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Community energy options under grid constrains – the case of Achiltibuie

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FINAL REPORT

EEM STUDENTS

This report has been prepared by:

Erika Nathalia Gama

Frank Stegmüller

Ganesh There

Gumilang Dewananta

Kamron Nahar Lipi

Livia Miethke Morais

Manoj Pantha

M. Abu Bakar Siddiq

Muhammad Irfan

Olson Abrams

Rojina Sharma

Samuel Girma

Sobia Khalid

Stephen Kanor Kudaya

Under the supervision of:

Prof. Dr. Bernd Möller

Dipl. Ing. Wulf Boie

Dipl. Soz. Dorsi Germann

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1 Introduction and Background of Study

Community scale renewable energy projects have been gaining prominence in recent years as a means of dealing with the developmental issues facing many rural areas. This has also been the case in Scotland and is buoyed by the Scottish government's renewable energy policies and plans which further promote their usage. These initiatives have already been successfully applied in combining the abundantly available renewable energy resources of the regions with the desire of the local people to improve their own living standards and the community as a whole.

The residents of the community of Achiltibuie Scotland, the site of this study, also have a similar vision in mind for the development of their own renewable wind and hydro power generation projects. The area is a part of the Highlands of Scotland and is therefore blessed with the characteristic pristine natural beauty and abundant renewable energy resources of the region.

The report presented on the following pages has been aptly titled "Community renewable energy under grid constraint – the case of Achiltibuie" because it highlights many of the key considerations in developing renewable energy power generation systems particularly in remote regions. It gives clear analyses of the interdependencies of the key project aspects namely; the Ben Mor Hydro Power and Coigach Wind Power Ltd. projects; the alternative options for management of the grid constraints and the potential benefits to be derived by the local community from the development of the projects.

The study was conducted by a team of engineering students from Europa Universität Flensburg Germany in a manner that addressed the many facets of the project. Very clear guidance and assistance was provided every step of the way by the members and partners of the Coigach Community Development Company (CCDC), the local project developers, as well as the community residents.

The overall goal of the study was to apply the appropriate level of technical, economic and social analyses to adequately represent the complex and varied nature of the problem.

The results therefore clearly indicate that the proposed renewable energy projects for development in Achiltibuie have the potential to foster the attainment of the community's development goals.

2 Problem Statement

The community of Achiltibuie and the larger Coigach area has been experiencing a trend of dwindling number of inhabitants and services over the last several years. Identified as the root cause of this negative trend is the remoteness of the Coigach area from major urban centers and the lack of socioeconomic incentives for both locals willing to remain in the area and outsiders willing to relocate to the area. Housing is very expensive in the area due to its location in a scenic area bounded by beautiful mountain ranges and charming Atlantic Ocean coastlines. At present, houses tend to be only affordable for the well-off from elsewhere in the UK who use them as holiday or second homes. The Coigach Community Development Company (CDCC), incorporated in March 2010 to address issues facing the Coigach community, is the local development body (CCDC, 2015). It has as its top priority, the objective "to do something to reverse the trend of the dwindling services and the threat of closure hanging over everything" by:

- providing affordable housing to meet the local demand and keep the population size at least stable
- providing workshop space for local small business
- revitalising the local pier and harbour
- improving facilities for tourists

As is the case in many Scottish communities, income from renewable energy projects such as the 50% CCDC-owned Ben Mor Hydro Ltd, in addition to income from Coigach Wind Power Ltd., a 100% subsidiary of CCDC, is seen as an important source of finance towards achieving the above targets of CCDC and other community development projects. While Ben Mor Hydro Ltd succeeded in securing grid access to the local 11kV distribution line for its planned 420kW mini hydro project, Coigach Wind Power Ltd was unsuccessful in doing the same for its planned 900kW wind power project due to local grid constraints. The local Distribution Network Operator (DNO) has instead offered to connect the proposed wind turbine directly to its 33kV feeder that supplies power to the primary Achiltibuie substation.

The problem with this offer is that the proposed site for the wind turbine is 5km away from the primary substation where the 33kV feeder terminates. To go ahead with this offer, CCDC through Coigach Wind Power Ltd. must therefore construct a 5km 33kV line from the turbine location to the primary substation and bear the full estimated cost of £750,000 for such an undertaking. As this is a huge investment for CCDC, it has expressed its interest in getting support to investigate alternatives.

This report attempts to provide such support and looks into alternatives that include:

- Using an active network management system to optimize the 11kV distribution line to allow both wind and hydro power plants to be connected.
- Downsizing the wind turbine from the current 900kW to an optimal size for active network management of the 11kV line.
- Suggesting additional sources of income in the event that a new 33kV line cannot be avoided with active network management.
- Using excess generated electricity from wind locally through a private supply line.

3 Stakeholder Analysis

The analysis presented in the following section of the report succinctly highlights the projects partners and other entities directly involved in the projects under consideration for the study. The Ben Mor Hydro Ltd. and Coigach Wind Power Ltd. projects present a complex mix of interactions between various regulatory, financial and social organisations. Community initiated renewable energy projects of this nature have established priority in the agenda of the UK government's sustainable development policies. As mentioned in the chapter on the Regulatory Framework, the Scottish Government has specific policies and mandates for Emission Reduction and Renewable Energy Supply Expansion.

The Ben Mor Hydro, 420KW, project has already achieved pre-accreditation and feasibility studies have been conducted in relation to Coigach Wind Power Ltd. project. The stakeholder analysis presented herein is done retrospectively for informational purposes but also to put into perspective the dynamic nature of the projects. The addition of the new grid integration offer and alternative wind and hydro projects has somewhat altered some details of the project.

The main problem facing the community of Coigach is the reduction in the population and subsequent availability of services. The Coigach Community Development Council (CCDC) is working to reverse these trends and foster sustainable development (CCDC, n.d.).

To achieve this, partnerships have been formed, as in the case of the Ben Mor Hydro with Scottish Wildlife Trust. Other such partnerships will become necessary as the work progresses and other ventures become available. The Highland Council and Community Energy Scotland are providing policy guidance as well as advice on technical and financial aspects of the projects.

The International Class of engineering students from the Europa Universität Flensburg, Germany, is working in cooperation with the CCDC and the wider community of Achiltibuie. The aim is to continue from the present status of the RE projects, consolidate the previous work with the relevant data analysis and derive options that are technically and financially feasible solutions to the problems facing the ongoing renewable energy projects.

3.1 Brief Project Description

Wind Power Project: Coigach Wind Power Ltd.: Installation and operation of an Enercon E44 900kW (WTN 500kW/Downrated E-44 500kW or Vestas V27 225kW) wind turbine for grid feed-in and supplying electricity to a district heating system via a private wire.

Alternatively, with the existing grid constraints restricting export of power, the option of a 5km 33kV grid extension is considered, once grid connection at that point has already been granted.

Hydro Power Project: The Ben Mor Hydro Project: Installation of a 420 kW run-of-the-river hydro power plant for generating and exporting power to the existing 11kV grid. Exploring the possibility of two additional 200kW and 60kW hydro power projects connected to the new 33kV grid.

Private Wire and District Heating Network: The construction of an 11kV Private Wire for supplying the proposed Highland Council funded District Heating System.

3.2 Main Entities Involved in the Wind and Hydro Projects

- Coigach Community Development Company – Coigach Wind Power Ltd.

The installation of the E44 900kW wind turbine is being developed by the Coigach Wind Power Limited (CWP Ltd.), a subsidiary of the Coigach Community Development Company. The CWP Ltd. community wind and grid extension projects are being used as a means of earning revenue, which will then be funnelled in community development projects.

- The Scottish Wildlife Trust (SWT)

The Ben Mor Hydro project is being jointly developed on a 50/50 basis by the CCDC and the Scottish Wildlife Trust (SWT). Ben Mor Coigach, with an area of 6000 hectares, is the largest of SWT's 120 Wildlife Reserves (SWT, n.d.) and the project has already achieved pre-accreditation status in December 2014. This makes eligible for commissioning by December 2016 and qualified for a Feed-in Tariff. Revenue generated from sale of electricity to the grid will be reinvested locally in projects to benefit the community (CCDC, 2014).

- Community Energy Scotland (CES) and Local Energy Scotland (LES)

CES, as a technical advisor for community renewable energy projects in Scotland (CES, 2013), are involved in project assessments of this nature. Local Energy Scotland (LES) manage the Scottish Government's Community and Renewable Energy Scheme (CARES) Loans which are used to finance projects for pre-accreditation. Together CES and LES are integral supporting entities.

- Scottish and Southern Energy (SSE)

A major constraint that has stymied the projects' progress is the technical grid limitations. The requirements for grid connection as set out by the District Network Operators (DNO) SSE Power Distribution is a major consideration. To ascertain the exact nature of the 11 kV grid limitation a grid study has been suggested but this requires 2-9 months for completion. For this reason CCDC-CWP Ltd. has consented grid access to the 33kV grid. This solution increases project costs by an estimated £750,000.

SSE is also connected to the projects through SSE Energy Supplier Ltd., the licensed FIT supplier through which the projects will receive the FIT payments applicable for renewable generated electricity.

- Highland Council (HC)

The construction of an 11kV Private Wire for supplying the proposed Highland Council (HC) funded District Heating System has been envisioned as another solution to the grid constraints and also as a means of deriving direct community benefit from sale of electricity from the renewable energy projects. The HC owns presently 15 council houses as well as the Primary School and has indicated interest in the purchasing of community renewable energy through a District Heating Network. For sustainable development in Coigach it is important to foster affordable housing improvement and the sale of excess renewable generated electricity via the private wire is seen as one of the ways of achieving this goal. This project will see the CCDC-CWP Ltd. establishing a local tariff through which excess electricity that cannot be exported to the grid is consumed locally.

- Other important entities and partners

Other important entities that are aligned with the community energy projects are the Funding Agencies which will become more integral as the projects move towards construction. Commercial loans are available for investment in renewable energy projects.

The table below illustrates the linkages of the different technical, funding and policy oriented entities to the two community renewable energy projects. Without their support and cooperation the projects would not have been able to achieve their present level of progress and their continued support increases the likelihood of a successful completion.

Table 3-1: Main entities and their link to the aspects of the Ben Mor Hydro and CWP Ltd. projects

Stakeholders	Funding	Grid connection	Environmental & Scenic Preservation	Technical Project Advice
SSE		X		X
SWT	X		X	X
CES/LES	X			
HC	X			

Figure 3-1: Partners and support entities of the Ben Mor Hydro and Coigach Wind Power Projects

In conclusion, it is clear that the projects under consideration in this study are very dynamic in nature. They involve a variety of different supporting organisations in a multiplicity of capacities performing a diverse set of tasks in order to achieve successful completion. As such, it is difficult to perform the regular stakeholder influence/interest analysis due to the nature of the projects. The main thread that can be seen as common among all the stakeholders is the interest in sustainable community development. This is the ultimate goal of the establishment of the projects and all individual and group efforts are being compounded to this end.

4 Objective, Methodology and Scope of the Study

4.1 Objective

The objective of this study is to assess available options in order to facilitate the decision process on the planned development of wind power and mini hydro projects by CCDC and the Achiltibuie community under current grid integration challenges.

Specifically, the study seeks to:

- Develop an understanding of the current limitations of grid connection, the potential for wind energy and hydro power, as well as the present energy use patterns in the community.
- Assess technical solutions to overcome current grid integration challenges inhibiting the development of wind and hydro power projects in the Achiltibuie community.
- Analyse the financial benefits of different combinations of wind and mini hydro power generation under present grid conditions in the Achiltibuie area in order to empower the community in its decision-making and thereby accelerate the development of the proposed wind and hydro power projects.
- Study the use of energy in the community and assess the feasibility of developing a district heating system that utilizes excess power generated from the proposed wind and hydro power projects.

4.2 Methodology

To achieve the objective of this study, the following methodology was used:

A community-wide household survey was conducted to assess and understand the energy use patterns in the community. This survey involved interviews with occupants of the buildings within the boundary of the study area. For the residences the data collection was facilitated via a questionnaire specifying the different aspects of energy consumption, occupancy and building conditions while for the other building types the data was collected in a more unstructured manner requiring only general information on building usage and energy consumption data when available. A heat demand curve was generated using Microsoft Excel spreadsheet for the simulation of a District Heating System for a selected area of Achiltibuie and the dimensioning of a thermal storage in order to optimize the use of excess renewable electricity. Profiles were generated with the use of tools such as TSol and the Heat Demand Profile Estimator developed by the University of Strathclyde and distributed according to Heating Degree Days specific for the region.

Meetings were held with stakeholders such as CCDC, CES and the Highland Council to ascertain the extent of the grid challenges inhibiting the development of renewable energy projects in the community. Information about the current state of the local Achiltibuie distribution network was obtained from copies of email and telephone correspondence between CCDC, CES and Scottish and Southern Energy (SSE) - the Distribution Network Operator - and from searches carried out on SSE's website. This information was collated and compared to data found in UK and global electrical distribution network literature to establish a clear understanding of the nature of the grid. Based on the information and data received, and assumptions made based on general literature, the local distribution network was simulated under both ideal and constraint conditions for technical analysis. Powerfactory simulation software from DIgSILENT was used for the grid simulations in this study. Current grid conditions were established based on the information mentioned above and the different technical options together with the associated implementation costs were assessed to overcome the grid constraints.

To analyse the individual and combined generation of power from the planned wind and hydro power projects, measured flow and wind data for both the hydro and wind turbine projects along with previous studies carried out with regard to these two projects were obtained from CCDC. In addition, NASA MERRA wind data for the Achiltibuie area was collated with the measured wind data. Observatory working visits to the wind and hydro sites were made by the research team in order that the members could be familiarized with the conditions of the project surroundings. Based on data collected and observations made, power generation curves were simulated for the various hydro and wind turbines. WindPro simulation software was used for simulating and analysing the various wind generation profiles. A Microsoft Excel spreadsheet was used for simulating the hydro power generation profile. The catchment area, head difference and other geographical parameters used in hydro power analysis were obtained using ArcGIS software. A project-specific Microsoft Excel spreadsheet tool was developed by the research team to simulate in hourly intervals, various combinations of power generation from the wind and hydro power plants under different grid conditions of the 11 kV network. These combined generation profiles were used as an input for revenue calculations carried out in the financial assessment of the different development options under the current grid conditions.

The baseline scenario was the installation of a 33 kV interconnector between the planned wind turbine and the Achiltibuie 33 kV feeder.

Based on the combination of certain grid conditions in the 11kV network and simulated combined wind and hydro generation profiles, local load supply options through privately-owned power lines were considered. A feasibility study on a district heating system that will make use of excess electricity was carried out in line with this. Power supply through a private power line to the local Scottish Water treatment facility was also mentioned as a viable way of making use of excess electricity but no detailed study was carried out in this regard.

Using standard financial rate of return values, interest rates and relevant assumptions, a second project-specific Microsoft Excel spreadsheet was developed to calculate the financial benefits, or otherwise, of the various generation combinations under different grid conditions.

4.3 Scope

This study seeks to contribute to ongoing work by the Coigach Community Development Company (CCDC) to overcome grid constraints to its planned wind and hydro power projects in order to maximize returns from these projects for CCDC and the community. The report therefore assesses different options to circumvent the current grid constraints in order to facilitate decision making by CCDC and accelerate the development of the proposed wind and hydro power projects.

5 Regulatory Framework

5.1 Climate Change and Renewable Energy Policy

Climate change has been considered as the greatest environmental problem facing the world nowadays. As a response to the climate change, the Scottish Government has set certain targets and a work plan needed in order to reduce the Green House Gas (GHG) emissions and to promote renewable energy utilization across the country. Those targets are written through the Scottish Climate Change Program and 'the 2020 Routemap for Renewable Energy in Scotland' within the context of the EU Renewable Energy Directive, the Energy Act 2008 and 2010, and the Renewables Obligation Orders (ROO) (Climate Change Committe , 2014).

5.1.1 The Climate Change (Scotland) Act

The Climate Change (Scotland) Act creates the legal framework for GHG reductions in Scotland and represents the instated national legislation with regards to the GHG emission reduction targets of the EU. Scotland obligated itself to the following targets (The Scottish Government, 2012):

- An interim 42% reduction target of GHG emissions by 2020 and
- A reduction target of 80% of GHG emissions by 2050.

Following the EU Climate Change Directive strategy, Scotland's emission targets are measured after clearing within the EU Emission Trading System (ETS), which covers the power sector and energy-intensive industries (Climate Change Committe , 2014).

5.1.2 Renewable Energy (RE) Policy- 2020 Routemap for Renewable Energy in Scotland

The Scottish Government has published the national renewable energy policy under the '2020 Routemap for Renewable Energy in Scotland'. The 2020 Routemap for Renewable Energy in Scotland is an update and an extension working plan to the Scottish Renewable Action Plan 2009. The paper has eager, sectoral implications and encompasses the following national targets (APS Group Scotland, 2011):

- 100% electricity demand (equivalent) from RE,
- 11% heat demand from renewable sources,
- 30% (at least) overall energy demand from RE, and
- 500 MW community and locally owned RE.

5.2 The Scottish National Planning

The Scottish Government has implemented the planning system that can be used to foster future development. The Scottish Planning Policy (SPP), as part of the Scottish Government's Planning Policy is a statement of the Scottish Government's policy on the land use, a section of which is to provide the policy statement for the development of renewable energy (The Scottish Government, 2010).

The development plan that has been adopted by the Coigach Community is basically based on the development plan released by the Highland Council. On 5th April 2012, the Highland Council adopted the Highland Wide Local Development Plan 2012 and Wester Ross Local Plan 2006 (Atmos Consulting, July 2013). When both development plans include specific policy for a certain form of development such as a wind turbine and hydro scheme, the starting point in the consideration of applications for that type of development should be with that policy.

5.2.1 Scottish Planning Policy (SPP)

Published in February 2010, SPP highlights the main concern of the country to reduce the GHG emissions in the certain paragraph (The Scottish Government, 2010):

- Paragraph 182: The commitment of the Scottish Government to increase the percentage of renewable energy in their national energy mix. Renewable energy can make a contribution to more secure and diverse energy supplies and support sustainable economic growth.
- Paragraph 183: The opportunities of communities and small business to invest and to own the renewable energy projects, which have local benefit for them. The planning authorities have an obligation to support "*the development of a diverse range of renewable energy technologies, guide development to appropriate locations and provide clarity on the issues that will be taken into account when specific proposals are assessed"* (The Scottish Government, 2010).
- Paragraph 187: The development of wind turbines in the locations where wind turbine technology can operate effectively and efficiently should be supported by planning authorities. The site selection of wind turbine should be considered carefully to ensure the environmental and visual impact can be minimized.
- Paragraph 137: The proposed renewable energy project in the Coigach Community is located in the Assynt-Coigach National Scenic Area, which is known as the area that is nationally important for scenic quality. Development that affects a National Scenic Area

(NSA), a Site Special Scientific Interest (SSSI) should only be permitted where (The Scottish Government, 2010):

- *It will not adversely affect the integrity of the area or the qualities for which it has been designated, or*
- *Any such adverse effects are clearly outweighed by social, environmental or economic benefits of national importance.*

5.2.2 Highland Wide Local Development 2012

According to a statement in the Highland Wide Local Development Plan Policy 68 Community Renewable Energy Development, the commercial renewable energy proposals will be assessed by Council through several tests of acceptability for a community project (The Highland Council, 2012).

In March 2010, Coigach Community Development Company (CCDC) conducted a wide ballot assessing the potential of wind development project, and asked: "*As a member of the Coigach Community on the Electoral Roll, do you support the progression of 900kW (or less) wind turbine at Achavraie, with the aim of generating funds for community benefit?*" (Atmos Consulting, July 2013)

The 184 returned ballot papers were counted by the Highland Council and found that 68% of respondents voted "yes". The result allowed the CCDC to progress with the community wind turbine project (Atmos Consulting, July 2013). It is also supported by the commitment of Highland Council, which will take the proposed renewable energy project as a material consideration if a community wishes to develop a small renewable energy project solely as a community venture, or takes a share in a larger renewable energy project in order to earn significantly benefit for local community (The Highland Council, 2012).

5.3 Council's Renewable Energy Strategies

As mentioned in the paragraph 184 of the Scottish Government policy statement (SPP), the Scottish Government gives a mandate to the planning authority to support all scales of development associated with the generation of energy and heat from renewable energy (The Scottish Government, 2010). It therefore gives the Council a special role to set up the policy frameworks, which has the main purposes of supporting the government's target to reduce carbon emission and to develop the local potential of renewable energy sources under the jurisdiction of Council area.

The Orkney Island Council is one community in Scotland that has successfully developed the renewable energy system on the Orkney Islands. Through their Sustainable Energy Strategy, the Council had visions which were not just for the Council, but for the whole community (Orkney Island Council, 2009):

1. To ensure Orkney uses energy as efficiently as possible and has a secure and affordable energy supply to meet its future needs.
2. To add value to Orkney's renewable energy resources, for the benefit of the local economy and local communities, whilst minimizing damage to the environment.
3. To reduce Orkney's carbon footprint.

Similarly, the Highland Council has set up the target, as their renewable energy obligation, to reduce its carbon emission by 3% annually under the Carbon Management Plan 2013-20. The plan focused in the sector of *Energy use Council Houses, fleet, business travel, street lighting, internal waste, and water* (The Highland Council, 2013).

Another concern that the Highland Council wants to address is the promotion of affordable warmth and reduction of local fuel poverty through the Council's Affordable Warmth Action Plan. There are three actions plan under the Council's Affordable Warmth Action plan: *maximise the coverage and uptake of energy efficiency works in privately owned and privately rented housing, maximise energy efficiency works in Council and Housing Association stock, and advice, assistance and income maximization* (the Director of Community Services, 2014).

The Ministers of Scottish Government launched the Renewable Heat Incentive (RHI) in 2011 to provide incentives for the usage of renewable sources to produce heat, and it is administered by the Office of Gas and Electricity Markets, Ofgem. The scheme is targeted to provide financial support to those home owners, which are off the gas grid and also is available for those communities who installed approved technology for heating, such as biomass, water heat pump, solar thermal panel, and air to air heat pump since 15th July 2009 (Green Scotland, 2014).

The external insulation of the Council Houses in the Coigach Community, which was one of the action plan that has been done by Highland Council, had a purpose to reduce the consumption of household energy for heating. The Highland Council also considers District Heating for their future plan to provide affordable heating to residents of Council Owned Houses.

5.4 Applicable Financial Incentives for Wind and Hydro Projects

5.4.1 The Feed in Tariff

Scotland has abundant renewable energy resources, particularly wind and hydro, and the government has the ambition of becoming a world leader in the field of renewable energy (Audit Scotland, 2013). In this regard it has introduced several schemes geared at incentivising community renewable energy. The projects proposed for implementation in Achiltibuie Scotland, with Total Installed Capacity (TIC) below 5MW, meet the criteria for receiving Feed-in Tariffs (FIT).

According to the regulations regarding FIT eligibility, certain types of equipment have been specifically excluded. Ownergy plc has set up a subsidiary called Feed-in Tariffs Ltd. with the sole purpose of disseminating information relevant to the FIT. One of its publications related to FITs in the UK stated that all refurbished and second-hand equipment (unless imported to the UK, see below) along with equipment eligible for support under the larger-scaled Renewable Obligations incentive are excluded from the FIT scheme (Feed-in Tariffs Ltd., n.d.).

This is relevant for the CCDC Renewable Energy project studies since one of the options under consideration, the refurbished Vestas V27 turbine, could potentially face issues of eligibility. This is due to the fact that the FITs are established on the basis of new equipment costs. The Department of Energy & Climate Change (DECC) has however previously stated ”We will keep this issue under review and consider whether or not there are merits to allowing renovated or refurbished technologies to receive FITs support in the future, bearing in mind the different costs and the fact that equipment may have received other financial support through its life” (REA, 2011). This bodes well for such investments and the CCDC may be able to proceed in this venture given this updated information.

Through the FIT scheme the Coigach Wind Power Ltd. and the Ben Mor Hydro Projects become eligible to receive payments for renewable energy for up to 20 years. These rates are payable by registered FIT licensed suppliers such as SSE Energy Supplier Ltd (ofgem, 2015) and are in the form of Generation and Export tariffs. The tariff rates are based on the period of eligibility and relevant price adjustments. Adjustments are performed annually, at the beginning of April, and coincide with changes in the Retail Price Index (RPI), this is done to reflect the impact of annual inflation on the FIT rates (DECC, 2012). The financial analysis of this study has, for the purposes of simplification, fixed the RPI at 2% per annum.

In the UK the period between preliminary accreditation and commissioning varies for different renewable energy technologies and types of projects (Feed-In Tariffs Ltd., n.d.). The table below shows the project types and the associated periods relevant for the community renewable energy in Achiltibuie.

Table 5-1: Allowable period between pre-accreditation and commissioning for various RE projects

Type of Projects	Allowable Period
Hydro	2 years
Wind	1 year

The Ben Mor Hydro project has received accreditation since December 2014 which makes it eligible for commissioning in December 2016. In order to receive the best FIT rates it is expedient that the remaining wind and hydro projects apply for accreditation soon after the completion of the grid study by the SSE. In this way the projects receive the rates applicable for the period from 1st April 2015 to 31st March 2016, this has been assumed in the financial calculations. They will then have the allowable periods, shown in the table above, in which to move towards commissioning.

An analysis of the FIT has been done since it is the main revenue generation mechanism for the projects under consideration in Achiltibuie. As stated above the Generation and Export Tariffs are adjusted based on the relevant rate of RE technology deployment and this is important in relation to the eligibility period. The adjustment invariably results in a lowering of the available FIT and any delay in applying for accreditation of the RE project can result in relegation to a later eligibility period and a lower FIT rate. Adjustments are also made yearly for inflation by using the Retail Price Index. This has the effect of increasing the FIT rate annually by an amount which represents the impact of inflation.

The Table 5-2 below, adopted from ofgem, illustrates the variation in tariffs received for different capacities of wind and hydro turbine technologies based on the eligibility dates (ofgem, 2015). Contingent degression, degression that is adjusted in time and percentage based on actual RE technology deployment rates, results in reduced price per unit of energy (Feed-In Tariffs Ltd., n.d.). These factors all reveal the need for urgency in obtaining accreditation and commissioning of the wind and hydro projects in order to optimize revenues.

Table 5-2: Relevant Feed-in Tariff Table for Wind and Hydro Projects in Achiltibuie

Technology	Tariff bands	Project Technology & Eligibility Status		Generation Tariff		Export Tariff
				Eligibility date 1	Eligibility date 2	Eligibility date
				1 Oct 2014 to 31 Mar 2015	1 Apr 2015 to Mar 16 2016	On or after Dec. 2012
Wind turbine	100kW < WTC ≤ 500kW	Downrated E44 (500kW)	Eligibility date 2	13.55 p/kWh	12.05 p/kWh	4.85 p/kWh
		V 29	Eligibility date 2			
	500 kW < WTC ≤ 1500kW	E 44	Eligibility date 2	7.36 p/kWh	6.54 p/kWh	
Hydro Turbine	15kW < HTC ≤ 100kW	60 KW	Eligibility date 2	18.03 p/kWh	16.03 p/kWh	
	100kW < HTC ≤ 500kW	200 KW	Eligibility date 2	14.25 p/kWh	12.67 p/kWh	
		420 KW	Eligibility date 1			
WTC - Wind Turbine Capacity				HTC - Hydro Turbine Capacity		

Source: (ofgem, 2015)

5.4.2 Local Tariff

Having secured FIT rates for the renewable energy generated by the community wind and hydro projects, the issue of optimizing revenues under the conditions of the grid constraints is now considered. Curtailment of the output of the wind turbine results in loss of revenue from the export tariff for sale of electricity to the grid. It is however necessary under the present technical grid constraints. This curtailment can however be limited by using the excess electricity in a district heating system, the supply of which is proposed via the 11kV private wire. This option presents the opportunity for the wind project to generate increased revenue through the establishment of a local tariff for electricity to be used in a district heating system. Electricity for meeting the heat demand is to be supplied at a rate that covers the investment in the private wire while also being comparable to rate for existing heating fuels as an incentive for promoting the investment in the District Heating System. This is further clarified in the chapter on the District Heating System as a part of the 11 kV Scenario.

According to the Scotland Consumer Council a significant number of households, particularly in rural areas such as Achilitbuie, do not have access to mains gas for heating. Another problem highlighted is the efficiency of home insulation which has a direct bearing on the requirement for heating. For the households without mains gas a variety of alternative heating fuels are utilized. It is the case in Achiltibuie as revealed from the conduction of the community survey that many homes have multiple heating systems ranging from central heating to wood-fired stoves. A Consumer Focus report (Baker, 2011) comparing the price of domestic heating in Scotland using various fuel types illustrates that there are significant differences in the associated costs. The local tariff must be comparable with prices paid for these alternative fuels. As it is seen as a community benefit venture plans should be implemented to supply energy as affordably as possible in a manner. This will enable local residents to have the opportunity of obtaining the benefits of the Renewable Heat Incentive (RHI) scheme.

Analysis of the local tariff will be conducted on the basis of excess energy generation form the renewable energy projects, the local heat demand, requirement for storage heating and configuration of the 11 kV private wire. This, taking into consideration current heating costs and the loss of earnings due to the grid limitations, aims to derive a local tariff that optimizes benefit for both supply and demand aspects.

6 Energy Demand of the Community

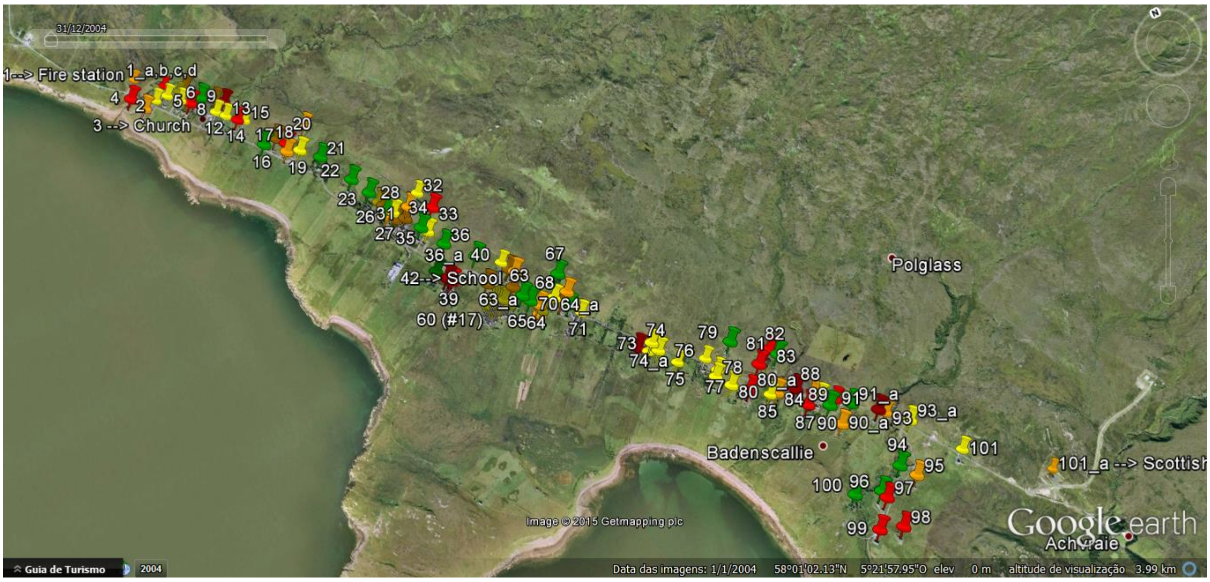
As part of the general objective of the study, the assessment of the local energy demand, particularly for heating, is necessary in order to evaluate the possibility of local supply of electricity from the renewable energy projects under development within the community. The aim is to model the existing demand profiles in the community so as to obtain a better understanding of the current patterns of energy use and possibilities of future demands.

The first step in assessing the energy demand of the community was to identify the geographical area covered by the present study along with the buildings and their uses. In the community being studied, Achiltibuie Coigach, the fire station along the road is considered as the northern extreme of the occupied area and the Scottish Water building, approximately 4km to the south, is the opposite extreme. All buildings subjected to the study were numbered and classified according to their predominant use (Residence, Second Home, Holiday House, Not occupied, Shed/Garage or other buildings) as shown in the Table and Figure below.

Table 6-1: Building Identification in Achiltibuie

Building		Amount of Buildings	Identification
Residences		48	Yellow
Second Home		20	Red
Holiday Houses		24	Green
Other Buildings	Unoccupied	6	Orange
	Shed/Garage	7	
	Fire Station	1	
	Church	1	
	Shop, Gas station	1	
	Post Office	1	
	Hotel	1	
	Bagpipe School	1	
	School	1	
	Community Hall	1	

Figure 6-1: Area Study and Building identification



Source: GoogleEarth

In order to obtain information regarding the energy use in the community, in terms of types of fuel and conversion technology, a survey was designed with an associated questionnaire to facilitate data collection from the residents. The field survey was conducted on February 20th, 2015 by all the students, working in pairs. Additional information regarding the survey is provided in the Annex D-1.

From the total of 48 houses identified as residences, 26 questionnaires were completed, this represents 54.17% of the community's residences. Additionally two questionnaires from houses located outside the boundary of the area of study were also completed. Information regarding second homes and holiday houses were obtained during a field visit with Alison Sinclair. For the collection of data on the other building types, site visits and interviews were conducted directly at those buildings.

6.1 Electricity Consumption in Achiltibuie

For the analysis of local electricity demand for the current study, the electricity demand can be subdivided in the types of uses of the several buildings within the community (as described in the Table 6-1above – residences and others), as well as its geographical location. To facilitate analysis of the electricity demand as a component of the study, demand has been categorised according to building usage and geographic location. For this purpose Achiltibuie can be divided into four sections:

- Section 1: comprising buildings located from the fire station up to the Summer Island Hotel (approx.. 1.2km extension along the road),
- Section 2: from the hotel (inclusive) up to the community hall (approx.. 0.5km extension along the road);
- Section 3: the community hall, primary school, schoolhouse building and Island View village (approx.. 0.1km extension along the road);
- Section 4: comprising the buildings from the Community Hall to the Scottish Water building (approx. 2.0km extension along the road).

Both wind and hydro projects are located to the west of the Scottish Water building (respectively 0.3km and 2.5km approximately).

Based on the data from the field survey, the distribution of residences, second homes and holiday houses along with the number of occupants and seasonality of the buildings' usage within each section is presented in the Table 6-2 below.

Table 6-2: Distribution of buildings and occupants in Achiltibuie

	RESIDENCES		SECOND HOMES		HOLIDAY HOMES		
Occupancy	**Occupied throught the year**		**Occupied from 4 to 15 weeks/year**		**Typically occupied 30 weeks/year**		
	# Buildings	**Occupants**	**# Buildings**	**Occupants**	**# Buildings**	**Occupants**	**Total Buildings**
Section 1	11	18	7	20	8	15	26
Section 2	3	7	4	9	3	16	10
Section 3	19	36	0	0	0	0	19
Section 4	15	34	9	23	11	31	25
TOTAL	**48**	**95**	**20**	**52**	**22**	**62**	

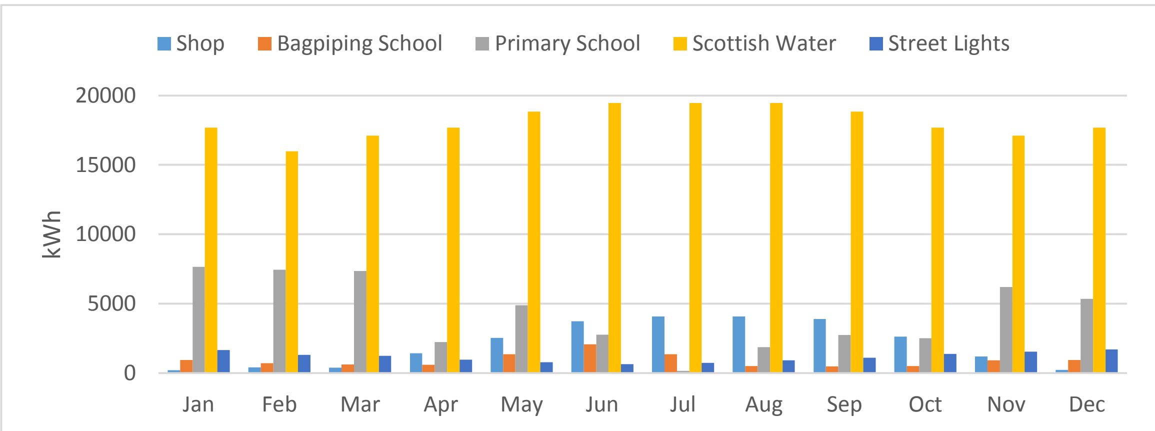
Almost 50 % of the buildings in Achiltibuie are second homes and holiday houses, which are occupied only some weeks of the year. The consequence of it is that seasonality plays an important role in the community's energy consumption and makes modelling the energy demand profile complex and uncertain.

The generation profiles of the proposed wind and hydro projects reveal an intermittency of supply which renders it ineffective as a means of efficiently meeting the local electricity demand, especially given its seasonal nature. However, information regarding individual energy consumers has been collected during the period of our stay in Achiltibuie, including yearly consumptions and usage patterns, as presented in the Table 6-3 below. The load profiles of the Shop, the bagpiping School, the Primary School, Scottish Water Building and the street lights can be seen in Figure 6-2 presented below (please refer to Annex D-2) for further description, details and assumptions regarding the load profiles). There is as yet no data regarding electricity consumption of the Summer Island Hotel and the Community Hall and therefore no review concerning the energy usage of these buildings in the report.

Table 6-3: Major electricity consumers within Achiltibuie

	Location	**Yearly electricty Consumption**	**Main characteristic**
Shop	Section 1	24.8MWh/year	Large refrigerating equipment
Summer Island Hotel	Section 2	Not available	Open from March to October
Community Hall	Section 3	Not available	Occupied throughout the year but oil-based heating
Bag-piping School	Section 3	11.0MWh/year	Operates a Café in Summer; electric storage heater
Primary School	Section 3	51.2MWh/year	Closed during School breaks; electric storage heater
Scottish Water building	Section 4	217.0MWh/year	Constant pumping load throughout the year
Street Lighting	All Sections	14.0MWh/year	Seasonality according to daylight

Figure 6-2: Monthly load profile of major electricity consumers in Achiltibuie



Based on the information presented above, it is possible to state that due to its location in Section 4 (close to wind and hydro plants) and its high and stable estimated consumption, Scottish Water building is a possible renewable electricity consumer for a private wire scenario to overcome grid constrains. Further consideration on the possible connection of Scottish Water are made in Chapter 10.

6.2 Heating Demand and Technologies in Achiltibuie

One of the main findings of the survey conducted within the Community of Achiltibuie was that there is a major consumption of energy for space heating and domestic hot water. This is in line with statistical information provided by Scottish House Condition Survey (SHCS), which “estimates that space heating accounted for 65% of domestic energy consumption in 2010, with water heating accounting for a further 17%” (The Scottish Government, 2012, p. 16). Statistics show that fuel poverty affected 39.1% of Scottish households in 2013 (The Scottish Government, 2014, p. 54). During interviews, residents mentioned that they cannot afford to heat their houses to a sufficient comfort level due to the high costs of fuel, coal or electricity. The building age and conditions also makes it more difficult for the heating systems to operate efficiently. From the 28 surveyed houses only 7 had been subjected to audits for the Energy Performance Certificate (EPC) and the ratings range from 45 (level E) to 78 (level B) (higher values are for more efficient buildings). According to the SHCS “most homes in Scotland would have an approximate energy efficiency rating of D (44%) or C (32%)” (The Scottish Government, 2012, p. 9). The field survey aligns with this statement as it shows the existence of such buildings within the Community. This presents the opportunity for energy efficiency improvements.

Space heating systems are the salient energy intensive element in Achiltibuie to keep houses warm in under the prevailing climatic conditions. Different types of heating technologies were identified in the community: Out of the 92 houses (residences, second homes and holiday houses) technology and fuel for primary space heating ranged from electric storage heating, electric direct heating, heat pump, oil, solid fuel (coal and/or wood) and gas as shown in the Table 6-4 below.

Table 6-4: Main primary space heating technologies present in Achiltibuie

Primary Space heating technology used	Number of houses	
electric storage heaters	8	8,7%
electric panel heater	13	14,1%
heat pump	4	4,3%
gas	9	9,8%
oil	25	27,2%
solid fuel	23	25,0%
Not known	10	10,9%
TOTAL	92	

Electrical heating systems amount to 25, including the heat pumps systems, and 57 houses use other fuels such as coal, oil and wood. During the interviews, residents expressed resistance to rely solely on electrical heating systems since they have experienced electricity supply interruptions in the past and during winter periods it is critical to be dependent on this source for space heating. Therefore, the choice of heating system does not depend only on its efficiency or cost, but mainly on the reliability of the heating system and the investments required for upgrading of space heating systems.

6.3 Future Local Demand for Private Wire

The combined electricity generation of the Ben Mor Hydro scheme and a large wind turbine exceeds the capacity of the 11 kV grid. Local consumption of this excess electricity through a private wire can improve the economy of the system considerably. A possibility of local consumption of electricity from the renewable energy projects that cannot be fed to the grid, in the event that a 33kV grid is not installed, is to use the electricity to supply heat through a district heating system.

Installation costs of the distribution network associated with district heating system is major factor in system location and design. The District Heating should be located as closely as possible to the highest density of buildings in Achiltibuie, which in this case is the Island View village (Section 3). In addition to the density factor, the buildings located in Section 3 are residences occupied throughout the year (residences as compared to second homes or holiday houses, which are predominant in other sections within Achiltibuie). Besides Island View village, the district heating could also provide space heating and hot water to the Community Hall and the Primary School.

The district heating system would be connected to the wind turbine and hydro power plants (located in the southern extreme of the area of study) through a private wire. The possibility of supplying the buildings along the line between the renewable power plants and the district heating (buildings of Section 4) to the private wire has been considered. It has however not been included in the present study since these buildings are mainly second homes and holiday houses (20 houses), compared to residences (15), and therefore present a varying heat demand. Furthermore, the survey showed that these residences in Section 4 are mainly new buildings with modern, efficient and diversified heating systems.

Should the district heating project be further developed, the possibility of extending the supply to the Hotel shall be considered, since it is a major consumer during times of operation. For the present study, there was not sufficient data with which to derive the heat demand of the Summer Island hotel. The benefits of extending the district heating grid, approximately 500m of piping, needs to be compared to the additional investment required.

The fact that 15 of the 19 houses as well as the primary school are council-owned, a district heating system supplied by private wire is a possible investment to be undertaken by the Highland Council. During the meeting with Local and Highland Council representatives, the possibility of installing a district heating supply for the council houses in Island View Village was mentioned. This establishes the Highland Council as a possible funding agent and important stakeholder in the future development of the community. The inclusion of the Council as part of the renewable energy project would also represent the achievement of two of its main objectives i.e. the supply of affordable warmth for its council houses and at the same time the reduction of carbon emissions through the use of renewable energy as a source of heat, as is shown in Chapter 5, Regulatory Framework.

In the next section, the heat demand profile is calculated in order to develop the scenario of the connection of a district heating system to the renewable energy power plants. See chapter 9 (District Heating System for Island View Village, Community Hall and Primary School).

6.4 Heat Demand of a District Heating

Although it is not possible to model a renewable energy supply of electricity for the community, it is possible to make use of the renewable energy for heating purposes. Heating was also identified as a main issue and cause of major energy consumption in the field survey. Since the area of Section 3 (19 houses of Island View Village, the Community Hall and the Primary School) presents the highest density of occupancy, it was chosen for the design of a district heating.

The first step in dimensioning a district heating system is to identify and quantify the heat demand and its distribution (heat demand profile). An hourly load profile of one year is required in order to compare the heat demand with renewable energy generation profiles from the wind and hydro projects and this is presented in the paragraphs that follow. It is also important to assess the impact of a grid constraint and to find the optimal size of storage.

6.4.1 Heat demand profile for Island View Village

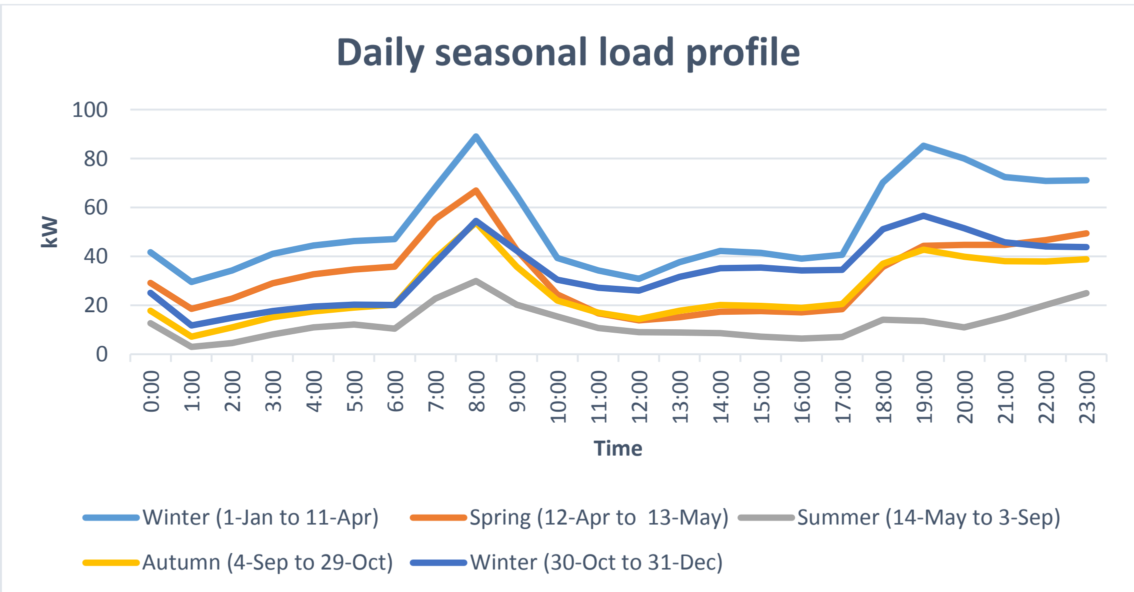
Based on information provided by Highland Council representatives, a heat energy demand of 237.6 MWh per year for adequate space heating for the 15 council owned houses within the Island View Village was calculated. This figure has been calculated using the NHER methodology and extrapolated for the 19 houses in order to be used in dimensioning the system. A total demand of 330.9MWh/y was obtained.

In order to generate the hourly space heat demand profile for the 19 houses in the village, the heat demand profile estimator tool was used. The tool was developed by University of Strathclyde UK (Strathclyde University UK, 2015) and is based on statistics for the UK. The input data was categorised according to the number of houses with the same characteristics i.e. type of house, occupants, age of the building, number of double and single rooms, a total of 7 categories were identified for the 19 houses in the village according to the selected criteria and the associated demand profile was subsequently generated.

Hourly heating load profiles were generated in kW by the tool on the basis of a typical day in winter, spring, summer and autumn. The tool generates 5 different profiles, for a first winter season from January 1st to April 11th, spring (April 12th to May 13th), Summer (May 14th to September 3rd), autumn (September 4th to October 29th) and a second winter profile for October 30th to December 31st. The daily load profiles are presented in Figure 6-3 and show that the different seasons present similar profiles.

Figure 6-3 shows the hourly heat load profile of 19 village houses for the different seasons of the year. The peak consumption is 90 kW in the 1st winter season during morning hours, the peak consumption in the spring is 67 kW and there is a slight difference in the load from 10:00 am to 11:00 pm. summer heating load is much lower than other seasons presenting a peak demand of 30kW in the morning hours.

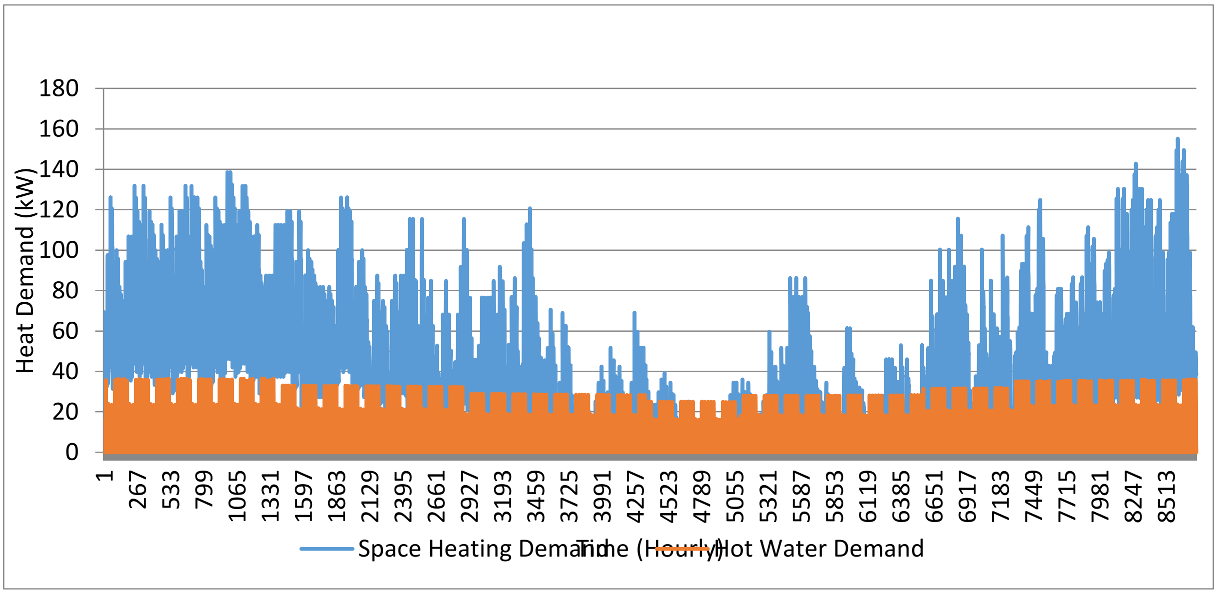
Figure 6-3: Hourly heat load profile generated by tool (Strathclyde University)



In order to obtain the yearly heat demand profile, the daily profiles above were distributed along the respective periods according to the heating degree days (HDD). HDDs for a specific location show the difference of the measured outside air temperature to a base temperature. This measure reflects the demand for energy needed for heating. Since there are no daily HDD profiles for the location of Achiltibuie, the nearest location with similar climate was selected: Dundonnell, in the same region of Wester Ross. Daily HDD profile for the year of 2014 was obtained from a specialized website (BizEE, 2015) for the temperature reference of 15.5°C. When compared with long term climatic data, the year of 2014 is a representative profile of HDD. From HDD information it is possible to realize that even during summer some amount heating is still needed. This resulted in the hourly heat demand distribution that can be seen in the Figure below.

In addition to space heating, a possible district heating can provide the 19 houses in the village with hot water. The heat demand profile of hot water has been estimated with the use of the software TSol. This software generates the water consumption pattern with variations for weekdays, Saturdays, Sundays and the months of the year. An assumption of 40L of hot water per day per person was used along with the consumption pattern of a detached house. A total of 3.8MWh annually is required for hot water for each of the houses in the Village.

Figure 6-4: Heat demand profile of the Island View Village

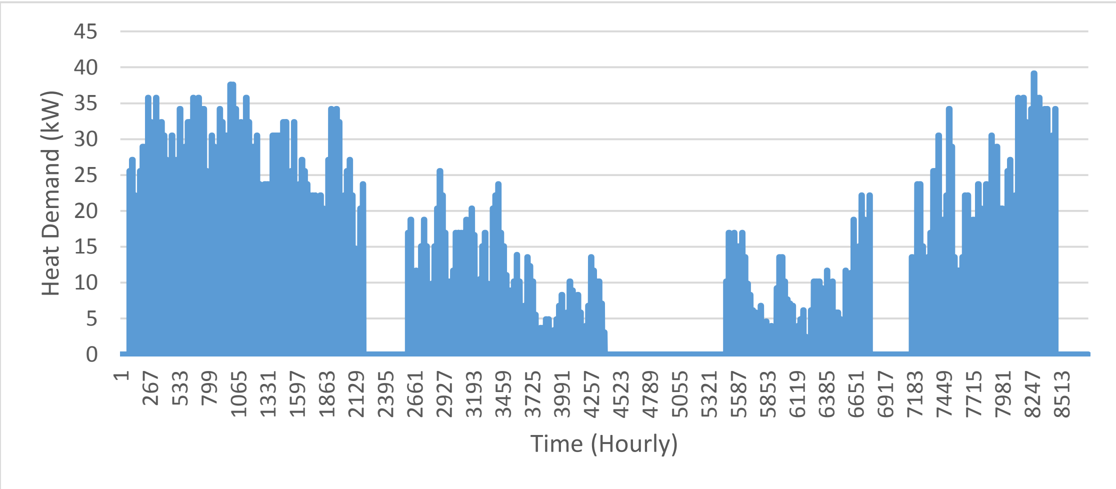


The total demand profile of the Island View Village can be determined by combining the above presented profiles and has a peak demand of 185.2kW and an average of 42.1kW.

6.4.2 Heat demand profile for Primary School

The primary school is currently heated by electric storage heaters and it was estimated that 80% of the electricity bill is for space heating (40.95MWh in the year). According to information provided during the visit, classes are in session from 9:15 to 15:15, therefore the heat demand hourly distribution was assumed from 8am to 3pm. The holidays according to the school calendar were not considered for the heat demand profile distribution and the HDD variation was used for the daily heat demand generation. This can be seen in the following heat demand profile for the primary school. The peak load of 39.2kW is reached and an average of 4.7kW has been obtained.

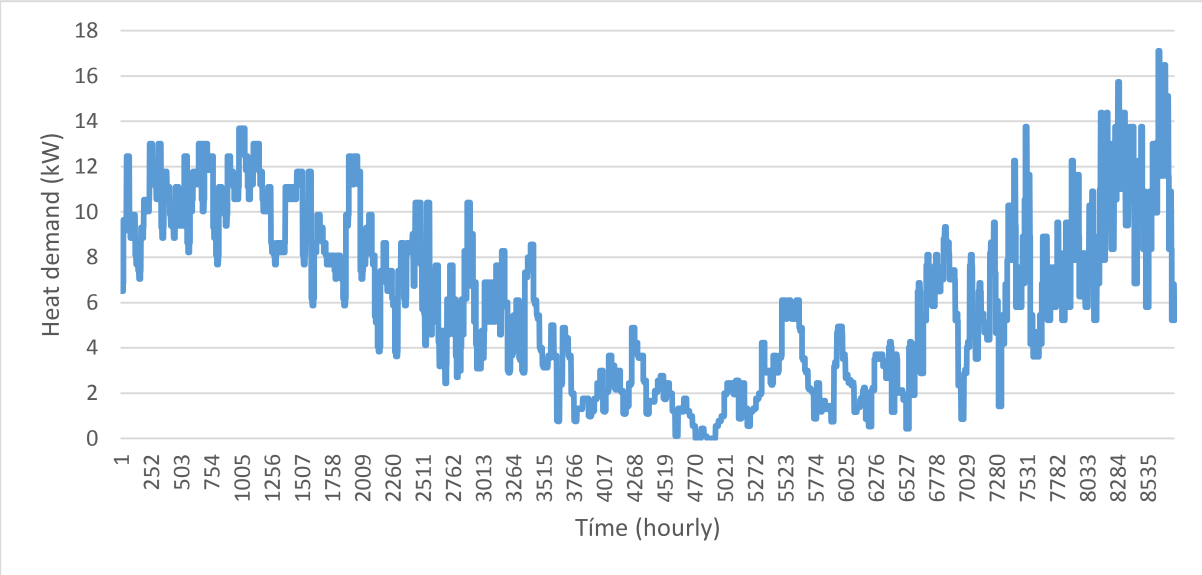
Figure 6-5: Heat Demand Profile of the Primary School



6.4.3 Heat demand profile for Community Hall

The Community Hall is currently heated by an underfloor heating system operated by an oil-fired boiler. The estimated heat demand for the community hall was calculated based on the yearly consumption of 9,000L of oil and 60% boiler efficiency and adds up to 54MWh per annum. For the hourly distribution of the heat demand, the daily HDD were used and a constant heat demand throughout the period of day (8am to 8pm) and night (8pm to 8am) was assumed. Since the building has a slow-responding underfloor heating system, a base temperature of 14°C is always maintained and the staff are required to increase the temperature in the morning prior to using the rooms. Therefore it was assumed that the building is heated continuously during the day. The ratio of day and night heat demand was based on the profiles for the different seasons calculated for the Village houses. The following heat demand profile was obtained, with a peak load of 17.1kW and average load of 6.2kW.

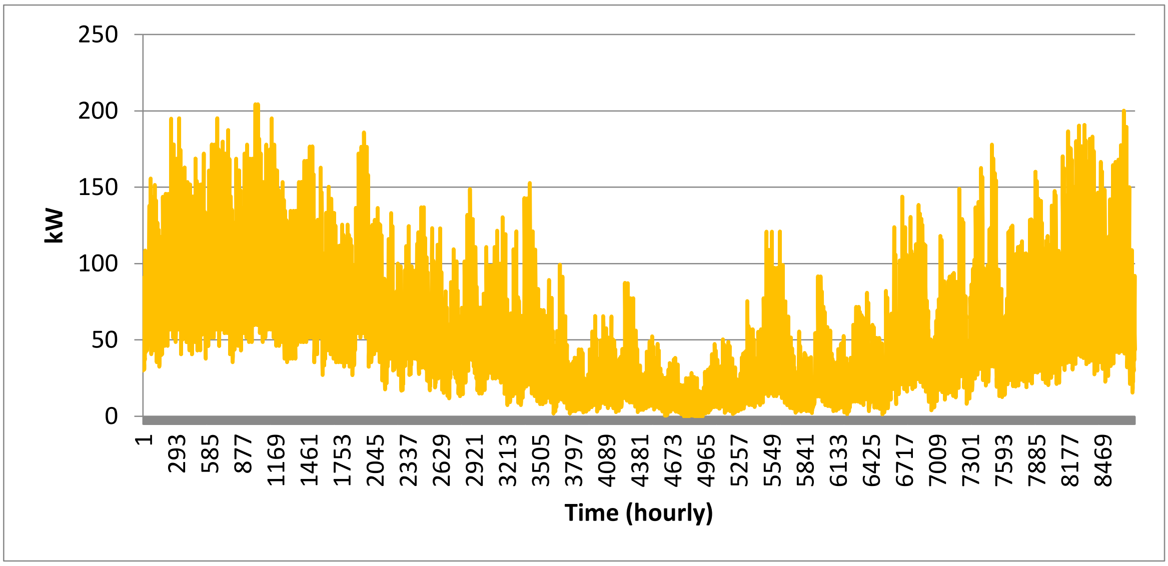
Figure 6-6: Heat Demand Profile of the Community Hall.



6.4.4 Combined heat demand profile for the District Heating design

The sum of the hourly heat demand profiles of the Island View Village houses, the Community Hall and the Primary School gives the following combined heat demand profile and will be used in Chapter 9 for the dimensioning of the district heating. Peak load is 204kW, while average hourly heat demand is 54kW. It is important to mention that the current 463.89MWh/year of heat demand combines the theoretical heat demand of the final consumer (Households, Community Hall and School) as presented above and distribution losses still have to be included when dimensioning the district heating.

Figure 6-7: Combined Heat Demand Profile for the District Heating



7 Renewable Generation: Wind

7.1 Context of Study

Following community meetings, relevant research and a detailed environmental impact assessment CCDC received planning permission from the Highland Council's north planning committee for the installation of one community owned Enercon-44 wind turbine with the capacity of 900 kW. In order to connect the Enercon-44 turbine to the grid with its full capacity, the grid operator SSE[1] requires the community to pay for a 5km 33kV line. There is also a constraint relating to connecting the turbine to the existing 11 kV grid. As yet it is unclear what quantity of electricity generation will be allowed by SSE for connection to the existing grid. The latest information is 600 kW. SSE has recently indicated the option of connecting the combined output of the Hydro and Wind in a manner that does not exceed the grid constraint. On the basis of the scenarios of the study this section of the report presents the analysis of three alternative wind turbines. They are:

1) The Enercon E44 (900 kW)
2) The WTN 500 and downrated Enercon E44 (500 kW)
3) The Vestas 27/ACSA 27 (225 kW)

7.2 Methodology

The computer programmes – WindPRO and WAsP along with an applicable Excel model have been used to simulate energy generation based on measured 10 minutes wind speed data for 2013. This year was selected as a "representative year" since it was observed that the average wind speed was close to the long term MERRA (Modern-Era Retrospective Analysis for Research and Applications) data. This data was manipulated to obtain the minimum (Worst Case) and maximum (Best Case) representative year scenarios. Further analysis of the 15 year data set showed that the maximum wind speed of the average wind speeds was 8.56 m/s in the year 2005 (6.3% above the 15 year average) and the minimum wind speed was 7.2 m/s in the year 2010 (9.5% less than 15 year average). The local load consumption data which is used is based on hourly data and as such the associated power generation from the turbines is calculated on an hourly basis. The wind speed measurement data used in the modeling was logged in 10 minute intervals and based on the larger volume of data it is better suited than hourly wind

[1] SSE Scottish and Southern Energy

speed data to show peak production from the turbine. The final depiction of the results is however shown on as an hourly generation.

7.3 Site Description

The met mast location is surrounded by hilly areas and grassland of Achiltibuie village. The hills are at the southeast direction of the met mast. The Site lies at an altitude of approximately 140m on the land sloping upwards in the vicinity of the public road approximately 5km to the north-west of Ben Mor Coigach. The nearest residential properties are approximately 600m to the south-west and 700m to the west. Figure 7-1 shows the wind turbine proposed site in Achiltibuie, Scotland (Council, 2014).

Figure 7-1: Met Mast Location

Source: WindPro 2.9

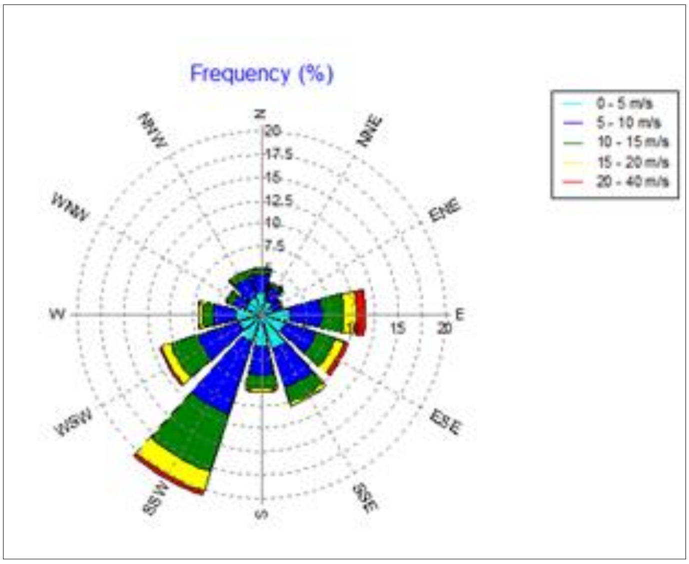
7.4 Wind Data Analysis

Wind data analysis plays a critical role in the assessment of annual energy yield estimation. In this study, wind data analysis has been done on the basis of measured wind data at met mast (East - 204927 & North - 906491). Measured wind data from the met mast was collected during the period of 1/10/2011 to 11/05/2014 in a ten minute time intervals.

7.4.1 Sector wise wind distribution of wind speed

The wind rose explains the direction and frequency of wind at the selected site. The wind rose in Figure 7-2 shows the wind direction in 12 sectors at a height of 50m. The most prevalent wind direction is South to South-West and least prevalent is the East to North-East direction. The different colors in the figure represent wind speeds ranging from 0-5m/s to 20-40m/s. The Weibull distribution of the selected site is included in the Annex W-2.

Figure 7-2: Frequency & Direction of wind



Source: WindPro 2.9

7.5 Turbine Selection

The wind turbines have been selected based on the following criteria:

- Grid constraint,
- Warranty and service contracts,
- Availability of turbine in the UK market,
- Reputation of turbine in the UK,
- Transportation and access to the project site,
- Availability of operation and maintenance teams

7.6 Energy Yield Estimation Process

Wind speed data from the top mounted anemometer at 50m height are used to calculate the energy yield at the turbine's hub height. WindPRO adjusts the wind speeds if the turbine hub height is greater than or less than the height of measured data.

The variation in wind speed with height can be modeled by the logarithmic law, where

C_1 and C_0 are the respective wind speeds at heights h_1 and h_2, and is the Shear Exponent or Roughness Exponent that will be used to scale the measured wind speed, this a constant dependent on the 'roughness' of surrounding land or water and areas with large barriers such as cities.

The values for C will be extrapolated using the Power Law:

$C_1 = C_o (h1/ho)^{\alpha}$

(Source: Wind resource Assessment for Achilitibuie)

Where:

C_1 is the scale parameter at height

C_O is the known scale parameter at (=50m)

α (=0.118) is the shear exponent

This report presents the production analysis of three wind turbines. The production analysis has been carried out based on data from a meteorological mast of 50m height placed on the site. The data used have been measured in the period from January to December 2013. The power curve corrected to an air density of 1.225kg/m^3 has been used in the production calculation. Roughness classes are used to model the terrain at a 40 km radius around Achiltibuie. The production estimate has not deducted array losses due to shadowing effects. Electrical and availability losses have not been deducted from the calculation.

7.6.1 Enercon 44 (Representative of 900kW Capacity)

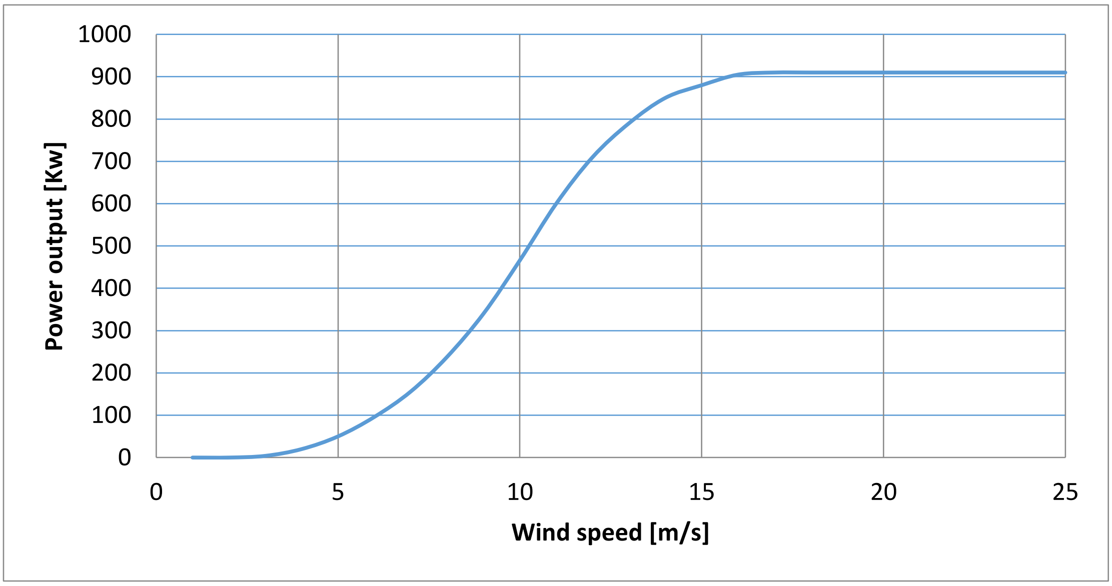
General Specifications

Enercon is a leading wind turbine manufacturing company that was started in 1984 in Germany and has a vast experience of installing wind turbines all over the world. The wind turbine class for E-44 wind turbine is IEC-IA (International electro-technical commission) with annual average wind speed of up to 10m/s and higher turbulence (18%). The rotor diameter of the turbine is 44m and the calculated swept area is 1521m^2. A direct drive annular generator (synchronous) with no direct grid coupling is used in the turbine, which avoids excitation requirement from the grid. The voltage output of the generator used in this turbine is 400V with a grid frequency of 50-60Hz. The annular generator is said to be less subjected to mechanical wear than a combination of standard speed generator and gearbox. The turbine is provided with MPU (main processing unit) control system which can control the power output at variable wind speed without a gearbox.

Power Curve: shows the standard power curve for the wind turbine. Enercon 44 has a rated power output 900kW. Power generation starts from 3m/s cut in wind speed and maximum power output of 910kW starts from wind speed 17m/s up to 25m/s. The cut out wind speed of the turbines is 28-34m/s with storm control. The Enercon 44 turbines can be installed at a hub height of 45m/55m. *(Enercon, 2012).*

Figure 7-3 shows the standard power curve for the wind turbine. Enercon 44 has a rated power output 900kW. Power generation starts from 3m/s cut in wind speed and maximum power output of 910kW starts from wind speed 17m/s up to 25m/s. The cut out wind speed of the turbines is 28-34m/s with storm control. The Enercon 44 turbines can be installed at a hub height of 45m/55m. *(Enercon, 2012).*

Figure 7-3: Power curve for Enercon-44 wind turbine

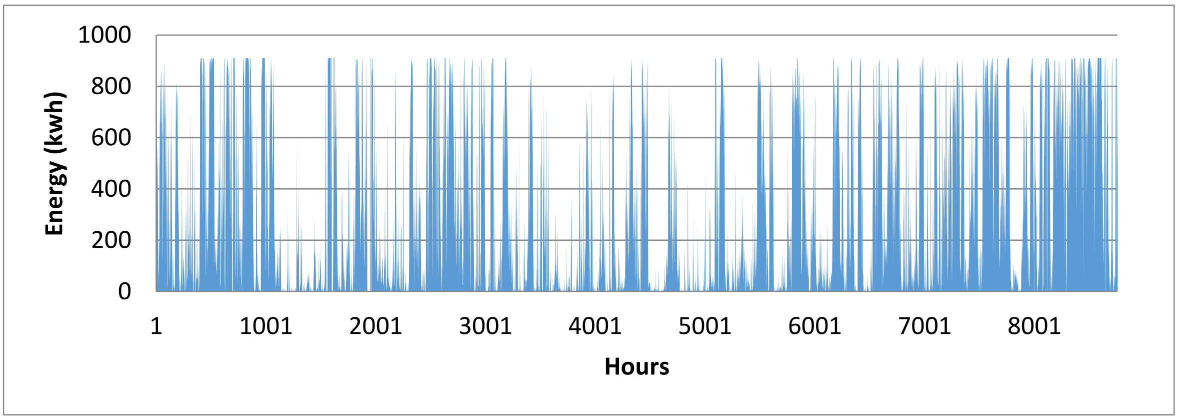


Source: Author – Based on Wind Pro results

7.6.2 Representative Hourly Production for Enercon-44

Figure 7-4 shows the representative hourly generation profile of E-44. The highest peak of energy generation is 900KWh.

Figure 7-4: Representative hourly generation profile - Enercon 44

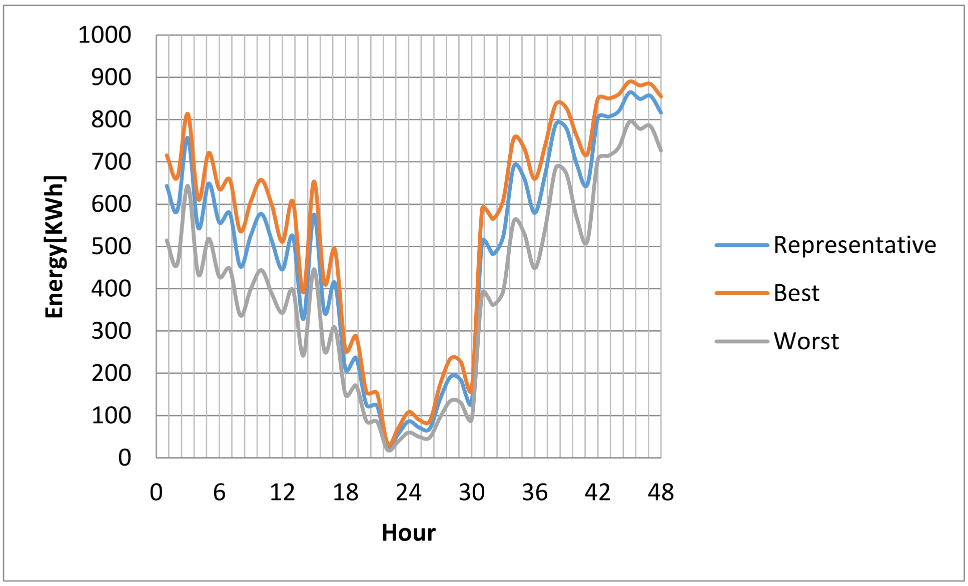


Hourly generation Profile-Comparison of three Scenarios

Figure 7-5 shows the comparison for hourly generation profile for the three scenarios. The total annual energy production for the turbine at average wind speed is 2.9GWh (representative case). The annual energy production at maximum wind speed is 3.1GWh (best case) and the energy production at minimum wind speed is 2.2GWh (worst case).

The 'Capacity factor' is a measure of the difference between the rated turbine power production and actual annual power generation and is calculated by dividing actual turbine generation by that which would have been produced if it were possible for the turbine to always operate at rated capacity. Capacity factors for Enercon 44 calculated by WindPro in the representative, best and worst case scenarios are 32.6, 35.5 and 27.9 respectively.

Figure 7-5: Comparison generation Profile for the three scenarios - Enercon 44 (Jan 1st and 2nd)



Source: Author – Based on Wind Pro results

7.6.3 WTN-500 (Representative of 500KW Capacity)

General Specifications

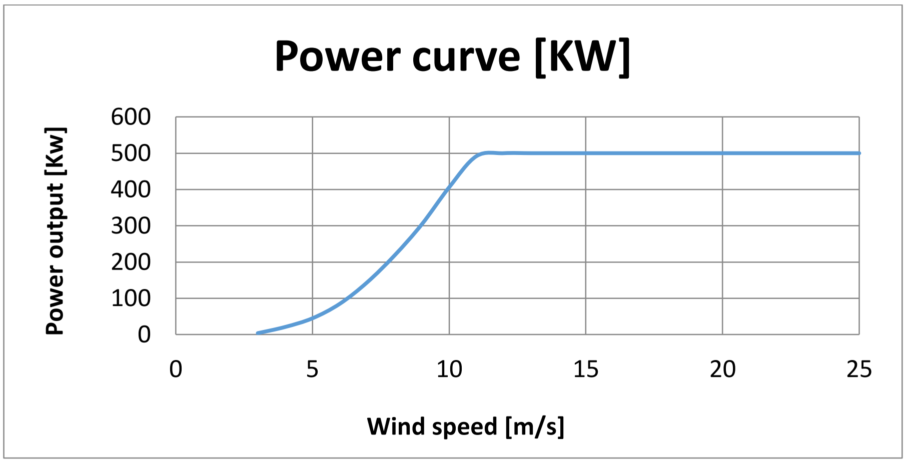
Wind turbines up to 500 kW qualify for a higher feed-in tariff as mentioned in the previous on Regulatory Framework chapter. This makes a 500 kW turbine a remarkable alternative to the 900 kW E44. The WTN 500 has been selected for this study as a representative of a 500 kW turbine. It is one of the very few machines which are still manufactured with this capacity. An alternative to the WTN 500 is a downrated Enercon E44. The WTN-500 is a pitch control turbine with variable operation, designed to be operated with the electrical grid. Rated power output of WTN-500 is 500 kW and the rotor diameter is 48 meters with a hub height of 50m. A gearbox and two asynchronous type generators are installed, each with a rated power of 250 kW and a voltage of 690 ± 10% Volts and frequency requirement of 50 ± 10% Hertz. Two "back to back" IGBT (Insulated Gate Bi-polar Transistor) inverters[2] are incorporated for the grid connection. (500KW WTN 500 Turbine, 2014).

The WTN-500 is categorized as a Class 2A wind turbine suitable for medium to high wind speeds and medium to high turbulence sites. *RM Energy*[3] is the authorized dealer for WTN turbines in Scotland. They are not only providing solutions for commercial, agricultural, business and developers but also provide key solutions to the community energy as well. The company has already installed more than 200 smaller turbines in the past eight years in different parts of Scotland. Their services also involve the 5 years warranty, support and maintenance package to customers. (500KW WTN 500 Turbine, 2014)

However, it seems that only one of these turbines is running in the UK. The information on practical experience with this turbine was insufficient. We therefore did not consider the WTN in our scenarios.

Power Curve: As shown in Figure 7-6, the power curve of WTN-500 indicates a cut-in wind speed of 3m/s, the rated wind speed is 12 m/s and the cut off wind speed is 25 m/s. However survival wind speed of WTN-500 is 59.5 m/s.

Figure 7-6: Standard Power Curve WTN-500



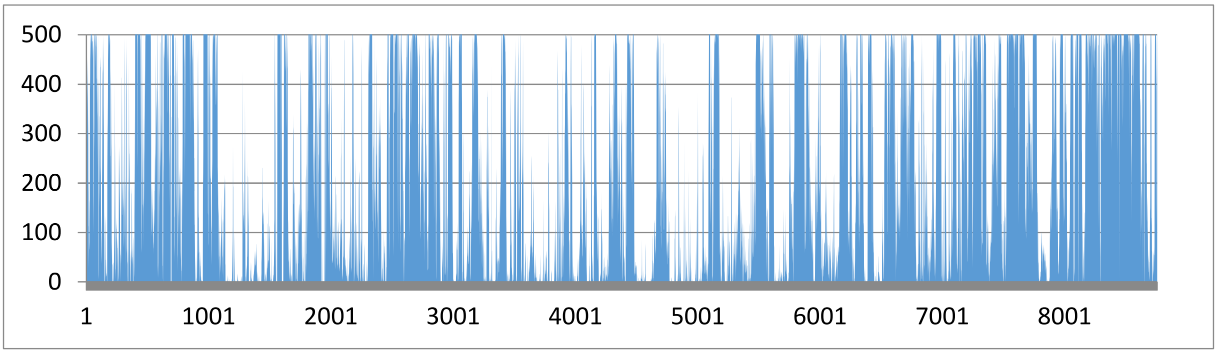
[2] www.windtechniknord.de/index.php/download?download=4...wtn-500

[3] http://www.rm-energy.co.uk/

7.6.4 Representative Hourly Production for WTN-500

The hourly generation profile is very important in terms of identification of lowest and highest peak of energy output. *Figure 7-7* shows the representative hourly generation profile of WTN 500. The peak energy generation is 500kW and the lowest value is 0 kW.

Figure 7-7: Representative hourly generation profile - Enercon 44



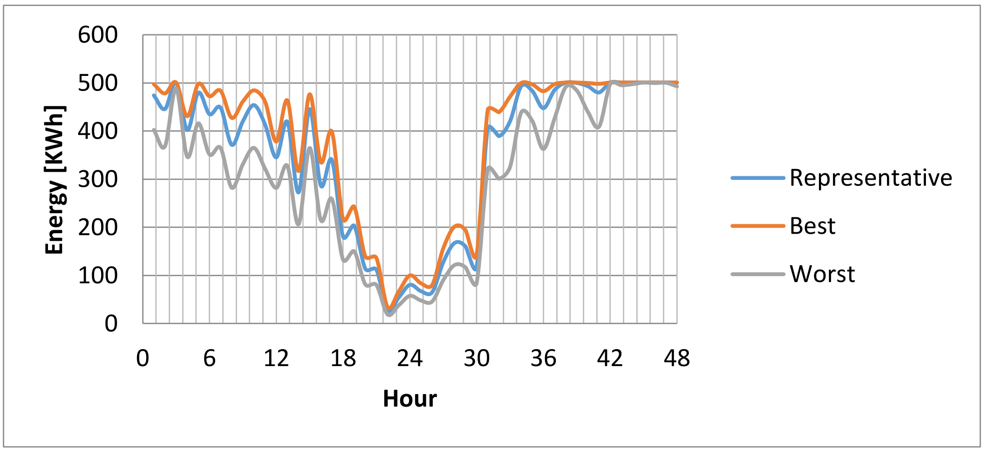
Source: Author – Based on Wind Pro results

Hourly generation Profile-Comparison of three Scenarios

The variation of energy generation profiles in different scenarios for two days in January is shown in

Figure 7-8. The total energy production in the representative year, 2013, is 1.9 GWh. However, for the best case scenario with maximum wind speed the annual energy increases to 2.1 GWh and for the worst case scenario with minimum wind speed the annual energy decreases to 1.7 GWh. Capacity factors in three scenarios also vary with the variation of wind speed. Capacity factor in representative year 2013 and in the best case and worst case scenarios are 40.5, 48.1 and 35.7 respectively.

Figure 7-8: Comparison generation Profile for the 3 scenarios -WTN-500 (Jan 1st and 2nd)

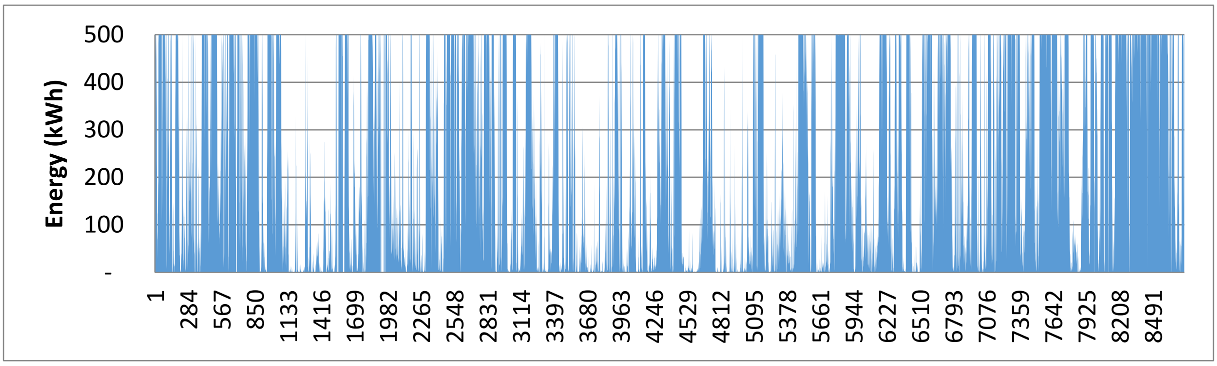


Source: Author – Based on Wind Pro results

7.6.5 Enercon-44 downrated to 500kW

There are number of turbines in the UK which have been down rated to the required capacity for several financial and technical reasons. Considering insufficient information about the practical experience of WTN-500, down rating of E-44 turbine from 900kW to 500kW could also be used as an alternative option to the WTN-500. Also a down rated E-44 turbine to 500kW would qualify for FIT for 500kW turbines. This option will be discussed in details in the financial analysis of turbines later in this report. Figure 7-9 shows representative hourly generation profile of down rated E44.

Figure 7-9: Representative hourly generation profile- Down rated E44



Source: Author – Based on Wind Pro results

7.6.6 V27/ACSA A27 (Representative of 225KW Capacity)

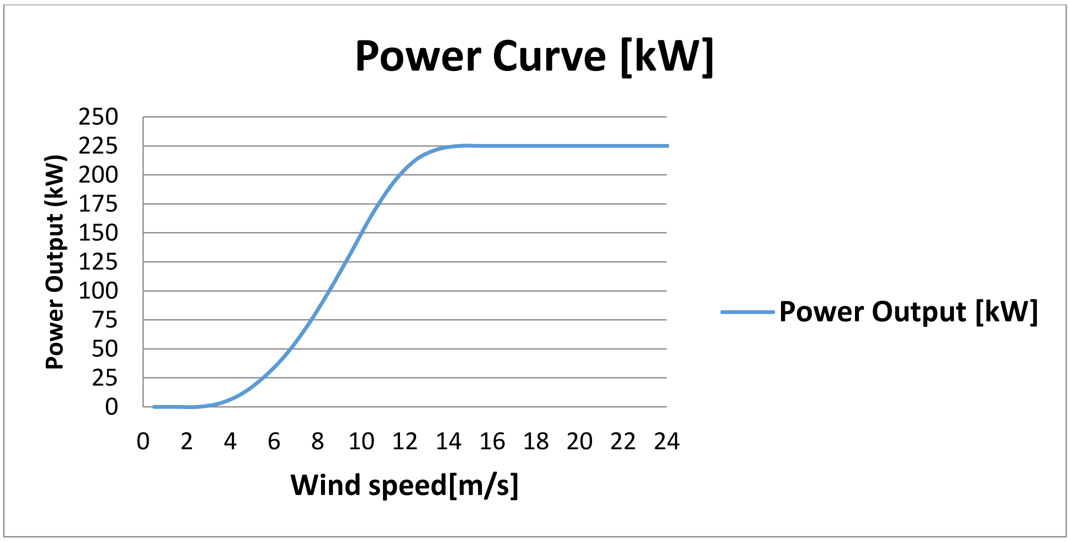
General Specifications and selection criteria

The Vestas V-27/ACSA A-27 has been considered as a representative of a small wind turbine with an output that would remain below a grid constraint of 600 kW for wind and hydro the majority of the time. Vestas has many years of reputation in UK, and the community of Gigha in Scotland implemented the first community wind turbines with refurbished V27-225KW turbines. Vestas no longer produces the V-27 but it is still manufactured under the brand name ACSA in Spain. The wind turbine class for V-27 wind turbine is IEC-IIA with rated wind speed 14m/s. The turbine has a rotor diameter of 27m and a hub height of 50m was chosen for the present location.

The voltage output of the generator used in this turbine is 400V with a frequency of 50 Hz (MWPS, 2015). At high speeds, the turbine has an output of 225kW and the type of generator is asynchronous. By means of a double-wound generator the turbines generates up to 50kW at low wind speeds before the 225kW takes over at higher wind speeds. The V27 as a class IIA turbine is suitable for a medium wind speed site such as Achiltibuie which had annual average measured wind speed of 8.16 m/s for the year 2013. The aftermarket supplier ACSA has also warranty options available with the possibility of extension of 2-5 years (MWPS, 2015).

Power Curve: The density corrected power curve for the V27-225kW (0.79GWh) is graphed in Figure10. The standard power curve of V27-225KW indicates a cut in wind speed of 3.5m/s, rated wind speed of 14 m/s and cut off wind speed of 25 m/s.

Figure 7-10: Power Curve Vestas V-27

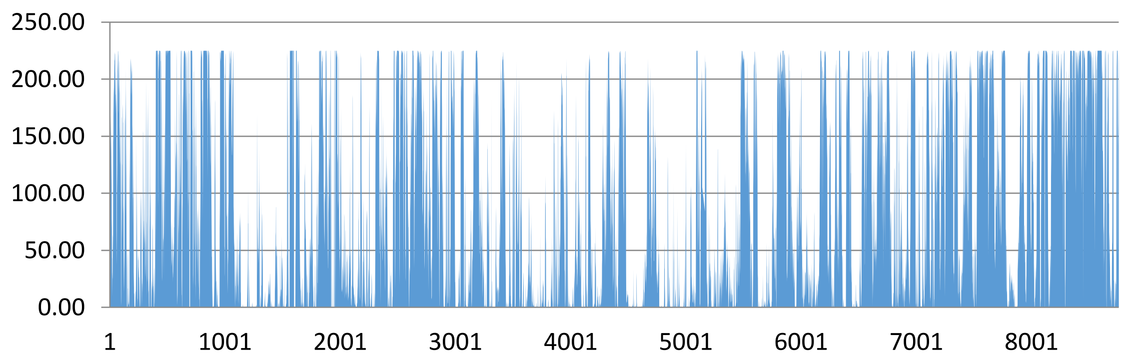


Source: Author – Based on Wind Pro results

Representative Hourly Production for V27

The hourly generation profile for the representative year is shown in the Figure 7-10. Peak hourly energy generation is 225kWh and the lowest is 0kWh.

Figure 7-11: Representative Hourly Production (2013)-V27



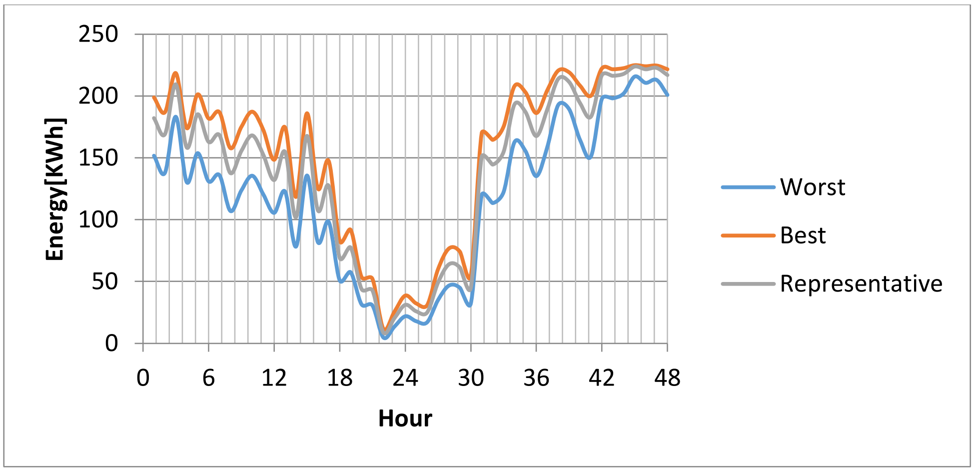
Source: Author – Based on Wind Pro results

Hourly generation Profile-Comparison of three Scenarios

We have now a simulated annual hourly power output profile for the V27-225KW turbine local demand and grid constraint, which can be used to calculate the financial viability and compared in the three generation profile scenarios. The total energy production in the entire year from measured 2013 representative data is 0.79 GWh. For the best case scenario with maximum average wind speed, the annual energy yield increases to 0.85 GWh/year. However, for the worst case scenario with minimum average wind speed the production decreases to 0.69 GWh/year. For January 1st and 2nd, the gap between the three hourly generation scenarios at 23 hours is closer.

The capacity factors for the representative, best and worst case scenarios are 40.1%, 43.4% and 35.2% respectively.

Figure 7-12: Comparison generation Profile for the three scenarios -V-27 (Jan 1st and 2nd)

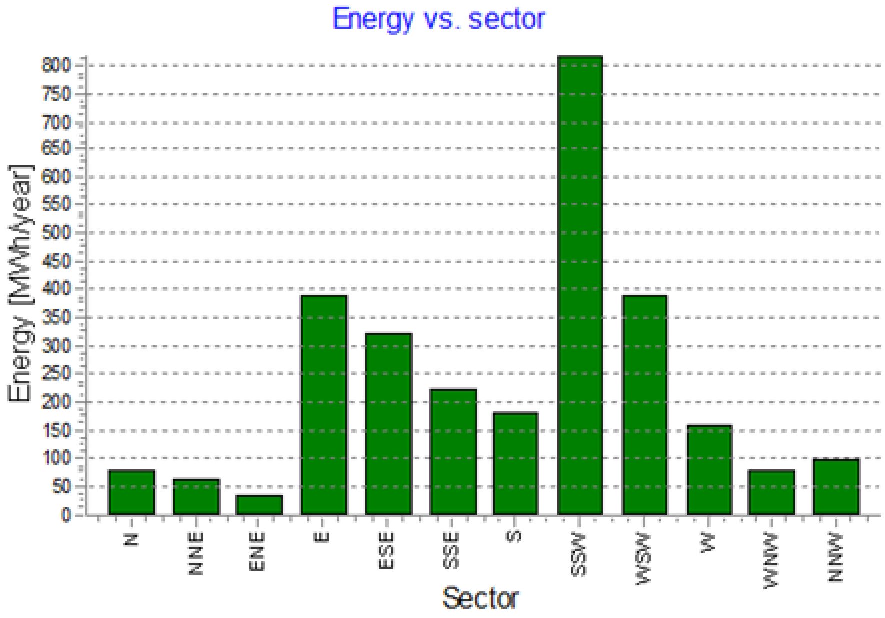


Source: Author – Based on Wind Pro results

7.6.7 Energy Generation by sector wise

Figure 7-13 indicates the graph for expected energy generation for the selected turbines by sector. As the flow of wind is mainly from the SSW direction, the annual energy production is greater from the SSW zone. The annual energy production of E-44, WTN-500 and V-27 wind turbines from the SSW zone is 816.1MWh, 550.7MWh and 225.4 MWh (Annex W.3, Annex W.6, and Annex W.9. The minimum energy generation comes from the ENE zone.

Figure 7-13: Sector Wise Energy Production for Enercon-44

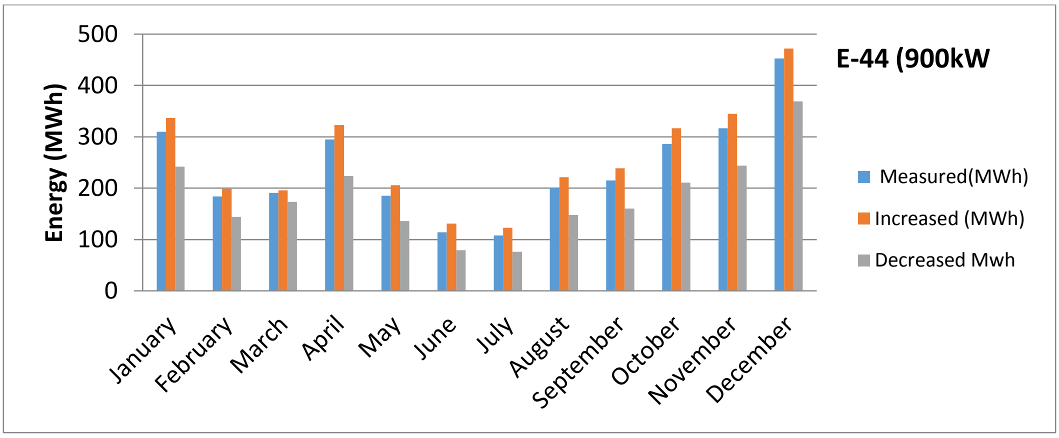


Source: Windpro 2.9 results

7.6.8 Monthly Energy Generation for Selected Turbines

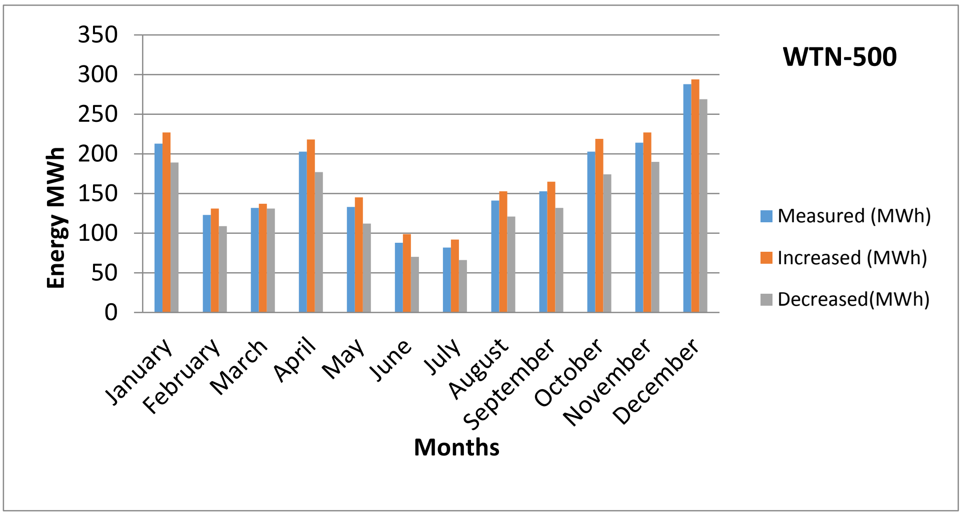
The figure below shows the comparison of monthly energy generation for the E-44, WTN-500 and V-27 turbines. The highest energy generation is obtained in the month of December. The lowest energy generation is observed between June and July. Monthly generation values can be seen in Annex W.5, W.8 and W.11.

Figure 7-14: Monthly Energy Generation Enercon 44



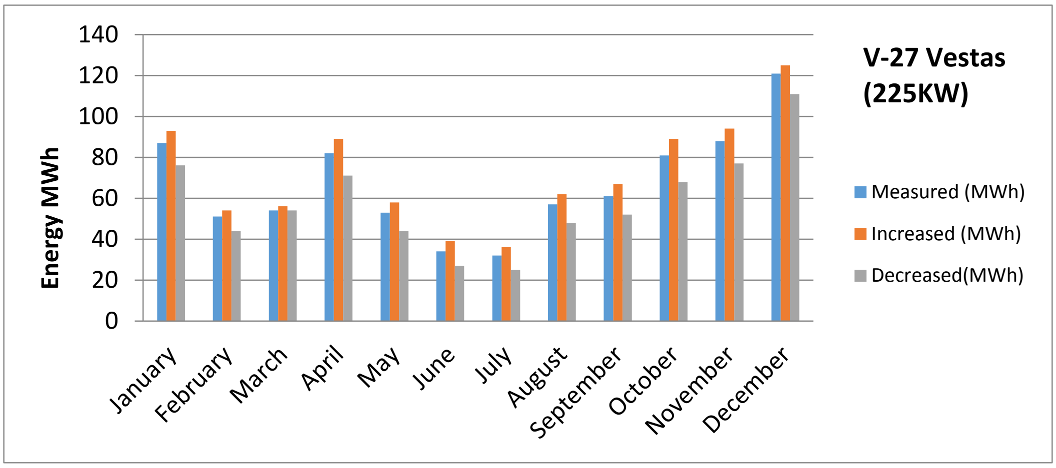
Source: Author – Based on Wind Pro results

Figure 7-15: Monthly Energy Generation WTN-500



Source: Author – Based on Wind Pro results

Figure 7-16: Monthly Energy Generation V-27



Source: Author – Based on Wind Pro results

7.7 Summary - Annual Energy Production from Representative 2013 Measured Data

Table 7-1: Summary Annual Energy Production

Turbine	Enercon-44	WTN-500	VESTAS (V-27)
Manufacturer	Enercon / Germany	Wind Technik Nord/ Germany	Vestas/ Denmark
Available in UK	Yes	Yes	Yes
Rated Power (KW)	900	500	225
Annual Capacity Factor % (Calculated from Windpro)	32.6	40.5	40.1
Hub Height (m)	55	50	50[4]
Class	1A	2A	2A
Net Annual Energy Production(GWh	2.82 (8.32m/s)	1.8 (8.16 m/s)	0.79 (8.16 m/s)
Net Annual Energy Production for Best Scenario(GWh)	3.1	2.1	0.85
Net Annual Energy Production for Worst Scenario(GWh)	2.2	1.74	0.69

7.8 Cost Analysis

The total cost of the community wind turbine is comprised of turbine supply & installation, civil works (tracks, foundations, and bridges), and operation and maintenance. Apparently, there is no fuel cost associated for power generation. Cost estimation for the V-27 are based on the statement of a supplier of refurbished turbines; and costs for a new Enercon turbine were taken from the financial analysis as provided by CES and CCDC[5]. For V-27, costs other than capital and annual expenses have been assumed on the bases of Enercon-44 per cost ratio.

[4] https://www.sparesinmotion.com/V27-225KW /rrb_brochure

[5] Excel spreadsheets as provided by CCDC.

Table 7-2: Cost Estimation for three turbines

Investment Costs		Comments	Source of information	900 kW E-44 Turbine	500 kW WTN Turbine	225 kW V-27 Turbine
				[1,000 £]	[1,000 £]	[1,000 £]
Generation equipment		Turbine Supply & Installation	CCDC/CES/MWPS[6]	840.00	800.00	300.00
Interconnection		11 kV connection	CCDC/CES	220.00	220.00	220.00
Civil works		acc. to CES calculation	CCDC/CES	90.00	90.00	90.00
Contingencies		guess (acc. to CES)	CCDC/CES (cost ratio assumes)	100.00	56.0	36.00
CARES loan to planning		Incl. interest rates	CCDC/CES	200.00	200	200.00
Further Professional Fees		Fees/Bank Fees/Restoration Bond (acc. to CES)	CCDC/CES (cost ratio assumes)	268.50	179.69	139.93
Total Investment cost				***1,718.50***	***1,545.69***	***985.93***
Annual Expense (O&M cost)	1-5 year (ct/Kwh)	Based on EWEA report (O&M cost estimation for selected sizes of turbines)	EWEA[7]	0.60	0.60	1.00
	12-20 year(ct/Kwh)			1.20	1.20	1.20
	5-12 year (ct/Kwh)			1.80	1.80	2.00
Administration((£/year)			CCDC/CES	11.00	11.00	11.00
Insurance and Rates(£/year)			CCDC/CES (cost ratio assumed)	13.00	7.22	7.22

[66] Phone call to MWPS on 12/03/2015, costs for a turbine: 300,000 pounds (V-27)

[7] The Economics of Wind Energy by European Wind Energy Association

8 Renewable Generation: Hydro

8.1 Context of Study

Coigach Community Development Company (CCDC) together with Scottish Wildlife Trust (SWT) has planned to construct a hydropower plant – Ben Mor Hydro in Achiltibuie/Coigach[8]. Planning for construction as well as grid connection permission of a hydropower plant of 420 kW has also already been granted[9]. In this context, the study has been undertaken in order to study the energy generation profile of the planned hydro as well as to explore other possible sites in the vicinity. This was done in order to assist the community of Achiltibuie/Coigach in making the best use of the planned new high voltage transmission line. In addition, the study also provides suggestions for the location of the intake of the proposed project as per the request of CCDC.

Thus the major focus of this sub-chapter is to study the hourly electricity generation profile of the planned hydropower project - Ben Mor Hydro.

8.2 Specific Objectives for Hydropower Study

To meet the main objective of the study, the following specific objectives for the hydropower study have been established:

- To generate an hourly electricity generation profile of Ben Mor Hydro, which helps to analyse the combined response of wind and hydro generation on the existing 11 kV grid
- To explore the additional hydro potential sites near to Ben Mor Hydro and develop their hourly electricity generation profile – to be used as additional sources of generation for the new high voltage grid
- To suggest a better intake location for Ben Mor Hydro thereby avoiding the risk of structural failure – as suggested by the community

8.3 Methodology Adopted

To meet the above stated objectives the following methodology has been adopted:

i) Ben Mor Hydro

- Collection of secondary data – includes topographical, already established design parameters, flow and cost data etc.

[8] Documents related to construction plans provided by CCDC

[9] Documents provided by CCDC regarding offer to provide grid connection and grid connection agreement

- Calculation of catchment area, head, penstock length – based on topographical data
- Hydrological data analysis – based on flow data
- Power and energy calculation - based on already set design parameters
- Development of hourly electricity generation profile
- Exploration of a better location of intake - through a site visit

ii) Other potential sites

- Calculations for other sites and their hourly electricity generation profile based on hydrological data of Ben Mor Hydro

8.4 Limitations and Assumptions

With the available information and time limitation, various assumptions have been made in the study, which are explained in detail under each topic. The main assumptions are as follows:

- Location of measured flow data was not known; hence it has been assumed that the data was measured at the intake of Scottish Water
- Due to the complex underground water flow between the Scottish Water intake and hydro intake, the flow at hydro intake was also assumed to be same as that of measured site
- Per kW cost of additional projects are comparable to that of Ben Mor Hydro

Other assumptions for discharge calculation have been explained in detail in Annex H.

8.5 Ben Mor Hydro

Proposed Ben Mor Hydro is a run off river type hydropower project located in Allt Achadh a' Bhraighe Burn (also called Acheninver Burn), Achiltibuie. The longitude and latitude of the proposed powerhouse location in WGS 1984 co-ordinate system is 57.99°, -5.31° and that of the proposed intake is 58°, -5.279°. Salient features of the proposed are listed below:

- Installed Capacity: 420 KW
- Design Discharge: 0.188 m^3/s
- Gross head: 285 meters
- Overall efficiency: 78.5%
- Catchment area: 3.11 Square Kilometres (As shown in Annex H, Figure H-20)

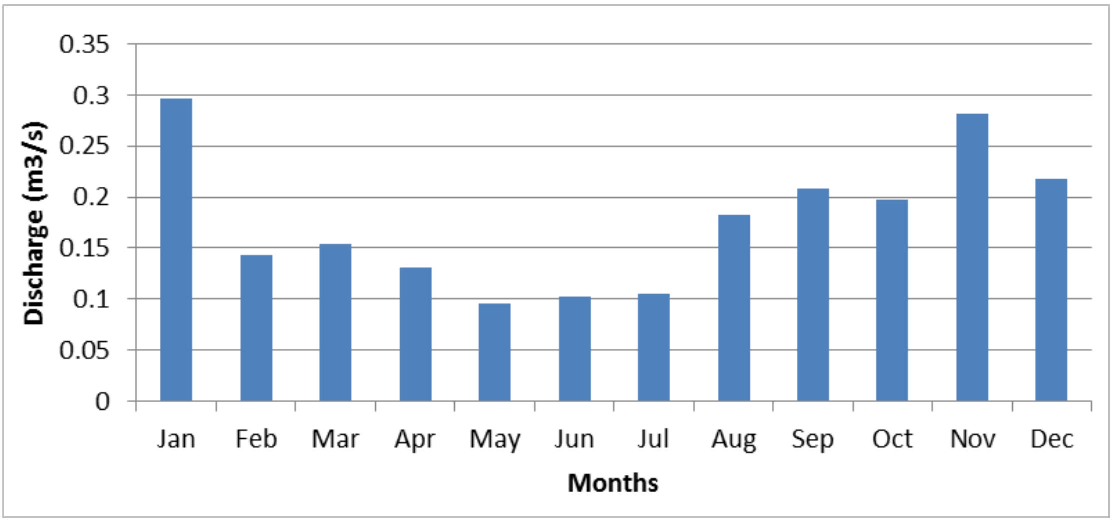
8.5.1 Discharge

Hourly discharge of the river has been estimated based on 15 minute stage measurements from 2002 to 2008 and 42 combined stage and flow measurements[10] provided by CCDC.

The pattern of the calculated hydrograph has been found similar to that of long term average monthly precipitation provided by MERRA (Modern-Era Retrospective Analysis for Research and Applications) data (MERRA, 2015) of 35 years (1979-2014). The analysis of long term precipitation data and average precipitation data for the years 2002 and 2008 revealed that these years represent an average year. A detailed description including graphs has been provided in Annex H.4, Figure H-4, Figure H-5, and Figure H-6.

The analysis of discharge resulted in an average discharge in the river of 0.176 m^3/s, with maximum and minimum discharge of 1.610 m^3/s and 0.024 m^3/s respectively. Details of the analysis done for obtaining the average hourly discharge from the raw data of stage and discharge has been explained in Annex H.1-H.5. The obtained average hourly and daily discharge pattern has been provided in Figure H.7 and H.8, and that converted into monthly discharge has been presented in the graph below:

Figure 8-1: Monthly average discharge: Allt Achadh a' Bhraighe Burn



Following the hourly discharge, a flow duration curve was created as explained in Annex H.5. This shows that the design discharge (0.188m^3/s) can be achieved at Q_{33}, which means that 33% of the time the discharge in river will be above this figure.

[10] Excel sheets provided containing stage and discharge measurement data

8.5.2 Downstream release

The intake of Scottish Water lies below the intake of Ben Mor Hydro. According to the documents provided by CCDC[11], Scottish Water requires a discharge of 0.0036m^3/s. The "Guidance for developers of run-of-river hydropower schemes" states that, no abstraction should be done below the hands-off flow (HOF) equivalent to Q_{90} or Q_{95} (SEPA, 2014). Hence, HOF equivalent to Q_{90} (0.063 m^3/s) plus the discharge required for Scottish Water (0.0036 m^3/s) has been considered as downstream release from the hydro intake.

8.5.3 Energy generation

Assuming the same discharge in the hydro intake as that of measured location, and based on hourly available discharge for power generation, selected design discharge (0.188m^3/s), available head (285m), and overall plant efficiency of 78.5%, the annual hourly energy generation has been calculated. The analysis shows that the project can generate an average annual energy of about 1283 MWh which leads to a capacity factor of 35%.

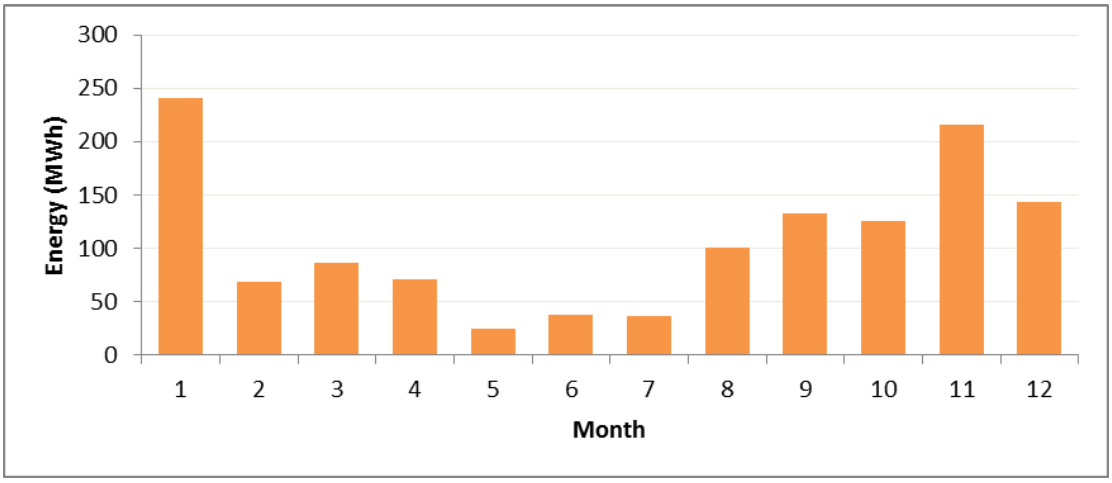
Similarly, the analysis of long term precipitation MERRA data of 35 years shows that the maximum precipitation was 10% higher than the average, and the minimum was 18% lower than average. Assuming that this is true for the discharge of Ben Mor Hydro also, the plant can generate a maximum of 1411 MWh and a minimum of 1052 MWh annually.

Detailed explanation, calculation, and pattern of hourly and daily energy generation is provided in Annex H.6, Table H-6, Figure H-10, and Figure H-11 respectively.

The obtained hourly energy generation profile has been simplified and presented in form of a monthly generation profile in the figure below. It has been observed that the plant generates its maximum energy in January and its minimum in May. Furthermore, the daily energy generation profile of January and May is also presented in Annex H, Figure H-12 and Figure H-13.

[11] Cover letter from Scottish Environment Protection Agency (SEPA); Ref CAR/L/1099734; dated as 2nd May 2012

Figure 8-2: Monthly energy generation profile – Ben Mor Hydro



8.6 Other Hydro Sites nearby Ben Mor Hydro

Two other potential hydro sites near Ben Mor Hydro have been identified based on Scottish Natural Heritage (SNH) database (SNH, 2015). Possible sites lie in the rivers Allt a' Choire Reidh and Badenscallie Burn. It is assumed that the hydrological patterns of these sites are similar to the Ben Mor intake. Details are explained along with graphs and maps in Annex H.9. The major findings related to the additional hydro sites with reference to Ben Mor Hydro is shown in the table below:

Table 8-1: Salient Features of Additional Hydropower Plants

Description	Ben Mor Hydro **(Allt Ach'a' Bhraighe)**	Additional 1 **(Allt a' Choire Reidh)**	Additional 2 **(Baden Scallie Burn)**
Catchment area (km^2)	3.11	1.56	2.53
Design Discharge ((m^3/s)	0.188	0.102	0.167
Gross head (m)	285	255	48
Penstock Length (km)	2.2	1.34	1.03
Installed Capacity (kW)	420	200	60
Annual Energy (MWh)	1283	784	240
Capacity Factor	0.35	0.45	0.46

Based on the assumptions, the additional hydro 1 and 2 have an installed capacity of 200 kW and 60 kW and will generate annual energy of about 784 MWh and 240 MWh respectively. Annual energy generation profile of these additional projects has been shown in Annex H, Figure H-17, and Figure H-18.

The obtained capacity factors of additional hydro sites are higher than Ben Mor Hydro because in Ben Mor Hydro, HOF and water requirement for Scottish Water are considered for downstream release, but for the additional hydro schemes only HOF (equivalent to Q_{90}) is considered.

Map of the hydropower sites with contour lines is provided in Annex H, Figure H-19 (Drawing No.2). Map of catchment area, penstock alignment and location of intake and powerhouse of two additional sites and Ben Mor Hydro is shown in Annex H, Figure H-21.

8.7 Cost Analysis

The cost analysis of Ben Mor Hydro has been provided by CCDC[12]. The approximate investment cost of the project is 1,820 thousand pounds with per kW cost of approximately £4,300. Ben Mor Hydro Ltd. estimates other annual costs such as annual operation and maintenance (O&M), administration, grid charges, and insurance as 3% of the total investment.

Per kW cost estimated by Green Highland Renewables Ltd. through desktop analysis is about £4500[13]. In addition, a 400kW new hydropower plant in Germany has an investment cost of about €6000 per kW (Bard, 2003) which is about £4,300 with conversion factor 0.72. Thus, per kW cost of Ben Mor Hydro seems to be reasonable when compared with other sources.

The purpose of the study is to obtain basic information about the new hydro schemes, and they lie near to Ben Mor Hydro, per kilowatt cost as well as other annual cost are taken same as Ben Mor to calculate the cost of additional schemes. Thus, it gives an initial overview only, a detailed feasibility study should be carried out in order to obtain a detailed cost estimate. Summary of the estimated cost has been presented in the table below:

Table 8-2: Summary of cost

Description	Ben Mor Hydro **(Allt Ach'a' Bhraighe)**	Additional 1 **(Allt a' Choire Reidh)**	Additional 2 **(Baden Scallie Burn)**
Total Capacity (kW)	420	200	60
Per kW cost (Pounds)	4,300	4,300	4,300
Total Investment (Thousand £)	1,820	860	260
Annual Operation and Maintenance Cost (Thousand £)	73	35	11

[12] Provided excel sheet from CCDC with cost analysis

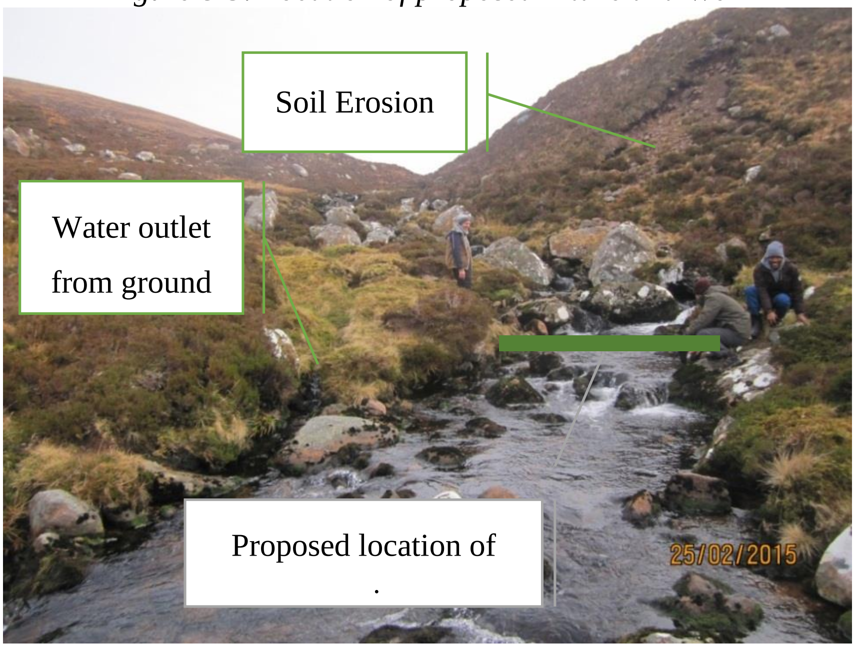
[13] Pdf file provided by CCDC containing desktop analysis done by Green Highland Renewables Ltd.

8.8 Location of Intake for Ben Mor Hydro

8.8.1 Analysis of Proposed Intake Site

A field visit to the Ben Mor Hydro site was conducted on 25th February, 2015. During the site visit it was observed that the weir of the proposed intake was proposed just below a site of soil erosion, as shown in the figure below. This may increase the amount of sediments passing through the intake. The probability of sheet erosion in rainy seasons also increases due to the exposed surface. This leads to the requirement for the construction of a larger sediment basin which is expensive and risky since it includes a large volume of earth excavation on the hill. In the event that silts and sediments are not removed to the desired level, it causes cavitation and erosion on the turbine blades. This eventually increases the operation and maintenance cost of project.

Figure 8-3: Location of proposed Intake and Weir



The width of the river in the planned intake location is also large, as shown in the figure above. Because of the larger width, it may be expensive to control the seepage of water through the weir and soil interference. Water has a particular characteristic – it tries to flow from the interference of hard and soft layers. Therefore, the soil at the ends of the weir may be eroded due to seepage of water and there is a risk of overturning of the entire weir.

The ground on the proposed intake site was observed to have holes and pits that makes the construction of weir and intake expensive for stabilization of the structures.

Figure 8-4: Proposed Intake area

8.8.2 Suggestion for New Intake Site

Due to the above mentioned reasons, search for a possible alternative intake site was undertaken. No better alternative sites for an intake location downstream of the proposed intake were found due to bank erosion. A newer better location of intake has been found at the upstream of the proposed intake.

The suggested intake is about 100 meters upstream of the originally proposed intake. The change in the amount of water between the two locations can be neglected because there is no stream between them that is discharging water. Although there is a slight increase in head, this also has been neglected. The figure below shows the location of the suggested intake and other structures on head-works.

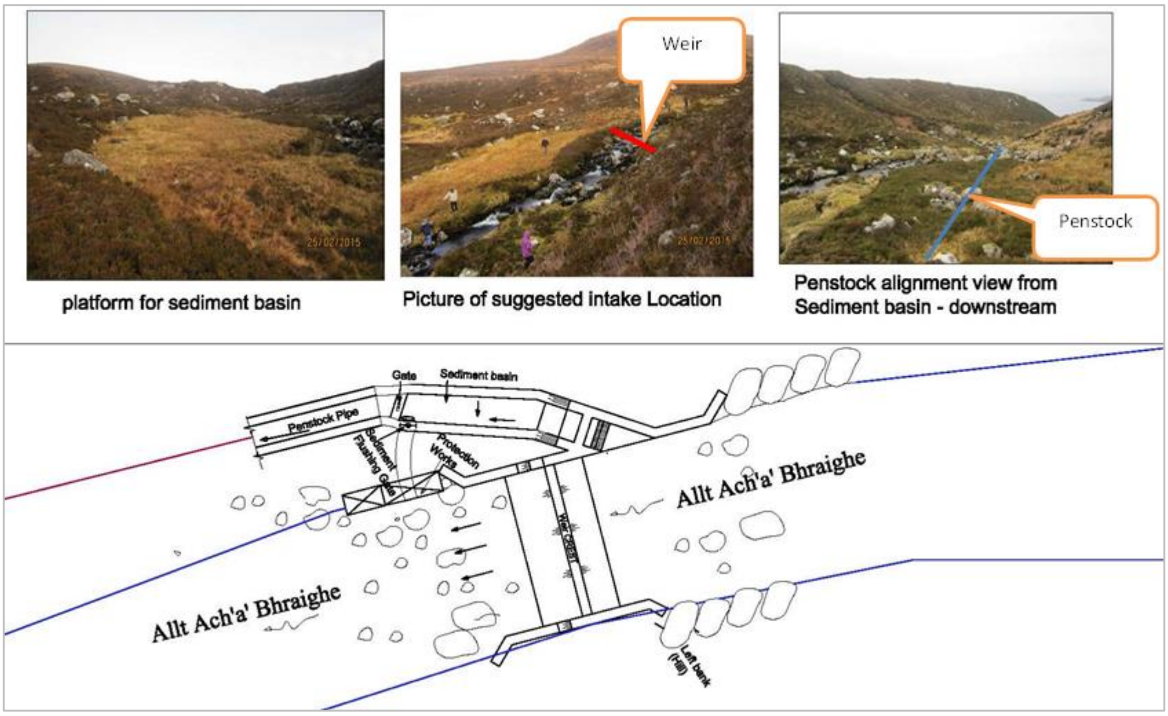
The main reasons for selecting the new intake location are listed below:

1. The width of the river on the suggested intake location is less. There is a stable steep rocky hill on the left side of the river bank. On the right side, it is comparatively flat which is suitable for an intake location constructed with flood walls.
2. No evidence of erosion was observed on the upstream of the suggested intake.
3. The location for structures of head-works like intake, sediment basin, flushing channel and intake for penstock is found to be appropriate and cost effective.
4. At this site, it also seems feasible to store water for some hours that can be used to generate electricity when there is low flow in the river. It can help in stabilizing variations in hourly generation.

5. The alignment of the penstock from the suggested sediment basin to the point of the previously proposed alignment is straight. Because of this, the alignment of penstock will be almost straight throughout the length and the head-loss in penstock due to bends will be reduced.
6. The flat ground on which the major structure lies seems to be comparably more stable than the intake site previously proposed.

The layout of the suggested intake is shown in the figure below. A detailed topographical map of the suggested intake location can be seen in Annex H, Figure H-23, (Drawing no. 7).

Figure 8-5: Layout plan of the suggested intake



8.9 Recommendations

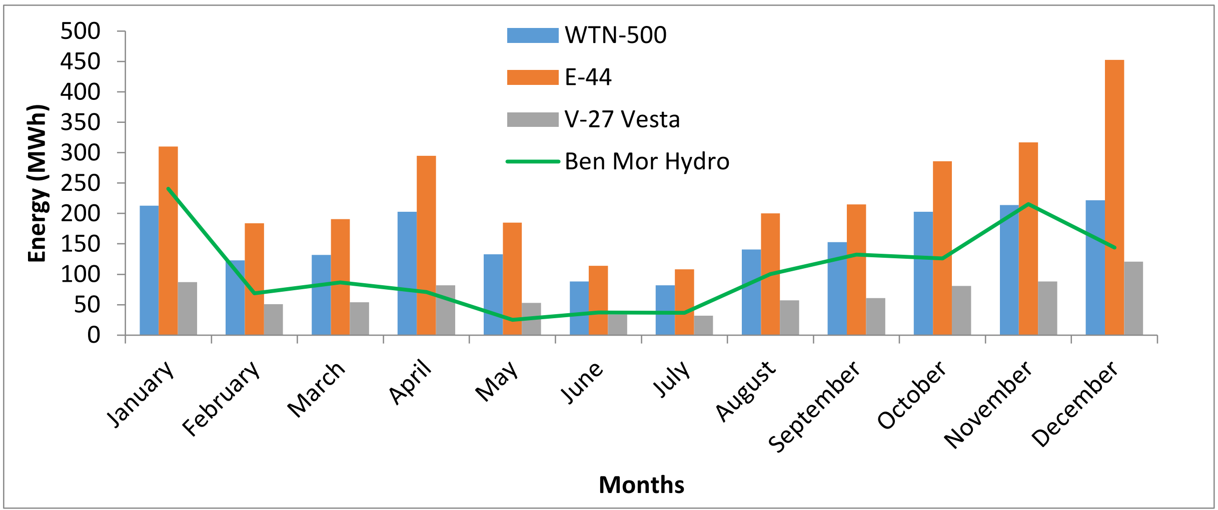
As this study was based on the measured data near the intake of Scottish Water, for Ben Mor hydro, it is recommended to measure the discharge at the location of hydro intake for at least one year. Detailed feasibility study of the project is recommended to reduce the risks and uncertainties within the project.

8.10 Generation Profiles of Wind and Hydro

The telephone call with the grid operator opened a possibility of combining the generation of wind and hydro and connecting to the grid. For a known grid constraint, the wind and hydro generation should be combined before it is connected to the grid. For the detail analysis of the different combinations of wind and hydro generation profiles, different scenarios have been built and will be explained in subsequent chapters.

The figure below shows the monthly energy generation of different wind turbines (E-44, WTN-500 &V-27) and Ben Mor Hydro. From the graph, it can be seen that wind and hydro have similar levels generation outputs (higher in winter season and lower in summer season).

Figure 8-6: Monthly energy generation of different wind turbines and Ben Mor Hydro



9 District Heating System for Island View Village, Community Hall and Primary School

9.1 The District Heating Scheme Overview

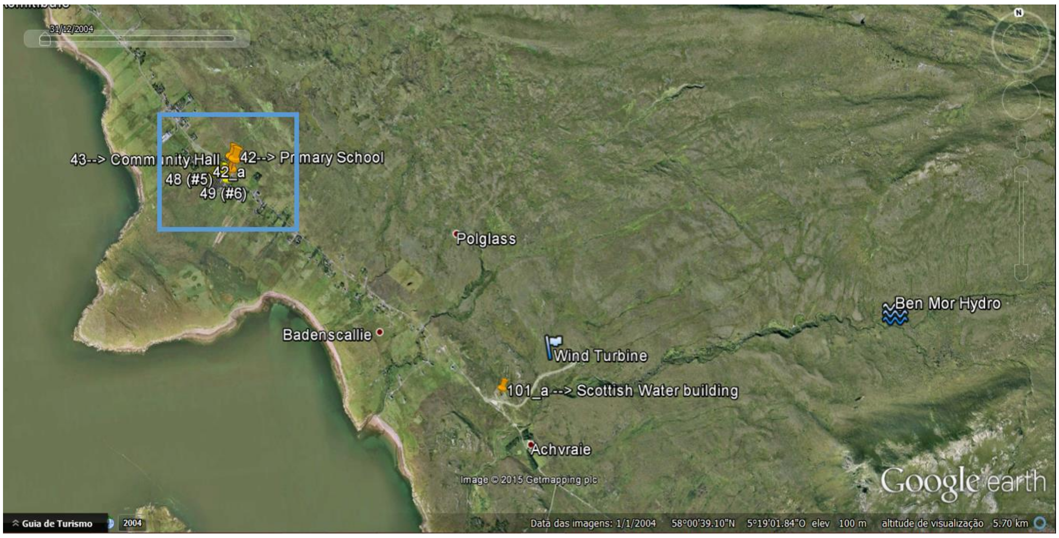
As contextualized earlier in chapter 6 Energy Demand of the Community, connecting of the renewable energy project to local demand is an option for overcoming the grid constrains. The present chapter of the report proposes a District Heating System (DHS) that will utilize excess electricity from the wind turbine and Ben-Mor hydro to provide heating to the community.

However, one challenge associated with the renewable energy system is the inherent variability and unpredictability of the electricity produced. Therefore, a central boiler equipped with thermal storage heating water system is used to supply heated water to the buildings, and the heat is transferred through a water based radiator system.

9.2 Potential Location for District Heating System

The DHS being proposed would be placed as close as possible to the main heating demand in order to minimize the investment required for the pipe network. The targeted demand selected for the present study is the area comprising the 19 houses within the Island View Village, the Community Hall, and the Primary School due to its high heat demand density, discussed in chapter 6 above. The best location for the proposed DHS will therefore be in close proximity to this high demand density area, as can be identified in the Figure 9-1 below.

Figure 9-1 Location of the proposed DHN



Source: GoogleEarth

9.3 Technical Analysis of District Heating System

As presented in chapter 6, the figure of 463.89MWh/year has been calculated based on theoretical heat demand of the 19 houses in Island View Village, Community Hall and Primary School. However the total annual heat demand that a district heating has to provide must consider that there is a 25% loss in the heat distribution network. As such, the daily values of heat demand were increased by 25% to 579.86 MWh and this is the actual dimensioning heat load of the district heating, as shown in Annex D.3. The components of the DHS, especially the capacity of the electric boiler was dimensioned according to the above stated demand.

An electric boiler with 100% efficiency has been dimensioned to meet the calculated peak heat demand of 370 kW. The chosen electric boiler capacity is, however 400kW since this is the commercial size readily available on the market (Carrier United Technology, 2015).

Another component of the DHS is a thermal storage that can temporarily and hydraulically decouple heat generation and heat consumption (University of Strathclyde, 2013). Based on the expected deficit in electricity supply for the DHS due to intermittency of supply from the renewable energy projects, the capacity of thermal storage is considered to be in the range of 50 m^3 and 100 m^3 (as is demonstrated in the section that follows).

9.4 Balancing Heating Demand and Supply

The main objective of the connection of renewable energy projects to an additional load through a private wire is to use electricity that exceeds grid constraints. As will be discussed in greater detail in Chapter 10, the excess electricity from the combined generation (de-rated E-44 wind turbine and Ben-Mor Hydro) that cannot be fed into the grid should be transmitted via the private wire and consumed by the DHS. Both yearly demand and supply profiles were calculated on an hourly basis, therefore it is possible to balance them by the addition of a thermal storage tank. The excess electricity is intended to meet the direct heat demand of the targeted consumers. If there is still excess electricity after the hourly direct demand is met, it will be stored in the form of heated water in a storage tank. This heated water can be used to meet required heat demand when there is no excess electricity due to the intermittency of the combined generation. At any time when there is no excess electricity in the private grid, and the stored hot water is used up, electricity generated from the combined generation that would have otherwise been exported to the grid would directly support the DHS in fulfilling the required heat demand at the time.

Our calculations show that the use of electricity from the wind turbine and Ben-Mor Hydro scheme can cover 89% of the heat demand. Therefore, an independent oil or gas boiler will be installed to supply the remaining demand. The boiler also serves as a backup for the electrical heating in case of technical failures. Energy used in the DHS could be optimized through a storage control system that takes into account short term forecasts of wind and temperature. This is likely to decrease the need for auxiliary heating from Gas or Oil, but was not considered in our calculations. A short summary of the various supply and demand scenarios is presented in Table 9-1 below. The scenarios are based on the following conditions:

- Different hot water thermal storage capacities, ranging from 50 m^3 to 100 m^3 may be used for the DHS.
- Electricity generation from wind is based on the generation profile of an Enercon E-44 wind turbine.
- Electricity generation from hydro is based on the generation profile of Ben-Mor hydro.

Table 9-1: Supply and Demand Scenarios for DHS

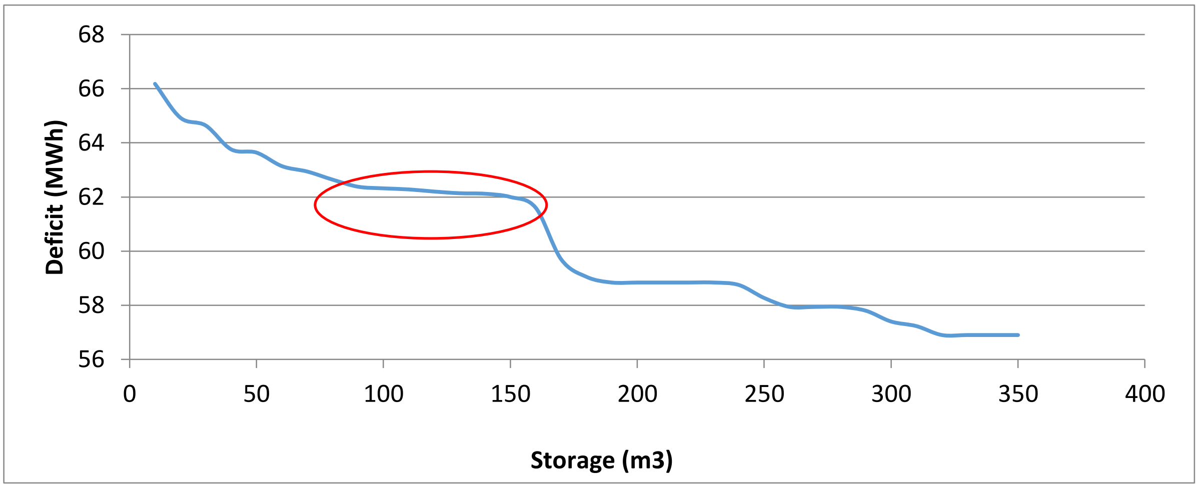
	Value (MWh)					
Capacity of thermal storage tank	**50 m^3**	**60 m^3**	**70 m^3**	**80 m^3**	**90 m^3**	**100 m^3**
Excess electricity after grid feed-in	383.48					
Heat demand supplied directly from excess electricity	142.96					
Excess electricity after directly supplying heat demand (for hot water thermal storage)	240.52					
Heat demand that cannot be directly supplied from excess electricity	436.90					
Heat demand supplied from the thermal storage	118.33	133.97	140.96	147.92	154.82	160.75
Heat demand that cannot be supplied from excess and storage	318.56	302.92	295.93	288.97	282.08	276.14
Heat demand directly supplied from electricity generation	254.81	239.78	232.99	226.32	219.69	215.20
Heat demand which cannot be covered (Needs Independent System) – Deficit	63.74	63.14	62.943	62.64	62.38	62.32

Further explanation of the supply and demand scenarios can be seen in Annex D-2, which presents a sampled time series analysis for 100 hours out of 8760 hours (annual hourly data).

As can be seen in Figure 9-2, increasing thermal storage capacity does not significantly reduce the heat supply deficit from DHS. The red circle shows that in the 50 m^3 to 100 m^3 range, the heat supply deficit is still constant. If we increase the capacity of thermal storage from 100 m^3 up to 150 m^3, the heat supply deficit reduces by 4 MWh/year. Further increase from 150 m^3 to 250 m^3 results in an insignificant decrease in heat supply deficit.

Since the cost of thermal storage is proportional to the capacity, a 4 MWh/year deficit in heat supply through an increase in thermal storage capacity of 50 m^3 (150 m^3 minus 100 m^3) or more is uneconomical; the financial calculation of DHS has been done by using thermal storage capacity of 100 m^3, and it can be seen in the following chapter of DHS. Therefore, this study considers thermal storage between 50 m^3 and 100 m^3 to be the best option for the proposed DHS.

Figure 9-2: Storage (m^3) and Deficit (MWh)



9.5 Costs and CO_2 Emission Saving

9.5.1 Investment Cost of District Heating Network (DHN)

Costs for the Residential dwellings

The costs of DHN for residential dwellings are associated with the installation of heat distribution network, infrastructure branches, and connections to the individual heating systems, which vary with the type of dwelling. Based on our survey, there are two such types found in the Council area; 7 houses are small terraced type and 12 houses are semi-detached (dense) type.

Table 9-2 shows the costs of individual heating systems, according to the type of dwellings:

Table 9-2: Cost of individual DHN for Residential Houses (Poyry, April, 2009)

Dwelling type	District Heating Network Infrastructure (£/dwellings)	District Heating Network Branches (£/dwellings)	Heat Interface Unit (HIU) and Heat Meter (£/dwellings)	Total Cost (£/dwellings)
Semi-detached (dense)	3,391	2,594	2,300	8,275
Small terraced	3,015	2,177	2,300	7,492

Costs for the Commercial Buildings

The Community Hall and Achiltibuie Primary School buildings are classified as commercial buildings. The cost of DHN associated with commercial buildings cover the heat network infrastructure, branches, and connections, as can be seen in Table 9-3.

Table 9-3: Commercial DHN Cost (Poyry, April, 2009)

Tranche Type	DHN (District Heating Network) (£/m^2)	Heat Interface Unit (HIU) and Heat Meter (£/kW)
City Center	8.4	20
Urban Area	16.5	20

In this study, due the high density of heat demand (19.3 kWh/m^2) compared to other locations in the Achiltibuie area, the tranche type of urban area has been chosen as an input to calculate the cost of DHN for commercial buildings. The area of community hall and school house are assumed to be approximately 500 m^2 and 200 m^2, respectively, based on information gathered during the demand survey.

Total Cost of District Heating Network

Based on the information described above, the total cost of DHN in Council Area can be seen in Table 9-4 below:

Table 9-4: The Total Cost of DHN (Poyry, April, 2009)

Building Occupancy	Type of Building	Ownership	No. of Buildings	Cost of Heating Network For Building (£/dwellings)	Conversion Cost From Electric Heating to the Water Based District Heating System (£/dwellings)	HIU Maintenance Cost
Council Houses	Semi-detached (dense)	Council Owned Houses	10	£8,275	£4500	£50 (per houses)
		Privately Owned Houses	2			
	Small terraced	Council Owned Houses	5	£7,492	£3,500	£50 (per houses)
		Privately Owned Houses	2			
Community Hall	-	-	1 (peak demand 80kW)	£9,850	-	£2.5 / kW
Achiltibuie Primary School	-	-	1 (peak demand 49 kW)	£4,280	£9,000 (Assumed: 2 Semi-Detached)	£2.5 / kW
Total DHN Investment			£253,372			
Operation Pumping Cost			(Additional 2% electricity demand of heat supplied) £1,971.53 with the electricity price 0.17 pounds/kWh – O&M and Operation Pumping Cost are used as an input for DHS financial calculation in Sub-Chapter below			

9.5.2 The Total Cost of District Heating System

In order to calculate the total investment cost of the DHS, the total cost of DHN should be combined with the total cost of equipment such as the cost of boiler, thermal heater storage, and fuel-oil boiler, as shown in Table 9-5. The information on cost of equipment are based on several studies that have been conducted in Denmark and Swedia (Energi Styrelsen, 2012; Danish Energy Agency, Energinet.dk, 2012)

Table 9-5: The Total Cost of DHS

Description	Capacity	Cost per Unit (£)	Total Cost (£)
Thermal Storage Heater	100 m^3	15,000	15,000
Electric Boiler	400 kW	20,000	20,000
Fuel Oil Boiler	400 kW	23,000	23,000
District Heating Network	-		253,372
Total Cost of DHS	£311,372		

9.5.3 CO_2 Emissions Savings

As mentioned in the Demand Chapter, the heating demand is supplied by different resources, such as electricity, coal, and fuel-oil. In this section, we carry out an assessment of how much CO_2 emission can be avoided if the DHS supplies heat to the 19 Council Houses, Community Hall, and Achiltibuie Primary School instead of the current heating supply methods in Achiltibuie. Table 9-6 below shows the total CO_2 emission for 19 Council Houses, Community Hall, and Achiltibuie Primary School.

Table 9-6: Total CO_2 Emission from Heating Demand (DECC UK, 2014)

	Type of Fuel	Annual Energy Consumption for Heating	Emission Factor (CO_2 kg/kWh)	CO_2 Emission (tonne) /year
19 Council Houses	Electricity	65,876.42 kWh	0.47	30.9
	Coal	321,769.4 kWh	0.313	100.7
Community Hall	Fuel-Oil	9,000 L of Oil	0.269	2.4
Achiltibuie Primary School	Electricity	40,945.6 kWh	0.47	19.24
Total CO_2 Emission (tonne) per year				153.24

The calculation for the council houses assumes that the calculated heat demand will be entirely supplied by the predominant heating system of the dwelling. For the Primary School and the Community Hall the real consumption was considered. As can be seen in Table 9-1 above, the deficit of heat demand from the DHS should be compensated from “external sources”, which could potentially be heating from the independent fuel oil boiler. The total CO_2 emission emitted from fuel-oil boiler is about 7.086 tonnes a year, based on the fuel-oil emission factor of 0.267 kg CO_2/kWh (Biomass Energy Center, 2011). Comparing the CO_2 emissions, the DHS can avoid about 146.17 tonnes of CO_2 a year.

The Highland Council is mandated to fulfill the Carbon Reduction Commitment (CRC) on energy efficiency. Since April 2010, the Highland Council has been purchasing carbon allowance in advance from heating, at a cost of about £12/tonne CO_2 emission (The Highland Council, 2013). If this value is multiplied by the CO_2 emission from fuel-oil boiler and "targeted demand", the Highland Council can save £1,753 a year.

10 Grid Situation and Options Available to CCDC

This section of the report reviews the grid conditions and options available for the development and integration of renewable energy into the local power network in Coigach. The present situation of the existing 11kV distribution line in Achiltibuie and the 33 kV feeder that supplies power to the community are analysed to determine the capacities available under ideal conditions for renewable energy development and integration. The study on the technical details of the incoming 33kV line to the Achiltibuie substation has been included because they are considered important inputs for the analysis of the first grid option available to CCDC – the construction of a new 33kV line that connects to the existing 33kV feeder to carry power generated from the wind turbine. The aim of this analysis is to determine the additional capacity available for the export of power from new generation sources, such as a new hydropower. Available capacities under constraint conditions are also analysed and technical options to overcome these conditions are proposed.

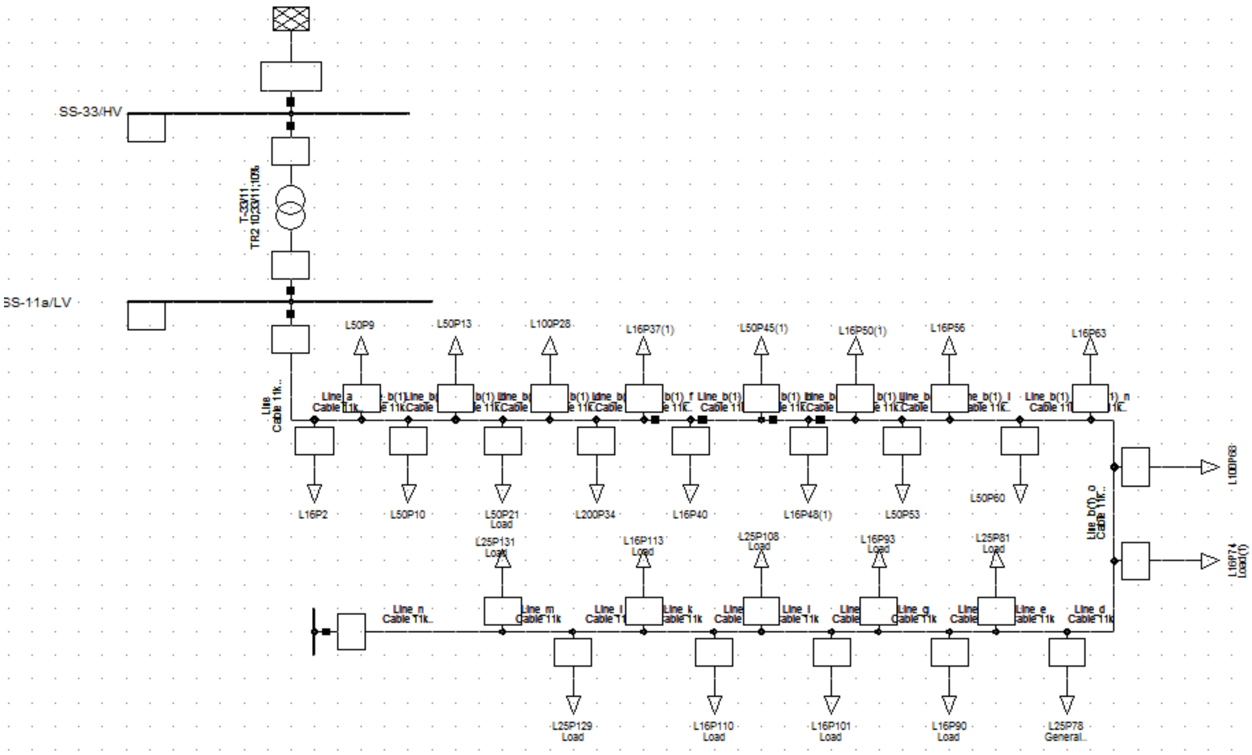
10.1 Current Grid Situation

In order to understand the performance of the network and the impact of the planned connections to the grid, the current network is simulated and load flow analysis are carried out using DIgSILENT's PowerFactory software. The modelled system, shown in Figure 10-1, was based on information retrieved from Scottish and Southern Energy's (SSE) grid map for Achiltibuie. SSE is responsible for the transmission and distribution network in Scotland. The main distribution network in Achiltibuie is the 11 kV line that starts at the primary Achiltibuie substation where the 33kV to 11 kV transformation takes place, until the Culnacraig distribution transformer at distribution pole 131.

From information provided on the SSE grid map, the 11 kV line is divided into two sections: three phase from pole 1 to pole 69, and two phase from pole 69 to pole 131 at the end. Supply to end-users in Achiltibuie is achieved through 28 low voltage (LV) transformers located along the length of the 11kV line as is shown in Figure 10-1. The total length of the line is approximately 9.63 km and theoretically, the total actual connected peak load on the line has a value equal to 1.083 MVA (sum of the LV distribution transformer capacities).

The primary substation belongs to the grid supply point group called Grudie Bridge, and in addition to local Achiltibuie demand on the 11kV line, demand from two other villages – Reiff and Achnahaird – are supplied from the substation on separate wires.

Figure 10-1: Primary Achiltibuie substation and 11 kV line with connected load



Source: Authors own figure from PowerFactory simulation

According to the SSE, presently there is no certainty about the maximum capacity of the local 11 kV distribution network, since a detailed study is required to determine this. From a phone call conversation with SSE representatives, it was mentioned that the network constraints may be related to issues regarding both the primary substation transformer and 11kV line that could be a result of both thermal (where power lines or transformers ratings could be exceeded) and voltage (where the voltage level could breach statutory voltage limits) limitations. A study by SSE to determine the actual grid capacity is scheduled to commence soon. However, this study is expected to last between to 2 to 9 months, a timeframe that falls outside the scope of this report. CCDC however confirmed that even without a study it has received various grid capacity figures from SSE over the years, with 600kW being the latest and lowest of these figures. Therefore, the maximum capacity of the 11kV distribution network is assumed to be 600kW until a study is carried out. For all grid constraint limits analysed in this section, the remaining capacity of the 11 kV network will be considered equal to 600 kW.

Information provided in the SSE Long Term Development Statement (Scottish Hydro Electric Power DIstribution, 2013), was also used as input in PowerFactory. This included technical details such as substation firm capacity, current local demand, minimum load, as well as the substation transformer rating (1MVA). However, due to the lack of complete technical information, some assumptions were made in order to complete the modelling and simulations: the transformer was assumed to be a 2-winding transformer and a scaling factor of 0.6 was used in order to take into consideration the remaining capacity of the network that is assumed to be 600kW. The 32mm^2 copper conductor as indicated in the SSE grid map has rated current for different seasons at 50°C operating temperature as follows: in summer, 158 A; in spring and autumn 184 A; and in winter 198 A, (BRB Cable Industries Ltda, 2013), (UK Power Networks, 2013). The rated currents are limited to the maximum operating temperature for each season where the ambient temperature is specified. Based on these values of rated current, theoretically, the maximum capacity of the 3-phase line is equal to 2.4MVA in summer.

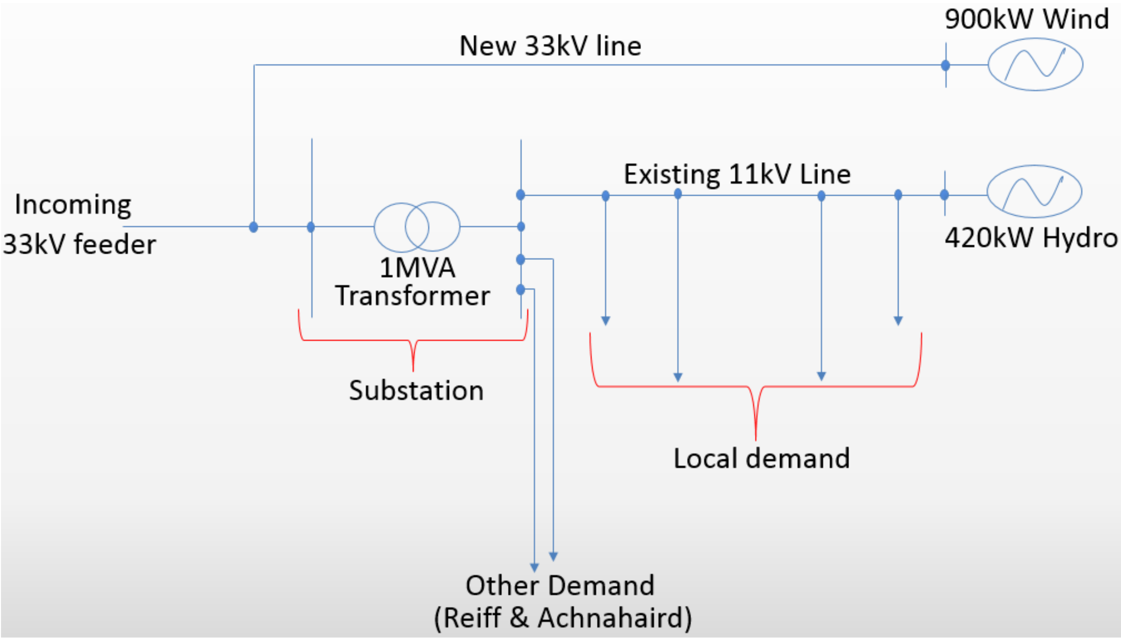
A PowerFactory simulation conducted under the conditions that: there is no 600kW grid constraint, the 420kW Ben Mor hydro and 900kW E-44 Wind are connected to the network; and no load is connected to the network, showed that the 11kV line is able to carry an additional capacity of 1000kW, without exceeding a limited loading range of 80% in the line, and with a rated current equal to 158 A in summer. In other words without any transformer restrictions at the substation, the 11kV line by itself could carry in excess of 2.32MW.

Figure 10-1 above also includes the existing 33kV feeder connected to the primary Achiltibuie substation. From the information provided on the SSE grid map, the conductor specifications for the 33 kV line are 3-phase CAD copper wire with a size equal to 60 mm^2, according to the SSE grid map. The rated currents for this conductor for the different seasons were taken as 197 A, 229 A, 247 A; for summer, spring/autumn and winter respectively, (BRB Cable Industries Ltda, 2013), (UK Power Networks, 2013). Theses conductor sizes and current ratings are maintained for the simulation of the new 33 kV line explained in the next section.

10.2 Connection to a new 33 kV line

Figure 10-2 below depicts how the local Achiltibuie network would look should CCDC accept the proposal to build a new 5km 33kV line dedicated to exporting power generated by the Enercon E-44 wind turbine. Knowledge of the additional capacity in both 11kV and new 33kV lines is important when in relation to planning and developing new renewable energy projects on the network.

Figure 10-2: Local Achiltibuie Network with new 33kV line

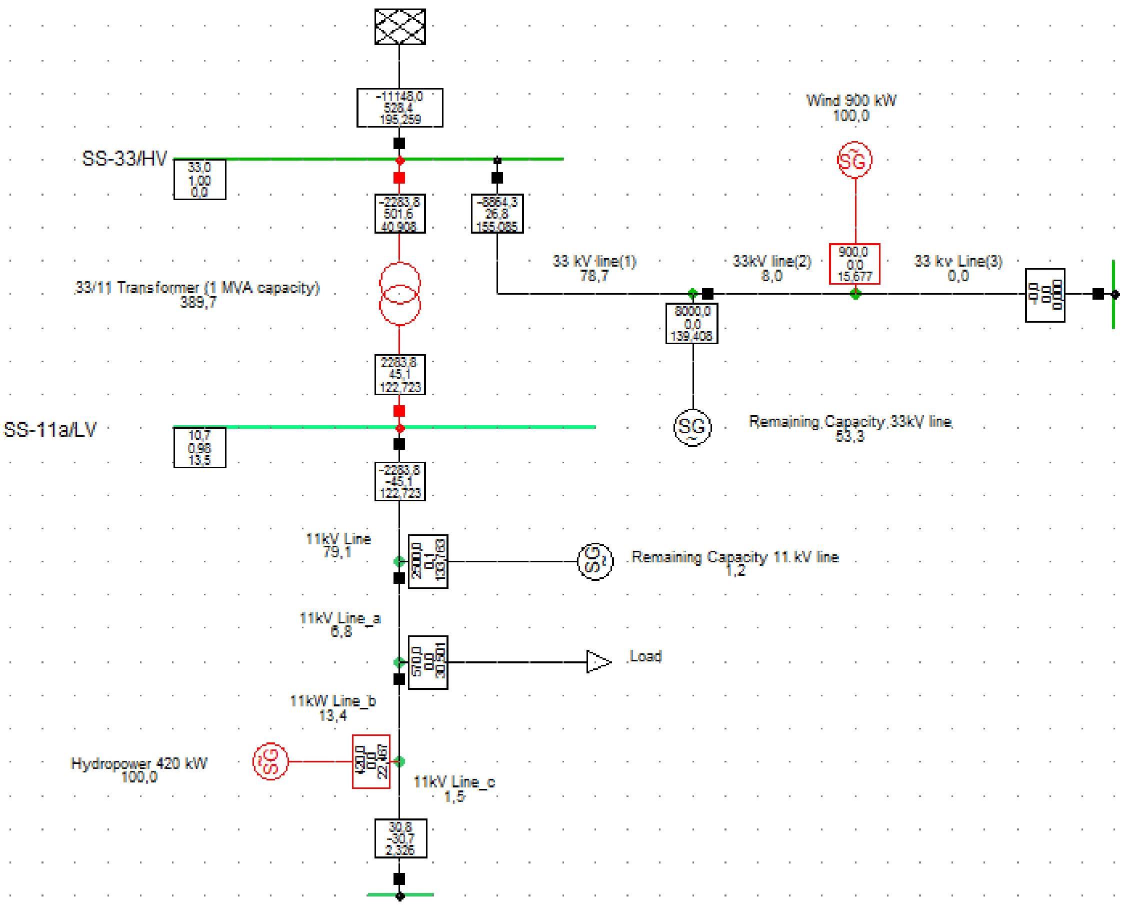


No-load connection on either line scenario, or a peak load of 570kW on the 11 kV line scenario are assessed to determine available capacities of the two lines after connection of both planned wind and hydro plants. Both scenarios are simulated with peak power generation from the hydro power plant on the 11kV line and the wind turbine on the 33kV line. *Figure 10-3* shows the PowerFactory diagram corresponding to these scenarios. The diagram shows the connection of the two generators, the connected peak load and the remaining capacity in both lines. *Table 10-1* summarises the results of the situations analysed. The results show that the 33kV line has sufficient additional capacity to export power from a new generation source, such as a new hydropower. It is worth emphasizing that the substation constraints have not been considered in this analysis, only actual specifications for the 11 kV and the 33kV cables were taking into account in order to determine the additional capacity that both lines are able to carry given the actual technical features of the cables.

Table 10-1 Remaining capacity in 11kW and 33kW line

Load type	**Remaining capacity on the exiting 11 kV line**	**Remaining capacity on the new 33 kV line**
Without load	1.9MW	8MW
Peak Load (570kW)	2.5MW	8MW

Figure 10-3: Remaining Capacity on the Achiltibuie network with new 33kV line



Source: Authors' own figure from PowerFactory simulation

10.3 Technical options for export of wind power on existing 11kV line

Should CCDC decide to go with the existing 11kV line and avoid the cost of building a new 33kV line dedicated to export of power generated from its planned Enercon E-44 wind turbine, it may be worth exploring the following options.

10.3.1 Substation transformer upgrade

Should the SSE's grid constraint study confirm the 11kV line to be technically sound and the transformer as the cause of the constraint, a simple upgrade from the current transformer (1MVA) to, for instance, 2MVA will remove any constraint and allow both hydro and wind power plants to be connected to the 11kV line. This option however is unlikely to be a solution even if the existing transformer is the cause of grid constraint. The operator has already said an upgrade would cost CCDC about £1,000,000 which is more than the cost of a new 33kV line. This cost is rather high, given that an upgraded transformer will likely be in the range of 2 or 4MVA. In a telephone conference held on the 23rd of February between CCDC, Community

Energy Scotland (CES) and SSE representatives, the operator agreed that although the existing transformer is only 1MVA and an upgrade of 2MVA would be suitable to carry current generation, it can only upgrade from 1MVA to 12MVA. The reason for this big gap in transformer sizes is unclear to the authors, especially in light of the fact that the DNO's own demand forecast for Achiltibuie does not exceed 600kW until 2019, (Scottish Hydro Electric Power DIstribution, 2013) and the fact that the maximum capacity in summer of the 11kV line itself is 2.4MW under ideal conditions. This implies that using an upgraded transformer of 12MVA still leaves a limited network capacity of 2.4MW due to the line capacity.

10.3.2 Adding another transformer to operate in parallel with current 1MVA transformer

If the transmission network constraints are primarily due to transformer limitations at the substation then a parallel operation of the current transformer with a second transformer may be a viable option to explore. The total power (kVA) available when two or more transformers are connected in parallel is equal to the sum of the individual transformer's ratings. Therefore should the SSE study establish a grid constraint of 600kW to be a result of the current 1MVA transformer being able to only operate at say 600kVA due to thermal issues, another 1MVA transformer could be installed to increase the total power of the substation to 1.6MVA. Such a system will adequately carry the combined generation of the planned wind and hydro projects (1.32MW). Detailed technical information on the operation of transformers in parallel can be found in Annex G.2.

First contact with the SSE regarding implementing this option was not encouraging in terms of cost. SSE representatives argued that a parallel transformer operation as solution to the grid constraints in Achiltibuie is likely to cost more than the estimated cost of a new 5km 33kV line. This they said is made worse due to land acquisition issues for a parallel substation. A price check in SEPD's statement of methodology and charges for connection reveals the cost of adding an additional transformer to an existing indoor substation to be in the range of £906,150 to £1,785,000. These figures were similar to those from connection charge documents of other distribution network operators in the UK (SP Energy Networks, 2014). These documents however do not mention the transformer KVA rating for which these costs apply.

In appendix-2 of SEPD connections methodology modifications (OFGEM, 2014) the 33kV substation sizes range from 5MVA to 15MVA. Based on this size range we can assume a price of £906,150 for 5MVA transformer. But this is a much higher rated transformer than what will be needed for parallel operation of transformers at the Achiltibuie substation. A smaller 1MVA 33kV/11kV transformer is likely to cost less than £906,150. Transformers rated 1MVA and 2.5MVA are available on the market and costs are much closer to the current 1MVA or less transformer at Achiltibuie. Should the grid operator agree, this option could be further explored.

10.3.3 Active Network Management system for wind turbine

The DNO has agreed, if the various parties concerned with the wind and hydro projects so request, to accept another grid connection offer for the 11kV local network that will allow the hydro and wind power plants to feed-in their combined generated output into the grid as a single generation entity. This request, if confirmed will supersede the current approved 11kV grid connection offer for the hydro power project. Therefore, any superseding offer will have to ensure that power generated from the hydro power plant has priority for grid feed-in over power generated from the wind turbine, otherwise stakeholders of the hydro power plant will have no incentive to accept a superseding offer requiring them to share the grid with power generated from the wind turbine.

Hydro will thus act as base supply for grid feed-in under constraint conditions, while power output from the wind turbine will be used to ensure any remaining grid capacity is utilized. To implement this superseding offer under the current constraints, it is essential that the output of the wind turbine is managed in a secured and guaranteed way. It is important to coordinate and control the operation of the hydro plant and especially of the wind turbine, given the intermittency of power generated from wind. To achieve this coordination and control requires actively managing power output from the wind turbine as well as all components and conditions involved in connecting and supplying power from the turbine to the grid in such a way that it always complements power generated from the hydro power plant.

Active Network Management (ANM) is a process that uses IT, automation and control to manage grid constraints associated with the integration of distributed generation. ANM can be used to manage energy producing devices such as wind turbines to resolve network constraints on both Transmission and Distribution systems (Kane & Ault, 2013). The use of ANM applications as alternative to grid reinforcement in addressing grid constraints has been gaining attention in recent years. These applications are being continually deployed by distribution network operators in the UK, including SSE. Although SSE has played a leading role and bore some of the cost (mainly through funds from government) of major ANM projects such as the Orkney Smart Grid project implemented in its operational zone, it appears the CCDC must take a leading and cost-bearing role for any ANM system required to connect its wind turbine to the local grid.

The superseding offer likely to be implemented in Achiltibuie requires the community to supply a combined fix amount of power from their wind and hydro renewable energy projects unto the grid. The operator in this case is only concerned with the community ensuring the power supplied unto the grid does not exceed its given constraint. The grid operator does not cater for what happens behind the connection or metering point. This means the community must devise a means of ensuring the possible total output from their combined generations (900kW + 420kW) does not exceed the 600kW limit allowed by the operator at the connection point. Should combined generation exceed 600kW, the community must ensure a maximum of 600kW is fed into the grid and formulate additional ways of using or getting rid of the excess generation. As all costs required to do this occur behind the meter and must be borne by the community. An ANM scheme to be implemented for the Achiltibuie project will require CCDC to invest in additional network management equipment that includes (Kane & Ault, 2013):

- Communications
- Controllers - for the 900kW wind turbine, and private wire if this option is exercised
- Additional Operation and Maintenance costs
- Staff hiring and or training

Smarter Grid Solutions, a pioneering smart grid solutions company with headquarters in Glasgow, were involved in the novel Orkney active network management system together with SSE. As such they have a range of ANM products that could be adopted for the automation and control of the operations of Coigach's wind and hydro power plants. This will ensure their combined export to the grid never exceeds the grid limit while also integrating the proposed 'private wire' being considered by CCDC for supplying excess electricity to nearby local demand.

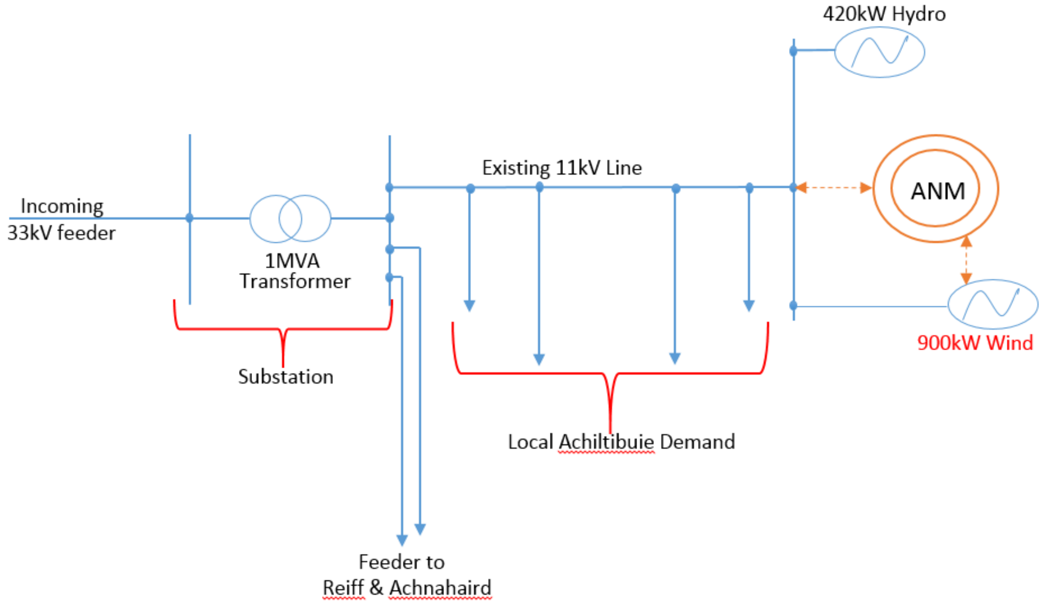
The most basic of Smarter Grid Solutions' ANM products is the CONNECT Plus (CONNECT+) suite. CONNECT+ employs a "real-time, autonomous and deterministic control" that allows it to operate connected distributed generations in a "pre-determined, repeatable and time-bounded manner" (Smarter Grid Solutions, n.a). "CONNECT+ provides a simple but reliable control mechanism to manage the real power of the DG relative to thermal or voltage thresholds for both of the constraint locations. A CONNECT+ unit handles up to 4 objects, including the DG, its associated circuit breaker, along with one local and one remote measurement point / constraint" (Smarter Grid Solutions, n.a).

CCDC's superseding offer may take two directions depending on which option CCDC decides to exercise.

Option One: (Grid constraint with no consideration for private line to supply local load):

Should CCDC decide to leave out private wiring and only supply the grid under the current constraint, an ANM system for this option will be very simple as only the wind turbine output needs to be controlled. A CONNECT+ ANM system with one unit will suffice to ensure the combined output of hydro and wind does not exceed the given grid limit of 600kW. Fault conditions and deployment of protective equipment for the wind turbine shall all be incorporated into the above controls to guarantee that faults do no lead to a breach of the grid limit. The figure below depicts the Achiltibuie distribution network with the implementation of an ANM system.

Figure 10-4: Single line diagram of the Achiltibuie network with ANM control of wind production



In this case the likely logic of operation would be as follows:

[Maximum combined output <= 600kW

ie, Hydro output (H) + Wind output (W) <= 600kW

Grid Feed-in Priority:

1. All Hydro power produced must first be exported.

2. Only then can Wind output power be considered for export.

Therefore, W = 600kW - H

Curtailment: Wind production must not exceed 600kW - H (a threshold limit just below this).]

A threshold just below the DNO's given grid constraint limit must be established to guarantee the operation of any ANM control mechanism. The ANM control mechanism for this option is shown in Annex G.2.

Cost of ANM option one

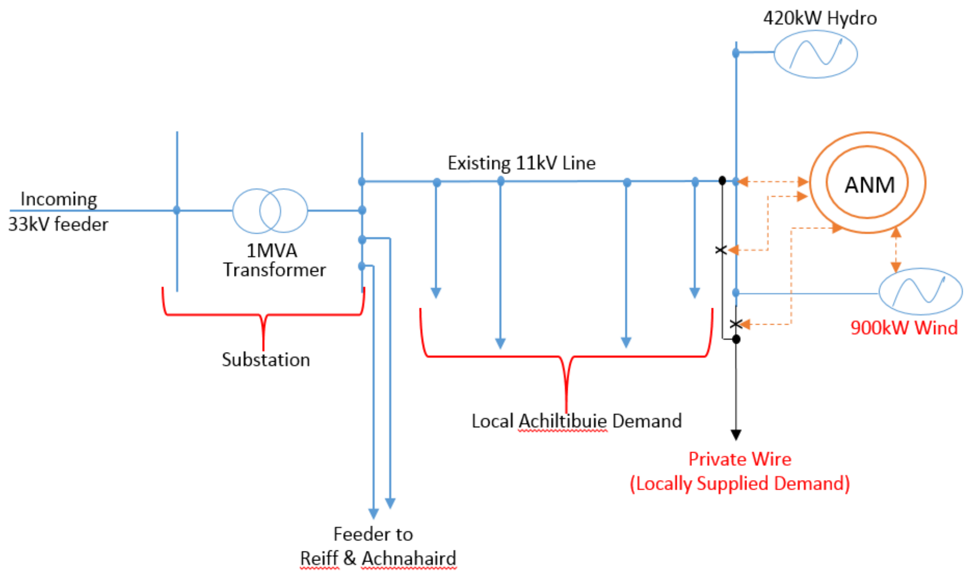
Based on a December 2014 Imperial College London report that described ANM projects carried out by the DNO UK Power Networks (Imperial College London, 2014), an ANM setup to control a single generator will cost £50,000. For this study however, it is assumed that an ANM system for this option will cost CCDC £70,000. With this option, which makes no provision for local demand on a private wire, if the amount of energy production from the 900kW wind turbine being curtailed is found to be too large then downsizing to another wind turbine will be a better option.

Option two: (Grid constraint with private wire consideration)

This study also explores the possibility of building a private electricity supply line to feed excess wind generation that will otherwise be curtailed to private local demand. This demand could be in the form of a district heating system that will use excess electricity to produce and supply heat to council houses, the Achiltibuie Community Hall, the primary school and possibly the privately-owned surrounding houses. Demand on the private wire is further discussed in chapter 6.

An ANM system that incorporates this private wire supply will be more complex than the case in option one. It will have to manage feeding-in up to 600kW into the grid and also ensure any excess is fed to the local demand through the private wire. The figure below depicts the Achiltibuie distribution network with the implementation of an ANM system and a private wire.

Figure 10-5: Single line diagram of the Achiltibuie network with ANM control of wind production and private wire



A likely logic for these operations may be as follows:

[Maximum combined output <= 600kW + PW

ie, Hydro output (H) + Wind output (W) <= 600kW + PW

Supply and Feed-in Priority:

1. All Hydro power produced must first be exported.
2. Only then can Wind output power be considered for supply.
3. If combined generation is below 600kW and there is no heat storage:
    a) First send power to district heating plant (PW)
    b) Export remaining power to the grid
4. If there is heat storage at district heating plant (PW):
    a) First export up to 600kW of generated power to grid.
    b) Send excess to district heating plant

Curtailment: Wind production must not exceed {(600kW + PW) – H} (or threshold just below this).]

The ANM control mechanism for this option is shown in Annex G.2.

Cost of Private Wire and additional ANM components

While it is ideal to locate any local demand intended to be supplied by excess electricity from the wind turbine as close as possible to the turbine for economic reasons, the case of Achiltibuie and CCDC's wind turbine presents a peculiar challenge. Households in the community are generally sparsely located and there is no readily available energy intensive load to be supplied. The closest energy intensive load to be supplied – a proposed district heating plant – is approximately 3 km away from the location of the wind turbine. An underground 11kV cable covering this distance will cost approximately £350,000 [okney project excel sheet]. An 11kV/400V step-down transformer with rating of 400KVA together with associated switchgear for both transformer and 11kV line will cost approximately £50,000.

An ANM setup for the control logic that considers the private wire will not only require a mechanism to control power output from the wind turbine but will also require a mechanism to switch and control power flow to the private wire and or the grid at any particular time. While the ANM setup for the wind turbine in option one may cost CCDC £70,000 as mentioned above, the power flow control required to ensure the desired supply priority is achieved implies an added cost. Additional components required to integrate the private wire into the ANM system for option one, such as power flow controls, data cables and measuring equipment are estimated to cost another £50,000. That is, option two with the private wire will cost £450,000 in additional to the cost of option one.

Alternative Load: Scottish Water Facility

Scottish Water, the main supplier of treated tap water to households in the Achiltibuie area is located only about 300m away from the wind turbine site. As identified in the local demand survey, this load includes two pump motors (with two others as replacement) that transfer water, that run for 14 hours a day on average. According to data obtained at the sire, over the course of a year, an amount of 217.0MWh is consumed. The close proximity of this load in comparison to the suggested location of the district heating plant implies that the huge investment needed for a private wire in the case of district heating can be avoided. In addition, the difference in total excess energy to be utilized by the proposed district heating plant and that by Scottish Water is not significantly large, and Scottish Water provides a local load that is already available in comparison to the extra investment, time and uncertainty that comes with establishing a district heating plant for the community of Achiltibuie. Efforts to supply power to Scottish Water, at least in the short-term should be seriously pursued.

11 Methodology for the Financial Analysis of the Community Energy Options

In the earlier sections of this report the elements of the local community energy concept for Achiltibuie have been clearly explained in terms relevant to the wind and hydro projects, the local demand and the corresponding grid system. The aim of the following chapters is to consolidate this information in the form of a combinational analysis – the results of which will be the issuing of different options for CCDC to foster the development of the region through renewable energies. A financial analysis shall be used to provide a comparative basis for the decision-making process in accordance with the different grid situations and thereby help to highlight the most promising options.

As the capacity constraint on the existing grid constitutes the main limitation for a simultaneous connection of hydro and wind, the chosen options are aligned with the potential grid options which have been identified and described in the preceding chapter. Along with the underlying grid configuration, the wind project also plays an integral role in identifying the various options but its connection to the 11 kV system was not initially granted as a part of the SSE grid offer. It is therefore the variable element in our analysis while Ben Mor Hydro is considered as constant and given primacy for feed-in to the existing 11 kV line. In accordance, the Ben Mor Hydro Project is analysed with regards to its financial outcomes in this chapter and will be referred to in combination with the wind projects in the following scenario chapter.

11.1 Methodology

The overall methodology is a business-economic investment analysis supported by a project-oriented energy systems analysis, which is based on the findings of the previous chapters. This has led us to the development of an excel tool for analysing the cash flows of the renewable energy projects utilising the different turbine combinations. It is inspired by the financial analysis provided by CES and CCDC[14] with certain key amendments, and aims at providing the real Cash Flows per annum and the Net Present Value of the resulting Profits or Losses as an outcome. By calculating an Internal Rate of Return for an investment, it is possible to assess the profitability of the analysed turbines and compare them on basis of individual performances.

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[14] Excel spreadsheets as provided by CCDC.

The tool uses the site-specific Generation Profiles as supplied by chapters 7 (Renewable Generation: Wind) and 8 (Renewable Generation: Hydro), and generates the cash flows in accordance with the actual, or respectively anticipated, values for the FIT as described in chapter 5 (Regulatory Framework) Framework Annual expenses for O&M, insurance and rates, the chosen loan schedule, taxes and grid connection costs represent the predominant negative cash flows and are incorporated according to the specifics of each project (see chapter 7 and 8)[15].

The analysis is being carried out for the individual wind and hydro projects and will be subsequently combined in the following chapters in order to display the overall returns for CCDC as the sole shareholder of Coigach Wind Power Ltd and 50% shareholder of Ben Mor Hydro Ltd.

11.2 Assumptions for the Financial Analysis

The following list consolidates all the main assumptions for the financial analysis:

- The date of FIT eligibility, associated with the date of grid connection, for the renewable energy projects has been assumed to be December 1st 2016 – according to the recent delay in the grid offer by SSE for the hydro project.
- The Export Tariff is 4.85 p/KWh for all projects according to Table 5-2.
- The Retail-Price-Index (RPI) is assumed to be 2.0% on average for the lifetime of the projects.
- According to (Renewables First, 2015) and based on the rather low level of the London Interbank Offered Rate (LIBOR)[16] at present, loans between 4-5 % should be achievable. We therefore assume an interest rate of 5% for a long-term loan of up to 20 years and an amount of up to £1.5 Mio. A higher interest rate of 6% for a short-term loan of up to 10 years, making up for the rest of the investment, is being presumed.

A detailed list of assumptions is included in Annex F.1.

11.3 Financial Analysis of Ben Mor Hydro Ltd.

As described in the foregoing chapters, Ben Mor Hydro Ltd. has been granted a grid offer for its rated capacity of 420 kW to the 3-phase 11 kV line. With its application for FIT accreditation

[15] The tool is described in detail in the annex to and attached to this report (see Annex F)

[16] see (Financial Forecast Center, 2015)

in December 2014, the scheme has secured a FIT-Rate of 14.25 p/kWh and an export tariff of 4.85 p/kWh for connection until December 2016. The analysis in chapter 8 shows that Ben Mor Hydro can be expected to generate 1,283 MWh per year resulting in an average yearly gross income of £296k through the 20 years of its lifetime.

Figure 11-1 displays the annual as well as cumulative cash flows for the project. Based on our calculations[17] the investment produces an average net income of almost £40,000 a year varying from £1,000 to £174,000 depending on loan and tax payments. On the bottom line, this results in total earnings for Ben Mor Hydro Ltd. of £374,000 at the net present value and an internal rate of return of 5.6%. This rate of return seems reasonable when comparing it with information on similar projects surveyed by the British Hydro Association[18].

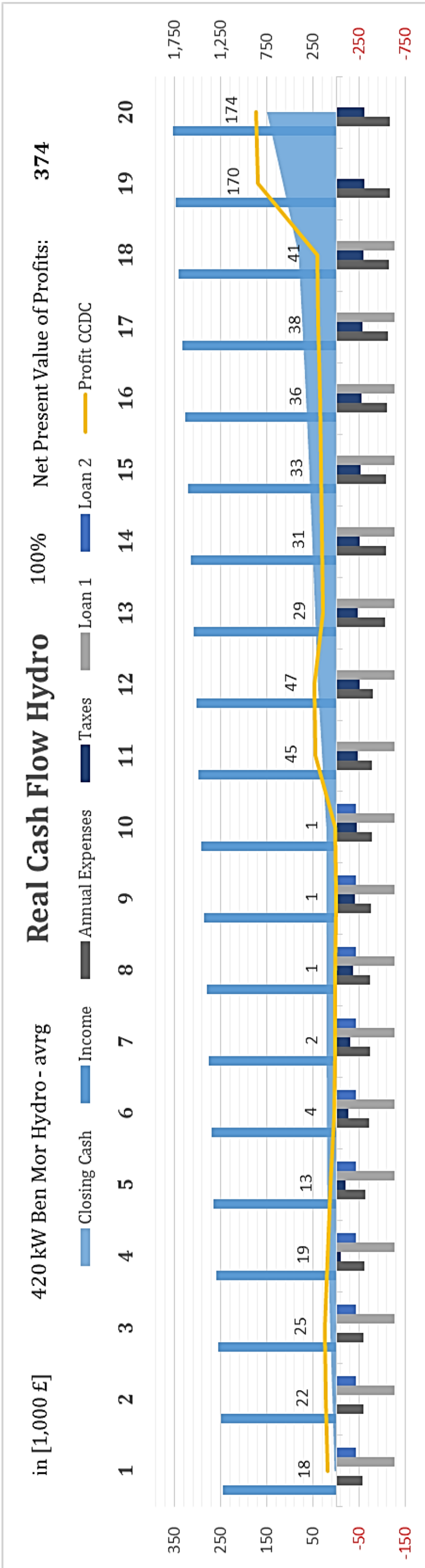
It is however important to note, that extreme weather conditions can lead to cases where the annual expenses exceed the yearly income and as a result losses of up to £35,000 in a year of minimal precipitation can be expected[19].

[17] assuming a loan of £ 1.5 mio. with an interest rate of 5% p.a. on an 18 year term in combination with a short-term loan of £ 0.32 mio. at an interest rate of 4% and a payback period of 10 years.

[18] according to a survey by the (British Hydro Association, 2012) for 171 hydro projects installed in 2011/2012 (IRR between 5-8%).

[19] worst-case scenario: 18% less precipitation and a substantially lower energy generation of 1052 MWh/a according to the minimum precipitation out of 35 years (see chapter Renewable Generation: Hydro)

Figure 11-1: Projected Cash Flow Ben Mor Hydro (average)



12 Scenario 1: Connection to a new 33 kV line

This scenario is based on the existing grid offer by SSE involving the connection of the proposed wind turbine to an extension of the 33 kV grid. In this configuration the constraints restricting usage of the 11 kV line and the sub-station limitations are bypassed and no longer relevant. A major disadvantage of this solution however, is the fact that Coigach Wind Power Ltd has the responsibility of constructing the 5 km 33 kV line thereby bearing the estimated cost of £750,000 for this undertaking. There is however a corresponding financial benefit which lies in the fact that the installed wind turbine is able to feed-in at its full capacity resulting in a higher financial yield, in conformity with the generation profiles presented in chapter 7. This unrestrained yield in kWh per annum is then directly linked to both financial income streams provided by the FIT – the generation tariff and the export tariff (see chapter 5). As follows, the scenario has major financial implications associated with it, which will be evaluated herein.

12.1 Financial Analysis

The table below presents the outcomes of the financial analysis for the E-44 900 kW turbine and its down-rated counterpart of 500 kW – each representing their corresponding Technology Class of wind turbines.

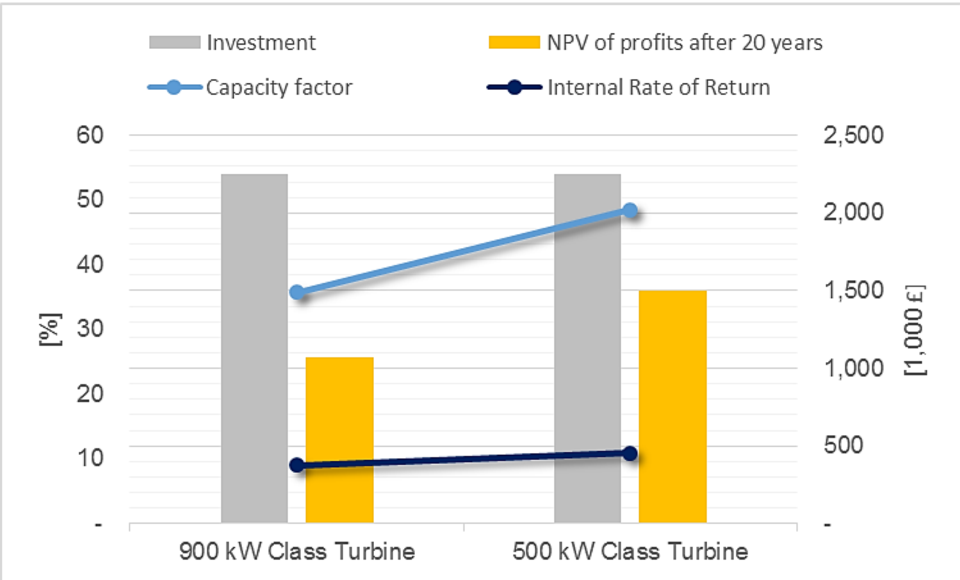
Table 12-1: Financial Analysis of a 33 kV connection

33 kV connection Technology Class / Project		900 kW Class Turbine	500 kW Class Turbine	Ben Mor Hydro
Investment	[1,000 £]	2,249	2,249	1,820
FIT rate	[p/kWh]	6.54	12.05	14.25
Energy Generation				
At rated capacity	[MWh/a]	2,820	2,119	1,283
Capacity factor	[%]	35.77	48.48	34.87
Full load hours	[h]	3,133	4,239	3,055
Financial Return				**50% CCDC**
Average annual profit	[1,000 £]	110	145	19
NPV of profits after 20 years	[1,000 £]	1,069	1,501	187
Internal Rate of Return	[%]	9.04	10.90	5.60

Our analysis shows that both wind turbines are well capable of bearing the additional investment for the grid connection. Due to the high energy yields which can be achieved at the projected wind site in combination with the selected turbines, the financial outcomes are very satisfactory and as expected lie above average in comparison to on-shore wind sites in noncoastal regions across Europe. The study by (IPA Energy + Water Economics, 2008), issues higher IRR rates for comparable sites on the Western Isles (9-13%), Shetland (16-30%) and Orkney with the highest of all capacity factors and figures ranging from 29-58% of IRR. As the study is based on different assumptions and regulatory conditions in 2008 (higher FIT rates) however, it cannot be directly transferred. The study clearly states though that grid constraints and the resulting costs to overcome them – such as the 33 kV line in this case – have a major impact on the returns.

When evaluating the two options for wind turbines against each other as presented here, the 500 kW turbine class achieves a higher financial return on its investment. This is mainly due to (1) the higher FIT rate and to a minor extent due to (2) the higher capacity factor. As both investments are equal – when comparing the E-44 with its down-rated counterpart – the impact of the higher FIT rate becomes more obvious. The principal reason is a better gross income per kW ratio[20]. This makes it the better choice of turbine according to our analysis.

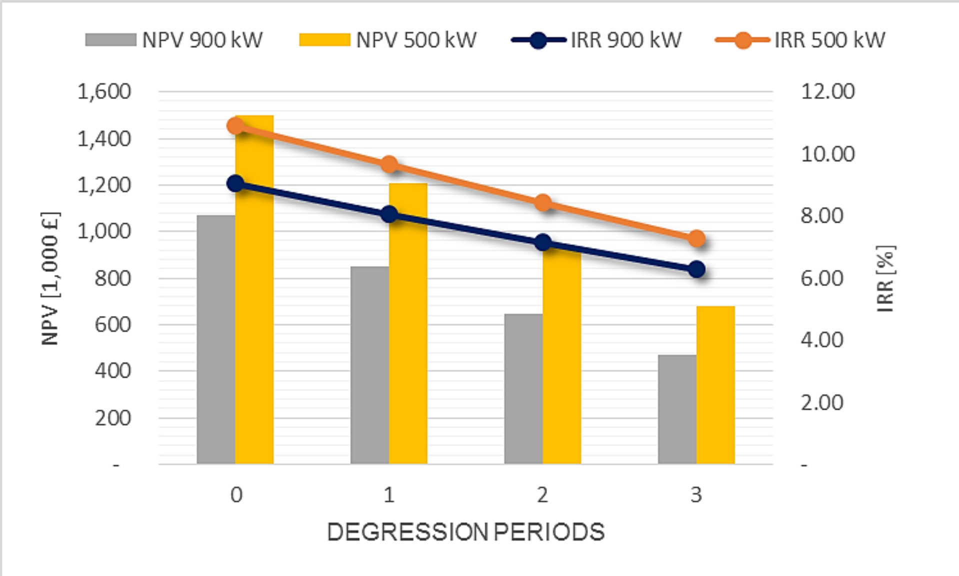
Figure 12-1: Financial Analysis of a 33 kV Connection



In addition, it is important to highlight that our assumptions are based on the successful application for FIT accreditation within the period 1. April 2015 to 31. March 2016. This means that the wind turbine would need to connect to a 33 kV line before 31. March 2017. Figure 12-2: displays the sensitivity analysis for a postponement of the project assuming a 10% degression between each of the periods.

[20] 500 kW: 17.3 [1,000£/kW]; 900 kW: 8.6 [1,000£/kW] – calculated with income over lifetime.

Figure 12-2: Income Degression / FIT Periods (33 kV)



The consequence of a further delay of the project would be crucial and effective throughout the duration of the project (20 years[21]). As our analysis has proven that the FIT has the most important influence on the economics of a wind turbine, the loss of considerable revenue is a possibility. It is therefore advisable to connect within the aforementioned period.

Another impact on the gross income of the projects is associated with the wind yield per year. Extreme weather conditions could lead to years where the annual expenses exceed the yearly income and as a result, losses of up to £32k (900 kW) could be expected[22].

In conclusion it can be said that the installation of a 33 kV line to connect the wind turbine is a technically[23] and financially sound option for connecting both generation projects to the public grid. Our investigation shows that the additional investment for the 5 km line can be borne by the wind project and that the overall investment in renewable energies provides a solid additional income for CCDC to pursue their plans of community development. The financial analysis shows furthermore, that a 500 kW class wind turbine with a corresponding high capacity factor is capable of delivering a higher rate of return than the projected E-44 turbine.

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[21] Period of FIT payments

[22] worst-case scenario: 18% less wind on average and a substantially lower energy generation of 2421 MWh/a according to the minimum wind speed assumed for one year (out of 15 years); see chapter 7.

[23] See section 10.2

Figure 12-3: 33 kV – 500 kW

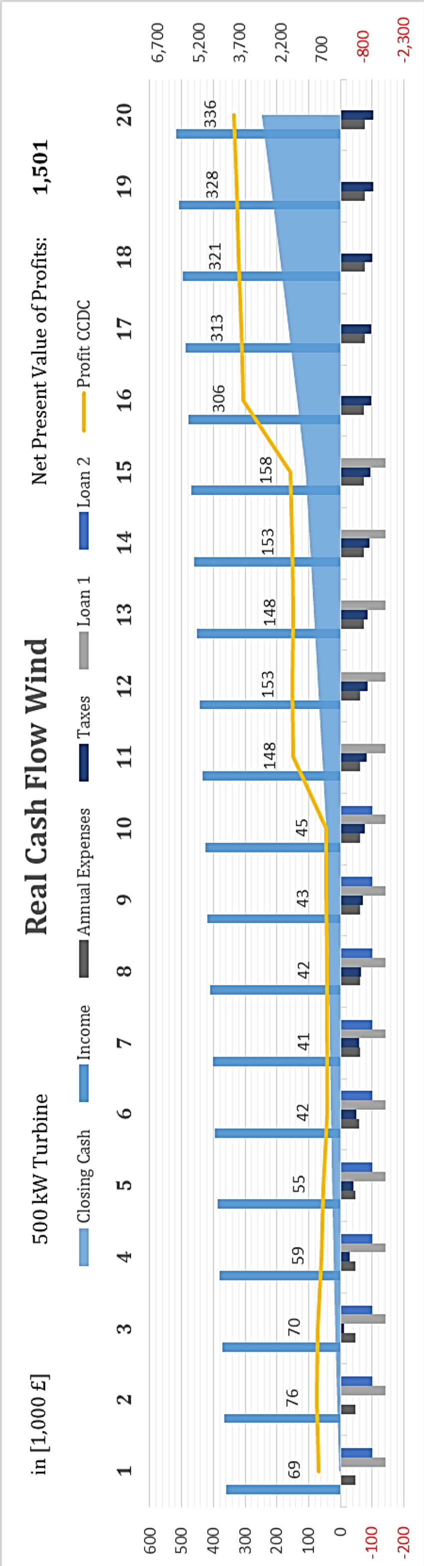
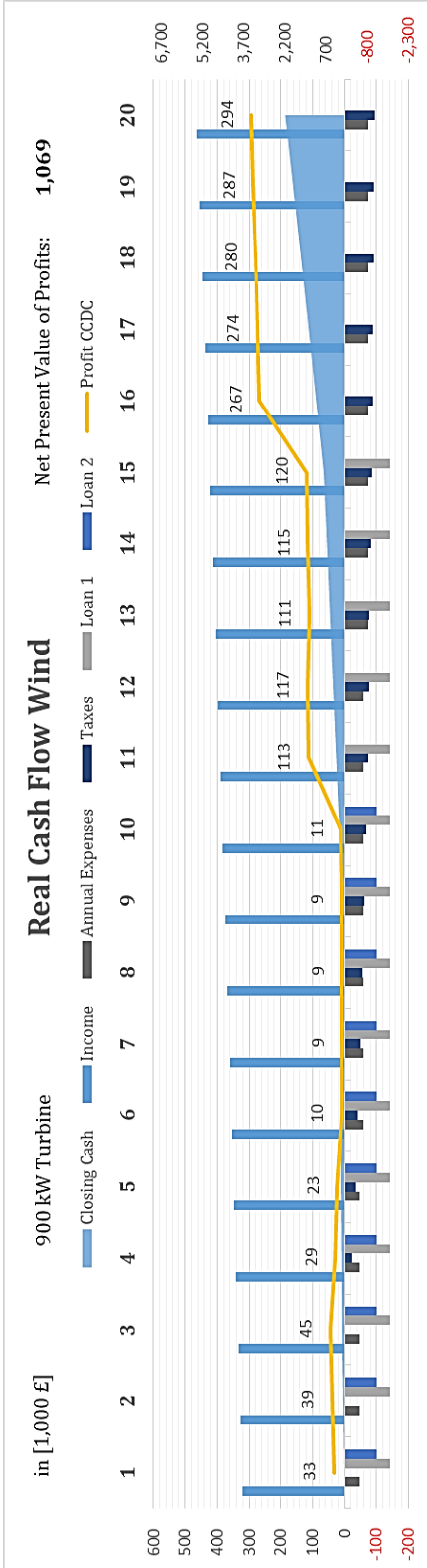


Figure 12-4: 33 kV – 900 kW



12.2 Additional Hydro Sites

The installation of the wind project and its connection to a new 33 kV line provides the opportunity for additional small-scale renewable energy projects to connect to the 11 kV along with Ben Mor Hydro. In section 8.6 we introduced two new hydro sites, which could serve as additional income generating projects for CCDC and Achiltibuie. This section consolidates the results of a simplified financial analysis in order to give an outlook with regards to their financial feasibility.

For the proposed 200 kW hydro scheme at *Allt a' Choire Reidh* a FIT rate of 12.04 p/kWh has been presumed[24]. Under these circumstances, the overall investment of £860,000 would lead to an internal rate of return of 9.3%[25] and a considerable net present value of the projected profits of £460,000. With an average annual income of £44,000, this scheme would deliver a noticeable additional margin to the aforementioned wind and hydropower projects.

The 60 kW site at *Badenscallie Burn* has been analysed presuming a FIT rate of 15.23 p/kWh[26]. With its similarly high capacity factor of 46% it represents a profitable investment with an IRR of 13.9%. The annual net income of £23,000 accumulate to £238,000 at net present value. As with the above described 200 kW site, *Badenscallie Burn* shows promising numbers and according to our assessment is an investment worthy of serious consideration.

[24] Based on a degression of 5% from the rate valid from 1 April 2015 to 31 March 2016 (12.67 p/kWh).

[25] As mentioned in chapter 8.6 the scheme delivers a higher capacity factor than Ben Mor Hydro resulting in a higher IRR.

[26] Based on a degression of 5% from the rate valid from 1 April 2015 to 31 March 2016 (16.03 p/kWh).

13 Scenario 2: Options for the Existing 11 kV Line

This scenario is based on the amended grid connection offer that will allow the hydro and wind projects to feed-in their combined generation output into the existing 11 kV grid. As indicated in chapter 10 (Grid Situation and Options Available to CCDC) and chapter 11 (Methodology for the Financial Analysis of the Community Energy Options), the combined generation entity cannot exceed the grid system's capacity restraints in this case. This ultimately results in the fact that the wind turbine needs to be levelled in accordance to (1) the feed-in by the hydro system and (2) the remaining grid capacity. From a business-economic point of view, this scenario is less capital intensive as compared with the investment of a 33 kV grid extension but has to bear the disadvantages associated with the restrained financial return on the wind project.

In order to evaluate the different options and to make them comparable with the preceding scenario, we aim to provide answers to the following questions:

1) Is the wind project economically viable in a situation of combined feed-in with Ben Mor Hydro under the 600 kW grid constraint?
2) How would the projects perform under higher grid constraints and could there be arguments derived by this for CCDC to approach SSE?
3) What are the benefits for CCDC and the Community when supplying a district heating system through a private wire?

13.1 Financial Analysis for a Connection under a 600 kW Grid Constraint

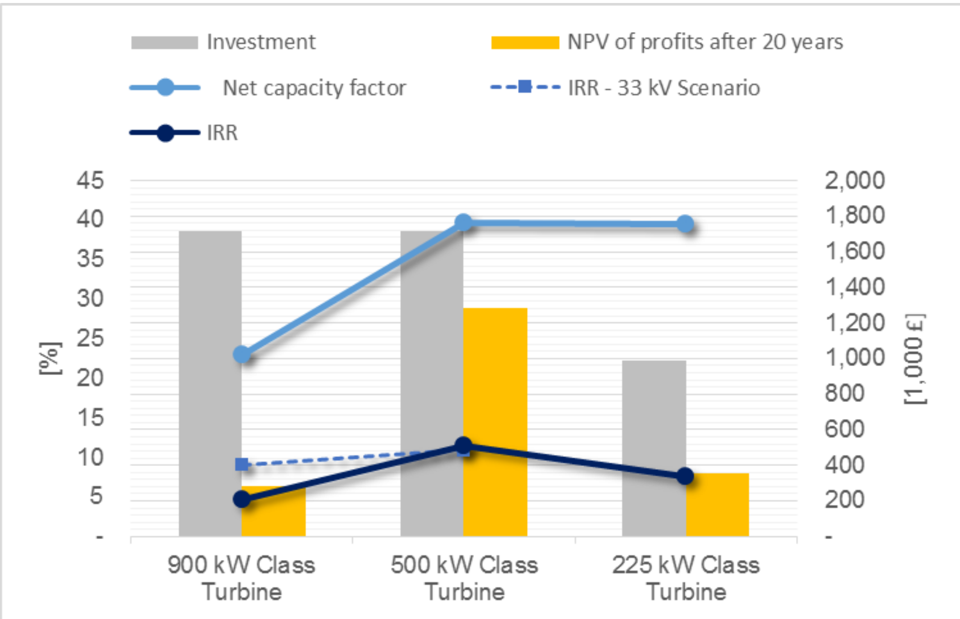
The negative effect caused by the restrained feed-in and therefore by the restrained gross income is large – yet not substantial for the economic feasibility of the projects. *Table 13-1* shows the results of the business-economic analysis.

Table 13-1: Financial Analysis of an 11 kV connection – 600 kW constraint

11 kV connection - 600 kW Technology Class / Project		900 kW Class Turbine	500 kW Class Turbine	225 kW Class Turbine	Ben Mor Hydro (50%)
Investment	[1,000 £]	1,719	1,719	986	1,820
FIT rate	[p/kWh]	6.54	12.05	12.05	14.25
Energy Generation					
Grid feed-in	[MWh/a]	1,817	1,736	778	1,283
% of generation capacity	[%]	64	82	98	100
Net capacity factor	[%]	23.04	39.71	39.49	34.87
Excess electricity	[MWh/a]	1,003	383	15	-
Financial Return					**50% CCDC**
Average annual profit	[1,000 £]	25	119	37	19
NPV of profits after 20 years	[1,000 £]	280	1,280	355	187
Internal Rate of Return	[%]	4.63	11.50	7.50	5.60

Due to the reduced income all absolute figures such as the NPV or the average annual net income are reduced by ~18% (500 kW) to ~77% (900 kW). For the 900 kW class turbine, a 40% drop in the IRR in comparison with the 33 kV line scenario results in the rather low value of 4.6%. This can be explained by the 1,003 MWh of excess electricity, which could have been generated and exported in a case of unrestrained grid connection.

Figure 13-1: Financial Analysis of an 11 kV Connection – 600 kW constraint



As the negative effect of the reduced gross income is proportional to the reduction of kWh exported to the grid, the 500 kW class turbine experiences less shortcomings. The increase of the IRR in comparison to Scenario 1 (Figure 13-1) can be explained through the slight decrease of the annual expenses (O&M), counterbalancing the negative effects for this figure. It is of minor importance however.

The 225 kW class turbine outperforms the 900 kW class with an NPV of £355,000 and a satisfactory internal rate of return of 7.5%. More importantly is to note that the smallest turbine category is capable of providing CCDC with an additional net income of £37,000 per year on average under this set-up. Taking into consideration that the total investment is just under £1 Million, this makes it the second best choice overall.

As a result of our analysis it can be said that all turbines remain financially stable under a 600 kW combined connection to the 11 kV grid. The economic tolerance to external effects such as a year of lower wind speeds however, is drastically reduced especially for the E-44 (900 kW). The fact that 36% of its generation capacity cannot be met by the grid to any further extent means that under extreme weather conditions the project could run into a loss of £17,000 in such a year. Furthermore, it can be concluded that a 500 kW turbine appears most profitable under such a grid constraint. The 225 kW turbine is a possible option for CCDC to look into as its investment is smaller and the annual returns nevertheless promising under this grid constraint.

Figure 13-2: 11 kV (600) – 500 kW

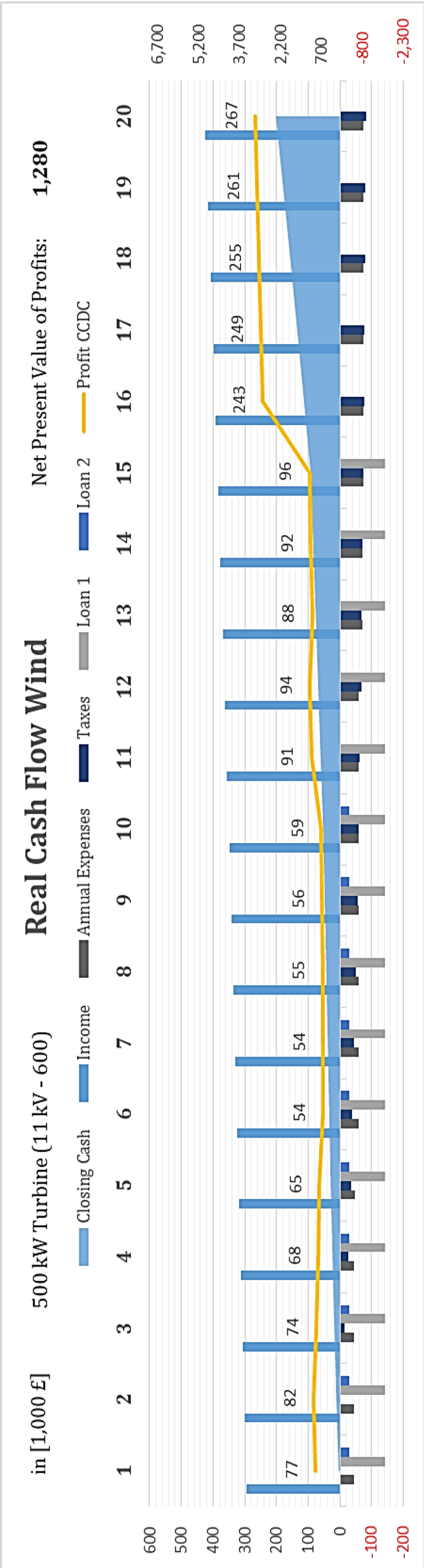
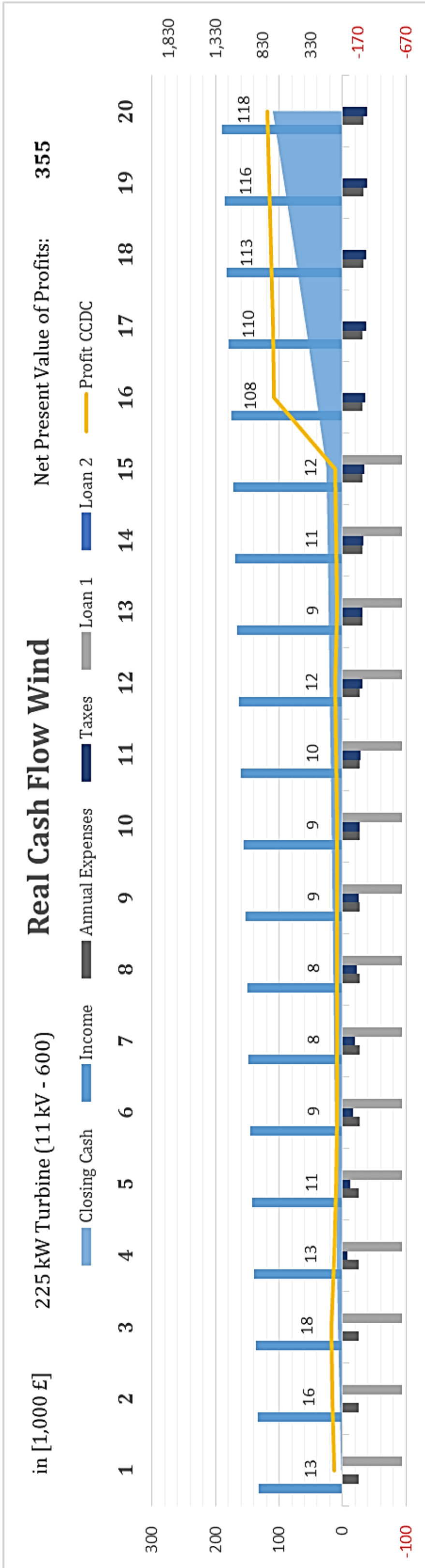


Figure 13-3: 11 kV (600) – 225 kW



13.2 Financial Analysis of the 11 kV grid under different feed-in capacity constraints

In many regards the existing limitations on grid connectivity is the main hindrance to maximising revenue from the proposed renewable energy projects. This section of the report will mainly assess the wind turbine operation under different grid constraints with hydro unchanged. This is shown in Table 13-2.

Assessment of the 900 kW turbine shows that with a grid constraint of 700 kW, the turbine is capable of feeding 15.74% more energy into the grid with a corresponding 28% reduction in the amount of excess electricity over the 600 kW grid constraint and a significant increase in both NPV and IRR. The high investment cost in combination with a low net capacity factor for this option of wind turbine is the main motivation for seeking an increase in grid access so as to improve the financial output.

Table 13-2: Financial analysis of the 11 kV grid under different feed-in constraints

11 kV connection Technology Class / Project		900 kW Class Turbine	500 kW Class Turbine	225 kW Class Turbine	Ben Mor Hydro (50%)
Investment	[1,000 £]	1,719	1,719	986	1,820
FIT rate	[p/kWh]	6.54	12.05	12.05	14.25
600 kW constraint					
Grid feed-in	[MWh/a]	1,817	1,736	778	1,283
Excess electricity	[MWh/a]	1,003	383	15	-
NPV	[1,000 £]	280	1,280	355	187
IRR	[%]	4.63	11.50	7.53	5.60
700 kW constraint					
Grid feed-in	[MWh/a]	2,103	1,912	794	
Excess electricity	[MWh/a]	716	207	-	
NPV	[1,000 £]	669	1,632	391	
IRR	[%]	7.20	13.47	7.85	
800 kW constraint					
Grid feed-in	[MWh/a]	2,342	2,030	794	
Excess electricity	[MWh/a]	478	89	-	
NPV	[1,000 £]	992	1,868	391	
IRR	[%]	9.18	14.71	7.55	
900 kW constraint					
Grid feed-in	[MWh/a]	2,530	2,108	794	
Excess electricity	[MWh/a]	289	12	-	
NPV	[1,000 £]	1,242	2,022	391	
IRR	[%]	10.66	15.52	7.55	

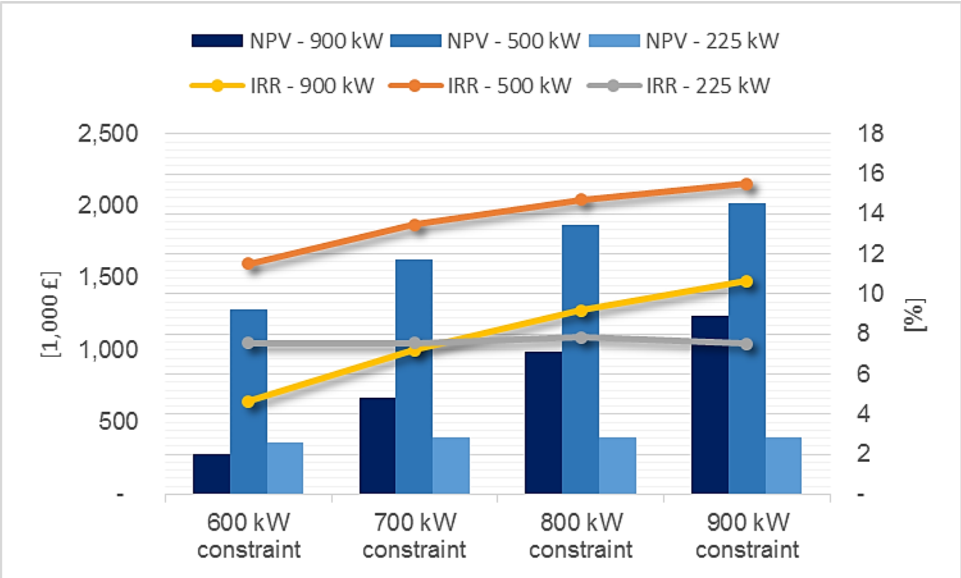
Comparatively, the 500 kW turbine which receives a significantly larger FIT over the 900 kW, is able to achieve a much more lucrative financial outcome. The NPV with this choice of turbine is of the order of 2-3 times greater than the corresponding 900 kW turbine mainly due to higher

FIT, this at a higher capacity factor with less excess electricity. Analysis under the different grid levels again illustrate that with a 700 kW grid feed-in the NPV improves by 25-30% over the 600 kW constraint. This is an average annual increase in profit over the project lifetime of £29,000.

The smaller 225 kW turbine produces less than half of the energy of the above two options. It still receives the same level of FIT as the 500 kW turbine but at a lower investment. The grid constraint is not an issue for this turbine since it does not produce any significant excess electricity. Here the CCDC can circumvent the present grid constraint problems with a turbine than earns a respectable return on investment (IRR 7.22%) and still have the option of repowering in the future with a higher capacity turbine for increase output and revenue.

The graphical representation of the above analysis is given below and clearly illustrates the advantage of the 500 kW turbine for each of the grid constraints under consideration.

Figure 13-4: Financial analysis of the 11 kV grid under different feed-in constraints



Furthermore it displays that the largest leap in figures of IRR and NPV is being achieved when changing the grid constraint from 600 to 700 kW. The changes from 700 to 900 kW are almost linear and comparatively less beneficial than the first stage. Analysis suggests that with a grid constraint of 700 kW an optimised equilibrium between CCDC supply and SSE grid availability could be reached, which would ultimately provide a higher contribution to the overarching goal of development in the region. Sharing this information with SSE could potentially assist them in targeting their efforts in respect to the gains to be had from a detailed grid study.

14 Scenario 3: Benefits of Supplying a District Heating System through a Private Wire

The options of connection of community energy project to the grid analysed up to the present stage (33 kV Scenario as well as the connection of RE under constraints to the 11 kV grid) have been carried out from the private investor's point of view. There are however additional benefits which can be derived from community-owned renewable energy. As indicated in section 5.4.2, the un-used generation potential which remains as a result of a circumventing the output of the wind turbine under a 600 kW grid restraint (see Table 13-1) could be consumed by a district heating system balanced with a thermal storage (chapter 9) – freeing additional benefits for the community as described in chapter 6. RE project can be linked to a district heating network through a private wire, bringing a considerable additional income from the Feed-in Tariff as more renewable energy is being consumed. This scenario will assess the overall benefits of this set-up and in-doing so, center it towards CCDC, The Highland Council and the Community as central stakeholders.

14.1 Financial Analysis for CCDC and Coigach Wind Power Ltd.

The financial results in figures of Gains and Losses associated with the establishment of a private wire are shown by the table below from point of view of the wind project.

Table 14-1: Gains and Losses – CCDC / CWP – Private Wire (11 kV)

CCDC / Coigach Wind Power Ltd. Gains and Losses	500 kW Turbine		Profit / Loss Annually	Net Present Value 20 years
	[MWh/a]	[p/kWh]	[1,000 £]	[1,000 £]
Gains				
Additional generation (FIT)	302	14.64	44	551
Income electricity sales	517	0.00	-	-
Losses				
Grid feed-in (Export Tariff)	215	5.89	-13	-158
Financial Results				
Net Income			32	393

Our technical analysis of the generation profile of an E-44 500 kW turbine feeding the storage unit of the District Heating System, shows that in an optimised operation of the storage[27], 298 MWh are now being used and respectively generated. This represents 78% of the 383 MWh,

[27] as dimensioned in chapter 9

which have been curtailed in a situation without the private wire (formerly excess electricity). This results in £44 thousand additional gross income from the FIT yearly. In contrast, 219 MWh are actually withdrawn from generation within the presumed grid constraint (600 kW). This portion of generated electricity could have been sold to the grid formerly for the value of the export tariff (5.89 p/kWh on average over 20 years). As a result, an annual loss of £13 thousand has to be accounted for.

In conclusion, this situation leads to a very positive effect for the wind project. An average annual net income of £32 thousand accounts for profitable £393,000 in net present value[28] whilst the District Heating System could be serviced at a rate of 0.00 p/kWh.

14.2 Financial Analysis for District Heating

In order to evaluate the viability of a district heating fed by community energy, a rough financial evaluation is done in the following lines. Looking into the point of view of the Highland Council, the estimated investment cost of £287.5 thousand in the district heating system including distribution network and conversion of the heating systems of the 15 council-owned houses as well as the school. Private houses from the Island View Village would have to invest of £4,500 or £3,500 for the conversion of the heating system per household (semi-detached or terraced, respectively). Since the community hall has already an underfloor heating system, there is no need for conversion, therefore no additional investments are required.

For the current scenario, the private wire costs of £450,000 (including upgrade of ANM, transformer and underground cable – section 10.3.3) is being considered as part of the district heating investment, to be taken over by the Highland Council. Therefore, a total investment of £737.5 thousand is required.

The financial evaluation that is presented in the Table and graph below shows the Internal Rate of Return (IRR) for the Highland Council investment in two different cases. In the first case the Council making the full investment and the Council taking 50% of the investment, considering that the second part of the DHN is subsidised by government support scheme or other entity such as European Union, for example. The input of expenditures consists of operation and Maintenance (O&M) costs as calculated in chapter 9. Revenue are accounted by the charge of a fixed annual district heating connection tariff, estimated in £100 per customer and the income from heat sell, considering that the calculated heat demand is consumed by the costumers. In

[28] assuming a discount rate of 5%

both cases the expenditures and revenues were considered as constant throughout the 30 years life-time of the district heating infrastructure.

Figure 14-1: District Heating Financial Analysis

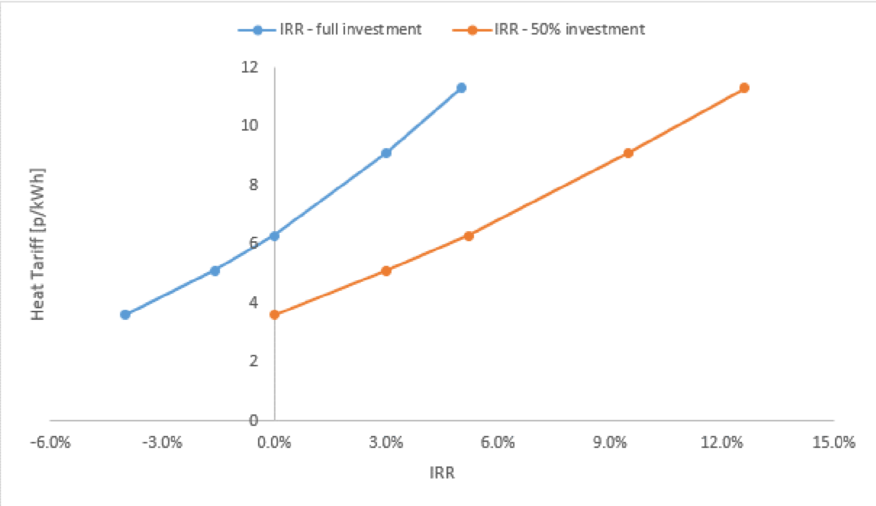


Table 14-2: District Heating Financial Analysis

Highland Council District Heating Operation	Heat Tariff 3.6 p/kWh [£]	Heat Tariff 5.1 p/kWh [£]	Heat Tariff 6.3 p/kWh [£]	Heat Tariff 9.1 p/kWh [£]	Heat Tariff 11.3 p/kWh [£]
Expenditures					
Electricty Purchase (517.5kWh/year)	0				
Oil Purchase (6,929L/year)	2938				
O&M, Houses	750				
O&M, School	122				
O&M, Pumping	1972				
O&M, Electric Boiler	567				
O&M, Fuel Boiler	360				
Revenue					
Annual Tariff	2100	2100	2100	2100	2100
Income heat sales (463.9kWh/year)	16700	23658	29225	42214	52419
Financial Results					
IRR - full investment	-4.0%	-1.6%	0.0%	3.0%	5.0%
IRR - 50% investment	0.0%	3.0%	5.2%	9.5%	12.6%

The financial evaluation of the investment in a district heating by the Highland Council show that for a electricity tariff of 0.00p/kWh offered by CCDC, the full investment presents a 0% IRR if a heat tariff of 6.4p/kWh is charged.

The investment decision in a district heating by the Highland Council has to go beyond the financial evaluation of the project. Social gains associated to the installation of a district heating attending social buildings, delivering adequate warmth to houses and making heat affordable cannot be accounted in financial terms. The environmental gains of replacing coal, oil and grid electricity based heating systems by a system fed by renewable energy directly through a private wire can be accounted as CO2 emission avoidance. A total of 153.24 tonnes of CO_2 per year as calculated in chapter 9 is a relevant gain for the environment. These outcomes are in fact fulfilling the Highland Council goals as cited in chapter 5.

Furthermore, the synergy of the combination of the community energy project and district heating supported by the Council is of great value for local development. The experience that Highland Council shall gain with the implementation of a district heating in a rural area such as Achiltibuie can bring benefits to many other communities throughout the Region.

15 Conclusions

The objective of this study has been to assess the available options for the planned development of wind and hydro power projects by CCDC and the Achiltibuie community under current grid integration challenges. In this regard it has been found that they are making progress in their aim of fostering development through use of renewable energy systems. The wind and hydro power generation projects indeed present the community with a variety of options and opportunities for earning the revenue needed to meet their developmental goals. A key outcome of the study, based on very thorough technical data analysis, has been in clarifying the possible revenue earning potential of the various projects.

The many linkages between the options for energy supply, technical grid integration and implementation of local development have resulted in a complex mix of interdependencies. This in many ways has restricted the completion of the project.

For this reason relevant scenarios were developed within this study as a means of combining the key aspects of the projects and were integral in clarifying the situation and facilitating data analysis. As a result of these scenarios, it has been found that even though the generation profiles and investment costs vary for the options explored, they all produce a degree of financial benefit for the community. The key consideration therefore rests with the community organisations in deciding upon the level of investment with which to foster future development.

The major revenue generation component of the project, the FIT payments, should therefore be kept as a primary focus since it becomes progressively less as time passes and has significant financial implications for the lifetime of the project.

The overall findings of the study are:

1. The wind and hydro projects under consideration are all viable revenue earning options
2. It is possible to manage the projects in a way that produces an optimum output under present grid limitations
3. With a relatively small increase in the existing grid capacity limit the projects can be combined to produce a significantly improved overall financial outcome
4. Management of the system can be modified so that the excess generation is used to meet local demand

The community of Achiltibuie is therefore uniquely positioned to chart a developmental pathway that provides socio-economic benefits in an environmentally conscious manner.

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