# OPTIONS FOR DEVELOPMENT OF COMMUNITY WIND ENERGY PROJECTS IN THE NORTH ISLES OF SHETLAND

A STUDY BY SESAM 2007

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**MARCH 2007**

# Acknowledgement

Throughout this study we received support from various persons and organisations on the Shetland Islands. We would like to heartily express our appreciations to all these individuals and organisations that helped us in organising, making contacts and getting the necessary information that was needed to do this study and write this report.

We extend thanks and appreciations to the Highlands and Islands Community Energy Company (HICEC), the North Yell Development Council (NYDC) and the PURE Energy Centre (PEC) for initiating and supporting us during the study.

We express our appreciations to Cullivoe Primary School, Uyea Sound Primary school and the Unst Community Learning Centre for allowing us to use their facilities and internet access during the course of the study.

We extend special thanks to Eric Dodd and Patrick Ross-Smith of HICEC for coaching us patiently throughout the 5 weeks, Andrew Nisbet of NYDC, Daniel Aklil, Ross Gazey and their team of the PURE Energy Centre, Lawrence Robertson of Unst Community Council, Gordon Thomson and Brian Hunter of Unst Partnership.

Bob Kelman of SSE, John Simpson of SIC, Aaron Priest of Viking Energy Ltd, David Thomson of Shetland Renewable Energy Forum, George Smith and Terry William of Shetland College, Neville Martin of Shetland Heat and Power Ltd., William Spence of Shetland Energy Recovery Plant and Ian Napier of the Marine Center are all appreciated for providing vital pieces of information needed for this study they gave to us through their presentations and discussions with them.

We also like to thank the caretakers of Lerwick and Unst Youth Hostel and Cullivoe Hall for the assistance during our stay in these places.

A very special thanks goes to Elizabeth Johnson for her caring friendliness and tireless effort to not only see us succeed with our work, but to refresh and discover the rich environment and culture of Unst Island.

Our supervisors, Wulf Boie and Dieter Klein must be appreciated for their support not only as academic guides but as special members of the team.

Last but not the least, we greatly recognize and thank the German Academic Exchange Service, DAAD, for funding our study in the University of Flensburg and allowing us to do this International Class.

## Executive Summary

This study has been carried out to identify options to optimize the utilization of energy generated from large scale and decentralized community wind projects. The data required for the study was collected through literature studies, attending presentation workshops, holding discussions with partner organizations, contacting relevant organizations personally, by telephone, emails and conducting surveys in households and commercial enterprises and public premises. The study was conducted from February to March 2007 by students undergoing an MSc course in Sustainable Energy Systems and Management (SESAM) at the University of Flensburg, Germany under the guidance of two of their Lecturers.

The wind energy resource of Shetland is one of the best in the world and provide a great potential for income generation for local communities. However, the successful installation of such community owned windfarms is constrained by the limited Shetland grid infrastructure and the fact that Shetland is not connected to the mainland.

The objective of the study was to develop and assess ideas how the communities in the North Isles can make more use of their wind resources, even in the special situation of an isolated island electricity grid. As heating and transport are the most important sectors for energy consumption in the North Isles and oil based fuels are the main energy carriers for heating and transport, the study focused on these sectors.

A problem of winds energy is its intermittence. A lot of research and pilot projects have already been implemented to better cope with this intermittence by innovative grid management technologies and storage technologies.

Within the study a survey was carried out in order to get up to date information on the energy consumption for heating and transport. The survey also asked questions on the attitudes of the residents in the North Isles towards energy from community windfarms.

From the survey it was found that 76% of the heat demand of households and commercial/public services in Unst is met with oil, 19% by electricity and the rest by coal and LPG. In Yell 80% of the heat demand of households and commercial/Public services is constituted by oil, 17% by electricity and the remaining by coal and LPG. In Fetlar, oil meets 70% of the heat demand for households and commercial sector, followed by electricity which is 23 %, 4.7 % by coal and remaining with peat and LPG. Based on the heat consumption data collected from the households and commercial sector and heating degree days (HDD) data, the monthly heat demand profile for Unst, Yell and Fetlar was generated. In 2006 the heat demand of Unst, Yell and Fetlar peaked in March while the lowest demand was in July.

Besides questions related to the heat demand the questionnaire the interviewees were also asked about their opinion on community windfarms and on their willingness to use electricity from such windfarms to support the concept of community ownership. It was found that about 50% of the people are willing to use electricity from community owned wind farms for their heating systems if this would help the community to implement a wind farm. Moreover, a considerable proportion of both households and commercial consumers (between 10 and 30% depending on the location) are even interested to use renewable electricity from community owned generation for heating if the cost is higher than at the present. More than 70% of the people are in favor of the idea of generating electricity/hydrogen for fueling vehicles from community owned wind turbines. Almost 90% of the people support the idea of creating income and jobs for the community through producing hydrogen/electricity from wind as a fuel for vehicle.

The findings of the survey were the basis for developing ideas for possible concepts how to reduce the intermittence of electricity production from wind and how to use wind energy for heating and transport. Three options have been explored.

### Option 1. Maximizing electricity generation from wind turbines by increasing the electricity demand for heating

This option would be to replace oil consumption for heating by electricity to increase the base electricity demand for heating and thereby allow more wind electricity to be fed into the grid. The electricity demand would increase as follows.

- Scenario 1 assumes that all existing non-electrical boilers will be converted into electrical boilers and estimates the increase of demand to be 16,771 MWh/year
- Scenario 2 assumes that only the proportion of people who are using non-electrical heating systems and showed their interest to use electricity for heating in SESAM survey would convert their heating system into an electrical system and estimates the increase of 6,341 MWh/ year.

To permit the connection to the grid, novel smart grid technologies could be implemented, e.g. smart hot water heaters which contain onboard intelligence to communicate with the turbines and respond to the intermittent generation by diverting the excess power to the hot water heaters and shutting off of the power flow to the storages when there is low power flow in the grid.

Based on the wind measurements of the NYDC for 2005/2006, about 10,990 MWh (66% of estimated increase) in scenario 1 is covered by energy from three Vestas V52-850kW wind turbines (capacity factor of 49%). In scenario 2, about 3,677MWh (58% of estimated increase) is covered by energy from one turbine.

From the financial analysis, both scenarios will be feasible if NYDC gets funding of 4 % of the total investment for scenario 1 and 68.8 % of the total investment for scenario 2. Both scenarios have payback periods of 7 years.

**Option 2. Grid Connected Wind Turbines with Flow Batteries and Hydrogen**

This option provides suggestions to feed quality electricity of constant voltage and current from wind turbines to the grid by means of a flow battery as a primary storage hydrogen as a secondary storage option  The hydrogen will be produced from the excess generated electricity after fed in to the grid and battery charging. The hydrogen which will be produced can be used as a fuel for vehicles and electricity generation.

In order to ensure constant maximum feeding into the grid different storage capacities of batteries are considered in different scenarios. It is considered that in the first three scenarios there will be hydrogen production after feeding electricity into the grid and in the fourth scenario the possible maximum generated electricity will be fed into the grid without any hydrogen production. It was found that a flow battery of a discharge capacity of 800 KW and a storage capacity of 2000 KWh without any hydrogen production will be the most feasible one among four different scenarios. A scenario with a battery of a discharge capacity of 600 KW and a storage capacity of 2000KWh with production of hydrogen will be the second most feasible one among others. It is to be mentioned that all the proposed scenarios will be feasible if 30% grants are available.

**Option 3: Decentralized wind to heat systems**

Considering the limitation on the amount of electricity generated from wind energy that can be fed into the grid, this option looked at the possibility of implementing off grid systems like wind to heat projects. Since several small scale wind2heat projects have been successfully implemented with the support of Highlands and Islands Community Energy Company HICEC and Scottish Community and Householder's Renewables Initiative SCHRI in Shetland, this option studied the feasibility of implementing upsized wind to heat projects in Unst and Yell.

Two types of connection systems, wet system and electrical cable system for connecting the turbines to the consumers were explored. It was found that the electrical heating system to be more feasible than the water bound system mainly due to high installation costs involved with the later. From the nine potential wind to heat project sites identified, 6 clusters have been identified in Unst and three in Yell. Mid Yell and Baltasound clusters were found to be financially viable even without any grant funding. However other wind to heat projects requires at least 25% - 90 % to become financially viable.

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ANNEXES

# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AC | Alternating Current |
| CEO | Chief Executive Officer |
| DAAD | Deutscher Akademischer Austausch Dienst (German Academic Exchange Service) |
| DC | Direct Current |
| DGI | Distributed Generation Incentive |
| DNO | Distribution Network Operator |
| DPCR | Distribution Price Control Review |
| DTI | Department of Trade and Industry |
| EC | European Community |
| EST | Energy Savings Trust |
| $H_2$ | Hydrogen |
| HDD | Heating Degree Days |
| HICEC | Highlands and Islands Community Energy Company |
| HIE | Highlands and Islands Enterprise |
| ICE | Internal Combustion Engines |
| IRR | Internal Rate of Return |
| KVA | Kilovolt Ampere |
| LHV | Lower Heating Value |
| MJ | Mega Joule |
| NIES | North Isles Energy Study |
| NPV | Net Present Value |
| NYDC | North Yell Development Council |
| O&M | Operation and Maintenance |
| OFGEM | Office of Gas and Electricity Markets |
| PBP | Pay Back Period |
| PEC | PURE Energy Centre, Unst |
| PEM | Polymer Electrolyte Membrane |
| PPA | Power Purchase Agreement |
| PURE | Promoting Unst Renewable Energy |
| RE | Renewable Energy |
| ROC | Renewable Obligation Certificates |
| RPZ | Registered Power Zone |
| SCHRI | Scottish Community and Householder’s Renewables Initiative |
| SESAM | Sustainable Energy Systems And Management |
| SHEPDL | Scottish-Hydro-Electric Power Distribution Ltd. |
| SLC | Standard License Conditions |
| SREF | Shetland Renewable Energy Forum |
| SSE | Scottish and Southern Energy |

| | |
|---|---|
| SSEPD | Scottish and Southern Energy Power Distribution |
| SVT | Sullom Voe Terminal |
| UDL | User Data Library |
| UP | Unst Partnership |
| VAT | Value Added Tax |
| VRB | Vanadium Redox Battery |

# LIST OF UNITS

| | |
|---|---|
| £ | Brit. Pound |
| kV | Kilovolt |
| kW | Kilowatt |
| kWh | kilowatt hour |
| $ms^{-1}$ | Meter per second |
| MW | Megawatt |
| MWh | Megawatt hour |
| p/kWh | Pence per kilowatt hour |
| £/kwh | pound per kilowatt |
| £/y | pound per year |
| $m^3$ | Cubic meter |
| $Nm^3$ | Normalized cubic meter |
| Km | Kilometer |

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# PART A

# CHAPTER 1: INTRODUCTION

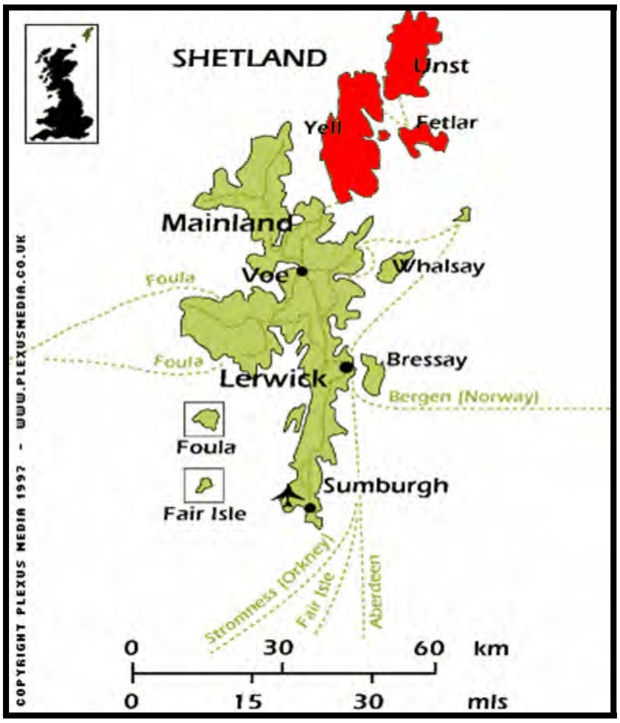
## 1.1. BACKGROUND AND PURPOSE OF THE STUDY

The Shetland Islands is a group of over 100 isles with a population of about 22,000 people. The people living on the islands are organized in small communities represented by community councils. These Islands host one of the largest oil terminals in the world and have enormous wind, wave and tidal power resources. The wind energy resource of Shetland is one of the best in the world where wind turbines can operate with a capacity factor of up to 50 % (sgurrENERGY company, 2004, p.7) Despite this enormous potential in renewable energy (RE) resources, the RE industry is relatively young compared to the industry in other countries like Germany and Denmark. However, this industry is fast growing with the first commercial wind farm commissioned at Burradale in 1998 (Shetland Island Council, 2004, p.56). Other RE projects have since then been carried out including the PURE hydrogen project, the 600 MW Viking wind farm project, several wind to heat projects, and others are underway (ibid).

In 1998 the monetary value of Shetlands' Economy stood at £761,261,000 (Shetland Island Council, 2004, p.13). Contributing to this economy are the Fishery Industry, Agriculture (particularly Crofting), Knitwear, Tourism, Craft and royalties from the Sullom Voe Oil terminal. Exploiting the abundant renewable energy resources, of the Islands, particularly wind, becomes a very important alternative source of revenue to supplement the decreasing income from the declining oil production for the communities of the Islands.

Therefore, there is great enthusiasm to develop community owned RE projects for the benefit of the communities. The North Yell Development Council (NYDC) proposed a 2.4 MW wind farm as one such community based RE Project which is already in the advanced planning stage. The successful installation of such commercial scale wind farms is constrained by the limited Shetland grid infrastructure. The grid network of the Islands consists of 33kV and 11kV distribution lines with no interconnections to mainland Scotland. 3.4 MW of the island's electricity generation capacity already comes from wind power which is 3.5% of the installed generation capacity of Shetland. Further conventional commercial scale turbine connections like the proposed NYDC 2.4MW wind farm, are likely to destabilize the grid and affect the quality of the power. The implementation of the NYDC wind farm project therefore requires careful study.

The main purpose of this study is to identify ways in which the contribution of wind energy to the Shetland electricity supply can be maximized from projects such as the NDYC 2.4MW wind farm and/or decentralised wind to heat systems. The study was done by students of the department of Sustainable Energy Systems And Management (SESAM) on invitation of the Highlands and Islands Community Energy Company (HICEC) in collaboration with the North Yell Development Council (NYDC) and the PURE Energy Center. SESAM is a department of the International Institute of Management at the University of Flensburg, Germany. The study covered a period of five weeks (February 17th to March 24th, 2007) and was done under the guidance of these organisations on the islands of Unst, Yell and Fetlar as shown on the map below.




Legend:

- Surveyed area

*Source: http://www.cali.co.uk/HIGHEXP/Shetisle.htm, downloaded 11.03.2007*

## 1.1. STUDY OBJECTIVES

The **general objective** of this study is to explore ways of maximizing output from the proposed NYDC 2.4 MW wind farm by feeding electricity into the grid and/or direct conversion of wind to heat through decentralized units.

The specific objectives hereunder are:

- To identify ways of increasing local demand for heat from electricity. This will increase the base load and allow more power than the 200kW stipulated by SSE to be fed into the grid.
- To identify options for storing excess energy generated from the proposed wind farm. Wind energy is a very intermittent source of energy. Storage of excess is very crucial to provide energy in times of no wind and to stabilize the frequency of the grid. Storage options considered are hydrogen storage and flow batteries.
- To identify settlement clusters for wind to heat generation. These clusters will provide the option of a decentralized wind to heat production.
- To investigate the attitude of the residents towards the use of electricity from community based wind energy generation

## 1.2. METHODOLOGY

Information on the current situation of energy consumption of the North Isles population and their attitudes towards wind energy generation was obtained through standardized questionnaires. In Unst and Fetlar the questionnaire for both household and commercial sectors were administered in face to face interviews. In Yell the household questionnaires were distributed through the local Newspaper delivery system and returned by same channel or by post while the commercial questionnaires were administered in a face to face interview. Information required for the study included household types, typical heat consumption and types of heating systems in households and commercial sector.

The methods and tools used to collect and analyze data and information were:

1. **Survey interviews**

   The survey questionnaire (see Appendix for full version) was designed for household and commercial sectors. The questionnaires were designed to seek basic information on current status of heating technology used, explore existing heat demands and demand variations in the surveyed areas and attitudes of the people towards energy from renewable energy sources. Further questions were asked on local knowledge of hydrogen cars and electricity driven vehicles.

2. **Literature review**

   Background information on household and commercial sectors which was used for planning of the survey was obtained from the database of the North Isles Energy Study (NIES). A summary report by Graham Ault on studies carried out by SHEPDL and University of Strathclyde was reviewed to understand the possibility of extending the generation capacity limit of the Shetland power system. A unpublished document on the financial feasibility study of the proposed NYDC wind farm prepared by sgurrENERGY Company was reviewed to have some background information of existing findings on the proposed wind farm. Internet websites of Shetland Renewable Energy Forum (SREF), Viking Energy Project, PURE Energy Center (PEC), Scottish and Southern Energy (SSE), Scottish Executive, European Energy Intelligent were visited to get related general and specific information. The Vestas website was also used to obtain the power curve of the V52-850kW turbine intended for use on the wind farm. The Ordnance Survey Map of Shetland-Unst, Yell and Fetlar were used to locate and navigate the surveyed area.

3. **Training, Study visits, Personal contacts, Expert interviews and Discussions**

   The team had a two days introduction to the Shetland Islands and energy related topics at Lerwick College as well as training at the Unst PURE Energy Centre to get hands on understanding of wind energy generation and storage through hydrogen technology and electrical heating and storage.

Focused interviews were conducted with the following experts

- Lawrence Robertson, the Chairperson of Unst Community Council for information on present and future plan for RE promotion in Unst;
- Daniel Aklil, of Pure Energy Centre, Unst for their future plan to promote hydrogen economy;
- Operators of P & T Coaches, Unst, R. S. Henderson, Cullivoe and R.G. Jamieson, Cullivoe on their views toward using hydrogen as alternative to fossil fuel for transport on the Islands;
- Andrew Nisbet for first hand information on the NYDC project.

Study visits were made to the Waste-to-heat Plant in Lerwick and PURE hydrogen production and storage facilities in order to understand their operations in relation to the study.

Presentation and handouts were used and discussions done with:

- Bob Kelman, Operations Manager of SSE to get technical information on the local grid and its ability to take supply from proposed wind power project;
- Aaron Priest of Viking Wind farm project and David Thomson, Chairman of Shetland Renewable Energy Forum to share their knowledge on wind energy development in Shetland;
- Neville Martin, Manager, Waste-to-Heat Plant for information on heat profile and tariff.
- Patrick Ross-Smith, HICEC on support to communities embarking on development projects.
- William Spence, Shetland on the Waste to heat plant (SHEAP)
- Eric Dodd HICEC on Renewable Energy and community ownership in Scotland.
- John Simpson, Energy Unit, Shetland Islands Council.

- Neville Martin, Lerwick District Heat Scheme.

Email and telephone conversations were conducted to collect more information from John Simpson (Energy Efficiency Officer with SIC) on energy use in the council houses and public buildings in the three Islands.

4. **Data processing and Analysis**

The wind power profile for the NYDC project was generated from the two years wind measurement using NOMAD software and the Vestas V52-850kW wind power curve.

Excel software was the main tool used to process and analyze data collected and to do the financial calculations.

Economic indicators like Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PBP) were used in a dynamic analysis to assess the viability of the different options.

## 1.3. LIMITATIONS OF THE STUDY

In the course of carrying out the study, we encountered the following limitations. Firstly, efforts to get detailed technical information on the Shetland grid system were not successful. This is a major limitation because the core of the study centers on how the grid can accommodate electrical energy generated from wind energy.

Secondly, 400 domestic questionnaires were delivered to 4 shops in Yell to be distributed via the Friday newspaper. However, completed questionnaires were not returned in the expected quantity. Due to low feedback from the questionnaire survey in Yell, some analysis was done based on extrapolation.

Finally, assumptions had to be made on two months wind energy data because there was an interruption of the reading of the anemometer caused by the destruction of the connecting cable by sheep.

## 1.4. STRUCTURE OF THE REPORT

This report is divided into two parts. Part A elaborates on the present situation and findings of the SESAM survey. Our study complemented the North Isles Energy Balance Study conducted by the Unst partnership in Unst Island by conducting a more representative survey in Unst, Yell and Fetlar.

Part B elaborates on three options that can encourage and promote wind energy development in Unst, Yell and Fetlar using the proposed North Yell Development Council wind farm as a reference project. The first option looks at maximizing the energy input into the grid by increasing heat demand. The second option explores the possibility of grid connected wind turbines with flow batteries and hydrogen production. The third option identifies the potential wind to heat project areas in Unst and Yell.

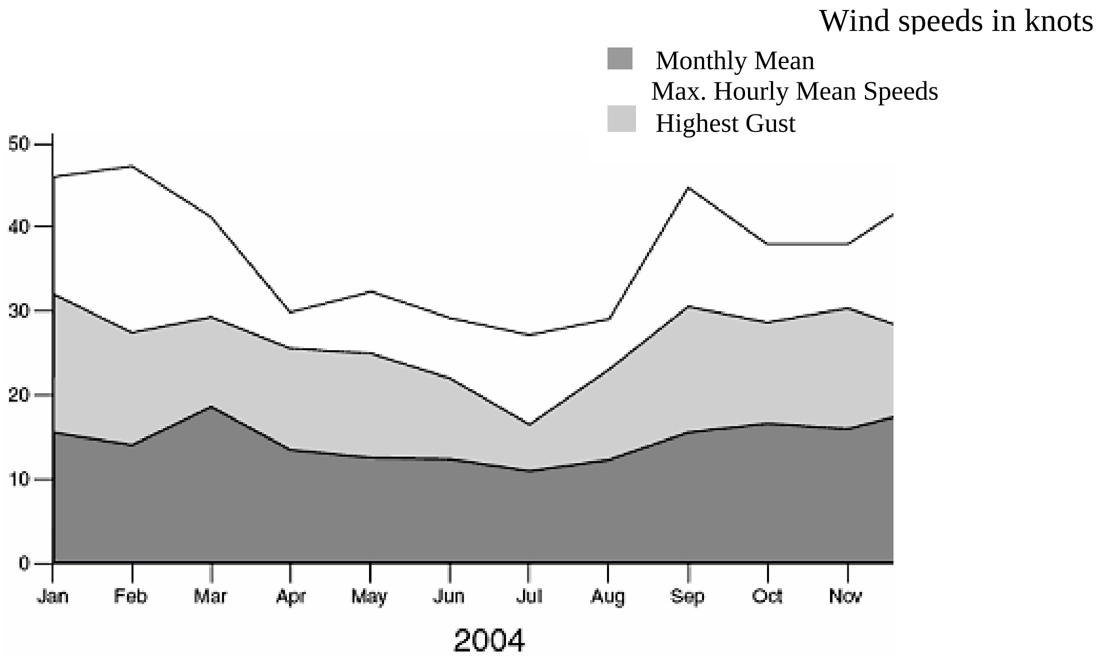
The last chapter concludes the report with a summary of the study and suggestions for further action.

# CHAPTER 2: WIND ENERGY STATUS AND ELECTRICITY GRID SYSTEM IN SHETLAND

## 2.1. WIND ENERGY GENERATION PROFILE

Shetland has one of the greatest wind energy potentials in the world. From The Shetland Statistics for 2004 and 2005 published by the Shetland Island Council[1], weather observations made at the Lerwick Meteorological Station show a general trend of lowest mean wind speeds of about 5.7 $ms^{-1}$ (i.e. 11 knots) during June to August and highest mean wind speeds of about 10.3 ms-1 (20 knots) in the period of November and February.

***Figure 2.1. Wind Speed Variations in 2004***




(1 knot =0.5144 $ms^{-1}$)

*Source: http://www.shetland.gov.uk/council/documents/18170-Shet-in-Statistics.pdf, pg 6, [03:12:07], p. 8*

The island of Yell, which is the proposed location of the community owned 2.4 MW wind farm, is located wholly within longitude 1° 12′W to 1°59′W and latitude 60°

[1] http://www.shetland.gov.uk/council/documents/18170-Shet-in-Statistics.pdf, pg 6, [03:12:07]

28′N to 60° 44′N. Wind speed regimes in Yell are ideal for electricity generation. In 2005 and 2006, records of wind speeds at 10 meter heights above sea level showed daily averages[2] in the range of 6.5ms$^{-1}$ and 12.5 ms$^{-1}$. Averages of daily highest wind speeds also range between 13.5 ms$^{-1}$ and 24 ms$^{-1}$.

***Table 2.1. Distributions of Monthly Mean Speeds for 2005 and 2006 at 10 m height***

| **Months** | **Monthly Mean Wind Speeds (ms$^{-1}$)** | | **Monthly mean Peak Speeds (ms$^{-1}$)** | |
|---|---|---|---|---|
| | **2005** | **2006** | **2005** | **2006** |
| Jan | N/A | 10.8 | 17.0 | |
| Feb | 10.1 | 9.2 | 13.9 | 17.0 |
| Mar | 9.3 | 10.3 | 14.9 | 13.9 |
| Apr | 10.4 | 9.8 | 11.8 | 14.9 |
| May | 7.2 | 8.2 | 11.1 | 11.8 |
| Jun[3] | 7.3 | 7.7 | 9.5 | 11.5 |
| Jul | 6.7 | 6.5 | 12.3 | 9.5 |
| Aug | 8.8 | 6.8 | 16.0 | 13.1 |
| Sep | 10.3 | 7.3 | 15.5 | 16.0 |
| Oct | 10.3 | 10.1 | 17.1 | 15.5 |
| Nov | 11.4 | 12.5 | 17.2 | 17.1 |
| Dec | 10.6 | N/A | 15.8 | N/A |

*Source: NYDC Wind Data*

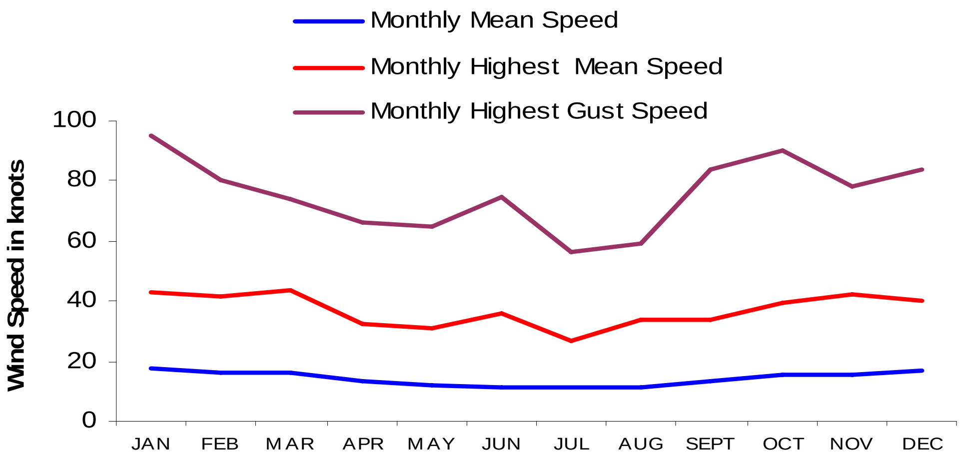
The wind data for the month of June, 2005 were obtained by means of interpolation of the corresponding data of the month of July, 2006. Similarly the data for the month of July, 2005 were obtained by means of interpolation of corresponding data of the month of July and August, 2006.

Similar to Yell, the island of Unst also possesses great wind energy potential. According to the data acquired from the old Baltasound Airport Weather Station[5], monthly average wind speeds range from 5.7 ms$^{-1}$ (11 knots) to 9.3 ms$^{-1}$ (17.9 knots) and mean peak wind speeds range from 13.8 ms$^{-1}$ (26.6 knots) to 22.5 ms$^{-1}$(43.4

[2] NYDC Wind Data
3 Adjusted values June 2005 and July 2005 due to defective data logging system.
[4] Source: NYDC Wind Data
[5] Source: Pure Centre Document

knots) . These were recorded at a height of 82 m above MSL (mean sea level) for the duration of January, 1930 to December, 2002.

***Figure 2.2. Long term mean wind speed from January 1930 to December 2003***




*Source: Author based on Baltasound Airport Weather Station data obtained from PURE centre. ((Wind speeds in knots, 1 knot =0.5144 ms$^{-1}$)*

## 2.2. PRESENT GRID CONSTRAINTS IN SHETLAND

The Shetland grid network is an isolated grid with no connection to the mainland Scotland. It has two main distribution lines of 33 kV and 11 kV. Currently, three power stations feed in their output into this limited grid. They are:

- 67 MW, Lerwick Power Station
- 25 MW, Sullom Voe Oil Terminal Power Station
- 3.4 MW, Burradale wind farm

This gives a total generation capacity of 95.4 MW[4]. On the demand side, the electrical peak demand in Shetland is 49 MW and the base demand is 14 MW (Kelman, B. presentation, 2/2007). The limited demand and the absence of an interconnector to the mainland places limits to the connection of additional generation capacity to the local grid system.

The technical requirements to be considered for a balanced grid system are as follows,

[4] http://www.reuk.co.uk/600MW-Shetland-Wind-Farm.htm , 09.03.07

- Voltage Level

  For low voltage acceptable voltage variations is within ±1%

  For steady state voltage variations range from -3% to +3%

  In order to achieve system stability the voltage should be kept within the limits of power variations which means that the allowable range of voltage variation should be within the limits of +10% and -6%. e.g. 230volts can vary from 216.2 -253volts.

- Frequency Range

  Constant frequency is an important precondition for any electrical network and therefore according to the regulations of the SSE, the allowable variation of frequency should be between 49.5 Hz to 50.5 Hz. Sometimes variations of -2% to +2% of 50 Hz are acceptable.

- Harmonics.

  Total harmonics should be -3% to +3% of 50Hz in terms of distortion

- Fault Ride Through

For system control and continuity of electrical supply the fault ride through should be eliminated in accordance with the load variation. Therefore large currents can be drawn through the fault causing large transient voltage depression across wide network areas[5].

With a high penetration of wind turbines in a small grid the intermittent nature of the wind generation can lead to voltage and frequency irregularities which can cause instability in the grid network. Though there is an allowable range of variation within the system, for the sake of system stability it is necessary to maintain voltage and frequency variations in an acceptable range.

According to studies carried out by SHEPDL and the University of Strathclyde up to 21 MW could be accommodated in the grid on a non-firm basis. However this is only possible if the Sullom Voe power station is connected to the grid and balances the frequency of the grid network (Ault G, 2005, p.4). During times of base load 8MW from Sullom Voe are required and only 6 MW wind energy could feed into the grid,

[5] Source: Southern Scottish Energy

according to the studies. This capacity is already used to a large extent by the Burradale wind farm (see table 2.2). Statements of SSE which are based on newer studies do not consider any non firm connection and allow only for a firm connection of 200 kW.

***Table 2.2. Limitation of wind generation***

| System Load demand (MW) | SVT Power Output Level (MW) | | |
|---|---|---|---|
| | 8 | 12 | 16 |
| 14 | 6 | 2 | 0 |
| 30 | 16 | 14.8 | 13.7 |
| 47 | 21 | 20 | 18.7 |

*Source: Ault G., 2005, p. 4*

## 2.3. PRESENT ELECTRICITY TARIFF SYSTEM

In Scotland, the final consumer electricity tariff consists of four components; generation, transmission/distribution and supply costs. The generation costs constitute 68-76%, the transmission cost is about 4 %, the distribution cost is 20-25% and the supply cost is 1-9% of the final consumer tariff.[6] The electricity generation and supply market is based on competition so both generation and supply tariff are not regulated. However generation and supply businesses are licensed by the regulator which is the Office of the Gas and Electricity Market (OFGEM). [7] The generation tariff of a generation company is fixed through a power purchase agreement between the generation company and the supply company. Transmission charges and distribution charges are paid to the transmission and distribution company for using the transmission and distribution network by the supplier. The supplier adds the service charge and Value Added Tax (VAT) to derive the final consumer tariff. There are 70 electricity suppliers licensed by the OFGEM, from which 36 suppliers are domestic and non-domestic supplier and 34 are non domestic suppliers as of 2nd

[6] Cost of supply business Scottish Hydro, , pg.115
7 http://www.competition-commission.org.uk/rep_pub/reports/1995/367scottish.htm, 3/11/2007

March 2007.[8] Table below shows some electricity tariffs for domestic customers in Scotland. Though there are many tariff structures for domestic customers including prepaid meters, the monthly and the quarterly payment tariff structures have been used to compare the standard prices for domestic customers.

***Table 2.3. Electricity tariff structure of domestic customers***

| Electricity Supplier | Monthly payment tariff (p/kWh) | | | Quarterly payment tariff(p/kWh) | | |
|---|---|---|---|---|---|---|
| | Single tariff | Dual tariff | | Single Tariff | Dual Tariff | |
| | Day | Day | Night | Day | Day | Night |
| Scottish Hydro | 9.269 | 10.155 | 4.33 | 9.67 | 10.497 | 4.478 |
| Scottish Power | 9.81 | 10.071 | 4.345 | 10.369 | 10.67 | 4.67 |
| Southern Electric | 7.5772 | 8.08 | 3.556 | 8.858 | 9.789 | 3.318 |

*Source: http://www.scottishpower.co.uk/Home_Energy/Product_Prices/Standard_Domestic_prices*

## Remuneration of Wind Energy

The tariff of the electricity generated from wind energy is also negotiated between the generator and the supplier and the tariff is fixed based on a Power Purchase Agreement (PPA). The Burradale wind farm in Shetland Mainland has negotiated the PPA with Scottish and Southern Energy (SSE). The tariff negotiated between the generator and supplier is kept confidential. However on the average the generation tariff for electricity from wind farms could be negotiated for 7-8p/kWh including the Renewable Obligation Certificates (ROC). Normally as the PPA term increases the negotiated tariff goes down. The commercial consumers pay a VAT of 17.5% and the domestic consumers pay 5 % for their electricity consumption. However VAT of 5% has been approved for the electricity generated under HICEC renewable energy projects (HICEC). The average price of a ROC as per the Non Fossil Purchasing Agency ROC auction on 23 January 2007 was £46.17/MWh[9].

[8] Reviewing the gas and electricity supply standard license conditions consultation document, 2005, OFGEM
9 http://www.nfpa.co.uk/id10_rocs.cfm?pid=18 ,3/11/2007 4:58 PM

## 2.4. POSSIBILITY OF NYDC TO BE AN ELECTRICITY SUPPLIER

Gas and Electricity License Applications guidance document 86/05 issued by OFGEM in March 2005 states that, "An electricity supplier's license allows the licensee to supply electricity to premises."[10] "Supply in relation to electricity means supply of electricity conveyed by a distribution system to premises other than premises occupied by a license holder for the purpose of carrying on the activities which he is authorized by his license to carry on"[11]

According to the same document, at present there are 33 Standard License Conditions (SLCs) that apply to all electricity suppliers. In addition, for domestic electricity suppliers there are further 19 SLCs to comply with. Since electricity from wind turbines is non firm generation, the main issue here is the difficulty to comply with the security and safety of supply (SLC Electricity no 15). Furthermore it is challenging for small companies to comply with technical requirements, accredited measuring and administration issues.

There are larger renewable electricity suppliers that can buy and sell electricity from renewable resources in the National Grid, such as Green Energy UK (www.greenenergy.uk.com). Unfortunately, based on the information collected from this company, they can not buy nor sell electricity from and to the area that is not yet connected to the mainland grid. This is because they need to prove that they import their electricity where and when their customers need it. Therefore this option is only possible if the Shetland grid is connected to the mainland grid.

[10] Electricity Act 1989 s6(1)(d)
[11] Electricity Act 1989 s4(4)

# CHAPTER 3: FINDINGS OF THE SURVEY

## 3.1. INTRODUCTION TO THE SURVEY

In Unst 45 out of 252 households were surveyed to supplement the data from the previous NIES survey (see chapter 1.3). The distribution of house types in Unst was derived from the NIES survey.

For Yell, where this information was not available from the NIES survey, the distribution of house types was obtained by observation of 403 houses. In addition, interviews were planned with 20 commercial/public premises. We obtained 32 completed household questionnaires and 17 completed commercial/public questionnaires. 13 households and 3 commercial/public energy users refused to answer.

In Cullivoe/Yell, a Community Consultation, done by NYDC in June 2005, showed that 43 out of 47 respondents supported the NYDC Wind farm project. To cover the whole island of Yell, we gave 400 questionnaires to 4 local shops in Cullivoe, Mid Yell, Aywick and Ulsta for distribution with the Friday's newspaper. However, the result was not as expected and we only received 24 completed questionnaires for a total of approximately 403 households. From face to face interviews we obtained 21 completed commercial/public premises questionnaires and there were no rejection in this sector. In Fetlar, we received 2 completed questionnaires for a total of 4 commercial and public energy consumers and 6 for households for a total of approximately 43 households.

The following findings are based on all completed questionnaires received (in the following to be referred to as SESAM survey) supplemented by data from the previous NIES survey.

## 3.2 HEAT DEMAND

### 3.2.1. Energy Mix

**Unst**

Based on the SESAM survey the total annual heat demand in Unst is estimated at 6,920 MWh per year. Out of the total annual heat demand, the household sector and commercial[12] sector constitutes 76% and 24% respectively.

The total annual household heating energy consumption of Unst is estimated at 5,260 MWh. Oil is the largest contributor in this energy consumption mix, standing at 3,729 MWh/year. Electricity is the second largest player in energy mix standing at 1,057 MWh/year followed by coal which stands at 321 MWh/year and a small quantity of LPG and peat.

The total annual commercial heating energy consumption in Unst is estimated at 1,660 MWh. Out of the total consumption, electricity is 236 MWh and oil is 1,423 MWh which constitutes 14% and 86% respectively of the annual commercial heat demand.

**Yell**

On the basis of the SESAM survey, the total heat demand in Yell is estimated at 12,560 MWh/year. Out of the total annual heat demand, household sector and commercial sector constitutes 71% and 29 % respectively.

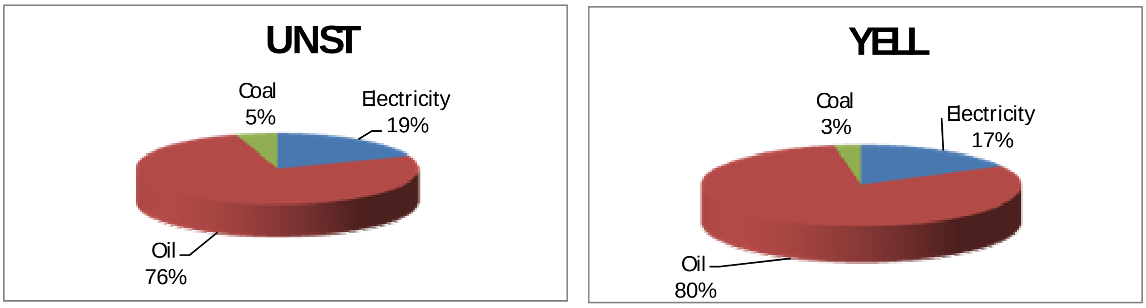
The total annual household heating energy consumption of Yell is estimated at 8,968 MWh. Oil is the largest contributor in this energy consumption mix, which is 7,042 MWh/year. Electricity is the second largest player in the energy mix standing at 1,223 MWh/year followed by coal which stands at 330 MWh/year and a small quantity of LPG and peat.

The total annual commercial heating energy consumption in Yell is estimated at 3,592 MWh. Out of the total consumption electricity stands at 855 MWh and oil stands at

[12] The commercial sector includes all commercial companies and public premises

2,737 MWh which constitutes 22% and 78% respectively of the total annual commercial heat demand. Fig 3.1 shows the percentage distribution total annual energy mix in Unst and Yell.

***Figure 3.1. Percentage distribution of total annual energy mix in Unst and Yell***




*Source: Result of SESAM survey, 2007*

**<u>Fetlar</u>**

Based on the SESAM survey the total heat demand in Fetlar is estimated at 877 MWh/year. Out of the total annual heat demand, household sector and commercial sector is 91% and 9% respectively. The total annual household heating energy consumption of Fetlar is projected at 797 MWh. Oil is the largest contributor in this energy consumption mix, standing at 556 MWh per year. Electricity is the second largest player in the energy mix standing at 182 MWh followed by coal which is 38 MWh /year and smaller quantities of LPG and peat. The total annual commercial heating energy consumption in Fetlar is estimated at 80 MWh. Out of the total annual heat demand, electricity and oil constitutes about 50% each.

## 3.2.2. Heat Demand Profile

The monthly consumption of the household sector has been calculated using heating degree days (HDD) data of North West Scotland[13]. As we obtained most of the data on heat consumption from the questionnaires for 2006, this year has been taken as the base year. An increase of 10% on the annual HDD has been distributed equally over the months to accommodate the effect of warm water consumption as shown in the table below. The modified HDD have been compared to annual heating percentage distribution data from the Lerwick district heating system as the HDD are theoretical

[13] Historical UK Degree Days Data, year 2006 from Carbon Trust

data while the data from Lerwick represent the real heat consumption distribution which is also influenced by other parameters such as wind chill and occupancy of the residences. Although the modified Heating Degree Days show a peak in March, the real heat consumption in Lerwick peaked in December due to the Christmas holidays. However the base load in summer will be lower on the North Isles compared to Lerwick due to the lower proportion of commercial consumers. Therefore the modified HDD has been chosen over the Lerwick data for a safety margin in demand estimation.

***Table 3.1. Modified HDD***

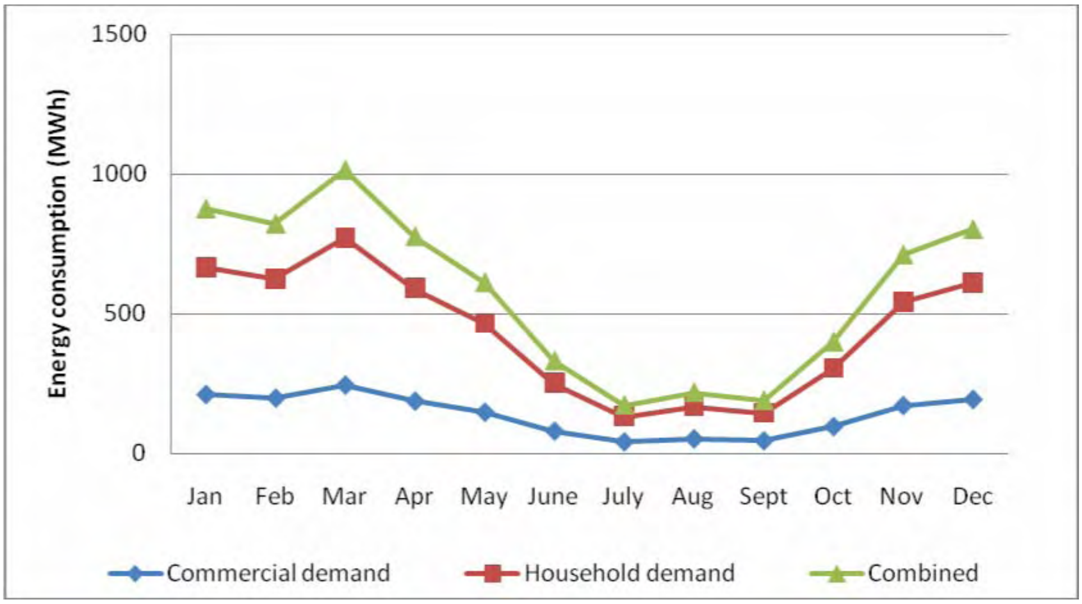
| Month | April | May | June | July | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heating degree days (HDD) 2006 | 256 | 198 | 99 | 43 | 59 | 49 | 123 | 233 | 265 | 291 | 272 | 340 |
| Modified HDD 2006 | 274 | 216 | 117 | 61 | 77 | 67 | 141 | 251 | 283 | 309 | 290 | 358 |
| % of annual heat consumption (Modified HDD) 2006 | 11.21 | 8.84 | 4.79 | 2.5% | 3.15 | 2.74 | 5.77 | 10.27 | 11.58 | 12.64 | 11.87 | 14.65 |
| % of annual heat consumption (Lerwick district heating) 2006 | 7.93 | 5.56 | 5.24 | 4.04 | 4.09 | 5.37 | 8.25 | 11.04 | 13.81 | 11.50 | 10.95 | 12.23 |

*Source: Carbon Trust and SESAM Survey calculation*

## Unst

The assumed heat demand profile in Unst is given in the figure below

***Figure 3.2. Monthly heating demand of household and commercial sector in Unst.***



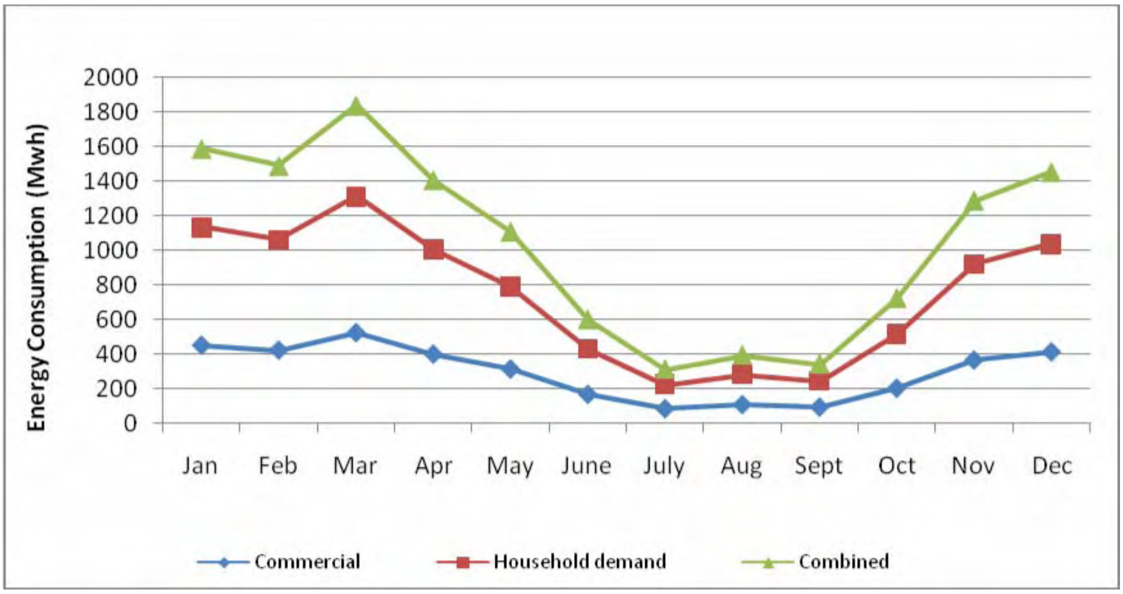

*Source: SESAM Calculation from result of NIES and SESAM survey, 2007*

Based on our aforementioned assumptions the highest heat demand for all sectors is in March and stands at 770 MWh for the households and 243 MWh for the commercial sector. The lowest household consumption is 131 MWh for July while the lowest commercial consumption is 41 MWh in July. The assumed distribution of heat demand is supported by the monthly record of oil consumption at Baltasound Junior High School and Unst Leisure Center which both show the highest consumption in March 2006.

## Yell

The heat demand profile in Yell is shown in the figure below

***Figure 3.3. Monthly heating demand of household and commercial sector in Yell.***




*Source: Author calculation from result of NIES and SESAM survey, 2007*

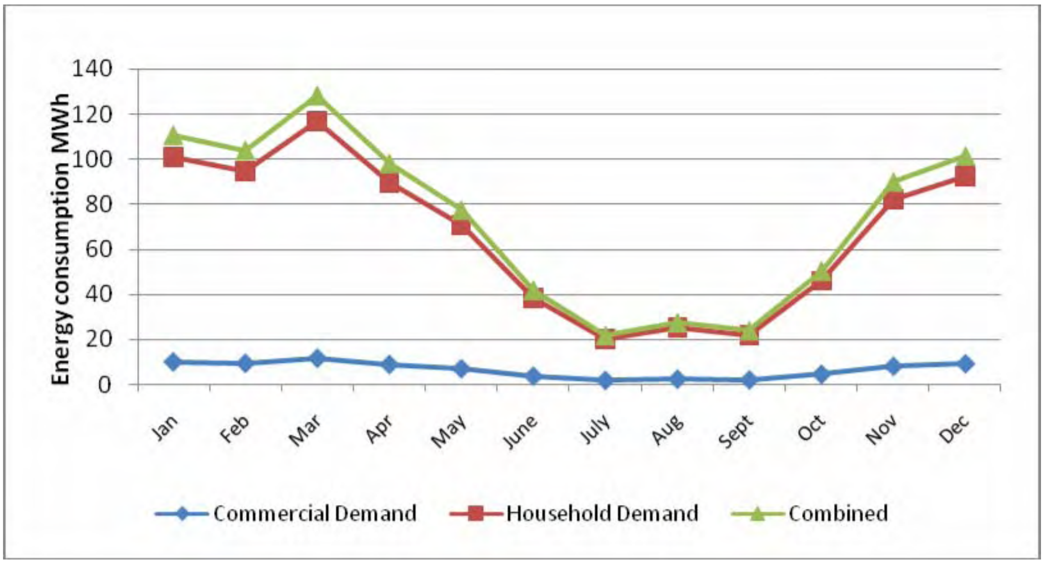
The highest heating demand for both household and commercial sector is in March and is 1314MWh and 526MWh respectively. The lowest demand for household and commercial sectors occurs in July, each consuming 224 MWh and 90MWh respectively. Shetland Norse Factory is the largest commercial consumer and takes about 53%[14] of the total commercial consumption.

[14] Calculation from result of SESAM Survey

## Fetlar

The Heat demand Profile of Fetlar is shown in the figure below.

***Figure 3.4. Monthly heating demand of household and commercial sector in Fetlar.***




*Source: SESAM Calculation from result of NIES and SESAM survey, 2007*

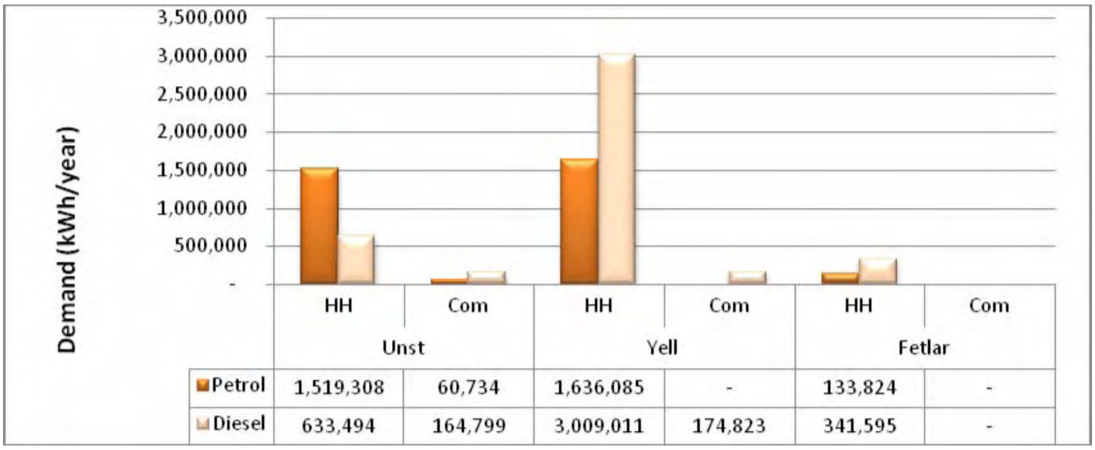
The highest commercial and household consumption is in March at 12 MWh and 117 MWh respectively. The lowest consumption is in July. In this month commercial sector consumes 2 MWh while the household sector consumes 20 MWh.

### 3.3. FUEL FOR TRANSPORT DEMAND

This topic was considered as the option to store the excess energy from the wind turbines into hydrogen storage (see chapter 5). This part was not included in the NIES survey.

For household sector, we calculated the average consumption per household from the results of SESAM survey and multiplied it by the number of households in the island to find out the total consumption for households. For the commercial sector we took the actual figure from SESAM survey for the calculation, since we covered most of the sector. The result is shown in the figure below.

***Figure 3.5 Fuel for transport demand***

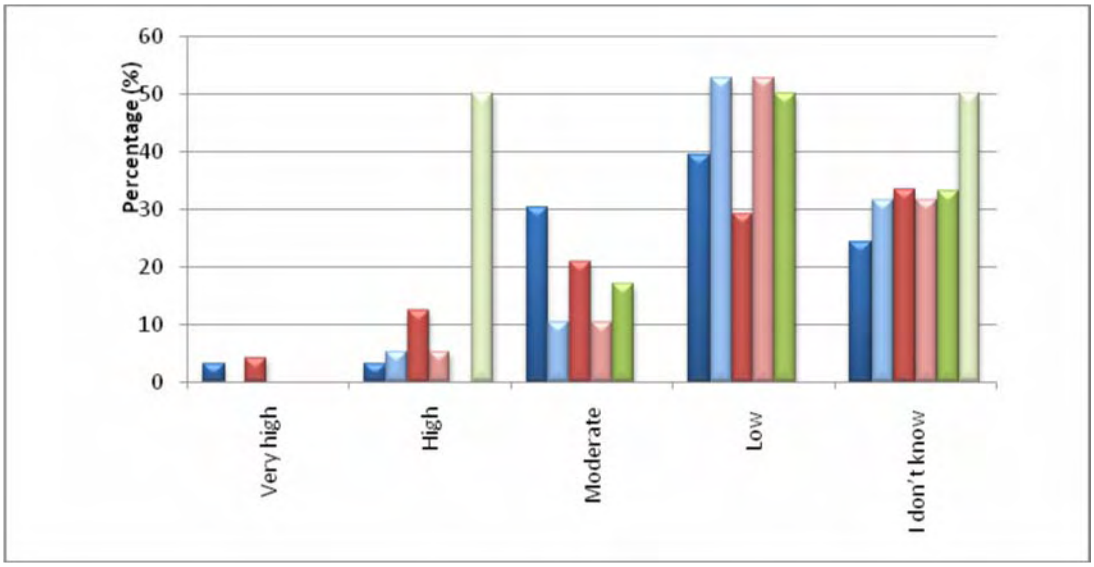



*Source: Calculation from result of SESAM survey, 2007*

For the commercial sector in Fetlar, there is no transport fuel demand data available since both respondents do not own any vehicles. From the figure above, it seems that the population in Yell and Fetlar drive more diesel fueled vehicles. For commercial/public services respondents which were surveyed, all of them own diesel fueled vehicles only. On the contrary, majority of the population in Unst drive petrol fueled vehicles.

Since we looked for storing the excess energy into hydrogen storage (see chapter 5), we asked the respondents about their level of information on hydrogen and electricity vehicles to see if they are familiar with these subjects. The response to the question about *"My level of information on hydrogen vehicles"* is shown on the figure below

***Figure 3.6. Level of information on hydrogen vehicle***

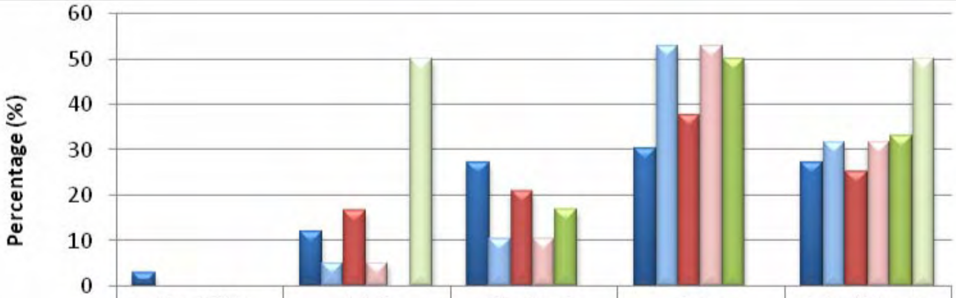



*Source: Result of SESAM survey, 2007*

The response of the commercial sector in Fetlar does not represent the whole commercial view as there were only 2 respondents and one of them is not the person in charge of giving the organization's opinion thus giving "I don't know" as the answer. From the figure above, we can see that, compared with commercial sector in both islands, there is a higher percentage in the Unst and Yell households sector having"very high" and "high" level of knowledge. However, most households in Unst and Fetlar have a "low" level of knowledge, and most households in Yell answered "don't know" when asked about their level of information.

The response to the statement of *"My level of information on electrical vehicles is"* is shown on the figure below

***Figure 3.7. Level of information on electrical vehicle***




| | Very high | High | Moderate | Low | I don't know |
|---|---|---|---|---|---|
| Unst HH (%) | 3 | 12 | 27 | 30 | 27 |
| Unst Com (%) | 0 | 5 | 11 | 53 | 32 |
| Yell HH (%) | 0 | 17 | 21 | 38 | 25 |
| Yell Com (%) | 0 | 5 | 11 | 53 | 32 |
| Fetlar HH (%) | 0 | 0 | 17 | 50 | 33 |
| Fetlar Com (%) | 0 | 50 | 0 | 0 | 50 |

*Source: Result of SESAM survey, 2007*

Similarly the response of the commercial sector in Fetlar is not representing the whole commercial view. From the figure above, there is more percentage of household respondents who have "very high" level of information in Unst, which could be due to the presence of the PEC hydrogen project in Unst. In Yell slightly more people in the household sector have "high" level of information compared with Unst. In the three islands, a greater part of the population has a "low" level of information of electrical vehicles.

Both figures shows that there is a need to improve the level of information of the people in general and commercial/public services sector particular by carrying out more public awareness activities.

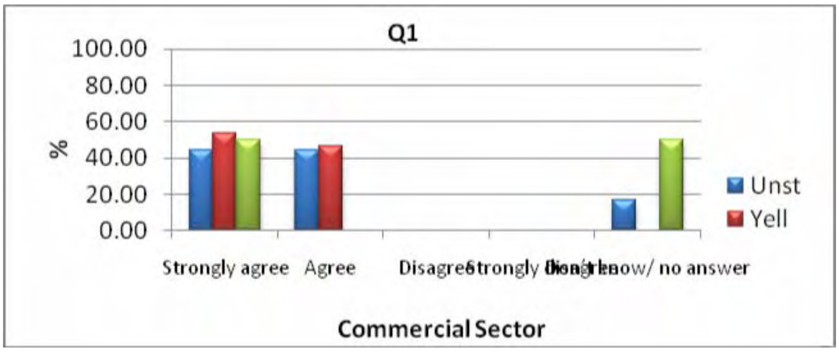
## 3.4 ATTITUDES

A set of statements concerning the attitudes towards electricity from community owned wind farms, towards electrical heater, and towards hydrogen and electricity driven vehicles were asked in order to find potential numbers of people who support the use electricity from their community owned wind farm. This potential numbers are used in this study to find options that would allow NYDC to supply more electricity for heating system, and/or hydrogen or electricity driven vehicle.

### 3.4.1. Attitudes towards Community owned wind farm

The following figures show the distribution of the answers to the statements concerning attitudes of the people towards community owned wind farms.

Q1: *I would prefer to use electricity generated from renewable energy sources than that of fossil fuels*



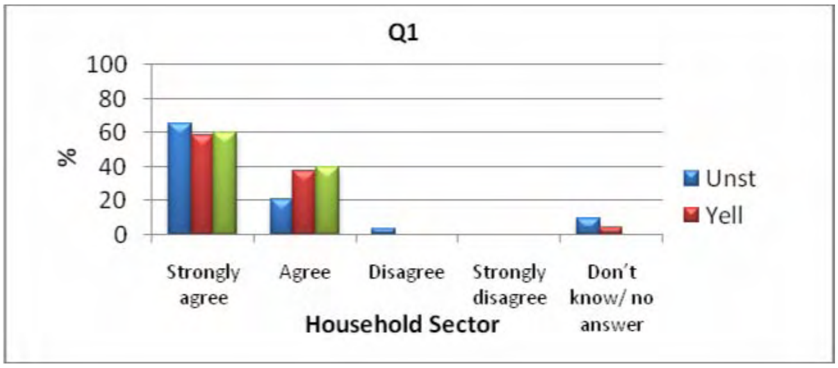
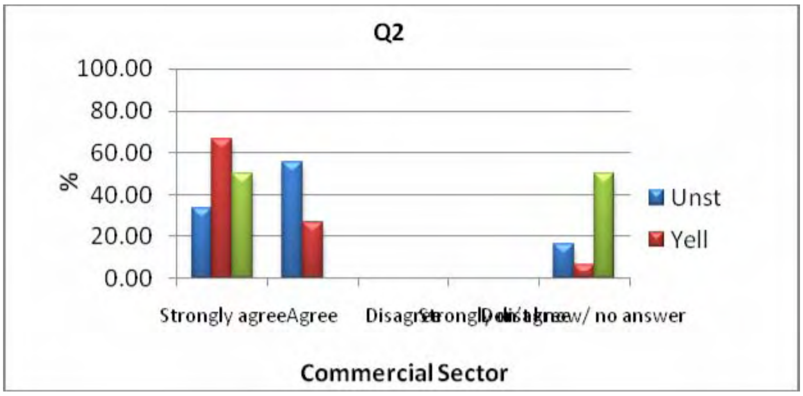




***Figure 3.8. Distribution of answers to statement 1***

Q2: *I support the idea of implementing community wind farms on the northern Isles*



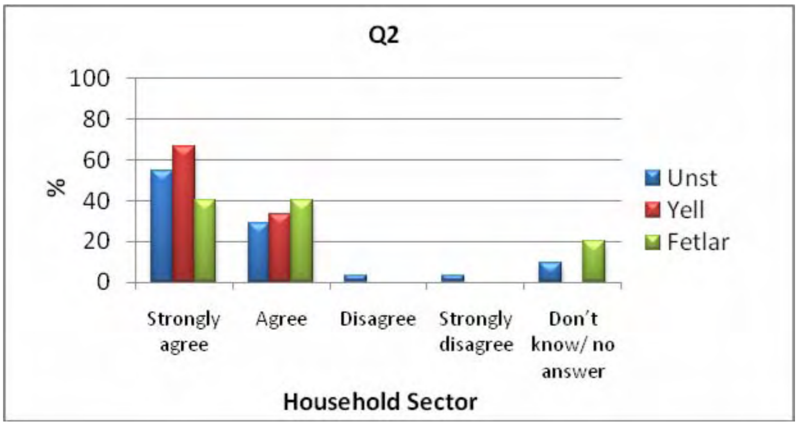
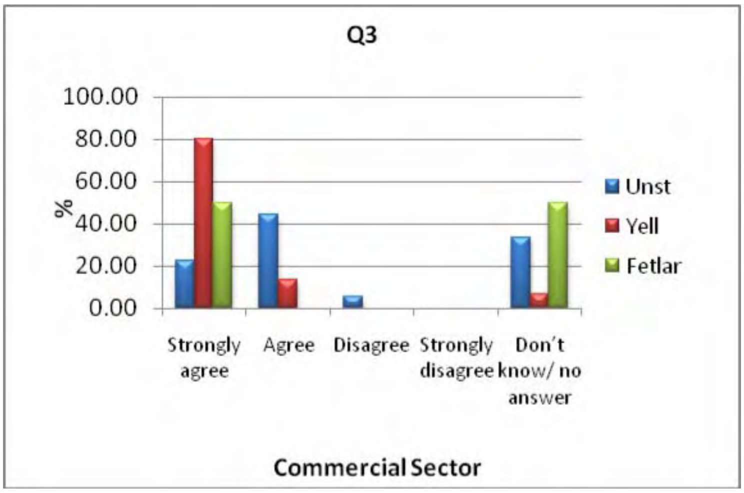



*Figure 3.9. Distribution of answers to statement 2*

Q3: A community owned windfarm is a good option to create income for the community.



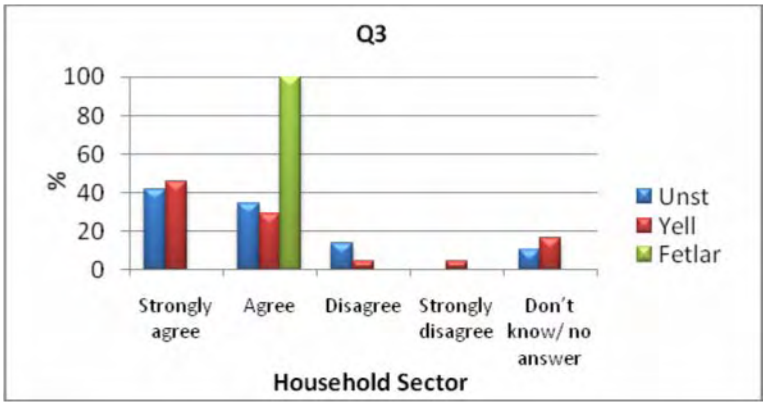



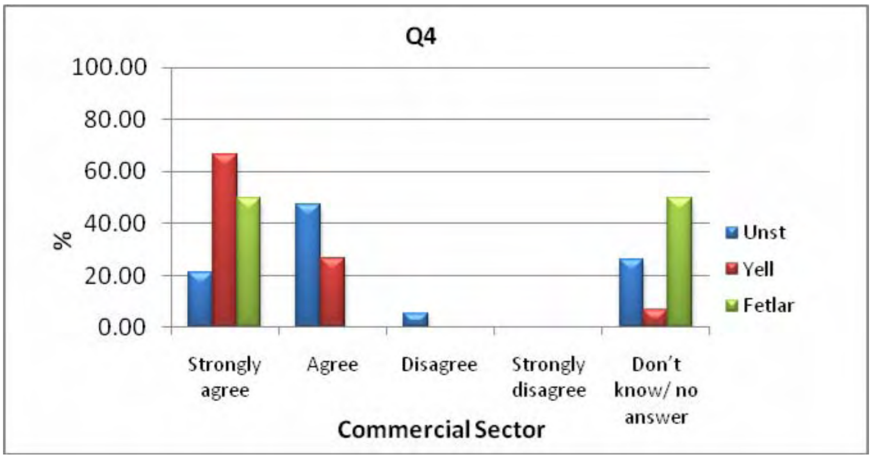

*Figure 3.10. Distribution of answers to statement 3*

Figures show that the majority of the people in both households and the commercial sector support the idea of having a community owned wind farm as the wind farm might create more income for the community. People would also prefer to use renewable energy rather than fossil fuel. Only few people disagree or strongly disagree to this idea. This finding of the SESAM survey conforms to the finding of the community consultation from NYDC[15] which states that 43 from 47 households supported the wind farm project.

### 3.4.2. Attitude Towards Wind To Heat Technology

The following figures show the distribution of the answers to the statements concerning the attitudes of the people on electricity for heating.

Q4: *I am interested to use electricity from a community wind farm for space and water heating if this would help to implement the wind farm*



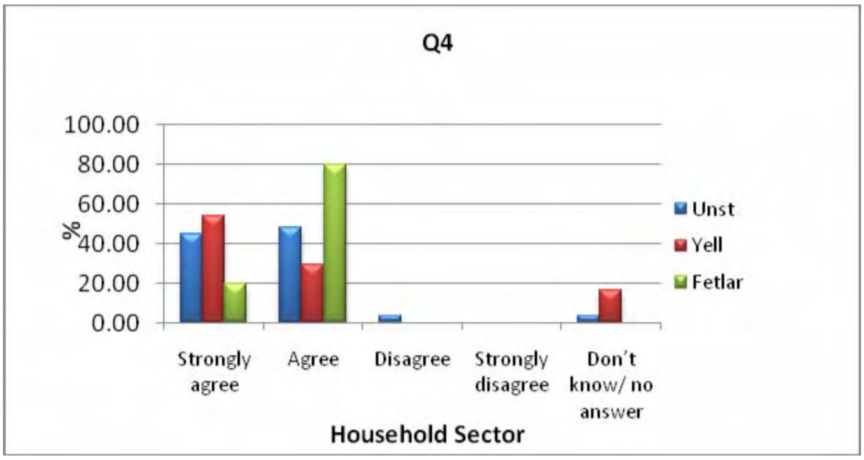




***Figure 3.11. Distribution of answers to statement 4***

[15] Results of Community Consultation 29/06/05 p.1

Q5: *I am interested to use electricity from a community wind farm for process heating if this would help to implement the wind farm*

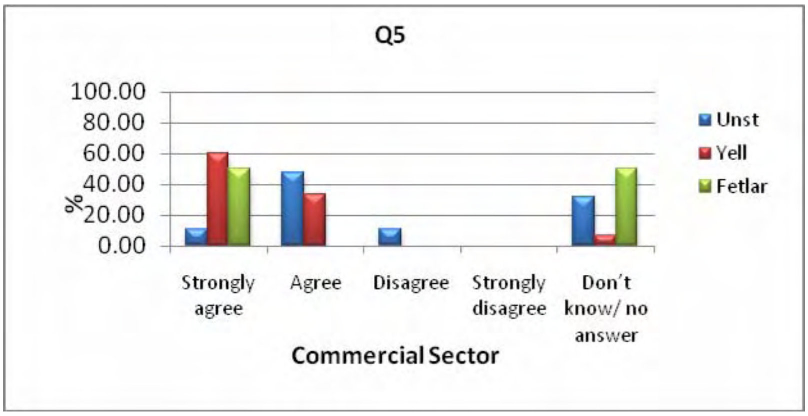



***Figure 3.12. Distribution of answers to statement 5***

Q6: *I would use electricity from a community owned wind farm for space, water and process heating if it* ***does not*** *cost more than at present and if the community benefits from the income*

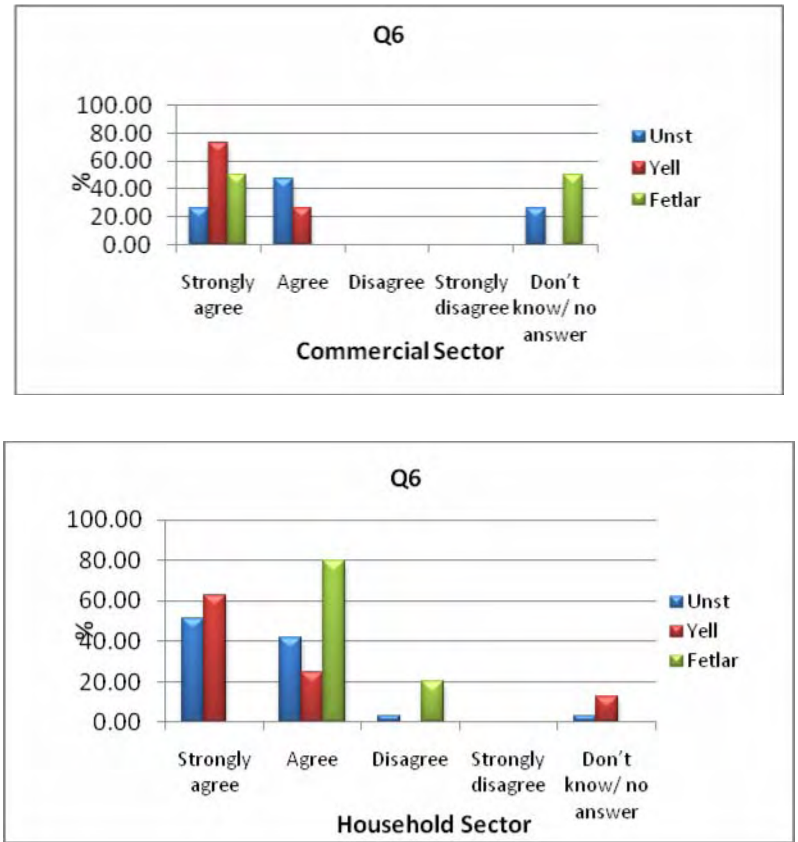
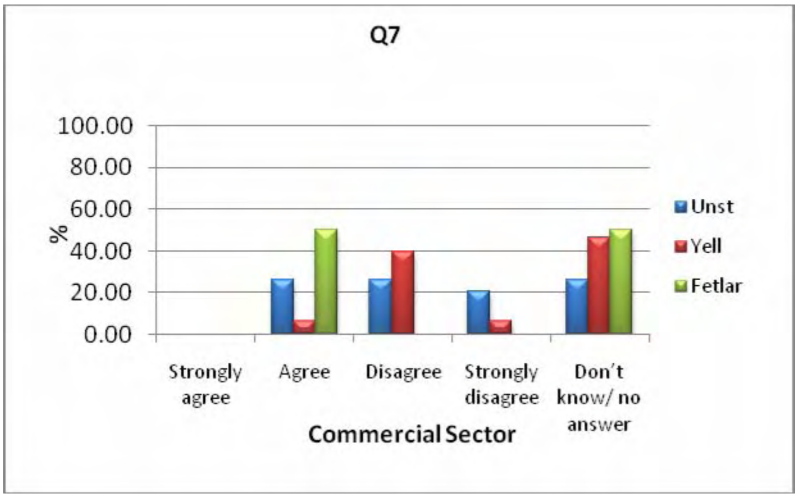



***Figure 3.13. Distribution of answer statement 6***

Q7: *I would use electricity from a community owned wind farm for space, water and process heating even if the cost **is higher** than at present and if community benefit from the income.*



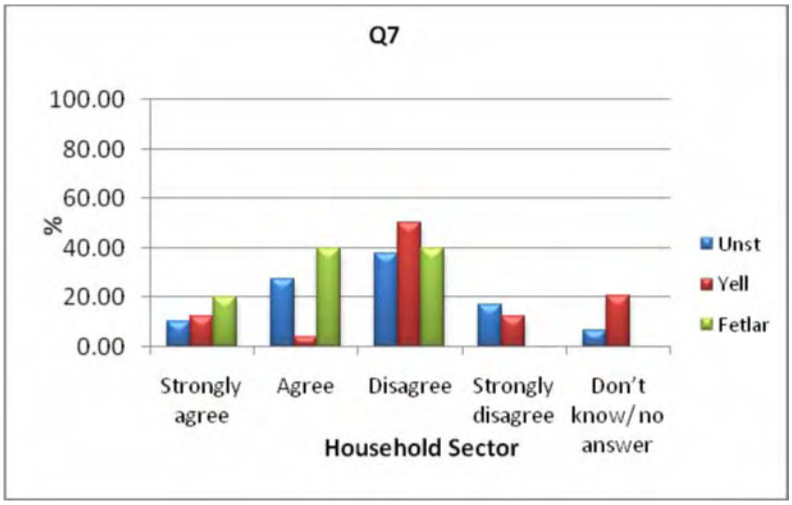
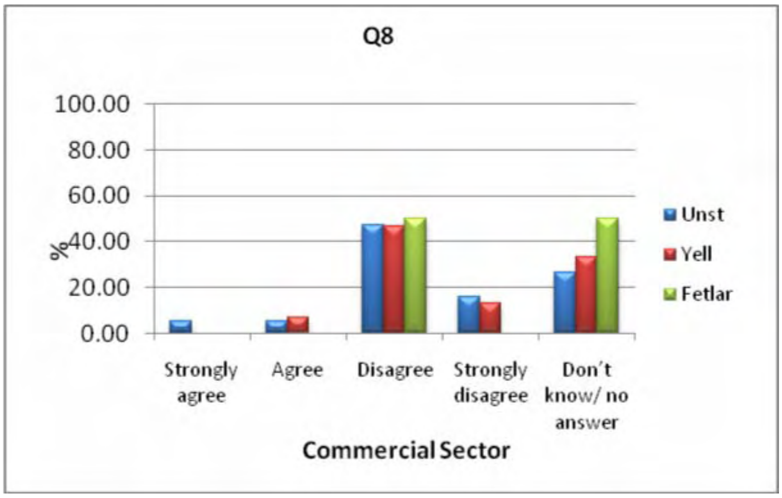




***Figure 3.14. Distribution of answers to statement 7***

*Q8: I would never install an electrical heating system*



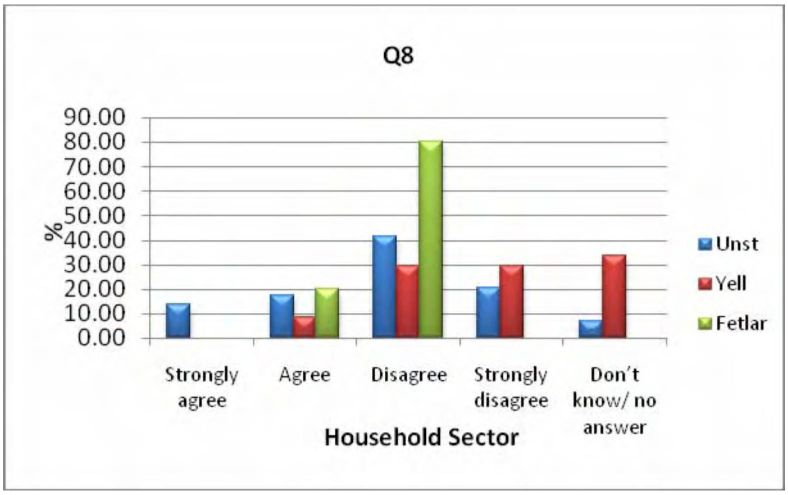
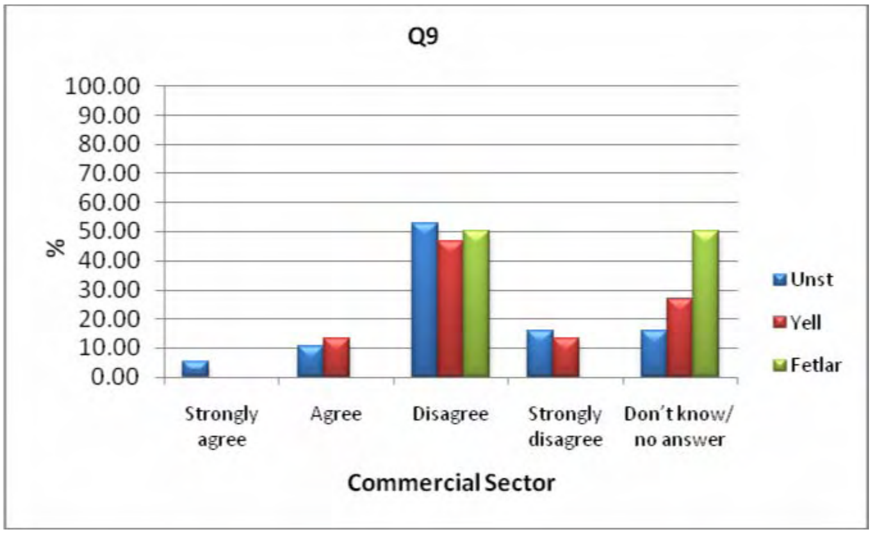




***Figure 3.15. Distribution of answers to statement 8***

Q9: *Electricity is not a reliable source of energy for heating*



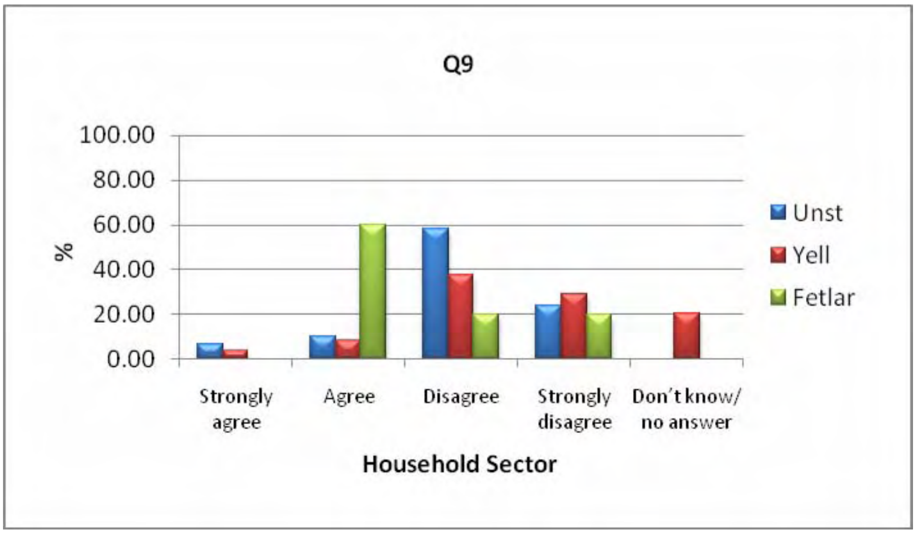
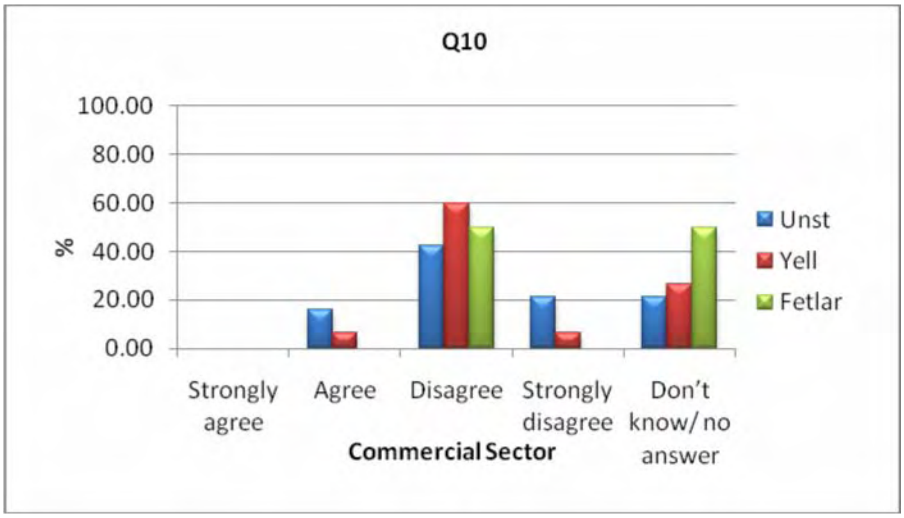



*Figure 3.16. Distribution of answers to statement 9*

Q10: *Electrical heater creates uncomfortable room atmosphere*



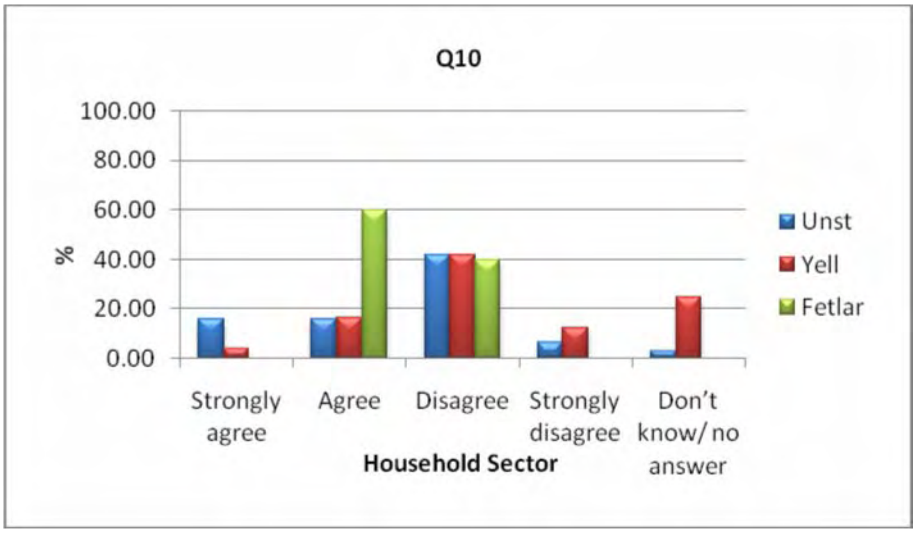



***Figure 3.17. Distribution of answers to statement 10***

The response to these statements indicate that about half of the people in both households and commercial sector are quite willing to use electricity from a community wind farm for their heating systems if this would help the community to implement a wind farm and if the community will benefit. About half of the people are interested in using the wind farm electricity for heating if the cost is not higher than at present.

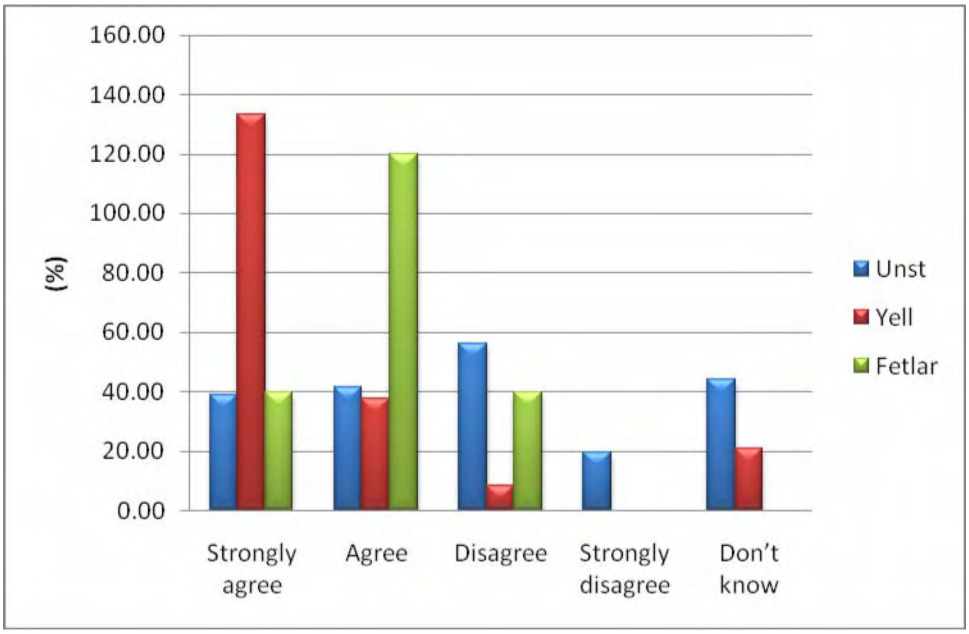
A considerable proportion of both households and commercial consumers (between 10 and 30% depending on the location) are even interested to use electricity for heating if the cost is higher than at the present. (see figure 3.14:distribution of the answers to statement 7).

The result of the survey on the attitudes of the people towards electricity from a community owned wind farm and towards wind to heat technology implies a high potential of the conversion of non-electrical heaters into electrical heaters. But the result does not show and does not differentiate whether the people who are interested to use electricity from the wind farm for heating are using any electrical heater. Chapter 4 will explain details how to find the possible increase of electricity demand for heating

### 3.4.3. Attitude towards Wind to Transport

This part of the questionnaire aims to find the opinion of consumers on the development of hydrogen/electricity driven vehicles in the North Isles to determine the potential of using hydrogen/electricity generated from wind turbine for transport. In addition, it also aims to get the opinion on the use of hydrogen/electricity as a fuel from wind energy.

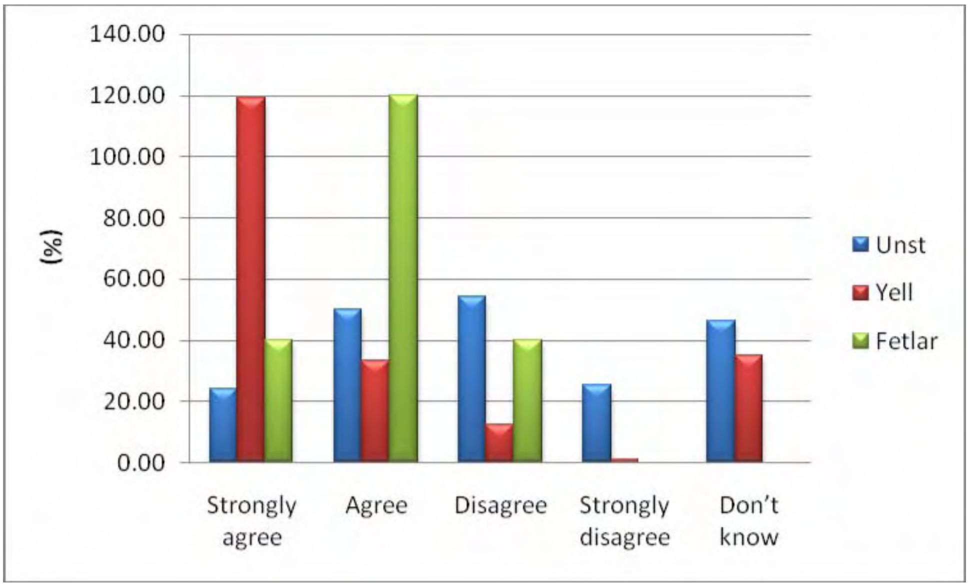
***Figure 3.18:*** **Attitude towards the statement *"I would be interested to use hydrogen driven vehicles if the mileage cost is the same as for fossil fueled vehicles"***




*Source: SESAM survey*

The analysis in the Fig.3.19 shows that, three fourth of the households and two third of the commercial enterprises interviewed are interested in using hydrogen driven vehicles if the mileage cost is the same as for fossil fueled vehicles. This is an excellent basis for introducing new environmental sound means of transport.

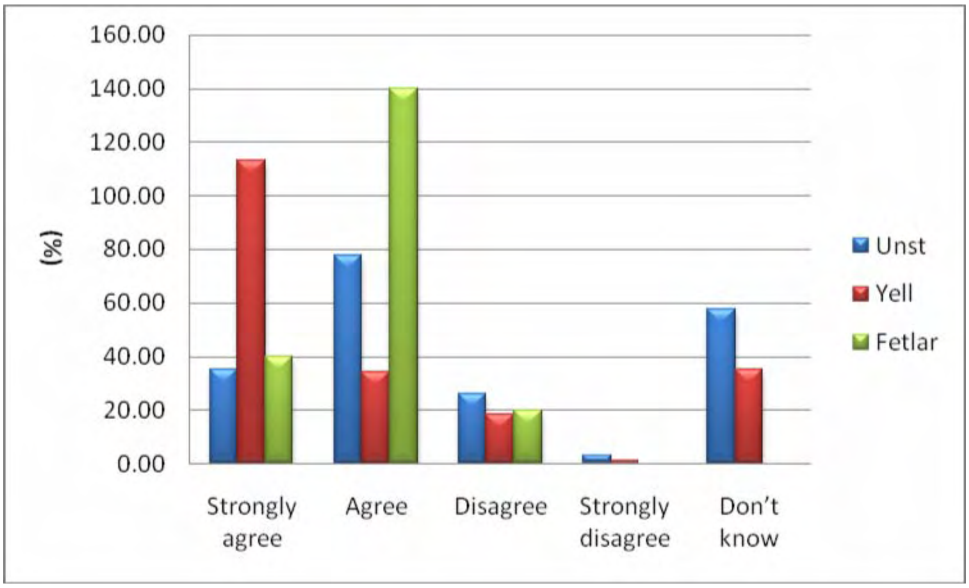
***Figure 3.19:*** **Attitude towards the statement *"I would be interested to use electricity driven vehicles if the mileage cost is the same as for fossil fueled"***



*Source: SESAM survey*

From Fig. 3.20 we can see that the idea of using electricity driven vehicles is less supported than the idea of using hydrogen driven vehicles. This could be due to the reason that people in the North Isles know PURE's hydrogen driven vehicle as a more common object than electricity driven vehicle.

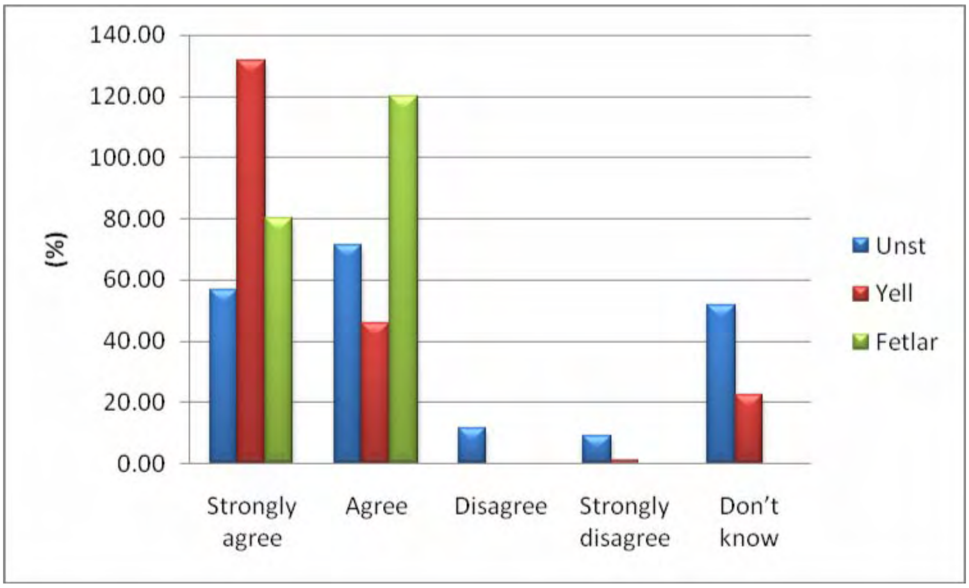
***Figure 3.20:* Attitude towards the statement *"I will support the idea of generating electricity/ hydrogen for fueling vehicles from community owned wind turbines"***




*Source: SESAM survey*

The analysis of Fig. 3.21 shows that more than 4/5 of the households and 2/3 of the commercial enterprises interviewed are in favor of the idea of generating electricity/hydrogen for fueling vehicles from community owned wind turbines. As shown in Fig 4, almost 5/6 of the interviewee supports the idea of creating income and jobs for the community through producing hydrogen/electricity from wind as a fuel for vehicle.

***Figure 3.21: Attitude towards the statement "Local production of Hydrogen/electricity from wind energy as a fuel for transport is an option to create income and jobs for the community"***




*Source: SESAM survey*

From these opinions it can be summarized that a solid majority of the population in the North Isles supports the idea of using hydrogen and electricity from wind to transport. The detail of the survey is attached as annex E.4.

# PART B

# CHAPTER 4: MAXIMISING ELECTRICITY GENERATION FROM WIND TURBINES BY INCREASING THE ELECTRICITY DEMAND FOR HEATING

## 4.1. INTRODUCTION

The main constraint in the North Isles is that there is not enough demand to tap more electricity generation and the addition of generation from wind energy can cause grid instability (see chapter 2.2). On the other hand, the oil consumption for heating is relatively high. Therefore the idea of this option is to replace oil consumption for heating by electricity to increase the base electricity demand for heating. This will theoretically enable the NYDC wind turbines to feed in more electricity into the grid. The result of this chapter is an estimation of the possible additional electricity generation from wind turbines to meet the heat demand. The chapter also discusses the technical requirements like type of turbine, control instruments, grid connection application and the possibility of Registered Power Zones (RPZ) and includes a cost benefit analysis for both, future customers and NYDC as the generator.

## 4.2. METHODOLOGY

In order to assess the increase of the electrical demand for heating and to match the increase of electricity demand with the wind generation profile in option 1, we carried out the following:

1) We used the findings of the existing heat demand for non-electrical heaters from the SESAM survey to calculate the possible increase of the electricity demand. The possibilities are shown in 2 scenarios.
    - Scenario 1: assumes that all existing non-electrical boilers will be converted into electrical boiler.
    - Scenario 2: assumes that only the proportion of people who are using non-electrical heating systems and showed their interest to use electricity for

heating in the SESAM survey would convert their heating system into an electrical system.

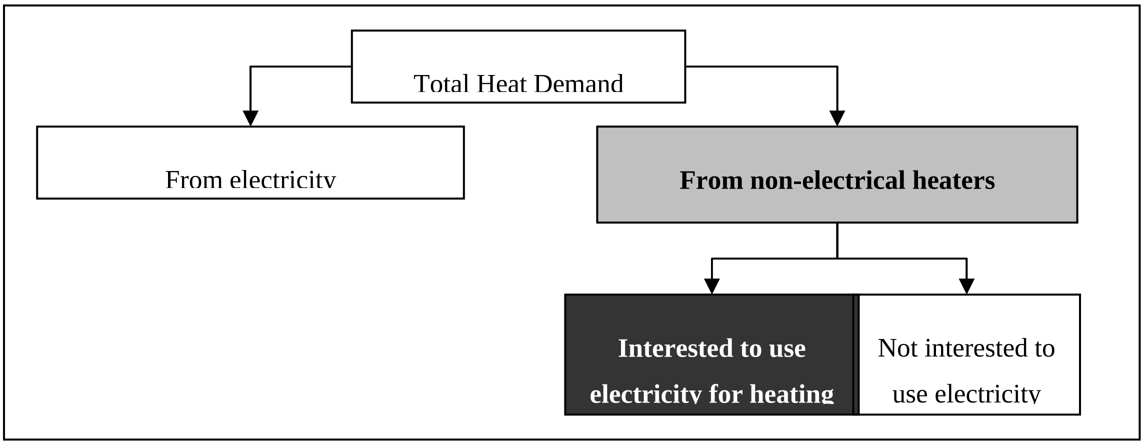
2) We distributed the increase of the annual heat demand along the annual heat demand profile. Based on the wind data of the years 2005 and 2006 from NYDC wind study, we created a wind generation profile for the 850kW V52, Vestas wind turbines, compared and matched it with the demand profile.
3) We determined, for both scenarios, the appropriate number of the turbines, the storage capacity, and some other technical equipments according to
   - Turbine specification data
   - Guidance notes for power park developers, issue 2 drafts 1, issued by National Grid plc.
   - The grid constraints from chapter 2.2.
4) The cost benefit calculations were developed from 2 perspectives: as a view from NYDC as the electricity supplier, and as a view from the customer.

## 4.3. POSSIBILITY OF INCREASING ELECTRICITY BASE DEMAND FOR HEATING

The possibility to increase the electricity demand for heating to allow NYDC to produce more electricity from wind turbines is based on the prediction on conversion of the existing non-electrical heaters into electrical ones.

The grey box in figure 4.1 illustrates how we found out the possible increase in scenario 1 while the black box illustrates scenario 2.

***Figure 4.1. Approaches to increase the electricity demand for heating***



*Source: Author*

The potential demand increase from both households and the commercial sector were summed up and shown in table 4.1.

Table 4.1. Possibilities to increase electricity demand for heating

| | Scenario 1 | | | Scenario 2 | | |
|---|---|---|---|---|---|---|
| | HH MWh/y | Commercial MWh/y | **Total MWh/y** | HH MWh/y | Commercial MWh/y | **Total MWh/y** |
| Unst | 4,210 | 1,423 | **5,634** | 1,887 | 597 | **2,484** |
| Yell | 7,745 | 2,737 | **10,482** | 3,472 | 69 | **3,541** |
| Fetlar | 615 | 40 | **656** | 276 | 40 | **316** |
| *Total* | *12,570* | *4,200* | | *5,635* | *706* | |
| | **Total scenario 1** | | **16,771** | **Total scenario 2** | | **6,341** |

*Source: Author*

Many of the enterprises and industries have already been using electrical boilers for their process heat, space heating and hot water requirements. Thus the increase in the electricity demand in scenario 2 is not as high as we expected. Nevertheless the total potential of electricity demand for heating was still considerably high. The existing electricity demand for heating is estimated to be 2,460 MWh/year. The increase in scenario 1 is about 470% and about 180% in scenario 2.

Details of matching this increase with wind generation profile will be explained in chapter 4.4.

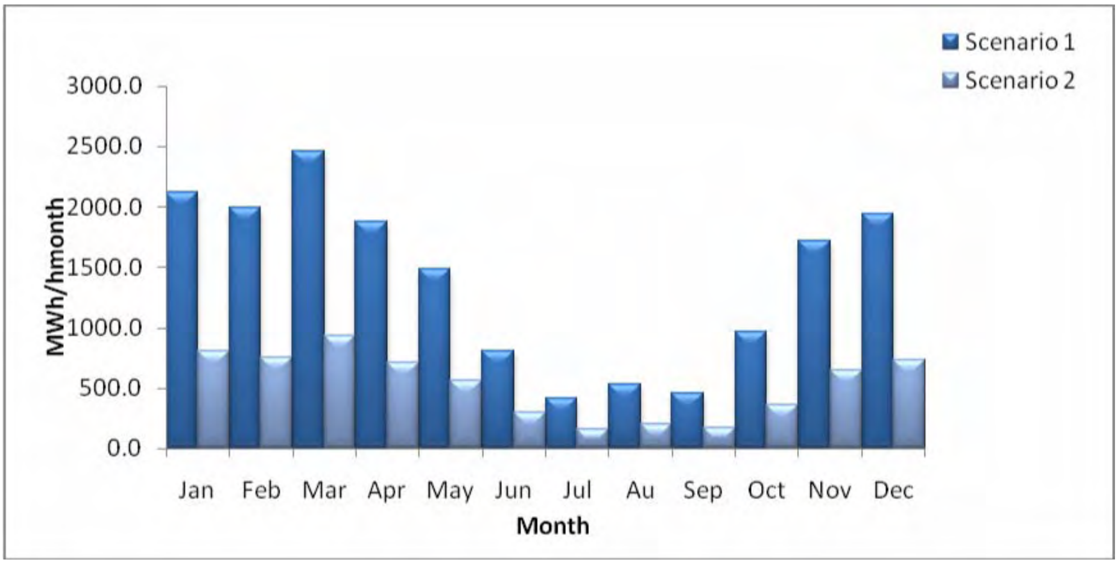
## 4.4. MATCHING HEAT DEMAND AND WIND GENERATION PROFILE

The total estimated increase in electricity demand in scenario 1 is 16,771 MWh/year and in scenario 2 is 6,341 MWh/ year. Based on the wind measurements of the NYDC for 2005/2006, each Vestas V52-850kW wind turbine could produce about 3,677 MWh/year with a capacity factor of 49%.

For both scenarios, the increase in the electricity demand due to the conversion of fossil fuel heating systems to electrical heating systems exceeds the electricity generation of the turbines. It is therefore worthwhile to prove how far the wind electricity generation matches with the seasonal variations of heat demand.

The HDD were used to distribute the increased heat demand in both scenarios into monthly averages over a period of one year, as shown in the graphs below.

***Figure 4.2. Increased heat load for scenario 1 and scenario 2***

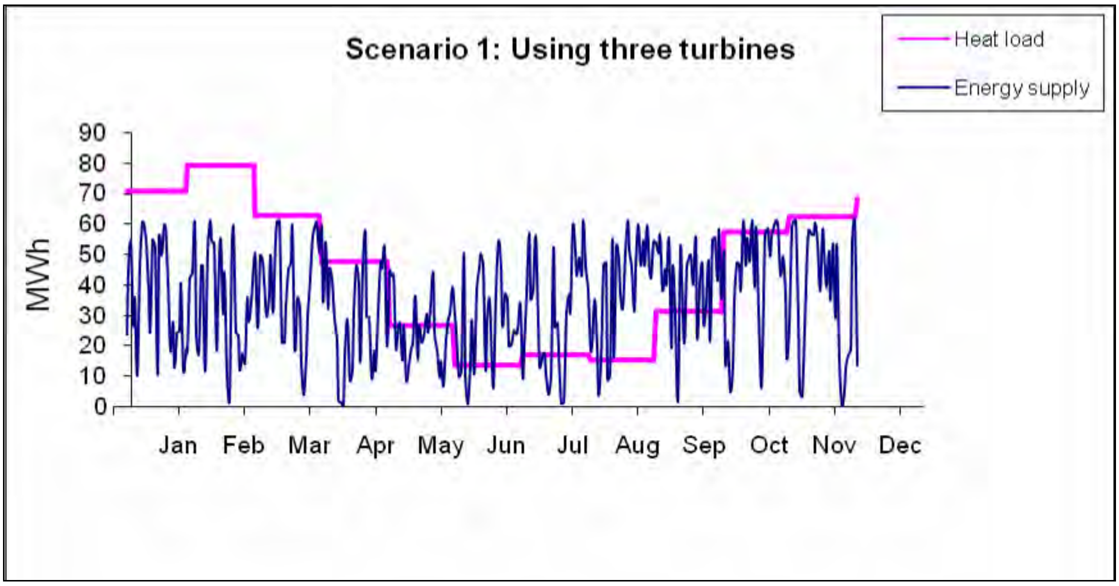


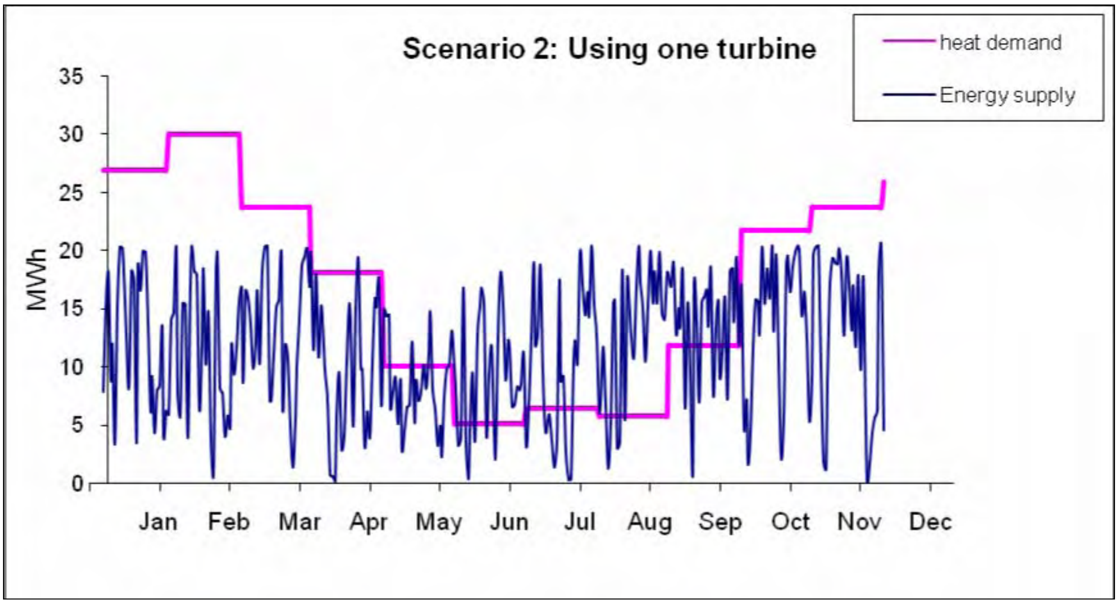

*Source: Author*

The resulting base heat demand increase is about 419 MWh/year for the month of July for scenario 1 and about 158 MWh/year for the month of July for scenario 2. The corresponding base heat load is about 563 kW for scenario 1 and about 213 kW for scenario 2.

Matching of the resulting heating load with the energy output from the V52-850kW wind turbine, we found that scenario 1 would be attractive with three turbines while one turbine would be attractive for scenario 2. This is shown on the graphs below.

*Figure 4.3. Matching heat load with energy from the turbines.*




*Source: Author*

As the energy supplied by the turbines does not match the heat demand at real time, heat storages are required. These can be electrical storage heaters, smaller hot water storage tanks for water bound residential heating systems or larger tanks for small district heating systems. Excess energy from the turbines could be stored to supply energy when the wind generation is low.

From the 16,771 MWh/year created by replacement of fossil fuel in scenario 1, about 10,990 MWh (about 66%) is covered by energy from three wind turbines. In scenario 2, out of the 6,341 MWh/year created heat load, about 3,677MWh (about 58%) is covered by energy from one turbine.

In scenario 1 there is an extra energy of about 4,466 MWh and 1,341 MWh which is needed between the months of January and April and between the months of October and December respectively to meet the increased heat load. In scenario 2 this extra energy requirements are about 1,867 MWh and 654 MWh for the same time periods. This energy could be supplied from the grid or from other renewable energy projects. If this energy is supplied from Fossil Fuel based generation of electricity there will be some $CO_2$ emissions. The $CO_2$ emissions are balanced as follows:

***Table 4.2. $CO_2$ Savings from the scenarios.***

| | Kg $CO_2$/kWh | Total kg $CO_2$/year | |
|---|---|---|---|
| | | Scenario 1 | Scenario 2 |
| Reduced CO2 emissions from Fossil fuel heating systems (mainly oil and coal) | 0.27 | 452,8440 | 1,712,070 |
| Additional CO2 emissions from grid electricity | 0.41 | 2,380,962 | 1,033,570 |
| Balance (savings) | | 2,147,478 | 678,499 |

*Source: Author*

If this extra energy is supplied from other renewable energy projects then a total of 452,844 kg /year of $CO_2$ in scenario 1 and about 1,712,070 kg/year of $CO_2$ in scenario 2 could be saved. However, if the consumers continue to use oil for heating when there is no wind rather than using electricity from the grid, $CO_2$ savings would be about 2,967,239kg/year and 1,038,176 kg/year in scenario 1 and scenario 2 respectively.

Storage is needed during the months between June and August to store energy to be used when there is no wind. The size of the required storage in scenario 1 is about 24 MWh (A household needs a storage of 69 kWh which is equal to 1.48m$^3$ of hot water at temperature difference of 40$^o$C). By using storage, about 95% of the heat demand during this period is generated by the turbines. This gives a practical capacity factor of the turbine of 44% for the whole year. If the storage is not used, about 93% of the heat demand during this period is generated by the turbines, giving a capacity factor of 43%. In scenario 2, the storage size is about 15MWh (A household needs a storage of 50kWh which is equal to 1.07 $m^3$ of hot water at a temperature difference of $40^oC$). The storage usage would result in 95% of the heat demand in summer covered from wind. Without the use of storage 93% would be covered from wind. The annual capacity factor in this case is 43%.

## 4.5. TECHNICAL ASPECTS

### 4.5.1. Wind Turbine Capacity

This option has selected 3 x 850 kW Vestas V52 turbines, in line with the feasibility study conducted by sgurrENERGY. The capacity factor of the turbine calculated by sgurrENERGY is 41.7%[16]. However with the wind data provided by NYDC for the years 2005 and 2006 we calculated the capacity factor of the turbine as 49%.

### 4.5.2. Instrument Control

The option described in this chapter requires a quick response of electrical water heaters to the conditions of the grid and the availability of wind electricity.

Smart Grid technologies can be used for the management of instability caused by feeding intermittent sources of energy like wind into the grid. Smart hot water heaters contain onboard intelligence that receives signals from the grid and respond to the intermittent generation by.

a) Diverting the excess power to the hot water heaters and
b) Shutting off of the power flow to the storages when there is low power flow in the grid

This is a relatively new technology. However, Shetland has already been experimenting, experiencing, and using some of the newest technologies related to wind energy. Wind to heat plants and wind to hydrogen technology are two examples for such innovative technologies. Therefore, in addition to these technologies

[16] North Yell Community Wind Farm-financial feasibility survey conducted sgurr ENERGY

Shetland has a good opportunity of being a showcase for other future smart grid technologies. With increasing penetration of wind turbines in electricity grids smart grid technologies will become indispensable for controlling increased variability not only in Shetland, but in all regions with a high penetration of wind energy and provide new business opportunities. It would have to be proved in how far such smart grid technologies could be introduced in the framework of a RPZ-project (see chapter 4.5.4).

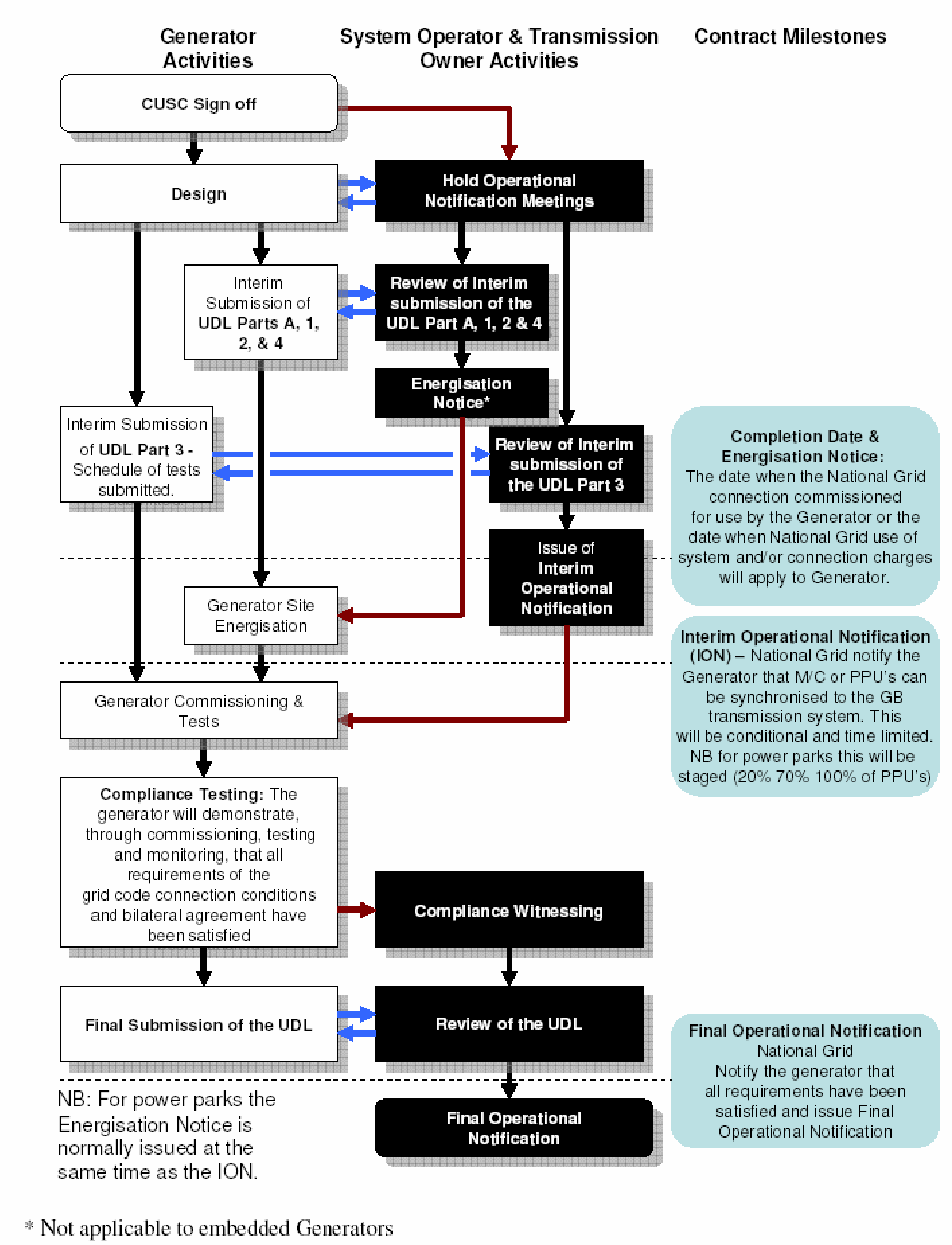
### 4.5.3. Grid connection process

This part is based on the Guidance Notes for Power Park Developers, issue 2 draft 1 published by National Grid Plc (February 2007). In this issue, CCCR is replaced with User Data Library (UDL) to simplify the compliance process as it provides convenient framework for data submission.

The NYDC wind farm is categorized as small Power Park (>10 MW), therefore SHETL as the relevant Distribution Network Operator (DNO) is responsible for the compliance process and forwarding the relevant data to National Grid and the Transmission Owner. The process starts with the generator applying for a Connection and Use of System Code (CUSC) contract with the System Operator (National Grid) and a Construction Agreement with the Transmission Owner. There are 6 stages in compliance process as follows:

- Stage 1 – Submission of Detailed Planning Data
- Stage 2 – Commissioning of the Plant
- Stage 3 – Energisation Process
- Stage 4 – Synchronisation Process
- Stage 5 – Compliance Testing and Model Validation
- Stage 6 – Final Operational Notification

***Figure 4.4 Compliance process and responsibility of each party***




*Source: Guidance Notes for Power Park Developers, p.71*

### 4.5.4. Possibility of RPZ Application

As part of the fourth Distribution Price Control Review (DPCR-4) operative from 1 June 2005, Ofgem introduced the Registered Power Zone (RPZ) incentive. RPZ is "a mechanism to encourage DNOs to develop and demonstrate, on their networks, innovative and more cost effective ways of connecting and operating generation. The aim is to deliver specific benefits to new distributed generators and broader benefits to consumers generally."[17]

At the moment, SSE Power Distribution (SSEPD) through Scottish-Hydro-Electric Power Distribution Ltd (SHEPD) has administered one RPZ project in Orkney, collaborating with Strathclyde University to develop Orkney Active Distribution Network Management enabling connection of 15 MW of new renewable generation to Orkney Distribution Network. In this active distribution network management system, should a non firm generation be connected; immediate power output will rely on existing load demand. The access for non-firm connected generating units also depends on the output of other generators in the system. Thus operating margins are introduced to ensure safe operation of the system (Ault, G and Currie, R., 2006)

SSEPD is considering two more potential RPZ projects, one of them is the Shetland Isles electricity network. The study carried out by SHEPDL and the University of Strathclyde mentioned 200 kW as the limit for connecting any additional wind generation. Further generation can only be connected if there is an active management system which still needs to be developed to maintain system security. (Kelman, B., presentation, 02/2007)

The Orkney active distribution network system was under trial stage in November 2006. Should the result be successful; SSPDE will consider implementing it in other potential RPZ projects. Theoretically, the energy generated from NYDC wind farms and other generators will possibly be accommodated by the active management system. However, Orkney is connected to Scotland Mainland grid while Shetland is not. Therefore, the realisation of Shetland RPZ project will not likely to happen in the near future unless the connection to the Scotland Mainland is built.

[17] Open Letter Consultation on the Innovation Funding Incentive and Registered Power Zone Schemes for Distribution Network Operators, 5 Oct 2006, Ofgem

Nevertheless, if the idea of Smart Grid implementation (see chapter 4.5.2) is implemented, it could be registered as RPZ project as it is considered as an innovative technology.

## 4.6. COST BENEFIT CALCULATION

The following table gives revenue calculation if a customer wants to change his/her oil heating system to electrical heating system. This calculation ignored the domestic water storage tank price and the system installation cost for the electrical heating system. Table 4.4 considers an option where this equipment is provided by the energy supplier.

***Table 4.3. Customer's revenue calculation***

| | **Household** | | **Commercial** | | |
|---|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 1 | Scenario 2 | Unit |
| Annual demand | 12,570,000.00 | 5,635,000.00 | 4,200,000.00 | 70,594.00 | kWh/y |
| Electrical heating system | | | | | |
| Electricity price-night tariff | 0.035 | 0.035 | 0.060 | 0.060 | £/kWh |
| Electricity cost | 439,950.000 | 197,225.000 | 252,000.000 | 4,235.640 | £/y |
| Oil heating system | | | | | |
| Heating value of oil | 11.830 | 11.830 | 11.830 | 11.830 | kWh/L |
| Annual oil demand | 1,062,552.832 | 476,331.361 | 355,029.586 | 5,967.371 | L/y |
| Oil price at present | 0.300 | 0.300 | 0.300 | 0.300 | £/L |
| - Annual oil cost | 318,765.850 | 142,899.408 | 106,508.876 | 1,790.211 | £ |
| - Annual revenue | -121,184.150 | -54,325.592 | -145,491.124 | -2,445.429 | £ |
| *Possibilities* | | | | | |
| *Decreased electricity tariff possible* | *0.025* | *0.025* | *0.025* | *0.025* | *£* |
| *Annual revenue* | *4,515.850* | *2,024.408* | *1,508.876* | *25.361* | *£* |
| *Increased oil price possible* | *0.420* | *0.420* | *0.710* | *0.710* | *£/L* |
| *Annual revenue* | *6,322.189* | *2,834.172* | *71.006* | *1.193* | *£* |

*Source: Author*

Based on the table above, from the customers point of view, this option would only be economically feasible if they can get grants for purchasing domestic water storage tank and installing the system and if the oil price reaches 42 pence/L for domestic sector and 71 pence/L for commercial sector or if the electricity price is lowered to 2.5 pence/kWh to be beneficial for both sectors.

The calculation is tabulated in the similar format to the study from sgurrENERY.

Calculations for scenario1were made to compare and find the feasibility of the project under some different critical points of view from supplier's side.

***Table 4.4 : Supplier's revenue calculation for Scenario1***

| **DESCRIPTION** | **1) AEO=10GWh, no investment on water storage** | **2) AEO=10GWh investment on water storage as grant** | **3) AEO=10GWh critical investment** | **Unit** |
|---|---|---|---|---|
| **Invesment** | | | | |
| turbine construction* | 2,215,444 | 2,215,444 | 3,299,017 | £ |
| heat exchanger for 350 household (heat exchanger @1200 /HH) | - | 420,000 | - | £ |
| heat exchanger for 7 commercial (heat exchanger @5000 £/HH) | - | 45,000 | - | £ |
| cost for hot water storage ( 550 $m^3$ @ 430£/$m^3$ ) | - | 236,500 | - | £ |
| control system (estimation) | - | 500,000 | - | £ |
| **TOTAL Investment** | 2,215,444 | 3,416,944 | 3,299,017 | £ |
| **Sales** | | | | |
| Annual Energy Output (AEO) | 10.48 | 10.48 | 10.48 | GWh/annum |
| sale price (ROC included) | 0.05 | 0.05 | 0.05 | £/kwh |
| Income (Revenue) | 523,973 | 523,973 | 523,973 | £/annum |
| min(-20%) | 419,178 | 419,178 | 419,178 | £/annum |
| max(+10%) | 576,370 | 576,370 | 576,370 | £/annum |
| **Expense** | | | | |
| O&M | 55,386 | 85,424 | 82,475 | £/annum |
| debts payment | - | 184,173 | - | £/annum |
| **Gross Income = Revenue -cost** | 468,586 | 254,376 | 441,497 | £/annum |
| min(-20%) | 363,792 | 149,581 | 336,703 | £/annum |
| max(+10%) | 520,984 | 306,773 | 493,894 | £/annum |
| **Net income** | 328,010 | 178,063 | 309,048 | £/annum |
| min(-20%) | 254,654 | 104,707 | 235,692 | £/annum |
| max(+10%) | 364,689 | 214,741 | 345,726 | £/annum |

| DESCRIPTION | 1) AEO=10GWh, no investment on water storage | 2) AEO=10GWh investment on water storage as grant | 3) AEO=10GWh critical investment | Unit |
|---|---|---|---|---|
| **NPV** | **1,190,736** | **-1,403,853** | **0** | |
| min(-20%) | 465,680 | -2,128,909 | -725,055 | |
| max(+10%) | 1,553,264 | -1,041,325 | 362,529 | |
| **Payback Period** | **7.0** | **-** | **11.0** | **yrs** |
| min(-20%) | 9.0 | - | - | yrs |
| max(+10%) | 7.0 | - | 10.0 | yrs |

0) To compare whether it is still feasible to invest without storage when the AEO from 3 turbines is 10.48 GWh/y
1) To compare whether it is still feasible to invest on water storage as grant to customers
2) To find the critical investment cost which makes the project starts to become infeasible

Remark:

*turbine cost is the proportional from ₤3,692,406 investment cost of 5 turbines

**this calculation based on 8%project discounting rate, 25 year life time

It shows, in column 1), that the project is feasible if NYDC does not have to provide hot water storage for the customers. The critical investment to make project

Still be feasible is about ₤3,299,017. Investment on hot water storage as a grant to customers will not be feasible unless NYDC get funding of ₤117,927 or about 4% of the total investment ₤3,416,944.

Further calculations for scenario2 were made w shown in table below with the same concept to scenario1

| DESCRIPTION | 1) AEO=3.6GWh, no investment on water storage | 2) AEO=11GWh investment on water storage | 3) AEO=3.6GWh critical investment | Unit |
|---|---|---|---|---|
| **Invesment** | | | | |
| turbine construction | 738,481 | 738,481 | | £ |
| heat exchanger for 300 household (heat exchanger @1200 /HH) | | 360,000 | | £ |
| heat exchanger for 7 commercial (heat exchanger @5000 £/HH) | | 21,000 | | £ |
| cost for hot water storage ( 550 $m^3$ @ 430£/$m^3$ ) | | 236,500 | | £ |
| control system (estimation) | | 500,000 | | £ |
| **TOTAL Investment** | 738,481 | **1,855,981** | **1,099,672** | £ |
| **Sales** | | | | |
| Annual energy output | **3.49** | **3.49** | **3.49** | GWh/annum |
| sale price (ROC included) | 0.05 | 0.05 | 0.05 | £/kwh |
| **Income (Revenue)** | 174,658 | 174,658 | 174,658 | £/annum |
| min(-20%) | 139,726 | 139,726 | 139,726 | £/annum |
| max(+10%) | 192,123 | 192,123 | 192,123 | £/annum |
| **Expense** | | | | |
| O&M | 18,462 | 46,400 | 27,492 | £/annum |
| **Gross Income** | 156,195 | 128,258 | 147,166 | £/annum |
| min(-20%) | 121,264 | 93,326 | 112,234 | £/annum |
| max(+10%) | 173,661 | 145,724 | 164,631 | £/annum |
| **Net income** | 109,337 | 89,781 | 103,016 | £/annum |
| min(-20%) | 84,885 | 65,329 | 78,564 | £/annum |
| max(+10%) | 121,563 | 102,007 | 115,242 | £/annum |
| **NPV** | **860,065** | **-831,105** | **0** | |
| min(-20%) | **514,800** | **-1,072,791** | **-241,685** | |
| max(+10%) | 1,032,698 | -710,263 | 120,843 | |
| **Payback Period** | 7 | 0 | 25 | yrs |
| min(-20%) | **9** | **0** | **0** | yrs |
| max(+10%) | 7 | 0 | 19 | yrs |

It shows, in column 1), that the project is feasible if NYDC does not have to provide hot water storage for the customers. The critical investment to make project still be feasible is about £1,099,672. Investment on hot water storage as a grant to customers will not be feasible unless NYDC get funding of £756,309 or about 68.8 % of the total investment

Without investment on water storage, about 25% grant on total investment is required in scenario1 and about 91% for scenario 2 to make the project feasible.

## 4.7. CONCLUSION

There is a potential to increase the electricity demand in the North Isles. This potential (16,771 MWh/year for Unst, Yell and Fetlar) could be achieved through the conversion of all fossil fuel based heating systems into electrical heating systems (scenario 1). From the SESAM survey, about 45% of household and commercial sectors interviewed were positive to convert their fossil fuel based heating systems to electrical heating systems. This could lead to the electricity demand in Unst, Yell and Fetlar increasing by 6,341 MWh/year (scenario 2).

These numbers of percentage would increase when all of Shetland Islands are considered. Such increase would allow for more electricity to be fed into the Shetland grid thereby expanding its present limits. With this limit expanded more renewable energy projects could be implemented.

Converting non-electrical heating to electrical heating, of course, has also constraints. Individuals, though, willing to convert their fossil fuel based heating systems to electrical heating systems may not have the financial means to do so. They could be encouraged through loans and / or grants schemes like SCHRI. Better still, wind farm operators may also undertake investments in electrical heating systems for its consumers.

Three V52-850kW wind turbines would provide the necessary energy if all present fossil fuel based systems are convert to electrical heating systems. Only one turbine will be required to meet the increased demand for those willing to convert to electrical heating systems. Considering production based on capacity factor of 44%, both scenarios would not be economically feasible.

Without consumers converting to electrical heating, it would be impossible for NYDC to feed in the output from their wind farm into the grid. Without an interconnector to mainland Scotland, introduction of an RPZ seems to be difficult at the moment. However, the introduction of Smart Grid technologies could justify an RPZ. This would allow for energy from intermittent sources to be fed into the grid and hence offering more possibilities for NYDC to feed energy from their wind farm into the grid.

# CHAPTER 5: GRID CONNECTED WIND TURBINES WITH FLOW BATTERIES AND HYDROGEN PRODUCTION

## 5.1 INTRODUCTION

### 5.1.1 Overview

The aim of this chapter is to identify possible ways to supply constant power as much as the operator of the grid can accept, devoid of frequency response problems associated with power from the wind. Previous studies carried out for SSE, revealed that the main limitations of accommodating more wind energy into the isolated Shetland grid included limited demand and the danger of frequency violations. Based on the conclusion of these studies, the grid operator could accept only 200kW additional firm generation from wind. The NYDC however, is concluding plans for a wind farm project that can generate up to 2.4 MW of power.

This chapter intends to provide suggestions on possible ways to feed in electricity from wind power with stable frequency by the use of flow batteries. It is also considered to use the peaks of wind generation to produce hydrogen, which could be used to generate electricity during peak demand periods and fuel vehicles as a pilot project.

### 5.1.2 Methodology

For the purpose of this study, the wind energy profile for the NYDC wind farm project was generated from wind speeds measured by NYDC over a period of two years, using NOMAD software and the Vestas V52 – 850kW wind turbine power curve as stated earlier in 1.3.4.

To select the appropriate size of the flow battery based on the wind energy profile, a Microsoft Excel spreadsheet was developed to determine and simulate the quantity of energy the battery could store. There has been communication between NYDC and VRB Power Systems Inc on the possibility to apply a flow battery in the project. VRB

Power Systems Inc proposed a battery system with a power of 600 kW and storage duration of 1.5 hours. In our study we simulated the following battery configurations:

***Table 5.1 Battery Configurations***

| | Power (kW) | Storage capacity (kWh) | Storage duration (hours) | Remarks |
|---|---|---|---|---|
| 1 | 800 | 2000 | 3.33 | Flow battery and hydrogen production |
| 2 | 600 | 900 | 1.5 | Flow battery and hydrogen production |
| 3 | 600 | 1500 | 2.5 | Flow battery and hydrogen production |
| 4 | 800 | 2000 | 1.5 | Flow battery only |

*Source: Author*

The Microsoft Excel spreadsheet was also used to calculate the excess energy that could be used to operate an electrolyser for hydrogen production. Using the rule of thumb assumption from industrial practice[18], that 4.5kWh of electrical energy produces 1Nm³ of Hydrogen,[19] was employed. The selection and sizing of the electrolyser was done based on the quantity of excess energy, capital cost per kWh and the mature technologies available. Decision on storage was made considering the possible uses of produced hydrogen

## 5.2. TECHNO ECONOMICAL ANALYSIS

### 5.2.1. System Configuration

The wind turbine produces alternating current (AC) which is converted to direct current (DC) by converter. The intelligent control unit controls the amount of energy

which flows into the battery for charging and also allows the battery to discharge into the grid when the generated power from the turbine is low. The battery through the

[18]http://np2010.ne.doe.gov/reports/NuclIndustryStudy.pdf (p.327)
[19] One Nm³ of a gas is the volume a gas occupies at atmospheric pressure (1013 mbar) and 273.15 K (= 0° C) http://aida.ineris.fr/bref/brefpap/bref_pap/english/bref_gb_glos.htm [15.03.07 (10:35am)]

control unit carries direct current to the inverter where it comes out as an alternating current that is compatible to the grid system.

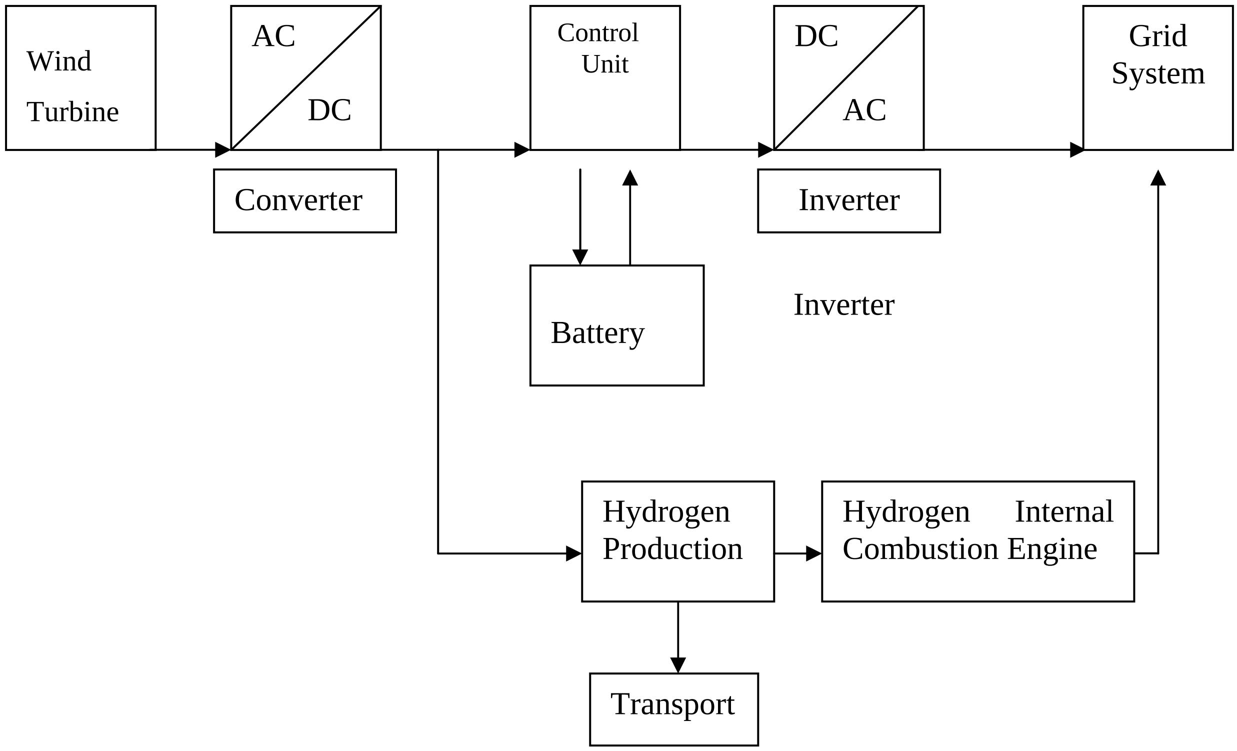



***Figure 5.1. Schematic Diagram of Energy Flow from Turbine to the Grid***

The electricity from the wind turbines that exceeds a certain limit is utilized for charging the flow batteries and producing hydrogen. In our calculations, we assumed flow batteries with storage capacities between 900 kWh and 2000 kWh and discharge capacities between 600kW and 800 kW. The storage battery feeds electricity into the grid when the wind electricity generation is low and stabilises the frequency. The hydrogen which will be produced can be utilized for electricity generation to be fed into the grid during peak periods and used as fuel for vehicles under a pilot hydrogen vehicle project.

## 5.2.2 Flow Battery

The following figures show some possible scenarios for balancing the wind power generation to be fed into the grid by the proposed NYDC wind farm by using flow batteries in a typical week in accordance with the wind data obtained from 1st February, 2005 to 30th November, 2006 from the NYDC.[20]

**Case 1:** In this case three scenarios may be considered where the consistency of electricity supply to the grid will be mainly managed by combination of wind generation and different capacities of flow batteries. The excess electricity is used to produce hydrogen for electricity generation by means of an internal combustion engine (ICE) which can be fed into the grid in order to meet the peak demand.

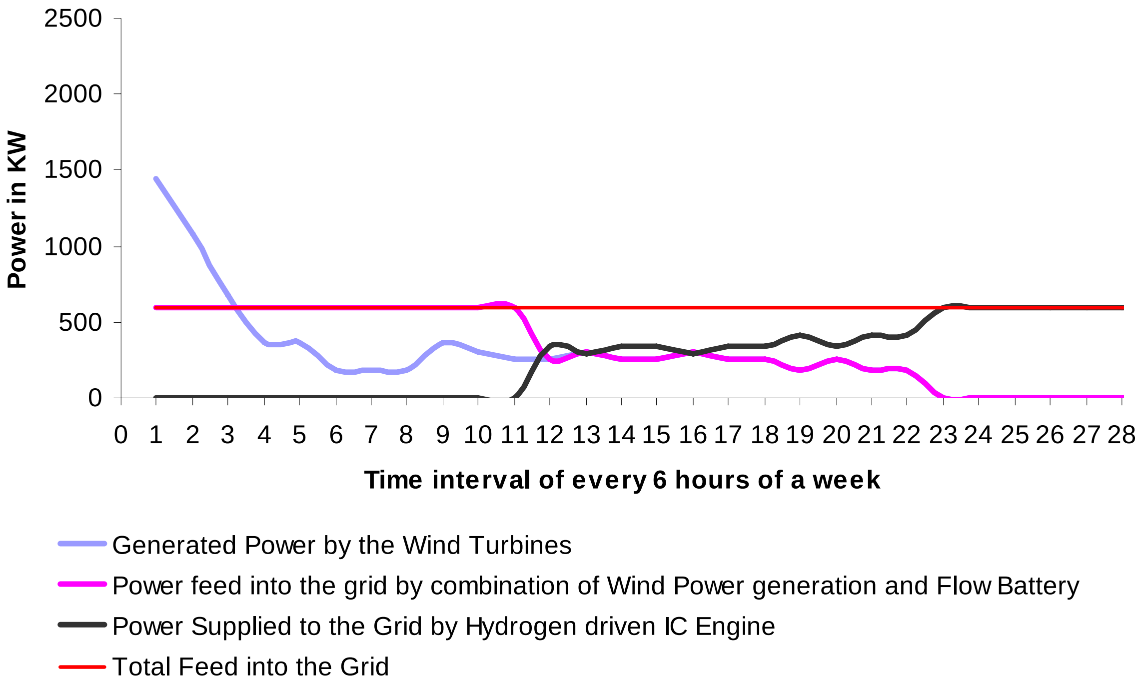



***Figure 5.2. Scenario 1 –The maximum capacityto be fed into the grid is 600 KW. The flow battery has a discharge capacity of 600 KW and a storage capacity of 900 kWh (21st to 28th September, 2006)[21]***

[20] Note: The detailed calculation of the selection of the storage capacity of the battery is shown in appendix.
[21] Created by the author according to the wind data profile of NYDC

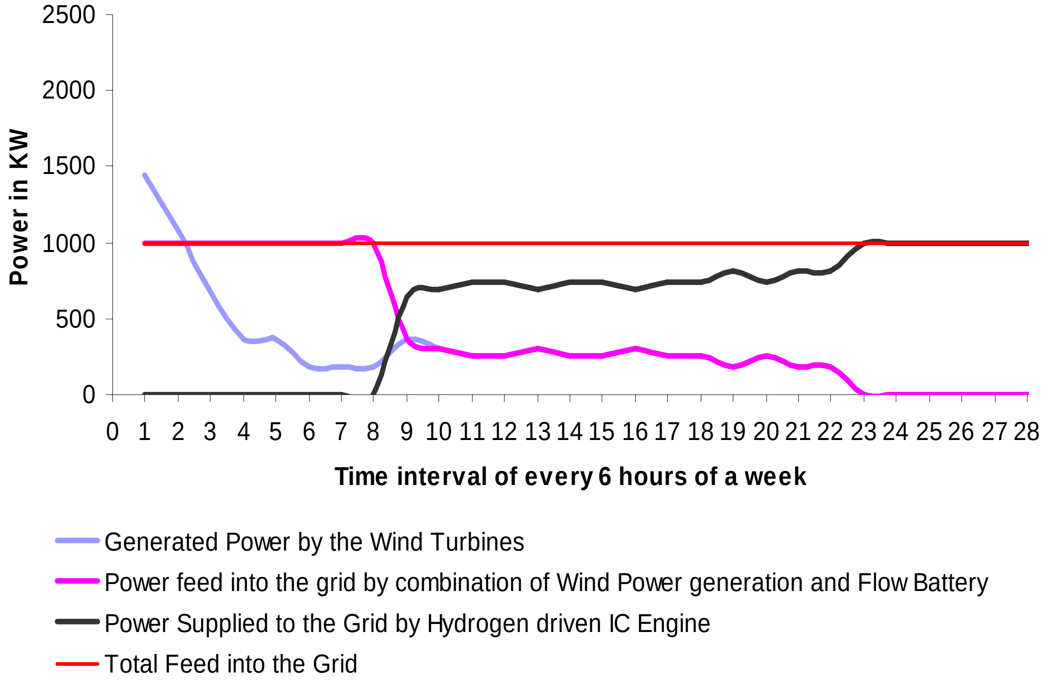



***Figure 5.3. Scenario 2 –The maximum capacity to be fed into the grid is 1000 KW. The flow battery has a discharge capacity of 600 KW and a storage capacity of 1500 KWh***

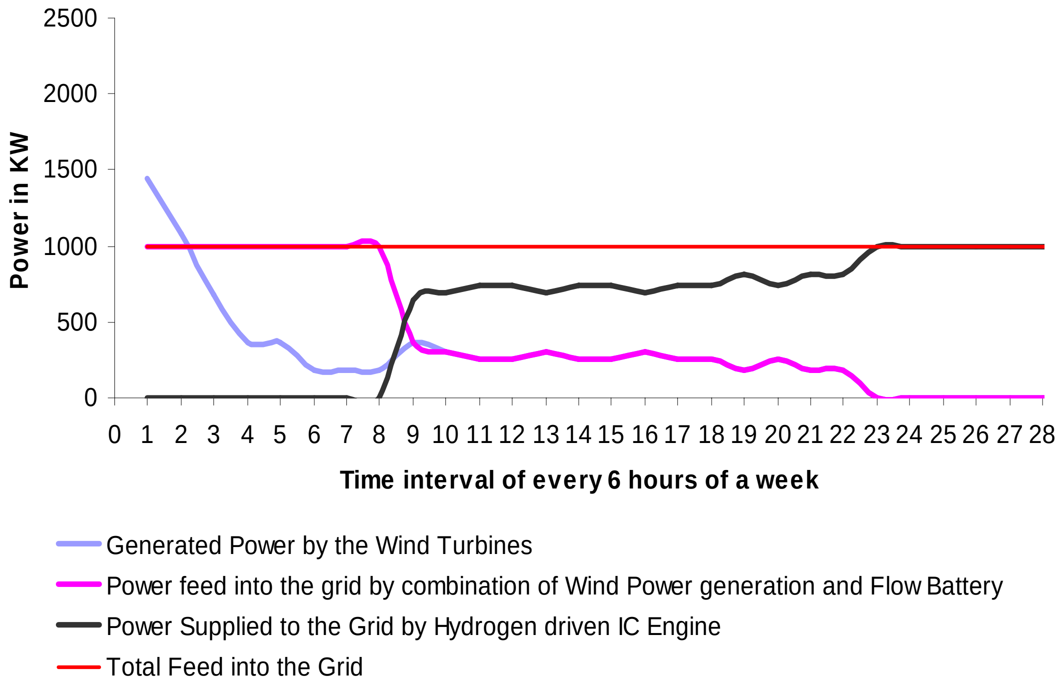



***Figure 5.4. Scenario 3 –The maximum capacity to be fed into the grid is 1000 KW. The flow battery has a discharge capacity of 600 KW and a storage capacity of 2000 KWh (21st to 28th September, 2006)***

From the above figures it can be concluded that the consistency of electricity supply from the wind turbines can be maintained if there is a back up system like a hydrogen driven IC engine besides storage system like flow battery. The hydrogen produced by utilization of excess electrical energy can be used as a secondary storage option.

**Case 2:** In this case the total generation from the wind turbines can be fed into the grid in combination with a flow battery. There is no electricity generation from hydrogen.

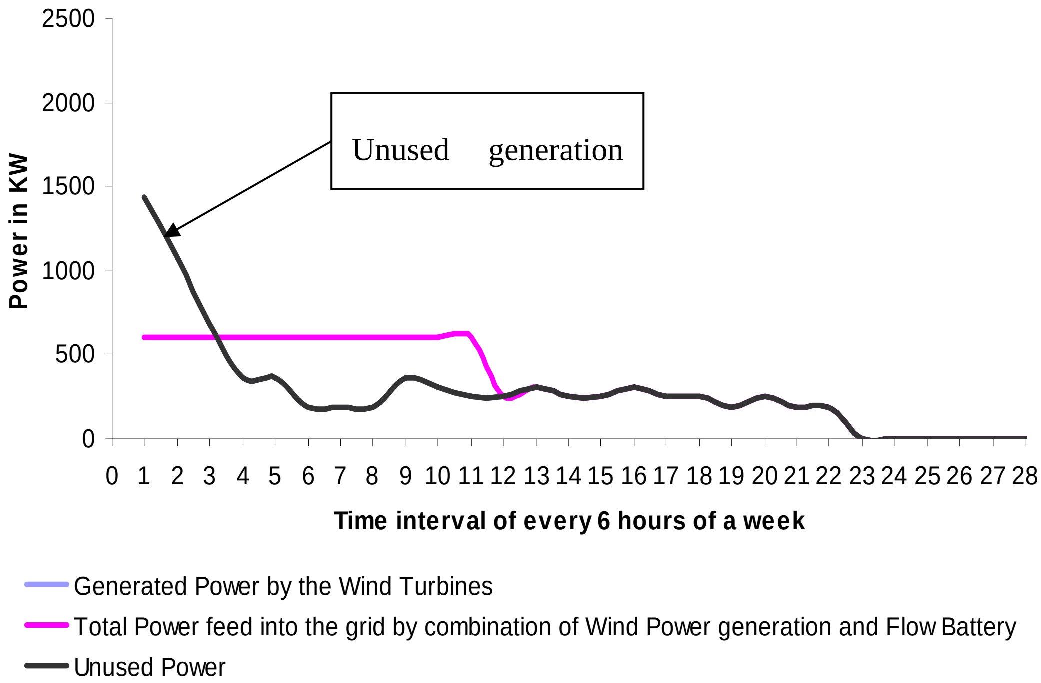



***Figure 5.5. Scenario 4- The maximum capacity to be fed into the grid is 1000 KW. The flow battery has a discharge capacity of 800 KW and a storage capacity of 2000 KWh (21st to 28th September, 2006)***

From the above figure it is evident that there will be some excess electricity which will remain unused. Moreover the consistency of supply of electricity to the grid cannot be maintained due to lack of backup and secondary storage system. It can be seen in the figure that the generated power and unused power lines coincide and form one line.

### 5.2.3 Hydrogen Production

Hydrogen will be used as a fuel for some selected vehicles under a demonstration project, primarily to increase public awareness and acceptance for hydrogen driven vehicles. The vehicles under consideration are vehicles from the Post Offices and Community Health Centres in Yell and Unst and a Council Mini-bus. Table 1 show the summary of annual estimates of fuel consumption which were obtained through interviews of the above sectors.

***Table 5.2. Annual Fuel Consumption for Pilot Transport Programme***

| **Sector** | **Annual Fuel Consumption [Litres]** | **$CO_2$ Saving [kg]** |
|---|---|---|
| One Council Mini Bus | 5,000 | 11,500 |
| Health Service Vehicles | 2,500 | 5,750 |
| Post Office Vans | 3,000 | 6,900 |
| **Total** | **10,500** | **24,150** |

By comparison of fuel heating values, the total consumption is equivalent to 31,893 $Nm^3$ of hydrogen as summarized in table 1.

Again from the result of the above survey, it was realized that the longest distance a vehicle could cover on the Isles is around 60 km. This makes hydrogen a suitable fuel for transport, considering the distance to a refueling point which in this case might be at the point of production of the hydrogen. A long term strategy would be for all land transport in the North Isles to adopt hydrogen as alternative to fossil fuel and later marine transport could use hydrogen as fuel.

Furthermore, a hydrogen fuelled internal combustion engine can be used to generate electricity during peak hours. The possible quantities of hydrogen required for the demonstration programme as well as electricity production are as tabulated in Table 2. It was assumed that the internal combustion engine will operate six hour of peaking times in a day. In this regard, a 360kW electrolyser will be required to operate throughout the year.

The storage of the hydrogen will require high pressure cylinder vessels which can sufficiently store hydrogen for maximum of one day consumption of vehicular and energy demands. The minimum capacities are shown in Table 2.

## 5.2.4. Technical assessment of the proposed system

| **Battery** | **Configurations** | | | | **Units** |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | |
| Max power fed into the grid | 1,000 | 600 | 1,000 | 1,000 | kW |
| Battery Power | 800 | 600 | 600 | 800 | kW |
| Storage capacity | 2,000 | 900 | 1,500 | 2,000 | kWh |
| Storage Duration | 2.5 | 1.5 | 2.5 | 2.5 | hrs |
| **Annual Feed Into The Grid** | | | | | |
| Direct from Wind Turbines | 15,632 | 10,373 | 16,193 | 15,632 | MWh |
| Battery Supply to Grid | 3,348 | 2,248 | 2,624 | 3,348 | MWh |
| From HICE [22] | 174 | 205 | 150 | | MWh |
| **Capacity Factors** | | | | | |
| All Turbine Outputs fed into Grid | 46 | 46 | 46 | 46 | % |
| With Flow Battery | 28 | 19 | 28 | 28 | % |
| With Flow Battery and HICE | 29 | 20 | 29 | | % |
| **Hydrogen Production** | | | | | |
| Electrolyser Size | 360 | 360 | 360 | | kW |
| Capacity Factor | 39 | 53 | 61 | | % |
| Total Annual Hydrogen Production | 232,258 | 313,358 | 237,053 | | Nm³ |
| **Hydrogen for Electricity Generation** | | | | | |
| Annual Electricity Generation | 174 | 246 | 180 | | MWh |
| Days per annum of Operation (6h/d) | 145 | 205 | 150 | | Days |
| Annual H2 Consumption | 197,167 | 278,753 | 203,966 | | Nm³ |
| HICE Efficiency | 25 | 25 | 25 | | % |
| **Hydrogen For Transport** | | | | | |
| Annual Fossil Fuel Requirement | 10,500 | 10,500 | 10,500 | | litres |
| Hydrogen Equivalent | 31,893 | 31,893 | 31,893 | | Nm³ |
| Storage Size at 40 bar for 3days | 2.94 | 3.98 | 3.02 | | m³ |
| $CO_2$ Savings | **24,150** | **24,150** | **24,150** | | |
| | | | | | |

***Table 5.3. Details of the Proposed System***

## 5.2.5. Financial and Economical Analysis

The financial assessment has been carried out for three technical configurations which are described in section 5.2.3. The following assumptions were made in the financial analysis:

[22] HICE : Hydrogen Internal Combustion Engine

***Table 5.4. Assumptions for Financial Calculation***

| | | |
|---|---|---|
| Inflation | 2.5 | % |
| Discount Rate | 8 | % |
| Plant Life Time (Years) | 25 | years |
| Electricity Price(Off Peak) | 0.01 | £/ kWh |
| Electricity Price (Peak) | 0.05 | £/ kWh |
| O &M Cost [23] | 2.5 | % |
| Tax Rate | 30 | % |
| ROC | 0.046 | £/ kWh |

For each configuration the net present value (NPV) has been calculated annually. The pay back period and the net present value are determined. The details have shown in annex section. The table 3 summaries the results:

***Table 5.5. Summaries of the results***

| **Description** | **Battery 1 (800 kW, 2000 kWh) with hydrogen production** | **Battery 2 (600 kW, 900 kWh) with hydrogen production** | **Battery 3 (600kW, 1500kWh) with hydrogen production** | **Battery 1 (800 kW, 2000 kWh) without hydrogen production** |
|---|---|---|---|---|
| Investment for wind turbines (3xV52 850 kW) | 2,220,000 | 2,220,000 | 2,220,000 | 2,220,000 |
| Investment for electrolyser installation (£) | 826,467 | 826,467 | 826,467 | |
| cost of storage tank(£) | 51,932 | 51,932 | 51,932 | |
| Investment for battery installation (£) | 1,747,368 | 1,234,211 | 1,376,316 | 1,747,368 |
| Investment for IC Engine (size 50 kW) (£) | 100,000 | 100,000 | 100,000 | |
| Total investment(£) | 4,945,767 | 3,412,609 | 3,554,715 | |
| Electricity fed into the grid by wind turbine (kWh/y) | 15632000 | 12621000 | 16193000 | 15632000 |
| Income at 0,057 £/kWh (£/year) | 897,276 | 724,445 | 929,478 | 897,276 |
| Electricity fed into the grid by Hydrogen IC engine(kWh/y) | 174,000 | 205,000 | 150,000 | |
| Income from hydrogen electricity (peak) at 0,098 £/kWh (£/year) | 17,121 | 20,172 | 14,760 | |

[23] O & M costs were estimated as 2.5% of Investment Costs

| Description | Battery 1 (800 kW, 2000 kWh) with hydrogen production | Battery 2 (600 kW, 900 kWh) with hydrogen production | Battery 3 (600kW, 1500kWh) with hydrogen production | Battery 1 (800 kW, 2000 kWh) without hydrogen production |
|---|---|---|---|---|
| Hydrogen sold as vehicle fuel (Nm³h/y) | 31,893 | 31,893 | 31,893 | |
| Income from hydrogen sales at 0,45 £/Nm³ (£/year) | 14,351 | 14,351 | 14,351 | |
| Net income (after tax) | 592,754 | 473,907 | 613,642 | |
| NPV (£) | 2,674,149 | 1,690,.140 | 3,.274,170 | 3,549,100 |
| Pay back Period (years) | 14 | 18 | 11 | 9 |
| Pay Back Period with 30% grant | 7 | 9 | 6 | 5 |

With and without cconsidering a grant of 30% on the investment all projects are financially feasible, although the pay back periods are relatively higher compared to wind energy projects without flow batteries.

The payback periods without 30% grant are in the range of 11-18 years for the options with hydrogen production.

### 5.2.6. Funding Opportunities and requirements for funding

There are funding possibilities available to the development of NYDC Wind to Hydrogen or any other related project in the North Isles. The funding options include but are not limited to:

- Shetland Island Council programme
- Scottish funding programme
- UK national programme
- EC programme

To be able to access these funds on renewable energy development especially from the Highlands and Islands Enterprise and Scottish Executive, the projects must be community based. The United Kingdom's Department of Trade and Industry has a hydrogen support package for the promotion of fuel cell and hydrogen technology too. The grants vary from 25% to 50% of the total investment costs in most of the agencies. Some details of the funding possibilities are listed in the Annex and more information could be available in the websites of the funding agencies.

## 5.3 CONCLUSIONS

In spite of the limited firm grid connection possibility, a number of options exist for optimum utilization of power generated from the community wind farm project. As a short term measure in order to drastically minimize fluctuating power in the grid, three sizes of flow battery have been analyzed. This creates avenues for diversification of energy use from wind, thereby opening it up for expansion. The major focus is to maximize the possibility to feed in as much power to the grid as possible, provided it meets the quality standard specified by the grid operators.

The second strategy is the production of hydrogen from the excess energy after the constant supply to the grid which could be used for peak period power generation and a demonstration transport programme in the Isles.

The project looks promising from the financial point of view and the community could take advantage of the funding opportunities from Shetland Islands Council and European Commission for renewable energy development and associated projects to bring down the investment cost.

This project also offers a high potential for green house gas savings. In fact, the project will put the Isles on the world map with their ambitious programme towards achieving 100% renewable energy coverage in the long run.

# CHAPTER 6: DECENTRALIZED WIND TO HEAT

## 6.1. INTRODUCTION

The decentralized wind to heat systems are small scale off grid wind generation systems which supplement the grid electricity to meet the heat demand. Till date, twelve wind to heat projects have been successfully implemented with the support of Highlands and Islands Community Energy Company HICEC and Scottish Community and Householder's Renewables Initiative SCHRI in Shetland. With the implementation of the wind to heat projects most of the beneficiaries like the Unst Heritage Center have been able to cut down their electricity costs by half[24]. Though the wind to heat projects have been highly instrumental in reducing emissions caused by use of fossil fuels for heating, they are not eligible for Renewable Obligation Certificates (ROCs) yet. This is due to the fact that the current energy meters are designed to read at 50Hz frequency and do not read the generation when the frequency goes beyond 50 Hz. However Proven Energy Ltd is in the process of manufacturing new energy meters which would record the energy generation at higher frequencies. The availability of ROCs for the wind to heat projects would play a major role to make such projects viable.

Considering the success of the wind to heat projects in Shetland and potential for bigger wind to heat projects, 6 areas in Unst and 3 in Yell have been identified during the SESAM study as potential sites for decentralized wind to heat projects. The electricity generated by the turbines could be directly used to power the electrical storage heaters or it could be used to heat water to distribute heat through a water bound system. The wind to heat projects in Unst and Yell have used electrical cables to connect the wind turbines to the electrical storage heaters. The water bound heating systems could be carried out as a district heating or individual hot water system. However the cost of installation of the district heating system would be much higher

[24] Source: Electricity bills years,2004 and 2007, Unst Heritage center

than an individual system. While designing the wind to heat systems we have tried to compare the costs and payback period of the water bound and electrical heating systems to determine the installation that could be more financially viable.

## 6.2 METHODOLOGY

**Clustering:** Different clusters were opted on the basis of concentration of heating load geographically. A high concentration of heat load from households and commercial enterprises in a radius of about 500 m was considered as a cluster. The minimum distance between the turbine and any building is 10 times rotor diameter of the selected turbine. Very scattered household and commercial enterprises were not considered in the clustering.

**Data collection and analysis:** Data were **c**ollected in the SESAM survey for different clusters. Total heat demand for each cluster is the summation of individual heat demand of households and commercial enterprises among the clusters. Where it was not possible to differentiate energy consumption for heating from other electrical appliances, it was considered in the calculation that about 70% to 80% energy is consumed for space and water heating.

**Technical and Financial analysis:** The turbine was selected for each cluster depending upon the heat load of the cluster. The existing wind data were analyzed to find out the probable seasonal energy generation by different wind turbines and then matched with the seasonal variation of heat demand to select the optimum size of the turbine. Seasonal heat demand for households was calculated as per the modified HDD presented in table 3.1. For the commercial sector seasonal heat demand was calculated from the actual data acquired through the survey. The thermal (hot water) storage capacity for the water bound heating systems was calculated on the basis of 20 minutes interval wind data of a week based on the critical month with the lowest heat demand. In the calculation of $CO_2$ savings, 2 scenarios were considered. In one scenario the $CO_2$ savings come from using oil as a back up system and in the second scenario the $CO_2$ savings come from using grid electricity as a back up system. A Financial analysis was conducted for a water bound heating system and an electrical heating system for each cluster. Net present value (NPV), internal rate of return and Pay back period were determined in the analysis.

In the financial analysis, the life time of each cluster project was considered to be 20 years. Furthermore, the analysis was based on the following parameters:

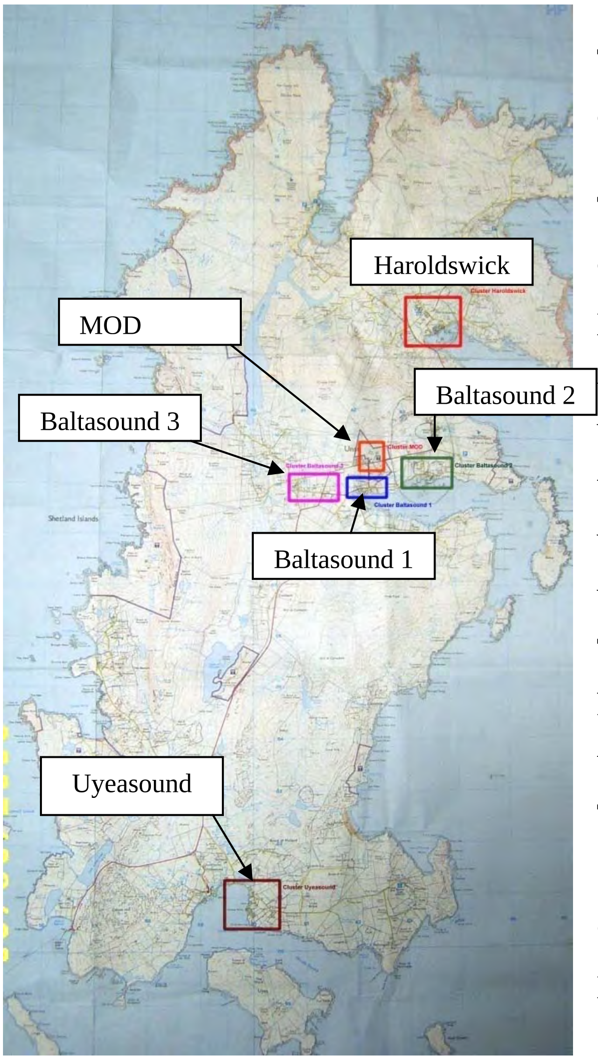
- a heat tariff of 2.5 pence/kWh for both the water bound heating system and the electrical heating system was considered. This has been derived from the cost of per KWh heat production from oil.
- per KW installation cost of wind turbines for small systems was derived from the PURE project and for larger system it was considered as £1000/KWh
- cost of district heating systems were derived from the Lerwick district heating system.
- cost of electricity distribution equipment for electrical heating system was considered as 8% of total investment cost whereas turbine cost was considered to be about 70% of the total investment cost [25].
- the amount of the back up energy required for the system and the excess energy generated from the turbine during the year was calculated from the monthly generation and demand profile.
- the installation cost of oil boiler for the back up system of a water bound system was not considered.
- the cost of oil for a water bound back up system was considered as 0.025 £/KWh
- the maintenance cost for the water bound system is considered as 20% of annual revenue.
- for the back up of an electrical heating system, the night electricity tariff was considered.
- the annual maintenance cost for electrical heating system was considered as 5% of annual revenue.
- income from selling heat is 2.5 p/kWh and income from ROCs is 4.61 p/kWh

[25] Wind energy fact sheet, DTI

- inflation was considered to be 2%, the discount rate as 10%

## 6.3. POTENTIAL OF DECENTRALIZED WIND TO HEAT PROJECTS IN UNST

### 6.3.1. Overview




The figure beside shows the location of difference clusters in Unst.

The following table summarizes the demand, investment costs and payback period of 6 potential wind to heat systems in Unst. The investment costs for the water bound system includes the wind turbine, district heating system pipes, valves, bends, pumps, and installation of water bound system in customer premises. The investment costs of the electrical heating system includes the cost of the turbine, electrical cables and equipments. The payback period of the two alternative systems has been calculated in order to compare the viability of the wind to heat projects.

***Figure 6.1. Location of different cluster in Unst***

***Table 6.1. Overview of decentralized wind to heat projects in Unst***

| Name of cluster | Annual heat demand (kWh) | Capacity of turbine (kW) | Wind to heat system | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Water bound heating system | | | Electrical heating system | | |
| | | | Investment cost (£) | Payback period (year) | IRR (%) | Investment cost (£) | Payback period (year) | IRR (%) |
| Uyeasound | 348,604 | 4 x 15(1) | 311,003 | 27 | 12 | 88,500 | 8 | 12 |
| Haroldswick | 165,582 | 2 x 15 | 249,764 | 28 | 13 | 47,500 | 5 | 12 |
| Baltasound 1 | 626,530 | 5x15 | 446,560 | 18 | 13 | 48,085 | 8 | 13 |
| Baltasound 2 | 188,559 | 2x15 | 78,523 | 18 | 12 | 72,571 | 12 | 15 |
| Baltasound 3 | 1541,312 | 330(3) | 601725 | 16 | 13 | 427,714 | 6.0 | 20 |
| (MOD) | 544,585 | 3x15 | - | - | - | 86875 | 13.0 | 15 |

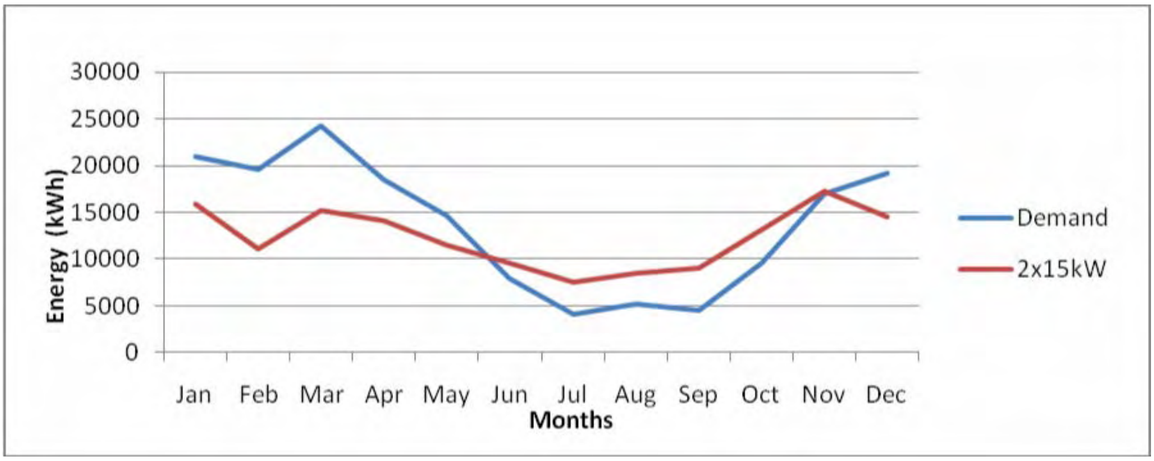
(1) Proven WT 15000 wind turbine – 15kW
(2) Enercon E33 – 330kW

*Source: SESAM, 2007*

## 6.3.2 Cluster 1 – Haroldswick

For the cluster in Haroldswick, 9 council houses, 1 new built or kit house[26] and Haroldswick community hall have been considered. The annual heat demand in this area is 165,582 kWh. Around 40% of the heat demand is met by oil, 50% by electricity, 8% by coal and remainder by LPG. The figure 1 below shows the heat demand profile per year of the area along with the energy output from 2x15 kW Proven WT15000 turbine.

***Figure 6.2. Generation and Demand profile of Haroldswick***




[26] Houses that are built after 1970

*Source: SESAM survey and NYDC*

As seen from the figure above the energy produced by the turbine will be able to meet the heat demand of the area for 6 months of the year. Therefore a backup system like oil boiler will be required to supply heat during the lean generation months. However, an oil boiler has to be installed as a back up system. The cost benefit analysis of the two heating systems is shown in the tables below.

***Table 6.2. Cost benefit analysis of water bound system in Haroldswick***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total cost with 79%grant (£) |
|---|---|---|---|---|
| **Installation costs** | | | | **47,639** |
| 1. Wind turbine (2 x 15 kW) | 30 | kW | 40,000 | 16,800 |
| 2. Cost of pipeline including (valves, bends etc.) | 450 | m | 270 | 25,515 |
| 3. Storage tank | 5 | m3 | 430 | 451 |
| 4. Pump | 1 | set | 10,000 | 2,100 |
| 5. Heat exchangers | 11 | set | 1,200 | 2,772 |
| **Annual Revenue** | | | | **10,143** |
| 1. Revenue per annum | 165,582 | kWh | 0.025 | 4139 |
| 2. Revenue from ROCs | 130,518 | kWh | 0.046 | 6003 |
| **Pay back period (years)** | | | | **17** |
| **Net Present Value (NPV)** | | | | **1908** |
| **Internal Rate of Return (IRR) (%)** | | | | **13** |

*Source: SESAM survey and NYDC*

***Table 6.3: Cost benefit analysis of electrical heating system in Haroldswick.***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 53% grant (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **50,357** |
| 1. Wind turbine (2 x 15 kW) | 30 | kW | 40,000 | 37,600 |
| 2. Electrical cables | 450 | m | 40 | 8,460 |
| 3. Equipments | 1 | set | 9,142.9 | 4,297 |
| **Annual Revenue** | | | | **10,143** |
| 1. Revenue per annum | 165,582 | kWh | 0.025 | 4139 |
| 2. Revenue from ROCs | 130,518 | kWh | 0.046 | 6,004 |
| **Pay back period (years)** | | | | **18.0** |
| **Net Present Value (NPV)** | | | | **574** |

| | |
|---|---|
| **Internal Rate of Return (IRR) (%)** | **13** |

*Source: SESAM survey and NYDC*

If oil is used as the back up system for the wind to heat project in this cluster the annual $CO_2$ savings will be 46 tonnes, however annual $CO_2$ savings will be 41 tonnes if electricity is used for the back up system.

### 6.3.3 Cluster 2 – Uyeasound

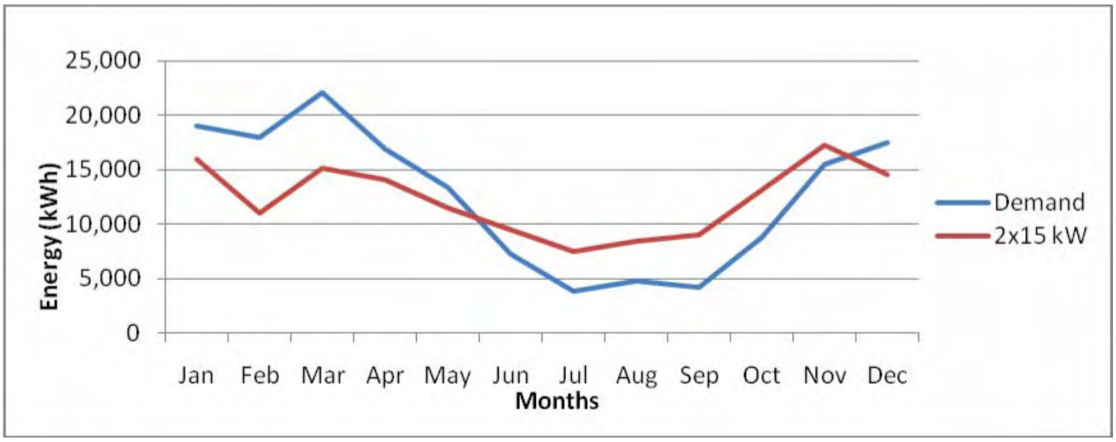
The Uyeasound cluster consists of 12 council houses having 1-3 bedrooms, one large stone building, Uyeasound primary school, the church, Uyeasound community hall, and Lakeland inshore base. The residents in this area use 13,162 liters of oil and 138,552 kWh of electricity from the grid annually. It is estimated that two 15kW turbines would be able to meet most of the heat demand of the area along with an oil boiler back up system. Considering the economics of installation and connection, two sites, site 1 and site 2 have been identified for the placement of the turbines. Site 1 will cover the council houses and the Lakeland inshore base which is located at close proximity. A 15kW turbine could be installed at that site to meet 79% of the heat demand. The generation profile of the 15kW Proven WT15000 along with the demand profile of site 1 is shown in figure 1 below.

***Figure 6.3. Generation and Demand Profile of Uyeasound Site 1***


*Source: SESAM survey and NYDC*

At site 2 which covers the Uyeasound primary school, church, Uyeasound community hall and a large stone building, another 15 kW WT15000 Proven turbine could be placed to supply the heat demand. This would help reduce the power losses in the cables and pipes by bringing the source of generation closer to the demand. The generation and demand profile of site 2 is shown in the figure below.

***Figure 6.4. Generation and Demand Profile of Uyeasound site 2***




*Source: SESAM survey and NYDC*

For both the sites, the cost of installing water bound heat systems and electrical heating systems have been estimated. Supplying the electricity generated from the wind turbines with electrical cables would give the flexibility to the users to either use the electricity for electrical storage heaters or for heating up water to distribute the heat through a water bound system. Table 1 and 2 shows the cost benefit analysis of the two systems.

***Table6.4. Cost benefit analysis of Water bound heating system of Uyeasound site 1&2***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 70% grant (£) |
|---|---|---|---|---|
| **Installation Costs** | | | | **99,630** |
| 1. Wind turbine (4 x 15 kW) | 60 | kW | 2,666 | 48,000 |
| 2. Cost of pipeline including (valves, bends etc.) | 500 | m | 270 | 40,500 |
| 3. Storage tank | 10 | m3 | 430 | 1,290 |
| 4. Pump | 1 | set | 10,000 | 3,000 |
| 5. Heat exchangers | 19 | set | 1,200 | 6,840 |
| **Annual Revenue** | | | | **20,960** |
| 1. Revenue per annum | 348,604 | kWh | 0.025 | 8780 |
| 2. Revenue from ROCs | 264,771 | kWh | 0.046 | 12179 |
| **Pay back period (years)** | | | | **19** |

| | |
|---|---|
| **Net Present Value (NPV)** | **495** |
| **Internal Rate of Return (IRR) (%)** | **12** |

*Source: SESAM survey and NYDC*

***Table6.5. Cost benefit analysis of the electrical heating system of Uyeasound site 1&2***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 49% (£) |
|---|---|---|---|---|
| **Installation Cost** | | | | **101,126** |
| 1. Wind turbine (4 x 15 kW) | 60 | kW | 2,666 | 81,600 |
| 2. Electrical cables | 500 | m | 40 | 10,200 |
| 3. Equipments | 1 | set | 18,285 | 9,326 |
| **Annual Revenue** | | | | **20,895** |
| 1. Revenue per annum | 348,604 | kWh | 0.025 | 8,715 |
| 2. Revenue from ROCs | 264,770 | kWh | 0.046 | 12,179 |
| **Pay back period (years)** | | | | **18** |
| **Net Present Value (NPV)** | | | | **1925** |
| **Internal Rate of Return (IRR) (%)** | | | | **13** |

*Source: SESAM survey and NYDC*

If oil is used as the back system in this cluster it generates 91 tonnes of $CO_2$ savings per year and with electricity as the back up system, the annual $CO_2$ savings is 79 tonnes.

### 6.3.4 Cluster 3: Baltasound 1

This cluster includes 2 commercial enterprises and 27 households. Among the households, there are 20 council houses having 2-3 bedrooms, 2 converted croft houses and 3 old grand stone buildings. The commercials in this cluster are Shop, Storage and Baltasound Hall. The annual heat demand in this area is met by using 26,310 liter oil and 278,204 kWh electricity. The seasonal generation and demand profile shown in the figure below. In order to meet the heat demand of the area we have simulated the generation profile of five turbines 15kW.

***Figure6.5. Generation and Demand Profile – Baltasound 1***


*Source: SESAM survey and NYDC*

A wind turbine could supply 367,279 kWh/year which is 58.62% of the total heat demand (626,530 kWh/year). The capacity factor of the turbine is 55.9%. By installing five 15 kW turbines, the supply could meet the demand from July to September; the other months could be covered by an oil boiler as backup system for water bound system or electricity from grid for an electric heating system. The financial details of a water bound heating system and an electricity bound heating system are shown in the table below.

***Table 6.6. Costs benefit analysis of water bound system – Baltasound 1***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost 93.5% (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **68,670** |
| 1. Wind turbine (5 x 15 kW) | 75 | kW | 2,666 | 13,000 |
| 2. Storage tank | 12 | m3 | 430 | 335 |
| 3. Cost of pipeline including (valves, bends etc.) | 700 | m | 270 | 12,285 |
| 4. Heat exchanger | 1 | set | | 42,400 |
| 5. Pump | 1 | | 10,000 | 650 |
| **Annual Revenue** | | | | **18,717** |
| 1. Revenue per annum | 626,530 | kWh | 0.025 | 15,781 |
| 2. Revenue from ROCs | 63,687 | kWh | 0.046 | 2,935 |
| **Pay back period (years)** | | | | **18** |
| **Net Present Value (NPV)** | | | | **624.36** |

| | |
|---|---|
| **Internal Rate of Return (IRR)** | **12** |

*Source: SESAM survey and NYDC*

***Table 6.7: Costs benefit analysis of electric heating system – Baltasound 1***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost (83% grant) (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **48,085** |
| 1. Wind turbine (5x15 kW) | 75 | kW | 2,666 | 34,000 |
| 2. electric cable | 1,500 | m | 40 | 10,200 |
| 3. Equipment | 1 | set | | 3,885 |
| **Annual Revenue** | | | | **18,717** |
| 1. Revenue per annum | 626,530 | kWh | 0.025 | 15,781 |
| 2. Revenue from ROCs | 63,687 | kWh | 0.046 | 2,935 |
| **Pay back period (years)** | | | | **8** |
| **Net Present Value (NPV)** | | | | **975** |
| **Internal Rate of Return (IRR)** | | | | **13** |

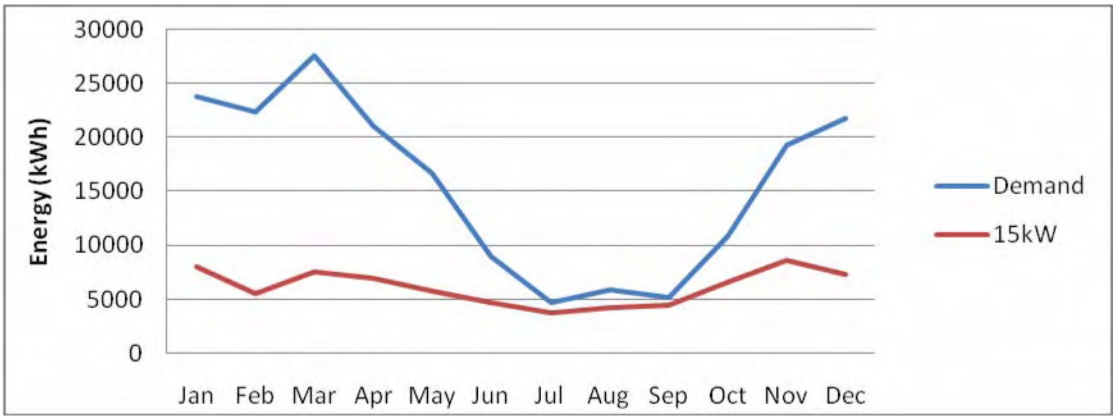
*Source: SESAM survey and NYDC*

The financial viability of the electrical heating system requires an 83% investment grant. This wind to heat project would result in $CO_2$ savings of 87 tonnes with a oil backup system and 11 tonnes with a back up from the existing grid.

## 6.3.5 Cluster 4: Baltasound 2

This cluster includes 2 commercial enterprises: Sandison & Sons and Baltasound Hotel. In order to meet the heat demand of the area we have simulated the generation profile of one turbine Proven WT 15000 (15kW). The demand and generation by season is shown in the figure below:

***Figure 6.6. Generation and Demand Profile – Baltasound 2***




*Source: SESAM survey and NYDC*

The cost benefit analysis of the two heating systems is shown in the tables below.

***Table 6.8: Cost benefit analysis of water bound system – Baltasound 2***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost (69% grant) (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **78,523** |
| 1. Wind turbine (15 KW) | 15 | kW | 2,666 | 12,400 |
| 2. Storage tank | 10 | m3 | 430 | 1,333 |
| 3. Cost of pipeline including (valves, bends etc.) | 700 | m3 | 270 | 58,590 |
| 4. Heat exchanger | 1 | set | | 3,100 |
| 5. Pump | 1 | | 10,000 | 3,100 |
| **Annual Revenue** | | | | **18,622** |
| 1. Revenue per annum | 626,530 | kWh | 0.025 | 15,781 |
| 2. Revenue from ROCs | 61,630 | kWh | 0.046 | 2,841 |
| **Pay back period (years)** | | | | **18** |
| **Net Present Value (NPV)** | | | | **616** |
| **Internal Rate of Return (IRR) (%)** | | | | **12** |

*Source: SESAM survey and NYDC*

***Table 6.9: Costs benefit analysis of electric heating system - Baltasound 2***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **72,571** |
| 1. Wind turbine (15 kW) | 15 | kW | 2,666 | 40,000 |
| 2. Electric cable | 700 | m | 40 | 28,000 |

| | | | | |
|---|---|---|---|---|
| 3. Equipment | 1 | set | | 4,571 |
| **Annual Revenue** | | | | **18,622** |
| 1. Revenue per annum | 626,530 | kWh | 0.025 | 15,781 |
| 2. Revenue from ROCs | 61,630 | kWh | 0.046 | 2,841 |
| **Pay back period (years)** | | | | **12** |
| **Net Present Value (NPV)** | | | | **11,773** |
| **Internal Rate of Return (IRR) (%)** | | | | **15** |

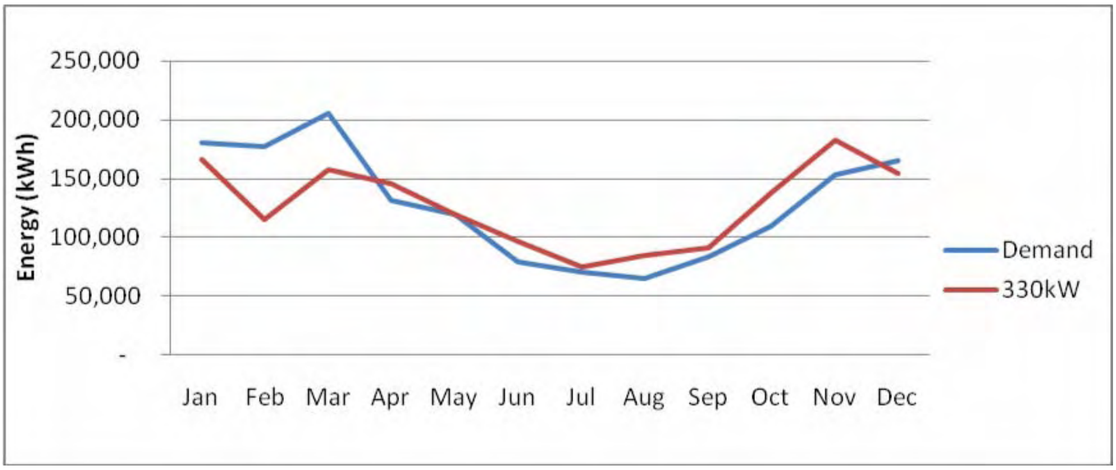
*Source: SESAM survey and NYDC*

With the installation of a water bound system in this cluster, the oil consumption for heat can be reduced by about 50%. The electrical heating system is financially feasible with a pay back period of 12 years. And from the SESAM survey, all commercial enterprises in cluster Baltasound 2 use electric panel heater, therefore the electrical heating system could be feasible. By installing a wind turbine, this project can save 32 tonnes of $CO_2$ per year with a oil back up system and 18 tonnes of $CO_2$ per year with the back up system from grid.

### 6.3.6. Cluster 5 - Baltasound 3

This cluster includes 5 commercial enterprises and 9 households. The main commercial enterprises are Unst Leisure center, Baltasound Junior High School, and Nordalea Care center. Among the households, there are 3 converted croft houses and 6 grand old stone buildings. The total annual heat demand for the cluster is estimated at 1,541 MWh, out of which oil demand is 1081 MWh/year and electricity demand 142 MWh/year respectively. The rest comes from coal, peat and LPG. The optimum size of the turbine is 330 KW (for example Enercon E-33) . The rotor diameter of the turbine is 33.4 meter. So the distance between the turbine and any buildings has to be 334 meter. The turbine could generate a maximum of 1,530 MWh per year. However, the maximum useful energy from the turbine could be 1,406 MWh/year. Fig 6 describes the seasonal generation and demand profile.

***Figure 6.7: Seasonal generation and demand profile Baltasound 3***




*Source: SESAM survey and NYDC*

The profile shows that the opted turbine could meet the demand from April to December of the year. Hence, it requires a back up system to meet the total heat demand for the rest of the time of the year.

For a water bound heating system, the existing oil boiler of Baltasound School, Leisure Center or Nordalea Care Center can be used as back up energy source during the period of deficit. However, it requires a contract with the concerned authorities if they agreed on such an arrangement. For the electrical heating system the deficit could be met by supplying energy from the grid. Implementing the project could save about 314 ton of $CO_2$ per year with a oil back up system and 295 ton of $CO_2$ per year with a back up from the existing grid.

In the financial analysis, the cost of leasing or renting of the back up system was considered as 0.01 £/KWh It was found in the analysis that the water bound heating system has a negative NPV which means that a water bound heating system is not financially feasible. However, 25% grant on investment could make the project feasible with the NPV £26,951 and a payback period of 16 years. The electrical heating system is financially feasible with a pay back period of 6 years. Financial details of a water bound heating system and an electrical heating system are shown in Table 10 and Table 11 respectively.

***Table 6.10. Financial detail of water bound system - Baltasound 3.***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 25% grant (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **601,725** |
| 1. Wind turbine (330 kW) | 330 | kW | 1,000 | 247,500 |
| 2. Cost of pipeline including (valves, bends etc.) | 1500 | m | 270 | 303,750 |
| 3. Storage | 50 | m3 | 430 | 116,125 |
| 4. Pump | 1 | set | 10,000 | 7,500 |
| 5. Heat exchanger | 14 | | | 26,850 |
| **Annual Revenue** | | | | **109,346** |
| 1. Revenue per annum | 1,541,312 | KWh | 0.025 | 38,823 |
| 2. Revenue from ROCs | 1,529,772 | KWh | 0.046 | 70,522 |
| **Pay back period (years)** | | | | **16** |
| **Net Present Value (NPV)** | | | | **26,951** |
| **Internal Rate of Return (IRR) (%)** | | | | **13** |

*Source: SESAM survey and NYDC*

***Table 6.11. Financial detail of electrical heating system - Baltasound 3.***

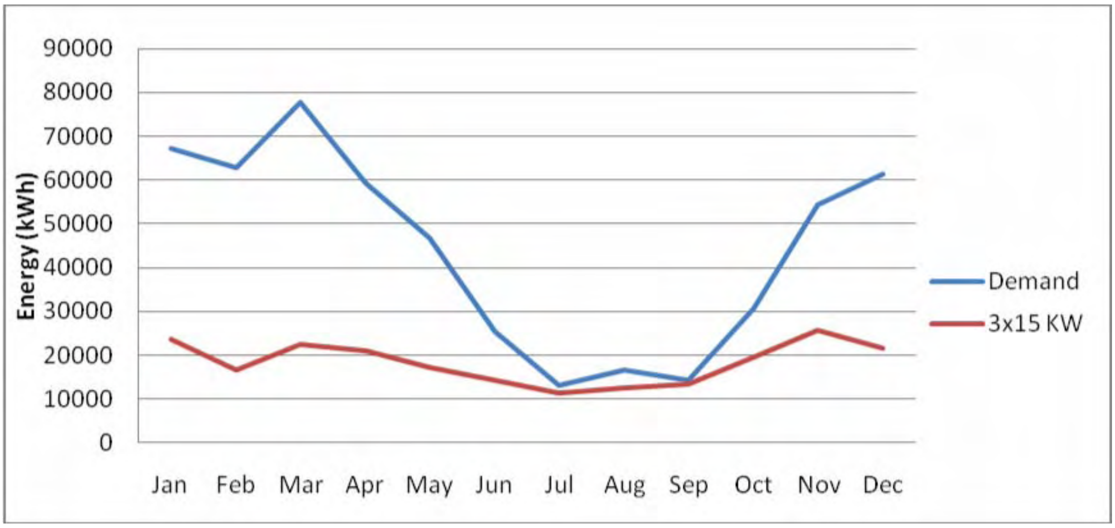
| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **427,714** |
| 1. Wind turbine (330 kW) | 330 | kW | 1,000 | 330,000 |
| 2. Electric cable | 1,500 | m | 40 | 60,000 |
| 3. Equipment | 1 | set | | 37,714 |
| **Annual Revenue** | | | | **109,346** |
| 1. Revenue per annum | 1,541,312 | kWh | 0.025 | 38,823 |
| 2. Revenue from ROCs | 1,529,772 | kWh | 0.046 | 70,522 |
| **Pay back period (years)** | | | | **6** |
| **Net Present Value (NPV)** | | | | **279,539** |
| **Internal Rate of Return (IRR) (%)** | | | | **22** |

*Source: SESAM survey and NYDC*

### 6.3.7 Cluster 6 (Council houses + MOD houses)

This cluster consists of 20 council houses which are located near MOD houses and 20 MOD houses. Out of the MOD houses only 20 houses were considered because they are currently occupied and the rest are empty. The total annual heat demand of the cluster is estimated at 530 MWh. Out of which consumption of electricity, oil and coal consumption is about 307 MWh/year, 98 MWh/year and 123 MWh/year respectively. The optimum size of the generator is 3X15KW Proven WT15000 turbine. The rotor diameter of the turbine is 9 meter. These turbines could generate maximum 220 MWh/year. Installing these wind turbines could save about 77 tonnes of $CO_2$ per year. Fig: 2 below shows the seasonal generation and demand profile.

***Figure 6.8: Seasonal generation and demand profile (Council houses + MOD houses)***




*Source: SESAM survey and NYDC*

The figure depicts that the turbine could not generate the energy required from January to June and from October to December of the year. However, it can meet the base heat demand of the cluster. It requires a back up system to meet the annual heat demand for the rest of the time of the year. The back up system could be an oil boiler for a water bound heating system or the existing grid for an electrical heating system. Implementing the project could save about 59 tonnes of $CO_2$ per year with a oil back up system and 16 tonnes of $CO_2$ per year with a back up from the existing grid.

It was found in the financial analysis that both the water bound heating system and electrical heating system has a negative NPV which means that the projects are not financially feasible. However, a 50% grant on investment could make the electrical heating system financially feasible.

Table 12 shows the financial details of electrical heating system with 50% grant.

***Table 6.12. Financial detail of electric heating system (Council houses + MOD houses)***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 50% grant (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **86,875** |
| 1. Wind turbine (3 x 15 kW) | 45 | kW | 2,666 | 60,000 |
| 2. electric cable | 1,000 | m | 40 | 20,000 |
| 3. Equipment | 1 | set | 13,714 | 6,857.14 |
| **Annual Revenue** | | | | **27,553** |
| 1. Revenue per annum | 544,585 | kWh | 0.025 | 13,614 |
| 2. Revenue from ROCs | 302,353 | kWh | 0.046 | 13,938 |
| **Pay back period (years)** | | | | **13** |
| **Net Present Value (NPV)** | | | | **12,837** |
| **Internal Rate of Return (IRR) (%)** | | | | **15** |

*Source: SESAM survey and NYDC*

## 6.4. POTENTIAL OF DECENTRALIZED WIND TO HEAT PROJECTS IN YELL

### 6.4.1. Overview

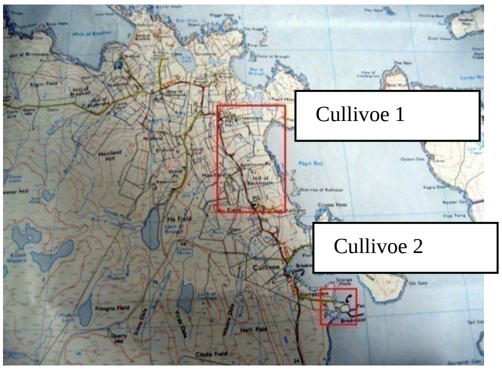




***Figure 6.9: Location of different cluster***

The figure above shows the location of difference clusters in Yell and the following table summarizes the demand, investment costs and payback period of the 3 possible wind to heat systems in Yell. The investment cost of the water bound system includes the wind turbine, district heating system pipes, valves, bends, pumps, and installation of water bound system in customer premises. The investment cost of the electrical heating system includes the cost of the turbine, electrical cables and equipment. The payback period of the two heating systems, water bound and electrical heating system, has been calculated in order to compare the viability of the wind to heat projects.

***Table 6.13. Overview of decentralized wind to heat projects in Yell***

| Name of cluster | Annual heat demand (kWh) | Capacity of turbine (kW) | Wind to heat system | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Water bound heating system | | | Electrical heating system | | |
| | | | Investment cost (£) | Payback period (year) | IRR (%) | Investment cost (£) | Payback period (year) | IRR (%) |
| Mid Yell | 2,796,471 | 2x330 | 1,155,800 | 15 | 13 | 795,428 | 5 | 25 |
| Cullivoe 1 | 251,251 | 3x15 | 72,630 | 17 | 12 | 278,835 | 18 | 12 |
| Cullivoe 2 | 67,287 | 6 | 14,744 | 19 | 12 | 48,085 | 14 | 13 |
| (1) Proven WT 15000 wind turbine – 15kW<br>(2) Enercon E33 – 330kW | | | | | | | | |

*Source: SESAM survey and NYDC*

### 6.4.2 Cluster 1 - Mid Yell Cluster

This cluster includes 6 commercial enterprises. The major heat energy consumers are Mid Yell JHS, Mainstream Ltd, Yell Leisure Center, Mid Yell Care Center and Shetland Norse Factory. The estimated heat demand of the cluster is 2,796 MWh per annum, out of which oil consumption is about 2,737 MWh/year and electricity consumption is about 59 MWh/year. Two 330 KW Enercon E-33 turbine were selected for this cluster. These could produce a maximum of 2,726 MWh/year. However, the maximum useful energy form these turbines would be 2641 MWh/year. Figure 8 below gives a picture of the seasonal generation and demand.

***Figure 6.10. Seasonal generation and demand profile of Midyell cluster***


*Source: SESAM survey and NYDC*

As seen in the figure above, the turbine can meet the heat demand from October to January and March to May. For the rest of the year it requires back up system. The back up system could be an oil boiler for a water bound heating system or the existing grid for an electrical heating system. For the back up system of water bound heating system the existing oil boiler of Leisure Center, Mid Yell Junior High School, Shetland Norse Factory or Care Center could be used. The heat demand of Shetland Norse Factory was included in the total heat demand of the cluster. Shetland Norse Factory is the leading energy consumer in Yell consuming about 3150 liter oil per week. Though most of the energy is used for process heating, a water bound heating system with the wind to heat project in this cluster could contribute in pre heating of the water required for the process of the factory. The use of the waste heat from Shetland Norse Factory for a district heating system could drastically reduce the demand for heat generation. However, this option was not considered in our calculation.

Implementing this project could save about 721 ton of $CO_2$ per year with the oil back up system and about 700 tonnes of $CO_2$ per year with the back up from the existing grid.

In the financial analysis, the cost of leasing or renting of the back up system was considered as 0.01 £/KWh. Table 15 and Table 16 shows the financial details of water bound heating system and electrical heating system respectively. In the analysis it was found that both the water bound heating system and the electrical heating systems are financially feasible. However, the water bound system has the advantage that different fuels can be used for back up and the waste heat from Shetland Norse Factory could be used for it.

***Table 6.14. Financial detail of water bound heating system***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **1,155,800** |
| 1. Wind turbine (2 X 330 kW) | 660 | kW | 1,000 | 660,000 |
| 2. Cost of pipeline including (valves, bends etc.) | 1,500 | m | 270 | 405,000 |
| 4. Storage | 60 | m3 | 430 | 25,800 |
| 4. Pump | 1 | set | | 10,000 |
| 5. Heat exchanger | 6 | | | 55,000 |
| **Annual Revenue** | | | | **192,208** |
| 1. Revenue per annum | 2,796,471 | kWh | 0.025 | 70,439 |
| 2. Revenue from ROCs | 2,641,389 | kWh | 0.046 | 121,768 |
| **Pay back period (years)** | | | | **15** |
| **Net Present Value (NPV)** | | | | **57,201** |
| **Internal Rate of Return (IRR)** | | | | **13** |

*Source: SESAM survey and NYDC*

***Table 6.15: Financial detail of electrical heating system***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **795,428** |
| 1. Wind turbine (2 x 330 kW) | 660 | kW | 1,000.00 | 660,000 |
| 2. Electric cable | 1,500 | m | 40.00 | 60,000 |
| 3. Equipment | 1 | set | | 75,428 |
| **Annual Revenue** | | | | **109,346** |
| 1. Revenue per annum | 2,796,471 | kWh | 0.025 | 70,439 |
| 2. Revenue from ROCs | 2,641,389 | kWh | 0.046 | 121,768 |
| **Pay back period (years)** | | | | **5** |
| **Net Present Value (NPV)** | | | | **686,176** |
| **Internal Rate of Return (IRR) (%)** | | | | **25** |

*Source: SESAM survey and NYDC*

### 6.4.3 Cluster 2 – Cullivoe 1

The Cullivoe 1 cluster consists of 15 council houses and the Cullivoe primary school. The total annual heat demand of the cluster is estimated to be around 251,251 kWh.

.As shown in the figure below, three 15kW wind turbine could meet the heat of the area between June and November.

***Figure 6.11: Generation and demand profile of Cullivoe 1***


*Source: SESAM survey and NYDC*

However during the other months only 50-60% of the heat demand can be met with the generation from the wind turbine. The costs of installing water bound heat system and electrical heating system has been estimated. An oil boiler would be used to provide the heat for the water bound system as back up when there is not enough generation from the wind turbines. The cost benefit analysis of the water bound and electrical heating systems are shown below.

*Table 6.16 Cost benefit analysis of water bound heating system - Cullivoe 1*

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 73% grant (£) |
|---|---|---|---|---|
| **Installation Costs** | | | | **72,630** |
| 1. Wind turbine (3x15 kW) | 45 | kW | 2,666 | 32,400 |
| 2. Cost of pipeline including (valves, bends etc) | 450 | m | 270 | 32,805 |
| 3. Storage tank | 10 | m3 | 430 | 1,161 |
| 4. Pump | 1 | set | 10,000 | 2,700 |
| 5. Heat exchangers | 11 | set | 1,200 | 3,564 |
| **Annual Revenue** | | | | **14,139** |
| 1. Revenue per annum | 251,251 | kWh | 0.025 | 6,281 |
| 2. Revenue from ROCs | 170,815 | kWh | 0.046 | 7,857 |
| **Pay back period (years)** | | | | **17** |
| **Net Present Value (NPV)** | | | | **2018** |
| **Internal Rate of Return (IRR) (%)** | | | | **12** |

*Source: SESAM survey and NYDC*

*Table 6.17. Cost benefit analysis of electrical heating system - Cullivoe 1*

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 50 % grant (£) |
|---|---|---|---|---|
| **Cost** | | | | **75,857** |
| 1. Wind turbine (3 x 15 kW) | 45 | set | 2,666 | 60,000 |
| 2. Electrical cables | 450 | m | 40 | 9,000 |
| 3. Equipments | 1 | set | 13,714 | 6,857 |
| **Annual Revenue** | | | | **14,139** |
| 1. Revenue per annum | 251,251 | kWh | 0.025 | 6,281 |
| 2. Revenue from ROCs | 170,815 | kWh | 0.046 | 7,857 |
| **Pay back period (years)** | | | | **18** |
| **Net Present Value (NPV)** | | | | **894** |
| **Internal Rate of Return (IRR) (%)** | | | | **12** |

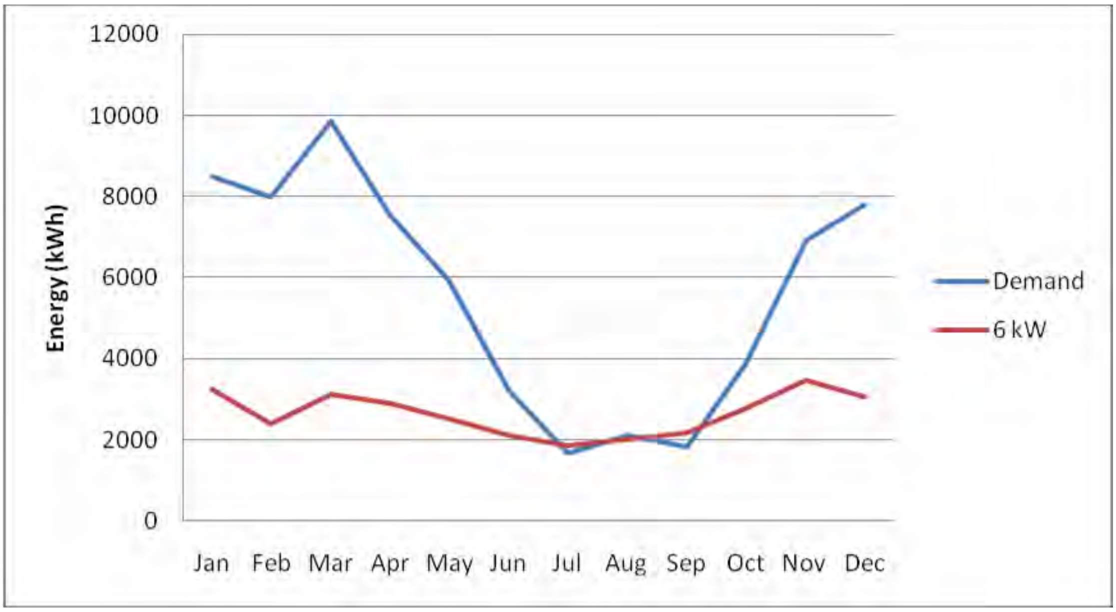
*Source: SESAM survey and NYDC*

By using the grid electricity as the back up system for the generation from the turbines, it results in 67 tonnes per year of $CO_2$ savings. However if oil is used as the back system the $CO_2$ savings equals 75 tonnes per year.

### 6.4.4 Cluster 3 - Cullivoe 2

This cluster consists of Cullivoe Hall and R.S. Henderson shop, both of these commercial enterprises use electricity for heat and hot water and their demand is 67,288 kWh electricity annually. In order to meet the heat demand of the area we have simulated the generation profile of Proven WT6000 (6kW) turbines and a capacity factor of the turbine of 60,06%. By installing the turbines 6kW the total generation annually is 31,566 kWh (46.9% of heat demand) could cover the demand for heating from July to October. The seasonal generation and demand profile is shown in figure below.

***Figure 6.12: Seasonal generation and demand profile of Cullivoe 2***




*Source: SESAM survey and NYDC*

The financial analysis of a water bound system and an electric heating system is shown in the table below.

***Table 6.18. Cost benefit analysis of water bound system – Cullivoe 2***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 84% grant (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **14,744** |
| 1. Wind turbine (6 kW) | 6 | kW | 2,666 | 2,560 |
| 2. Cost of pipeline including (valves, bends etc.) | 200 | m | 270 | 8,640 |
| 3. Storage | 5 | $m^3$ | 430 | 344 |
| 4. Pump | 1 | Set | 10,000 | 1,600 |
| 5. Heat exchanger | 2 | | | 1,600 |
| **Annual Revenue** | | | | **3,625** |
| 1. Revenue per annum | 67,287 | kWh | 0.025 | 1,694 |
| 2. Revenue from ROCs | 41,881 | kWh | 0.046 | 1,930 |
| **Pay back period (years)** | | | | **19** |
| **Net Present Value (NPV)** | | | | **159** |
| **Internal Rate of Return (IRR) (%)** | | | | **12** |

*Source: SESAM survey and NYDC*

***Table 6.19. Costs benefit analysis of electric heating system - Cullivoe 2***

| Item | Quantity | Unit | Cost per unit quantity (£) | Total Cost with 41% grant (£) |
|---|---|---|---|---|
| **Installation cost** | | | | **15,238** |
| 1. Wind turbine (6 kW) | 6 | kW | 2,666 | 9,440 |
| 2. Electric cable | 200 | m | 40 | 4,720 |
| 3. Equipment | 1 | set | | 1,078 |
| **Annual Revenue** | | | | **3,625** |
| 1. Revenue per annum | 67,287 | kWh | 0.025 | 1,694 |
| 2. Revenue from ROCs | 41,881 | kWh | 0.046 | 1,930 |
| **Pay back period (years)** | | | | **18** |
| **Net Present Value (NPV)** | | | | **237** |
| **Internal Rate of Return (IRR)(%)** | | | | **13** |

*Source: SESAM survey and NYDC*

From the financial analysis the water bound heating is only financially feasible with an investment grant of 84%. However, the electrical heating system is financially feasible with a a grant of 41%. Furthermore, Cullivoe Hall and R.S. Henderson shop already have an electrical heating system. Therefore it will easy to implement and maintain an electrical heating system with a wind turbine. By installing al wind turbine, this project can save 20 tonnes of $CO_2$ per year with an oil back up system and 17 tonnes of $CO_2$ per year with the back up system from the grid.

## 6.5. CONCLUSION

In contrast to the big wind farms which have been a subject of much public discussion, the decentralized wind to heat systems have been pretty well accepted by communities in Shetland. With twelve wind to heat projects already up and running and 6 more projects in the pipeline, it can certainly be said that several more wind to heat projects will follow. Considering the huge potential and benefit of such small scale wind to heat projects and its ease in implementation in terms of cost and installation, this part of the study tried to identify the most viable sites for such projects. A total of 9 wind to heat project sites were identified for the islands of Unst and Yell. The financial feasibility of both water bound and electrical heating system were carried out for the sake of comparison. Compared to the electrical heating system, the water bound heating system has a longer payback period mainly due to the high installation costs. However the water bound heating system is considered as a highly efficient means of distributing heat and has much lower maintenance costs once installed. As in a water bound district heating system virtually all fuels can be used for back up the system is more flexible and saves more $CO_2$ than electrical systems, where only electricity from the fossil fuel based grid can serve to back up the wind energy.

Though it might not be possible to implement all the wind to heat projects in the 9 clusters, it is recommended that big oil consumers like leisure and care centers, be considered for future wind to heat projects mainly for environmental and energy security reasons.

# CHAPTER 7. CONCLUSION AND SUGGESTIONS

After 5 weeks of study and elaboration of work in this report and in presentations done at Yell and Unst we come to the following conclusions and suggestions for further action.

- Oil is the highest contributor for the heating system in the Northern Isles (between 68% to 78% of the energy mix depending on the location). Large parts of the heating demand could be supplied by electricity generated from wind energy.
- The attitudes of the people towards using wind energy from community owned wind farms is overwhelmingly positive as obtained from the SESAM:
  - More than 80% of the people prefer to use renewable energy rather than fossil fuel and support the idea of having a community owned wind farms.
  - About half of the people are interested in using electricity from wind for heating if the cost of this electricity is not higher than the cost of the fuel they are using. A considerable proportion of both households and commercial consumers (between 10% and 30% depending on the location) are interested to use electricity for heating even if the cost is higher than at present.
  - More than 70% of the people are in favor of the idea of generating electricity/hydrogen from community owned wind turbines for fueling vehicles.
- There is a possibility to replace oil for heating demand with electricity from wind. However this option is only economically feasible, if the cost of converting non-electrical based heating systems into electrical heating systems is not taken into account in the economic analysis. In this case, three Vestas V52-850kW turbines can satisfy 66% of the total demand of 16,771 MWh/year if theoretically all oil heating systems would be converted into electrical systems. One turbine can satisfy 58% of the total demand of 6,341 MWh/year if only the portion of people is considered who stated in our survey they are willing to convert their systems to electrical heating

- The consistency of electricity supply from the wind turbines can be maintained by a back up system like a hydrogen driven internal combustion engine in addition to storage systems like a flow battery. The hydrogen produced by utilization the excess electrical energy can be used as a secondary storage option. According to our technical and economic analysis, the flow battery option with storage a capacity of 2000 kWh (discharging capacity of 800 kW, storage duration of 2.5 hours), without hydrogen production, is the most feasible one. So it would be more profitable to feed in as much generated electricity as possible into the grid.
- For decentralized wind2heat projects, from nine clusters identified, there are two clusters (Mid Yell and Baltasound-2) which are economically feasible without any funding. However the other seven will be viable if they could receive grants between 25%-70% of the total investment.
- Due to our limitation in time, we suggest that a more in-depth survey and financial analysis should be carried out, before any of the options would be explored for planning and implementation.

Shetland has already successful experience in using innovative technologies like the district (waste to) heat plant at Lerwick, the small scale wind to heat systems and the hydrogen project of PURE, which are supported by most people.

Based on this support which is also backed up from our survey, there are good opportunities to take the hydrogen technology a step further and develop larger scale projects. The Northern Isles could also become a showcase for future smart grid technologies with the implementation of the North Yell community wind farm. And also the suggested mini district wind to heat plants could be good examples for renewable energy supply in small islands communities.

We encourage the relevant organizations and people of the Northern Isles to look more into these kinds of novel technologies and wish them all the best for successful implementation.

# References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