, the total annual energy consumption has been calculated to be 41.08 MWh (David Shearer, 2008, p. 3).

### 4.3.3 Electricity consumption in the brewing process

All installations in the brewing process utilize electricity as their power source (PBC Brewery Installations Ltd., 2008). The calculations for electricity consumption in the brewing process have been performed in order to get the final annual energy consumption for the whole microbrewery premises. Now, the Durness Development Group Ltd. (DDG) is planning to install an 8 barrel brewery, i.e. a brewery with a production capacity of 1300 litres per brew. Overall, for a standard 8 barrel brewery size, the total electrical load would be around 37 kW (PBC Brewery Installations Ltd., 2008). However, the actual electrical load requirements in the brewing process for the microbrewery have been calculated as approximately 40 kW depending on the load details extracted from the e-mails exchange between PBC Brewery Installations Ltd. and DDG. Now, assuming 50 weeks of beer production per year (1300 hl/year with 2 weeks off during Christmas and New Year and a day off on February's last working day too) with 2 brews per week (Monday and Thursday), the annual energy consumption in the brewing process of brewery turns out to be around 50.27 MWh, after considering special daily consumption profile of certain loads. This is 39 kWh/hl and falls in the lower range of the results of a research for Danish microbreweries where the electricity consumption was between 22 and 106 kWh/hl with breweries using electricity for heating at the higher end (Johansen).

### 4.3.4 Total annual energy consumption of the microbrewery premises

After calculating annual energy consumption for both the main areas and brewing process (see Table 10), the total annual energy consumption of the microbrewery premises reaches **175 MWh**, however it is computed on the basis of preliminary data and will certainly change as the design matures.

| Area/Process in Microbrewery Premises | Annual Energy Consumption (MWh) |
|---|---|
| Semi-detached house | 15.8 |
| Flats | 12.8 |
| Bistro/brewery area | 95.83 (54.75+41.08) |
| Brewing process | 50.27 |
| **Total** | **175** |

*Table 10: Annual energy consumption for microbrewery premises (MWh)*

For detailed analysis of energy calculation for the whole microbrewery premises, refer to Appendix E.

### 4.3.5 Daily demand profile for microbrewery premises

The total annual space heating, water heating, lighting, and auxiliary demand for the whole microbrewery complex has been calculated as 85.87 MWh, 18.72 MWh, 8.80 MWh, and 11.05 MWh respectively; considering 62% of the total energy use for space heating, 18% for water heating, 3.1% for lighting, and rest for auxiliary loads (Jason Palmer, 2013, pp. 35-37). Now, in order to estimate the daily demand profile for the expected microbrewery complex in Durness, methodology of 'Heating Degree Days' (applicable for space heating demand only) has been applied here as well. Loads other than space heating have been distributed uniformly for 365 days, throughout the year. As a result, the following graph (shown in Figure 21) is generated which will be utilised to estimate the capacity of micro hydro scheme being discussed in the later section of the report.

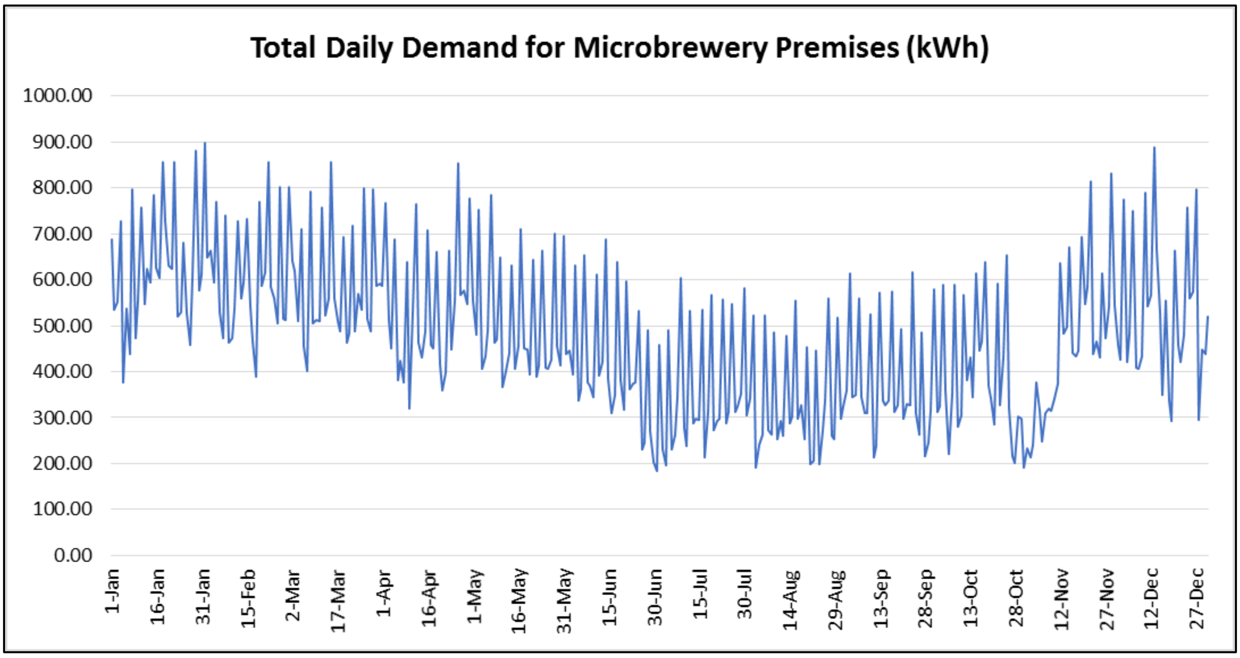



*Figure 21. Daily demand for the microbrewery premises in Durness*

## 4.4 Sensitivity of Future Demand

Future heat demand should be considered in designing the overall heating system. The forecast of this heat demand development is significant for planning over the time horizon and is most important for technical and economic consideration (CHRAMCOV & VAŘACHA, 2012). From the obtained hourly heat demand curve, the idea is to estimate future load. The average monthly heating load was picked for ease of analysis, where the demand was noted to be low in the month of June, July and August.

Due to lack of historical heat demand data and insufficient information about the population trend and EE improvements for Durness, we came up with following three scenarios (see Figure 22). These three scenarios are based on the following assumptions.

### 4.4.1 Scenario 1: the overall heating demand increases by 20%

Tourism is the most important industry in Scotland (Visit Scotland, 2013). If we consider that the number of tourists will increase in Durness in future, we can assume an increase in economic growth in the area. Indeed, the implication of economic development on population growth is not clear (The University of Sheffield, 2014). In this scenario, we assume that to increase in economic activities, there is a corresponding increase in population growth and therefore, a growth in demand. To simplify analysis, a demand increase of 20% in the near future has been considered. This scenario does not consider energy efficiency improvement in residential buildings. The annual demand in this case becomes 4.0 GWh.

### 4.4.2 Scenario 2: The overall heating demand decreases by 10%

From the survey, it was seen that the most people living in Durness were elderly. The younger generation may have migrated to the big cities (source: Household survey). This might result in a decrease in population in the future. Just like scenario 1, this case does not include energy efficiency improvements. However, it differs from scenario 1 in the fact that a decrease in population has been assumed. Therefore, heat demand is presumed to decrease by 10 % that gives an annual heating demand of 3.0 GWh

### 4.4.3 Scenario 3: The overall heating demand remains almost same

In this scenario, an increase in population followed by the increase in economic development activities has been assumed. With increase in population, a significant number of people could be interested in implementing energy efficiency measures for heating. For example, businesses in Craft village are interested to improve their heating system with the efficient insulation (source: Household survey). Therefore, due to energy efficiency improvements in households, overall demand is supposed to decrease. It is also assumed that increasing demand due to population growth will cancel out decreased demand due to energy efficiency improvements. Thus, the heating demand will remain constant, i.e. 3.34 GWh in future.

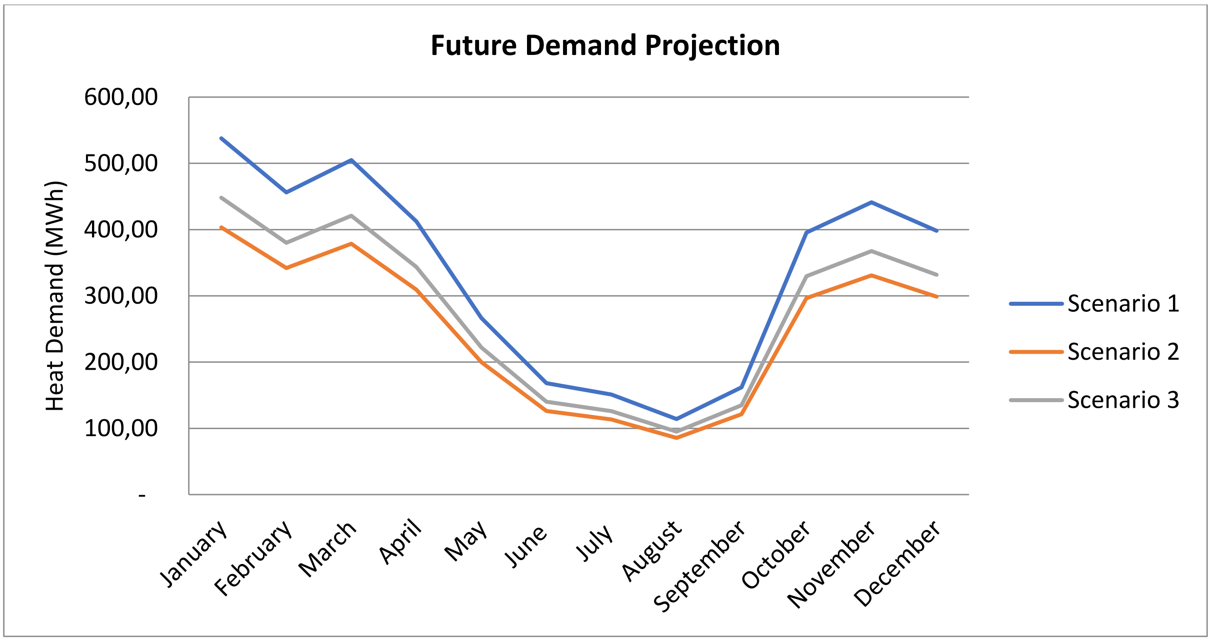



*Figure 22: Different scenario for future demand (own analysis)*

# 5 Wind Resource Assessment

## 5.1 Wind Project Development Methodology

In this study, the software WindPRO®3.0 by EMD International (EMD, 2016) has been used to assess the wind potential of the proposed sites in Durness. For the wind turbines in the proposed locations the wind resources, energy yield, shadow effects and noise factors have been analysed during the initial investigations. The analysis in WindPRO® is based on the 10 years purchased EMD mesoscale wind data which have been generated with the "Weather Research and Forecasting (WRF)" with small spatial resolution and on hourly basis. It includes:

- 10 years of hourly data: from 31 August 2006 to 31 August 2016 (the most updated data from EMD)
- The position/coordinates of the data: Longitude: -4.7393620° Latitude: 58.550034°

The data has been modelled for a position near Loch Meadaidh and has been used to create a wind resource map of the area in WindPRO®3.0. Though mesoscale data from EMD is good data source, it is strongly recommended that on-site wind resource measurement is conducted for both proposed locations (Loch Meadaidh & Craft Village) for at-least one year before the project is implemented.

**Loch Meadaidh**

The proposed wind turbines location is near Loch Meadaidh to supply energy to meet Durness community heating demand. For this location, 3 different wind turbines have been modelled. Refer to Chapter 5.1 for the details of selection criteria.

**Craft Village**

Bearing in mind that it could take a long time to realize the proposed project near Loch Meadaidh due to the economic and environmental constraints, another option consisting of a small wind turbine at Craft Village has been proposed. In the village, a district heating system could be suitable since the population density of the area is high. Moreover, it is possible to supply electricity from a wind turbine to the district heating system through a private connection and convert it to heat, which can conveniently be stored in an insulated water tank. Also, the results of the survey showed that the motivation of the residents in this area was high to have a district heating system powered by renewable energy sources. Therefore, small turbines have been considered to supply the heat demand of locals living in Craft Village.

## 5.2 Site Selection

In selecting a suitable location for wind turbines installation, the following criteria has been considered.

- Wind Resource
- Distance from residential buildings
- Access to site
- Access to Grid
- Avoidance of key environmental areas

Wind resource assessment involves analysing the wind regime to estimate and calculate the power output of a candidate site. The site should be accessible for ease of construction and away from buildings to reduce noise, shadow or flicker and visibility. Grid accessibility is equally important, distance to the grid and its capacity should be considered.

Key environmental areas are also one of the main considerations, as any proposed location for installing a wind turbines have some environmental many issue to be considered such as the nature, protected zones, birds and many other factors could affect the decision making. More details regarding the above-mentioned criteria of the proposed site will be demonstrated further in this chapter.

## 5.3 Wind Resource Assessment

In this section, the potential wind resources throughout the specified region have been examined to define the optimum locations for wind turbines. Basically, the preliminary area identification, area wind resource evaluation, and micro-siting of wind turbines will be provided in the following chapters.

### 5.3.1 Wind direction

The turbine must avoid obstacles in the wind direction with the highest energy contribution in order to use the turbine effectively. The wind direction with the highest wind speeds and frequencies needs to be identified to ensure the highest electricity production. To determine the wind direction and distribution, energy rose can be useful (Windustry, 2017). The 10 years purchased EMD mesoscale data have been used for the wind-flow modelling in WindPRO®.  Based on this, the parameters such as wind direction, frequency distribution and mean wind speeds have been generated.

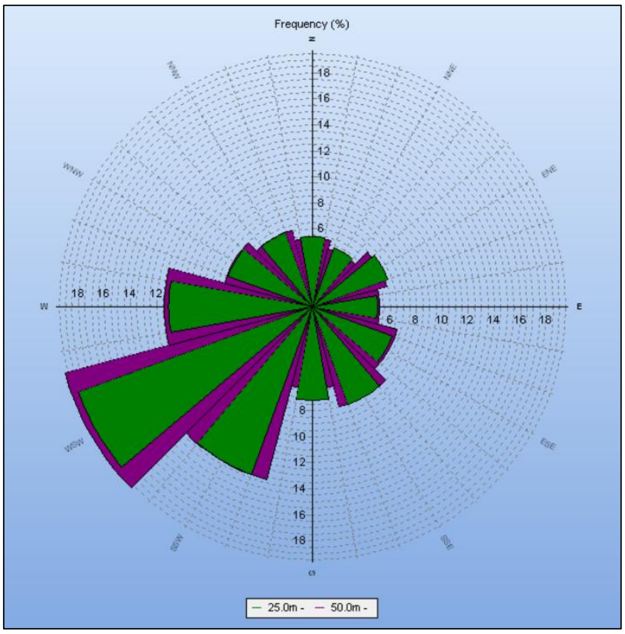



*Figure 23: Wind Direction of the EMD Mesoscale Long-term Measured Data (Source: WindPRO®3.0)*

As two different turbines with 25m and 50m hub heights have been used, the wind direction graph at these heights has been generated. As it is seen in Figure 23 the predominant wind comes from WSW (west south west) direction. Therefore, the turbines should be located on a site that allows good access to WSW wind to obtain more energy generation.

### 5.3.2 Mean wind speed & frequency distribution

Wind speed usually fluctuates from time to time and there is a cubic relationship between the wind speed and the power of a wind turbine. In other words, the energy generation increases by a factor of 8 when the wind speed doubles. Therefore, the mean wind speed is a crucial factor affecting the energy production and the cost effectiveness of a wind turbine (Windustry, 2017).

The wind statistics are generated by using STATGEN in WindPRO® (EMD, 2016). The monthly mean wind speed graph which is shown in Figure 24 below has been extracted from the wind data analysis of STATGEN module to see the wind variations in a year. As it can be seen from the graph below, the mean wind speed at 25m is lower than the mean wind speed at 50m. It is also clear that the mean wind speed is comparatively higher in the winter season than it is in the summer season.

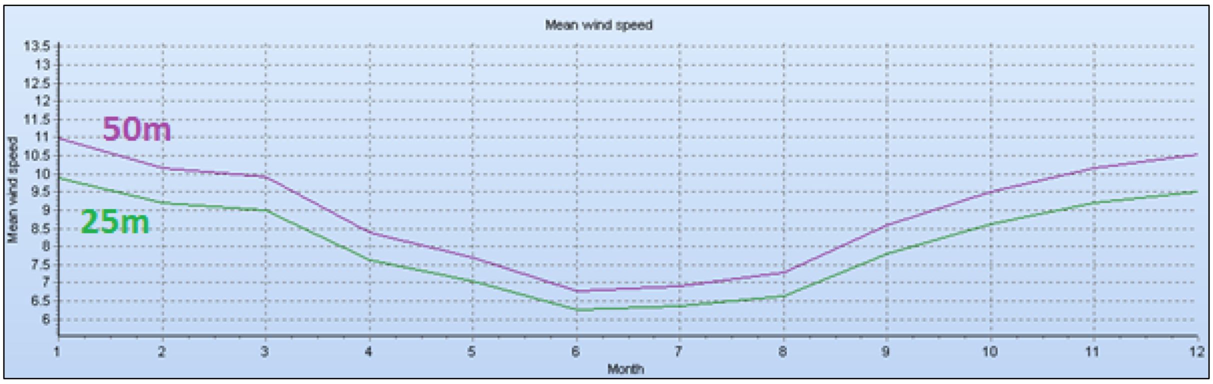



*Figure 24: Annual Mean Wind Speed (WindPRO®3.0)*

Similarly, the wind speed frequency by Weibull distribution graph has been generated which represents how frequent a specific wind speed occurs. In this graph, the time during which wind speed occurs over a period of one year has been shown. The most prevalent wind speeds are between 6-8 m/s at 25m height and 7-9 m/s at 50m height. This means that the most commonly occurring wind speed is quite high in Durness and this region can be considered as one of the best location for wind energy generation.

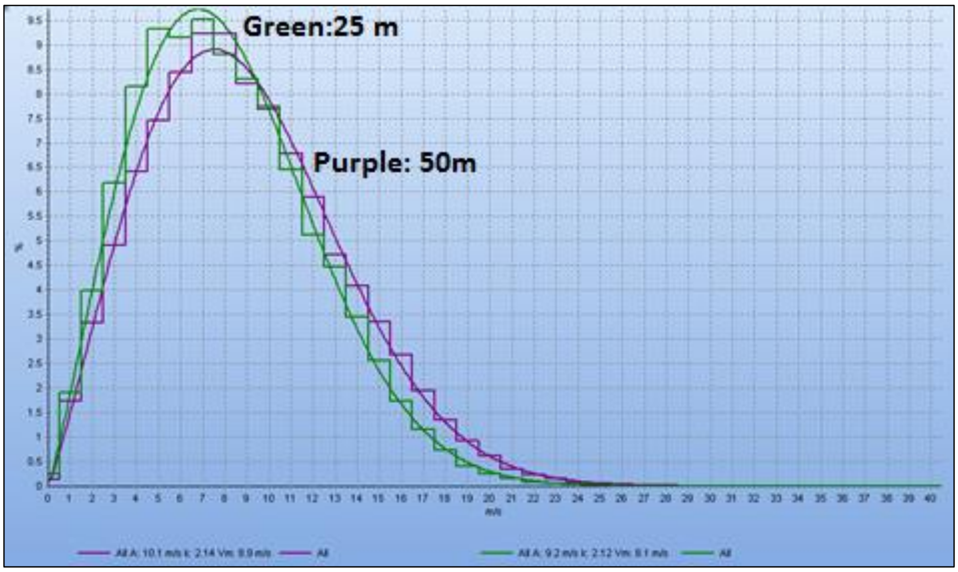



*Figure 25: Weibull Distribution (Source WindPRO®3.0)*

### 5.3.3 Wind resource map

A wind resource map is a way to show the wind resources available in the proposed project areas. By using the EMD mesoscale data the Wind Resource Map has been generated to show the wind speed distribution around both proposed project sites (Loch Meadaidh & Craft Village). In creating Wind Resource Map, the WindPRO model has considered the roughness and obstacles. Figure 26 shows a wind resource map for Loch Meadaidh site.

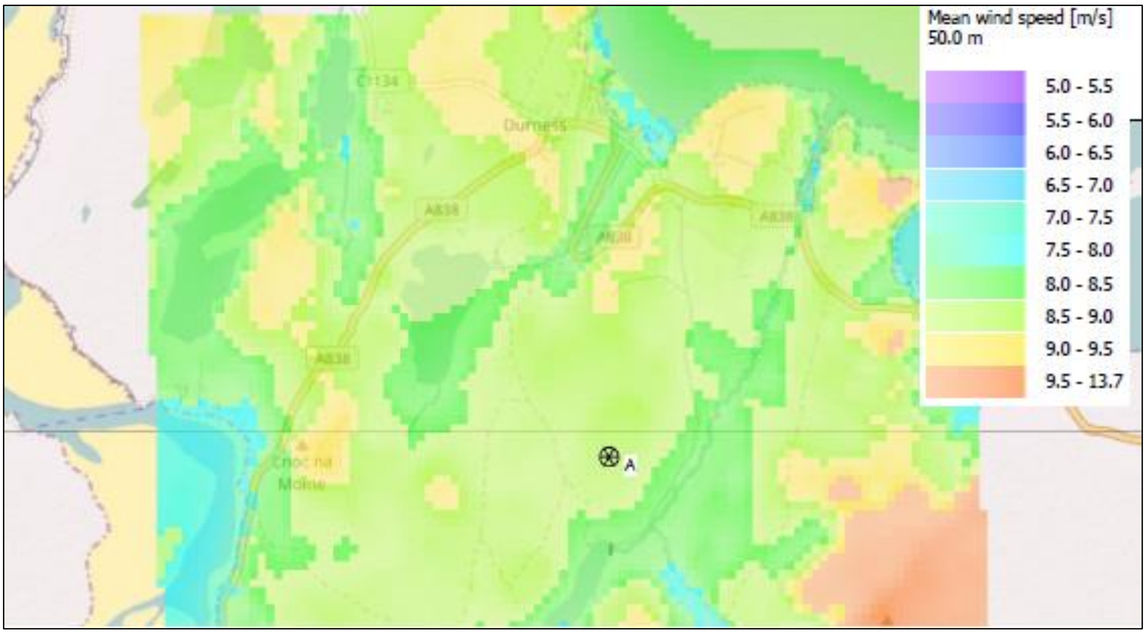



*Figure 26. Wind Resource Map*

## 5.4 Turbine Selection

The Scottish wind turbine market was studied by considering turbines in terms of a size (between 60kW and 100 kW for Craft Village, and between 500kW and 1 MW for Loch Meadaidh) and market availability. Due to the high mean wind speed and extreme weather conditions in Scottish Highlands, a turbine of Class I or Class S of International Electrotechnical Commission (IEC) Turbine classification[2], that can withstand extreme weather conditions, is required. Refer to Table 11 for the pre-assessment of turbines available on the world and UK market.

EWT offers 500kW - 900kW turbines, which are not Class I. Siemens, Vestas, GOLDWIND (VENSUS) and GE have no turbines smaller than 1.5 MW. The smallest and available turbine of Class I and Class S suitable for Loch Meadaidh site are ENERCON E53 800kW and E44 900kW turbines.

A Windflow 33/500 turbine was also considered. It is a 2-bladed Class IA turbine with a rotor diameter of 33.2 meters. (WINDFLOW UK, 2017). Also, the second-hand market was studied for a possibility of installing a turbine of about 500Kw in Durness. Scotland has experience of refurbished turbines installation with the companies specialized on maintenance and service support, some of them particularly offering services for Vestas or Vestas-derived turbine brands. (Realise Energy Services, 2017) . Vestas V39 500kW refurbished turbine is available on the second-hand market. It is a bigger

[2] According to International Electrotechnical Commission (IEC) Turbine classification Wind Class I and Class II turbines are designed to work in the tough operating conditions with average wind speeds above and above 7.7 m/s and 8.5 m/s respectively. The S class is for user defined designed turbines. (Renewables First, 2017)

turbine comparing to Windflow 33/500, therefore generates higher annual energy production (AEP). Windflow 33/500 can be considered in the future as another option for wind turbine development.

| Brand | Country of the company | Sizes of turbines up to 2 MW (IEC Class) | Source |
|---|---|---|---|
| ENERCON | Germany | 800kW (Class S), 900kW (Class IA) | (ENERCON, 2015) |
| Siemens | Denmark | N/A (the lowest capacity 2.3 MW, Class IIA, IIB and IEC IIS) | (SIEMENS, 2017) |
| Vestas | Denmark | 1.8/2 MW (Class S) | (VESTAS, 2017) |
| GE | USA | 1.85 MW (Class IIS) | (GE Renewable Energy, 2017) |
| GOLDWIND (licenced the manufacturing of turbines designed by Vensys) | China/ Germany | 1.5 MW (Class IA) | (VENSUS, 2017) |
| EWT | Netherlands (office in UK, Edinburgh) | 500kW, 750kW, 900kW (Class IIA, IIIA) | (EWT, 2017) |
| Windflow | UK | 500kW (Class IA and IIA) | (WINDFLOW UK, 2017) |

*Table 11: Turbines brands and sizes overview[3]*

Table 12 shows the technical specifications of the 5 WTG's with different sizes.

For the Craft Village, small-turbines market was checked for wind turbines in the range of 60-100 kW. UK Harbon 60kW Class I and Belgiam XIANT M-21 Class IA turbines available on the market were proposed for Craft Village wind power development.

| Characteristics of the Turbines | Loch Meadaidh | | | Craft Village | |
|---|---|---|---|---|---|
| | Enercon | Enercon | Vestas | Harbon | Xant |
| | E53 | E44 | V39 | HWT60 | M-21 |
| Rated Capacity [kW] | 800 | 900 | 500 | 60 | 100 |
| Number of Turbines | 1 | 1 | 1 | 1 | 1 |
| Total installed capacity [kW] | 800 | 900 | 500 | 60 | 100 |
| Status | New | New | Refurbished | New | New |
| Tower (Hub) Height [m] | 50 | 55 | 40.5 | 18.6 | 38 |
| Rotor diameter [m] | 53 | 44 | 39 | 16 | 21 |
| Estimated operational life[years] | 20-25 | 20-25 | 15-20 | 20 | 20 |
| Annual power generated [MWh] | 3803 | 3472 | 1930 | 221 | 454 |
| Turbine capacity factor [%] | 54.3% | 44 % | 44.1% | 42.02% | 51.9% |

*Table 12. Site specifications of the 3 proposed WTG's (WindPRO®)*

[3] Please use the Table for reference only. It was compiled to have an overview, and do not do not claim that these are all turbines available on the market.

From Table 12, the annual energy production (AEP) in Loch Meadaidh of the Enercon 800 kW and 900 kW wind turbine generators (WTG's) is 3803 MWh and 3472 MWh respectively, while the AEP of the Vestas 500 KW wind turbine is 1930 MWh. Additionally, Table 12 shows capacity factors of above 42% for each turbine, hence a promising potential of energy generation for both sites. Hub height selection plays an important role in the energy generation from a WTG. For instance, for Enercon turbines it was observed that an increase of 23.3 m in the hub height would slightly increase the capacity factor by 4%. However, due to the capital cost considerations the hub height values given in Table 12 are recommended.

## 5.5 Options Assessment

### 5.5.1 Loch Meadaidh - annual energy production (AEP)

Power output for the three wind turbines generators under consideration and average wind speed for the period from 2007 to 2015 were plotted. Figure 27 illustrates the average of power output in kW and the wind speed average in m/s from the three WTG's for the period of 9 years from 2007 to 2015. The average output of the three turbines is 427 kW, 389 kW and 216 kW respectively for an averaged wind speed of 8.92 m/s at 50m height.

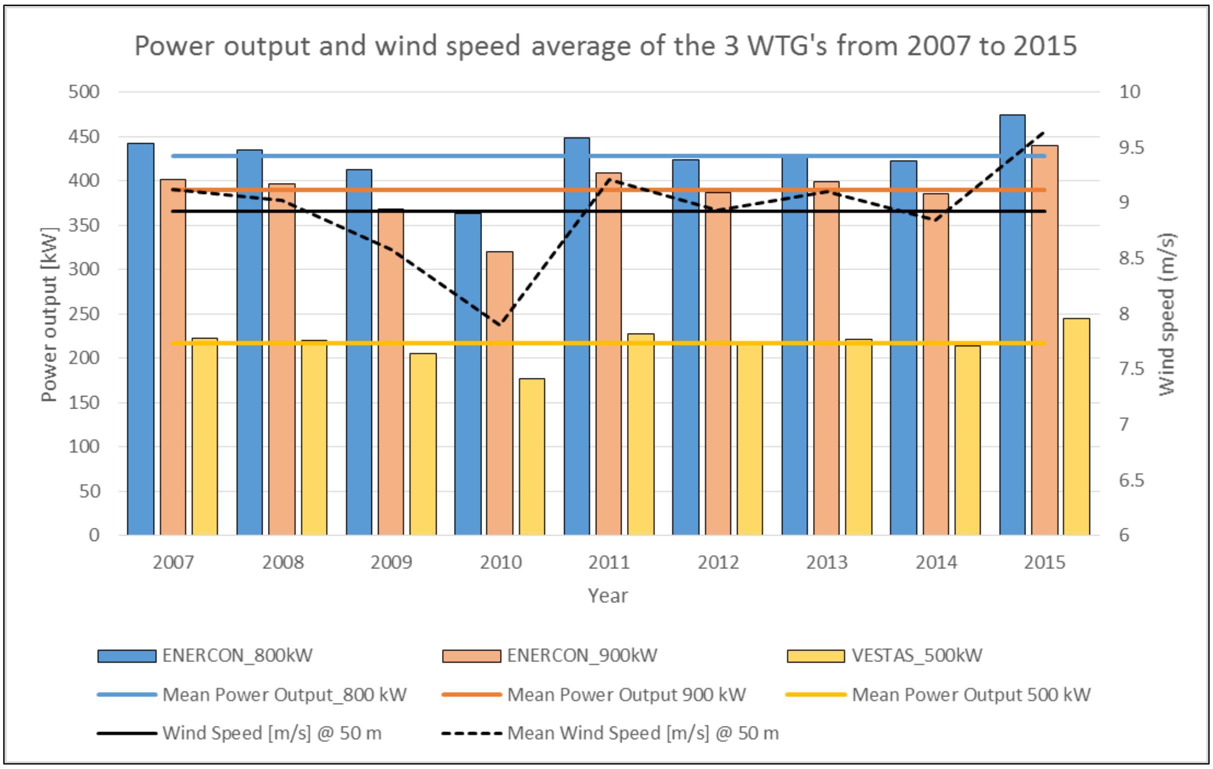



*Figure 27. Power Output of the 3 Turbines from 2007 to 2015.*

From Figure 27, there are 2 years whose averages considerably represent the 9-year average power output for each turbine. Therefore, years 2008 and 2013 could be the possible cases to consider as a reference year which can be applied for predicting power output values along the lifetime of the wind turbine generator.

For further analysis 2008, has considered as the reference year and 2013 as the worst-case scenario year based on the heat demand profile.

On the other hand, it can be also seen that the ENERCON 800 kW Turbine (E-53) has higher values of power output than the ENERCON 900 kW turbine (E-44) because of the larger rotor area. Due to the fact that, ENERCON 900 kW has a smaller rotor, even with a bigger generator it a less power output compared to the ENERCON 800 kW turbine for the period under consideration, at 50 m height as shown in Figure 28 below.

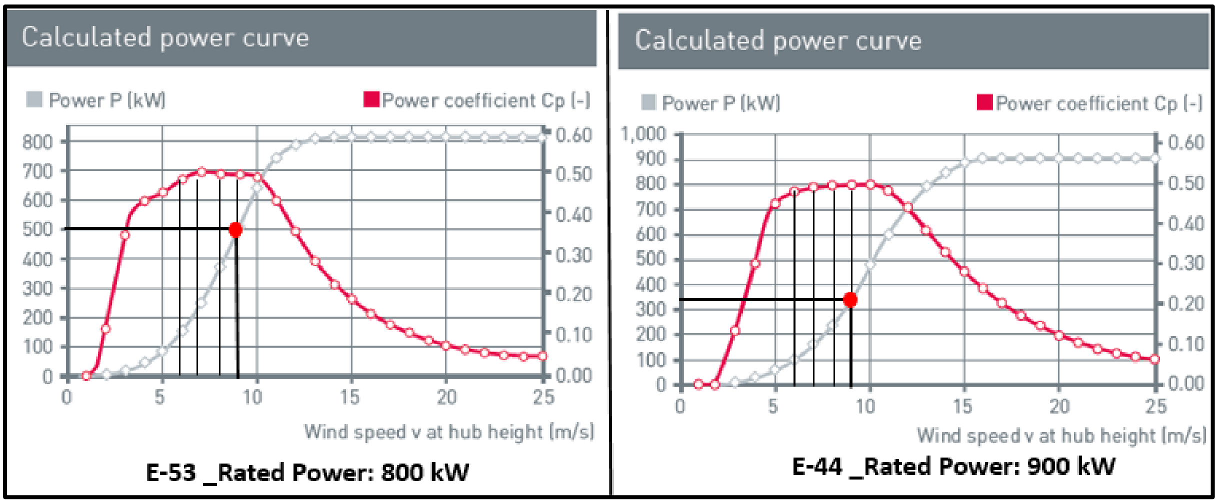



*Figure 28. Calculated power curve of E-53 and E-44 WTG's*

The annual energy production of the turbine calculated in WindPRO® software is shown below.

**Calculated Annual Energy for each of 1 new WTGs with total 0.8 MW rated power**

| Links | Valid | Manufact. | Type-generator | Power, rated [kW] | Rotor diameter [m] | Hub height [m] | Displacement height [m] | Power curve Creator | Power curve Name | Annual Energy Result [MWh] | Annual Energy Result-10.0% [MWh] | Park Efficiency [%] | Mean wind speed [m/s] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 A | Yes | ENERCON | E-53-800 | 800 | 53.0 | 50.0 | 0.0 | EMD | Level 0 - official - 01/2013 | 3,734.7 | 3,361 | 100.00 | 8.91 |

**Calculated Annual Energy for each of 1 new WTGs with total 0.9 MW rated power**

| Links | Valid | Manufact. | Type-generator | Power, rated [kW] | Rotor diameter [m] | Hub height [m] | Displacement height [m] | Power curve Creator | Power curve Name | Annual Energy Result [MWh] | Annual Energy Result-10.0% [MWh] | Park Efficiency [%] | Mean wind speed [m/s] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 A | Yes | ENERCON | E-44-900 | 900 | 44.0 | 55.0 | 0.0 | EMD | Level 0 - official - 900kW - 12/2014 | 3,405.1 | 3,065 | 100.00 | 9.10 |

**Calculated Annual Energy for each of 1 new WTGs with total 0.5 MW rated power**

| Links | Valid | Manufact. | Type-generator | Power, rated [kW] | Rotor diameter [m] | Hub height [m] | Displacement height [m] | Power curve Creator | Power curve Name | Annual Energy Result [MWh] | Annual Energy Result-10.0% [MWh] | Park Efficiency [%] | Mean wind speed [m/s] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 A | No | VESTAS | V39-500 | 500 | 39.0 | 40.5 | 0.0 | EMD | Man. 24-08-00 1.225 25.00 0.0 | 1,894.1 | 1,705 | 100.00 | 8.56 |

*Figure 29. AEP of the 3 WTGs*

### 5.5.2 Craft village - energy production analysis

As stated earlier, two options have been considered for the Craft Village site. A turbine in the range of 50-60 kW or 80-100 kW could be appropriate to meet the annual heating demand. It has been assumed that small-scale wind turbines at the Craft Village will feed into a district heating network with a thermal storage system. A 60kW HWT60 and a 100kW XANT M-21 wind turbines have been considered for installation. Turbine selection was based on availability in the market, existing installations in Scotland and the current tariff and financial schemes.

The results for annual energy production of a Harbon 60kW or Xant 100kW turbine are shown in Table 13. The annual energy output for Harbon and XANT turbines is 221 MWh and 454 MWh respectively.

| Sector | 60 kW HARBON | 100kW XANT |
|---|---|---|
| Total Energy Output [MWh] | 221 | 454 |
| Average Power Output (kW) | 25.21 | 51.8 |

*Table 13: Annual Energy Output of 60kW HARBON & 100kW XANT Turbines (Source: WindPRO®)*

### 5.5.3 Grid connection

As the energy produced from the proposed turbines near Loch Meadaidh will be used for the local heating demand through the local grid, the possible point of connection of these turbines to the local grid network has been examined. In Loch Meadaidh the closest grid connection point is a 2-phase 11 kV, 1180m away from the wind turbine location. The proposed turbine near Craft Village does not require a connection to the grid because it is assumed that the energy produced from this turbine will be transmitted to a district heating system designed only for Craft Village through a private power line. Grid connection cost for the turbines located near Loch Meadaidh and the private power line cost for the Craft Village installation has been estimated and a detailed breakdown of the cost is presented in the next chapter.

### 5.5.4 Preliminary cost analysis

To assess the economic feasibility of the options described above, investment and operational costs of the proposed turbines were estimated. Though wind turbines projects are a capital-intensive, they have no fuel costs. The key parameters considered in cost-economic analysis are investment costs, operation and maintenance costs (O&M), capacity factor, and project lifetime. The cost of the wind turbine and auxiliaries comprise 64%-69% of the total project cost. (IRENA, 2012) (Renewables First, 2015). The total project includes, the cost of the turbine, grid connection, civil works (including foundation) installation and access roads construction costs (Renewables First, 2015). It varies from region to region depending on local costs of services (for example, construction works, electrical and installation, connection to the grid).

Total project costs for the Craft Village and Loch Meadaidh sites are listed in Table 14. Land rent is assumed to be 5 % of the annual profit (Vidal, 2012).

| | 800 kW Enercon | 900 kW Enercon | 500 kW Vestas | HARBON 60kW | XANT 100kW | Unit |
|---|---|---|---|---|---|---|
| **Capacity** | 800 | 900 | 500 | 60 | 100 | kW |
| **Gross Specific Yield** | 4754 | 3858 | 3862 | 3691.2 | 4544.7 | kWh/kWp |
| **Performance Ratio** | 54.3% | 44% | 44.1% | 42% | 51.9% | % |
| **Estimated degradation of equipment** | 0.3% | 0.3% | 0.3% | 0.3% | 0.3% | %/year |
| **Investment** | | | | | | |
| **Equipment & auxiliaries & installation** | 1588860 | 1548860 | 1357560 | 241061 | 271049 | £ |
| **Project management** | 10000 | 10000 | 10000 | 5000 | 5000 | £ |
| **Grid connection** | 164244 | 164244 | 164244 | 16916 | 16916 | £ |
| **Construction costs** | 190000 | 200000 | 176250 | 15066 | 16941 | £ |
| **Total** | **1953104** | **1923104** | **1708054** | **278043** | **309906** | £ |
| **Costs** | | | | | | |
| **O&M** | 45638 | 45502 | 32500 | 7232 | 8131 | £/year |
| **Land rent** | 5% | 5% | 5% | 5% | 5% | £/year |
| **Insurance** | 12000 | 12000 | 6000 | 6000 | 6000 | £/year |

*Table 14. Investment and Operational Costs of Options[4]*

Grid connection costs were estimated from information on connection charges from Scottish electricity distribution system (Scottish Hydro Electric Power Distribution plc, 2016).

In Scotland, the community sector renewable energy development comparing to commercial purposes, shows 25% to 275% higher pre-planning costs, longer time framework and different labour requirement. At the same time, the community projects are still economically feasible (Harnmeijer, et al., 2015, p. 2).

### 5.5.5 Environmental considerations

Wind energy development includes the environmental impact assessment as one of the main requirements to be fulfilled before obtaining a planning permission. The framework for Environmental Impact Assessment (EIA) is provided by European Directive: 85/337/EEC, as amended by 97/11/EC and 2003/35/EC. (Scottish Natural Heritage, 2016) Various statutory regulations which assess and approve wind projects have been examined. The starting point is Scottish Planning Policy 2014, Onshore Wind

[4] The costs were calculated based on assumptions from the previous community owned projects and literature review (Harnmeijer, et al., 2015), (Renewables First, 2015), (IRENA, 2012).

section, which describes the overall planning framework, and states that wind energy developments are likely to include landscape and visual impacts, effects on the natural heritage and other environmental impacts (The Scottish Government, 2014, p. 40).

### 5.5.6 Environmental impacts of windfarm development

In planning stage, it is required that developers to collaborate with relevant stakeholders during EIA. The government and regulatory agencies in Scotland are represented by Scottish National Heritage (SNH) and Scottish Environmental Protection Agency (SEPA). Scottish National Heritage provides advice and guidance on the assessment of the impacts of the project (Scottish Natural Heritage, 2016).

During the site selection process a spatial framework analysis as required by Scottish Planning Policy was studied. Scottish Planning Policy defines 3 groups for wind farm developments in terms of environmental aspects. National Parks and National Scenic Areas, classified as group 1, are areas where the windfarms will not be acceptable. The 2nd group comprises of protected areas, where windfarms can be developed in some circumstances. Lastly, group 3 includes areas where wind farm development is not limited (The Scottish Government, 2008).

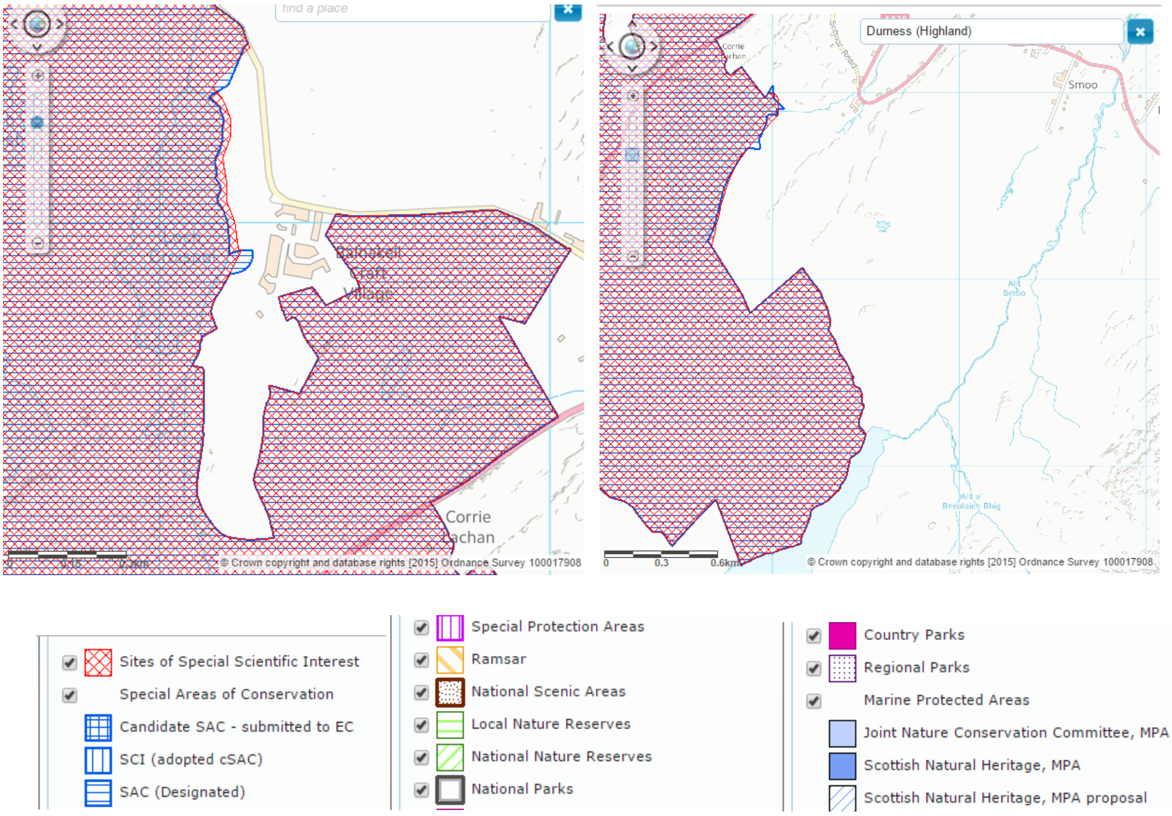



*Figure 30. Map of environmental areas in Durness. Left – Barnakeil Craft Village Site. Right - Loch Meadaidch lake site (Scottish Natural Heritage, 2015)*

Two sites Loch Meadaidh lake and near Balnakeil Craft Village are located outside of environmentally protected areas, but close to Sites of Special Scientific Interest (SSSI) and Special Areas of Conservation (SAC). Refer to Figure 30.

A Highland Council Countryside Ranger for Northwest Sutherland and SNH office in Golspie were contacted to provide an overview of environmental constraints relating the selected sites. With its beauty and natural scenery, the Scottish Highlands region attracts many tourists. One of the main concerns during the planning stage in Durness has been protected species.

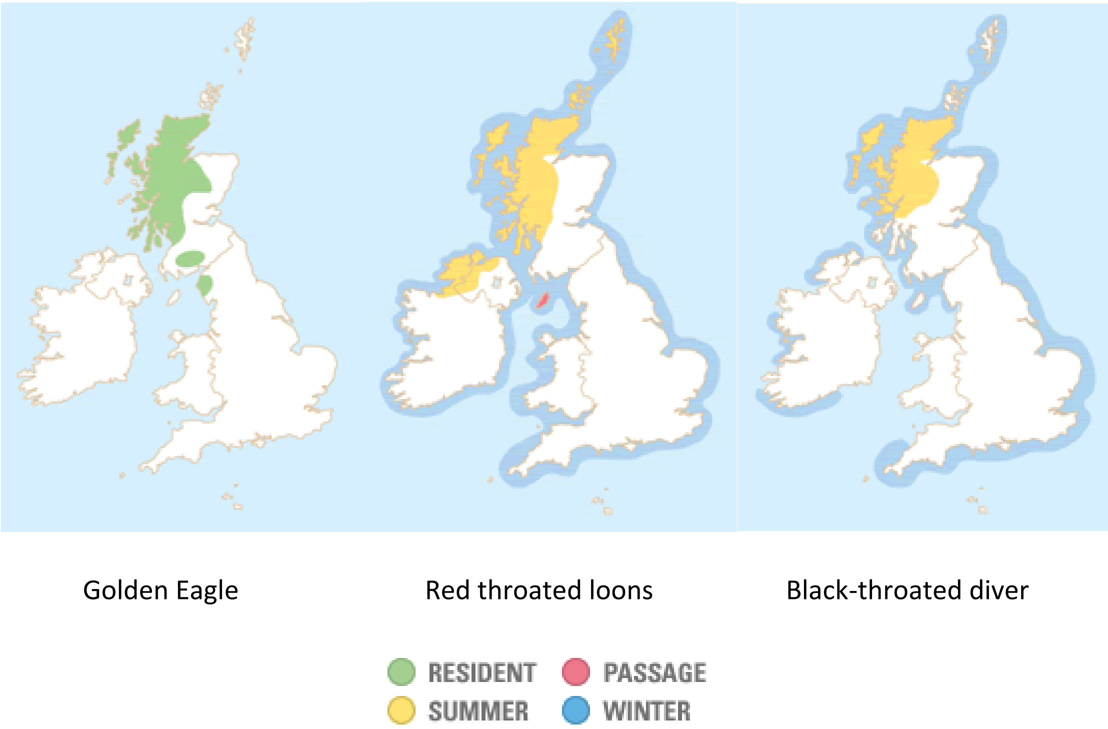



*Figure 31: General distribution map of birds (The Royal Society for the Protection of Birds (RSPB), n.d.)*

In Durness, the black and red throated loons (divers) and Golden eagles are one of the local birds protected by Wildlife and Countryside Act 1981 (Scottish Natural Heritage, 2015). Golden eagles have traditional territories and nesting places whole year. In the breeding season between August and October Red-throated divers fly to UK's east and west coasts. Therefore, it is important to find out if their flight path crosses the proposed wind turbine locations. Another protected bird species is Corncracke, which is seen mostly in Durness village and very rarely in Balnakeil. At this point, it can be stated, that the proposed sites are out of environmentally protected areas and suitable for wind energy development. However, it is recommended that a detailed EIA should be conducted.

In the following section, the results of Visual Impact, Noise, and Shadow flickering assessment in WindPRO® are presented.

#### 5.5.6.1 Visual impact from a wind turbine

Scotland is well known for its beautiful landscapes and diversity that attract people's attention throughout the world. Wind turbines are large structures that may be visible from certain part of the area. Therefore, this might represent an impact on the surrounding landscape and dwelling close to the site from the wind turbine generators.

Assessing the visual aspect that might alter the visual amenity of the properties, is crucial t for the pre-feasibility environmental study of a wind park, and it can be done by generating a preliminary Zones of a Visual Influence (ZVI) map. In this study, possible critical points were identified in the visual impact ZVI map. Thereafter, photomontage method of visualization was applied for each critical view point to give a realistic visual impression of the turbine in WindPRO®, wind energy modelling software tool.

#### 5.5.6.2 Zone of visual influence: ZVI modules in WindPRO®

Six possible viewpoints were picked and photomontage visualization done for each point to evaluate visibility of wind turbine from these points. Smoo Cave Hotel, Durness Village Hall, Caberfeidh bed and breakfast and the nearest dwellings from the 800 kW WTG evaluated as shown below.

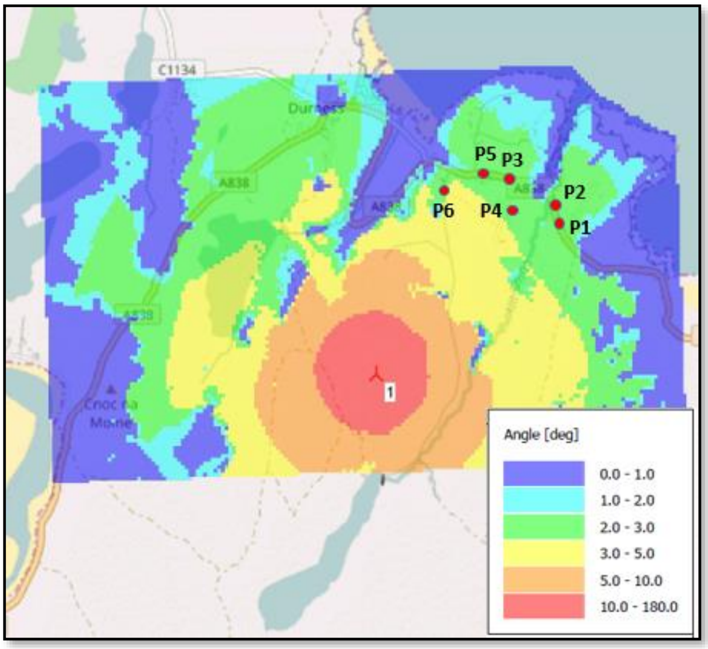



*Figure 32. ZVI map: Analysis of the long distance visual impact of the 800 kW WTG.*

From these 6 points of view, the wind turbine is hardly visible as demonstrated by the ZVI mapping and by the realization of photomontages.

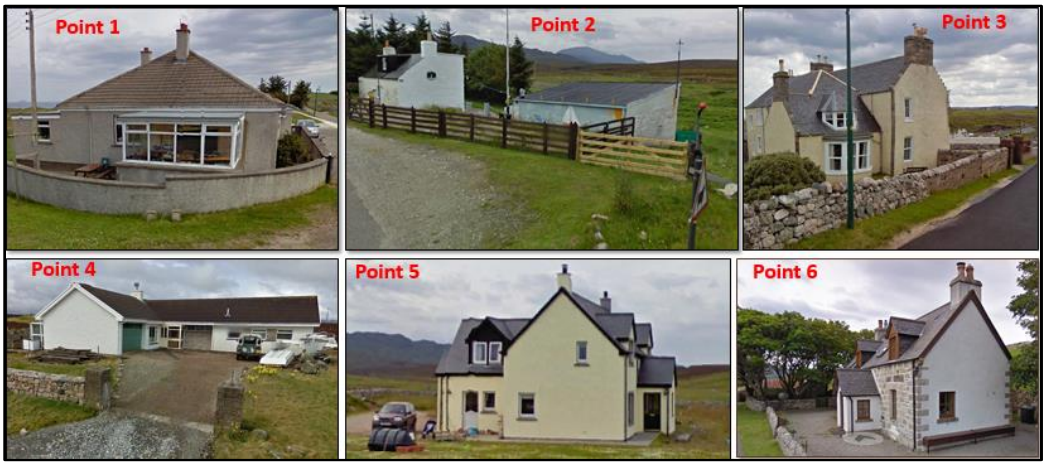



*Figure 33. Places and houses considered as possible critical points of visual impact*

| Coordinates of the critical points of the ZVI analysis in Durness | | | | | | |
|---|---|---|---|---|---|---|
| **Type of coordinate and properties** | **Point 1** (Smoo Cave Hotel) | **Point 2** (Nearby the "Power house of the proposed Hydro Scheme") | **Point 3** (Caberfeidh Bed and Breakfast) | **Point 4** (House nearby Bed and Breakfast) | **Point 5** (Durness Village Hall) | **Point 6** (The closest house to the WTG) |
| Latitude | 58°33'37.91"N | 58°33'43.21"N | 58°33'49.99"N | 58°33'41.62"N | 58°33'51.65"N | 58°33'45.81"N |
| Longitude | 4°43'6.95"W | 4°43'11.38"W | 4°43'28.44"W | 4°43'33.24"W | 4°43'41.78"W | 4°43'57.77"W |

*Table 15. Possible critical point of visual impact*

#### 5.5.6.3 Photomontage in WindPRO®

A photomontage was done for each of these six viewpoints to visualise how large the turbine would appear near to its surrounding area.

Both ZVI map and the photomontage may facilitate the visualization of a possible visual impact, however this concept of visual impact depends mainly in part on the people's acceptance of having a WTG nearby a property (see Appendix G).

#### 5.5.6.4 Noise impact

Noise impact is one of the main concerns in wind energy projects, since they might be located nearby to households. Nowadays manufacturers are focused in the production of low noise emission devices. At lower wind speeds emitted noise is reduced while at higher wind speeds the ambient noise from the wind helps to mask the noise emission.

For analysing the noise and shadow flickering effect in the surrounding area (for 500, 800 and 900 Kw turbine option) three points (A, B and C) which represent some houses close to the project site (Loch

Meadaidh) were assessed. The same procedure was repeated in the craft village for the proposed 60 kW turbine with placing point A, which is representing the closest building to the turbine.

The permitted threshold values of noise according to Legislative Background, Technical Standards and Codes of Practice (Noise, 2011).

| **Range of Permitted Noise value in dB** | 45 - 35 |
| --- | --- |

*Table 16. Permitted threshold values for noise emission according to the Assessment and Rating of Noise from WindPRO®3.0 (Noise, 2011)*

We can choose the maximum noise level to be 45 dB, which represents the threshold for a mixed area (individual houses, farms, etc.) like the village of Durness. In Figure 34 be seen the plot of the noise calculation made in WindPRO®3.0 for the 800 kW turbine and for the other turbines (see Appendix F). All the area between the red ring to the end of the yellow circle are affected by noise level of 45 dB or below. It is worth to mention that if the craft village turbine moved from the proposed location for 60 m in -44° direction, point A will lie in the acceptable noise range area (below 45 dB).

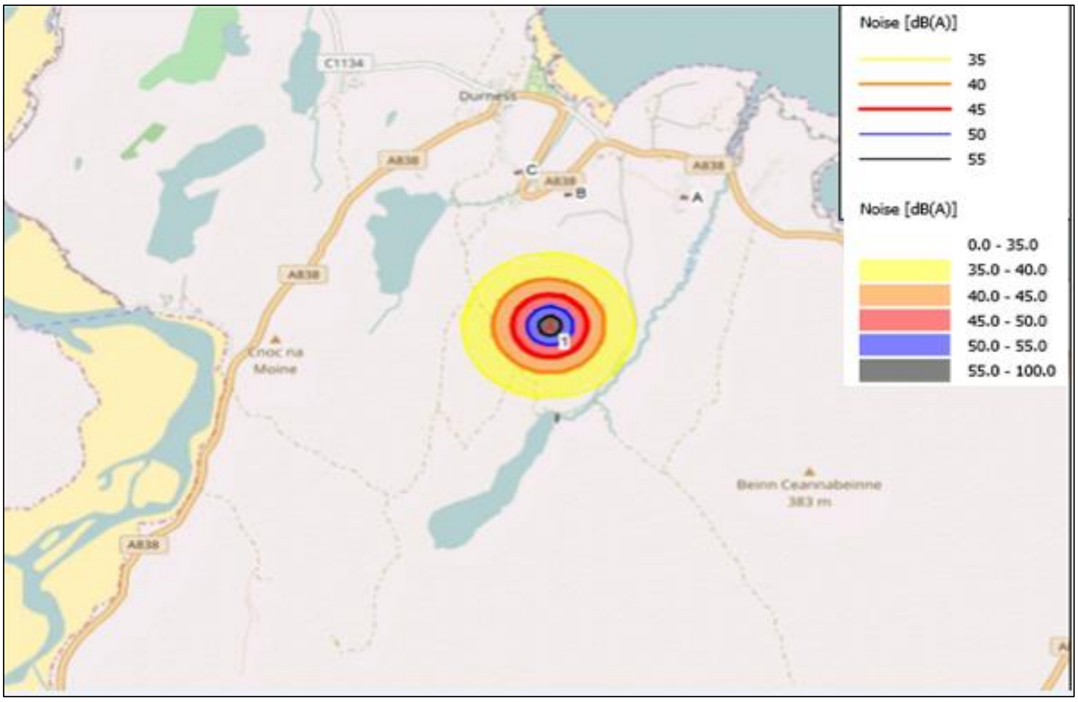



*Figure 34. Plot of Noise Results (WindPRO®3.0)*

| Point No. | Noise Threshold (dB) | Noise Received from WTG (dB) | Distance to noise demand (m) | Noise Limit Fulfilled? |
|---|---|---|---|---|
| (800kW)<br>(900kW) A<br>(500kW) | 45.0 | 25.2<br>25.4<br>21 | 1,102 | **YES** |
| (800kW)<br>(900kW) B<br>(500kW) | 45.0 | 25.2<br>27.7<br>23.9 | 798 | **YES** |
| (800kW)<br>(900kW) C<br>(500kW) | 45.0 | 25.2<br>25.4<br>21.7 | 995 | **YES** |
| 60 kW Craft village turbine | 45.0 | 48.5 | 30 | **NO** |

*Table 17. Values of noise in points A, and B (Generated by WindPRO®3.0)*

In the table above, the column "distance to noise" shows the minimum distance necessary to comply with the limit.

#### 5.5.6.5 Shadow flickering

Shadow flickering impact is one of the main negative effects to considered in any wind parks calculation and design. It is caused by the moving blades of a wind turbine on the ground and stationary objects, like houses, and its intensity and frequency depend on the light intensity casting shadow and rotor rotation velocity. So, the distance from the nearest dwellings to the turbine should be carefully assessed, to reduce visual pollution and nuisance to people living nearby. There are regulations for different countries about the maximum allowable number of hours per year of shadow flickering.

As described in the noise section, three sensitive points were placed nearby the wind turbine to measure the shadow flickering in WindPRO® (same three points A, B and C considered in noise calculation). Regulations state that any object close to a wind park should not be subjected to more than 30 hours per year of shadow flickering according to UK standard (Edwards, 2013 ) . In Figure 35 the shadow flickering map generated by WindPRO® 3.0 for the 800-kW turbine and for the other turbines (see Appendix F). From this map and the calculations report generated by the software, we can conclude that the three sensitive points are in the region of acceptance. As point A, B and C are having a shadow flickering value of 0 hours per year for the three turbines scenarios.

According to the WindPRO® report calculations shown in, the three points A, B and C have zero measure of shadow flickering. According to UK standards, the 3 points would be considered in the accepted area (Edwards, 2013 ).

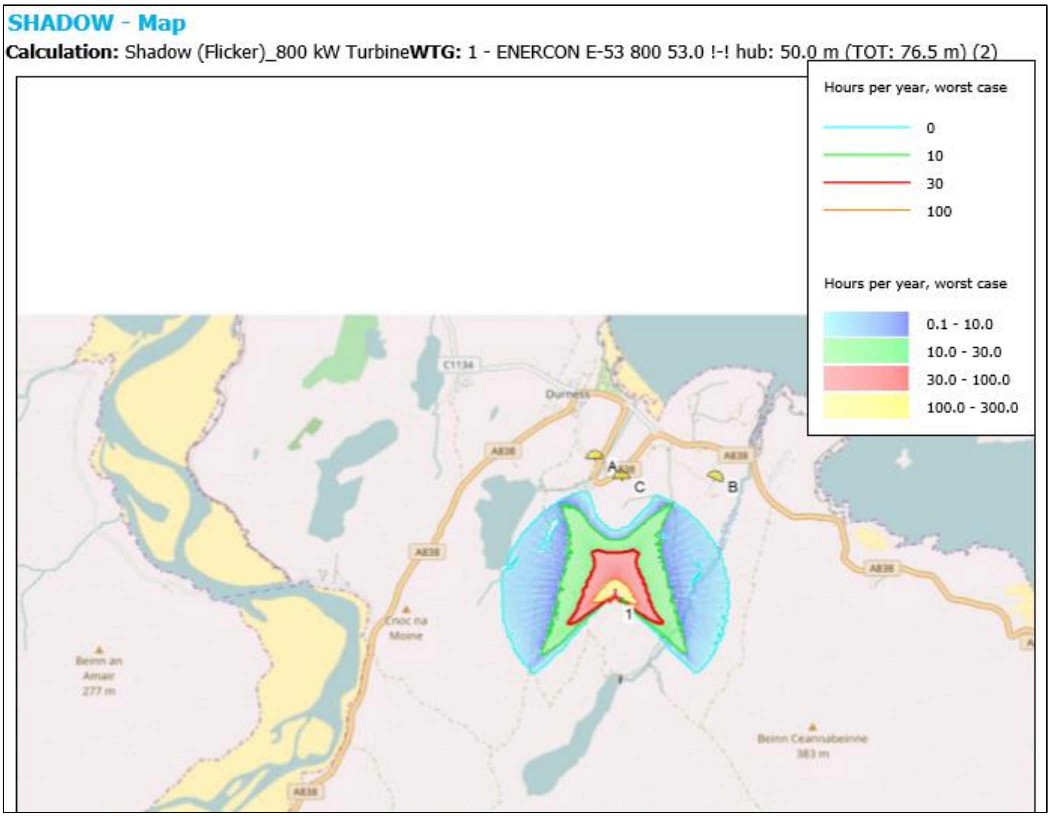



*Figure 35: Plot of Shadow Results (WindPRO®3.0)*

The red line separates between the zone which vary between 0.1-30 hours per year with an accepted shadow flickering value and the rest of the zones with different colours and values with unaccepted levels of shadow flickering.

From the WindPRO® report calculations shown in Figure 35, the three points A, B and C have zero measure of shadow flickering. According to the UK standards, the 3 points would be considered in the accepted area (Edwards, 2013 ).

# 6 Hydro Resource Assessment

## 6.1 DDG's Previous Work on Hydro Energy Development

Significant efforts have been made by the Durness community through Durness Development Group (DDG) to look at ways of utilizing the available local renewable resources for the benefit of the community. One of the technologies considered has been a micro hydro power project. A hydro scheme project of 50kW capacity had been considered before with an intake at Loch Meadaidh. A report by Grangeston Economics in 2012 for DDG concluded that a hydro scheme on the Allt Smoo was unlikely to be technically and economically viable (Mackay, 2012). However, the plans to build a bistro with flats and potentially a microbrewery close to the location of the powerhouse of the proposed hydro scheme make it worth to reconsider the project. It is assumed that electricity supply of the premises through a private wire could make the project feasible.

## 6.2 Overview of Hydro Technology

Hydro schemes are classified according to installed capacity, operation regime or available head. Micro hydro schemes are generally run- of -river type. A run-of-river hydro power scheme abstracts water from a river, uses it to turn a turbine to generate electricity before returning the water to the river. The generation potential of hydro scheme depends mainly on the head, the flow available and its seasonal variations. The power output of a hydro scheme is directly proportional to the available head (H) and the flow rate (Q). Since run-of-river schemes have no or limited storage capacity, they are subject to weather and seasonal variations resulting to variable power generation. The peak power operation could also be limited to a few hours.

The key components of the hydro plant include the weir, intake, penstock, powerhouse housing the machinery, tailrace. Figure below shows a typical layout of a run-of-river scheme.

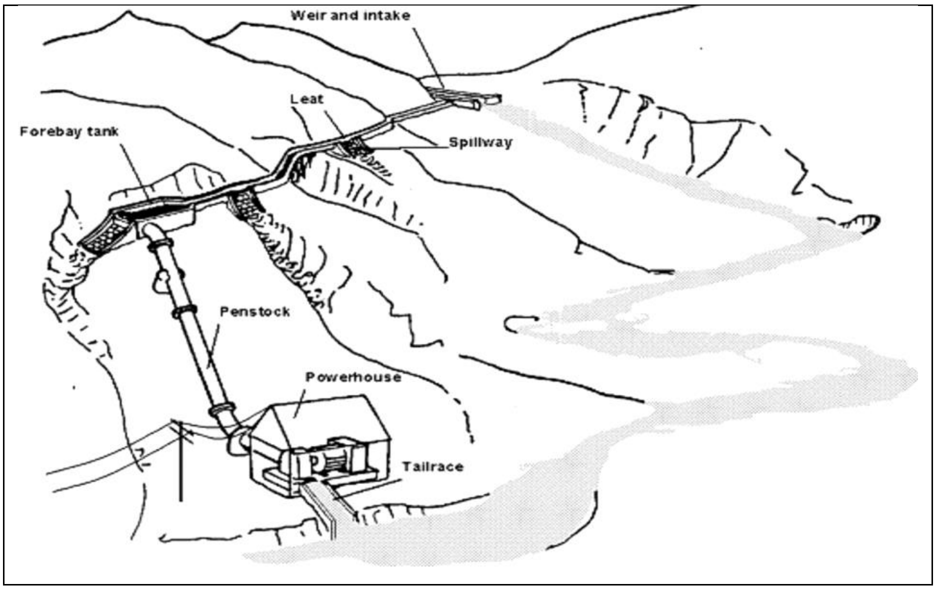



*Figure 36. Typical run-of-river scheme layout (BHA, 2012)*

Usually schemes are categorized according to the head:

| | |
|---|---|
| low head: | $H < 30$ m |
| medium head: | $30m < H < 100m$ |
| high head: | $H > 100$ m |

## 6.3 Resource Assessment

### 6.3.1 Hydro project development methodology

The methodology deployed for this project assessment includes site visit for physical view of the lake, rivers, topography, flow and other characteristics required for hydro project potential assessment. Flow data were obtained from report by Wallingford Hydro Solutions (WHS) low flow studies (Jones, 2016). As only flow duration profiles were made available, daily distribution of flow has been estimated using an energy modelling software. Catchment area were identified in GIS[5]. Possible intakes were derived from site visit. Desktop studies were carried out relating to environmental impact assessment, especially to know special area of conservation (SAC), permitting and licensing for micro hydropower scheme in line with SEPA[6] requirement. Handheld GPS as well as mapping tools like ARCGIS ® were used to obtain catchment area, elevation, distance and possible intake points of selected sites to study their potentials in details.

The annual energy production from the scheme was calculated with the flow data from WHS for Allt Smoo. Allt Port Charmuill energy production results are based on estimated flows on the site with the assumption that the catchment area shares similar characteristics with that of Allt Smoo, bearing in mind that it only allows a rough estimation of potential. Due to the small catchment area of this site, modelled flow data as those from WHS have very limited validity for Allt Port Charmuil. Measured data will be required to ascertain the potential of the area. Cost estimations were carried out through literature studies and recent quotations.

### 6.3.2 Rivers and lake availability

As earlier identified by DDG, the first site considered is Allt Smoo which is an outflow from Loch Meadaidh. This presented options to either choose the outlet of the lake (Loch Meadaidh outlet) or downstream of the river after its first tributary (Allt Smoo inlet) for the penstock intake. In addition, an assessment of a third option at Allt Port Charmuill located around Souterrain near Portanamco was carried out. The site seemed attractive due to high head and its catchment characteristic was assessed with possibility of diversion of one of its tributaries.

The potential of each of these sites was fully assessed and later discussed using the following criteria:

- Size of catchment area
- Flow, head and resulting annual energy production capability
- Cost of project

[5] GIS – Geographic Information System
[6] Scottish Environmental Protection Agency (SEPA) guidance on run of river hydropower scheme

#### 6.3.2.1 Catchment area

Catchment area was calculated for each intake point of our options using the Hydrology Tool set for Spatial Analyst in ArcGIS 10.3 (ESRI), ASTER_GMT2 DEM[7] and OS[8] DTM. Figure 37, Figure 38 and Table 18 show the results obtained.

| Options | Coordinates converted from British National Grid (BNG) | | Catchment Area ($Km^2$) |
|---|---|---|---|
| | `Longitude | Latitude | |
| **1. Loch Meadaidh outlet** | -4.7382 | 58.5451 | 4.4 |
| **2. Allt Smoo intake (300 meters downstream)** | -4.7325 | 58.5491 | 6.7 |
| **3. Allt Port Charmuil** (With Diversion of tributary) | -4.7088 | 58.5133 | 1.5 |

*Table 18. Catchment description of options*

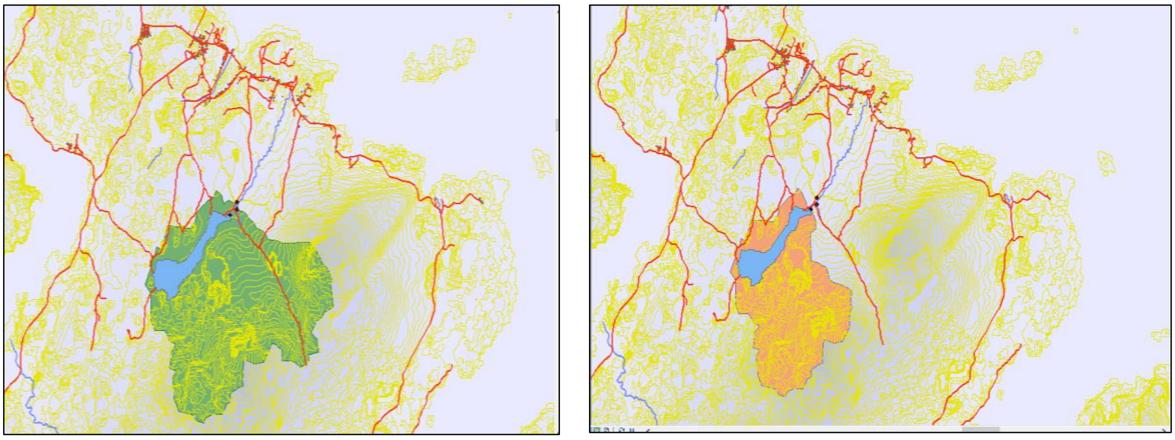


*Figure 37. Catchment location for Allt Smoo downstream inlet (left) and Loch Meadaidh (right)*

[7] DEM – Digital Elevation Model
[8] OS - Ordinance Survey

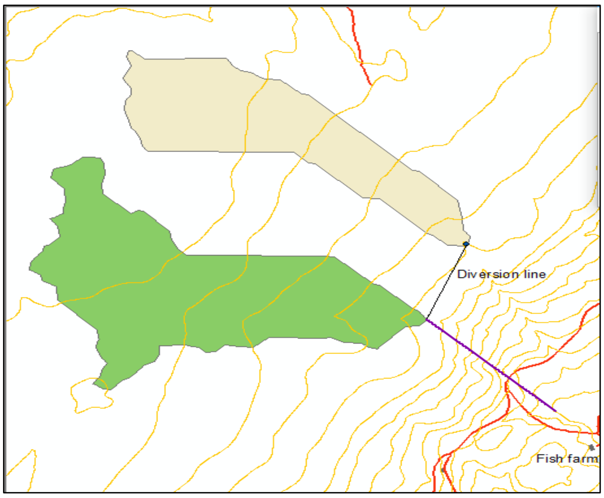



*Figure 38. Catchment size for Allt Port Charmuill*

### 6.3.3 Head and flow calculation

**Gross Head**

The gross head is the height difference between penstock intake point and the power house. Figure 39 below shows the height above sea level and coordinates of proposed intake and power house, given a gross head of 35m for Allt Smoo.


*Figure 39. Proposed intake and power house location for Allt Smoo*

For Allt Port Charmuill site, the proposed intake and the power house lie 110m and 10m above sea level respectively, giving a gross head of 100m (see Figure 40).

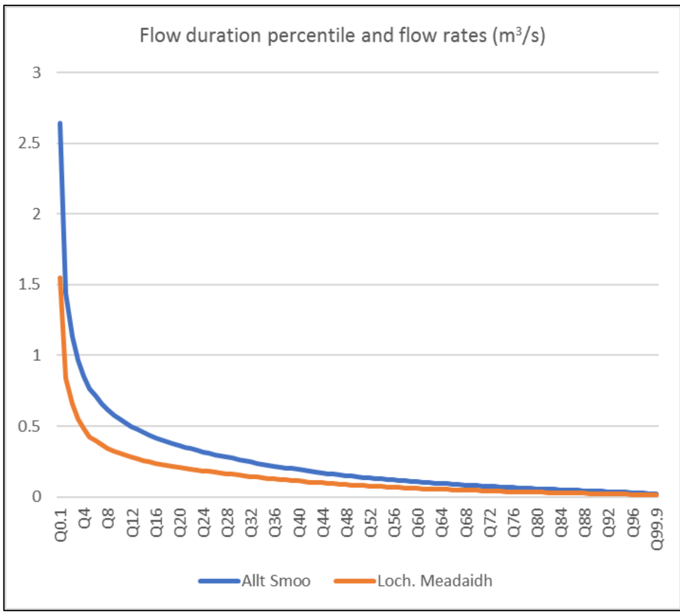

*Figure 40. Proposed intake for Allt Port Charmuill*

**Net Head**

Net head is the difference between the gross head and the head losses caused by friction in pipe, pipe tapering, bent, entrance shape, trash rack and gate valves (Penche, 1998).

**Long Term Flow**

Annual flow data showing seasonal variations and monthly flow percentile for the two options in Allt Smoo has been provided by WHS. From these data, the design flow rates corresponding to annual mean flow of 0.151m$^3$/s and 0.255m$^3$/s for Loch Meadaidh outlet and Allt Smoo respectively have been used to find out which is a more viable option. From this initial assessment, Loch Meadaidh was found less viable and dropped. Thus, the decision to choose and size the micro hydro scheme for Allt Smoo.




| Month | Allt Smoo | Loch Meadaidh |
|---|---|---|
| Jan | 0.429 | 0.233 |
| Feb | 0.347 | 0.19 |
| Mar | 0.294 | 0.174 |
| Apr | 0.19 | 0.112 |
| May | 0.138 | 0.074 |
| Jun | 0.102 | 0.066 |
| Jul | 0.112 | 0.067 |
| Aug | 0.184 | 0.098 |
| Sep | 0.19 | 0.13 |
| Oct | 0.316 | 0.209 |
| Nov | 0.35 | 0.219 |
| Dec | 0.409 | 0.239 |
| **Mean** | **0.255** | **0.151** |

*Figure 41. Flow duration curve (left) and monthly mean flow (right)*

Furthermore, for a preliminary estimation of the potential of Allt Port Charmuill, the specific flow per km² catchment area of Allt Smoo was used to estimate flow percentile for Allt Port Charmuill through interpolation. Figure 42 below is the flow duration curve (FDC) for the site and it was used in assessing its potential. From the preliminary assessment made Allt Smoo was found to be the most viable option for the hydro scheme. The reason is that though Allt Charmuill is 3times larger in head compared to Allt Smoo, its catchment size is more than 4 times smaller and possess a steeper terrain which could result in higher variation of flow. More so, higher cost due to diversion of tributary and possibility of grid constraints could negate the eventual benefits of the project.

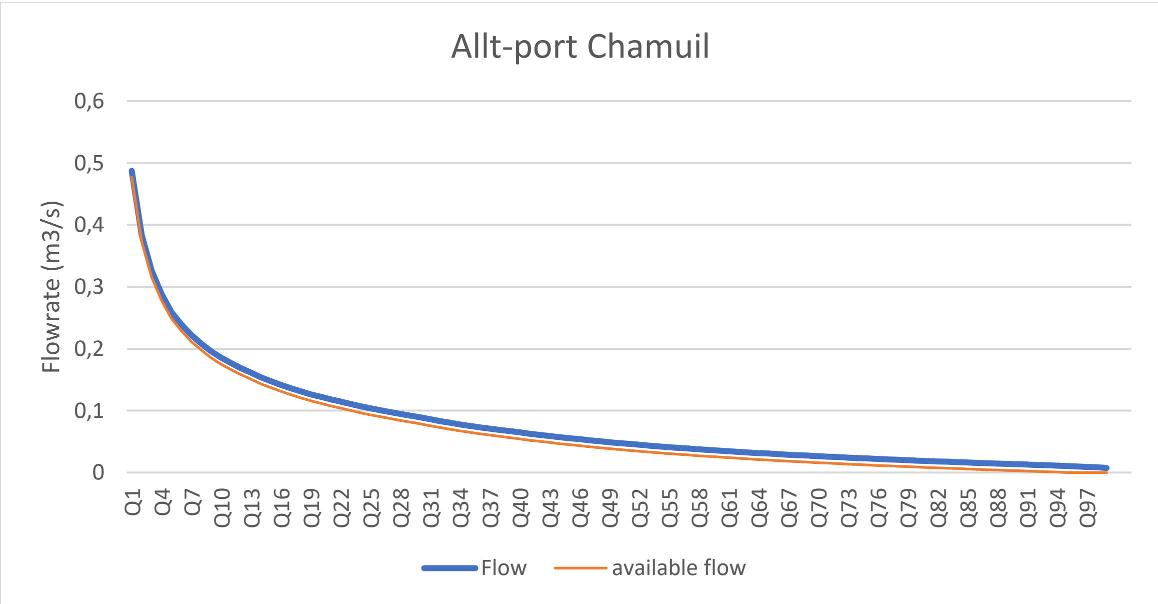



*Figure 42. Flow duration curve for Allt Port Charmuill*

### 6.3.4 Technology – component selection and specification for Allt Smoo

Component selection for Allt Smoo is based on the following design flow rate consideration:

| **Options** | **Flow rates ($m^3/s$)** |
|---|---|
| Annual mean ($Q_{mean}$) | 0.255 |
| 1.3 x $Q_{mean}$ | 0.332 |
| 1.5 x $Q_{mean}$ | 0.383 |
| 0.75 x $Q_{mean}$ | 0.191 |

*Table 19: Design flow rates*

#### 6.3.4.1 Penstock

Penstock pipes are used to convey the water from intake to the power house. A penstock can be installed over or under the ground depending on factors such as soil nature, material type, ambient temperature and environmental requirements[9]. Polyethylene was chosen based on the following criteria:

| Selection Criteria | Description | Rationale |
|---|---|---|
| Material Type | Polyethylene (PE) | Very easy to install due to light weight, less corrosive, less frictional losses and excellent in pressure resistance compared to others[10] |
| Market Availability | Readily | Many suppliers of this material exist in UK |
| Suitability for Durness | Underground | Durness being a cold region and with the requirement for underground buried penstock to also minimise the visibility of the scheme. |

*Table 20. Penstock selection criteria*

Figure 43 shows the proposed penstock layout for Allt Smoo.

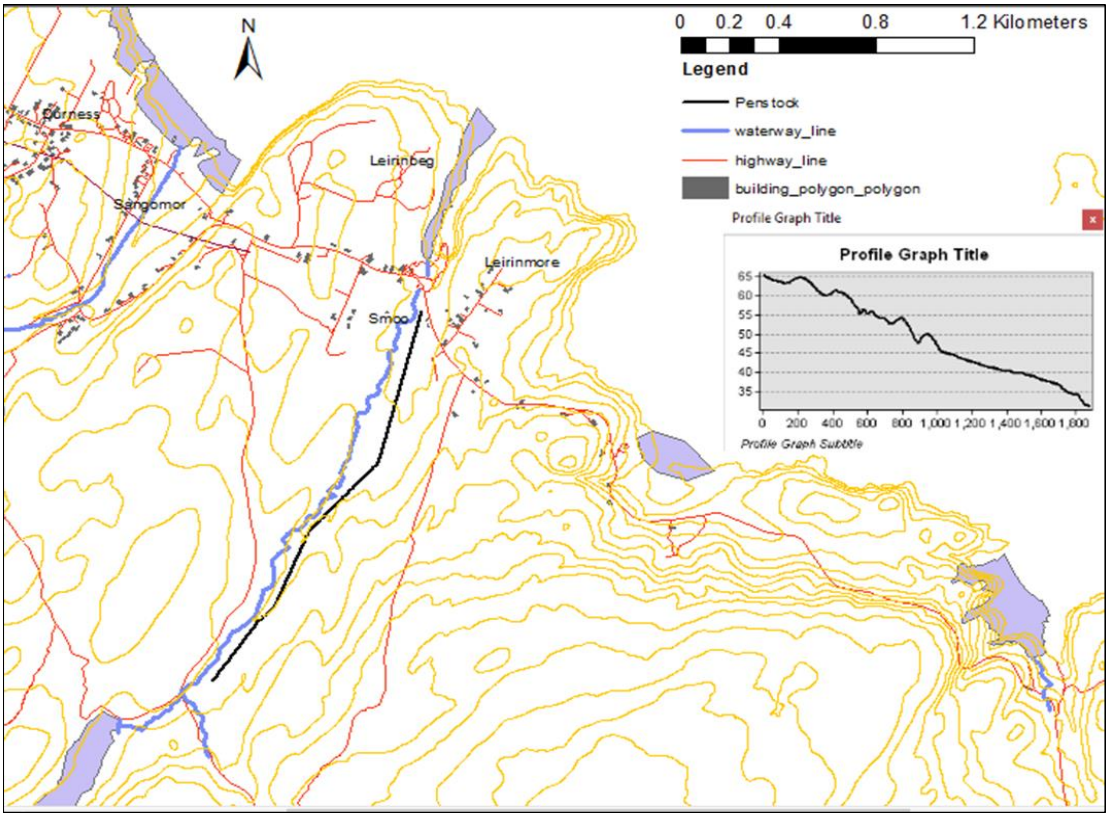



*Figure 43. Penstock layout and elevation profile for Allt Smoo*

[9] [ Bilal Abdullah Nasir, Advances in Energy & Power 2(1), Suitable Selection of Components for the Micro-Hydro-Electric Power Plant, 2014]:

[10] Fraenkel, Peter, et al. Micro-Hydro Power System: A Guide for Development Workers, London, UK (1991)

### 6.3.4.2 Turbine

Turbine choice is determined based on head and flowrate. Crossflow turbine is classified as low-head and medium-head turbine which operates up to 50 m head (Paish, 2002). The most appropriate turbine for this project is crossflow turbine which has efficiency of 77% (DOE & JICA, 2009).

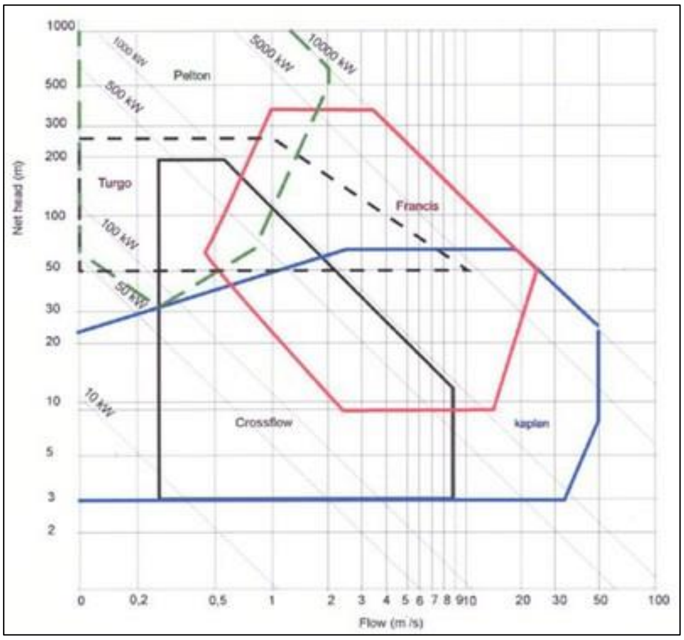



*Figure 44. Turbine Application Range Chart (A.H. Elbatran, November 2014)*

### 6.3.4.3 Turbine rating

Suitable turbine rating for this scheme has been calculated based on design flow rates in the four options described above. Turbine specifications are as in Table 21 for different options:

| | $Q_{mean}$ (Option 1) | $1.3Q_{mean}$ (Option 2) | $1.5Q_{mean}$ (Option 3) | $0.75Q_{mean}$ (Option 4) |
|---|---|---|---|---|
| **Turbine type** | Crossflow | Crossflow | Crossflow | Crossflow |
| **Design net head H (m)** | 33 | 33 | 33 | 33 |
| **Design flowrate Q (m3/s)** | 0.26 | 0.33 | 0.38 | 0.19 |
| **Frequency F (Hz)** | 50 | 50 | 50 | 50 |
| **Rotational speed Nt (rpm)** | 1123 | 985 | 917 | 1296 |
| **Turbine rating (kW)** | 65 | 85 | 100 | 50 |
| **Turbine efficiency** | 77% | 77% | 77% | 77% |

*Table 21. Turbine Output Calculation in Different Scenario*

### 6.3.4.4 Generator

Generator selection depends on turbine operation mode, type of load and desired output (Nasir, 2014). In this scheme, the desired output power is AC which could supply power to micro-brewery.

Also, a constant frequency of 50Hz is desired to run equipment in the proposed plant. At the same time, there is a possibility of connection to the grid to supply heating demand in-case the micro-brewery plant is halted. Therefore, an asynchronous (induction) generator is recommended in case of connection to the grid since it allows for simple grid connection and can withstand periods of over speed. If used in a stand-alone system, then a dummy load will be required for frequency regulation. However, a synchronous generator is better suited for an off-grid system. For this option a DC battery bank will be required for excitation.

| Generator selection | |
|---|---|
| **No of Poles** | **Speed at 50Hz (rpm)** |
| 4 | 1500 |
| 6 | 1000 |
| 8 | 750 |
| 10 | 600 |
| 12 | 500 |

*Table 22. Generator selection (DOE & JICA, 2009)*

From Table 22 above, the turbine rotates below 1500 rpm. Therefore, it is recommended to employ a speed increaser to match generator and turbine speeds. It should be noted that higher speed generators are less expensive as compared to low speed machines (Natural Resources Canada-Renewable & Eletrical Energy Division, 2004).

#### 6.3.4.5 Control system

A control system is required to regulate operation of the turbine, generator and associated plant equipment. The system takes care of grid synchronization and regulation flow in the turbine according to the available river flows at a particular time. For an isolated system using an induction generator, the controls will monitor the load and adjust generator speed as per load variation and dissipate excess generation through water heating or other means to maintain a constant operational frequency. For instance, supplying storage heating load can be a cost-effective way of damping excess generation.

### 6.3.5 Energy production analysis

Power and energy calculations were done using an excel model for the two sites Allt Smoo and Allt port Charmuill. Available flow data provided for proposed site at Allt Smoo and estimated flows on Allt port Charmuill were used. Available gross head of 35m and 100m was taken for the two sites respectively. The power output was calculated using the general formula for hydro power;

$$P = \frac{\eta \rho g Q H}{1000}$$

Where: **P** is Power output in kW

**H** is the net head in meters

**η** is the overall efficiency of power plant

**ρ** is the density of water [1000 kg/m³]

**g** is the acceleration due to gravity [9.81 m/s²]

**Q** is the volume flow rate passing through the turbine [m³/s]

#### 6.3.5.1 Allt Smoo

Turbine and generator efficiencies of 77% and 90% respectively were assumed while the transformer efficiency taken as 98%. The annual mean flow rate of 0.255m$^3$/s was taken as the design flow rate. Hands-off flow was taken as Qn90 corresponding to 0.04m$^3$/s. Three other cases were considered based on different design flow rates as shown in Table 23. An excel model was created and used to calculate the energy and power outputs for different cases. An excel model was created and used to calculate the energy and power outputs for different cases.

| **Design flow** | **Turbine size (kW)** | **Max net power output (kW)** | **Annual Energy production (kWh)** |
|---|---|---|---|
| Annual mean ($Q_{mean}$) | 65 | 56.0 | 231802 |
| 1.3 x $Q_{mean}$ | 85 | 72.8 | 261591 |
| 1.5 x $Q_{mean}$ | 100 | 84.0 | 276254 |
| 0.75 x $Q_{mean}$ | 50 | 42.0 | 197198 |

*Table 23. Design Flow and corresponding turbine power output*

The design considers that the generation will only be possible down to 10% of the turbine rated output below which generation must be shut down. The results from the calculations indicate comparatively higher energy production in the winter seasons and low output during the summer periods. There are significant variations in output among the four cases in the winter periods. In the summer, the energy output from the four cases do not vary significantly. Figure 45 shows the monthly energy produced by the different cases considered.

During summer, less water is available for generation due to low precipitation as well as the hands-off flow requirement. Figure 46 shows abstraction and residual volumes in case of the 65kW plant size. The worst case is the month of the June with only 34% of total flow usable.

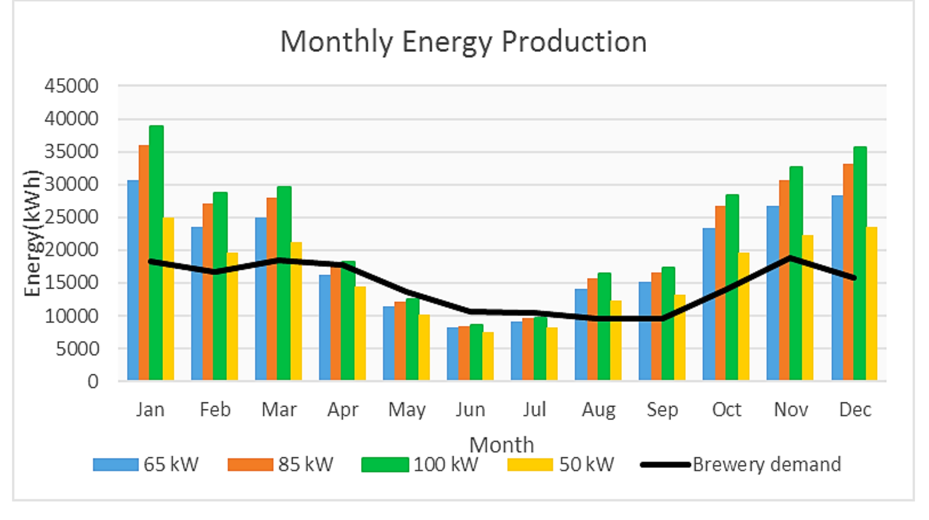



*Figure 45. Monthly energy production on Allt Smoo scheme from different plant sizes*

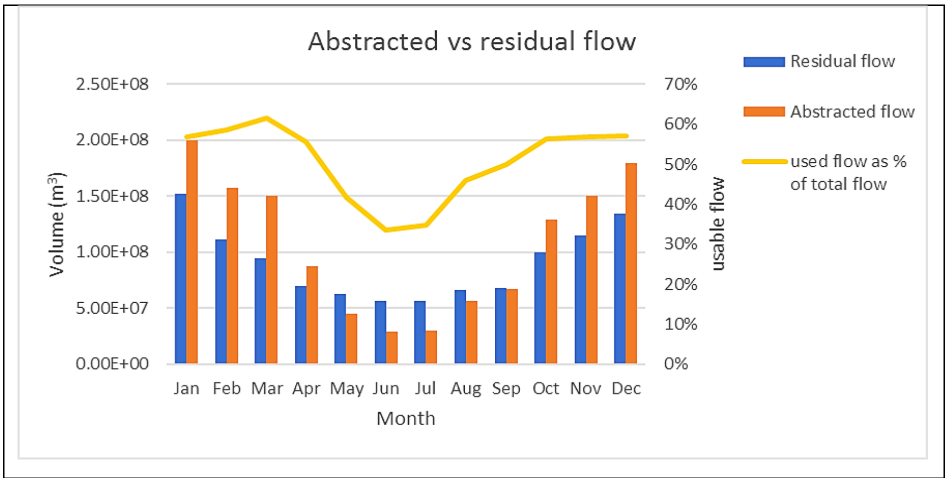



*Figure 46. Monthly abstraction and residual flow by the Allt Smoo scheme*

#### 6.3.5.2 Daily energy generation

Since the scheme is meant to supply power to a proposed brewery, a daily energy generation curve has been generated from Homer Energy software using low flow data for Allt Smoo inlet (refer to Appendix H).

From Figure 47 above, the generation profile follows the demand pattern of a small-scale enterprise such as a microbrewery. However, a backup storage is needed if used for heating or other similar loads.

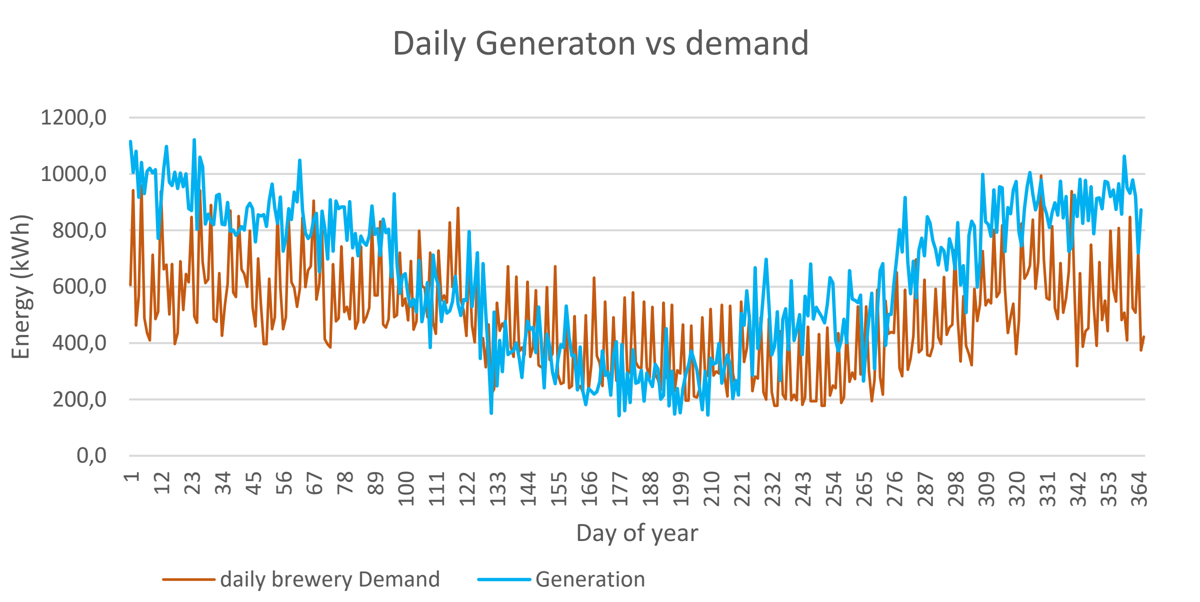



*Figure 47. Generation potential from the Allt Smoo hydro scheme against the microbrewery demand*

#### 6.3.5.3 Allt Port Charmuill

Using estimated flow data, the annual energy production potential was calculated for the proposed site. Four cases were considered based on different flow rate design for the case where a second stream is diverted and channelled to Allt port Charmuill using a pipe. An assumption of annual mean flow rate was again taken as the flow at $Q_{mean}$, 0.058 $m^3/s$. Table 24 below shows the results of the power output and energy calculations.

| Design flow rate considered | Max net power output (kW) | Annual Energy potential (kWh) |
|---|---|---|
| Annual mean ($Q_{mean}$) | 38.8 | 160655 |
| 1.3 x $Q_{mean}$ | 50.4 | 181305 |
| 1.5 x $Q_{mean}$ | 58.2 | 191471 |
| 0.75 x $Q_{mean}$ | 29.1 | 136668 |

*Table 24: Power output and annual energy production from Allt Port Charmuill*

### 6.3.6 Cost analysis

In this project, two methods of cost analysis have been considered which are described below:

#### 6.3.6.1 Method 1

This method is based on computing average per kW investment cost of three micro hydropower projects in Scotland. In Sunart Community Renewable Ltd project, a unit cost of £6,904 was obtained from a 99kW project (Smart Community Renewables Ltd., January, 2015). In Harlaw 65kW Hydro-Electric Scheme a cost of 6,456 £/kW was obtained (Jonathan Webb, 2010) while for Green Valley community 15 kW project a cost of 5,120 £/kW (Nigel Woodruff, 31 May, 2011). Therefore, the average investment cost of these three projects is given as of 6,160 £ /kW.

The intake structure cost was taken as £1,007/kW from a past project quotation in the Highlands and pipeline cost taken from online price list[11]. The turbine, generator and controller cost were calculated using the following formula:

$$\text{Cost}_{\text{(turbine, generator and controller)}} = 12{,}000(kW/H^{0.2})^{0.56}\ (£2008)\ \text{(G.A. Aggidis, 15 May 2010)}$$

The formula matches with the data from previous feasibility reports and project quotations in Scottish Highlands.

Table 25 shows total investment cost for different options. An inflation rate of 2% has been applied to determine the present value of the total investment cost. Project management, land purchase and permit costs have been assumed constant for the different options.

| Investment Costs | $Q_{mean}$ (Option 1) | $1.3Q_{mean}$ (Option 2) | $1.5Q_{mean}$ (Option 3) | $0.75Q_{mean}$ (Option 4) |
|---|---|---|---|---|
| **Intake structure costs (£)** | 65,455 | 85,595 | 100,700 | 50,350 |
| **Penstock costs (£)** | 304,000 | 387,600 | 490,200 | 239,400 |
| **Turbine, generator and controller costs (£)** | 100,402 | 116,677 | 127,794 | 86,683 |
| **Connection (£) (55,000 for grid connection)** | 22,000 | 22,000 | 22,000 | 22,000 |
| **Installation costs (£)** | 32,032 | 41,888 | 49,280 | 24,640 |
| **Project management (£)** | 24,640 | 24,640 | 24,640 | 24,640 |
| **Land purchase (£)** | 21,560 | 21,560 | 21,560 | 21,560 |
| **Permit costs (£)** | 3,080 | 3,080 | 3,080 | 3,080 |
| **Total (£)** | **573,169** | **703,040** | **839,254** | **472,353** |

*Table 25: Investment Costs in Different Options*

Operation and maintenance costs have been assumed to be 1% of penstock cost and 3% of electromechanical equipment cost. Table 26 shows the annual O&M costs for different options.

| Costs | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **O&M (£/year)** | 6052 | 7376 | 8736 | 4994 |
| **Insurance (£/year)** | 5150 | 5566 | 5868 | 4824 |
| **Total (£/year)** | **11202** | **12942** | **14604** | **9818** |

*Table 26: O&M Costs in Different Scenario*

[11] Matrix Piping Systems (2017) www.matrixpiping.com.au/pages/poly-pipe-prices

### 6.3.6.2 Method 2

In this method, cost analysis has been done using an empirical formula developed by Aggidis et al in 2010. It is based on data from projects accomplished in North-Western UK. The formula is given below

$C_p = 25000\ (P/H^{0.35})^{0.65}$ £ (2008) (Aggidis, Luchinskaya, Rothschild, & Howard, 2010)

Where $C_p$ is the cost of overall project, P is the installed capacity in kW, and *H* the hydraulic head in meters.

Based on this method, the overall cost of the different options has been calculated as by indexing 2008 values to 2017 applying inflation rate of 2% as shown in the Table 27 below.

| | **Option 1 (Qmean)** | **Option 2 (1.3 Qmean)** | **Option 3 (1.5 Qmean)** | **Option 4 (0.75 Qmean)** |
|---|---|---|---|---|
| **Capacity(kW)** | 65 | 80 | 100 | 50 |
| **Project Cost (£)** | 203364 | 242104 | 269079 | 171479 |

*Table 27: Method 2 Cost Analysis*

The cost estimated by this method are way below the market due to the fact that the penstock cost of the scheme is exceptionally high because of its long length. Therefore, method 1 which gives more accurate cost has been used for further economic analysis.

## 6.3.7 Environmental aspects

Abstraction of water from the river Allt Smoo will require a water use licence from the Scottish Environmental Protection Agency (SEPA). It should be noted that water abstraction licence are timed to between 6 and 18 years and therefore require renewal in the life of the project (BHA, 2012). For micro-hydro schemes generating less than 0.35GWh a year, SEPA provides a list of guidelines to ensure the proposed scheme avoids significant adverse impact on the water environment (SEPA, 2010). There are impacts associated with the construction period and other impacts associated with the schemes' operation.  Local wildlife, the public, site geology, site hydrology, aquatic ecosystem may be impacted by activities during construction and the operation of the scheme.

It is necessary to consider measures to mitigate the negative impacts of the project. This will include measures taken to avoid, cancel, reduce, remedy or compensate for the adverse effects. Impacts could be noise, loss of habitat for protected species, loss of vegetation among others. Some protected species of animals in Durness include birds and otters. A nesting bird survey and otter survey will be required to assess possible impacts on the species. Going by the local ranger there is presence of otters in Allt Smoo area (Mitchell, 2017).  In 2010, a nesting bird survey was done in the area and concluded that there is potential for an impact on the breeding birds (Astell Assosiates, 2010). Another survey on otters concluded that a scheme on the area would have no impact on the conservation of the European otters (Astell Assosiates, 2010).

The main concern during the schemes operation is the amount of water left downstream of the intake due to its impact on the aquatic ecosystem and fish. The allt Smoo and Loch Meadaidh upstream are fish habitats (Astell Assosiates, 2010). SEPA requires that certain river flow standards be maintained during operation. The scheme should ensure mitigation against low and high flows, ensure flow variability and safe passage of fish. The catchment area of the proposed site is less than 10km$^2$, this requires that hands-off flow be at Qn 90 (SEPA, 2010) which translates to 0.040 m$^3$/s.

### 6.3.8 Conclusion

The micro hydropower scheme at Allt Smoo can generate energy as much as 0.27GWh/annum while that of Allt Port Charmuill could produce up to 0.19GWh/annum all conditions and assumptions remaining the same. The output and closeness of Allt Smoo to the proposed brewery makes it a better option. Therefore, it is recommended that this energy resource is explored for the benefit of the community.

# 7 System

## 7.1 Grid Capacity

The main goal of this project is to generate energy from local wind and hydro resources to maximize benefits to the community. Early attempts have been made to export energy to the grid, but hit a deadlock due to grid constraints. The current approach is to use energy locally for heating. In this regard, District Heating has been considered for Central Durness and Craft Village and electric heating for the rest of Durness. However, it should be noted that grid distribution capacity and constraints will be based on estimates. It is recommended that further studies be carried out in consultation with the local grid operator SSE. Particularly in central Durness, it is worth to investigate whether wind energy generated from turbines installed near Loch Meadaidh can be distributed through the local 11KV grid infrastructure to the district heating plant located near the central area. This proposal explores possibility of leasing SSE grid for distributing electrical energy from one part of the village to the other without exporting to the national grid.

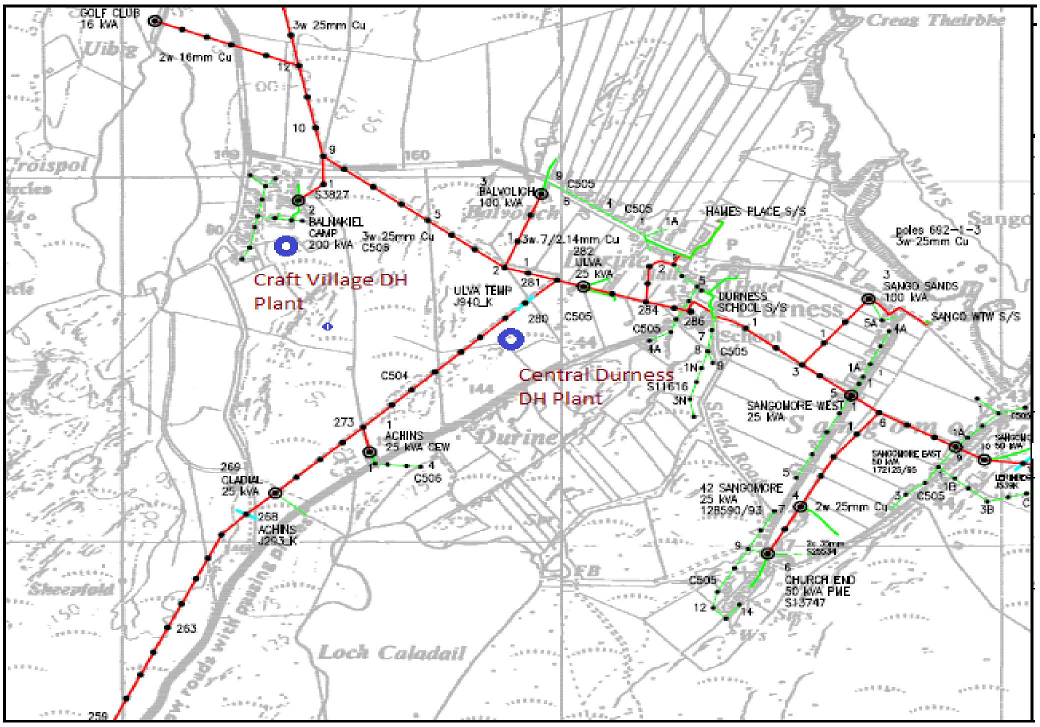



*Figure 48. Grid coverage in relation to District Heating*

Figure 48 above shows the proposed location of Central Durness and Craft village district heating plants in relation to grid infrastructure. Since the Craft Village District heating plant does not require a grid connection, grid capacity has been analysed in relation to central Durness DH plant as shown in Table 28 below:

| **Local 11kV 3-Phase Grid Capacity Estimate** | |
|---|---|
| Voltage Size | 11kV |
| Conductor Type and Size | Cu 25mm2 |
| Current carrying capacity | 133 A |
| Power factor | 0.9 |
| **Maximum Capacity (90% loading)** | **2053kW** |

*Table 28. Grid capacity*

Capacity shown in the table above includes other electric non-heating load. Therefore, a more detailed study is recommended to find out the actual capacity in the local distribution grid.

### 7.1.1 District heating system

District heating systems are a means of distributing heat to homes, business and public buildings, to allow us to use a range of heat sources. Heat exchanger in the system helps the end users to meet their heat demand accordingly.

In Central Durness and Balnakeil buildings are more clustered together than in the rest of the Durness. Therefore, Balnakeil (Craft Village) and Central Durness were taken as sites for a case study of a District heating system. The region of study can be seen in an aerial map below:

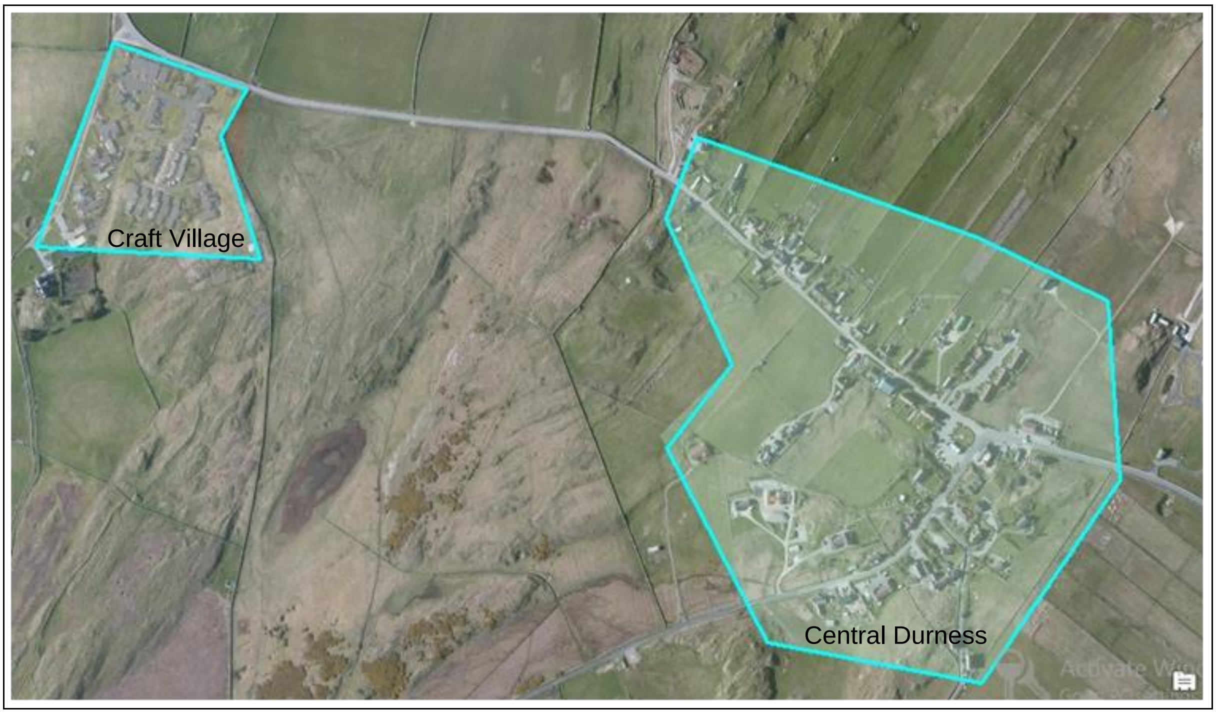


*Figure 50. Proposed District Heating location (from ArcGIS Imagery)*

The methodology used in working out the capacity of a DH system for the selected area is as follows:

1. Area Calculation
2. Pipeline length measuring
3. Heat demand density calculation
4. District Heating system sizing
5. Cost analysis

The aerial image was used in order to mark the land area for the selected two zones. With the help of ArcGIS, the area of the supply zones was roughly estimated. Similarly, the pipeline length was measured along possible trench routes to houses. Having computed heat demand in Chapter 4, the heat demand density in both areas was calculated as shown in the table below:

| **Location** | **Balnakeil** | **Central Durness** |
|---|---|---|
| Land Area ($m^2$) | 41097 | 221994 |
| Area of Houses ($m^2$) | 6600 | 10538 |
| Pipeline length (m) | 690 | 1295 |
| Heating Demand (kWh) | 290731 | 875570 |
| Heat Density (kWh/$m^2$) | 7.07 | 3.95 |

*Table 29. Heat density calculation*

### 7.1.2 District heating system sizing

The peak heating demand estimated from household survey data was used to determine the district heating capacity. Boiler capacity calculation results are shown in the table below:

| Boiler system sizing - Peak Demand Method | | |
|---|---|---|
| **Location** | **Balnakeil** | **Central Durness** |
| Load factor | 0.9 | 0.9 |
| Peak demand (kW) | 118 | 323 |
| Efficiency of DH distribution | 70% | 70% |
| Boiler heat loss | 5% | 5% |
| Final peak demand (kW) | 169 | 461 |
| Boiler Capacity (kW) | 159 | 437 |

*Table 30. Boiler sizing calculation*

In a District Heating System, inclusion of storage enables greater flexibility of operation. Thermal storage capacity has been computed as follows; in Craft Village and Central Durness unmet demand was plotted against storage capacity. A value of 5000 kWh was arrived at beyond which an increase in storage capacity has no effect on reducing unmet demand. For Central Durness and a capacity of 40,000 kWh selected.

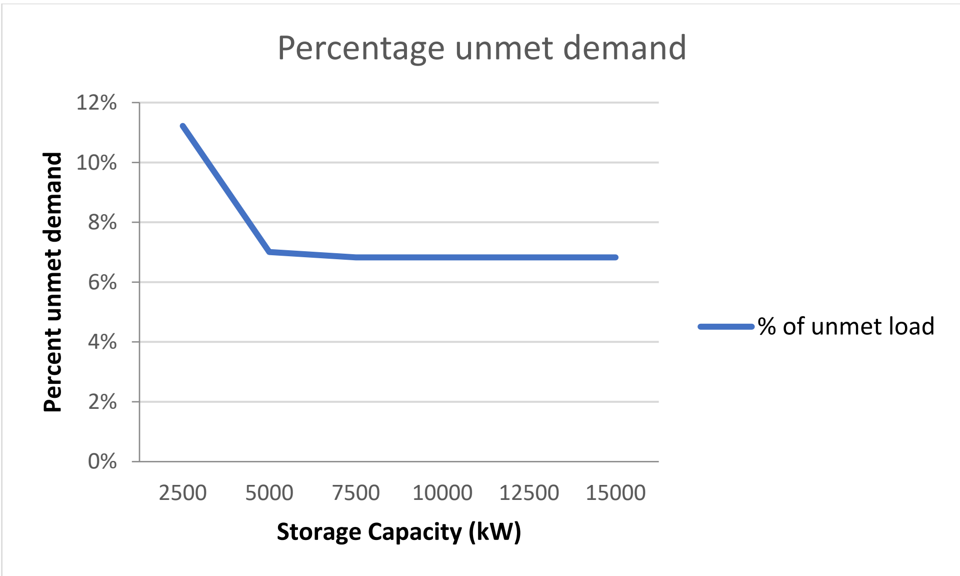



*Figure 51. Unmet demand percentage, Balnakeil*

Unmet demand corresponding to the selected storage capacities for Balnakeil and Central Durness is 18,058 kWh and 293,443 kWh respectively. For Craft Village, energy efficiency has been considered in the calculation that reduce final energy demand by 30%.

A backup gas boiler of the same capacity as main boiler has been considered in the design to meet the deficit. Therefore, the District Heating Plant can run even when the main boiler is under maintenance.

From storage sizing results, tank capacity was calculated using the formula; Q= $mc\Delta T/_{3600}$ . (homemicro)

| Storage Size sizing | | |
|---|---|---|
| **Location** | **Craft Village** | **Central Durness** |
| Storage size (kWh) | 5000 | 40000 |
| Specific Heat Capacity of Water(KJ/Kg/K) | 4.184 | 4.184 |
| Temp Diff. (95/40) K | 55 | 55 |
| Storage size(cubic meters) | 78 | 626 |

*Table 31. Storage sizing*

From the table above it can be shown that Craft Village will take a storage capacity of 78 cubic meters while that of Central Durness will be 626 cubic meters.

### 7.1.3 Cost Estimation of District Heating System

The District Heating System cost has been estimated from a study by Pöyry energy (Pöyry Energy (Oxford) Ltd, 2009) consultants of different projects in the UK. The table below shows total capital cost. This cost compares well with other estimation models and studies such as Stratego[12], Danish Energy Agency (Danish Energy Agency, 2013) and IEA ETSAP (IEA ETSAP, 2013).

| Cost estimates | | |
|---|---|---|
| **Location** | **Craft Village** | **Central Durness** |
| Gas Boiler | £9,581.00 | £ 14,371.50 |
| Electric Boiler | £11,304.35 | £ 27,685.00 |
| Storage | £20,280.00 | £ 96,000.00 |
| Pipe Line cost | £176,000.00 | £ 277,586.00 |
| House Interface (DH) | £55,000.00 | £ 110,000.00 |
| Radiators and pipeworks | £35,500.00 | £ 52,000.00 |
| **Total Cost** | **£307,665.35** | **£ 577,642.50** |

*Table 32. Capital cost estimations*

## 7.2 Energy Storage Calculation Based on Electric Storage Heaters

In order to calculate the amount of storage provided by electric storage heaters, a review on the different types of technologies available in the UK market was made. Based on it, the Quantum series from Dimplex was selected as a reference due to its complete availability of technical specification (Dimplex, s.f.). Further, based on the average number and size of rooms per property, the total storage capacity per house was calculated. It was assumed that an average property has 3 bedrooms (3.2 was the average obtained from the survey), one kitchen and one bathroom. The type of electric storage heater according to the type of room, its output rating and maximum storage capacity can be seen in Table 33. Based on the above, the total storage capacity per property was found to be 71.4kWh.

[12] The EU IEE Stratego research project. www.stratego-project.eu , WP2 Main Report.

| Rooms | Number of Heaters | Type | Output rating (W) | Max. Storage Capacity (kWh) |
|---|---|---|---|---|
| Living room | 1 | QM125 | 1250 | 19.3 |
| Bedrooms (1 per bedroom) | 3 | QM070 | 700 | 10.9 |
| Kitchen | 1 | QM070 | 700 | 10.9 |
| Bathroom | 1 | QM050 | 500 | 8.5 |

*Table 33: Type of electric storage heater per room*

To determine if the calculated capacity was enough to supply the properties requirements, three cases were analysed on the assumption that the storage will be charged at least twice a day (every 12 hours). In the first case, the 12-hours heat demand per property was calculated based on the average demand. In the second case, the 12-hour demand was calculated based on the 95% peak. In the third case, the 12-hour demand was calculated taking the maximum demand. In all three cases, the storage of the five panels can supply the required heat demand. Results can be seen in Table 34.

| | Heating Demand | | | | Heating Supply |
|---|---|---|---|---|---|
| | Total Durness (kWh/h) | Per property (kWh/h) | Per property (kWh/day) | Per property (kWh/12h) | Storage capacity of the 5 electric storage heaters |
| Average | 381 | 1.66 | 39.76 | 19.88 | 71.4 |
| 95 % peak | 810 | 3.52 | 84.52 | 42.26 | 71.4 |
| Max demand | 1299 | 5.65 | 135.55 | 67.77 | 71.4 |

*Table 34: 12-hour property demand*

After verifying that the proposed capacity per property could supply the required demand, the number of houses in Durness that will implement electric storage heaters was calculated. For that, the properties in Central Durness and Craft Village were excluded on the basis that they will have district heating. In the rest of the properties it was assumed that only the ones currently using electrical panels heaters and electrical storage heaters will implement this technology because replacement cost will be moderate. According to the survey results, 7 properties meet these criteria. Extrapolating this value to the 230 properties in Durness based on the proportion of building per zone, 45 properties will adopt this technology. Based on that, the total storage capacity provided by electric storage heaters will be 3.2MWh.

## 7.3 Household Cost Analysis for Implementing Proposed Heating System

This section attempts to estimate the require investments required in the heating system of each property, to make it compatible with the proposed project. To estimate the total cost, the analysis was divided into two parts. In the first part, the cost was estimated from Central Durness and Craft Village, because in both locations a district heating system was proposed. In the second part, the cost was estimated for the remaining part of Durness (Zones 3 to 6), because in those areas the energy distribution was proposed through the electric grid.

For Central Durness and Craft Village, it was considered that only the properties that are using a dry heating system were required change their devices. This is based on the assumption that properties with wet heating system can adapt their system to the proposed district heating without a significant investment. To calculate the required investment, two items were considered: First, the supply of radiators. Its cost was estimated using as a reference the price of the series Vita Deco from Stelrad (Stelrad, s.f.). The detailed estimation of cost and output rating can be seen in Table 35. Secondly, the installation cost of radiators and pipework was assumed to be £ 2000. Based on the above, the estimated cost per property was found to be £ 2,363.

| Number and type of radiators per household | | | | | |
|---|---|---|---|---|---|
| **Room** | **Number of Heaters** | **Type (serie)** | **Output rating (W)** | **Unitary Price (£)** | **Total cost of radiators per household (£)** |
| Living room | 1 | 82601114 | 1218 | 98 | 98 |
| Bedrooms (1 per bedroom) | 3 | 82601108 | 696 | 56 | 168 |
| Kitchen | 1 | 82601108 | 696 | 56 | 56 |
| Bathroom | 1 | 82601106 | 522 | 42 | 42 |
| **Total** | **6** | | **4524** | | **363** |

*Table 35: Estimation of radiators cost per property*

Afterwards, based on the information collected from the surveys and further extrapolation to the real amount of properties in each of the area, it was found that 22 properties in Central Durness and 15 properties in Craft Village would need to change their heating system. This will represent a total cost of £ 52,000 for Central Durness and £ 35,500 for Craft Village. The detailed calculation can be seen in Table 36.

| | **Cost of adapting households heating system in Central Durness and Craft Village** | |
|---|---|---|
| **Area** | **Central Durness** | **Craft Village** |
| **Number of properties** | 22 | 15 |
| **Cost per property (£)** | 2,363 | 2,363 |
| **Total cost (£)** | 52,000 | 35,500 |

*Table 36: Cost of adapting households heating system in Central Durness and Craft Village*

For the remaining properties in Durness (zones 3 to 6), the required investment depends on the type of heating technology being used. For the properties that have a dry heating system, it was assumed that they will replace their current heating panels, by the electric storage panels suggested previously in this report, with a cost of £ 4,524 per property. For the properties that have a wet heating system, it was proposed the installation of a 1000-liter tank and an electric boiler to use the electricity from the grid without changing the property heating system. In this case, the estimated cost was £ 1258 per property. Considering that for the remaining properties of Durness (zones 3 to 6), 45 properties have a dry heating system and 50 properties a wet heating system, the total cost of adapting the heating system in this area will be of approximately GPB 266,480. A table summarizing the total cost can be seen in Table 37.

| Cost of adapting households heating system in zones 3 to 6 | | |
|---|---|---|
| **Heating System** | **Dry** | **Wet** |
| **Number of properties** | 45 | 50 |
| **Cost per property (£)** | 4,524 | 1,258 |
| **Total cost (£)** | 203,580 | 62,900 |
| **Total cost (Zones 3 to 6)** | **266,480** | |

*Table 37: Cost of adapting households heating system in zones 3 to 6*

## 7.4 System Model

A Microsoft Excel model was built to match the energy supply from a wind turbine with the heating demand in both the district heating as well as the electric storage system in every hour of the year. The model includes heating demand, wind generation output, storage and grid supply as well as losses. The heating load is divided in to two priority levels with the electrical storage heaters given priority before the district heating system. Storage is only charged when there is excess generation available after meeting the demand and discharged when load exceeds generation.

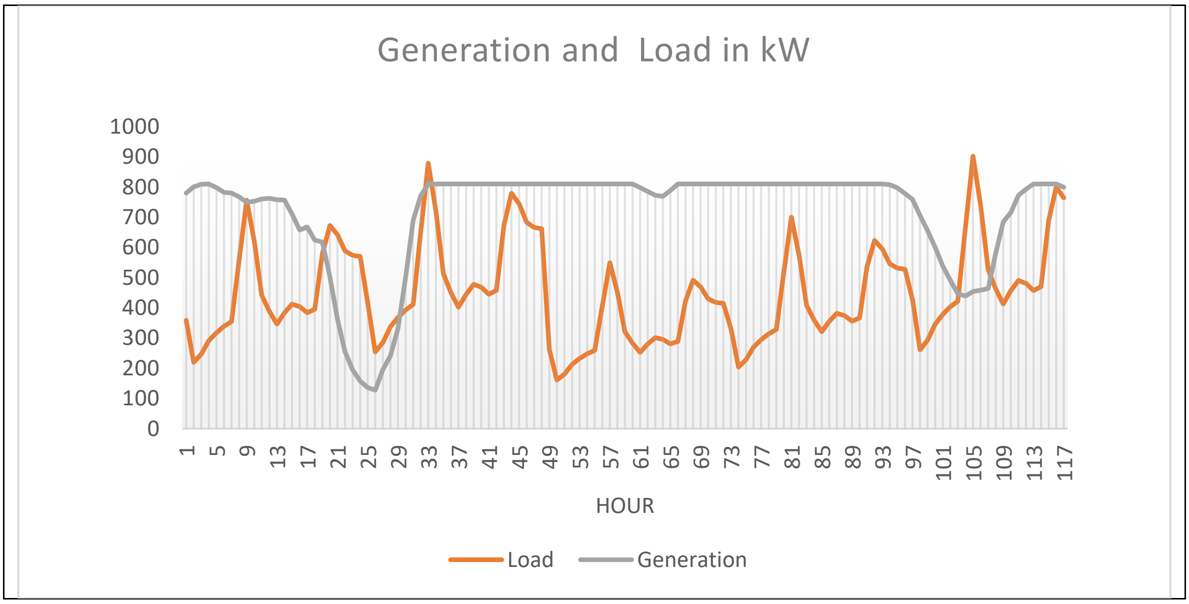



*Figure 52. Hourly 800kW wind generation and load profile*

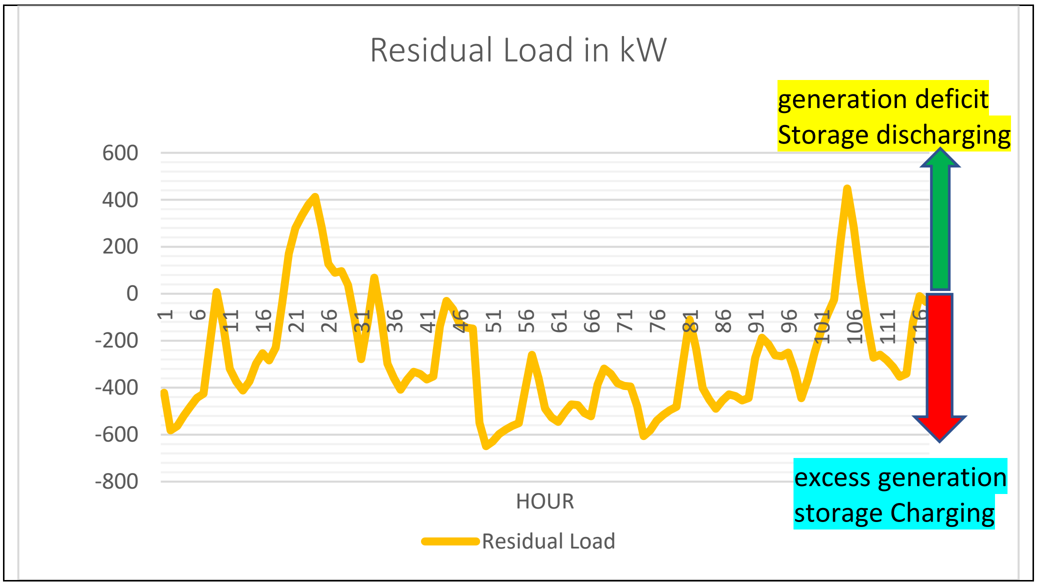


*Figure 53. System residual load*

When generation is greater than demand of the electrical storage heaters, the excess charges the electrical storage heaters first. If there is residual load after charging the electrical system, it feeds into the district heating system. District heating storage system is charged when there is still excess generation after meeting all the demand and the electrical storage capacity is full.

The system performance was analysed considering two cases, one system for Balnakeil and another case considering a system for rest of Durness.

### 7.4.1 Supplying rest of Durness

Wind generation capacity chosen for the simulation was the 800kW turbine due to the higher power production comparatively matching the demand. The dimensioned district heating storage capacity of 40000 kWh and electrical storage of 6810kWh was used. The result indicated an annual unmet demand of 18%. The monthly unmet demand with and without storage is as shown in Figure 54 below.

| System | Unmet Demand (kWh) | Total Demand(kWh) |
|---|---|---|
| District heating | 293,000 | 1,138,200 |
| Electrical storage heating | 295,000 | 2,173,700 |

*Table 38. Annual unmet demand*

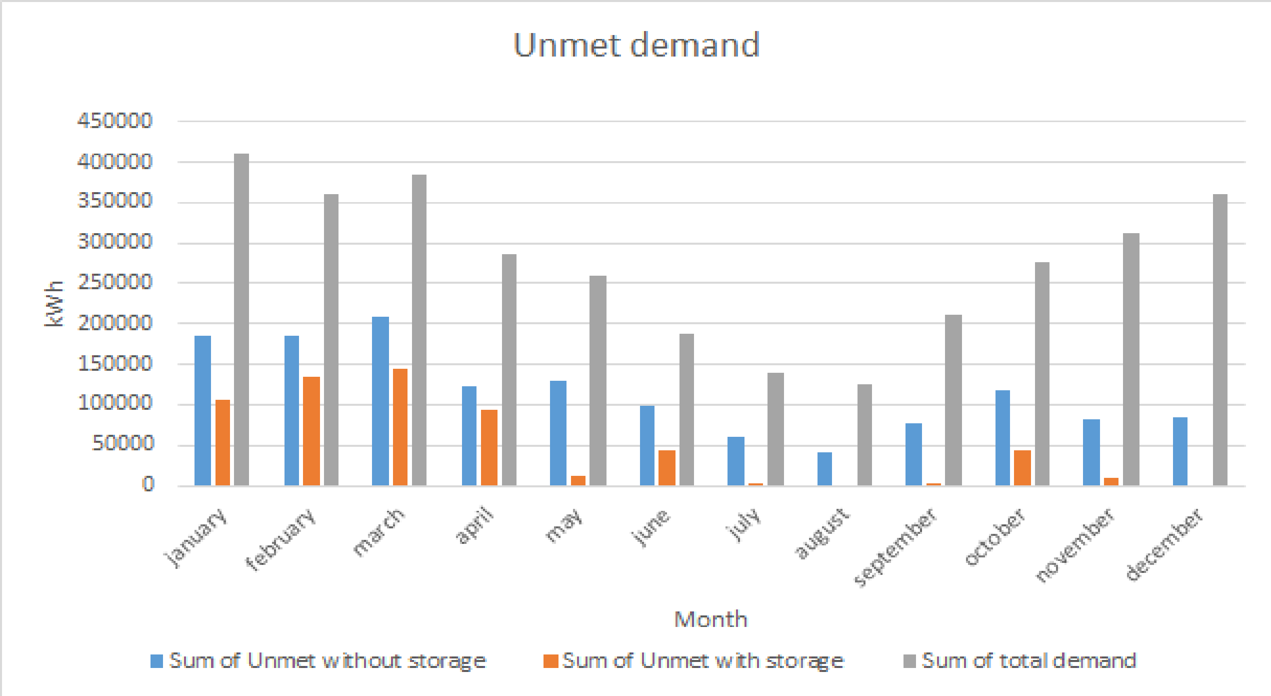



*Figure 54. Unmet heating demand based on 2013 wind profile.*

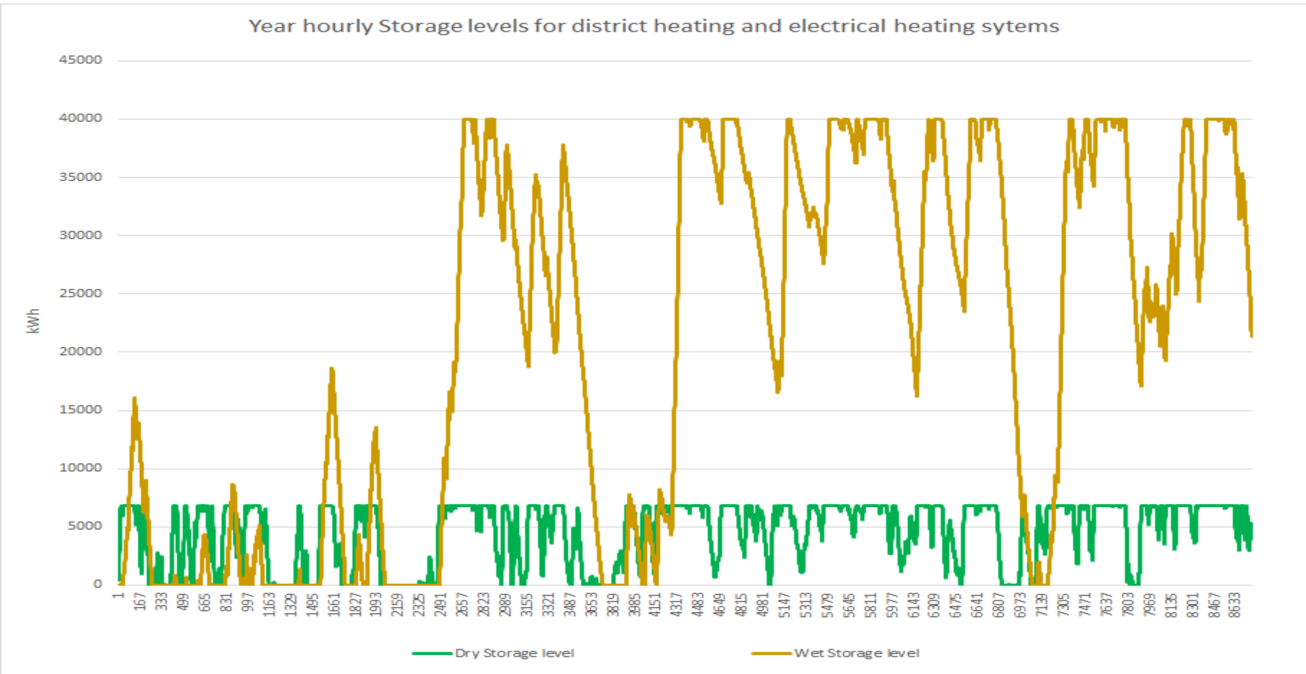



*Figure 55. Hourly storage level for electric storage and district heating storage*

### 7.4.2 Balnakeil Craft Village

The system performance was analysed using 100kW wind turbine which was selected based on the demand for the area. Storage capacity of 5000 kWh as dimensioned for the district heating system was used. The results indicate that the annual unmet demand with storage at zero level at start of the year is 7%.

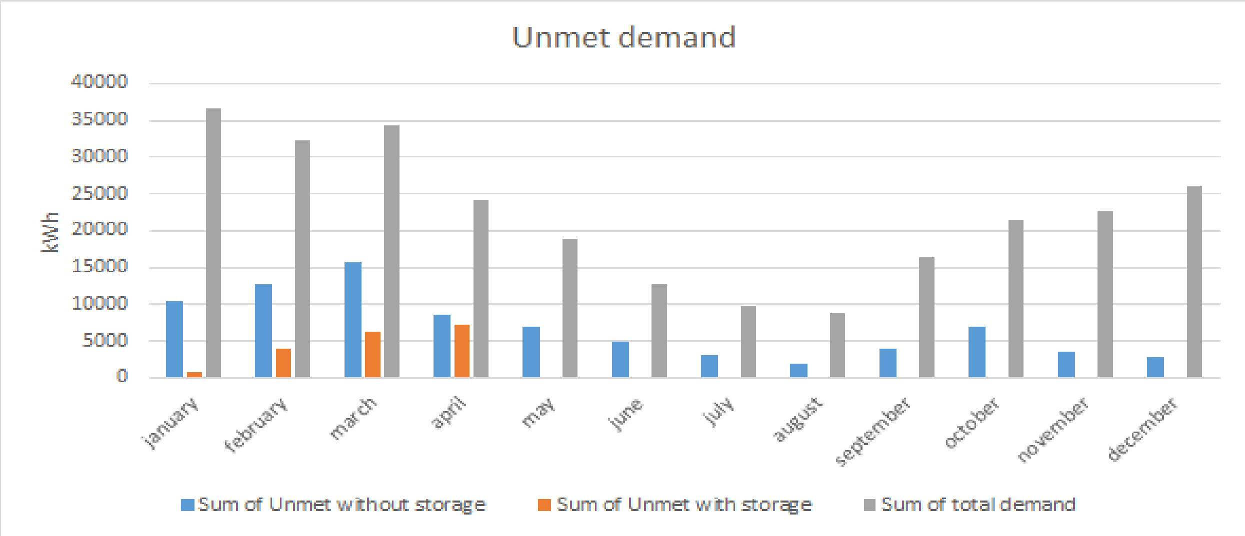



*Figure 56. Monthly unmet demand for Balnakeil craft Village case with 100kW turbine*

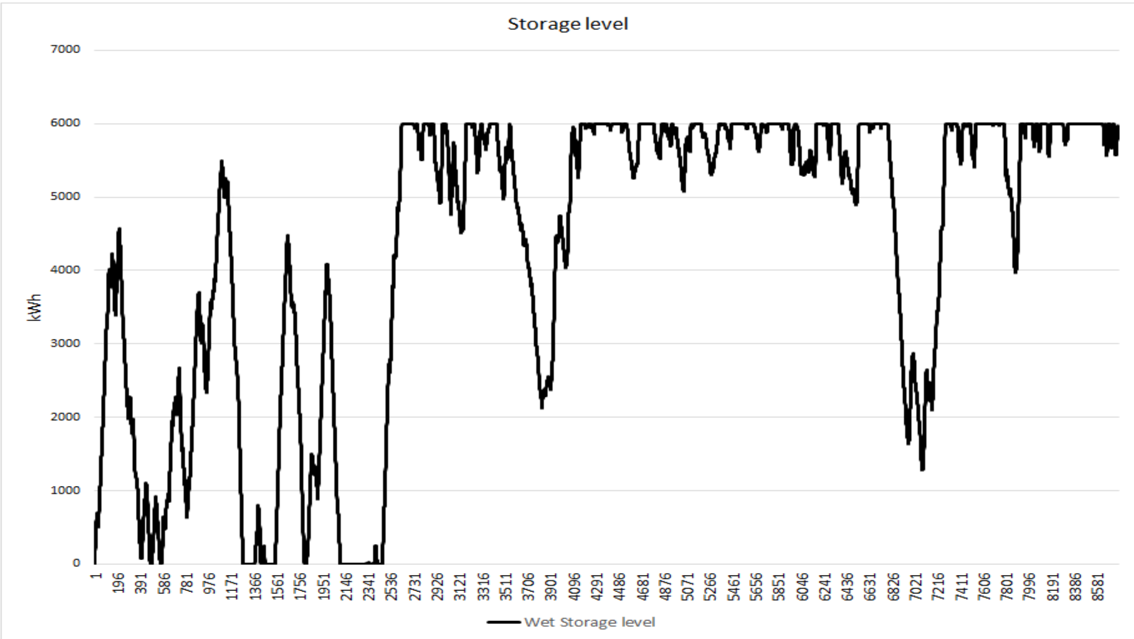



*Figure 57. Hourly storage level*

# 8 Economic Feasibility Study

## 8.1 Introduction: support schemes available

Over the recent years, the UK government and particularly, the Scottish government has encouraged communities to engage in renewable energy projects with a specific goal of attaining 500 MW from community and locally-owned projects but also as part of a greater target set for 2020; to have 100%

of the electricity demand met through renewable energy. In this quest, several schemes have been established such as feed-in-tariffs, grants and loans to aid in achieving this goal.

### 8.1.1 Feed-in-tariff (FIT)

One of the prominent government schemes available to community-owned energy projects is the feed-in-tariff (FIT) scheme. The scheme is administered by both the Office of Gas and Electricity markets (OFGEM) E-serve and the FIT licensees; the latter who are required to make fixed tariff payments for electricity generated and exported to the national grid. The FIT tariff consists of a generation tariff and export tariff and runs for 20 years from the eligibility date[13] of the installation.

The FIT rates have been published for every tariff period up to March 2019. A tariff period[14] is composed of 3 months where a specific FIT tariff is applied; usually starts from 1st January, 1st April and so on. The FIT tariff rates are subjected to two types of degression at the beginning of each tariff period; default degression and contingent degression. In the default degression, the tariff automatically reduces in each tariff period while in the contingent degression, the tariff rate for a tariff period is reduced by a further 10% when the deployment cap[15] for the previous tariff period is reached (OFGEM, 2016). Once a deployment cap has been reached, the generator's application is automatically moved to the next tariff period (TP). In addition, the FIT tariff rates are index-linked thus they are adjusted every April by the percentage increase or decrease of the Retail Price Index (RPI) set by the Office of National Statistics (ONS).

The proposed Loch Meadaidh and Craft Village wind technologies as well as the Allt Smoo micro hydropower plant (MHP) technology are all eligible for the FIT scheme through the Renewable Obligation Order (ROO-FIT) scheme as the scheme is reserved for wind installations of declared net capacity of greater than 50kW up to and including 5MW and all hydro installations. The ROO-FIT accreditation can be processed either through full accreditation application or through preliminary accreditation (PA). Preliminary accreditation is recommended for the Durness projects because the process guarantees that a FIT tariff will be locked in against the tariff period that the projects will fall in to, even though the project will be in planning stage and yet to be commissioned. However, the PA means that the FIT tariff is valid for a specific period upon which the PA needs to be converted to full accreditation failure to which the FIT tariff guarantee will be lost (OFGEM, 2016). Additionally, for the full accreditation the generation plant must also have been commissioned within this tariff validity

[13] The eligibility date is the later date between when the full accreditation application is submitted to OFGEM or when the installation was commissioned.
[14] A tariff period is a financial quarter.
[15] A deployment cap is a queueing system that was introduced in February, 2016 to limit the amount of total capacity that could receive a FIT tariff applicable to a tariff period (OFGEM, 2016).

period. For wind installations, the tariff validity period is 12 months while for hydropower plants is 24 months (ibid.).

However, should a wind turbine of 50kW or less be chosen for the Craft Village, it will be eligible for the Microgeneration Certification Scheme (MSC) as it is smaller in size than the other proposed turbines. Unlike the ROO-FIT scheme, the MSC scheme does not allow for preliminary accreditation thus a FIT tariff is applicable only when the application has been fully processed. However, similarly to the ROO-FIT scheme, the MSC scheme is also subject to deployment caps and FIT degression. In addition, to commission the plant in question, one must utilize a MSC certified installer using MSC-certified equipment to acquire the MSC certificate (OFGEM, 2017).

### 8.1.2 Community and Renewable Energy Scheme (CARES)

Other than the FIT scheme that is available to the whole of United Kingdom, the Scottish government has established other support schemes to encourage communities to engage in energy projects, particularly promoting direct or shared ownership (Scottish Government, 2015). One such support scheme is CARES which includes a range of loans and grants delivered by Local Energy Scotland. These include Start-up Grants, Pre-planning Loans, Post-Consent Loans and the Infrastructure and Innovation Fund (IIF) among others. The scheme also provides financial advice, mentoring and support and has local development officers throughout Scotland in proximity to the communities.

#### *8.1.2.1 Start-up Grants*

The Start-up Grant is issued to cover the initial costs of early stage activities of a renewable energy project that a community would incur and without which the project would not be feasible or successful. These activities include feasibility studies, establishment of a legal entity to run the renewable energy project, community consultation and capacity building as well as organised visits to visit other communities' renewable energy projects. The maximum funds available for this grant are £10,000 or £20,000 for joint ventures (LES, 2017).

#### *8.1.2.2 Pre-planning Loans*

The Pre-planning Loan is aimed to fund the development phase of the project as this phase is viewed as a high-risk stage acting as a barrier for community groups. The pre-planning costs envisioned include technical feasibility studies, environmental impact assessment costs, grid connection feasibility studies among many others. The loan can cover up to 95% of the agreed costs and can be issued for a maximum amount of £150,000 (ibid.). It is issued at a fixed interest rate of 10% with no security required and includes a write-off facility if the project does not gain planning consent or encounters an insurmountable obstacle (LES, 2017).

#### *8.1.2.3 Post-consent loans*

The Post-consent Loan is made available for community energy projects that have gained planning permission and advanced into the delivery stage but still face issues with funding. Communities can apply for such loans through the Renewable Energy Investment Fund (REIF) administered by the Scottish Government. However, the REIF expires in March 2017 and there is no updated information from the CARES website whether it is going to be extended into the next year (ibid.). In addition, communities can also apply for the Infrastructure and Innovation Fund (IIF) which provides grant funding for community projects designed to have the local generation linked with local energy use or projects that look at novel distribution or storage options. Unfortunately, this fund was closed to new applications at the time of writing this report (LES, 2017) .

### 8.1.3 Low Carbon Infrastructure Transition Programme (LCITP)

The programme was established with an aim to provide financial support, expert advice as well as offer project management services to the development of low-carbon projects in Scotland. The programme received European match funding and community projects are eligible to apply for the funding. The programme will support community projects at following stages; 1) the catalyst stage where feasibility studies are being carried out; 2) the development stage by providing support for business plan development, financial options appraisal, market demand analysis among others; 3) the demonstrator stage where the project installation and/or commissioning is underway and the community still requires substantial investment and support (Scottish Government, 2017).

### 8.1.4 Local Energy Challenge Fund (LECF)

Similarly, to the Infrastructure and Innovation Fund (IIF), the Local Energy Challenge Fund (LECF) encourages communities to create local energy economies and supports large-scale renewable energy systems and solutions. Round 2 of the fund has been developed in partnership with Low Carbon Infrastructure Transition Programme (LCITP) and run through the CARES scheme. The fund's goal is to not only support creation of low carbon economies but also aims to encourage investment, knowledge-sharing and collaboration among participants (Scottish Government, 2017). The fund is administered in two phases namely the development phase where environmental, technical, grid connection feasibility studies are undertaken and the demonstration or delivery phase where the project is executed.

There are many other schemes targeted at community projects such as Scottish European Green Energy Centre (SEGEC), Innovate UK, SMART Scotland that offer funding, with various eligibility criteria dependent on the nature of the energy projects (LES, 2017). These options can be explored further once the project design has been decided.

## 8.2 Acceptance of renewable energy technologies

### 8.2.1 Level of acceptance of a Wind turbine

From the questionnaire survey, out of the 59 respondents, 85% of them indicated that they would welcome a community-owned wind turbine project. The remainder was composed of 8% who were uncommitted and 7% who strongly disagreed with the idea of such a project. These results are favourable towards further development of the project as community acceptance is crucial for the success of any project. In addition, some of the funding options discussed above require consultation and acceptance of the project by the community before approval. Figure 58 summarizes the results.

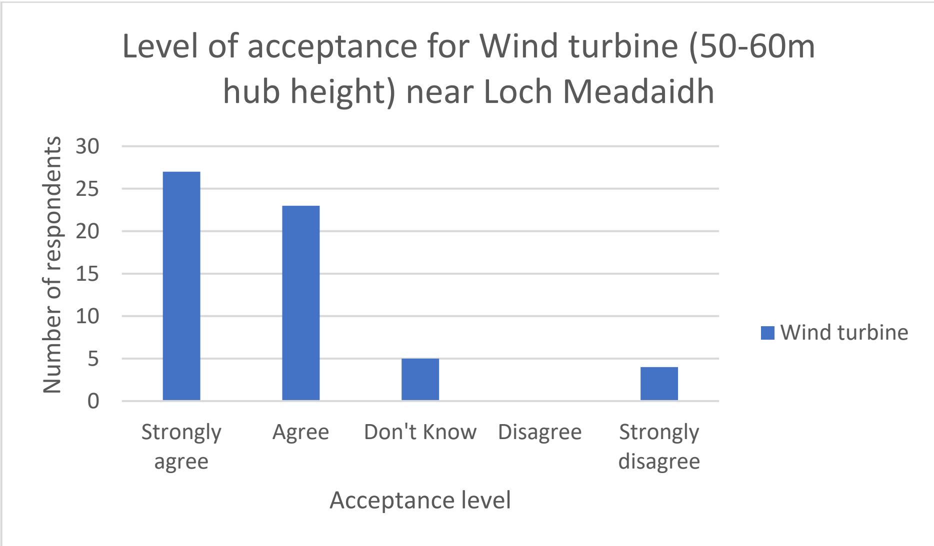



*Figure 58. Level of acceptance of a wind turbine (50-60m) near Loch Meadaidh*

### 8.2.2 Level of acceptance of the micro hydropower plant

Similarly, to the wind turbine project, majority of the respondents also subscribe to the idea of a community-owned micro hydro scheme as can be seen in Figure 59. Interestingly, the Allt Port Chamuill micro hydro scheme received a total of 49 respondents who were in its favour; two (2) additional respondents than the Allt Smoo scheme. The impartial responses received for Allt Smoo and Allt Port Chamuill were 19% and 15% respectively with 1 respondent in each scheme averse to the project. It can be concluded that the community is generally agreeable to the hydro schemes.

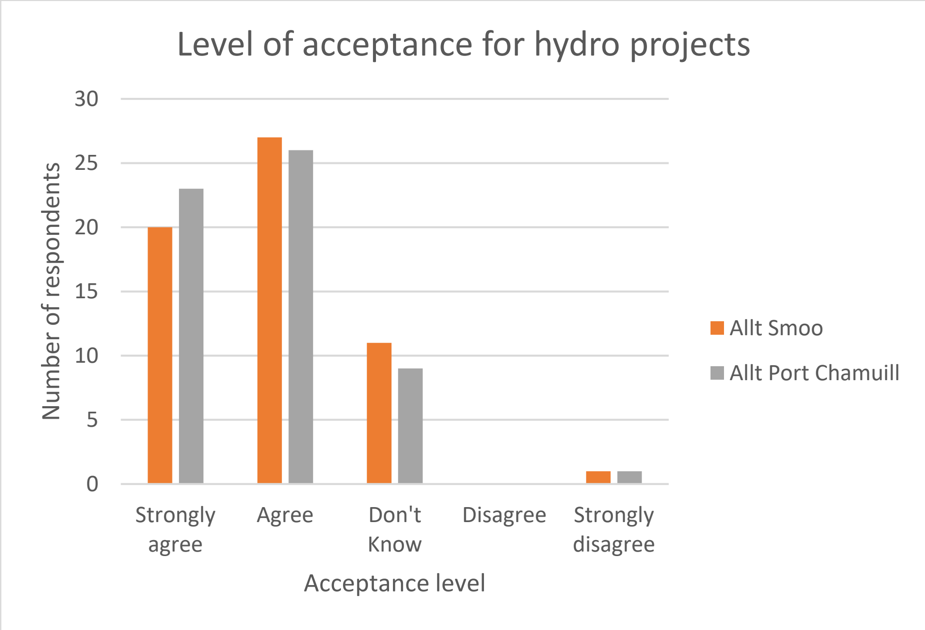



*Figure 59. Level of acceptance of micro hydro schemes at Allt Smoo and Allt Port Chamuill*

### 8.2.3 Level of acceptance of a local energy economy and in its participation

The respondents were also asked whether they were agreeable to a system like the one in the Isle of Mull being implemented in Durness; a system where the hydro scheme sells electricity for heating directly to the community through the grid operator and earns income for community development. A total of 92% respondents were generally agreeable with the idea; composed of 41% strongly agreeing while 51% chose "agree". The remainder of 5% were neutral and 3% strongly disagreed with the idea. The prospect of community development was popular with the respondents with some giving suggestions of what the Durness parish could do with the income. Some of the suggestions given included investing the money to start small businesses such as small distilleries to attract more working age population to the area or ploughing the money in the tourism industry in activities that will promote Durness to reel in more visitors and increase revenues from this industry.

A similar trend was seen in the enquiry of whether the respondents would like to become prospective customers if a system like the Isle of Mull was implemented with 90% being agreeable to it. 7% of the respondents were non-committal while 4% were against the idea or didn't not answer the question. However, for the prospective shareholder question, the level of acceptance fell to 61% while 24% were uncommitted while the rest were not willing to take part with numerous reasons cited such as the respondents had no spare money to invest or were aged thus they reasoned that project would outlive them. These findings question the amount of the equity that can be accumulated from the community and therefore, another way of community buy-in can be considered such as a share issue in the future.

Additionally, it can be deduced that majority of the respondents placed importance on the community earning income as well as becoming prospective customers enabling them to participate and make their contribution towards the project. Another motivation for involvement was presumed to be the cost of electricity from the generation plant; it was either to be maintained at the current SSE off-peak tariffs or lower.  Figure 60 summarizes the results.

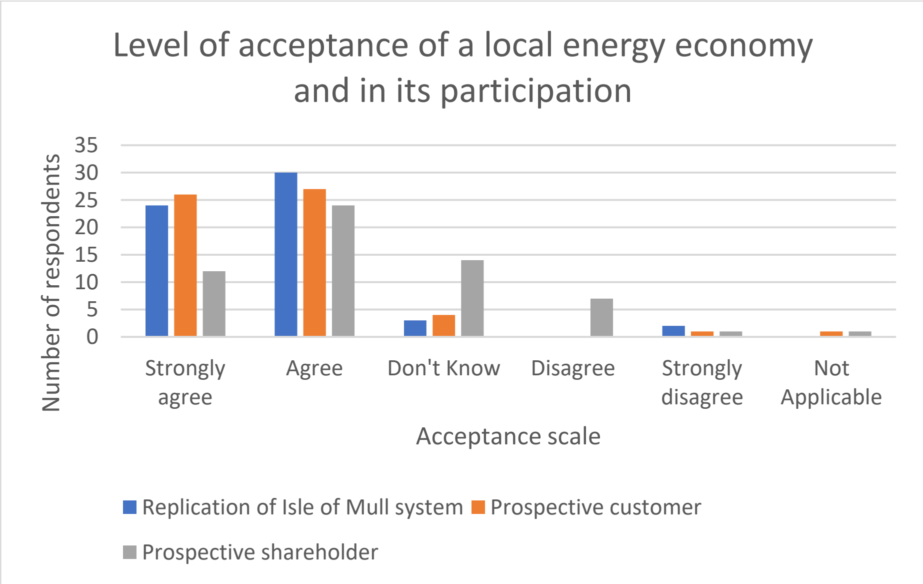



*Figure 60. Level of acceptance of a local energy economy and in its participation*

## 8.3 Description of the business models

The business models are organised by technology; into wind business models and hydro business models based on the assumption that the wind turbine and the micro hydropower plant (MHP) are separate generation plants. Moreover, in each technology, a range of architectures have been considered such as wholly exporting to the local grid, to wholly consuming of the electricity locally.

Table 39 summarizes the different wind business models with the example of the FIT tariff rates of the tariff band applicable to the Loch Meadaidh wind turbine technology while Table 40 shows the hydro business models.

| **Wind** | | | | | |
|---|---|---|---|---|---|
| **Business model (BM)** | **Feed in tariff (p/kWh)** | | | | |
| | **Generation tariff** | **Export tariff** | **Selling price** | **Consumed locally** | **Export to the grid** |
| *Baseline model [BM 1]* | 1.88 | 5.16 | Electricity sold into the grid at the export tariff [5.16 p/kWh] | 0% | 100% maximum |
| *Virtual private wire network with SSE [BM 2]* | 1.88 | 5.16 | Electricity sold locally at 5.16 p/kWh | 95% maximum | 5% |

| | | | | | |
|---|---|---|---|---|---|
| *Virtual private wire network with local sales [BM 3]* | 1.88 | 5.16 | Electricity or heat sold directly to the community at 9.15 p/kWh | 95% maximum | 5% |

Table 39. Wind business models

| **Hydro** | | | | | |
|---|---|---|---|---|---|
| **Business model (BM)** | **Feed in tariff (p/kWh)** | | | | |
| | **generation tariff** | **export tariff** | **Selling price** | **Consumed locally** | **Exported to the grid** |
| *Baseline model [BM 1]* | 7.90 | 5.16 | Electricity sold into the grid at export tariff [5.16 p/kWh] | 0% | 100% |
| *Private wire network with local sales [BM 2]* | 7.90 | 5.16 | Price set at off-peak tariff or less | 100% maximum | Remainder |

Table 40. Hydro business models

It is noteworthy to mention that although, the generation and export tariffs have been used depending on the different business models, all models have also been evaluated without the FIT to evaluate their economic stability in case they get accredited with no or negligible FIT in place.

### 8.3.1 Wind business models

The models are explained with the bigger wind turbines (greater than 100kW and less than 1.5MW) as an example for better understanding.

#### *8.3.1.1 Baseline model*

In this model, it is assumed that all the electricity generated by the wind turbine is exported to the grid while overlooking the grid constraint. Therefore, the FIT tariff applicable comprises of the generation tariff of 1.88 p/kWh which has been adapted per the degression for the 1st Tariff period of 2019 and export tariff of 5. 16 p/kWh is applicable. The purpose of this model is to have a baseline for comparison purposes against the other business models.

#### *8.3.1.2 Virtual private wire (VPW) network with SSE*

A virtual private wire network is one that connects the generation plant with the local demand using the existing distribution network but behind a point of constraint in the network (Gill, Plecas, & Kockar, 2014). A similar system is being implemented in the Isle of Mull which is explained further in the introduction section of the main report. In this VPW model, it is assumed that most of the generated electricity is used locally and sold by the grid operator (SSE). After considering losses in the distribution system, 5% of the generation can be exported to the national grid.

##### 8.3.1.3 Virtual private wire (VPW) network with local sales

This business model is like the previous one but in this case, most of the electricity generated is consumed via electric storage heaters as well as the wet district heating system while the remainder is exported to the national grid. This implies that the generation plant sells electricity directly to the local customers as well as to the district heating power plants.

### 8.3.2 Micro hydropower plant business models

##### 8.3.2.1 Baseline model

Similarly, to the wind baseline model, this model assumes that all the electricity generated is exported to the grid. Therefore, both the generation tariff and export tariff have been applied as sources of income. The purpose of this model is to provide a baseline against which to compare the other hydro business model.

##### 8.3.2.2 Physical private wire network with local direct sales

The business model is unique as it is based on connecting the generator plant with the demand over a privately-owned distribution network. The targeted demand here is the proposed micro-brewery or any other small industry which is to be located nearby as well as the planned bistro plus additional households. It is envisioned that the electricity will be sold to these consumers at a price which is similar to the SSE's off-peak tariffs. The exportation of electricity to the grid is dependent on grid capacity, demand and generation profiles among many other factors.

## 8.4 Assumptions of the economic model

### 8.4.1 Feed-in tariff (FIT)

The FIT generation tariff for wind of a total installed capacity (TIC)[16] of greater 100kW and less than 1.5MW has been adjusted by the RPI of 2.5% (ONS, 2017) and both default and contingent degressions have been applied because it is assumed that the deployment caps are breached in every tariff period and the application for the wind project in Durness is allocated to the 1st tariff period in 2019 (TP1 2019). The resulting generation tariff of 1.88 p/kWh is applied to all three scenarios proposed of 900kW, 800kW and 500kW turbines. However, for wind of a TIC between 50kW and 100kW that is proposed for the Craft Village, the generation tariff is only subjected to an RPI adjustment and the automatic default degression resulting to 5.33 p/kWh taking that the application is submitted in TP1 2019 as in the other bigger wind turbines but in its case, the deployment caps are not breached.

The FIT generation tariff for hydro of a TIC of 100kW or less is also treated similarly to the smaller wind turbine generation tariff as it is index-linked and automatically degressed resulting to an amount of 7.90 p/kWh. However, the export tariff is adjusted only by the RPI to stand at 5.16 p/kWh in the said

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[16] Total installed capacity (TIC) means the maximum capacity that an eligible installation can be operated, at a sustained period without causing damage to it (OFGEM, 2016).

period of TP1 2019. It is noteworthy to mention that an RPI of 2.5% has been chosen for adjustment in the 2nd tariff period (starting 1 April) in 2018 for all the business models though this will likely change in future.

### 8.4.2 Electricity price for local sales

The off-peak commercial price has been set against the SSE's variable business rates[17] for non-half hourly metering under the quarterly and monthly billing category amounting to 12.60 p/kWh (SSE, 2017). Although this rate is used in the economic model, it should be noted that the actual rate for businesses that have a fixed term contract was not available and would have been more accurate. The 12.60 p/kWh price is also chosen over the off-peak price of 16.00 p/kWh for deemed contract rates[18] as it was on the higher side and presumably not accurate against the fixed term contract rate.

On the other hand, the off-peak residential price of 9.15 p/kWh with Value Added Tax (VAT) of 5% included has been chosen. The proposed system includes two different heating systems namely wet district heating system and electrical storage heating system with majority of the households (about 80%) allocated to the former district heating system. The current SSE's 1 year fixed domestic economy 7 and Total Heating and Total Control (THTC)[19] tariffs were averaged each according to the number of households to compute the residential off-peak price (SSE, 2017).

Table 1.3 shows a summary of the common assumptions taken for the economic model.

| | | |
|---|---|---|
| **RPI** | **2.5%** | |
| **Inflation rate** | 2.5% | |
| **Discount rate** | 6.0% | |
| **Debt** | 100% | |
| **Interest rate** | 8% | |
| **Repayment schedule** | Annuity | |
| **Local tax** | 100% relief | |
| **VAT** | 20% | |
| **Tariff period** | TP1 2019 | |
| | Wind | Hydro |
| **Degradation factor** | 0.3% | 0.5% |
| **Depreciation [years]** | 10 | 30 |
| **Lifetime of project [years]** | 20 | 50 |

*Table 41. Summary of assumptions taken for the economic model*

[17] The variable business rates are the rates charged by SSE to a business that is supplied electricity by SSE and their fixed term contract has come to an end but has not renewed it or given a termination notice.
[18] Deemed contract rates are the rates charged by SSE to a business that is supplied electricity by SSE but has no contract in place.
[19] Total Heating and Total Control (THTC) metering is used where electricity is used for both space and water heating, found mostly in certain parts of Scotland.

## 8.5 Loch Meadaidh: economic results of the proposed business models for wind turbines

As mentioned in the wind resource section of the main report (section 5), three wind turbine generators (WTG) of 800kW, 900kW and 500kW were proposed and whose annual generation was simulated in WindPro. As an input to the economic model, for each wind turbine, the outputs were decreased by 10% as a conservative measure. There are additional assumptions that have been used for the business models (BM) such as; in Wind BM 1 and 2, it is assumed that the land will be leased and thus the rent will be 5% of the annual income. With the rent tied in to the revenue of the scheme, it ensures that the landlord also has an incentive for the turbines to be operating (BHA, 2012). In Wind BM 3, the land rent is reduced to 3% because as the revenue streams increase so do the costs of the project and the rent is no longer comparable to the other BMs.

In the Wind BM 2, it is assumed that the price of the electricity sold to the SSE is equal to the export tariff of 5.16 p/kWh while in Wind BM 3, the electricity is sold locally at the off-peak residential price of 9.15 p/kWh (same tariff for heating sales) and the theoretical tariff to be paid to the SSE for the use of the local grid (distribution use of system charges charged to the generator for connection between him and consumer) is assumed to 1.703 p/kWh. During the initial analysis of the 900 kW, it was recognised that although the investment costs were 1.5% less than the 800kW, the output was 8.7% less than its counterpart it was decided that it was not worthwhile to pursue this option further.

### 8.5.1 Net Present Value (NPV) results for 800 kW and 500 kW

Following a detailed system analysis (refer to the system section for more information), the remaining two turbines of 800 kW and 500kW were evaluated against all the business models with and without FIT. An exception to this was that no analysis was carried out for the BM 1 when the FIT was not in place for both turbines because as defined previously, the FIT is the only revenue in this model without which the model becomes irrelevant.

For both the 800 kW and 500 kW, in BM 1 where FIT is available, 95% of the electricity is exported to the national grid with the rest is attributed to losses. For 800 kW, in BM2 and BM3, 82% of the electricity is used locally for heating and storage, while the surplus of 13% is exported to the national grid with the remainder being system losses. In these models, no curtailment is experienced due to the storage requirement. For the 500 kW, in BM2 and BM3, only 95% of the electricity is available for use locally after supplying the storage, leaving no surplus to supply to the national grid. According to the system analysis, with the 800kW turbine, there is an unmet heating demand of 18%, while for the 500kW turbine, the unmet heating demand reaches 50%.

As can be seen in Figure 61 and based on the assumptions taken, Wind BM 1 and 2 have positive NPVs for the 800kW turbine when the FIT is in place and only Wind BM 3 is not profitable due to the higher investment costs. It shall be noted that in BM3 the cost of the district heating system plus the electric storage heaters replacement increase the investment costs of the whole system in approximately £ 931,000 (resulting in total investment costs of approximately £ 2,885,000). The NPV´s of the 500kW turbine were also analysed, but adversely, all are negative with or without FIT in the three different BMs.

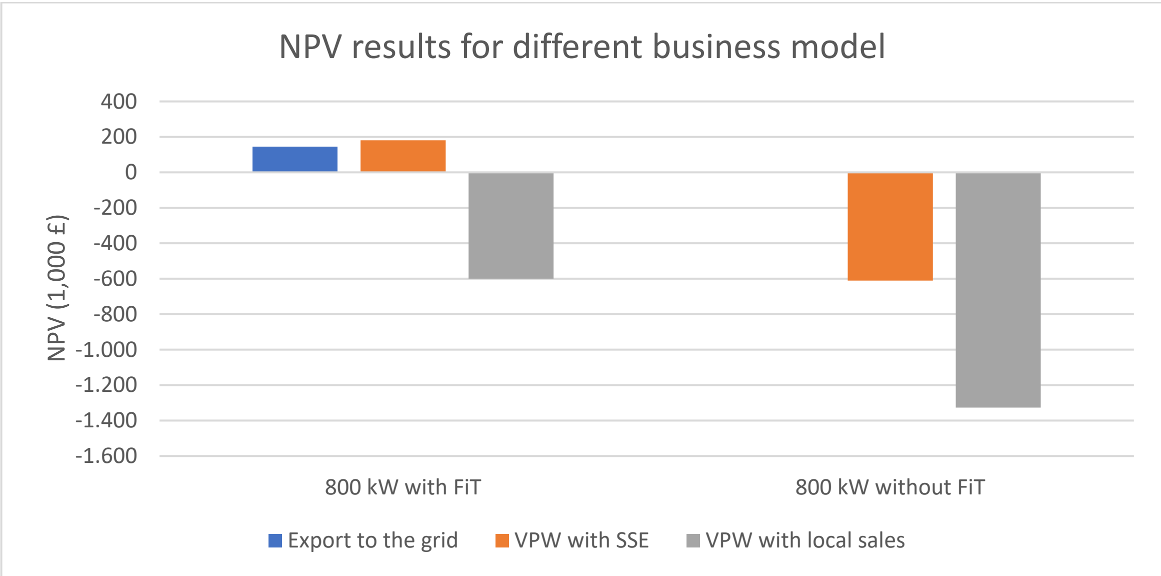


*Figure 61. Loch Meadaidh: NPV results for 800 with and without FIT*

### 8.5.2 Economic indicators for the 800kW wind turbine

Following the results for the NPV of the two turbines, the 800kW wind turbine is recommended over the 500kW. It is noteworthy to mention that it is assumed that the FIT tariff applied is 1.88p/kWh of TP 2019. In addition, the project is financed 100% through debt with maturity period of 15 years at 8% interest which is repaid through the annuity method. Table 42 shows a summary of the various economic indicators at the said tariff. Looking at Wind BM 1 and 2, the NPV values are positive and the IRR values are above 6% which is the discount rate, fortifying that the project is profitable. On the other hand, the Average Debt Service Cover Ratio (ADSCR) is an indicator used for project financing; a ratio that shows whether the cash flows after taxes are sufficient to service the loan. As can be seen, even though BM 1 and 2 are profitable, the ADSCR is lower than 1, meaning that different options of financing the project should be considered.

The Levelized Cost of Electricity (LCOE) is the sum of the costs over the lifetime of the project against the sum of electrical energy produced over the same lifetime. The LCOE of the BM 3, is higher than the other the two BMs, due to the increase of investment costs such as those of the district heating system and due to the theoretical tariff that ought to be paid for “renting” the local grid from the SSE.

| | Export to the grid [BM 1] | VPW with SSE [BM 2] | VPW with local sales [BM 3] |
|---|---|---|---|
| **NPV (£)** | 145,056 | 181,202 | - 599,675 |
| **IRR** | 6.9% | 7.1% | 3.3% |
| **LCOE p/kWh** | 7.7 | 7.33 | 12.05 |
| **ADSCR** | 0.8 | 0.8 | 0.6 |

*Table 42. Loch Meadaidh: Economic indicators for 800kW for all three business models*

The cash flows available for debt service for Wind BM 2 and 3 are shown in Figure 62. As can be seen, both BMs have increasing cashflows with BM 3 having slightly higher figures than BM2 but all that changes in year 15 for BM 3 and year 17 for BM 2 when the cashflows take a dip attributed to the onset of tax payments.

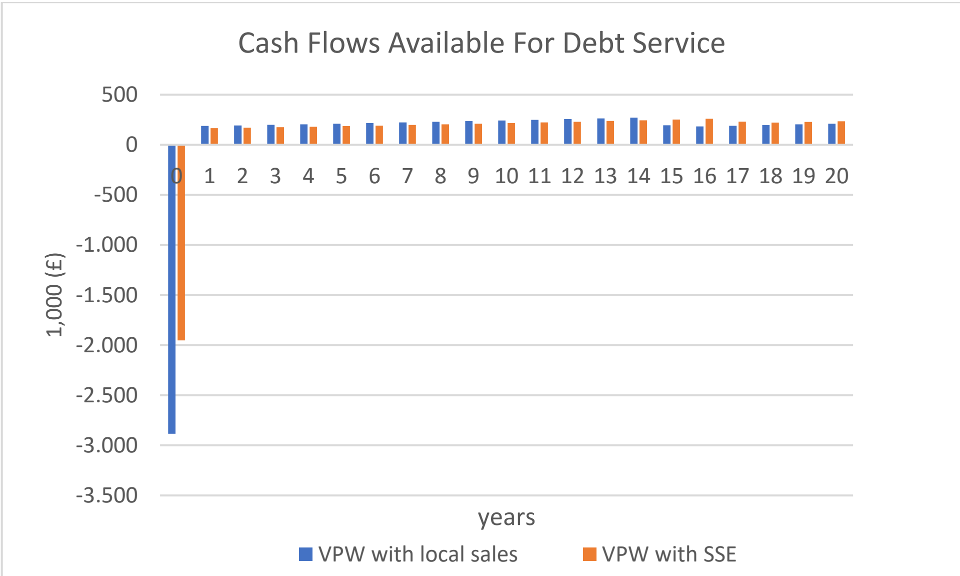


*Figure 62. Loch Meadaidh: Cash Flow Available for Debt Service (CFADS)*

As can be seen in Figure 63, in both BMs there are no cash flows available for the shareholders before year 11 with BM 2 having small cashflows in year 12. Additionally, BM 3 starts paying taxes in year 15 thus the reason for the spike in the figure while BM 2 starts paying taxes only in year 17. Thereafter, in year 16 both BMs have their cash flows increase significantly as the loan payments stop because the maturity period expires.

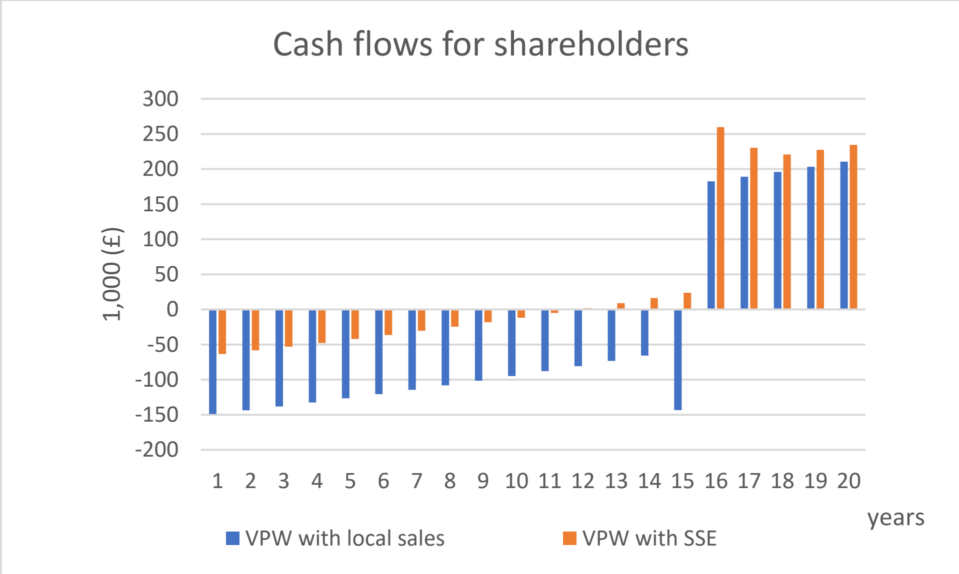


*Figure 63. Loch Meadaidh: Cashflows for Shareholders*

### 8.5.3 Sensitivity analysis for 800 kW

For the sensitivity analysis, three parameters namely investment costs, the discount rate and inflation rates are varied to determine how these parameters affect the NPV of all the BMs under the prescribed assumptions as well as to check the robustness of the business models.

#### 8.5.3.1 Sensitivity analysis of the investment costs

When the investment costs are increased by 20%, all three BMs cease to be profitable as all the NPVs for BM 1, 2 and 3 stand at £-217,833, £-176,599 and £-1,144,754 respectively. Conversely, when the investment costs are decreased in the same magnitude, the NPVs for BM 1 and 2 are positive but BM 3 remains negative (See Appendix K for more information). Figure 64 shows the aggregated change of NPV for the BMs and as can be seen, the BM 3 is more susceptible to the changes in investments costs than the other two BMs. This is attributed largely due to the included investment costs for the district heating plants and associated electric storage heaters equipment.

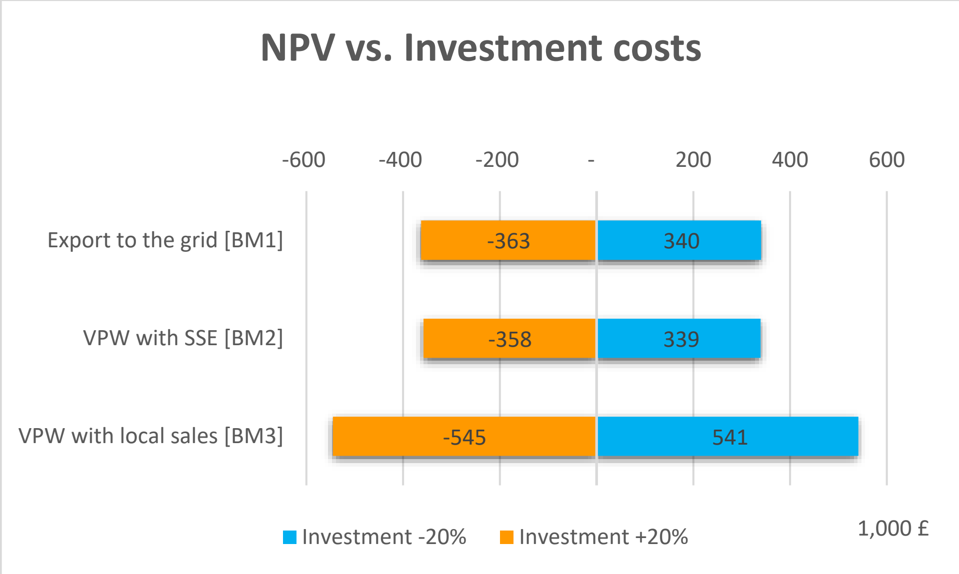


*Figure 64. Loch Meadaidh: Changes in NPV vs. Investment costs*

### 8.5.3.2 Sensitivity analysis of the discount rate

When the discount rate is increased to 8%, the NPV of Wind BM 1 which stood at £145,056 reduces by £319,302 as can be seen in Figure 65 to amount to £-174,246 making this model no longer profitable. Similarly, the NPV of both Wind BM 2 and Wind BM 3 also follows the same pattern, all showing negative NPV values making them unprofitable. When the discount rate is decreased to 3.5%, the NPVs of BM 1 and 2, show positive values but for BM 3, the NPV remains on the negative scale (See Appendix K for more information). In general, it can also be seen that the effect of the discount rate is comparable to all BMs.

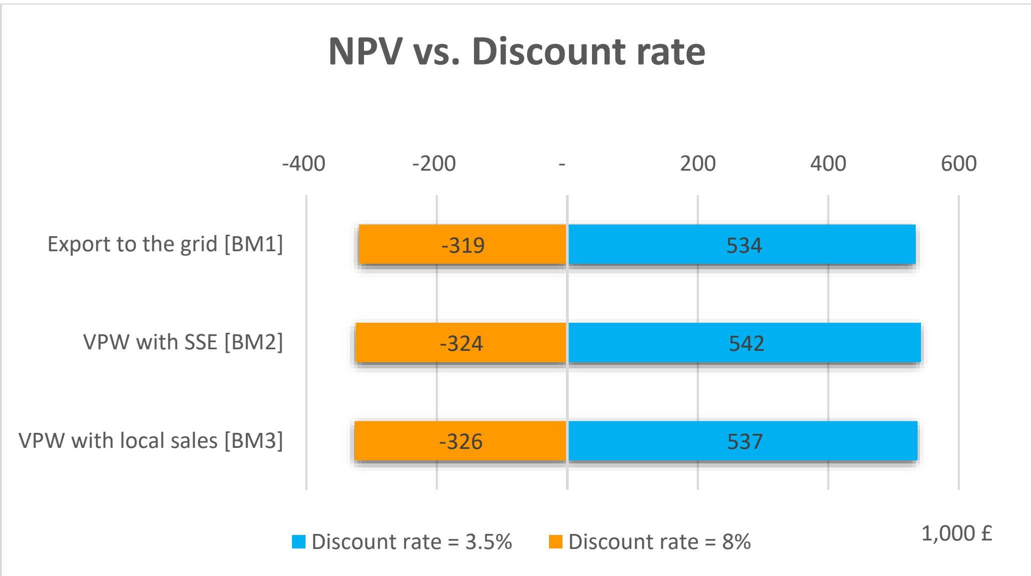


*Figure 65. Loch Meadaidh: Changes in NPV vs. discount rate*

#### 8.5.3.3 Sensitivity analysis of inflation rate

When the inflation rate is reduced from 2.5% to 0%, the NPV of all three BMs reduce to stand at £-318,632, £-286,341, £-1,004,390. This is because a change in inflation affects the revenue streams such as the FIT and local sales as well as costs such as operation and maintenance costs. In the case of no inflation rate, the costs outweigh the revenues thus the negative NPVs. On the other hand, when the inflation rate is increased to 3.5%, all NPVs increment accordingly as can be seen in Figure 66 except for Wind BM 3 which remains in the negative making it the least profitable of three BMs (See Appendix K for more information). It can be deduced that the increase in the inflation is not enough to cover the higher investment costs incurred in Wind BM 3.

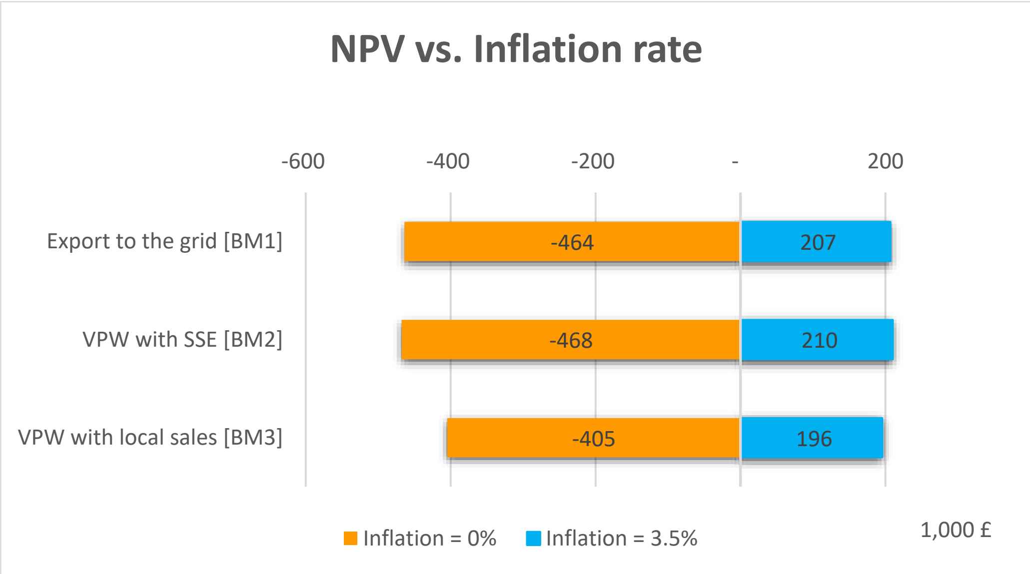


*Figure 66. Loch Meadaidh: Changes in NPV vs. Inflation rate*

## 8.6 Balnakeil Craft Village: independent analysis of a private wire business model for wind turbines

Two different wind turbines namely 60 kW and 100 kW were proposed to supply the wet district heating for the Craft Village through a private wire connection. For the economic analysis, it was assumed that heating would be sold to the consumers at 9.15 p/kWh.

Following the system analysis for the 100kW turbine, around 33% of the yearly production is curtailed after the storage is full since the option of exporting to the national grid is not available. Additionally, the unmet heating demand after storage is approximately 7% meaning that the model will require a backup system with gas as the preferred option as it is relatively affordable compared to other options such as electricity. On the other hand, for the 60kW turbine the curtailment is marginal, representing only 2% of the yearly generation, but the unmet heating demand reaches 32% owing to the magnitude of its yearly production. Similarly, to the 100kW turbine, this model requires a backup system too.

As can be seen in Figure 67, all the NPVs for both turbines are all negative. However, the magnitude of the 100kW turbine is less than the 60kW with or without FIT and a sensitivity analysis is carried out to study how this economic indicator could be improved.

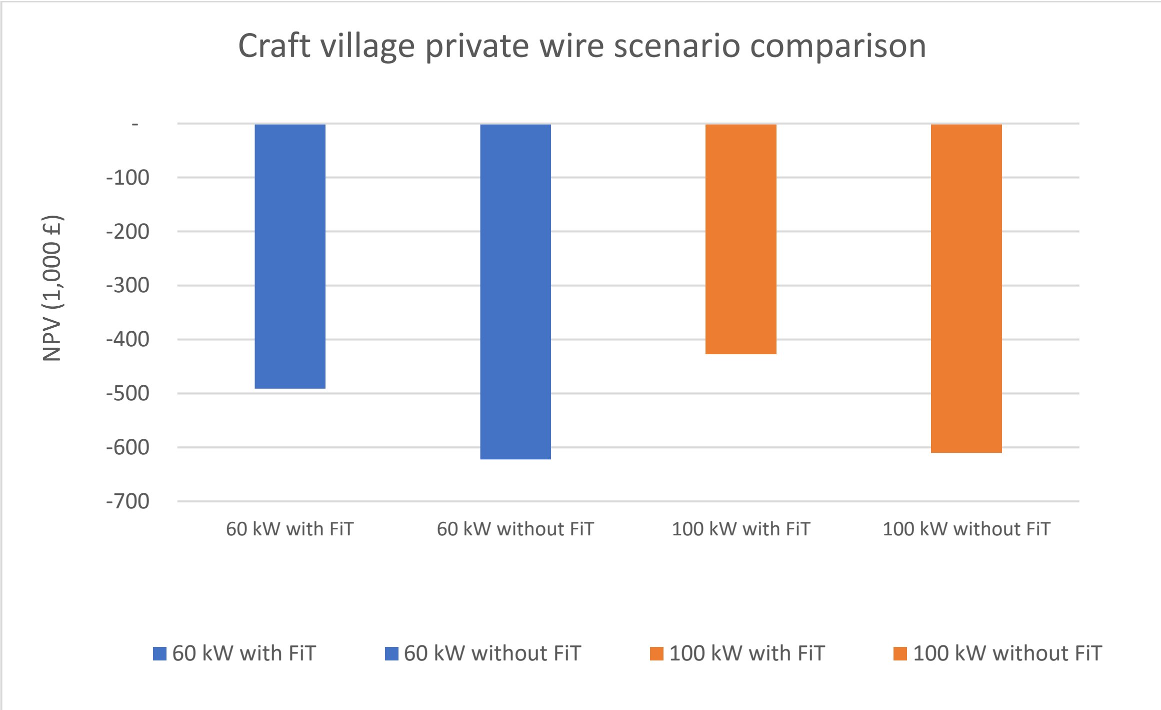


*Figure 67. Balnakeil Craft village: Private wire scenario comparison*

### 8.6.1 Sensitivity analysis for the Balnakeil 100kW wind turbine

The wet district heating system that is proposed to serve the Craft Village has been estimated to have an investment cost of around £617,751. These costs have a significant impact and it is important to see how the variation of the discount rate can affect the NPV for the 100kW. A breakdown of the costs is shown in Table 43 below.

| **Investment costs** | **£** |
|---|---|
| **100 kW wind turbine project** | 309,906 |
| **Wet district heating system** | 307,665 |
| **Total investment costs** | 617,571 |

*Table 43. Balnakeil: Investment cost for wet district heating system*

As can be seen in Figure 68, a reduction of the discount rate from 6% to 3.5% still shows negative NPVs for the different amounts of investment costs when the system is not connected to the grid. This indicates that the revenue streams with this case as it is, are not enough to recover the proposed investment.

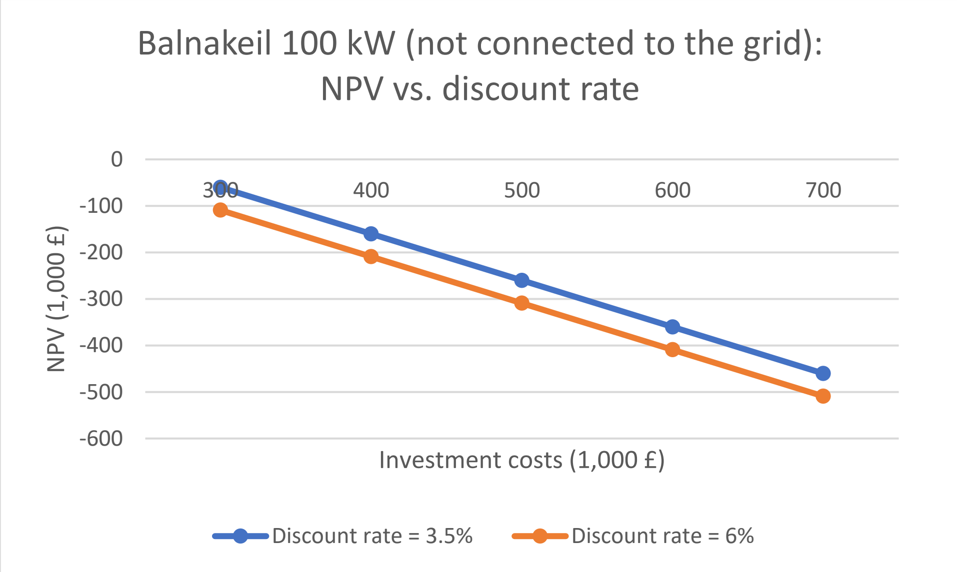

*Figure 68. Balnakeil: NPV vs. discount rate of the 100kW not connected to the main grid*

However, if there is an option to connect the project to the main grid, this could facilitate another revenue stream needed to cover the investment. From the system analysis, the level of curtailment was calculated to be around 33%, which necessitated the need to analyse an "export to the grid" scenario. This means that there would not be the need for curtailment and this electricity would now be sold to the grid, generating the much-needed incomes through the export tariff. As can be seen in Figure 69, the breakeven points for both discount rates of 6% and 3.5% shift to around £370,000 and £472,000 respectively. It should be noted that the costs of connection have to be studied in detail and the aim should be to keep them as minimal as is possible.

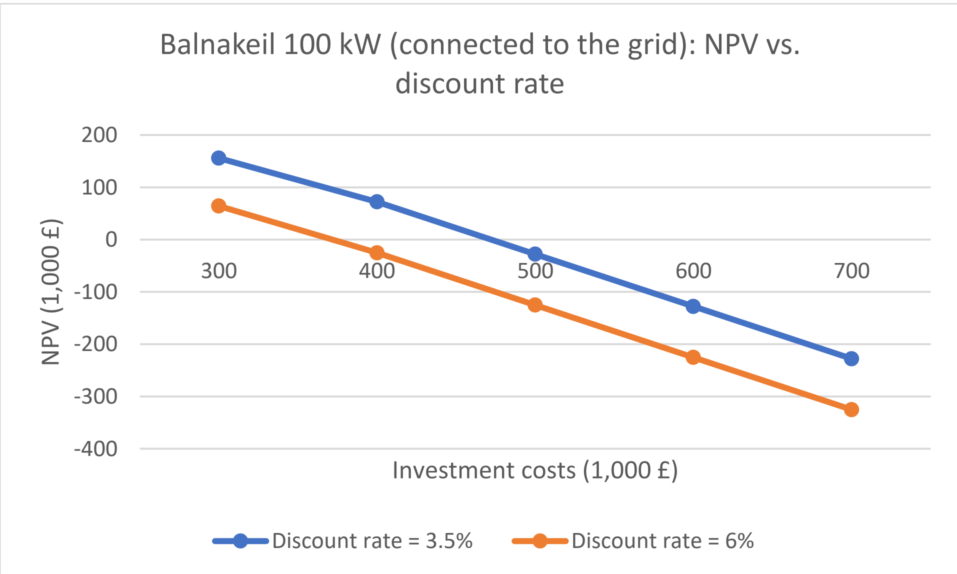

*Figure 69. Balnakeil: NPV vs. discount rate of wind turbine connected to the main grid*

## 8.7 Allt Smoo: economic results of the proposed hydro business models

For the Allt Smoo site, four different plant capacities were proposed namely 50kW, 65kW, 85kW and 100kW. However, for the hydro baseline model where all the generation is wholly exported to the national grid, all proposed plant capacities had negative NPVs thus this model is not profitable. This fortifies the general understanding that for this MHP will be most profitable when the demand is nearby and generation is used locally. However, for a definite conclusion further economic analysis was carried out.

For the second business model, the electricity is sold to a small craft business and in this case, the proposed micro-brewery at the commercial tariff of 12.6p/kWh while the remainder is sold to the households at the residential off-peak tariff. Table 1.6 shows three economic indicators for Allt Smoo. As can be seen from this table the 50kW has the NPV closest to zero and its output can cover the estimated demand of the micro-brewery (of approximately 124,000 kWh) and the remaining output can be sold locally. Based on these reasons, a sensitivity analysis will be carried out only for the 50 kW MHP.

| | NPV (£) | IRR | LCOE (p/kWh) |
|---|---|---|---|
| **65 kW** | - 56,675 | 5.2% | 23.62 |
| **85 kW** | - 131,413 | 4.4% | 24.94 |
| **100 kW** | - 254,368 | 3.4% | 27.48 |
| **50 kW** | - 27,796 | 5.5% | 23.44 |

*Table 44. Allt Smoo: Economic indicators for different plant capacities*

### 8.7.1 Sensitivity analysis for the 50kW hydro plant

#### 8.7.1.1 Sensitivity of the discount rate

From Figure 70, the breakeven point of the 50kW MHP at the assumed discount rate of 6% is approximately £440,000 but the estimated investment costs input in the economic model is £472,000 resulting to a negative NPV. In other words, for the 50kW MHP to be profitable, the investment costs cannot be greater than £440,000. This means that the costs considered for the model require further analysis and diverse options should be explored to reduce them.

Additionally, if the discount rate is reduced to 3.5%, the NPV results improve and the breakeven point shifts to approximately £650,000. This is significant as it shows the variation of the discount rate against investment costs and possible ways to should be explored to reduce the discount rate, if the investment costs will be kept as they are.

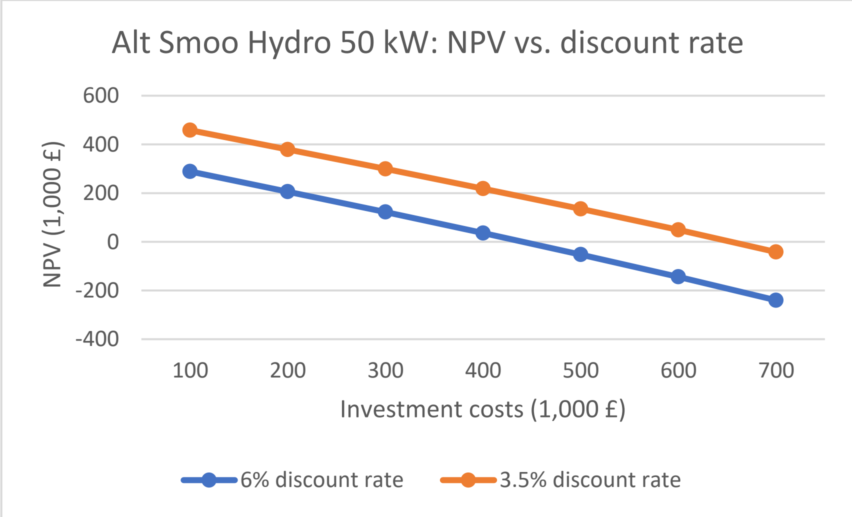


*Figure 70. Allt Smoo 50kW: NPV vs. discount rate*

#### 8.7.1.2 Sensitivity analysis of the inflation rate

Figure 71 shows that an increase in the inflation rate could improve the NPV of the project (grey line). This is because the inflation rate impacts the feed in tariffs, the tariffs for the electricity sold locally and the O&M costs. The increase on the incomes counteracts the increase of the costs, therefore improving the NPV of the project. On the contrary, when inflation decreases to 0%, no adjustments are applied to the tariffs during the lifetime of the project, which results in less NPV for each level of investment.

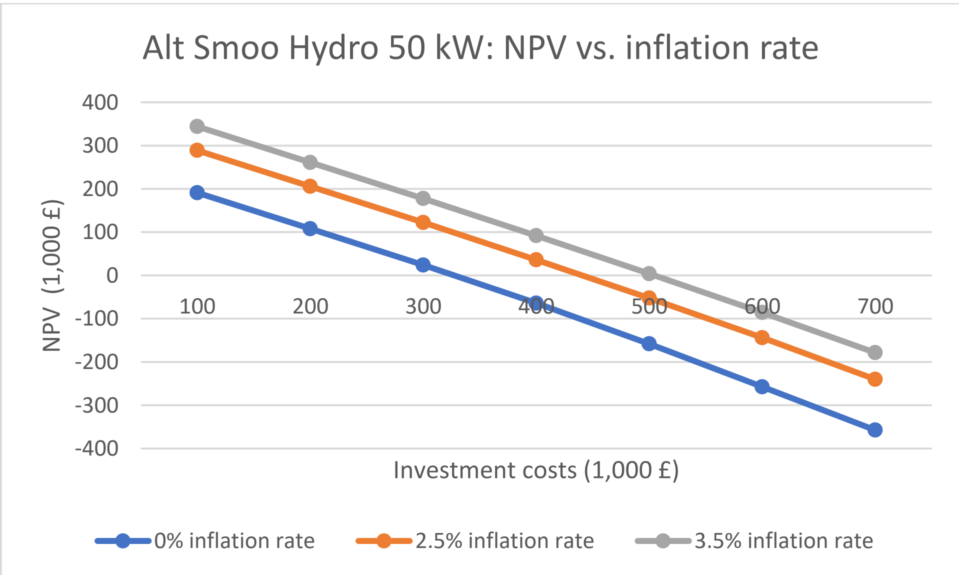


*Figure 71. Allt Smoo 50kW: NPV vs. Inflation rate*

## 8.8 Allt Port Chamuill: Economic Analysis

As mentioned earlier in the hydropower section of the main report, Allt Port Chamuill was also considered as a potential site to put up the MHP. Four plant with rated power of 35 kW, 45kW, 60kW and 65kW were proposed. An economic analysis was carried out by trial and error method to determine a limit on the investment costs, beyond which the Net Present Value (NPV) would be negative and the Internal Rate of Return (IRR) would be less than the discount rate of 6% rendering the investment not profitable. For the analysis, it was assumed that all electricity generated was exported to the national grid thus the plant received the FIT of the hydro tariff band of a TIC of less than 100kW which includes a generation tariff of 7.90 p/Kwh and export tariff of 5.16 p/kWh. Moreover, as the lifetime of the project is projected to be 30 years and the FIT runs only for 20 years, it is assumed that after the 20 years, the plant will continue to sell the electricity to the national grid at the export tariff rate. The operation and maintenance (O&M) costs are assumed to be 1% of the investment costs, VAT of 20% is applied and the inflation is kept at 2.5%.

For the 35kW MHP to be viable, the investment costs must not be higher than £218,580 as the NPV is a little bit above zero and the IRR of the project is equal to the discount rate of 6% displaying that the plant can break even. With higher costs, the NPV becomes negative and the IRR is lower than the discount rate meaning that the project is not profitable. However, to increase the IRR of the project to say for example 10%, the investment costs reduce considerable to £156,000. Similarly, for the MHPs of 45kW, 60kW and 65kW, for the plants to be viable with the NPV near zero and the IRR at 6%, the investment costs must not be greater than £256,970, £290,000, £306,250 respectively. Figure 72 summarizes these results and the complete range of values including LCOE and ADSCR can be found in Appendix J.

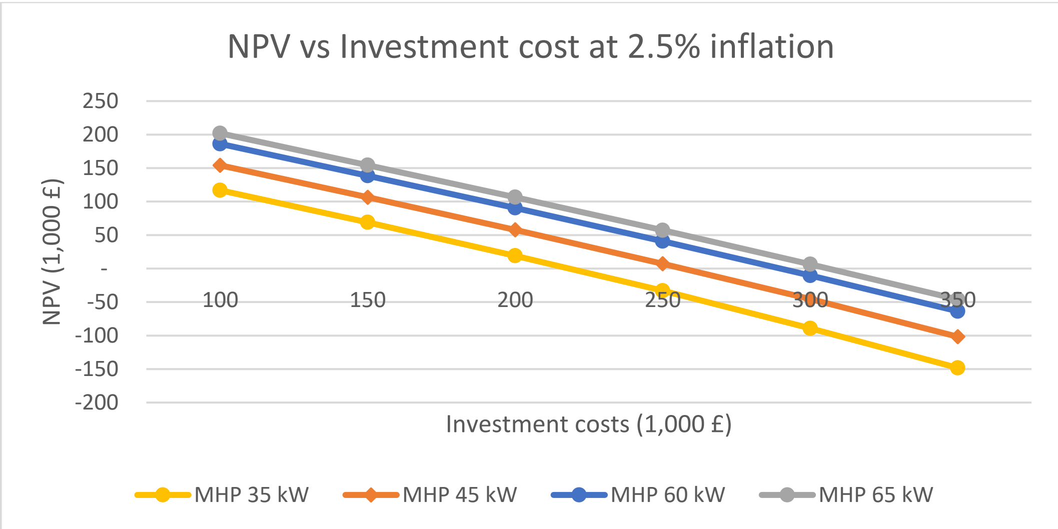


*Figure 72. Allt Port Chamuill: NPV vs Investment costs of the proposed plant capacities*

In addition, Table 1.7 shows the investments costs per rated power for all four scenarios when the NPV is kept positive but near zero and discount rate at 6%. As can be seen, the 65kW MHP has the least investment costs per rated power against the world data that gives a range of £2,700 to £8,100 (USD 3,400- USD 10,000) for small scale hydropower plants (IEA-ETSAP; IRENA, 2015). A project in the United Kingdom (UK) called the Abernethy Trust Hydro with a rated capacity of 89kW had investment costs of around £390,000 amounting to approximately 4,300 £/kW (GILKES, 2010). This shows that the below values are somewhat within range but cannot be generalised for all UK as total installed costs for hydropower plants are site-specific.

| Rated power (kW) | 35 | 45 | 60 | 65 |
|---|---|---|---|---|
| Investment costs (£) | 218,580 | 256,970 | 290,000 | 306,250 |
| Investment (£)/kW | 6,245 | 5,710 | 4,833 | 4,712 |

*Table 45. Allt Port Chamuill: Investment costs per rated power: different plant capacities*

## 8.9 Conclusions

From the above analysis, the Loch Meadaidh 800kW turbine should be considered even though the economic indicators such as the NPV are negative in value. This is because, the benefit of such a project is beyond its economic value and its intrinsic value outweighs the cost of investment. Additionally, such a project uses local renewable energy to provide heating to the community and the price at which this service is provided can be kept relatively stable making it sustainable for the community. The project also cushions the community from fluctuations of commodity prices such as oil and gas which impact on electricity and heating prices because the project will be independent of these external variables.

It is recommended that as the investment costs are high, the project should apply for loans or grants some of which were previously mentioned in the introduction section of the economic feasibility study. Furthermore, the assumptions used in this study are conservative and thus for the next project steps these figures ought to be improved with an aim of improving the economic feasibility of the project. For instance, the interest rate used is 8% and one of the measures to be explored, is to look for loans that have a reduce interest rate. This also applies at the discount rate among many others which the project developers can aim to reduce or improve accordingly.

Similarly, the Balnakeil 100kw turbine also is proposed to supply district heating to the Craft Village and like the previous case, different options for funding should be explored and the economic indicators used to improve the economic results of the project. Additionally, to increase the revenues streams of this case, connection to the main grid should be considered so as to maximize the benefits that can be realised from the project.

# 9 Synthesis

One of the main motivations to develop this project is to provide affordable heat for the community. Currently the community is spending £ 478,000 per year in fuels to heat their homes and businesses.

Therefore, the purpose of this study is to determine if this value could be reduced by implementing the proposed wind and hydro projects. Apart from the reduction in annual expenditures for fuels, a heating system based on renewable energy attempts to reduce the possible fluctuations on the expenditures due to the variation in fuel prices. This would allow to guarantee the community an affordable heating throughout the lifetime of the project, especially under the scenario of a significant increase in the international price of commodities such as oil, coal and gas.

On the other hand, it is important to mention that heating with a renewable energy source such as the one proposed has remaining challenges. The main one is trying to match an intermittent energy generation from sources such as wind and hydro with heating demand profile that has a different pattern. To overcome this challenge, a combination of two alternatives have been analyzed. First, a storage system has been proposed to store the excess energy whenever the supply is higher than the demand, and later where supply is not enough-, the stored energy will be used. However, the designed storage may not be able to supply the required heat demand leading to unmet demand. In an attempt to solve this problem, calculations have been done to identify the relationship between an increase in the storage capacity and a reduction of the unmet demand. After a certain threshold, an increase in capacity will not lead to a significant reduction in unmet demand. Therefore, a gas backup system has been proposed to cover the remaining unmet demand after storage.

From the economic analysis presented previously, it was found that this project may not be feasible if it is seen solely from the perspective of an investor (because it would have negative NPV). But if the project is analyzed from the community perspective, it could be attractive. The reason behind it is that if the annual fuel expenditures of the community could be replaced with a lower annual expenditure to pay for the project, the community will perceive benefits through savings.

Within this context, the total annual cost of the Loch Meadaidh project (800kW wind turbine) has been compared with the annual cost of the community current fuel expenditures. It was found that under the scenario of feeding the electricity to the grid with a FIT, the community will begin to reduce their annual heating expenditures starting from the second year of the project and increasing throughout the lifetime of the project. For the second year, savings are GPB 17,300 and will increase to £ 423,700 for the $20^{th}$ year.

Similar calculations have been done for the proposed project in Craft Village. In this case, it was assumed that the heat demand will be reduced by 30% due to energy efficiency measures, which are required to be able to apply for an affordable public loan. According to the obtained results, the project will only generate saving during the last three years, which makes it not economically feasible. An alternative scenario to make the project economically attractive will be to find a grant for GPB

200,000, or the equivalent between different sources such smaller grants including kindly contribution of the community members. In this case, it will generate savings after the 8th year, but those benefits will increase throughout the project until reaching a value of £ 35,000 during the 20th year.

Based on the above, it can be concluded that from the perspective of the community, the Loch Meadaidh project is attractive, generating savings in the annual heating expenses of the community for 19 years. For the case of Craft Village, the project by its own will not be economically attractive. But with community contribution such as kindly work and external grants, the project could generate saving for the community. Therefore, is important to have an adequate community management and engagement to make this type of projects feasible.

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# Appendix A

## Questionnaire

| HOUSEHOLD QUESTIONNAIRE, DURNESS 2017 |
|---|

**Interviewers : Master students of Engineering in Energy and Environmental Management Europa-Universität Flensburg, Germany.**

| Questionnaire Purpose |
|---|
| Your participation will be useful for evaluationg options for generating community benefits from locally available renewable energy sources in Durness. |
| ***Study feedback will be shared with "Community Energy Scotland" and "Durness Development Group"*** |
| **Data Privacy** |

The following questionnaire is conducted by the students of the Master programme in Energy and Environmental Management under the supervision of the University of Flensburg, Germany. Your responses will be helpful in assessing the energy status and determining whether renewable energy projects could provide a paradigm shift in the livelihood of Durness. Your responses will be treated with confidence such that your identity cannot be connected with specific published information. All questionnaire response sheets will be destroyed at the end of this study. Research findings will be shared with Durness Development Group and community members in a common meeting.The estimated duration of the survey is 40 minutes and we solicit your time and assistance in completing it.We would like to thank you in advance for participating in our short survey. Should you have any queries or further comments, please feel free to contact us via the following contact information.

Email : euf.eem.ic2017@gmail.com

DURNESS DEVELOPMENT GROUP

Community Energy Scotland
Cumhachd Coimhearsnachd na h-Alba

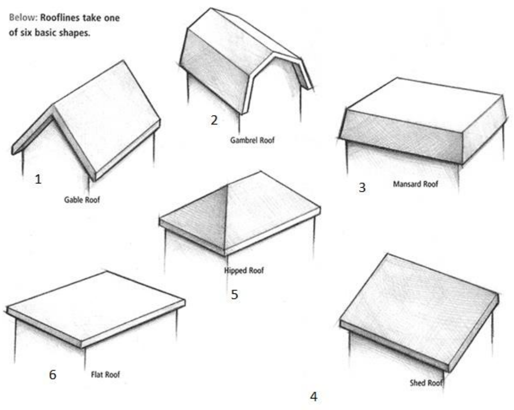
Europa-Universität Flensburg
Interdisciplinary Institute of Environmental, Social and Human Sciences
Department of Energy and Environmental Management

**To be filled in by interviewer**

| Questionnaire ID | Interviewer's name |
|---|---|
| | |

Date: ________ Starting Time: ________

**Type of roof**




A. Property Code: ____________

B. Number of storeys without loft: ____________

C. Is there any room in the loft? ____________

D. Purpose of the property?
- ☐D.1 Residential Only
- ☐D.2 Residential+Commercial
- ☐C.3 Commercial Only

| **1,0** | **Initial Information** |
|---|---|

1,1 Respondent's name : ____________ 1,2 Respondent's address : ____________

1,3 Contact Information (Optional)

1.3.1 Phone ____________ 1.3.2 Email ____________

1,4 *(Residential Only)* How many household members belong to each category?

| 1.4.1 | 1.4.2 | 1.4.3 | 1.4.4 | 1.4.5 |
|---|---|---|---|---|
| **Young Children (0 - 12)** | **Teenagers (13 - 19)** | **Adults aged (20-45)** | **Adults aged (46-60)** | **Adults aged (>60)** |
| | | | | |

1,5 How many occupants are in the property during the morning, afternoon, evening and during the night?

| 1.5.1 | 1.5.2 | 1.5.3 | 1.5.4 |
|---|---|---|---|
| **Morning** | **Afternoon** | **Evening** | **Night** |
| | | | |

1,6 Property type status ?

1 ☐ Owned
2 ☐ Rented
3 ☐ Holiday
4 ☐ Others ____________________

**2,0 ENERGY STATUS OF THE PROPERTY**

2.1.1 When was this property built?

1 ☐ Before 1919
2 ☐ 1919-1944
3 ☐ 1945-1964
4 ☐ 1965-1982
5 ☐ after 1982

2.1.2 Was there any extension in this building?

☐No ☐Yes, Please provide information (year and size of the extension)

2,2 How would you describe your property ?

1 ☐ Detached
2 ☐ Semi Detached
3 ☐ Terrace
4 ☐ Mid terrace
5 ☐ Flat
6 ☐ Other (specify) : ____________________

2,3 What is the property size ? (specify the right units)

_____________ $ft^2$ / $m^2$

2,4 How many rooms are there in this property?

| Places | | Number of rooms |
|---|---|---|
| 2.4.1 | Bedroom | |
| 2.4.2 | Living room | |
| 2.4.3 | Kitchen | |
| 2.4.4 | Bathroom | |
| 2.4.5 | | |
| 2.4.6 | | |
| 2.4.7 | | |
| 2.4.8 | | |

2,5 Have any **improvements** been done to reduce **energy consumption** in this property in the past 15 years ?

0 ☐ No — **Go to [ Q 2.7 ]**
1 ☐ Yes — **Go to [ Q 2.6 ]**
2 ☐ I don't know — **Go to [ Q 2.7 ]**

2,6 What sort of **improvements? ( Insulation: wall, window, floor, roof, door, Heating: heating system , radiator)**

☐

2,7 Do you have any plans to implement any kind of **improvements**?

0 ☐ No — **Go to [ Q 3.1 ]**
1☐ Yes
2 ☐ I don't know — **Go to [ Q 3.1 ]**

2,8 If "**Yes**", which sort of **improvements** will you implement ? ( Insulation: wall, window, floor, roof, door, Heating: heating system , radiator)

## 3,0 ENERGY CONSUMPTION

3,1 Do you have / use any **Renewable Energy** Technologies in this property ?

0 ☐ No 1 ☐ Yes

If "Yes" , what kind of technologies

Please specify ______________________________

3,2 What sort of **space heating** system is being used for this property ? (Multiple Answers Possible)

3.2.1☐ Gas-fired central heating syst 3.2.2 ☐ Oil fired central heating system 3.2.3☐ Electrical pannel heater

3.2.4 ☐ Electrical storage heaters 3.2.5 ☐ Ground source heat pump 3.2.6☐ Electrical heat pump

3.2.7 ☐ Solid fuel heater 3.2.8 ☐ Air source heat pump 3.2.9 ☐ Other (specify)

3,3 What is the **water heating** system in this property ? (Multiple Answers Possible)

3.3.1 ☐Electric Instantaneous heater 3.3.2 ☐ Gas heater

3.3.3 ☐ Oil Heater 3.3.4 ☐ Electric Immersion Heater (manual and remote control)

3.3.5 ☐Part of the central heating system 3.3.6 ☐ Others (specify) : ______________________________

3,4 How much do you spend on **electricity** monthly?

| | **Electricity Meter** | **Energy consumed (kWh/month)** | **Cost (£)** |
|---|---|---|---|
| 3.4.1 | Normal Standard Meter | | |
| 3.4.2 | White Meter (Separate meter for heating) | | |

3,5 Please indicate the quantities and expenditures for your heating fuels.

| **Applicable Fuel** | | **Quantity** | **Units** | **Money ( £ )** |
|---|---|---|---|---|
| 3.5.1 | LPG | | | |
| 3.5.2 | Oil | | | |
| 3.5.3 | Coal | | | |
| 3.5.4 | Peat | | | |
| 3.5.5 | Wood | | | |
| 3.5.6 | | | | |
| 3.5.7 | | | | |
| 3.5.8 | | | | |

3,6 How satisfied are you with the heating system in your household to meet your heating demands?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **(Very satisfied)** | **(Satisfied)** | **(Neutral)** | **(Dissatisfied)** | **(Very dissatisfied)** |
| | | | | |

## 4,0 Only for COMMERCIAL PURPOSE otherwise go to Section 5

4,1 What is the commercial purpose for this building?

| 4.1.1 | 4.1.2 | 4.1.3 |
|---|---|---|
| **Bed&Breakfast/ Self Catering** | **One-room office** | **Others (Please specify)** |
| | | |

Go to [ Q 4.5 ]

4,2 How many people are working in this business? ______________________________

4,3 Average working hour per day? ______________________________

4,4 Working days (yearly)? ______________________________

4,5 How many **rooms** are rented in this building ?

| 4.5.1 | 4.5.2 | 4.5.3 |
|---|---|---|
| **Single bedroom** | **Double bedroom** | **Others** |
| | | |

## 5,0 RENEWABLE ENERGY TECHNOLOGIES

Please indicate in how far you agree or disagree to the following statements.

5,1 I support the idea of a community owned wind turbine (50-60 m hub height) near Loch Meadaidh

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Strongly agree** | **Agree** | **Don't know** | **Disagree** | **Strongly Disagree** |

5,2 I support the idea of a community owned micro hydro scheme at Allt Smoo

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Strongly agree** | **Agree** | **Don't know** | **Disagree** | **Strongly Disagree** |

5,3 I support the idea of a community owned micro hydro scheme at Allt Port Chamuill

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Strongly agree** | **Agree** | **Don't know** | **Disagree** | **Strongly Disagree** |

5,4 The community development organisation of the Isle of Mull generates and sells hydro electricity for heating directly to the community members through the local electrical grid, earning income for the development of the community.

I support the idea of implementing a similar system in Durness

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Strongly agree** | **Agree** | **Don't know** | **Disagree** | **Strongly Disagree** |

5,5 I would be interested in becoming a customer, if a similar system as on the Isle of Mull is implemented in Durness, assuming the cost are not higher than the SSE off peak tariffs.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Strongly agree** | **Agree** | **Don't know** | **Disagree** | **Strongly Disagree** |

5,6 I would be interested in becoming a shareholder in such a system.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Strongly agree** | **Agree** | **Don't know** | **Disagree** | **Strongly Disagree** |

5,7 Do you have any additional comments ?

Thank you for participating.

**END OF QUESTIONNAIRE** Ending Time: Total time of the interview:

# Appendix B

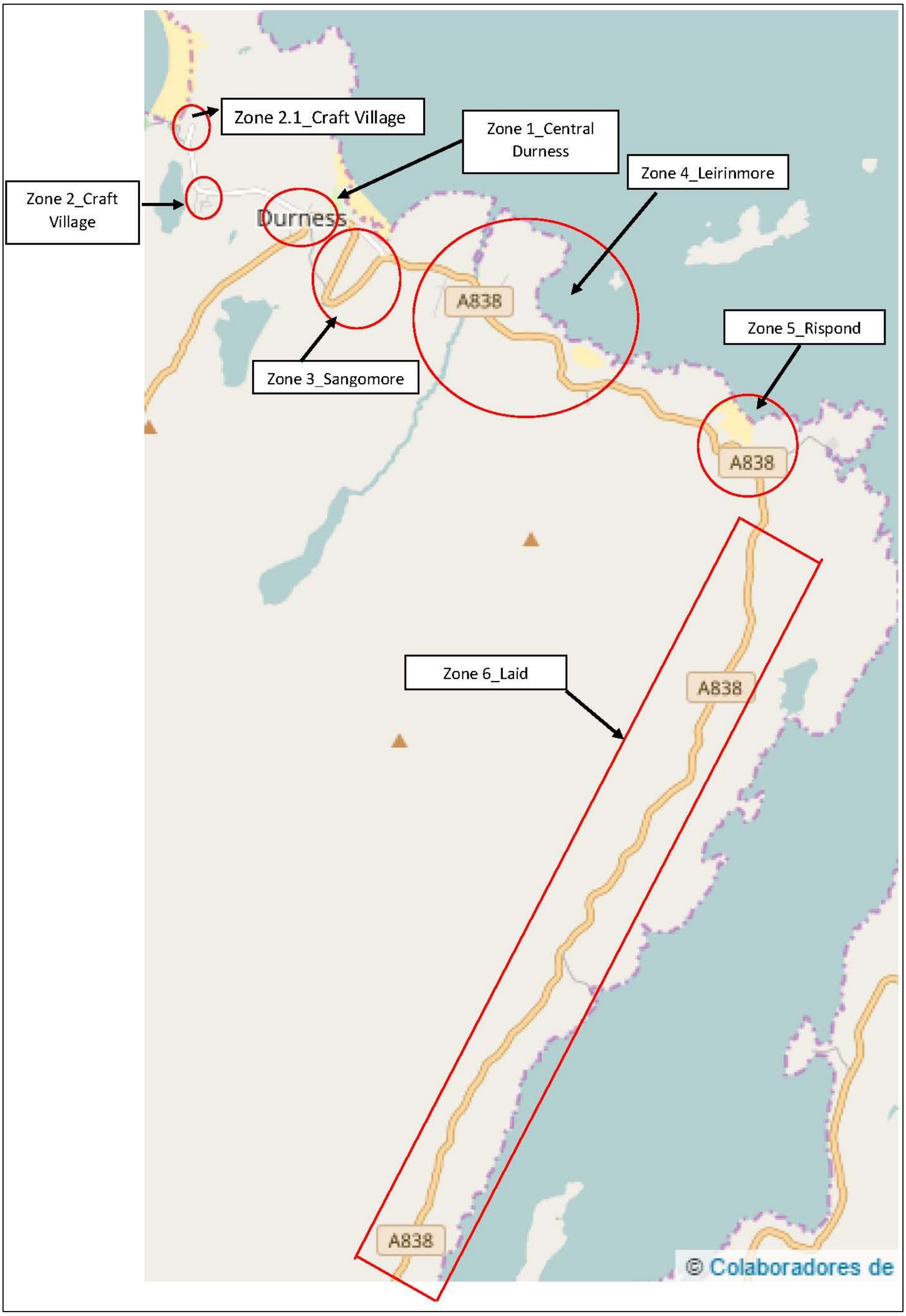



*Figure B. 1. Survey zones*

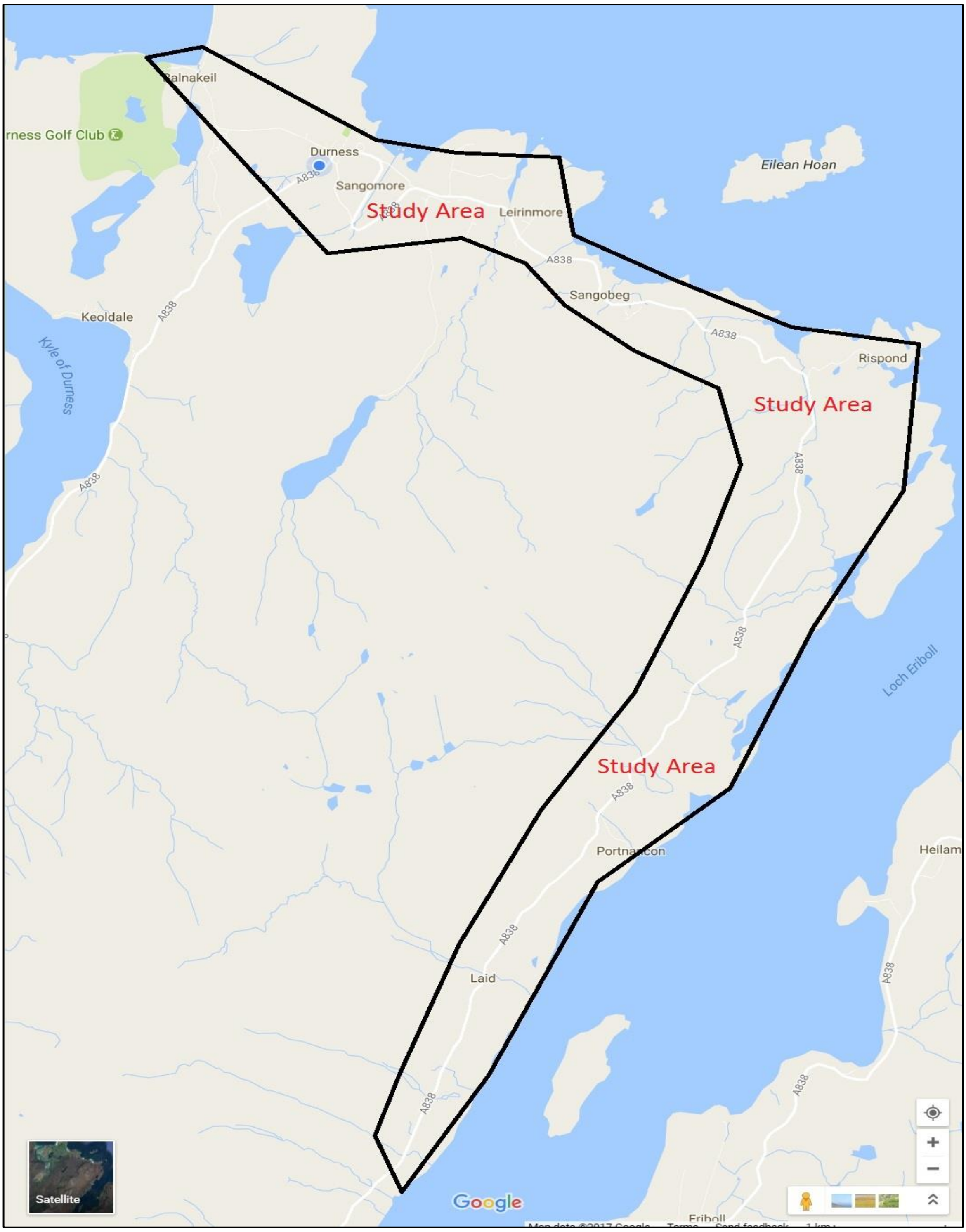



*Figure B. 2. Study area map*

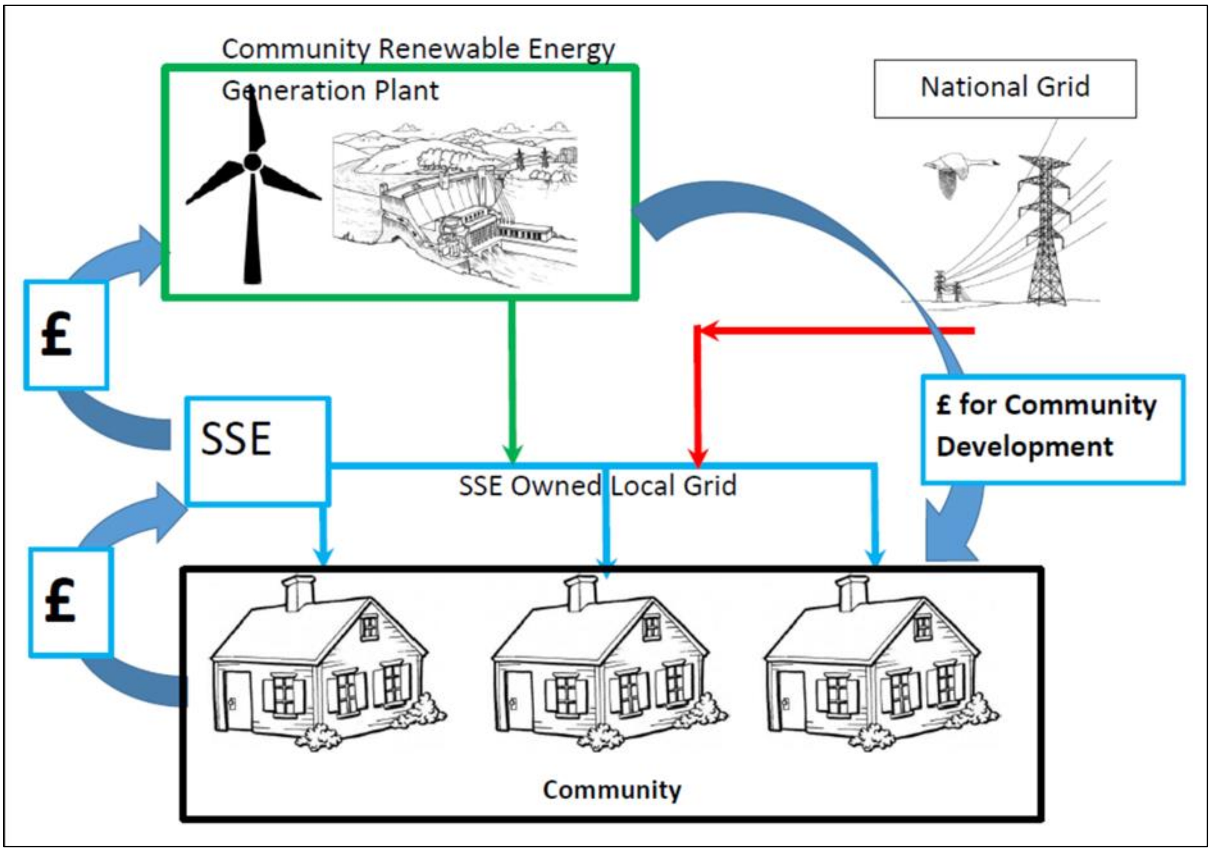
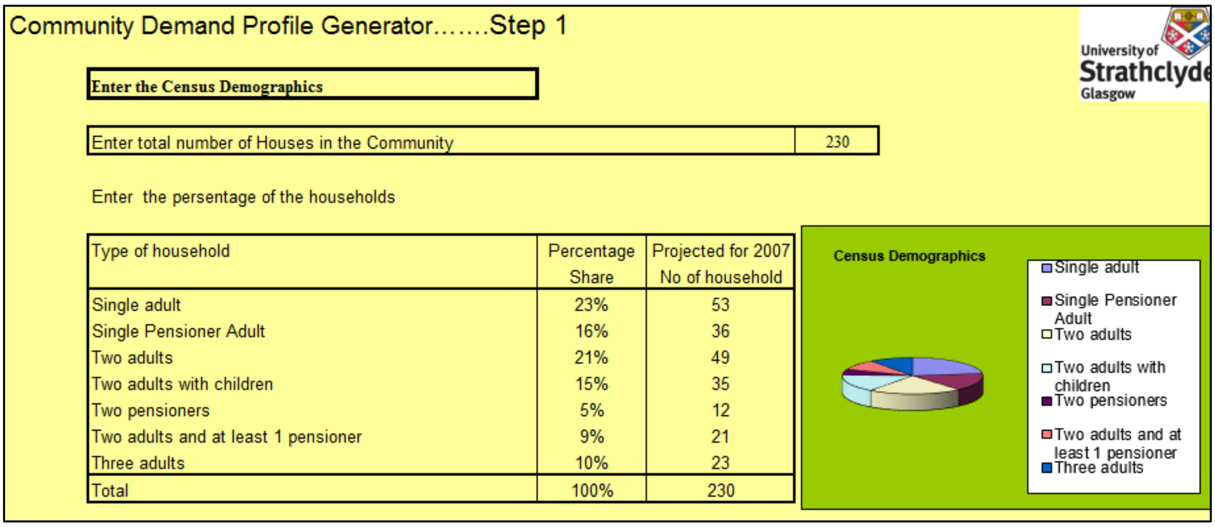



*Figure B. 3. Concept of "Isle of Mull" system, which was showed to the interviewees during interviews*

# Appendix C

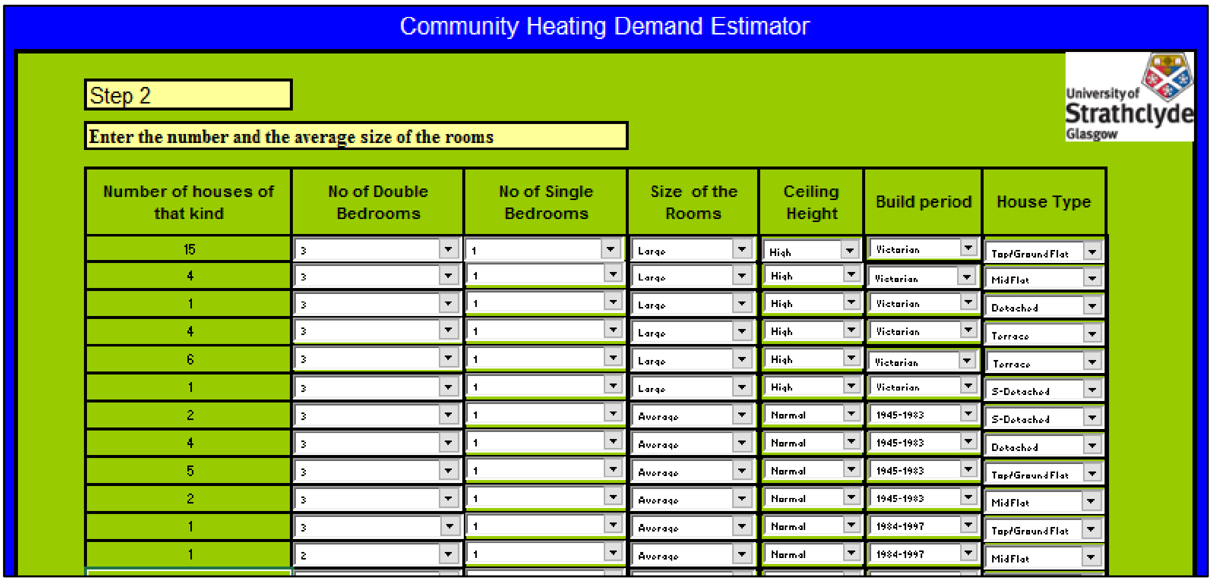
## Additional information from Strathclyde model

### Interfaces of Strathclyde model




| Type of household | Percentage Share | Projected for 2007 No of household |
|---|---|---|
| Single adult | 23% | 53 |
| Single Pensioner Adult | 16% | 36 |
| Two adults | 21% | 49 |
| Two adults with children | 15% | 35 |
| Two pensioners | 5% | 12 |
| Two adults and at least 1 pensioner | 9% | 21 |
| Three adults | 10% | 23 |
| Total | 100% | 230 |

*Figure C. 1. Step 1 of Strathclyde model: demographic information*




| Number of houses of that kind | No of Double Bedrooms | No of Single Bedrooms | Size of the Rooms | Ceiling Height | Build period | House Type |
|---|---|---|---|---|---|---|
| 15 | 3 | 1 | Large | High | Victorian | Top/Ground Flat |
| 4 | 3 | 1 | Large | High | Victorian | Mid Flat |
| 1 | 3 | 1 | Large | High | Victorian | Detached |
| 4 | 3 | 1 | Large | High | Victorian | Terrace |
| 6 | 3 | 1 | Large | High | Victorian | Terrace |
| 1 | 3 | 1 | Large | High | Victorian | S-Detached |
| 2 | 3 | 1 | Average | Normal | 1945-1983 | S-Detached |
| 4 | 3 | 1 | Average | Normal | 1945-1983 | Detached |
| 5 | 3 | 1 | Average | Normal | 1945-1983 | Top/Ground Flat |
| 2 | 3 | 1 | Average | Normal | 1945-1983 | Mid Flat |
| 1 | 3 | 1 | Average | Normal | 1984-1997 | Top/Ground Flat |
| 1 | 2 | 1 | Average | Normal | 1984-1997 | Mid Flat |

*Figure C. 2. Step 2 of Strathclyde model: dwelling characteristics*

### Conversion of construction period from survey to model

As the construction period defined in the questionnaire were different from the ones required by the model, the conversion shown in the below table was used. The houses "post 1982" in the questionnaire, were categorized as "1998-2002" in the model, therefore the category "1984-1997" was not used in the model.

| | Construction period of Dwelling | | | | | |
|---|---|---|---|---|---|---|
| **Survey** | Pre-1919 | 1919-1944 | 1945-1964 | 1964-1982 | Not used | Post 1982 |
| **Model** | Pre-1945 (Victorian) | | 1945-1983 | | 1984-1997 | 1998-2002 |

*Table C. 1 Equivalence of construction period from survey to model*

## Type and period of properties

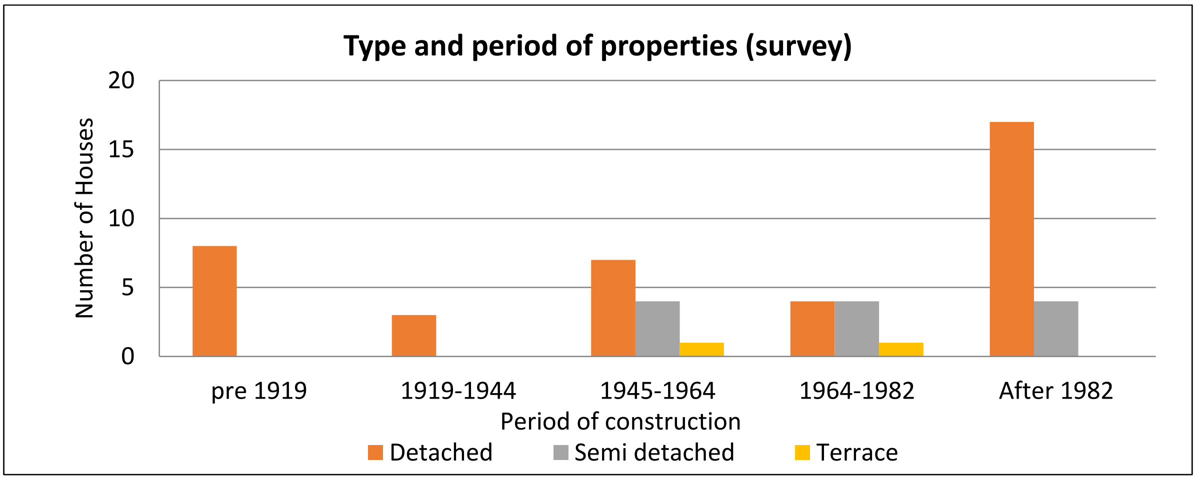



*Figure C. 3. Type and construction period of properties according to survey*

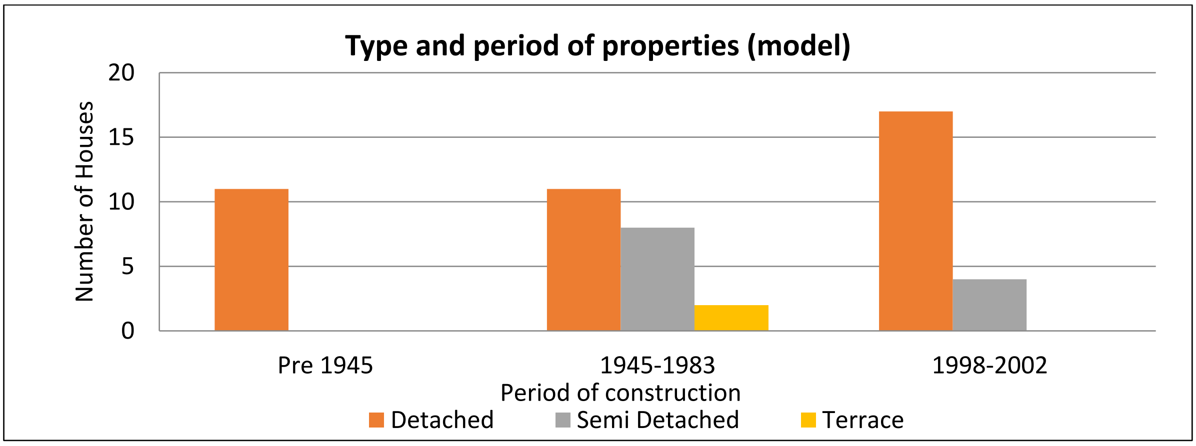



*Figure C. 4. Type and construction period of properties according to Strathclyde model*

## Size of rooms in properties

The Excel model from the University of Strathclyde assumes the following areas of rooms per property.

| Room | | Area ($m^2$) |
|---|---|---|
| Double rooms | Compact | 15 |
| | Average | 22,5 |
| | Large | 30 |
| Fixed size kitchen | | 16 |
| Fixed size bathroom | | 10 |

*Table C. 2. Size of rooms according to Strathclyde model*

## Equivalence between types of rooms in surveys and Strathclyde model

As some of the rooms obtained from the survey were not available in the model, the following assumptions were made. All bedrooms were assumed to be double bedrooms. Additional Kitchen and offices were modelled as double bedrooms. Workshops were not included as rooms, because in most of the cases they are not heated.

| | **Number of Rooms** | | | |
|---|---|---|---|---|
| **Survey** | Bedroom | Additional Kitchen | Office | Workshops |
| **Model** | Double Bedroom | Double Bedroom | Double Bedroom | None |

*Table C. 3. Equivalence between type of rooms in surveys and Strathclyde model*

## Number of properties per type, construction period and number of bedrooms

| **Number of properties** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Detached Houses** | | | **Semi-detached Houses** | | | **Terrace Houses** | | |
| **Number of double bedrooms** | **Pre-1945** | **1945-1983** | **1998-2002** | **Pre-1945** | **1945-1983** | **1998-2002** | **Pre-1945** | **1945-1983** | **1998-2002** |
| **1** | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| **2** | 1 | 1 | 6 | 0 | 1 | 3 | 0 | 1 | 0 |
| **3** | 2 | 5 | 6 | 0 | 2 | 0 | 0 | 1 | 0 |
| **4** | 3 | 3 | 1 | 0 | 3 | 1 | 0 | 0 | 0 |
| **5** | 5 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **11** | **11** | **17** | **0** | **8** | **4** | **0** | **2** | **0** |

*Table C. 4. Number of properties per type, construction period and bedrooms*

## Definition of the season

The seasons in the Strathclyde model are defined according to the follow table.

| **Season** | **Start** | **End** | **Number of days** |
|---|---|---|---|
| **Winter 1** | 01-Jan | 11-Apr | 101 |
| **Spring** | 12-Abr | 13-May | 32 |
| **Summer** | 14-May | 03-Sept | 113 |
| **Autumn** | 04-Sep | 29-Oct | 56 |
| **Winter 2** | 30-Oct | 31-Dec | 63 |
| **Total** | | | **365** |

*Table C. 5. Season definition according to Strathclyde model*

## Demand estimation for craft village

The following table shows the seasonal heat demand for craft village.

| Season | Start - Season | End - Season | Num. of days | Space Heating (kWh) | Water Heating (kWh) | Total Heating (kWh) |
|---|---|---|---|---|---|---|
| **Winter 1** | 01-Jan | 11-Apr | 101 | 108.314 | 16.090 | 135.393 |
| **Spring** | 12-Apr | 13-May | 32 | 20.700 | 5.098 | 25.875 |
| **Summer** | 14-May | 03-Sept | 113 | 28.752 | 18.001 | 35.939 |
| **Autumn** | 04-Sept | 29-Oct | 56 | 30.341 | 8.921 | 37.927 |
| **Winter 2** | 30-Oct | 31-Dec | 63 | 44.478 | 10.036 | 55.597 |
| **Total** | | | **365** | **232.585** | **58.146** | **290.732** |

*Table C. 6. Seasonal heat demand for craft village*

The following graph shows the hourly heat demand for craft village.

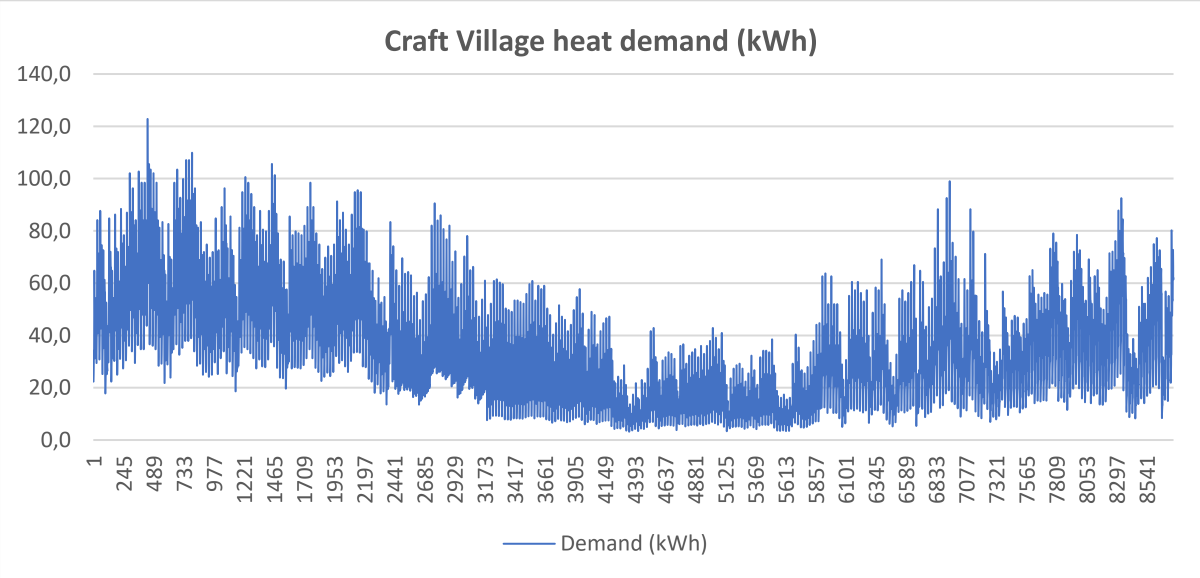



*Figure C. 5. Hourly heat demand for craft village*

## Demand estimation for central Durness

The following table shows the seasonal heat demand for central Durness.

| Season | Start - Season | End - Season | Num. of days | Space Heating (kWh) | Water Heating (kWh) | Total Heating (kWh) |
|---|---|---|---|---|---|---|
| **Winter 1** | 01-Jan | 11-Apr | 101 | 275.569 | 48.456 | 344.461 |
| **Spring** | 12-Apr | 13-May | 32 | 60.574 | 15.352 | 75.717 |
| **Summer** | 14-May | 03-Sept | 113 | 112.902 | 54.213 | 141.127 |
| **Autumn** | 04-Sept | 29-Oct | 56 | 96.210 | 26.867 | 120.262 |
| **Winter 2** | 30-Oct | 31-Dec | 63 | 155.202 | 30.225 | 194.003 |
| **Total** | | | **365** | **700.456** | **175.114** | **875.570** |

*Table C. 7. Seasonal heat demand for central Durness*

The following graph shows the hourly heat demand for central Durness.

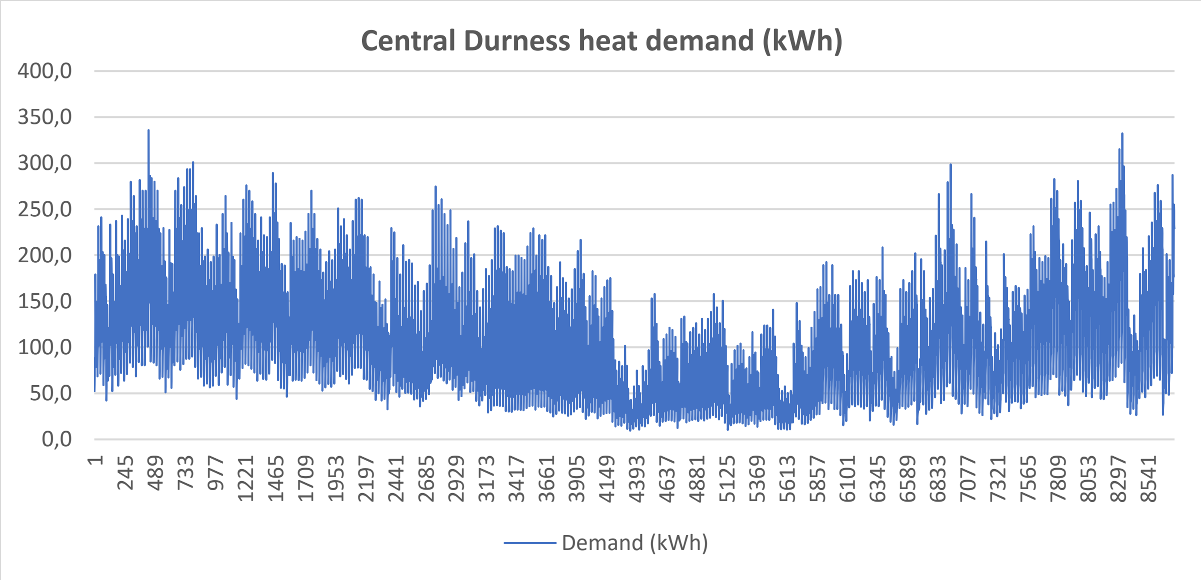
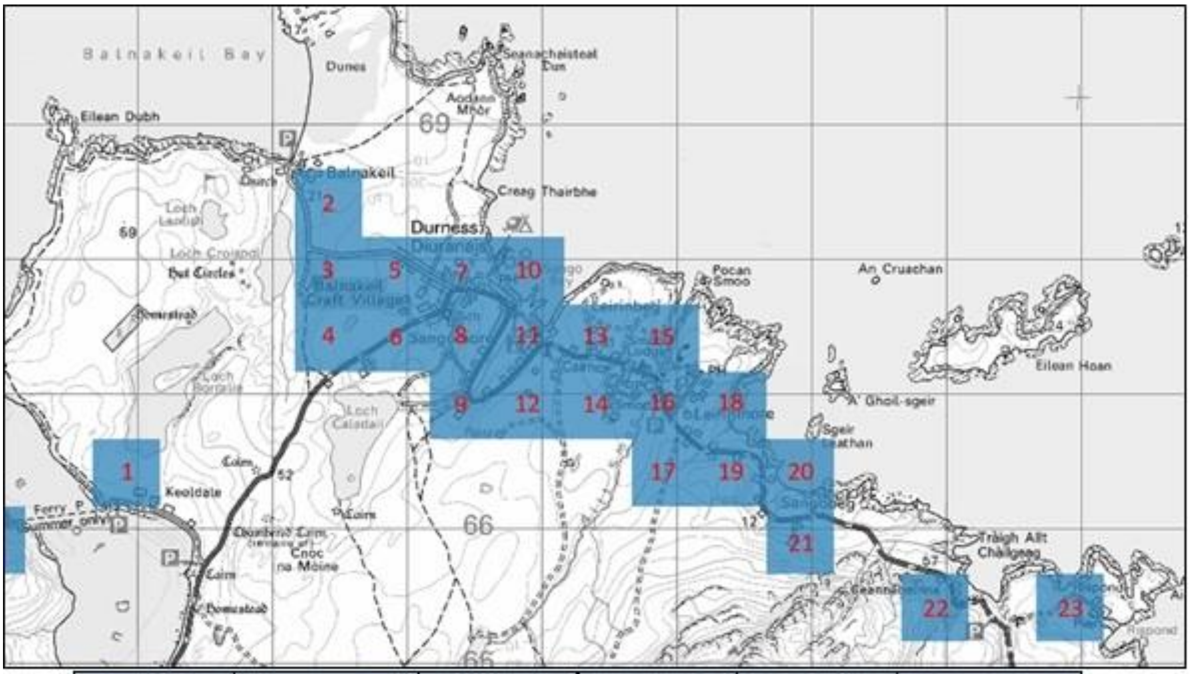



*Figure C. 6. Hourly heat demand for central Durness*

# Appendix D

## Scottish Heat Map of Durness




| Block | kWh/yr | Block | kWh/yr | Block | kWh/yr |
|---|---|---|---|---|---|
| Block 1 | 54.525 | Block 9 | 183.463 | Block 17 | 34.907 |
| Block 2 | 21.544 | Block 10 | 183.876 | Block 18 | 57.080 |
| Block 3 | 695.858 | Block 11 | 220.573 | Block 19 | 76.463 |
| Block 4 | 19.499 | Block 12 | 45.270 | Block 20 | 15.135 |
| Block 5 | 253.006 | Block 13 | 104.096 | Block 21 | 49.633 |
| Block 6 | 74.450 | Block 14 | 198.419 | Block 22 | 53.915 |
| Block 7 | 676.260 | Block 15 | 53.960 | Block 23 | 82.591 |
| Block 8 | 339.307 | Block 16 | 315.991 | **Total** | **3.809.821** |

*Figure D. 1. Scottish heat map of Durness*

## Appendix E

### Sketch plan and energy calculations for microbrewery premises

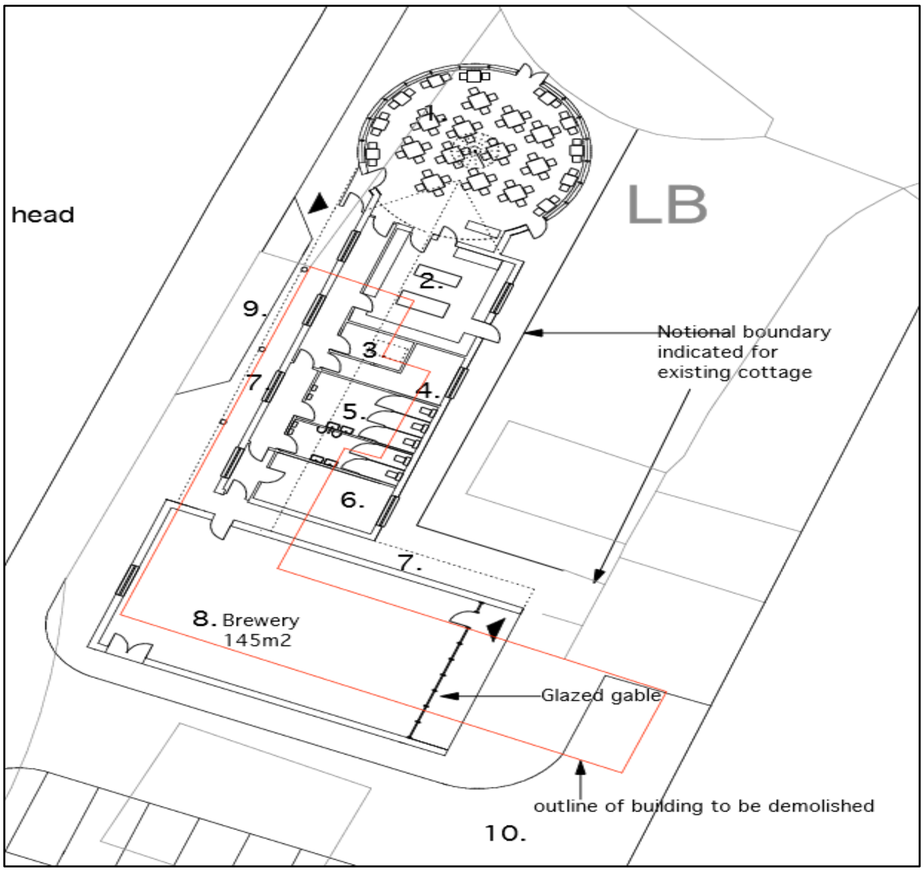



*Figure E. 1. Sketch plan of the bistro/brewery area*

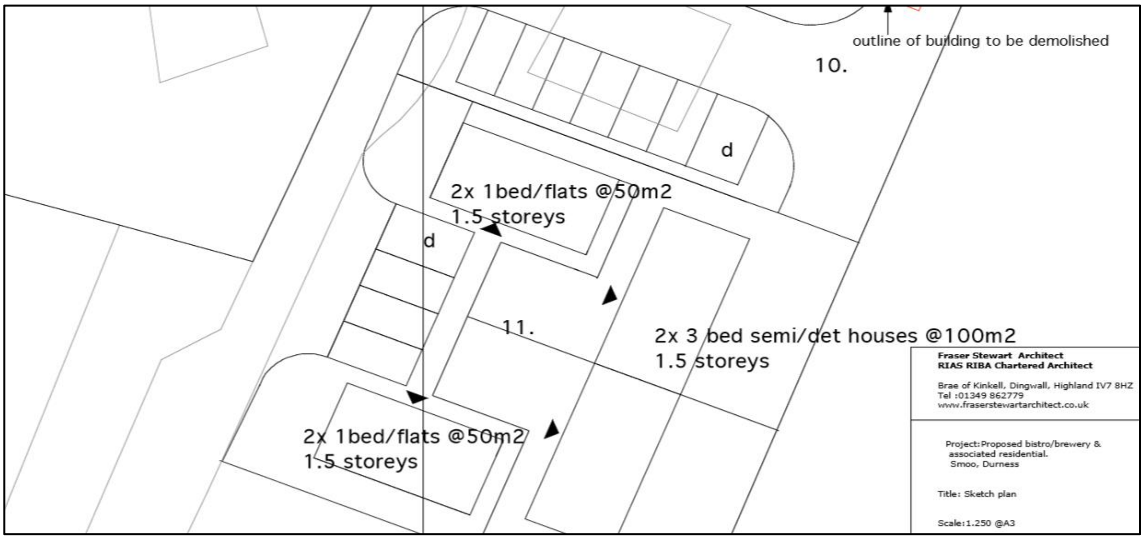



*Figure E. 2. Sketch plan of the residential area*

| Loads | Area/ Process | Voltage (V) | Current (A) | Power Factor | Phase | Intermittent Factor | Power Rating (W) | Annual Energy Consumption (kWh/m2) | Annual Energy Consumption (kWh) |
|---|---|---|---|---|---|---|---|---|---|
| Pumps x 3 @ 400W | Brewing Process | 240 | 6.3 | 0.8 | 1 | 1 | 1200 | - | - |
| 2x3kW elements | Brewing Process | 240 | 31.3 | 0.8 | 1 | 1 | 6000 | - | - |
| one double 3 pin socket (FV room) | Brewing Process | 240 | 13.0 | 0.8 | 1 | 0.2 | 499.20 | - | - |
| Refrigeration units | Brewing Process | 240 | 13.0 | 0.8 | 1 | 1 | 2496 | - | - |
| Automatic controllers for FV | Brewing Process | 240 | 13.0 | 0.8 | 1 | 1 | 2496 | - | - |
| 1x15kW no stat for copper switch | Brewing Process | 415 | 26.1 | 0.8 | 3 | 1 | 15000 | - | - |
| 1x12kW no stat for copper switch | Brewing Process | 415 | 20.9 | 0.8 | 3 | 1 | 12000 | - | - |
| Lighting Loads (area=265m2) | Bistro/brewery (except bistro) | - | - | - | - | - | - | 20 | 5300 |
| Space heating (area=265m2) | Bistro/brewery (except bistro) | - | - | - | - | - | - | 128 | 33920 |
| Auxiliary (area=265m2) | Bistro/brewery (except bistro) | - | - | - | - | - | - | 3 | 795 |
| DHW (area=265m2) | Bistro/brewery (except bistro) | - | - | - | - | - | - | 4 | 1060 |
| Bistro (area=75m2) | Bistro | - | - | - | - | - | - | 730 | 54750 |
| Lighting Loads (area=200m2) | Residential (Semi-detached house) | - | - | - | - | - | - | 4 | 800 |
| Space heating (area=200m2) | Residential (Semi-detached house) | - | - | - | - | - | - | 55 | 11000 |
| Auxiliary (area=200m2) | Residential (Semi-detached house) | - | - | - | - | - | - | 2 | 400 |
| DHW (area=200m2) | Residential (Semi-detached house) | - | - | - | - | - | - | 18 | 3600 |
| Lighting Loads (area=200m2) | Residential (Flats) | - | - | - | - | - | - | 5 | 1000 |
| Space heating (area=200m2) | Residential (Flats) | - | - | - | - | - | - | 35 | 7000 |
| Auxiliary (area=200m2) | Residential (Flats) | - | - | - | - | - | - | 3 | 600 |
| DHW (area=200m2) | Residential (Flats) | - | - | - | - | - | - | 21 | 4200 |

*Table E. 1. Energy load list for microbrewery premises*

| Days | Weekly Energy Consumption (kWh) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **2x3kW elements** | **Pumps x 3 @ 400W** | **one double 3 pin socket (FV room)** | **Refrigeration units** | **Automatic controllers for FV** | **Copper Switch (Heating Load)** | **Total (kWh)** |
| Monday | 60 | 3.6 | 11.981 | 7.49 | 59.90 | 180 | 322.97 |
| Tuesday | 0 | 0 | 11.981 | 0.00 | 59.90 | 0 | 71.88 |
| Wednesday | 0 | 0 | 11.981 | 0.00 | 59.90 | 0 | 71.88 |
| Thursday | 60 | 3.6 | 11.981 | 7.49 | 59.90 | 180 | 322.97 |
| Friday | 0 | 0 | 11.981 | 0.00 | 59.90 | 0 | 71.88 |
| Saturday | 0 | 0 | 11.981 | 0.00 | 59.90 | 0 | 71.88 |
| Sunday | 0 | 0 | 11.981 | 0.00 | 59.90 | 0 | 71.88 |

*Table E. 2. Weekly energy consumption (kWh) for the brewing process*

## Appendix F

Noise and shadow plots of the 3 proposed turbines

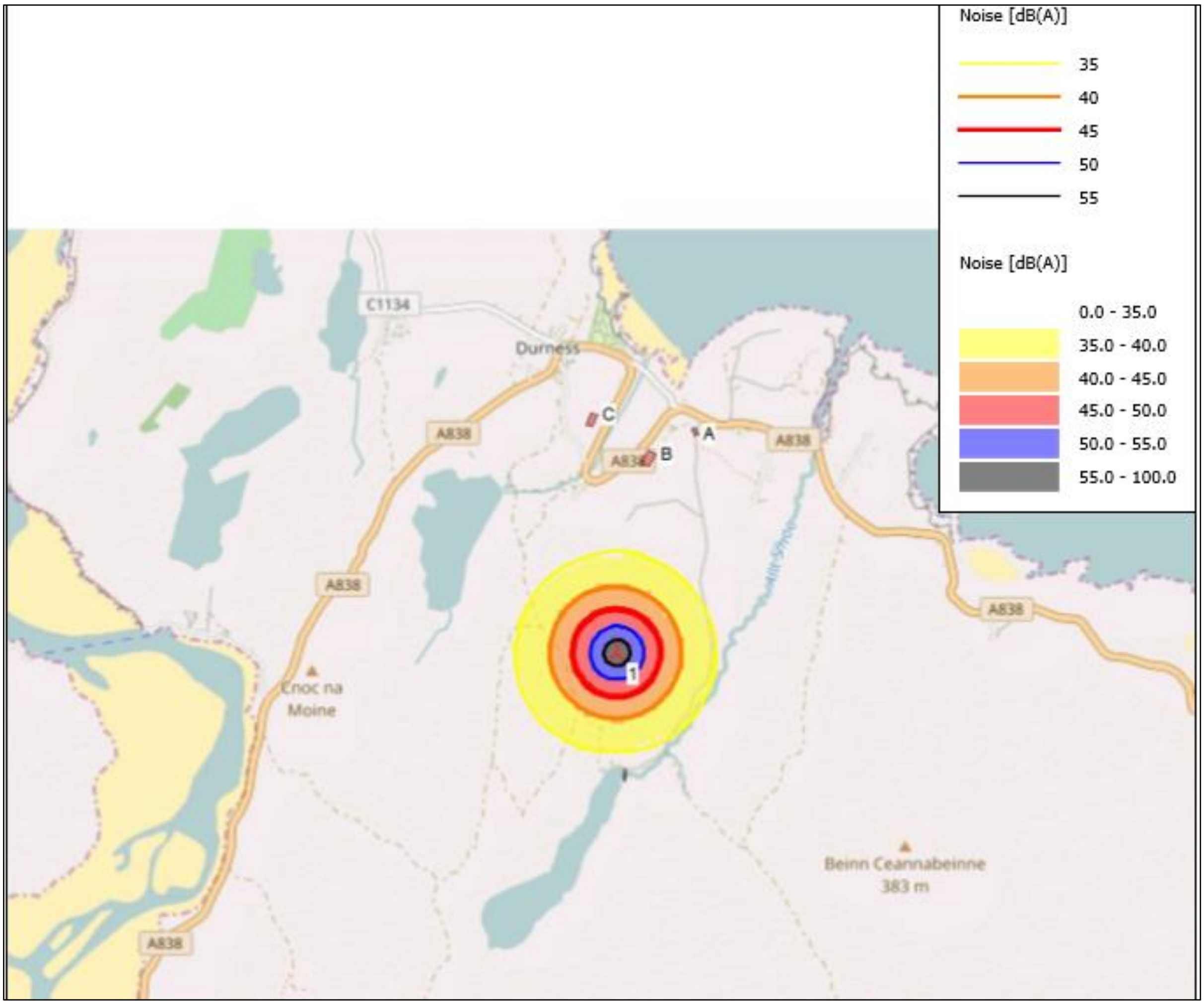



*Figure F. 1. 900kW Noise Map (Generated by WindPRO®3.0)*

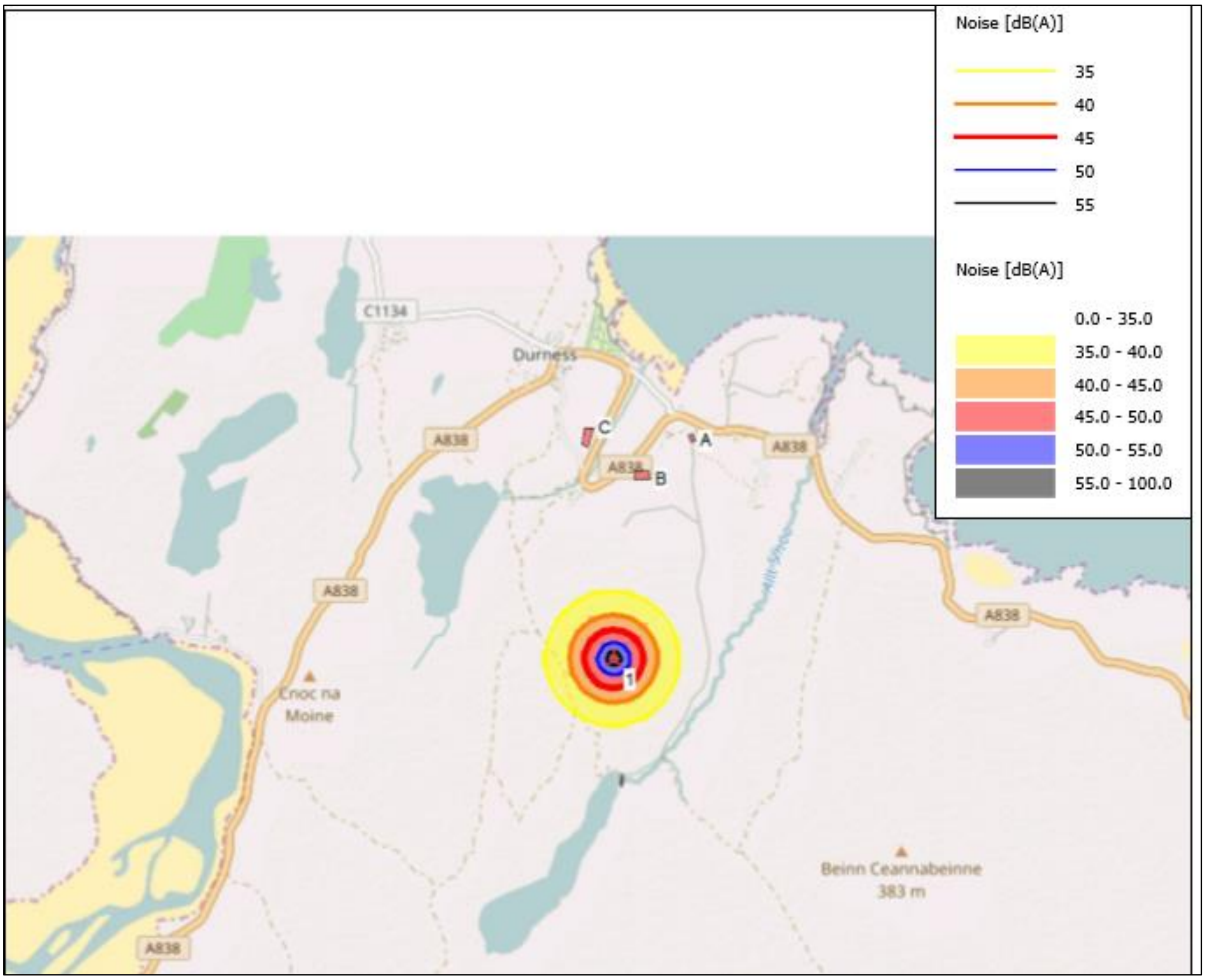



*Figure F. 2. 500kW Noise Map (Generated by WindPRO®3.0)*

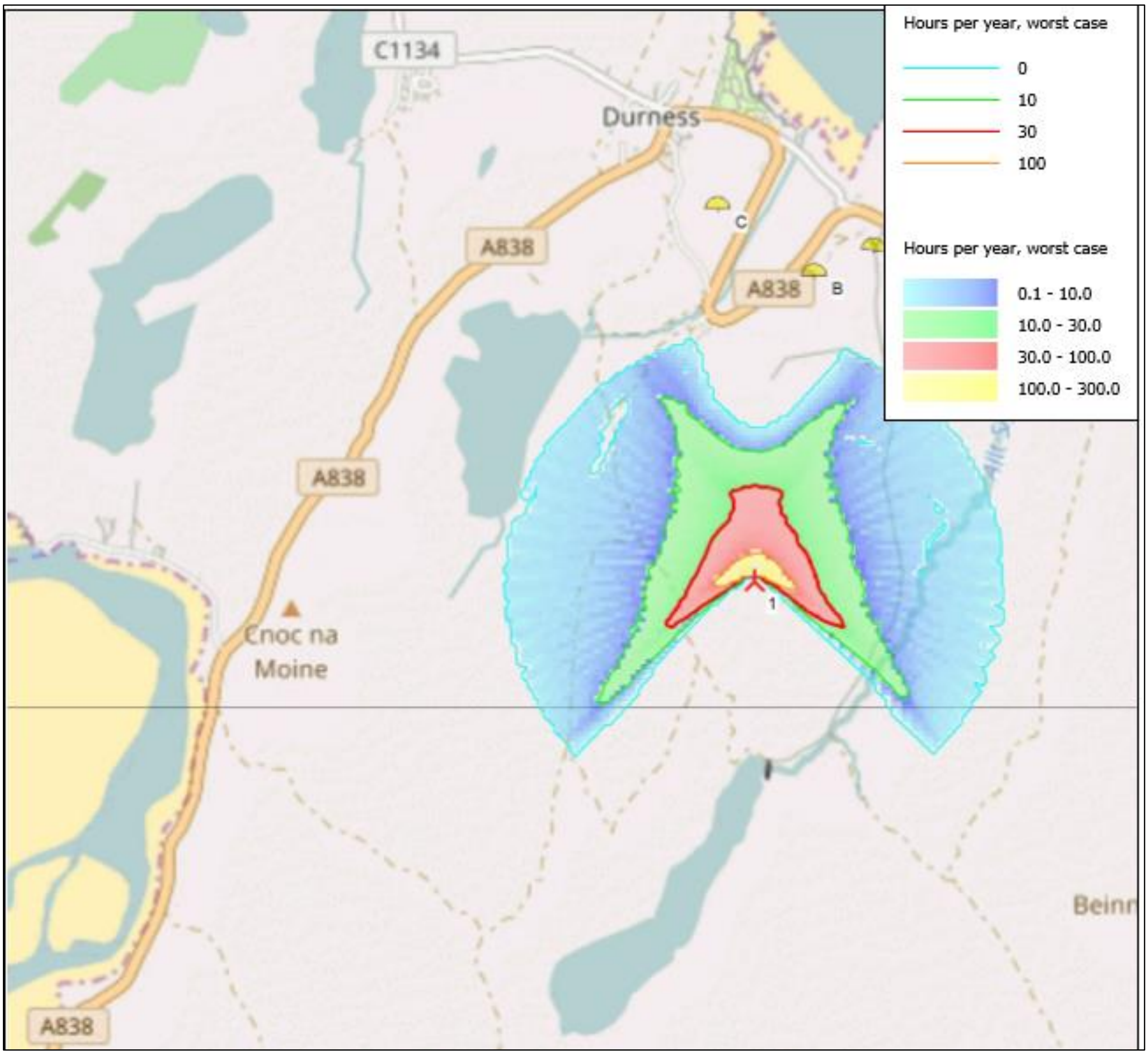



*Figure F. 3. 900kW Shadow Map (Generated by WindPRO®3.0)*

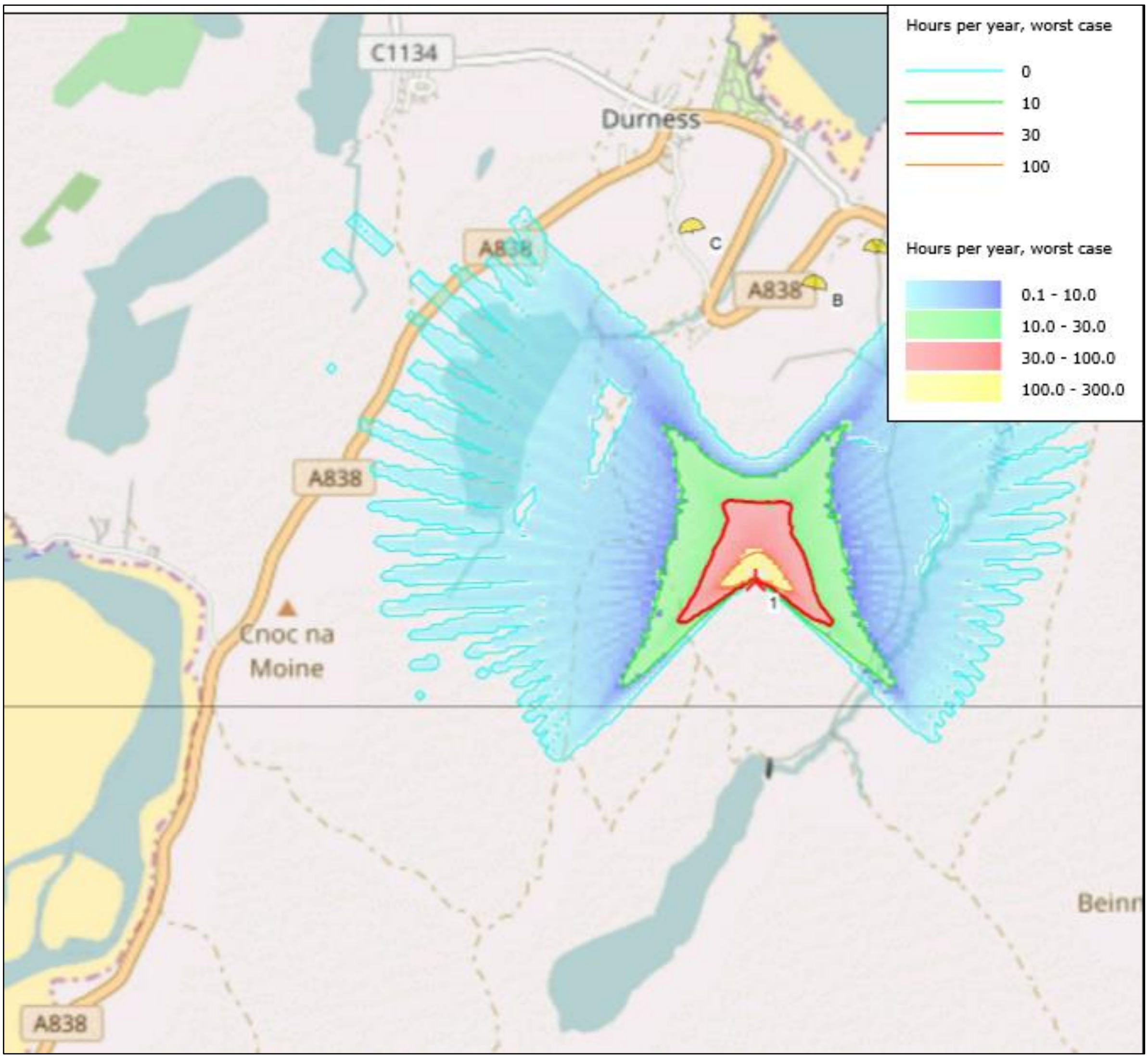



*Figure F. 4. 500kW Turbine Shadow Map (Generated by WindPRO®3.0)*

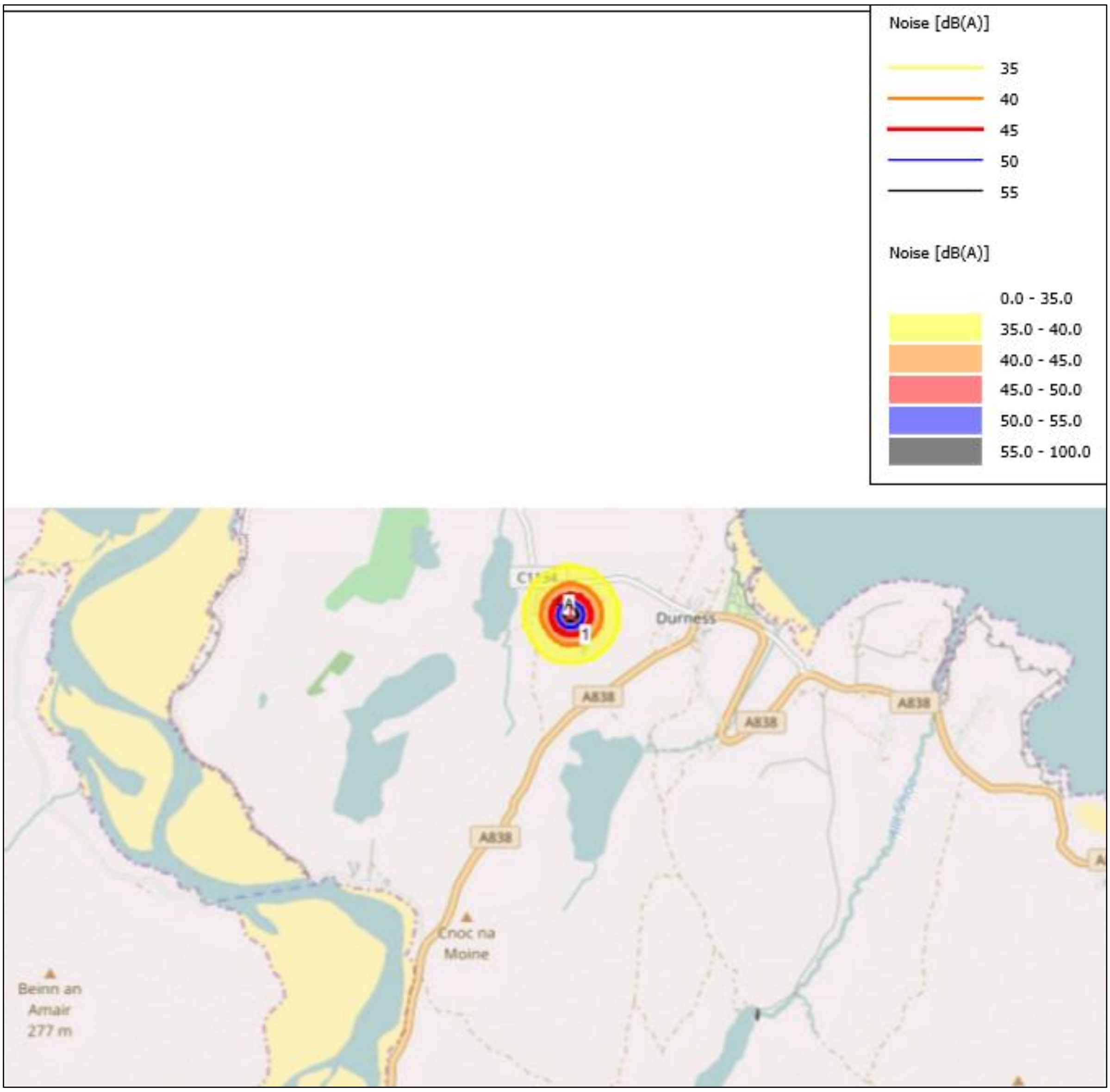



*Figure F. 5. Craft Village Noise Map*

# Appendix G

## Photomontages of possible critical points


*Figure G. 1. Photomontage Point 1: Smoo Cave Hotel*

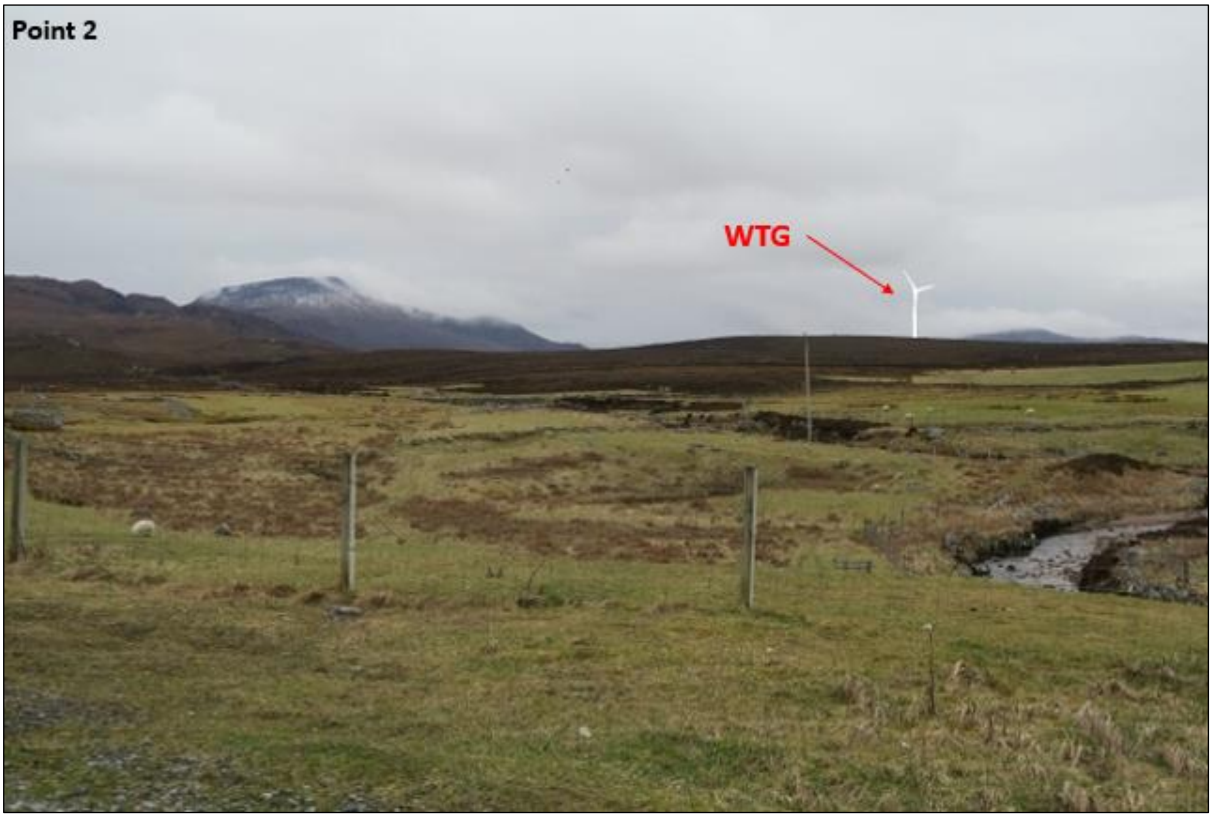



*Figure G. 2. Photomontage Point 2*


*Figure G. 3. Photomontage Point 3: Nearby Caberfeidh Bed and Breakfast*


*Figure G. 4. Photomontage Point 4: Nearby Caberfeidh Bed and Breakfast*


*Figure G. 5. Photomontage Point 5: Durness Village Hall*


*Figure G. 6. Photomontage Point 6*

# Appendix H

## Energy calculations and flow data

| | January | | | | | | |
|---|---|---|---|---|---|---|---|
| Exceeden | Flow | available flow | Usable flow | Net Head | Efficiency | Power o/p(kW) | Energy (kWh) |
| Q1 | 1.485 | 1.445 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q2 | 1.263 | 1.223 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q3 | 1.158 | 1.118 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q4 | 1.018 | 0.978 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q5 | 0.982 | 0.942 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q6 | 0.909 | 0.869 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q7 | 0.850 | 0.810 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q8 | 0.819 | 0.779 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q9 | 0.784 | 0.744 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q10 | 0.765 | 0.725 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q11 | 0.730 | 0.690 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q12 | 0.707 | 0.667 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q13 | 0.689 | 0.649 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q14 | 0.669 | 0.629 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q15 | 0.646 | 0.606 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q16 | 0.622 | 0.582 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q17 | 0.616 | 0.576 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q18 | 0.600 | 0.560 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q19 | 0.577 | 0.537 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q20 | 0.567 | 0.527 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q21 | 0.555 | 0.515 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q22 | 0.534 | 0.494 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q23 | 0.520 | 0.480 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q24 | 0.516 | 0.476 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q25 | 0.504 | 0.464 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q26 | 0.489 | 0.449 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q27 | 0.478 | 0.438 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q28 | 0.464 | 0.424 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q29 | 0.455 | 0.415 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q30 | 0.447 | 0.407 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q31 | 0.436 | 0.396 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q32 | 0.426 | 0.386 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q33 | 0.419 | 0.379 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q34 | 0.408 | 0.368 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q35 | 0.397 | 0.357 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q36 | 0.392 | 0.352 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q37 | 0.383 | 0.343 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q38 | 0.377 | 0.337 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q39 | 0.368 | 0.328 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q40 | 0.359 | 0.319 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q41 | 0.352 | 0.312 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q42 | 0.346 | 0.306 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q43 | 0.342 | 0.302 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q44 | 0.334 | 0.294 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q45 | 0.328 | 0.288 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q46 | 0.321 | 0.281 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q47 | 0.314 | 0.274 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q48 | 0.310 | 0.270 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q49 | 0.304 | 0.264 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q50 | 0.299 | 0.259 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Q51 | 0.292 | 0.252 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q52 | 0.286 | 0.246 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q53 | 0.281 | 0.241 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q54 | 0.273 | 0.233 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q55 | 0.267 | 0.227 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q56 | 0.261 | 0.221 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q57 | 0.255 | 0.215 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q58 | 0.250 | 0.210 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q59 | 0.245 | 0.205 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q60 | 0.239 | 0.199 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q61 | 0.233 | 0.193 | 0.191 | 32.956 | 0.679 | 41.992 | 312.422 |
| Q62 | 0.226 | 0.186 | 0.186 | 32.956 | 0.679 | 40.840 | 303.846 |
| Q63 | 0.222 | 0.182 | 0.182 | 32.956 | 0.679 | 39.961 | 297.312 |
| Q64 | 0.216 | 0.176 | 0.176 | 32.956 | 0.679 | 38.644 | 287.510 |
| Q65 | 0.211 | 0.171 | 0.171 | 32.956 | 0.679 | 37.546 | 279.342 |
| Q66 | 0.205 | 0.165 | 0.165 | 32.956 | 0.679 | 36.229 | 269.541 |
| Q67 | 0.200 | 0.160 | 0.160 | 32.956 | 0.679 | 35.131 | 261.373 |
| Q68 | 0.195 | 0.155 | 0.155 | 32.956 | 0.679 | 34.033 | 253.205 |
| Q69 | 0.190 | 0.150 | 0.150 | 32.956 | 0.679 | 32.935 | 245.037 |
| Q70 | 0.184 | 0.144 | 0.144 | 32.956 | 0.679 | 31.618 | 235.236 |
| Q71 | 0.178 | 0.138 | 0.138 | 32.956 | 0.679 | 30.300 | 225.434 |
| Q72 | 0.173 | 0.133 | 0.133 | 32.956 | 0.679 | 29.202 | 217.266 |
| Q73 | 0.168 | 0.128 | 0.128 | 32.956 | 0.679 | 28.105 | 209.098 |
| Q74 | 0.164 | 0.124 | 0.124 | 32.956 | 0.679 | 27.226 | 202.564 |
| Q75 | 0.159 | 0.119 | 0.119 | 32.956 | 0.679 | 26.129 | 194.396 |
| Q76 | 0.153 | 0.113 | 0.113 | 32.956 | 0.679 | 24.811 | 184.595 |
| Q77 | 0.148 | 0.108 | 0.108 | 32.956 | 0.679 | 23.713 | 176.427 |
| Q78 | 0.141 | 0.101 | 0.101 | 32.956 | 0.679 | 22.176 | 164.992 |
| Q79 | 0.137 | 0.097 | 0.097 | 32.956 | 0.679 | 21.298 | 158.457 |
| Q80 | 0.132 | 0.092 | 0.092 | 32.956 | 0.679 | 20.200 | 150.289 |
| Q81 | 0.126 | 0.086 | 0.086 | 32.956 | 0.679 | 18.883 | 140.488 |
| Q82 | 0.121 | 0.081 | 0.081 | 32.956 | 0.679 | 17.785 | 132.320 |
| Q83 | 0.117 | 0.077 | 0.077 | 32.956 | 0.679 | 16.907 | 125.786 |
| Q84 | 0.114 | 0.074 | 0.074 | 32.956 | 0.679 | 16.248 | 120.885 |
| Q85 | 0.110 | 0.070 | 0.070 | 32.956 | 0.679 | 15.370 | 114.351 |
| Q86 | 0.106 | 0.066 | 0.066 | 32.956 | 0.679 | 14.491 | 107.816 |
| Q87 | 0.102 | 0.062 | 0.062 | 32.956 | 0.679 | 13.613 | 101.282 |
| Q88 | 0.099 | 0.059 | 0.059 | 32.956 | 0.679 | 12.954 | 96.381 |
| Q89 | 0.095 | 0.055 | 0.055 | 32.956 | 0.679 | 12.076 | 89.847 |
| Q90 | 0.092 | 0.052 | 0.052 | 32.956 | 0.679 | 11.418 | 84.946 |
| Q91 | 0.089 | 0.049 | 0.049 | 32.956 | 0.679 | 10.759 | 80.045 |
| Q92 | 0.084 | 0.044 | 0.044 | 32.956 | 0.679 | 9.661 | 71.878 |
| Q93 | 0.082 | 0.042 | 0.042 | 32.956 | 0.679 | 9.222 | 68.610 |
| Q94 | 0.077 | 0.037 | 0.037 | 32.956 | 0.679 | 8.124 | 60.443 |
| Q95 | 0.074 | 0.034 | 0.034 | 32.956 | 0.679 | 7.465 | 55.542 |
| Q96 | 0.070 | 0.030 | 0.030 | 32.956 | 0.679 | 6.587 | 49.007 |
| Q97 | 0.066 | 0.026 | 0.026 | 32.956 | 0.679 | 5.709 | 42.473 |
| Q98 | 0.062 | 0.022 | 0.022 | 32.956 | 0.679 | 4.830 | 35.939 |
| Q99 | 0.058 | 0.018 | 0.018 | 32.956 | 0.679 | 3.952 | 29.404 |

*Table H. 1. Monthly energy calculation for January*

Low-Flow Estimates from LowFlows Enterprise

All flow-values in $m^3/s$

Basin Details

| | |
|---|---|
| Easting | 240614 |
| Northing | 965150 |
| Region | Highland Islands and Grampian Area |
| Area | HA96 - Naver |
| Hydromet | 96 |
| Climb-Typ | DTM |
| Catchmen | 3.801 |
| Runoff(m | 1250 |
| BFI | 0.218826 |
| Total Lake | 0.2176 |
| % Lake Ar | 5.72% |

Flow-Duration Percentiles

Natural (adjusted for lakes)

| | Annl | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.151 | 0.233 | 0.19 | 0.174 | 0.112 | 0.074 | 0.066 | 0.067 | 0.098 | 0.13 | 0.209 | 0.219 | 0.239 |
| Q0.1 | 1.547 | 1.238 | 0.95 | 1.148 | 0.918 | 1.082 | 0.679 | 0.844 | 0.891 | 0.986 | 1.619 | 1.03 | 1.371 |
| Q1 | 0.841 | 0.8 | 0.763 | 0.717 | 0.561 | 0.403 | 0.381 | 0.401 | 0.608 | 0.691 | 0.866 | 0.781 | 0.821 |
| Q2 | 0.655 | 0.704 | 0.647 | 0.617 | 0.433 | 0.326 | 0.312 | 0.322 | 0.45 | 0.528 | 0.732 | 0.636 | 0.747 |
| Q3 | 0.552 | 0.6 | 0.568 | 0.522 | 0.389 | 0.283 | 0.27 | 0.265 | 0.384 | 0.454 | 0.657 | 0.583 | 0.668 |
| Q4 | 0.482 | 0.548 | 0.516 | 0.469 | 0.34 | 0.255 | 0.239 | 0.232 | 0.339 | 0.406 | 0.591 | 0.534 | 0.627 |
| Q5 | 0.426 | 0.51 | 0.489 | 0.416 | 0.311 | 0.234 | 0.217 | 0.215 | 0.307 | 0.368 | 0.541 | 0.499 | 0.576 |
| Q6 | 0.394 | 0.479 | 0.441 | 0.37 | 0.286 | 0.221 | 0.2 | 0.199 | 0.281 | 0.347 | 0.494 | 0.474 | 0.555 |
| Q7 | 0.366 | 0.445 | 0.411 | 0.354 | 0.267 | 0.204 | 0.183 | 0.185 | 0.26 | 0.323 | 0.464 | 0.437 | 0.505 |
| Q8 | 0.344 | 0.425 | 0.386 | 0.336 | 0.249 | 0.191 | 0.174 | 0.172 | 0.244 | 0.301 | 0.422 | 0.419 | 0.484 |
| Q9 | 0.325 | 0.409 | 0.358 | 0.317 | 0.236 | 0.18 | 0.166 | 0.165 | 0.227 | 0.288 | 0.399 | 0.396 | 0.459 |
| Q10 | 0.308 | 0.394 | 0.344 | 0.302 | 0.222 | 0.17 | 0.155 | 0.157 | 0.212 | 0.273 | 0.372 | 0.379 | 0.428 |
| Q11 | 0.294 | 0.377 | 0.328 | 0.292 | 0.212 | 0.162 | 0.145 | 0.149 | 0.203 | 0.258 | 0.36 | 0.365 | 0.414 |
| Q12 | 0.281 | 0.364 | 0.318 | 0.282 | 0.205 | 0.154 | 0.136 | 0.142 | 0.195 | 0.246 | 0.349 | 0.352 | 0.391 |
| Q13 | 0.269 | 0.356 | 0.304 | 0.274 | 0.194 | 0.147 | 0.127 | 0.133 | 0.188 | 0.232 | 0.334 | 0.337 | 0.374 |
| Q14 | 0.258 | 0.346 | 0.295 | 0.262 | 0.189 | 0.138 | 0.121 | 0.127 | 0.18 | 0.226 | 0.319 | 0.329 | 0.362 |
| Q15 | 0.247 | 0.332 | 0.284 | 0.253 | 0.184 | 0.131 | 0.115 | 0.119 | 0.172 | 0.216 | 0.309 | 0.321 | 0.351 |
| Q16 | 0.238 | 0.325 | 0.275 | 0.248 | 0.177 | 0.126 | 0.109 | 0.114 | 0.164 | 0.208 | 0.298 | 0.306 | 0.342 |
| Q17 | 0.229 | 0.314 | 0.264 | 0.243 | 0.168 | 0.119 | 0.104 | 0.107 | 0.159 | 0.198 | 0.291 | 0.297 | 0.331 |
| Q18 | 0.222 | 0.305 | 0.258 | 0.233 | 0.162 | 0.113 | 0.1 | 0.102 | 0.151 | 0.192 | 0.28 | 0.29 | 0.315 |
| Q19 | 0.214 | 0.3 | 0.252 | 0.23 | 0.157 | 0.109 | 0.095 | 0.097 | 0.144 | 0.185 | 0.276 | 0.279 | 0.31 |
| Q20 | 0.208 | 0.294 | 0.243 | 0.223 | 0.152 | 0.103 | 0.091 | 0.094 | 0.136 | 0.179 | 0.269 | 0.274 | 0.299 |
| Q21 | 0.201 | 0.289 | 0.237 | 0.218 | 0.145 | 0.099 | 0.088 | 0.09 | 0.13 | 0.174 | 0.257 | 0.268 | 0.293 |
| Q22 | 0.195 | 0.277 | 0.229 | 0.211 | 0.141 | 0.095 | 0.084 | 0.087 | 0.124 | 0.167 | 0.25 | 0.261 | 0.287 |
| Q23 | 0.189 | 0.271 | 0.225 | 0.208 | 0.137 | 0.09 | 0.08 | 0.084 | 0.118 | 0.163 | 0.241 | 0.254 | 0.278 |
| Q24 | 0.183 | 0.266 | 0.22 | 0.202 | 0.131 | 0.087 | 0.078 | 0.081 | 0.113 | 0.157 | 0.235 | 0.251 | 0.272 |
| Q25 | 0.178 | 0.259 | 0.213 | 0.197 | 0.128 | 0.083 | 0.075 | 0.078 | 0.109 | 0.152 | 0.228 | 0.245 | 0.263 |
| Q26 | 0.174 | 0.252 | 0.21 | 0.193 | 0.123 | 0.08 | 0.073 | 0.076 | 0.106 | 0.146 | 0.223 | 0.24 | 0.256 |
| Q27 | 0.168 | 0.247 | 0.207 | 0.188 | 0.12 | 0.076 | 0.07 | 0.071 | 0.102 | 0.141 | 0.216 | 0.234 | 0.247 |
| Q28 | 0.164 | 0.24 | 0.202 | 0.184 | 0.116 | 0.073 | 0.068 | 0.068 | 0.098 | 0.136 | 0.21 | 0.228 | 0.242 |
| Q29 | 0.159 | 0.237 | 0.196 | 0.18 | 0.112 | 0.071 | 0.065 | 0.066 | 0.095 | 0.131 | 0.206 | 0.225 | 0.238 |
| Q30 | 0.155 | 0.231 | 0.192 | 0.176 | 0.108 | 0.068 | 0.063 | 0.064 | 0.092 | 0.128 | 0.201 | 0.22 | 0.23 |
| Q31 | 0.15 | 0.226 | 0.187 | 0.173 | 0.105 | 0.066 | 0.061 | 0.062 | 0.089 | 0.123 | 0.196 | 0.215 | 0.224 |
| Q32 | 0.144 | 0.221 | 0.182 | 0.17 | 0.103 | 0.064 | 0.059 | 0.06 | 0.085 | 0.12 | 0.191 | 0.211 | 0.219 |
| Q33 | 0.139 | 0.218 | 0.178 | 0.167 | 0.1 | 0.062 | 0.057 | 0.058 | 0.082 | 0.117 | 0.188 | 0.207 | 0.214 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q34 | 0.135 | 0.213 | 0.176 | 0.163 | 0.097 | 0.061 | 0.055 | 0.056 | 0.079 | 0.113 | 0.184 | 0.203 | 0.209 |
| Q35 | 0.13 | 0.209 | 0.171 | 0.16 | 0.094 | 0.059 | 0.054 | 0.054 | 0.077 | 0.11 | 0.181 | 0.198 | 0.204 |
| Q36 | 0.126 | 0.205 | 0.168 | 0.158 | 0.093 | 0.057 | 0.052 | 0.052 | 0.075 | 0.106 | 0.177 | 0.194 | 0.199 |
| Q37 | 0.122 | 0.201 | 0.164 | 0.155 | 0.09 | 0.055 | 0.051 | 0.051 | 0.072 | 0.103 | 0.174 | 0.19 | 0.195 |
| Q38 | 0.119 | 0.197 | 0.161 | 0.151 | 0.087 | 0.055 | 0.049 | 0.049 | 0.07 | 0.098 | 0.169 | 0.186 | 0.19 |
| Q39 | 0.115 | 0.193 | 0.159 | 0.148 | 0.085 | 0.053 | 0.048 | 0.047 | 0.068 | 0.095 | 0.165 | 0.181 | 0.187 |
| Q40 | 0.111 | 0.189 | 0.156 | 0.143 | 0.083 | 0.051 | 0.047 | 0.046 | 0.066 | 0.092 | 0.16 | 0.178 | 0.183 |
| Q41 | 0.107 | 0.186 | 0.15 | 0.14 | 0.081 | 0.05 | 0.046 | 0.045 | 0.064 | 0.089 | 0.156 | 0.175 | 0.178 |
| Q42 | 0.104 | 0.182 | 0.147 | 0.138 | 0.078 | 0.048 | 0.045 | 0.043 | 0.061 | 0.087 | 0.153 | 0.172 | 0.175 |
| Q43 | 0.101 | 0.179 | 0.143 | 0.135 | 0.076 | 0.047 | 0.044 | 0.042 | 0.059 | 0.084 | 0.148 | 0.169 | 0.171 |
| Q44 | 0.098 | 0.176 | 0.139 | 0.132 | 0.074 | 0.046 | 0.043 | 0.041 | 0.058 | 0.082 | 0.143 | 0.165 | 0.166 |
| Q45 | 0.094 | 0.173 | 0.134 | 0.129 | 0.073 | 0.045 | 0.042 | 0.04 | 0.056 | 0.079 | 0.139 | 0.161 | 0.162 |
| Q46 | 0.092 | 0.169 | 0.132 | 0.126 | 0.071 | 0.043 | 0.041 | 0.039 | 0.054 | 0.076 | 0.134 | 0.16 | 0.159 |
| Q47 | 0.089 | 0.167 | 0.127 | 0.123 | 0.07 | 0.042 | 0.04 | 0.038 | 0.053 | 0.074 | 0.132 | 0.156 | 0.154 |
| Q48 | 0.086 | 0.164 | 0.125 | 0.121 | 0.069 | 0.041 | 0.039 | 0.038 | 0.051 | 0.072 | 0.128 | 0.153 | 0.15 |
| Q49 | 0.083 | 0.161 | 0.121 | 0.118 | 0.067 | 0.04 | 0.037 | 0.037 | 0.049 | 0.07 | 0.124 | 0.149 | 0.145 |
| Q50 | 0.08 | 0.158 | 0.117 | 0.115 | 0.065 | 0.039 | 0.037 | 0.036 | 0.048 | 0.067 | 0.122 | 0.144 | 0.141 |
| Q51 | 0.078 | 0.155 | 0.114 | 0.112 | 0.063 | 0.038 | 0.036 | 0.035 | 0.046 | 0.065 | 0.118 | 0.14 | 0.137 |
| Q52 | 0.075 | 0.15 | 0.111 | 0.11 | 0.063 | 0.037 | 0.035 | 0.034 | 0.046 | 0.063 | 0.115 | 0.137 | 0.133 |
| Q53 | 0.073 | 0.146 | 0.107 | 0.107 | 0.061 | 0.037 | 0.034 | 0.033 | 0.044 | 0.062 | 0.111 | 0.134 | 0.13 |
| Q54 | 0.071 | 0.142 | 0.105 | 0.104 | 0.06 | 0.036 | 0.034 | 0.033 | 0.043 | 0.06 | 0.108 | 0.13 | 0.125 |
| Q55 | 0.069 | 0.139 | 0.102 | 0.101 | 0.059 | 0.035 | 0.033 | 0.032 | 0.041 | 0.058 | 0.105 | 0.129 | 0.122 |
| Q56 | 0.067 | 0.135 | 0.099 | 0.098 | 0.057 | 0.035 | 0.032 | 0.031 | 0.04 | 0.057 | 0.102 | 0.125 | 0.119 |
| Q57 | 0.065 | 0.133 | 0.096 | 0.096 | 0.056 | 0.034 | 0.031 | 0.031 | 0.039 | 0.055 | 0.099 | 0.122 | 0.116 |
| Q58 | 0.063 | 0.129 | 0.093 | 0.093 | 0.055 | 0.033 | 0.031 | 0.03 | 0.038 | 0.053 | 0.097 | 0.119 | 0.114 |
| Q59 | 0.061 | 0.126 | 0.091 | 0.092 | 0.055 | 0.032 | 0.03 | 0.029 | 0.036 | 0.051 | 0.093 | 0.116 | 0.111 |
| Q60 | 0.059 | 0.124 | 0.089 | 0.089 | 0.053 | 0.032 | 0.029 | 0.029 | 0.036 | 0.05 | 0.09 | 0.112 | 0.106 |
| Q61 | 0.057 | 0.12 | 0.086 | 0.086 | 0.052 | 0.031 | 0.029 | 0.028 | 0.035 | 0.048 | 0.087 | 0.11 | 0.104 |
| Q62 | 0.056 | 0.117 | 0.083 | 0.083 | 0.051 | 0.031 | 0.028 | 0.027 | 0.034 | 0.047 | 0.085 | 0.107 | 0.101 |
| Q63 | 0.054 | 0.114 | 0.081 | 0.081 | 0.05 | 0.03 | 0.028 | 0.027 | 0.033 | 0.046 | 0.082 | 0.104 | 0.1 |
| Q64 | 0.052 | 0.111 | 0.079 | 0.079 | 0.049 | 0.029 | 0.027 | 0.026 | 0.032 | 0.044 | 0.08 | 0.101 | 0.097 |
| Q65 | 0.051 | 0.108 | 0.077 | 0.077 | 0.048 | 0.029 | 0.027 | 0.025 | 0.031 | 0.043 | 0.077 | 0.099 | 0.093 |
| Q66 | 0.049 | 0.105 | 0.075 | 0.074 | 0.047 | 0.028 | 0.026 | 0.025 | 0.03 | 0.041 | 0.075 | 0.096 | 0.091 |
| Q67 | 0.048 | 0.101 | 0.072 | 0.073 | 0.046 | 0.028 | 0.026 | 0.025 | 0.03 | 0.04 | 0.073 | 0.094 | 0.088 |
| Q68 | 0.046 | 0.098 | 0.07 | 0.071 | 0.045 | 0.027 | 0.025 | 0.024 | 0.029 | 0.039 | 0.071 | 0.092 | 0.086 |
| Q69 | 0.045 | 0.096 | 0.068 | 0.069 | 0.044 | 0.027 | 0.025 | 0.024 | 0.028 | 0.039 | 0.069 | 0.088 | 0.084 |
| Q70 | 0.044 | 0.094 | 0.066 | 0.067 | 0.044 | 0.027 | 0.024 | 0.023 | 0.028 | 0.038 | 0.067 | 0.086 | 0.081 |
| Q71 | 0.042 | 0.091 | 0.064 | 0.066 | 0.043 | 0.026 | 0.024 | 0.023 | 0.027 | 0.036 | 0.065 | 0.083 | 0.079 |
| Q72 | 0.041 | 0.088 | 0.062 | 0.064 | 0.042 | 0.026 | 0.024 | 0.022 | 0.026 | 0.035 | 0.062 | 0.08 | 0.077 |
| Q73 | 0.04 | 0.085 | 0.06 | 0.063 | 0.041 | 0.025 | 0.023 | 0.022 | 0.026 | 0.034 | 0.06 | 0.078 | 0.074 |
| Q74 | 0.039 | 0.082 | 0.058 | 0.061 | 0.04 | 0.025 | 0.023 | 0.022 | 0.025 | 0.033 | 0.058 | 0.076 | 0.073 |
| Q75 | 0.037 | 0.08 | 0.056 | 0.059 | 0.039 | 0.024 | 0.022 | 0.021 | 0.025 | 0.032 | 0.056 | 0.074 | 0.07 |
| Q76 | 0.036 | 0.078 | 0.054 | 0.057 | 0.038 | 0.024 | 0.022 | 0.021 | 0.024 | 0.031 | 0.054 | 0.072 | 0.069 |
| Q77 | 0.035 | 0.075 | 0.053 | 0.055 | 0.037 | 0.024 | 0.022 | 0.02 | 0.023 | 0.03 | 0.052 | 0.069 | 0.067 |
| Q78 | 0.034 | 0.072 | 0.051 | 0.054 | 0.037 | 0.023 | 0.021 | 0.02 | 0.023 | 0.03 | 0.05 | 0.068 | 0.065 |
| Q79 | 0.033 | 0.069 | 0.05 | 0.052 | 0.036 | 0.023 | 0.021 | 0.019 | 0.023 | 0.028 | 0.049 | 0.066 | 0.063 |
| Q80 | 0.032 | 0.067 | 0.049 | 0.051 | 0.035 | 0.023 | 0.021 | 0.019 | 0.022 | 0.027 | 0.047 | 0.065 | 0.061 |
| Q81 | 0.031 | 0.065 | 0.047 | 0.049 | 0.034 | 0.022 | 0.02 | 0.019 | 0.022 | 0.027 | 0.045 | 0.062 | 0.059 |
| Q82 | 0.03 | 0.062 | 0.046 | 0.048 | 0.033 | 0.022 | 0.02 | 0.018 | 0.021 | 0.026 | 0.044 | 0.06 | 0.058 |
| Q83 | 0.029 | 0.06 | 0.044 | 0.046 | 0.032 | 0.021 | 0.02 | 0.018 | 0.021 | 0.025 | 0.042 | 0.059 | 0.057 |
| Q84 | 0.028 | 0.058 | 0.043 | 0.045 | 0.031 | 0.021 | 0.019 | 0.018 | 0.02 | 0.024 | 0.041 | 0.057 | 0.055 |
| Q85 | 0.027 | 0.056 | 0.042 | 0.043 | 0.031 | 0.021 | 0.019 | 0.017 | 0.019 | 0.023 | 0.039 | 0.056 | 0.053 |
| Q86 | 0.026 | 0.053 | 0.041 | 0.042 | 0.03 | 0.02 | 0.019 | 0.017 | 0.019 | 0.023 | 0.037 | 0.054 | 0.051 |
| Q87 | 0.025 | 0.052 | 0.039 | 0.041 | 0.029 | 0.02 | 0.018 | 0.017 | 0.018 | 0.022 | 0.036 | 0.052 | 0.05 |
| Q88 | 0.024 | 0.05 | 0.038 | 0.04 | 0.029 | 0.019 | 0.017 | 0.016 | 0.018 | 0.021 | 0.035 | 0.05 | 0.048 |
| Q89 | 0.023 | 0.049 | 0.037 | 0.039 | 0.028 | 0.019 | 0.017 | 0.016 | 0.018 | 0.021 | 0.033 | 0.048 | 0.047 |
| Q90 | 0.022 | 0.047 | 0.036 | 0.038 | 0.027 | 0.018 | 0.016 | 0.016 | 0.017 | 0.02 | 0.032 | 0.046 | 0.045 |
| Q91 | 0.022 | 0.045 | 0.035 | 0.037 | 0.026 | 0.018 | 0.016 | 0.015 | 0.016 | 0.019 | 0.031 | 0.045 | 0.044 |
| Q92 | 0.021 | 0.044 | 0.034 | 0.035 | 0.025 | 0.017 | 0.015 | 0.015 | 0.016 | 0.018 | 0.03 | 0.043 | 0.042 |
| Q93 | 0.02 | 0.042 | 0.033 | 0.034 | 0.024 | 0.017 | 0.015 | 0.015 | 0.016 | 0.017 | 0.029 | 0.041 | 0.04 |
| Q94 | 0.019 | 0.04 | 0.032 | 0.033 | 0.023 | 0.016 | 0.014 | 0.014 | 0.015 | 0.017 | 0.027 | 0.04 | 0.038 |
| Q95 | 0.018 | 0.038 | 0.03 | 0.032 | 0.023 | 0.016 | 0.014 | 0.014 | 0.014 | 0.016 | 0.026 | 0.037 | 0.036 |
| Q96 | 0.016 | 0.036 | 0.029 | 0.03 | 0.022 | 0.015 | 0.014 | 0.014 | 0.014 | 0.015 | 0.025 | 0.035 | 0.034 |
| Q97 | 0.015 | 0.034 | 0.028 | 0.028 | 0.02 | 0.015 | 0.013 | 0.013 | 0.013 | 0.015 | 0.024 | 0.033 | 0.032 |
| Q98 | 0.014 | 0.032 | 0.026 | 0.026 | 0.019 | 0.014 | 0.013 | 0.013 | 0.013 | 0.014 | 0.022 | 0.03 | 0.028 |
| Q99 | 0.013 | 0.029 | 0.025 | 0.024 | 0.017 | 0.013 | 0.013 | 0.012 | 0.012 | 0.013 | 0.02 | 0.027 | 0.024 |
| Q99.9 | 0.011 | 0.025 | 0.02 | 0.018 | 0.015 | 0.013 | 0.012 | 0.012 | 0.011 | 0.012 | 0.015 | 0.021 | 0.021 |

*Table H. 2. Flow data of Allt Port Charmuil*

All flow-values in m³/s

Basin Details

| | |
|---|---|
| Easting | 240890 |
| Northing | 965305 |
| Region | Highland Islands and Grampian Area |
| Area | HA96 - Naver |
| Hydromet | 96 |
| Climb-Typ | DTM |
| Catchmen | 6.463 |
| Runoff(m | 1244 |
| BFI | 0.201214 |
| Total Lake | 0.2176 |
| % Lake Ar | 3.37% |

Low-Flow Estimates from LowFlows Enterprise

Flow-Duration Percentiles

Natural (adjusted for lakes)

| | Annl | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.255 | 0.429 | 0.347 | 0.294 | 0.19 | 0.138 | 0.102 | 0.112 | 0.184 | 0.19 | 0.316 | 0.35 | 0.409 |
| Q0.1 | 2.642 | 1.852 | 1.69 | 1.965 | 1.527 | 2.117 | 1.059 | 1.447 | 1.628 | 1.574 | 2.343 | 1.763 | 2.764 |
| Q1 | 1.443 | 1.485 | 1.344 | 1.239 | 0.97 | 0.735 | 0.588 | 0.694 | 1.123 | 1.074 | 1.376 | 1.315 | 1.41 |
| Q2 | 1.136 | 1.263 | 1.217 | 1.005 | 0.76 | 0.609 | 0.477 | 0.532 | 0.883 | 0.834 | 1.196 | 1.089 | 1.288 |
| Q3 | 0.966 | 1.158 | 1.106 | 0.874 | 0.677 | 0.526 | 0.412 | 0.457 | 0.75 | 0.721 | 1.045 | 0.993 | 1.177 |
| Q4 | 0.854 | 1.018 | 0.949 | 0.778 | 0.586 | 0.482 | 0.358 | 0.402 | 0.657 | 0.642 | 0.938 | 0.9 | 1.14 |
| Q5 | 0.767 | 0.982 | 0.928 | 0.716 | 0.541 | 0.433 | 0.329 | 0.367 | 0.591 | 0.583 | 0.891 | 0.842 | 1.031 |
| Q6 | 0.708 | 0.909 | 0.858 | 0.673 | 0.496 | 0.398 | 0.302 | 0.338 | 0.543 | 0.536 | 0.812 | 0.798 | 0.959 |
| Q7 | 0.657 | 0.85 | 0.804 | 0.625 | 0.466 | 0.369 | 0.275 | 0.313 | 0.506 | 0.5 | 0.745 | 0.74 | 0.919 |
| Q8 | 0.616 | 0.819 | 0.771 | 0.594 | 0.432 | 0.343 | 0.26 | 0.288 | 0.471 | 0.469 | 0.703 | 0.712 | 0.866 |
| Q9 | 0.579 | 0.784 | 0.698 | 0.564 | 0.405 | 0.325 | 0.247 | 0.274 | 0.438 | 0.439 | 0.661 | 0.681 | 0.826 |
| Q10 | 0.549 | 0.765 | 0.665 | 0.539 | 0.385 | 0.306 | 0.225 | 0.259 | 0.411 | 0.418 | 0.635 | 0.65 | 0.791 |
| Q11 | 0.523 | 0.73 | 0.632 | 0.518 | 0.366 | 0.292 | 0.211 | 0.243 | 0.388 | 0.395 | 0.606 | 0.629 | 0.755 |
| Q12 | 0.499 | 0.707 | 0.612 | 0.502 | 0.351 | 0.273 | 0.199 | 0.231 | 0.371 | 0.378 | 0.572 | 0.603 | 0.725 |
| Q13 | 0.477 | 0.689 | 0.58 | 0.485 | 0.338 | 0.265 | 0.188 | 0.219 | 0.353 | 0.36 | 0.552 | 0.575 | 0.685 |
| Q14 | 0.455 | 0.669 | 0.562 | 0.467 | 0.319 | 0.249 | 0.179 | 0.208 | 0.335 | 0.347 | 0.522 | 0.56 | 0.653 |
| Q15 | 0.437 | 0.646 | 0.545 | 0.452 | 0.31 | 0.236 | 0.172 | 0.194 | 0.318 | 0.333 | 0.508 | 0.55 | 0.639 |
| Q16 | 0.419 | 0.622 | 0.524 | 0.444 | 0.298 | 0.227 | 0.164 | 0.184 | 0.301 | 0.317 | 0.491 | 0.528 | 0.619 |
| Q17 | 0.403 | 0.616 | 0.51 | 0.425 | 0.281 | 0.219 | 0.158 | 0.177 | 0.291 | 0.305 | 0.475 | 0.512 | 0.597 |
| Q18 | 0.388 | 0.6 | 0.494 | 0.416 | 0.271 | 0.208 | 0.153 | 0.166 | 0.279 | 0.295 | 0.453 | 0.493 | 0.569 |
| Q19 | 0.374 | 0.577 | 0.484 | 0.404 | 0.261 | 0.201 | 0.146 | 0.159 | 0.267 | 0.283 | 0.442 | 0.48 | 0.557 |
| Q20 | 0.362 | 0.567 | 0.46 | 0.393 | 0.254 | 0.192 | 0.141 | 0.151 | 0.252 | 0.272 | 0.427 | 0.462 | 0.548 |
| Q21 | 0.35 | 0.555 | 0.449 | 0.384 | 0.244 | 0.182 | 0.137 | 0.145 | 0.241 | 0.266 | 0.415 | 0.45 | 0.53 |
| Q22 | 0.339 | 0.534 | 0.435 | 0.372 | 0.236 | 0.176 | 0.131 | 0.141 | 0.232 | 0.257 | 0.396 | 0.446 | 0.514 |
| Q23 | 0.328 | 0.52 | 0.423 | 0.361 | 0.229 | 0.167 | 0.128 | 0.137 | 0.222 | 0.248 | 0.386 | 0.43 | 0.498 |
| Q24 | 0.317 | 0.516 | 0.413 | 0.351 | 0.22 | 0.16 | 0.124 | 0.133 | 0.213 | 0.237 | 0.375 | 0.422 | 0.487 |
| Q25 | 0.307 | 0.504 | 0.399 | 0.344 | 0.216 | 0.153 | 0.12 | 0.127 | 0.206 | 0.23 | 0.365 | 0.407 | 0.473 |
| Q26 | 0.298 | 0.489 | 0.389 | 0.337 | 0.209 | 0.148 | 0.116 | 0.122 | 0.202 | 0.22 | 0.356 | 0.4 | 0.459 |
| Q27 | 0.289 | 0.478 | 0.38 | 0.327 | 0.203 | 0.142 | 0.111 | 0.118 | 0.194 | 0.214 | 0.345 | 0.391 | 0.441 |
| Q28 | 0.28 | 0.464 | 0.374 | 0.32 | 0.198 | 0.138 | 0.108 | 0.113 | 0.187 | 0.206 | 0.336 | 0.379 | 0.429 |
| Q29 | 0.272 | 0.455 | 0.363 | 0.314 | 0.193 | 0.133 | 0.104 | 0.109 | 0.18 | 0.198 | 0.329 | 0.37 | 0.42 |
| Q30 | 0.264 | 0.447 | 0.357 | 0.307 | 0.187 | 0.128 | 0.101 | 0.106 | 0.173 | 0.192 | 0.322 | 0.362 | 0.409 |
| Q31 | 0.255 | 0.436 | 0.348 | 0.301 | 0.182 | 0.124 | 0.098 | 0.103 | 0.169 | 0.186 | 0.311 | 0.354 | 0.403 |
| Q32 | 0.246 | 0.426 | 0.339 | 0.297 | 0.177 | 0.121 | 0.095 | 0.1 | 0.163 | 0.181 | 0.304 | 0.349 | 0.39 |
| Q33 | 0.238 | 0.419 | 0.33 | 0.29 | 0.173 | 0.117 | 0.092 | 0.096 | 0.157 | 0.174 | 0.296 | 0.34 | 0.381 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q34 | 0.23 | 0.408 | 0.323 | 0.285 | 0.169 | 0.115 | 0.09 | 0.093 | 0.151 | 0.17 | 0.289 | 0.332 | 0.373 |
| Q35 | 0.223 | 0.397 | 0.316 | 0.278 | 0.165 | 0.111 | 0.088 | 0.09 | 0.147 | 0.166 | 0.284 | 0.326 | 0.364 |
| Q36 | 0.216 | 0.392 | 0.309 | 0.276 | 0.162 | 0.108 | 0.085 | 0.087 | 0.143 | 0.161 | 0.278 | 0.319 | 0.355 |
| Q37 | 0.21 | 0.383 | 0.303 | 0.268 | 0.156 | 0.105 | 0.083 | 0.084 | 0.138 | 0.155 | 0.27 | 0.312 | 0.35 |
| Q38 | 0.204 | 0.377 | 0.295 | 0.264 | 0.152 | 0.103 | 0.081 | 0.082 | 0.134 | 0.151 | 0.263 | 0.307 | 0.341 |
| Q39 | 0.198 | 0.368 | 0.288 | 0.256 | 0.149 | 0.1 | 0.079 | 0.08 | 0.13 | 0.144 | 0.253 | 0.299 | 0.331 |
| Q40 | 0.192 | 0.359 | 0.283 | 0.25 | 0.146 | 0.098 | 0.077 | 0.078 | 0.126 | 0.14 | 0.242 | 0.294 | 0.324 |
| Q41 | 0.185 | 0.352 | 0.276 | 0.243 | 0.144 | 0.095 | 0.075 | 0.076 | 0.121 | 0.135 | 0.237 | 0.287 | 0.315 |
| Q42 | 0.18 | 0.346 | 0.269 | 0.238 | 0.139 | 0.093 | 0.074 | 0.074 | 0.117 | 0.131 | 0.23 | 0.282 | 0.308 |
| Q43 | 0.175 | 0.342 | 0.262 | 0.235 | 0.136 | 0.09 | 0.072 | 0.072 | 0.113 | 0.127 | 0.224 | 0.277 | 0.3 |
| Q44 | 0.169 | 0.334 | 0.255 | 0.229 | 0.134 | 0.087 | 0.071 | 0.07 | 0.11 | 0.123 | 0.218 | 0.269 | 0.293 |
| Q45 | 0.164 | 0.328 | 0.245 | 0.224 | 0.13 | 0.085 | 0.069 | 0.068 | 0.106 | 0.119 | 0.212 | 0.264 | 0.286 |
| Q46 | 0.16 | 0.321 | 0.24 | 0.218 | 0.128 | 0.082 | 0.067 | 0.067 | 0.102 | 0.115 | 0.207 | 0.258 | 0.28 |
| Q47 | 0.154 | 0.314 | 0.232 | 0.214 | 0.125 | 0.081 | 0.066 | 0.066 | 0.099 | 0.112 | 0.202 | 0.252 | 0.271 |
| Q48 | 0.15 | 0.31 | 0.226 | 0.209 | 0.123 | 0.079 | 0.064 | 0.064 | 0.096 | 0.108 | 0.196 | 0.247 | 0.266 |
| Q49 | 0.145 | 0.304 | 0.221 | 0.205 | 0.12 | 0.077 | 0.063 | 0.063 | 0.092 | 0.104 | 0.19 | 0.241 | 0.258 |
| Q50 | 0.141 | 0.299 | 0.215 | 0.2 | 0.118 | 0.075 | 0.062 | 0.062 | 0.087 | 0.101 | 0.186 | 0.234 | 0.251 |
| Q51 | 0.137 | 0.292 | 0.21 | 0.197 | 0.116 | 0.073 | 0.061 | 0.06 | 0.085 | 0.097 | 0.181 | 0.228 | 0.246 |
| Q52 | 0.133 | 0.286 | 0.204 | 0.193 | 0.113 | 0.071 | 0.059 | 0.059 | 0.083 | 0.096 | 0.176 | 0.223 | 0.239 |
| Q53 | 0.129 | 0.281 | 0.199 | 0.189 | 0.111 | 0.07 | 0.058 | 0.057 | 0.08 | 0.093 | 0.17 | 0.217 | 0.234 |
| Q54 | 0.125 | 0.273 | 0.197 | 0.183 | 0.109 | 0.069 | 0.057 | 0.056 | 0.078 | 0.09 | 0.167 | 0.213 | 0.227 |
| Q55 | 0.121 | 0.267 | 0.191 | 0.18 | 0.107 | 0.067 | 0.055 | 0.055 | 0.075 | 0.088 | 0.162 | 0.21 | 0.223 |
| Q56 | 0.118 | 0.261 | 0.185 | 0.175 | 0.105 | 0.066 | 0.054 | 0.054 | 0.072 | 0.085 | 0.157 | 0.205 | 0.217 |
| Q57 | 0.115 | 0.255 | 0.179 | 0.171 | 0.104 | 0.065 | 0.053 | 0.053 | 0.07 | 0.083 | 0.154 | 0.201 | 0.212 |
| Q58 | 0.111 | 0.25 | 0.175 | 0.166 | 0.101 | 0.064 | 0.053 | 0.052 | 0.068 | 0.081 | 0.149 | 0.195 | 0.207 |
| Q59 | 0.108 | 0.245 | 0.171 | 0.162 | 0.1 | 0.063 | 0.051 | 0.05 | 0.067 | 0.078 | 0.145 | 0.189 | 0.203 |
| Q60 | 0.105 | 0.239 | 0.168 | 0.158 | 0.098 | 0.062 | 0.05 | 0.049 | 0.065 | 0.076 | 0.14 | 0.185 | 0.196 |
| Q61 | 0.102 | 0.233 | 0.163 | 0.154 | 0.096 | 0.06 | 0.049 | 0.048 | 0.063 | 0.074 | 0.136 | 0.181 | 0.191 |
| Q62 | 0.099 | 0.226 | 0.159 | 0.15 | 0.094 | 0.059 | 0.048 | 0.047 | 0.061 | 0.072 | 0.132 | 0.177 | 0.188 |
| Q63 | 0.096 | 0.222 | 0.155 | 0.147 | 0.092 | 0.058 | 0.047 | 0.046 | 0.059 | 0.07 | 0.129 | 0.174 | 0.183 |
| Q64 | 0.093 | 0.216 | 0.15 | 0.143 | 0.09 | 0.057 | 0.047 | 0.045 | 0.057 | 0.068 | 0.125 | 0.17 | 0.178 |
| Q65 | 0.091 | 0.211 | 0.146 | 0.139 | 0.089 | 0.056 | 0.046 | 0.044 | 0.056 | 0.066 | 0.122 | 0.165 | 0.172 |
| Q66 | 0.088 | 0.205 | 0.142 | 0.135 | 0.087 | 0.055 | 0.045 | 0.044 | 0.055 | 0.064 | 0.119 | 0.161 | 0.168 |
| Q67 | 0.085 | 0.2 | 0.138 | 0.133 | 0.085 | 0.054 | 0.044 | 0.043 | 0.053 | 0.062 | 0.115 | 0.157 | 0.164 |
| Q68 | 0.083 | 0.195 | 0.134 | 0.129 | 0.084 | 0.053 | 0.043 | 0.042 | 0.052 | 0.061 | 0.113 | 0.154 | 0.16 |
| Q69 | 0.081 | 0.19 | 0.13 | 0.126 | 0.082 | 0.052 | 0.043 | 0.042 | 0.051 | 0.06 | 0.109 | 0.149 | 0.156 |
| Q70 | 0.078 | 0.184 | 0.127 | 0.123 | 0.08 | 0.051 | 0.042 | 0.041 | 0.05 | 0.058 | 0.105 | 0.145 | 0.152 |
| Q71 | 0.076 | 0.178 | 0.123 | 0.119 | 0.079 | 0.05 | 0.041 | 0.04 | 0.049 | 0.056 | 0.102 | 0.142 | 0.148 |
| Q72 | 0.074 | 0.173 | 0.12 | 0.116 | 0.077 | 0.05 | 0.041 | 0.039 | 0.048 | 0.055 | 0.098 | 0.139 | 0.144 |
| Q73 | 0.071 | 0.168 | 0.117 | 0.114 | 0.076 | 0.049 | 0.04 | 0.039 | 0.047 | 0.053 | 0.094 | 0.135 | 0.14 |
| Q74 | 0.069 | 0.164 | 0.114 | 0.111 | 0.074 | 0.048 | 0.04 | 0.038 | 0.046 | 0.052 | 0.092 | 0.131 | 0.136 |
| Q75 | 0.067 | 0.159 | 0.11 | 0.107 | 0.072 | 0.047 | 0.039 | 0.037 | 0.044 | 0.051 | 0.089 | 0.129 | 0.132 |
| Q76 | 0.065 | 0.153 | 0.107 | 0.104 | 0.071 | 0.047 | 0.038 | 0.036 | 0.043 | 0.049 | 0.086 | 0.124 | 0.129 |
| Q77 | 0.063 | 0.148 | 0.105 | 0.101 | 0.069 | 0.046 | 0.038 | 0.036 | 0.043 | 0.048 | 0.083 | 0.12 | 0.125 |
| Q78 | 0.061 | 0.141 | 0.102 | 0.099 | 0.068 | 0.045 | 0.037 | 0.035 | 0.042 | 0.046 | 0.081 | 0.118 | 0.122 |
| Q79 | 0.059 | 0.137 | 0.099 | 0.097 | 0.067 | 0.044 | 0.036 | 0.035 | 0.041 | 0.045 | 0.078 | 0.115 | 0.119 |
| Q80 | 0.057 | 0.132 | 0.097 | 0.093 | 0.065 | 0.044 | 0.036 | 0.034 | 0.041 | 0.043 | 0.075 | 0.112 | 0.116 |
| Q81 | 0.055 | 0.126 | 0.093 | 0.091 | 0.064 | 0.043 | 0.035 | 0.033 | 0.04 | 0.042 | 0.073 | 0.108 | 0.112 |
| Q82 | 0.053 | 0.121 | 0.091 | 0.088 | 0.062 | 0.042 | 0.035 | 0.032 | 0.039 | 0.041 | 0.071 | 0.106 | 0.109 |
| Q83 | 0.052 | 0.117 | 0.089 | 0.086 | 0.061 | 0.041 | 0.034 | 0.032 | 0.038 | 0.039 | 0.068 | 0.103 | 0.107 |
| Q84 | 0.05 | 0.114 | 0.087 | 0.084 | 0.059 | 0.041 | 0.033 | 0.031 | 0.037 | 0.038 | 0.066 | 0.1 | 0.103 |
| Q85 | 0.048 | 0.11 | 0.084 | 0.081 | 0.058 | 0.04 | 0.032 | 0.03 | 0.036 | 0.037 | 0.063 | 0.097 | 0.1 |
| Q86 | 0.046 | 0.106 | 0.082 | 0.079 | 0.056 | 0.039 | 0.032 | 0.03 | 0.035 | 0.036 | 0.061 | 0.094 | 0.097 |
| Q87 | 0.044 | 0.102 | 0.08 | 0.077 | 0.055 | 0.038 | 0.031 | 0.029 | 0.034 | 0.034 | 0.058 | 0.091 | 0.094 |
| Q88 | 0.043 | 0.099 | 0.078 | 0.075 | 0.054 | 0.037 | 0.03 | 0.029 | 0.033 | 0.033 | 0.055 | 0.088 | 0.091 |
| Q89 | 0.041 | 0.095 | 0.076 | 0.073 | 0.052 | 0.036 | 0.029 | 0.028 | 0.032 | 0.033 | 0.054 | 0.086 | 0.088 |
| Q90 | 0.04 | 0.092 | 0.074 | 0.071 | 0.051 | 0.035 | 0.028 | 0.028 | 0.031 | 0.031 | 0.051 | 0.082 | 0.086 |
| Q91 | 0.038 | 0.089 | 0.072 | 0.068 | 0.049 | 0.034 | 0.027 | 0.027 | 0.03 | 0.03 | 0.05 | 0.079 | 0.083 |
| Q92 | 0.036 | 0.084 | 0.069 | 0.066 | 0.048 | 0.033 | 0.027 | 0.026 | 0.029 | 0.029 | 0.047 | 0.075 | 0.08 |
| Q93 | 0.035 | 0.082 | 0.067 | 0.064 | 0.046 | 0.032 | 0.026 | 0.026 | 0.028 | 0.028 | 0.045 | 0.073 | 0.076 |
| Q94 | 0.033 | 0.077 | 0.065 | 0.061 | 0.045 | 0.031 | 0.025 | 0.025 | 0.027 | 0.026 | 0.043 | 0.069 | 0.073 |
| Q95 | 0.031 | 0.074 | 0.063 | 0.059 | 0.043 | 0.029 | 0.024 | 0.025 | 0.026 | 0.025 | 0.042 | 0.065 | 0.07 |
| Q96 | 0.029 | 0.07 | 0.06 | 0.057 | 0.04 | 0.028 | 0.023 | 0.024 | 0.025 | 0.025 | 0.039 | 0.06 | 0.065 |
| Q97 | 0.027 | 0.066 | 0.057 | 0.052 | 0.037 | 0.027 | 0.023 | 0.023 | 0.024 | 0.023 | 0.037 | 0.056 | 0.06 |
| Q98 | 0.025 | 0.062 | 0.054 | 0.049 | 0.034 | 0.026 | 0.022 | 0.022 | 0.023 | 0.022 | 0.035 | 0.052 | 0.053 |
| Q99 | 0.022 | 0.058 | 0.05 | 0.044 | 0.031 | 0.024 | 0.021 | 0.022 | 0.022 | 0.021 | 0.03 | 0.046 | 0.044 |
| Q99.9 | 0.02 | 0.048 | 0.04 | 0.033 | 0.027 | 0.022 | 0.02 | 0.021 | 0.021 | 0.02 | 0.024 | 0.038 | 0.037 |

*Table H. 3. Flow data of Allt Smoo*

## Appendix I

Simulation results (800kW wind turbine, 40MWh DH storage and 6.8MWh electric storage)

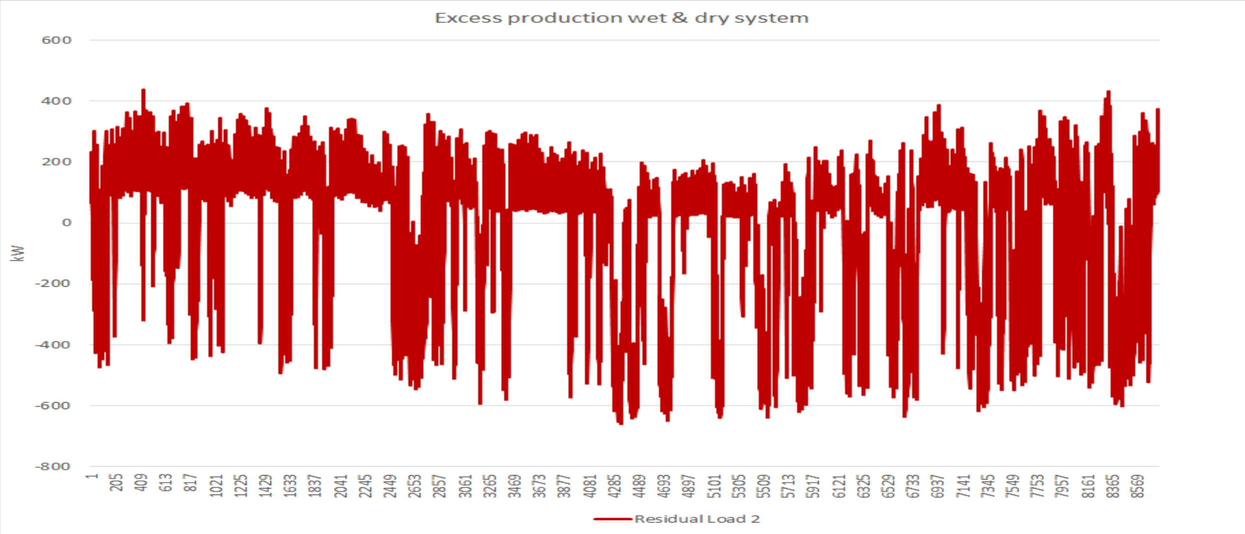



*Figure I. 1. Residual load after electric storage system and direct DH load*

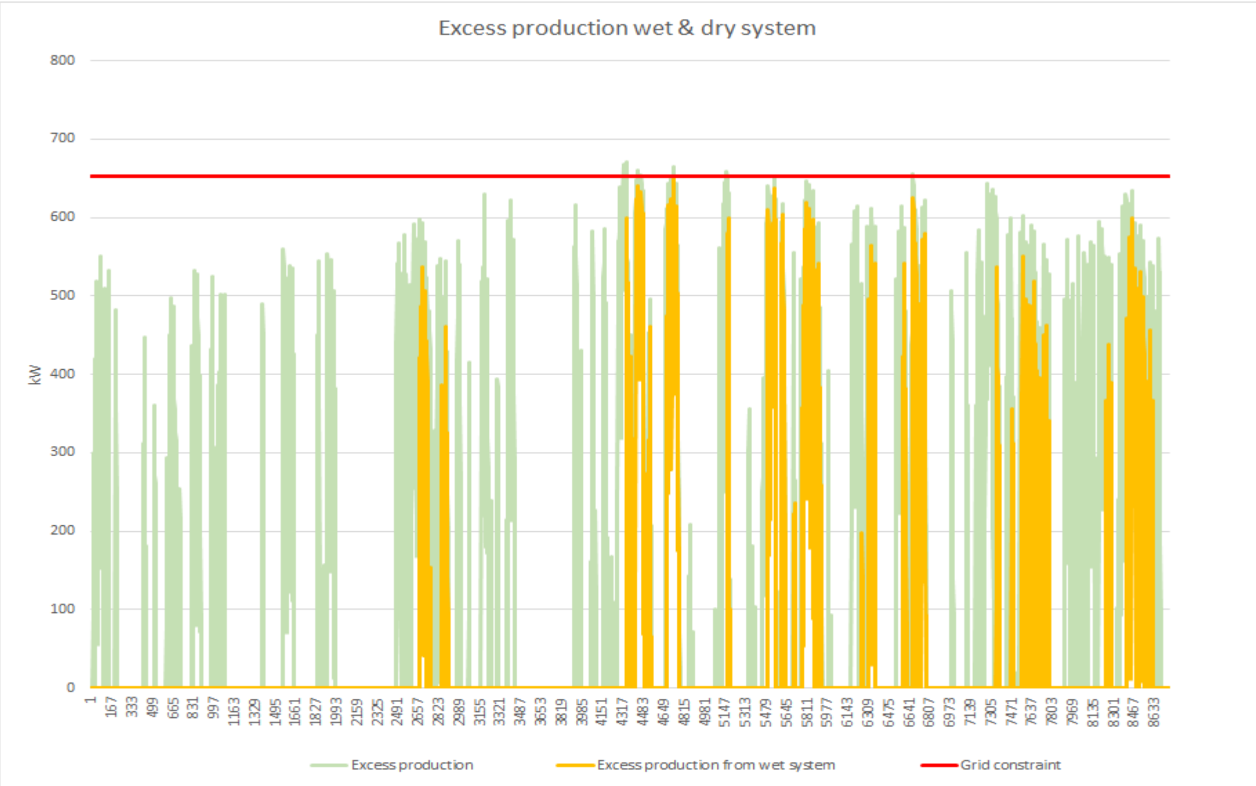



*Figure I. 2. Excess generation into the local grid*

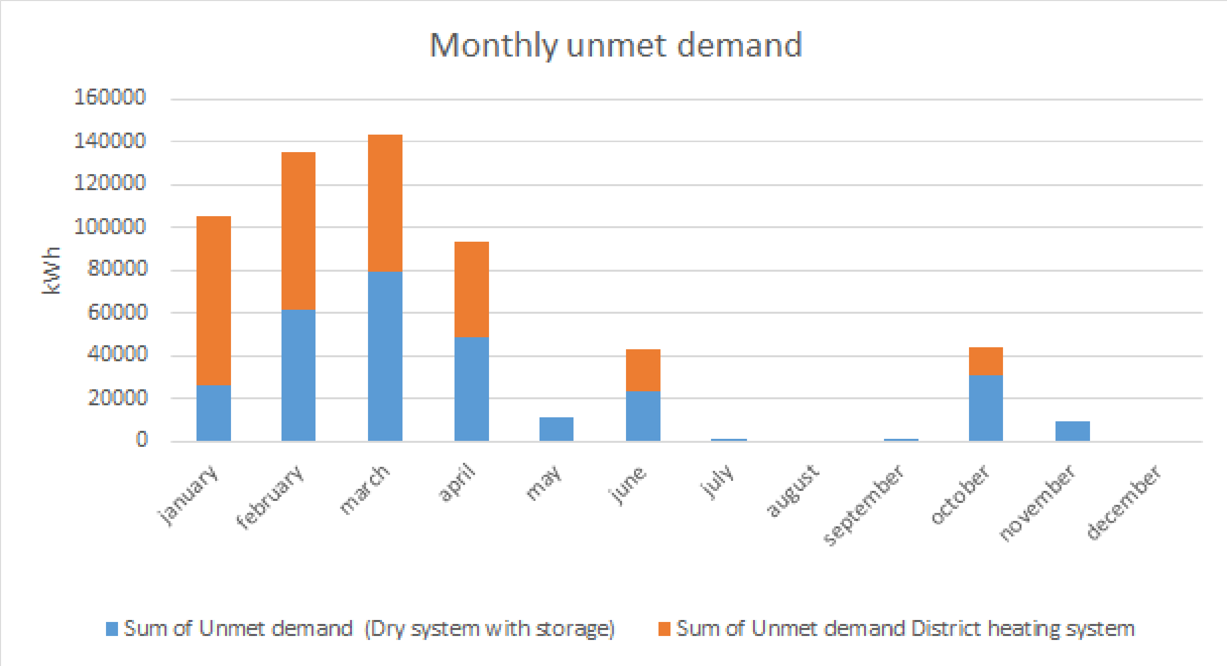



*Figure I. 3. Monthly unmet demand for DH system and electric heating system*

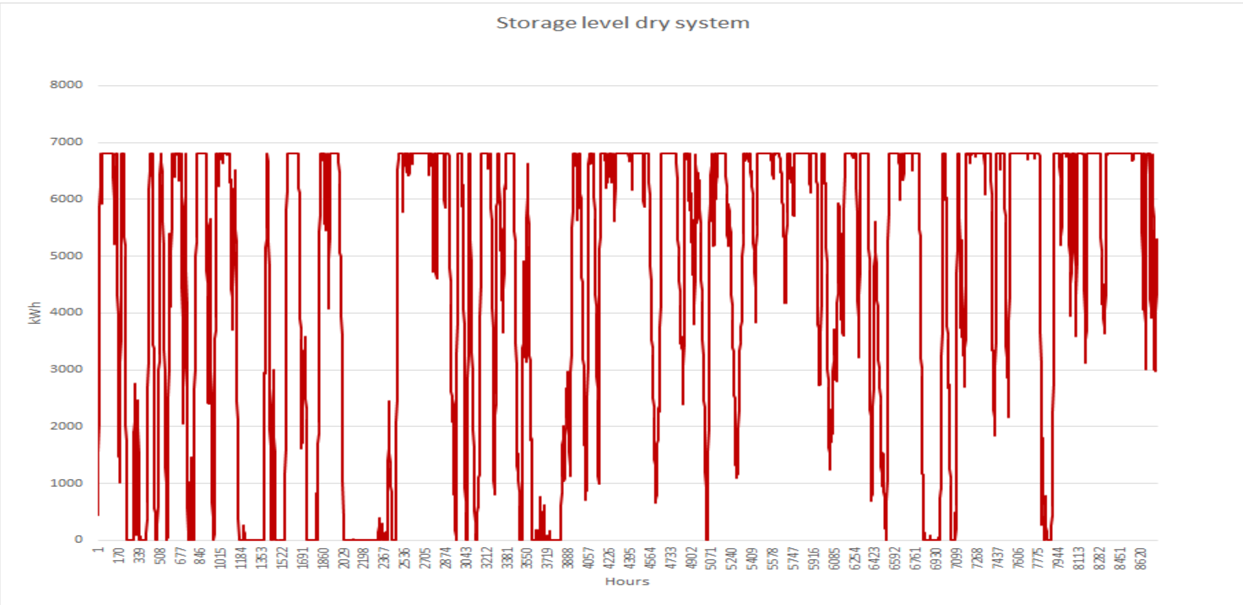



*Figure I. 4. Hourly storage level for the electric storage system*

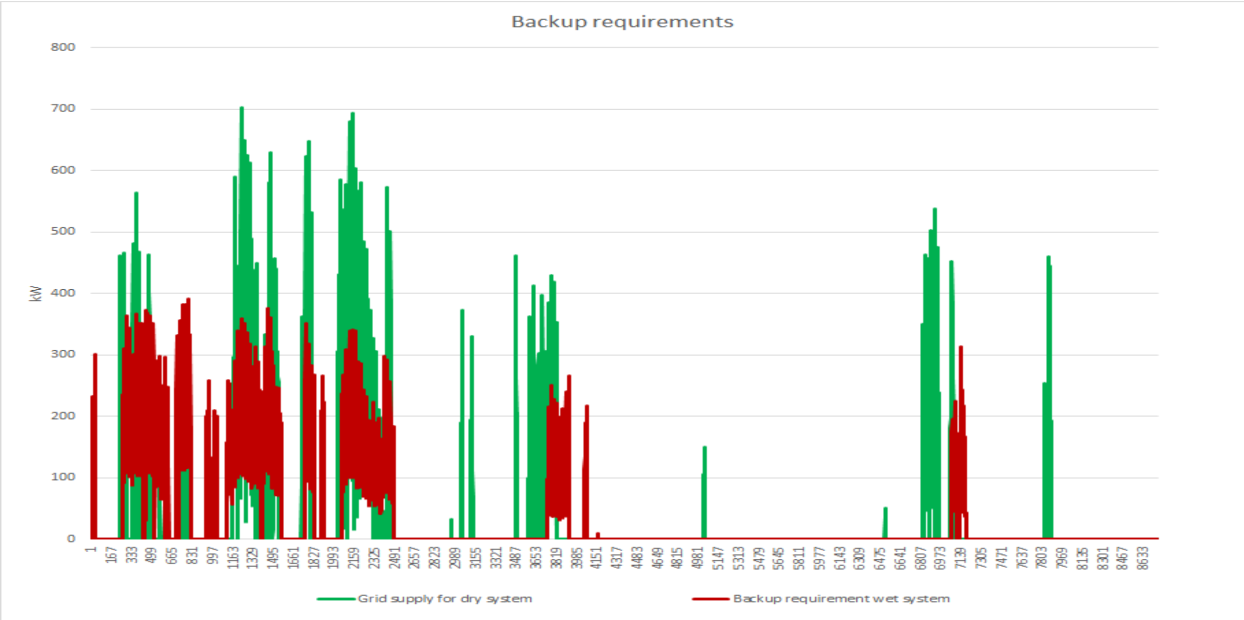



*Figure I. 5. Hourly unmet demand for the DH system and the electric storage system*

# Appendix J

## Results of economic analysis for the various plant capacities at Allt Port Chamuill site

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Hydro 35 kW** | | | | | | | | |
| *Investment costs (£)* | **100,000** | **150,000** | **156,000** | **200,000** | **218,580** | **250,000** | **300,000** | **350,000** |
| *IRR* | 16.4% | 10.5% | 10.0% | 7.0% | 6.0% | 4.6% | 2.6% | 0.9% |
| *NPV (£)* | 116,886 | 69,019 | 63,153 | 19,117 | 27 | - 33,045 | - 89,190 | - 148,259 |
| *ADSCR* | 1.12 | 0.77 | 0.74 | 0.58 | 0.52 | 0.45 | 0.36 | 0.30 |
| *LCOE (p/kWh)* | 7.92 | 10.41 | 10.72 | 13.02 | 14.02 | 15.75 | 18.70 | 21.82 |
| **Hydro 45 kW** | | | | | | | | |
| *Investment costs (£)* | **100,000** | **150,000** | **183,000** | **200,000** | **250,000** | **256,970** | **300,000** | **350,000** |
| *IRR* | 19.2% | 12.7% | 10.0% | 8.9% | 6.3% | 6.0% | 4.4% | 2.7% |
| *NPV (£)* | 154,125 | 106,480 | 74,610 | 57,816 | 7,204 | 3 | - 45,422 | - 101,711 |
| *ADSCR* | 1.31 | 0.89 | 0.75 | 0.69 | 0.54 | 0.52 | 0.44 | 0.37 |
| *LCOE (p/kWh)* | 7.18 | 9.29 | 10.70 | 11.45 | 13.70 | 14.02 | 16.04 | 18.56 |
| **Hydro 60 kW** | | | | | | | | |
| *Investment costs (£)* | **100,000** | **150,000** | **200,000** | **206,000** | **250,000** | **290,000** | **300,000** | **350,000** |
| *IRR* | 21.6% | 14.4% | 10.4% | 10.0% | 7.7% | 6.0% | 5.6% | 4.0% |
| *NPV (£)* | 186,184 | 138,539 | 90,575 | 84,712 | 40,900 | 4 | - 10,399 | - 63,677 |
| *ADSCR* | 1.46 | 1.00 | 0.77 | 0.75 | 0.62 | 0.52 | 0.50 | 0.42 |
| *LCOE (p/kWh)* | 6.70 | 8.57 | 10.45 | 10.68 | 12.41 | 14.02 | 14.43 | 16.53 |
| **Hydro 65 kw** | | | | | | | | |
| *Investment costs (£)* | **100,000** | **150,000** | **200,000** | **219,000** | **250,000** | **300,000** | **306,250** | **350,000** |
| *IRR* | 22.7% | 15.3% | 11.1% | 10.0% | 8.3% | 6.2% | 6.0% | 4.6% |
| *NPV (£)* | 201,967 | 154,322 | 106,539 | 88,038 | 57,290 | 6,476 | 15 | - 46,031 |
| *ADSCR* | 1.54 | 1.05 | 0.81 | 0.74 | 0.66 | 0.54 | 0.52 | 0.45 |
| *LCOE (p/kWh)* | 6.51 | 8.27 | 10.05 | 10.74 | 11.88 | 13.78 | 14.02 | 15.74 |

# Appendix K

## Sensitivity analysis of Loch Meadaidh 800 kW wind turbine

Variations on investment costs:

| NPV (£) | -20% Investment | Base case | +20% Investment |
|---|---|---|---|
| **Export to the grid [BM1]** | 485,043 | 145,056 | - 217,833 |
| **VPW with SSE [BM2]** | 520,314 | 181,202 | - 176,599 |
| **VPW with local sales [BM3]** | - 58,589 | - 599,675 | - 1,144,754 |

Variations on discount rate:

| NPV (£) | Discount rate = 3.5% | Discount rate = 6% | Discount rate = 8% |
|---|---|---|---|
| **Export to the grid [BM1]** | 679,021 | 145,056 | - 174,246 |
| **VPW with SSE [BM2]** | 723,059 | 181,202 | - 142,992 |
| **VPW with local sales [BM3]** | - 62,981 | - 599,675 | - 925,698 |

Variations on inflation rate:

| NPV (£) | Inflation = 0% | Inflation = 2,5% | Inflation = 3.5% |
|---|---|---|---|
| **Export to the grid [BM1]** | - 318,632 | 145,056 | 352,037 |
| **VPW with SSE [BM2]** | - 286,341 | 181,202 | 391,531 |
| **VPW with local sales [BM3]** | - 1,004,390 | - 599,675 | - 403,974 |