Assessment and Future Scenarios of Knoydart's Electricity System

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EXECUTIVE SUMMARY

This report has been prepared for the Knoydart Foundation to provide a basis for making decisions on the development of community-owned energy projects on the Peninsula of Knoydart. The report presents the findings and results of a five-week assessment study conducted on the peninsula in February/March, 2013 by a team of 14 students of the Energy and Environmental Management Master Programme at the University of Flensburg, Germany.

Knoydart has been experiencing power disruptions during periods of high demand and is forced to rely on its diesel generator to supply the peninsula's electricity demand. The diesel generator is used as backup during outages and maintenance of a hydro scheme, which is the peninsula's main source of power.

The aim of this study is to propose a plan to better manage the existing electricity system of Knoydart and to assess the possible sources of energy as well as technologies available that can be utilized to meet the electricity demand of the community by using locally available resources.

The projects identified by the Foundation for evaluation are:

1. A long term Electricity Plan for Knoydart
2. Assessment of sites for a new micro hydropower plant
3. Improvement of monitoring and electricity output of the existing hydropower plant
4. Productive uses of excess electricity

The main findings of this study are as follows

Improvement of existing hydropower plant

The existing hydro power plant of Knoydart can be improved by eliminating the excessive head losses along the penstock, which were identified to be causing the lowered power output from the hydro power plant.

The monitoring system can also be improved to be able to identify technical problems of the plant and to better manage the system. Indicators are recommended to ensure proper monitoring; these indicators are

(1) overall efficiency, to see how changes such as adjustments in the spear valve affect the performance of the whole system;

(2) rainfall and flow characteristic to become able to make long-term predictions of possible electricity production; and

(3) risk of vortexes, which essentially means monitoring the level of the dam and the flow to ensure that it is above the critical level under which the risk of occurrence of vortexes is high.

Included also in the recommendations for monitoring is the use of a new dataTaker monitoring system for analysis and presentation of results and indicators. It is recommended to replace dataTaker DT50 with DT80M, to make the monitoring tasks more user friendly. Integration of the diesel generator in the monitoring system is also suggested to discover technical problems in time. A team for management of data, made up of three personnel is also recommended.

Evaluation of electricity supply potential and heating options from biomass

There are a number of options presented for the future electricity supply of Knoydart. Knoydart has 11,000 hectares of wood resources. Biomass energy systems such as wood boilers, gasifiers, and Combined Heat and Power (CHP) systems were considered but they are presently not available at a scale that is suitable for Knoydart. They would also require a centralized heat demand of considerable size that Knoydart does not have. A centralized biomass heating system would require changing already existing household heating systems that would not only be cumbersome but quite costly. Decentralized biomass energy systems for bigger buildings in Knoydart are seen as more feasible. Small scale CHP systems are risky investments and it is difficult to look for suppliers providing systems for the scale that Knoydart resources are fit for. The conclusion is that the utilization of wood for space and water heating is best for Knoydart. The Bunkhouse was used as a model for application of this technology.

New micro hydro power schemes

Four new sites namely Allt a Mhuilinn, Allt a Mogha (white Gate), Scottas Burn, and Loch Glaschoille were considered for putting up a new micro hydro power plant. Allt a Mhuillin has the biggest capacity of 85 kW and proved to be the most economically sound investment, followed by Scottas Burn. Economic analysis for the two smaller rivers, Allt a Mogha (white Gate) and Loch Glaschoille, showed that the investment costs cannot be recovered.

Using Loch Glaschoille as hydro storage to collect flow from the catchment areas of Loch Glaschoille and Scottas Burn to supply the electrical needs of the peninsula during outage or maintenance of the existing hydro power plant is not seen to be a good investment. The investment cost is too high considering that the hydro plant would only be needed to run for a few hours in a year.

Another option considered is the installation of a new turbine to the existing hydropower plant to add an extra 20 kW to the output of the current system. This proved to be a profitable investment, given that the excessive head losses in the current system are eliminated.

Long term Electricity Plans

A long term plan for the electricity system of Knoydart is modelled using the Long-range Energy Alternatives Planning (LEAP) software. This is done to be able to match electricity supply options with projected demand. The electricity demand of Knoydart is projected until 2032 considering drivers such as population and tourism. There are three resulting scenarios: (1) low growth demand scenario, (2) medium growth demand (reference) scenario, and (3) high growth demand scenario. In the medium growth demand (reference) scenario, when the electricity demand of Knoydart increases to 1,200 MWh in 2032, it is sufficient to refurbish the existing hydro power plant to be able to produce 250 kW. In this scenario, diesel consumption during hydro outages is still needed. In the high growth demand scenario, when the electricity demand of Knoydart reaches up to 1,400 MWh in 2032, two new sites for a micro hydro power plant namely, Mhuilinn 85kW and Scottas Burn 65kW, can add alternatively to the existing hydro plant of Knoydart. Allt a Mhuilinn , however, seems to be financially and technically more feasible than Scottas Burn.

Load management from the demand side can also manage excess electricity demand during peak demand hours. It is recommended to follow up on implementation of load management measures from the demand side as stated in the Senergy Econnect report (Senergy Econnect Limited 2009). Considering the present deficit of hydroelectricity, the storage of electricity is more expensive than balancing the deficit from diesel fuel. Demand side peak management is by far the cheapest solution. In the future, storage technologies such as flow batteries for peak demand management or hydrogen can be considered again once their prices go down and the y are more mature.

Productive use of excess electricity

Electric vehicles is an option to make use of excess electricity during off peak demand hours. A pilot programme of renting electric vehicles to tourists can be carried out. Certain conditions such as proper maintenance and charging facilities are required for this programme to be feasible as well as improvement of road conditions.

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1 INTRODUCTION

This report is prepared by the students of the Energy and Environment Management Master Programme at the University of Flensburg in collaboration with the Knoydart Foundation. For the past eleven years, the University of Flensburg has been working with Community Energy Scotland (CES) on various energy and environmental studies on island communities in Scotland.

The aim is to present options for improvement and future development of Knoydart´s electricity system. The report presents the findings of a 5-week field research conducted in the Peninsula of Knoydart between 18th of February and 22nd March 2013.

The collaboration is based on the vision to help Knoydart become a green and sustainable peninsula, with the specific mission of designing a roadmap towards a Sustainable Electricity System, serving as a helpful information base for further decision making and planning.

1.1 Background

Knoydart, located in the West Highlands of Scotland, is not grid connected and the principal access to it is by boat across Loch Nevis from Mallaig. Knoydart is home of slightly above 100 residents. The size of the peninsula is 55,000 acre, from which 17,200 acre are Knoydart state, owned by the Knoydart Foundation. (Foundation, 2013)

The electricity of the peninsula is supplied by a micro hydro scheme and a diesel generator in Inverie. There are also several Pico hydro plants and small diesel generators in the non-grid connected areas. The diesel generator is used for backup when the hydro plant is shut down or undergoing maintenance. The expensive cost of diesel for power generation has a big impact in the community, for this reason the Knoydart foundation is looking for better use of their natural and financial resources to improve Knoydart’s energy system.

1.2 Objectives

The overall objective of the project is to elaborate and present options for improvement and future development of the electricity system to the Knoydart community. The project focuses on four study areas with the following sub-objectives:

1. A long term Electricity Plan for Knoydart is developed
2. A feasibility Study for new micro-hydropower plants to reduce Knoydart’s dependency on standby generation is elaborated
3. Options for improvement of monitoring and electricity output of the existing hydropower plant are elaborated.
4. Uses of surplus electricity for productive uses are proposed

1.3 General Methodology

By early October 2013, while in Flensburg, **desk studies** started in order to have a better understanding of the situation in Knoydart and to assess the probable technologies and techniques that could make the objectives achievable. During this time a **questionnaire** was developed to assess the energy scenarios.

The 14 students were divided into 4 **working-teams** according to the 4 sub-objectives. They worked in close contact with counterparts from the Knoydart foundation.

Area-visits: During the beginning of the stay in Knoydart, the team got to know stakeholders, location and characteristics of the area.

The **energy survey/questionnaire** and individual and group **interviews** were conducted with special interest in future developments of population and dwelling size, the number of businesses, heating means, transport means, and the acceptability of new technologies.. Data were collected, processed and analysed, reflecting data quality and the interest of Knoydart Foundation. Several **Computer Softwares** were used, such as LEAP, Excel, AutoCAD, GPS, GIS for model analysis, statistical analysis, financial analysis and others.

2 ENERGY DEMAND

Energy models assess the whole energy situation of a country, region or community. Due to the large number of variables which have to be evaluated, it is useful to use planning software for calculations. When creating an energy model it is necessary to develop a set of scenarios for comparison of different alternatives. Scenarios are self-consistent storylines of how an energy system might evolve over time (Heaps, 2012).

This section discusses the electricity system of Knoydart modelled using the Long Range Energy Alternative Planning software LEAP. With this tool, analysts can create and then evaluate alternative scenarios by comparing their energy requirements, their social costs and benefits and their environmental impacts (*ibid*).

The main purpose of this section was to model the current status of Knoydart's electricity system in 2012 and to project a reference scenario until 2032 as well as possible future alternative scenarios. The electricity consumption in Knoydart is linked with population and tourism growth. In all scenarios tourism is assumed to be the main economic activity in Knoydart and a growth of population requires a growth of tourism. For both sectors similar growth rates have been assumed. Under that premise the following scenarios were modelled:

- Low growth scenario: the population was assumed to grow to 150 in 2032; day visitors and camping will grow annually by 2%. Similarly, bed and breakfast/full board, Bunkhouse and self-catering will grow by 1.7% annually.

- Medium growth (reference): the population was assumed to be 185 in 2032; day visitors and camping will grow annually by 3%. Similarly, bed and breakfast/full board, Bunkhouse and self-catering will grow by 2.7% annually.

- High growth: In this scenario, the population of Knoydart residents is assumed to reach 220 in 2032; day visitors and camping will grow annually by 4%. Similarly, bed and breakfast/full board, Bunkhouse and self-catering will grow by 3.7% annually.

Information for these scenarios was received from Knoydart Foundation personnel, Scotland national statistics, highland statistics and the local community survey that was carried out by the team. Assumptions were made in order to fill in gaps due to lack of community specific information. These assumptions are further explained later in this chapter.

2.1 Current Electricity Demand

To clearly understand the electricity trend of demand for Knoydart, there is need to know the main drivers for the overall electricity demand. The main drivers identified are population and tourism.

Demand Sectors and Assumptions

The main sectors which require electricity in Knoydart are the residential, service, commercial and tourist related sector. To find out the demand of each category the electricity bills from the year 2012 were used. In the case of the residential sector, it was possible to subdivide into different energy end uses (lighting, cooking, heating and electrical home appliances). For the rest of the sectors, it was not possible to subdivide due to lack of information on share of fuel under each energy end use. Therefore only the electricity consumption obtained from Knoydart renewable was considered.

The following table explains the sectors and the assumptions that had to be made:

Table 1 Demand categories, energy intensities and assumptions

Main Categories	Sub Categories	Technologies/fuel	Driver	Energy Intensity	Assumptions
Residential	Grid connected	-Light -Heating -Cooking -Home- Appliances	Population/Number of households	Electricity consumption per household, Source: Knoydart hydro invoices, generic data on distribution of household electricity consumption in Scotland	End use shares in Knoydart are as Scottish average: -Light: 2% -Heating: 85% -Cooking: 4% -Home-Appliances: 9% (The Scottish Government, 2006)
	Off-grid			Electricity consumption per household, Source: Survey	
Tourist accommodation	Grid connected	Electricity	Bed nights - Self catering - Bunk house - Bed and Breakfast	Total annual electricity consumption of tourist accommodation divided by bed nights	Electricity consumption of the tourist accommodation depends only on the number of tourist.
Services	Grid connected	Electricity	Number of premises for non-tourism related services (School, foundation office, Post office (without shop)	Electricity consumption per building, Source: Knoydart hydro invoices	All electricity consumption of the service sector is independent of number of tourist. It depends on number and size of buildings
Tourist related Commerce	Grid connected	Electricity	Number of premises Old Forge(Pub) and Pier Shop (Post Office)	Electricity consumption per building, Source: Knoydart hydro invoices	All electricity consumption of the commercial sector is dependent of number of tourist and residents
Others	Grid connected	Electricity	Broadband and Emergency Mast	Electricity Consumption (kWh) Source: Knoydart hydro invoices	We assumed a small growth in the electricity consumption in this sector.

Source: Author, 2013

2.1.1 Drivers

Population

Based on most recent data for 2012 the Knoydart population consists of only 108 people, its growth from 68 inhabitants in 2001 has resulted in an increase in electricity demand. Table 2 below summarizes the demographic facts of Knoydart based on 2012 data.

Table 2 Demographic Factors

Demographic Factor	Grid connected	Off grid	Unit
Population (in 2012)	108		People
Household Number	42	14	Households
Household Size	1.93		People per household
Projected Population in 2032 (Low growth scenario)	113	37	People
Projected Population in 2032 (Reference scenario)	139	46	People
Projected Population in 2032 (High growth scenario)	165	55	People

Source: Author adapted from (Williams, 2013), own survey and assumptions

Based on the community survey that was carried out from 22nd – 27th of February 2013, it was also found that electricity supply to the various properties was supplemented with fuels like diesel for electricity generation in the off-grid areas, wood, fuel oil, gas and kerosene for heating and cooking.

Tourism

This is the main economic activity in Knoydart. Increase in the number of visitors/tourists to Knoydart influences electricity demand directly through the demand of tourist accommodation and indirectly through tourism related services. A survey of tourists/visitors coming to the peninsula, carried out between June and November 2011, showed that the majority of visitors stayed between 3 nights and 1 week (Knoydart Foundation, 2011). While day visitors use electricity only indirectly by using services such as the pub, the tearoom, the shop, the energy needs of overnight visitors are similar to those of the residents, although there are variations depending on the type of accommodation and the duration of stay. For the purpose of this study it was assumed that bunkhouses and camping sites mainly host short time visitors while self-catering accommodation mainly hosts guests who stay for a longer period. Bed and Breakfast accommodation hosts all visitor categories. A summary of the assumed tourism demographic is shown in Table 3 below.

Table 3 Tourism Distribution according to duration of stay and accommodation

Tourists	No. of visitors		Type of accommodation		
			Bunkhouse	**B&B**	**Self-catering/friends**
			40%	35%	25%
			2387	2065	1522
One night	8,50%	508	400	108	
2-3 nights*	32,34%	1932	1164	768	
3-5 nights*	21,69%	1296	823	473	
1 week	22,61%	1351		587	764
2 weeks	7,72%	461		75	387
More than 2 weeks	7,13%	426		54	371

Source: own calculations based on (Knoydart Visitor Survey, 2011) Share of accommodation and duration of stay based on visitor survey, corrected according to known figures for some accommodation categories. Total number of tourists: Knoydart Foundation estimations. Interrelation between type of accommodation and duration of stay: Own assumptions. *) The categories for duration of visits were taken from the visitors survey. There is an overlap in the categories for visitors staying 3 nights. For the demand analysis 2-3 night visitors were assumed to stay 2.5 nights, 3-5 day visitors 4 nights.

2.1.2 Demand assessment

Based on the above-mentioned data and assumptions the following information for the base year 2012 was used for the model:

Table 4 Technologies and energy intensities for demand assessment

Main Categories	Sub Categories	Technologies	Fuels	Energy Intensity	Unit	Assumptions/sources
Residential	Grid connected	Cooking	Electricity	274.21	kWh/household	The figures represent an average household share of different fuels, based on results of the survey carried out by the team. The share of end uses is based on figures on national domestic energy consumption.
			Gas	454.17	kWh/household	
			Wood	68.55	kWh/household	
			Kerosene	59.98	kWh/household	
		Heating	Electricity	3641.91	kWh/household	
			Wood	10925.73	kWh/household	
			Oil	1456.76	kWh/household	
			Gas	182.10	kWh/household	
			Kerosene	2185.15	kWh/household	
		Lighting	Electricity	428.46	kWh/household	
		Home Appliances	Electricity	1928.07	kWh/household	
	Off-grid	Cooking	Gas	711.2	kWh/household	
			Oil	94.3	kWh/ household	
			Wood	51.4	kWh/household	
		Heating	wood	11107.83	kWh/household	
			oil	4006.10	kWh/ household	
			Electricity	3095.62	kWh/household	
		Lighting	Electricity	428.46	kWh/household	
		Home Appliances	Electricity	1928.07	kWh/household	
Tourism	Grid connected		Electricity	3.7	kWh/person day	The energy intensities are based on the electricity bills from Knoydart renewables Ltd

Main Categories	Sub Categories	Technologies	Fuels	Energy Intensity	Unit	Assumptions/sources
Commercial	Grid connected		Electricity	0.99	kWh/person day (considering both, inhabitants and tourists)	The energy intensities are based on the electricity bills from Knoydart renewables Ltd
Service	Grid connected		Electricity	6781.64	kWh/building	The energy intensities are based on the electricity bills from Knoydart renewables Ltd

Source: own calculations based on energy bills from (Williams, 2013)

The model shown in Table 4 leads to the following distribution of electricity consumption in 2012:

Table 5 Electricity Sector Demand

Sector	Subcategory	MWh
Residential (Household)	Grid	263.2
	Off-grid	76.28
Service		74.6
Tourism	camping and day visitors	17.54
	Self-catering	102.04
	bunk house	97.35
	bed & breakfast	57.12
Commercial		73.35
Others		59.75
Total		821.23

Source: Authors with LEAP Software, 2013

2.1.3 Sources and data assessment

As already mentioned at the beginning, data and information used in the model is categorized into four main groups based on their qualities:

A = Local institutions (Knoydart Foundation, Knoydart Renewables)
B = Household Survey made by the team
C = Surveys/modelling estimates by research institutes, universities, consultants, industrial, associations
D = Estimations made by the team for the project

Table 6 Sources assessment

	Category	Quality	Source
Key Assumptions			
Population	A	good estimate	Knoydart Renewables, Utility Company
No of Household	A	good	Knoydart Renewables, Utility Company
Average Household Size	A,B	good	No. Of Households
Properties	A	good	Knoydart Renewables, Utility Company
Demand			
Residential Energy Intensity	B,D	good estimate	Survey (Fuel consumption) , Energy Intensity Team Calculation
Services Energy Intensity	B,D	Good estimate	Survey (Fuel consumption) , Energy Intensity Team Calculation
Tourism Energy Intensity	A, C	Estimate	Based on Knoydart Renewables (Annual No. of visitors), Knoydart Visitor Survey, Collation of results: Long version (Duration of visits, type of accommodation) survey of 200 tourists in 2011, Energy Intensity Team Calculation

Source: Author, 2013

Throughout the modelling a few assumptions were made mainly to project future scenarios and fill in some information gaps. The assumptions considered are summarized in the table below. However, it persists the uncertainty in the development of energy intensity per household and per bed night. The energy intensity can reduce due to higher energy efficiency and increase due to more and larger appliances. The assumption that these contradicting developments balance each other is supported in (The Scottish Government, 2009) and (Highlands and Islands of Scotland, 2010).

Table 7 Assumptions to model current situation and future scenarios

Assumptions	Justification
Energy intensities see table 2-3 (new)	The percentage contribution of different fuels to domestic energy use was based on the survey carried out. Energy use for different sectors of household/residential, service and tourism considered in the model was based on the national studies for Scotland. This is because the electricty consumption per household in Knoydart is similar to the consumption in(other parts of Scotland. The compendium of Scottish energy statistics and information was used. Reference was also made to the domestic energy consumption per capita, taken from the Scottish energy study (The Scottish Government, 2006)
Peak load occurs 40 hours/year	Time slices of 40 hours duration were used. This was preferred instead of using hourly data to reduce calculation times and loss of data. Information for generation of the peak load was based on the data recorded by the data taker for 2010.
Hydropower scheme has presently 180 kW capacity and it can be upgraded to 250 kW.	Different sources claimed the same data

Source: Author, 2013

2.2 Future Demand Scenarios

The main objective of the demand scenarios is to forecast the energy demand for the next 20 years. Therefore, the output of the demand scenarios provides information for decision makers in order to plan the future energy supply.

2.2.1 Low growth demand scenario

This scenario is based on the following growth assumptions:

Table 8 Assumptions for low growth demand scenario

Driver	Growth rate
Population	Grows from 108 in 2012 to 150 in 2032
Day and Camping visitors (person days)	2% annual growth
Bed and breakfast visitors	1.7% annual growth
Bunkhouse visitors	1.7% annual growth
Self- catering visitors	1.7% annual growth

Source: Author assumptions, 2013

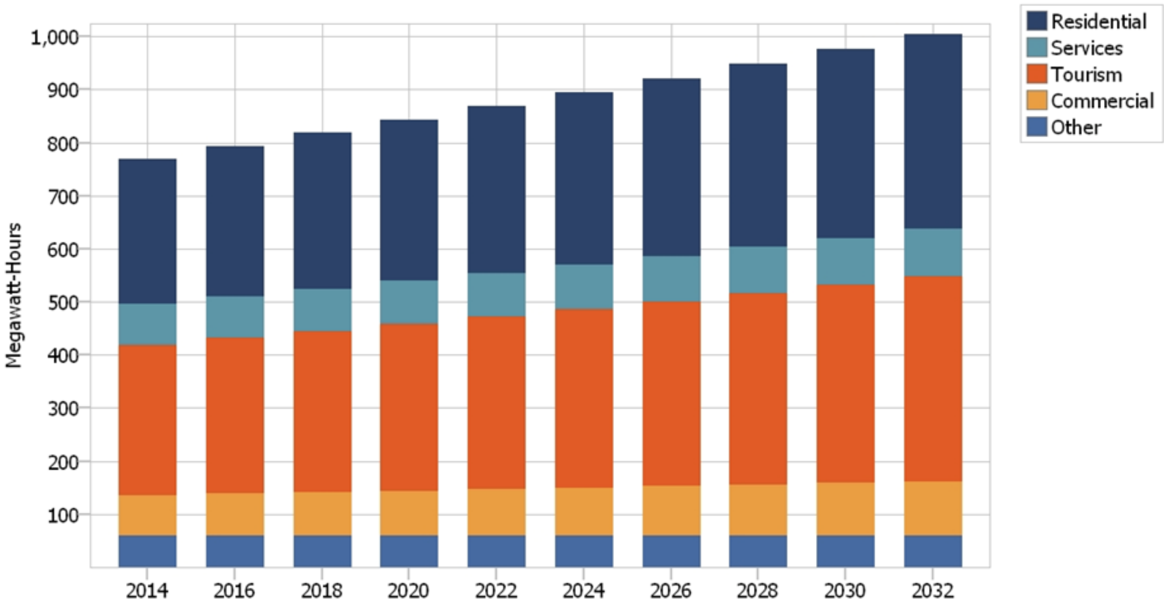


Figure 1 Energy demand for Low growth demand scenario

Source: Authors with LEAP Software, 2013

The analysis of total electricity consumption in this scenario shows that the consumption of the tourism sector grows from 274 MWh in 2012 to 385.4 MWh in 2032, followed by the commercial sector that grows from 73.4 MWh in 2012 to 102.3 MWh in 2032. The total electricity consumption of residential sector increases from 263.3 MWh to 365.6 MWh, followed by the service sector with a moderate growth passing from 74.6 MWh in 2012 to 91 MWh in 2032.

2.2.2 Medium Growth Scenario (Reference)

The reference scenario is based on the following growth assumptions:

Table 9 Assumptions for medium growth demand scenario

Driver	Growth rate
Population	grows from 108 in 2012 to 185 in 2032
Day and Camping visitors (person days)	3% annual growth
Bed and breakfast visitors	2.7% annual growth
Bunkhouse visitors	2.7% annual growth
Self- catering visitors	2.7% annual growth

Source: Author assumptions, 2013

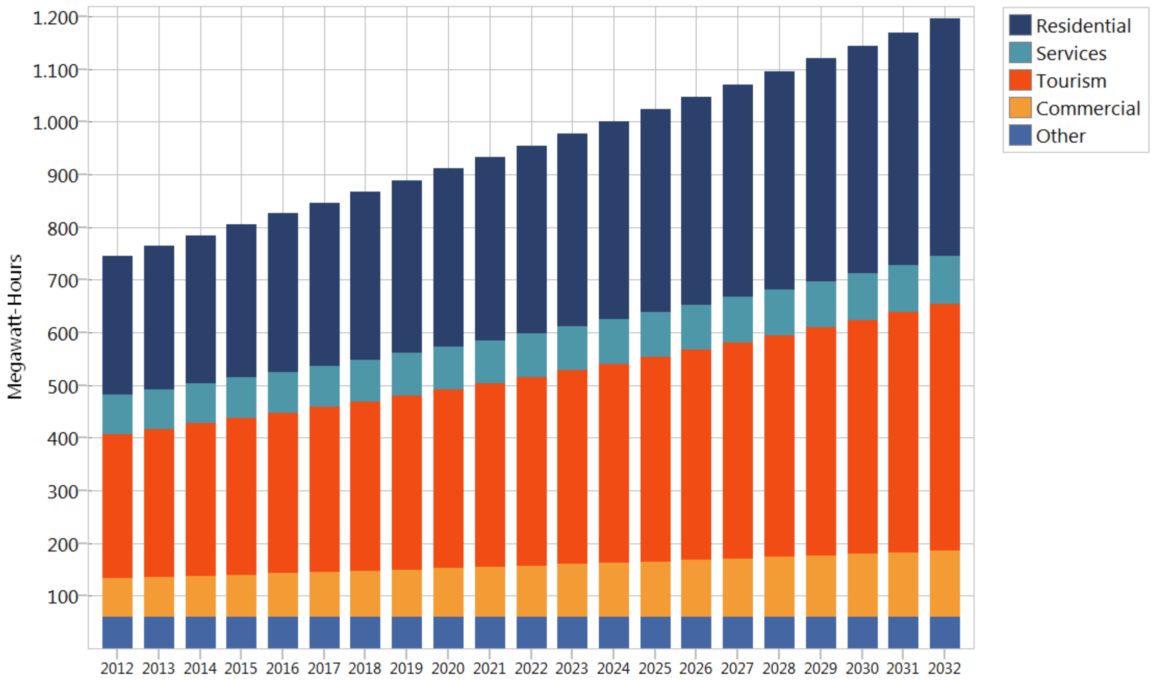


Figure 2 Energy demand for medium growth demand scenario.

Source: Authors with LEAP Software, 2013

The analysis of total electricity consumption in this scenario shows that the residential sector is the one that has the most accelerated growth from 263.25 MWh in 2012 to 450.93 MWh in 2032, followed by the tourism sector from 274.05 MWh in 2012 to 468.71 MWh in 2032. Similarly, total electricity consumption of the commercial sector increases from 73.35 MWh to 125.33 MWh, followed by the service sector with a moderate growth passing from 74.60 MWh in 2012 to 91.02 MWh in 2032.

2.2.3 High Growth Scenario

This scenario is based on the following growth assumptions:

Table 10 : Assumptions for high growth demand scenario

Driver	Growth rate
Population	Grows from 108 in 2012 to 206 in 2032
Day and Camping visitors (person days)	4% annual growth
Bed and breakfast visitors	3.7% annual growth
Bunkhouse visitors	3.7% annual growth
Self- catering visitors	3.7% annual growth

Source: Author assumptions, 2013

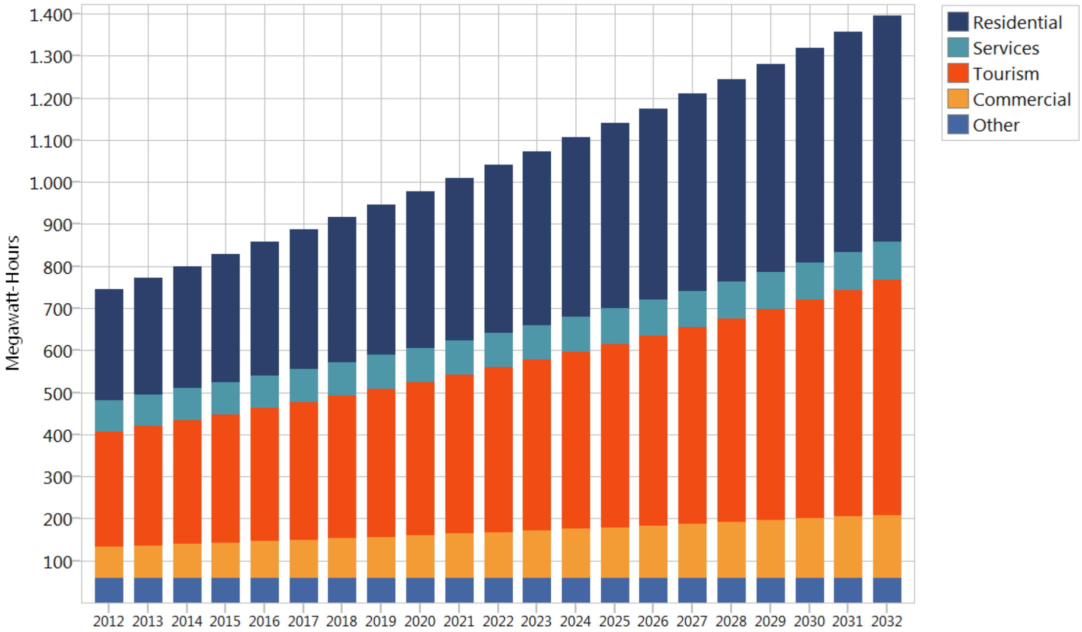


Figure 3 Energy demand for high growth demand scenario

Source: Authors with LEAP Software, 2013

The analysis of total electricity consumption in this scenario shows that the tourism sector is the one that has the most accelerated growth from 274.05 MWh in 2012 to 558.80 MWh in 2032, followed by the residential sector from 263.25 MWh in 2012 to 536.24 MWh in. Similarly, total electricity consumption of the commercial sector increases from 73.35 MWh to 149.13 MWh, followed by the service sector with a moderate growth passing from 74.60 MWh in 2012 to 91.02 MWh in 2032.

3 CURRENT ENERGY SUPPLY

3.1 Current System: Hydro Scheme and Diesel Generator

Knoydart peninsula has 8 main regions, Inverie Village, Draich, Sandaig, Doune, Joiners Croft, Airor, Samadland and Inverguseran. The electricity supply in each of the regions is different. In Inverie Village, the main electricity supply is from hydropower plant and diesel generator which acts as a backup during shutdowns. The rest of the regions use pico hydropower plants or fossil fuel generators.

This chapter focuses on the operation of the existing hydropower plant, analysis of community concerns about the limitations of power output of the hydro scheme, indicators for monitoring and data management. In the following paragraphs, the hydro scheme, diesel generator and the monitoring system are described before the concerns from the community are assessed.

3.1.1 Hydro Scheme

The current hydro scheme was designed for a capacity of 280 kW, with a design head of 274.3 m and pipe flow of 129 liters per second. The annual production varies annually. Based on this annual variation the total production for 2008 was calculated as 548,414 kWh while that of 2009 was 672,293.92 kWh. Reviewing power generated from half hourly data for 2009, Figure 4 shows that the system currently doesn't deliver more than 180 kW.

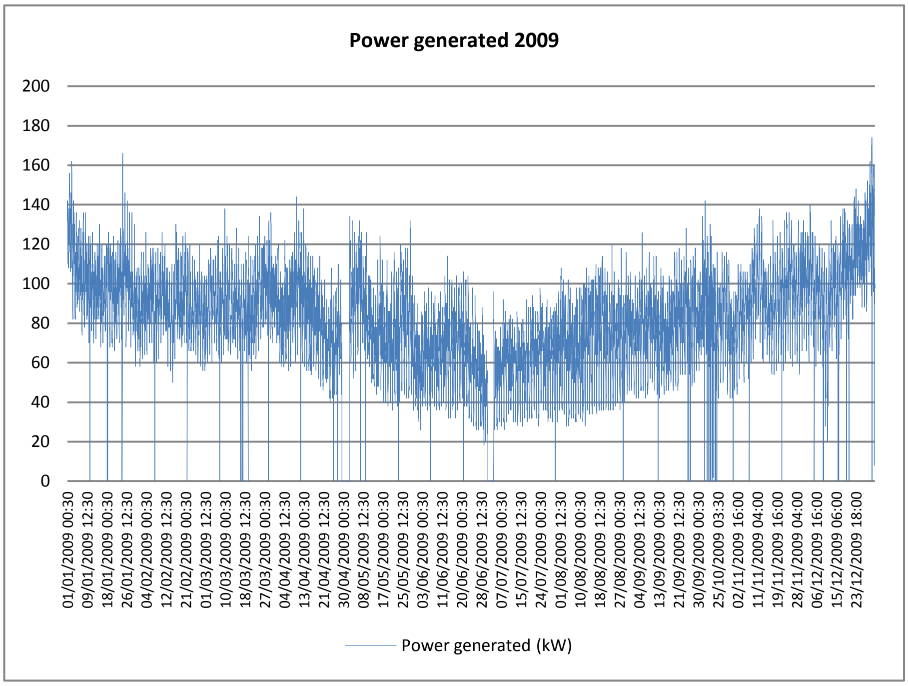


Figure 4 Power generated 2009

Source: Author, 2013

The Inverie hydroelectric scheme was installed in the 70's and comprises the following:

Dam

The dam, which is located at the northern end of Loch Bhraomisaig Reservoir, was built in the early 70's. It has a maximum height of 2.8 m and a crest length of 33m (Gowans, 2000).

A fixed spillway of length 15.9 m is constructed on the left abutment and it discharges over the downstream face into the Allt Dubh river (Gowans 2000).

Outlet pipe work at the dam

From observation, a steel penstock is built through the dam above a sediment pipe that has its bottom end sealed with a metal plate held in place by metal straps. This section of the penstock runs for approximately 40 m before being connected to an enlarger of 300 mm then changing to a plastic pipe of external diameter 315 mm.

Penstock

The penstock has sections of steel and plastic pipes of internal diameters 258 mm and 295 mm respectively (Knoydart Renewables Limited, 2012).

From the dam, the penstock has approximately 5 lengths of steel pipes with the second pipe going through the butterfly valve chamber. The penstock then changes to new plastic pipes that have 9 air vents in total (Knoydart Renewables Limited, 2012). From the gorge downstream to the turbine house, the penstock is made up of old and new steel pipes.

Turbine

The installed turbine is a single jet pelton turbine manufactured by Gilbert Gilkes & Gorden Ltd. It is rated to produce 389 BHP (290 kW) of mechanical power when operating at a head of 900 feet (274.3 m) and pipe flow of 4.6 cfs (129 lps). The nameplate indicates it was commissioned in 1978.

The turbine has an 18" pitch circle diameter (pcd) phosphate bronze runner and is fitted with a Woodward governor (Caledonia Energy Ltd, 1999).The governor ensures the turbine runs at constant speed despite load changes by regulating the spear valve. The spear valve, which operates for gradual load changes, alters the diameter of the jet depending on power demand. However, sudden loss in load requires a more rapid response. This is achieved by temporarily deflecting the jet with a deflector plate so that the water does not reach the bucket. The use of deflector plate ensures the system does not suffer from pressure surges (Dixon, 1998, p. 284).

The turbine drives a 300 KVA, 3 phase, 50 Hz generator manufactured by Mawdsley Ltd.

Refurbishment and major breakdowns

The turbine was refurbished in 2001/2002 and the whole system has been operating in good condition. However, the generator had major breakdowns in 2008 and 2011 (Knoydart Renewables Limited, 2012). Figure 5 illustrates the power production in 2011 between April and May. There was a prolonged shutdown period due to a major breakdown.

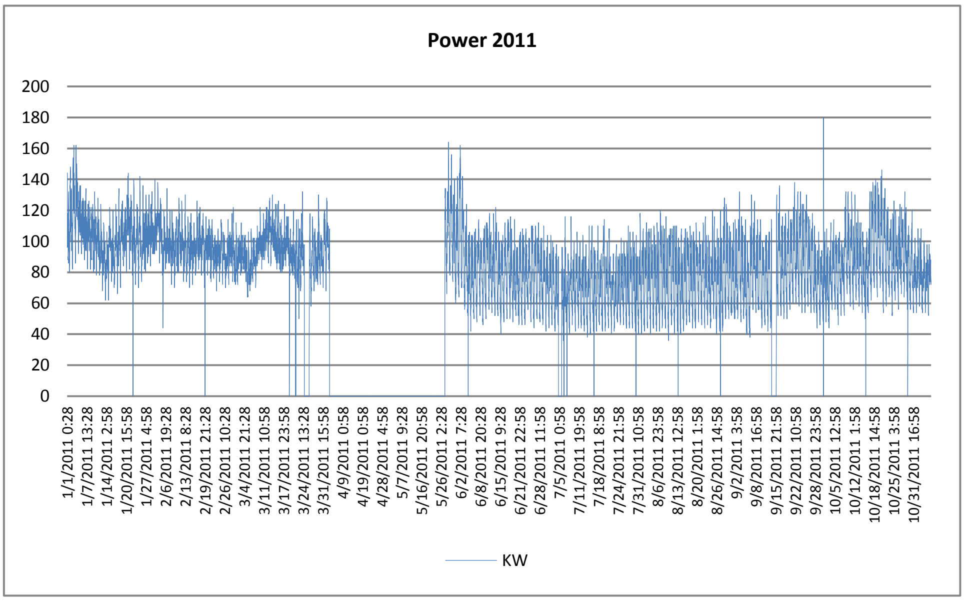


Figure 5: Power generated 2011

Source: Author, 2013

The zero values can be explained by the following three reasons:

- Due to lack of information, the monitoring system stops recording.
- During planned shutdown the system is turned off.
- Unplanned shutdown, in cases of breakdown.

It is important to clarify the meaning of the words shutdown and breakdown. Basically, breakdown is unplanned shutdown, it implies something is broken; a shutdown can happen because of e.g. overload.

Distribution system

According to literature, the distribution system consists of a 3-phase 11,000 volt single spur network mounted with wooden poles. It has low voltage sub-distribution of 415 volts, 3 phase and 240 volts 1 phase (Caledonia Energy Ltd, 1999).

3.1.2 Diesel Generator

A 160kW diesel generator is located at Inverie village. It is used as a backup power source when the hydro plant shuts down either during maintenance or when there is a fault. The generator is not synchronized with the main power plant and has to be started independently during power shutdowns.

The generator is manufactured by SDMO Industries and from the manufacturer nameplate it produces 160 kW of power when operating as prime power and 176 kW when operating as an Emergency standby power.

3.1.3 Monitoring System

The hydropower scheme has a monitoring system which collects and stores hydrological and energy data. The monitoring system consists of hydrological gauges, energy meter, a data logger which collects and stores the measurements, a remote communication system and a computer to analyse the data.

The hydrological data collected includes; penstock flow, dam level, spillway and compensation level, and rainfall. The instrument to measure the flow is located in the penstock near the turbine shed while the remaining hydrological instruments are located at the dam. The dataTaker converts the power measured by the power meter into energy. Both are located at the power house. The Table 11 gives a summary of the data, the measurement units, and their locations.

Table 11: Summary of measurement gauges at Knoydart hydropower scheme

Data	Units of measurement	Location
Penstock flow	Cubic meters/half hour	Penstock near the power house
Dam level	meters	Dam
Spillway and compensation level	meters	Near the dam
Rainfall	mm	Near the dam
Energy	kWh/half hour	Power house

Source: Author based on (Ledingham, 2010)

The data logger which is located in the power house collects and stores the hydrological and energy measurements in an internal memory. A radio link communication system is used for remote communication between the data logger in the power house and a computer in Knoydart Renewables' office. This radio link communication system is in the process of being changed to a wireless local network communication system.

From the observations and assessment of the existing hydropower system, it is important to highlight that the civil structure related with the spillway and compensation level gauge is not in good working condition. Therefore the data on spillway and compensation flow are presently not reliable.

3.1.3.1 Available Data Inventory

The following data was received from the Foundation Office;

- DataTaker information regarding flow, dam level, spillway and compensation level, annual rainfall data from 2007 to 2011 as well as partial data from May to July 2012.
- Complete guide for data transfer from turbine house to office. This helped to understand how to get data from the monitoring system.
- Chart for hydro data.
- ABB data about minimum, average and maximum power from May 2005 until September 2010.
- Manual of dataTaker logger and Elster power meter.

3.1.3.2 *Consistency of Information*

In order to verify and validate the input data for the analysis, it was necessary to carry out some exercises to find the most reliable data for the calculations. In particular, the following was checked: gross head figures, comparison between the figures from the dataTaker and power meter, impact of decimals on data accuracy for calculations, consistency of the hydrological figures and power relationship with pipe flow.

Gross head

Different sources give different head figures as shown below:

- 305 m – from calculations made in excel sheet call “coefficient in formula for kW 2006-2007”
- 900 ft – 274,3 m – from turbine plate
- 340 m – from pressure test John Duncanson Study.

To verify the value that was used in this study, 2 m contour maps were purchased for use in the software *QuantumGIS*. The software measured the contour lines from the Dam at 330 m height to the turbine House at 14 m height. The difference gave a gross head of 316 m. The Figure 6 taken from the software shows the contour lines and the location of the turbine house and the dam.

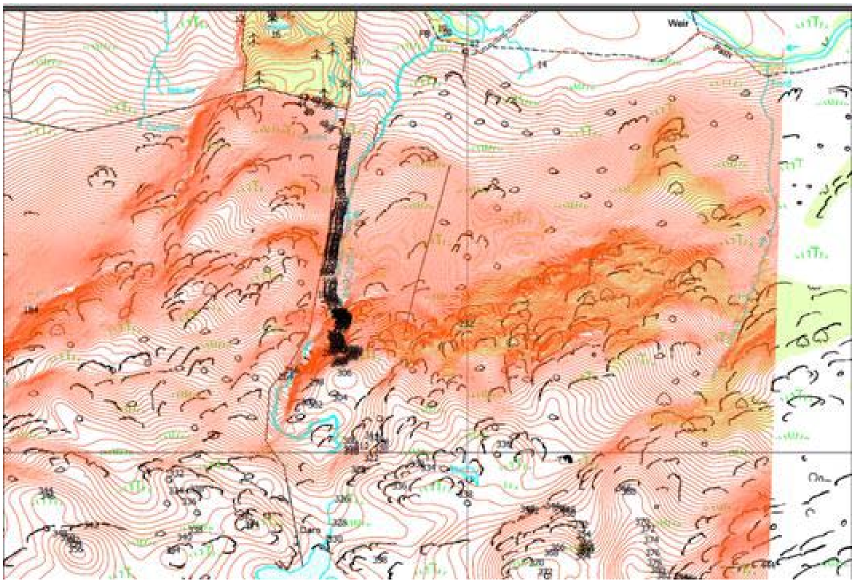


Figure 6: Gross head calculated from GIS software

Source: Author, 2013

Based on the above, the gross head used was 316 m.

Verification of power data

A comparison between data from the power meter and data from the dataTaker was carried out. The power (kW) produced by the hydropower plant was measured by the power meter which was replaced in 2012. On the other hand, the dataTaker collects the energy data (kWh). Since the power figures are in half hourly schedule, the figures were multiplied by two to get energy per hour, resp. power. These figures were then compared with the energy figures from the dataTaker. Table 12 shows the results.

Table 12: Results of power data verification

	COMPARISON	
DATE	dataTaker (kWh)	Power Meter (kWh)
09.09.09	1,855	1,852

The detailed calculations are in the Annex VII.

As a result some differences were found which could be explained by the following reasons:

1. Lack of synchronization between clock of dataTaker and power meter.
2. The figures from the dataTaker were rounded or some decimals were missing.

To verify mistakes by the rounding of the figures in the dataTaker, an exercise to measure how decimals from flow and power figures could affect the results of efficiency calculation was carried out. It showed that the difference does not significantly affect the calculations because the calculated real efficiency remains between the lower and upper range (see Figure 7 below).

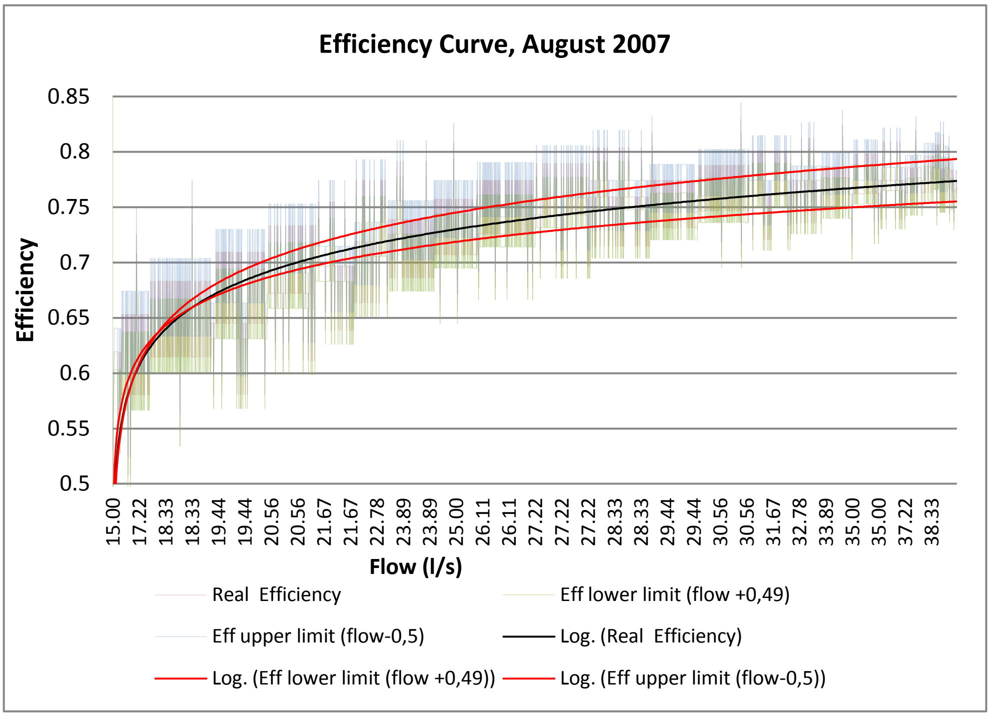


Figure 7: Efficiency curve adding decimals to power and flow values

Source: Author, 2013

Flow and power figures were also changed simultaneously by entering more decimals for efficiency calculations. As a result the differences were found to be in the order of hundredths.

This indicates the use of decimal does not have a significant effect on the calculations. Detailed calculations are in the ANNEX VIII.

.Verification of rainfall vs dam level data

In general, high rainfall means an increment in dam level and when the dam height is over 1.5 m the spillway flow starts to record values. To verify consistency of these phenomena, charts from 2008 until 2012 were developed. From the analysis, it was found that in 2009 the variable behaviour showed clearly a logical relationship. However, in 2012 the chart did not show a clear link between the variables. The compensation and spillway measurements did not match with the dam level. Also, it is important to highlight that there are many low values for dam level measurements (see Figure 8 and Figure 9).

From observation the gauge for measuring the compensation and spillway depth is not working. Since the sensor was not allocated properly on site, the measurement from recent time has not been possible.

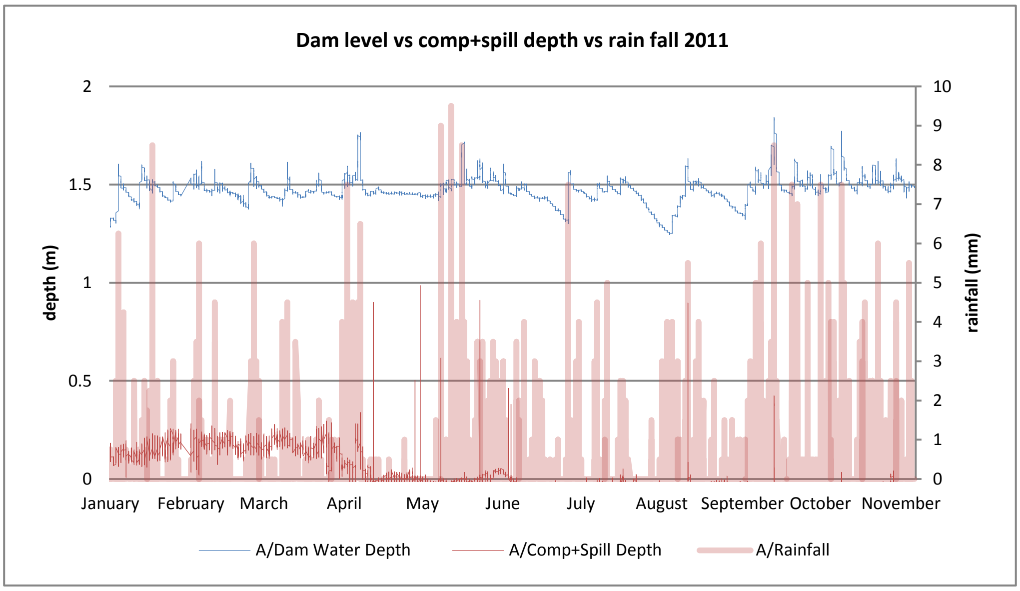


Figure 8: Dam level vs comp+spill depth vs rain fall 2009

Source: Author, 2013

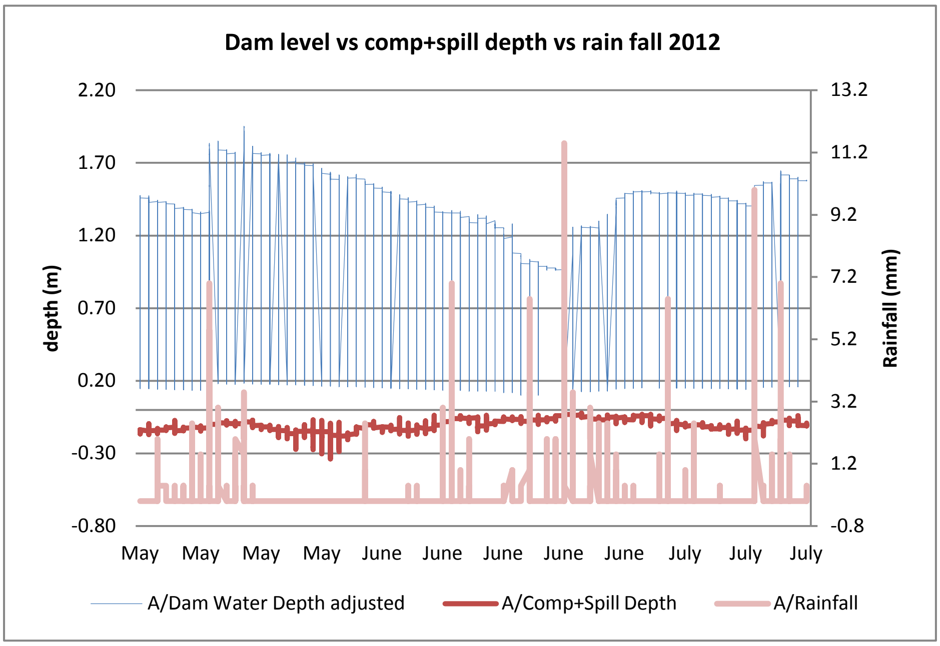


Figure 9: Dam level vs comp+spill depth vs rain fall 2012

Source: Author, 2013

Figure 9 shows negative values for spillway and compensation flow. It indicates that the measurements are not reliable. From observations, a leakage was found in the dam as shown in Figure 10.

Figure 10: Leakage in the dam 2012

Source: Author, 2013

It is important to carry out civil works in the dam, in order to get reliable data for spillway and compensation level.

Verification of relationship between pipe flow and power

As an example, a graph was made to verify the relationship between flow and generated power; Figure 11 shows a clear direct relationship between them.

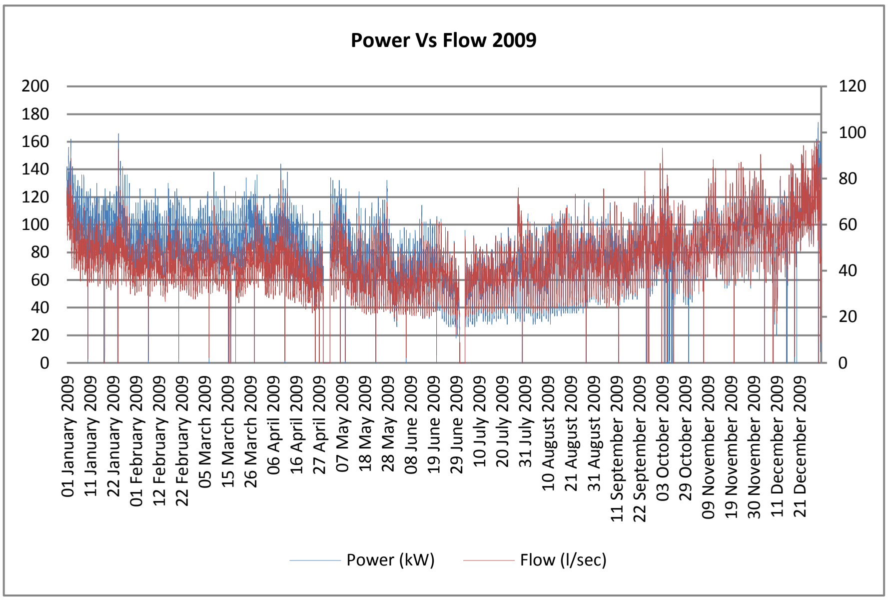


Figure 11: Power vs Flow 2009

Source: Author, 2013

From this graph it is clear that during the second half of 2009, less power was produced with more flow as the first half of the year. This phenomenon will be investigated through the calculation of overall efficiency.

3.2 Assessment of the Hydro Scheme

Knoydart Renewables Ltd. requested that the team analyse the following areas of the hydro scheme:

1. Low power output: Here, the reasons for lower power production were to be investigated.
2. Indicators: Key indicators which would be used to ascertain proper working of the hydro plant were to be identified.
3. Data management. A data system that simplifies data collection, storage, analysis and presentation was to be developed.

The study was carried out following the steps below;

1. Understanding the hydropower system.
2. Desk analysis of the information.
3. Field visit.
4. Field analysis of the gathered information.
5. Writing of the report.

3.2.1 Problem Description

The hydro power plant has a data collection system that was installed in 2005 and by 2012 over 7 years of historical data had been archived (Barrell, 2012). Due to the large volume of accumulated data, it was difficult to retrieve information when needed and in addition analysis of the data took a considerable length of time. The Knoydart community was also interested in knowing which key indicators they should focus on. Finally, the power plant which is rated to produce 280kW shuts down at 180kW causing blackouts during peak demand as experienced during New Year's Eve.

3.2.2 Problem Analysis

To respond to the request regarding low power output, different hypotheses were formulated and analysed. Afterwards, indicators were developed for overall efficiency, spillway vs rainfall and risk of vortexes. Finally the current data management system was reviewed and recommendations formulated.

3.2.2.1 Lower Power Output

Theoretical power available from the power plant is given by the equation below:

$$P = \rho * g * \eta * Q * H \qquad \text{Kilowatts [kW]}$$

Where:
ρ = specific density of water (kg/m^3)
g = acceleration due to gravity (m/s^2)
η = efficiency of turbine and generator (%)
Q = pipe flow, in cubic meters per second (m^3/s)
H = net head, in meters (m)

From the formula above, it is evident that a number of factors affect the power output. The specific density of water and acceleration due to gravity are considered as constants, hence they do not have an impact on the power output. The pipe flows, net head, efficiency of both turbine and generator have an impact on power generated. These were considered when formulating the hypotheses.

Tests conducted by Senergy Econnect Limited during 17th and 18th March 2009, showed that the governors on both the hydro generator and the diesel generator were working well in maintaining a steady system frequency and keeping it within limits of 50 Hz.

The study also found that the total harmonic voltage distortion was below 3%. This is within the acceptable BS EN50160:2007 limits of 8%. High harmonics can cause problems with electronic equipment and may cause power meters to read incorrectly. "These measurements indicate the Knoydart power system provides good quality electrical supply and meets the criteria set out in BS EN 50160:2007when the power system is running from either the hydro or diesel generators" (Senergy Econnect Ltd, 2009, p. 12).

3.2.2.1.1 Hypothesis 1: Peak power actually reaches 280 kW

The rated power output of the hydropower plant is 280 kW but unexpected shutdowns occur at 180 kW. The energy output is stored in the monitoring system on a basis of average half hourly. These values do not give the maximum power that the hydropower plant can generate, therefore the assumption is that the output power does reach the rated output but it is not recorded by the monitoring system.

The hypothesis is reinforced by the study of load management options in Knoydart made by Senergy Econnect Ltd. on March, 2009. The company did a research to understand the power system parameters. A Power Harmonic Analyser was installed to measure minimum, maximum and average power of the system as well as others parameters such as frequency and voltage. TheFigure 12 shows the result of the overall power consumption of Knoydart for twenty four hours.

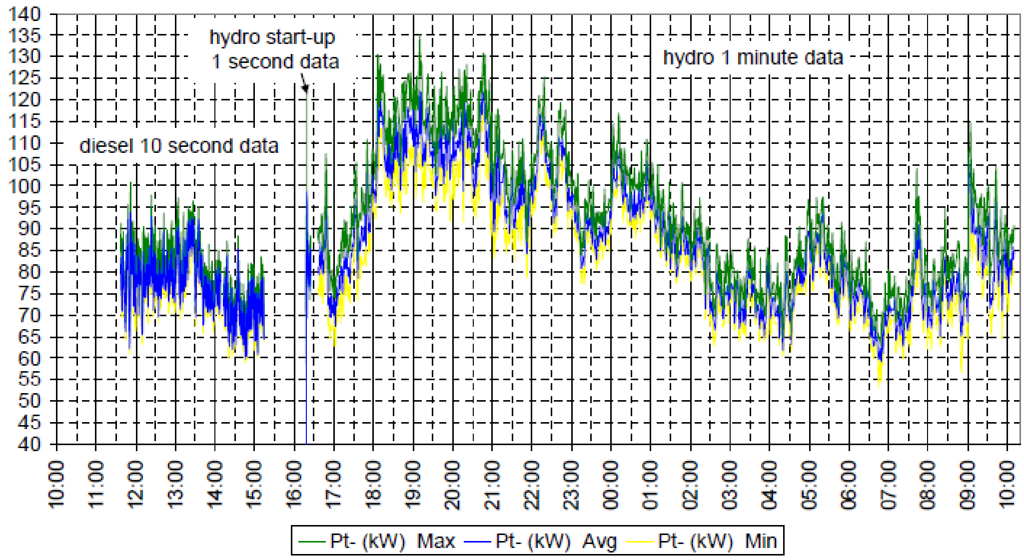


Figure 12: Knoydart power consumption

Source: Senergy Econnect (2009)

The power output of the diesel generator and the hydropower plant are shown together in Figure 12. The graph illustrates the maximum power output of the hydropower plant being above its average power output at any given time. This pattern suggests that the maximum power, which includes the peak power, cannot be observed through the present monitoring system by the personnel of Knoydart Renewables. It can be emphasized that the measurements were done for every minute.

Due to this hypothesis, it was recommended to change the time of measurements of the monitoring system from 30 minutes to 1 minute to observe this pattern during this research. A first approach was to change the settings of the monitoring system at the computer in Knoydart Renewables' office but it was not possible since the new remote communication infrastructure was still under development. Nevertheless, a direct connection with the data logger at the power plant was done to change the settings. The new data with 1 minute timeframe was acquired. Due to the characteristics of the measures, the new data could not be analysed since it presents the sum of energy for each minute instead of power. Additionally, the 1 minute energy data is rounded to full kWh. The number of displayed digits could be increased but it seems that the data logger does not receive them. It is recommended to integrate a power meter which has the functionality of measuring the maximum power and send this value to the existing data logger.

3.2.2.1.2 Hypothesis 2: The power plant experiences high head losses that decrease power output

The pipe flow, which is the amount of water entering the turbine, has an effect on the power output of the hydro generator as shown in the power equation at the beginning of section 3.2.2.1. However, no leakage was found in the pipeline that might have led to a decrease in the flow.

According to Knoydart Renewables Ltd. and the documentary on the hydropower system of Knoydart (Knoydart Foundation, 2012), lower power output was assumed to be caused by:

- Poor joints especially Viking Johnson (VJ) coupling joints
- Small diameter pipe near the dam
- Corroded/rust nodules in the pipeline near the turbine house

The team received a pressure test report that showed the performance of the penstock. The pressure test revealed gradual pressure losses at the VJ coupling in the pipeline. The report further indicated that when the pipe flow was 96 l/sec, the head losses were 60 m (John Duncanson Engineering Ltd.).

From the pressure test results, an equivalent roughness coefficient was calculated. This was then used to calculate head losses for different flows as shown in Figure 13 below. Theoretical power output calculations established that a maximum of 210 kW of power can be produced due to the high real head losses. It should be clarified that this value is a rough estimate. The estimated maximum power (210 kW) indicates that the real peak power could be approximately 17% higher than the 30 minute average (180 kW). The measurements of Senergy support this assumption.

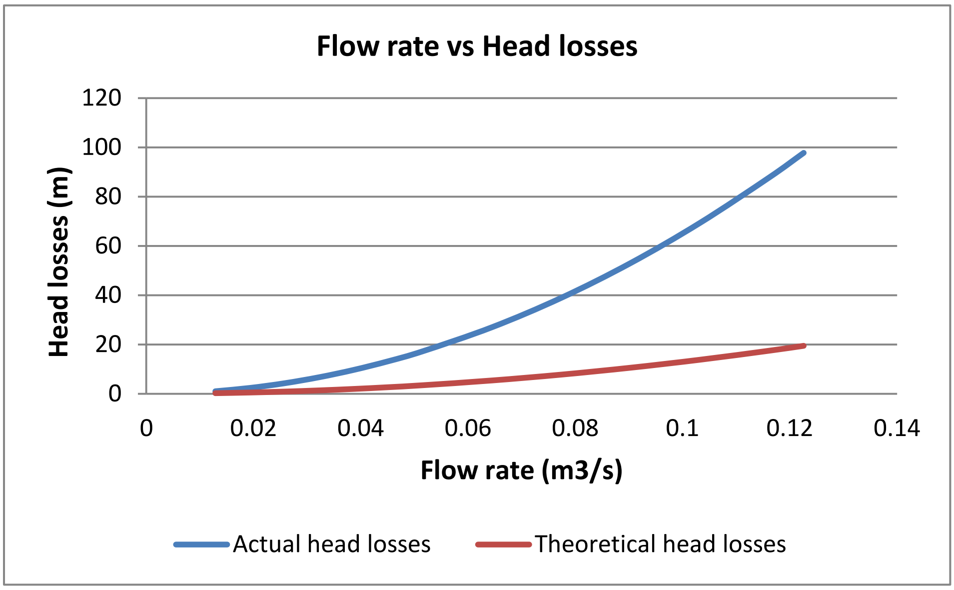


Figure 13: Relationship between flow rate and head losses with theoretical design head loss and extrapolated head losses, based on the pressure measurements

Source: Author, 2013

Figure 13 above shows that:

- The higher the flow, the higher the losses and,

- The real head losses are significantly higher than the theoretical head losses.

The head losses have a direct effect on the power output. A comparison between theoretical power and the calculated actual power shown in Figure 14 illustrates that at high flow, the difference between the theoretical power and the calculated actual power gets bigger. The actual power is based on the theoretical extrapolation of head losses.

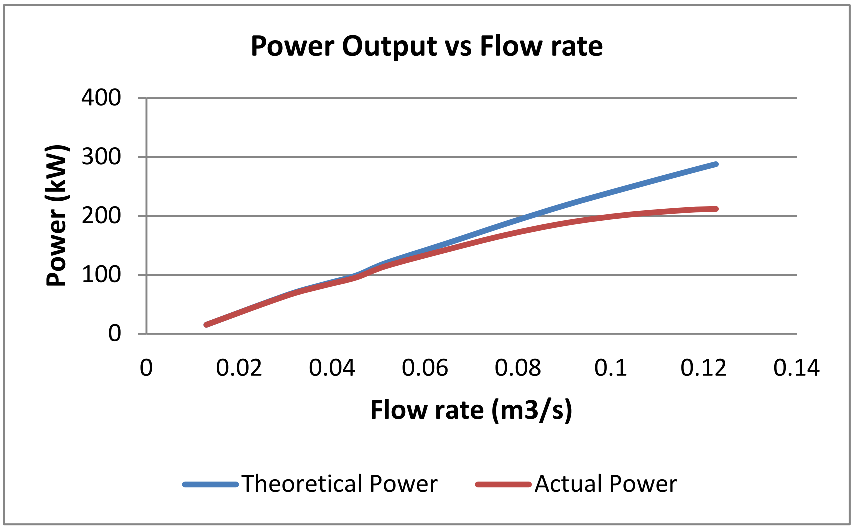


Figure 14: Relationship between design and real power versus flow rate

Source: Author, 2013

3.2.2.1.3 Hypothesis 3: Decrease in efficiency of the turbine and the generator

As it was explained in the Section3.2.2, the power output of the hydropower plant depends on the penstock flow, the net head, and the combined efficiency of the turbine and generator. The turbine was built in 1978 which means that it has a service life of almost 35 years together with the generator. Even that the turbine was overhauled by a private contractor in 2001/02 and the generator was rewinded in 2011/12, the efficiency of the turbine and generator could not be the same as when they were built. Possible physical damages could have occurred during their long service life. The potential decrease of their efficiency might reduce the maximum power output that can be reached by the hydropower plant.

Consultation was made with the manufacturer of the turbine Gilbert Gilkes & Co. in order to get the efficiency curves of the turbine and generator in order to make a comparison between the calculated efficiency using real data and the theoretical efficiency. The company provided the efficiency contour graph of a similar turbine as the one in Knoydart (see Annex IX). Figure 15 shows the efficiency curve derived from the manufacturer graph.

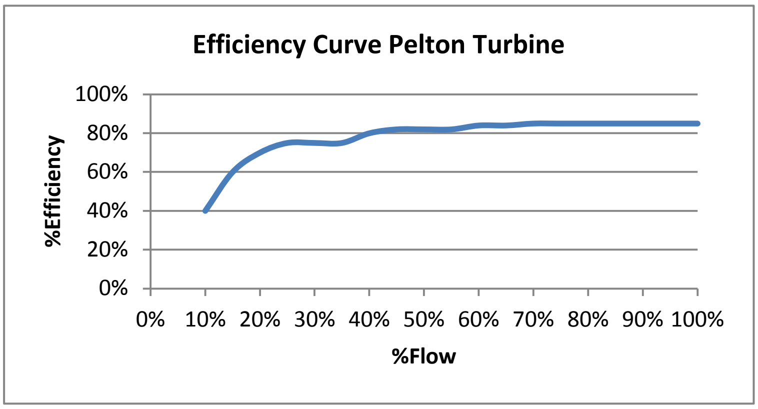


Figure 15: Efficiency curve of a Pelton turbine

Source: Author based on Gilbert, Gilkes & Gordon Ltd, 1980

The efficiency of the turbine at high flows is 85%. The efficiency of the generator was taken from RET Screen software. A comparison was done with calculations of efficiency of the data from Knoydart. The taken reference values were:

- Generator efficiency: 95%
- Turbine efficiency: 85%

The combined theoretical efficiency of the turbine and generator is 81%. Calculations done using data of 2012 showed that the overall efficiency of the hydropower scheme in Knoydart is 79.9%. From historical data of 2011 (see Annex X).

), the calculated overall efficiency was mostly above 76%. This result of overall efficiency is reasonable since it includes periods with flow far below design flow. Pelton turbines in general work at lower efficiencies at low flows as it is shown in the Figure 15.

3.2.2.1.4 Hypothesis 4: Air entering the intake decreases the pipe flow/Vortexes

"The Hydro generator maybe tipping below its rated output of 280kW due to air entering the hydro pipeline at the intake at high flow rates" (Senergy Econnect Ltd, 2009, p. 14) . The penstock inlet can suck in air if it is not sufficiently submerged when water levels are low. However, the penstock should not be too low to avoid blockage by sediments/silt building in front of it.

Further research during the field work indicated that flow disturbances at the intake contribute to losses in the hydro plant. The disturbances are usually in form of turbulences which are caused by sudden flow changes that increases head losses. Also if the penstock is not sufficiently submerged it will result in formation of whirlpools and vortexes which may carry air in the penstock and in the process decrease water flow rate at the intake.

According to (Penche, 1998, p. 119) the disadvantages of vortexes are:

- Production of non-uniform flow condition
- Introduction of air in the flow that have unfavourable consequences on the turbine
- Increase head losses and decrease efficiency
- Draw trash into the intake

Literature further states that lack of sufficient submergence and asymmetrical approach are the commonest causes of vortex formation (Penche, 1998). From data provided during the field work, calculations were done to determine the critical height of water in the dam below which vortexes could be formed. The risk of vortex formation was assessed based on Gordon formula.

The Gordon formula from (Schröder & Zanke, 2003) is as follows:

$$h = C*v*(\sqrt[2]{d/g}) \qquad \text{meters [m]}$$

Where:
h = minimum required height above intake, in meters (m)
C = 2.3, constant depending on entrance of penstock
v = velocity (m/s)
d = diameter (m)
g = acceleration due to gravity (m/s^2)

When the height from Gordon's formula is smaller than dam water depth, then there is risk of ***vortex***. Table 13 shows the calculations for critical dam level values for different flows.

Table 13: Vortex risk – dam critical level

Date	flow meter (m^3 in 15 Min)	m^3 per second	Dam Water Depth	Velocity	Minimum dam level (Gordon formula)	Condition Gordon
16/12/2009 06:30	73	0.040	0.01386	0.826	0.303	risk
08/01/2010 01:00	131	0.072	0.54396	1.482	0.544	risk
08/01/2010 01:30	144	0.08	0.54283	1.629	0.598	risk
09/01/2010 01:00	128	0.071	0.50728	1.448	0.531	risk

Source: Author, 2013

For details, see Annex XI.

The calculations showed risks of vortex formation during the dry periods between December 2009 and January 2010. From Gordon formula, the critical value of dam level for vortex formation depends on the flow velocity. When dam level is below the calculated height, there is a risk of vortex formation.

3.2.2.1.5 Summary of the hypotheses

The hydropower plant was analyzed based on the principal variables that affect its maximum output. Firstly, the hypothesis that the plant actually reaches its maximum output and this is not measured by the equipment was analyzed. It was established that with the present monitoring system even with one minute data, it is not possible to see peaks on power, since it presents the sum of energy for each minute instead of power. The actual peak power might be higher than 180 kW since the monitoring system records average values rather than maximum values, but probably only in the range of about 17%. Secondly, the head losses were analyzed to identify the effect of this variable and the pipe flow on the power output. Leakages were not found in the pipeline, hence decrease in the pipe flow was not considered. High head losses were found out through the pressure test that had been carried out before this research. The analysis shows that the high head losses are the main source of the low power output. Thirdly, the decrease of the efficiency of the turbine and generator was studied. The result indicates that the turbine and generator still operates within the rated efficiency range. Finally, the risk of air going into the pipeline was analyzed. Some critical values of dam level in which there is risk of vortexes were calculated. Vortexes might contribute to the problem of outages at high power generation and low dam levels.

3.2.2.2 Indicators

3.2.2.2.1 Overall Efficiency

This indicator is developed to show the overall efficiency (turbine and generator). This system uses a Pelton turbine which is used for very high head and when small quantities of water are available. In general, overall efficiency is not 100% because it is not possible to transform the total hydraulic energy into mechanical work due to losses through friction. For example, depending on the construction of the turbine only 60-90% of the energy can be converted into mechanical work (Harvey A., 1993).

The inputs are:

- Half hourly data, available from 2007 until 2012 from the dataTaker.
- Power is calculated from the Energy parameter that is measured by the dataTaker.
- Efficiency (η) = power/(flow*density*gravity*head).

The average overall efficiency from the data available was calculated like 68.3%. It includes shutdowns. The results are summarized in Table 14.

Table 14: Average overall efficiency

	2008	2009	2010	2011	2012	Average
Average overall efficiency	62.5%	60.0%	63.5%	75.7%	79.9%	68.3%

Source: Author, 2013

Figure 16 portrayed the overall efficiency in 2009. On 20th of June 2009, it was done an adjustment in the spear valve to get more water. This lead to more frequent diversion of water flow by the deflector and higher water consumption without increasing power output. This represents a decrement in the overall efficiency.

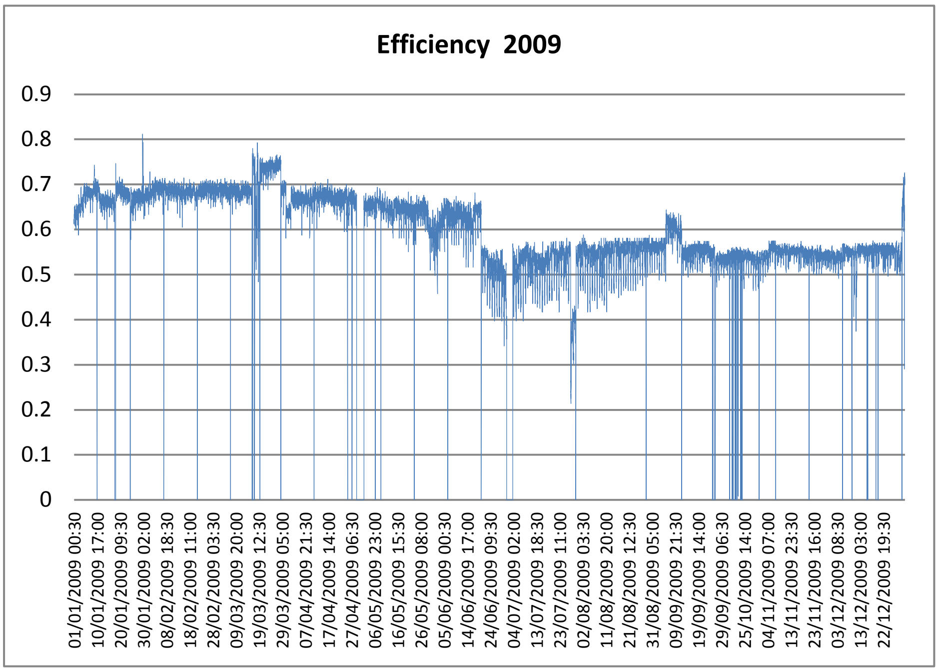


Figure 16: Overall efficiency 2009

Source: Author, 2013

On 30th of December 2009, maintenance was done that involved the adjustment in the turnbuckle that eventually closes the spear valve reducing the water flow and improving the pressure. This change represented an improvement of the overall efficiency as indicated in the Figure 17.

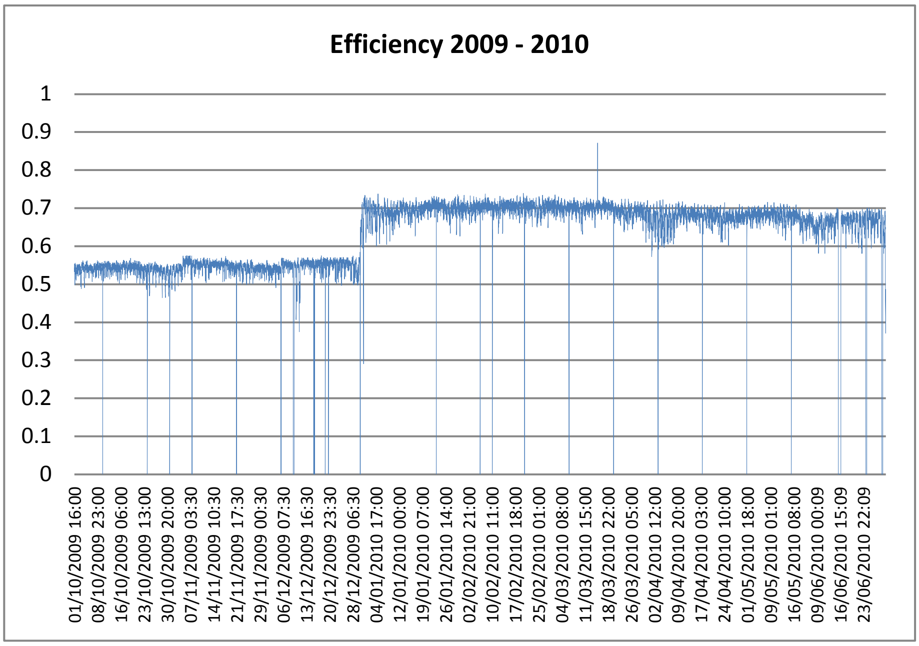


Figure 17: Overall efficiency 2009 - 2010

Source: Author, 2013

It is important to monitor the overall efficiency of the system. This will help to optimize adjustments and to identify changes in the system that can cause possible decrease on efficiency and thereby power output.

3.2.2.2.2 Spillway vs Rainfall

This indicator is relevant to assess the feasibility of installing one more turbine in order to use the actual spilled water. To compute the amount of water that could be used to produce energy, it is necessary to calculate the amount of water running over the spillway in the periods of one year. The amount of water running over the spillway can then be related to the rainfall over the same period. To generate more long-term estimates of water loss it is necessary to develop a relationship between periodical rainfall and spillway flow. It is possible to do this on a seasonal basis for different periods to account for different meteorological conditions.

However, since the spillway flow data is not accurate due to the leakage in the weir, it is recommended that this calculation is redone once the weir is repaired.

The inputs are:

- Rainfall
- Spillway flow level

3.2.2.2.3 Risk of Vortexes

As it was shown in the Section 3.2.2.1.4, risk of vortexes may exist at certain values. The Gordon Formula can be used as indicator to monitor the risk of vortexes. This becomes especially relevant for drought seasons. It helps to be aware about critical dam levels that might affect the power output. Based on the Gordon formula, the risk of vortexes depends on the velocity of flow, thus this value could be taken into consideration for water management. This is relevant for decision makers to take actions on load management to conserve water.

The inputs are:

- Dam level
- Pipe flow

3.2.2.3 Data Management Plan

The Data Management Plan (DMP) provides the strategy to manage monitoring of data including infrastructure and database system.

3.2.2.3.1 Data Management Infrastructure

3.2.2.3.1.1 Hardware

Currently Knoydart Renewables (KR) uses dataTaker DT50 to collect data from a monitoring kit which consists of a rain gauge, loch level gauge, pipe flow gauge, spillway level gauge and an energy demand meter. All monitoring data in dataTaker DT50 can be downloaded remotely from Knoydart Foundation office in Inverie. However, the dataTaker DT50 has storage limitation. When data is not downloaded regularly, overwriting of older data takes place resulting in loss of data. To overcome this problem, dataTaker DT80M was proposed since it has features not available with dataTaker DT50. The following are some advantages of dataTaker DT80M:

1. Automatic data delivery features will automatically emailed to personnel inbox at a preset time interval. More sophisticated systems can make use of the automatic data delivery features to send logged data to an FTP server. Alarm conditions can also trigger data delivery in addition to sending alarm messages to multiple email addresses or mobile phones.

2. The dataTaker DT80M can be configured in web browser using dEX graphical interface. Thus, the personnel responsible can carry out the monitoring activities not only from KR office but also from his/her house or other places, especially during weekends or holidays.

Based on the advantages above, it is recommended to replace the older dataTaker DT50 with DT80M.

From the dataTaker website, the detailed specifications of DT80M are as follows:

- Robust, Stand Alone, Low Power Data Logger with Dual Channel Isolation Technology
- Integrated cellular modem
- Record Temperature, Voltage, Current, 4-20mA Loops, Resistance, Bridges, Strain Gauges, Frequency, Digital, Serial and Calculated Measurements
- Up to 15 Analog Sensor Inputs with ±30 Volt Range
- Expandable to 300 Analog Inputs
- Records up to 25 Hz Maximum
- Store up to 10 Million Readings/Samples
- Automatic data transfer to email or FTP
- Modbus for SCADA connection
- SDI-12 (multiple networks)

It is suggested to include the diesel generator in the monitoring system. The power output and diesel consumption can be monitored. This will entail installing a new dataTaker for the diesel generator.

3.2.2.3.1.2 Software

DataTaker DT80M is supported by DEX logger software. DEX logger software is an intuitive graphical interface that allows configuring data logger, viewing real-time data in mimics, trend charts or tables, retrieving historical data for analysis, defining and calculating indicator. The programming module allows manipulating data as well to build indicators and alarms (see Annex XII). Furthermore, DEX logger software runs directly from web browser and can be accessed locally or remotely, wherever a TCP/IP connection is available including worldwide over the Internet. By using DEX logger software, one or more dataTakers can be monitored through the web.

3.2.2.3.1.3 Budget and Funding

To replace the older dataTaker DT50 with DT80M, Knoydart Renewables needs to allocate funds. It is estimated that the price of one DT80M is £2,670. The total price for two dataTakers for hydropower and diesel generator is £5.073 (tax excluded) (see quotation in Annex XIII).The price is inclusive of the software. Funding sources can be obtained from Scottish Government's Community and Renewable Energy Scheme (CARES) support. CARES Infrastructure and Innovation Fund is a limited grant fund available for communities to investigate and develop projects that link local energy generation with local energy use. The maximum grant available in year 2013 is £150,000[1].

3.2.2.3.1.4 Data Management Team

One of the problems in monitoring and data management is lack of human resources. Currently, only one person is responsible for monitoring and data management. For future improvements, it is suggested to have a data management team. The role of this team would be to be in charge for collecting data from data logger, analysing, presenting in table or graph, and archiving it. The core tasks of data management team are listed in Table 15.

[1]http://www.communityenergyscotland.org.uk/cares_infrastructure_innovation_fund

Table 15: Tasks of data management team

Position	Personnel suggested	Tasks	Frequency	Estimated Duration
Monitoring Staff	(Hydro manager)	Checking the accuracy and precision of meters or gauges e.g. checking the position of rainfall gauges that is not under catch	Every 3 months as part of regular maintenance	1 hour
	(office manager)	Checking indicator from the office or web interface (Overall efficiency, power output, rainfall, dam water level, flow). Reporting to team leader in case of deviations from regular range	Daily as part of daily routine	5 minutes
	(Hydro manager)	Collecting data by downloading from dataTaker software(DT50) or from email account (DT80M)	Monthly	15 minutes
Analysis Staff	(Hydro Board, Data Manager)	Making analysis of indicator and alarms in dataTaker DT80M and then export files to excel as an output format.	Monthly	1 hour
		making report and archiving data	Monthly	1 hour
Monitoring Team Leader	(lHydro Board, Data Manager)	Supervising or controlling the monitoring and data management activities.		
		Taking actions to cope problems.	When required	
		Preparing strategic plan for improvement of monitoring and data management in the future.	Yearly	3 hours

Source: Author, 2013

According to the table above, the minimum personnel for data management is 3 people and the total time required is estimated to be in the range of 50-70 h/year. Most of the tasks above can be carried out as part of current daily activities and use the available human resources.

3.2.2.3.1.5 Database System
Data stored in the data logger memory should periodically be downloaded; otherwise data logger overwrites the oldest data with the new data once the memory is full. Since the data logger registers a large variety of data, KR should consider developing a database system to manage the data. The ability to query data is one of the most significant advantages of using a database. The importance of archiving data is as follows:

- Develop the database system in a way that permits ordinary users with typical desktop computers to access and analyse the data;
- Provide access to and distribution of archived data through the Internet or portable storage devices such as CDs or DVDs;
- Save original data as collected from dataTaker for some specified period of time and make summaries of this data available for most users;
- Use quality control methods to flag or remove suspect or erroneous data from the data archive; and
- Provide adequate documentation on the data archive and the corresponding data collection system.

3.2.2.3.2 Options for Analysis of the Data

3.2.2.3.2.1 DataTaker for Indicators
The actual dataTaker DT50 and DT80M software provides options to configure alarms, charts, and build equations for indicators (see Annex XII). It is recommended to use the dataTaker software to:

- Make tables & charts
- Build indicators
- Set alarms

The alarms suggested are:

- Critical value power output more than 170 kW (yellow alarm), more than 180 kW (red alarm).
- Gordon condition for vortex risk (to be calculated from flow and dam level)
- Critical level of efficiency (suggested value: 60%)

3.2.2.3.2.2 EXCEL for Indicators
In case that dataTaker software is not available, for data management it is proposed to continue monitoring the following indicators, which was explained in the previous section.

- Overall efficiency
- Spillway vs Rainfall
- Vortex risk

Excel Templates are provided to make the calculations.

3.2.2.3.3 Presentation of the Analysis

3.2.2.3.3.1 Reports from DataTaker Software

It is possible to get reports for alarms as it is shown in the Figure 18.

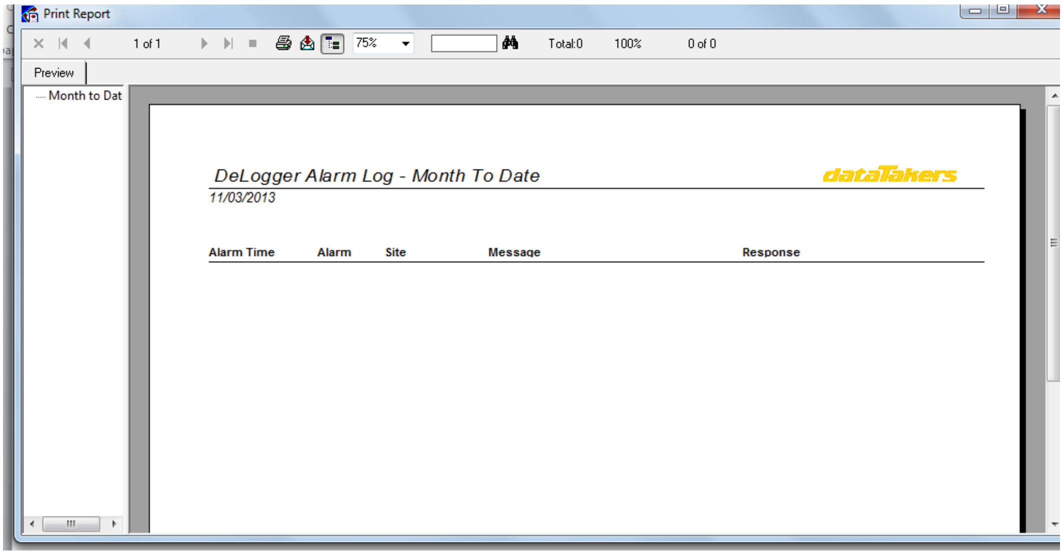


Figure 18: DataTaker software – Alarm report

Source: DataTaker software

When the dataTaker detects an error in a command, an error in an input channel, or an operational difficulty, it is logged and presented as an error report is requested (see Figure 19).

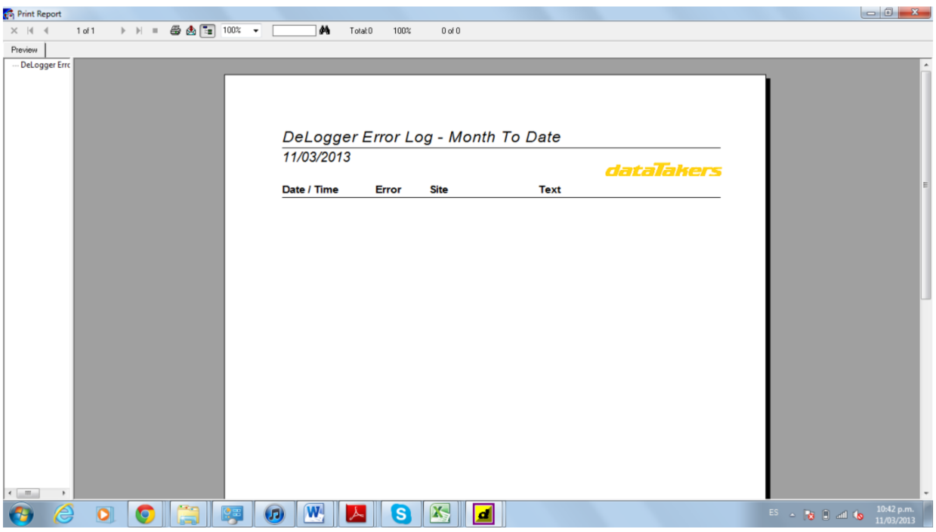


Figure 19: DataTaker software – Error report

Source: DataTaker software

3.2.2.3.3.2 Monitoring Report

The monitoring report is prepared by the analysis staff and it is submitted to the Knoydart Renewables Board.

The frequency of the report is monthly and shows:

- Power generated chart
- Hydrological chart
- Indicators
- Maintenance activities
- Comments

The template for the monitoring report is shown in Figure 20.

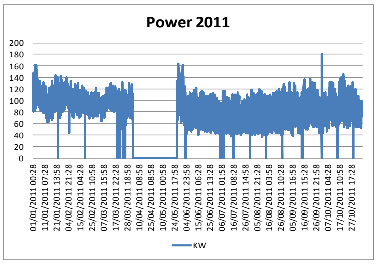
Renewables Knoydart

Monitoring Report

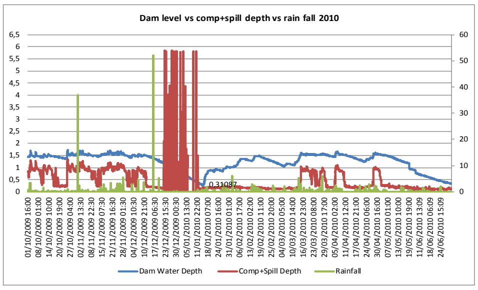
Date	from	05.05.12	until	24.06.12
Data source	Data taker		**Schedule**	Half hourly

1. Power generated in the period

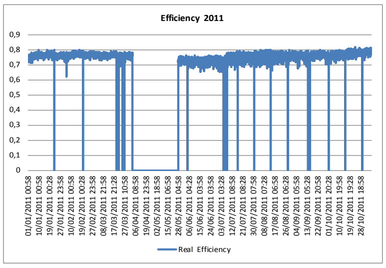
Graph



2. Hydrological Data



3. Overall efficiency of the System (tick the box)	**During this period It remains?**		**decrease?**		**increase?**



3. Is the Dam level below 0,598 m Vortex Risk?	**YES**		**NO**	

4. COMMENTS AND / OR FINDINGS

5. IMPROVEMENTS

Activity	**Date to be accomplished**	**Status**

Prepared by ***Revised by***

Figure 20: Template monitoring report

Source: Author, 2013

4 ALTERNATIVE FUTURE SUPPLY OPTIONS

4.1 Biomass

4.1.1 Potential

In line with Knoydart foundation`s goal of increasing the electricity supply using renewable energy sources, the foundation was interested in identifying possibilities of generating electricity using woody biomass to partly substitute the current electricity generation using the diesel generator. This drive was backed up by the fact that Knoydart has at 350 hectares of forest cover consisting of different tree species. Based on the Knoydart Forestry Plan, about 400m^3 of wood can be harvested. Based on the information above, the rough calculation of the yield from biomass is 290 Tons/year. The air-dried heating value, which is 12.4GJ/tonne, was used to calculate the energy content of wood used on Knoydart. Based on this air dried heating value of wood , the estimated energy content of the wood harvested in the first year was calculated as 3586.08 GJ. This is equivalent to 996,133.3 kWh.

4.1.2 Electricity Generation

Biomass can be converted into electric power through several methods. The most common is direct combustion of biomass material, such as agricultural waste or woody materials. Other options include gasification, pyrolysis, and anaerobic digestion. A brief discussion of these technologies is done in the following section.

Direct combustion for electricity generation in steam turbines

This process involves directly burning or combusting biomass in a boiler which coupled with a steam cycle. Direct combustion of biomass produces hot gases, resulting in steam from the hot gases via a heat exchanger. The steam produced then generates power using a steam turbine. For decades this technology has been one of the most commercially available option for the production of electricity from wood. Total electricity generation potential (assuming specific fuel wood consumption as 1.1 kg/kWh) is approximately 263MWh/year. The capacity of the power plant in kW (assuming that the plant would operate for 8 hours per day) would be 90.04 kW (Baris & Dessie, 2012). The smallest steam turbines currently on the market have a capacity of 0.5MW.

Pyrolysis to produce bio oil

Pyrolysis of wood involves partial combustion at temperatures between 450 °c to 600 °C. The products are liquid bio-oil, gaseous and solid products. The resulting bio oil is then used to generate electricity although the acid contained it has to be removed first. The solid product, called char or charcoal, is also used as fuel. The Electricity Yield from Pyrolysis is between 0.38 and 1.3 kWh/kg of dry feed (BROWNSORT, 2009)

Given the annual harvest of 289.12 tons/year, an electrical output of 121.43 MWh/year is the calculated potential for Knoydart. This would require a 42 kW capacity pyrolysis unit. The smallest slow pyrolysis retort kilns currently operating are in the range 10kW -1438kW but are not yet commercially proven (Gareth Mayhead, 2011).

Gasification to generate producer gas.

Gasification involves burning of wood with a controlled quantity of Oxygen to produce a combustible gas mixture called Synthetic Gas or Producer Gas. The gas which consists of 22% CO, 18% H2, 3% CH4 , 6% CO2 and 51% N2 can then be fed to an electric generator set to produce electricity. The electric potential for Knoydart from gasification of wood is 111.2 MWh/year. This would require a 38kW capacity gasifier. This technology is still considered unreliable on a small scale. The smallest gasification units currently on the market are in the range of 100 kW. According to literature and consultation with suppliers, units of smaller capacities less than 100kW are not yet mature and thus purchasing a 38kW gasifier would be risky.

Hydrolysis for production of ethanol

Ethanol is produced from Wood by the process of Hydrolysis and Fermentation. Ethanol, in turn, is used as fuel for internal combustion engines or fuel cells to produce electricity. Knoydart's potential wood yield is equivalent to approximately 90000 litres of Ethanol per year.

1liters of ethanol has an energy content of approximately 6 kWh. Considering an overall generator efficiency of 15-30% the electricity output from Knoydart's biomass resources would total to 80 – 160 MWh. Ethanol production from cellulosic biomass is complicated and expensive because the sugars from these sources are harder to release or hydrolyze and some byproducts inhibit the process of fermentation. The smallest plant currently operating on a commercial market has a capacity of 1MW.

From the brief discussion of the technologies, it's evident that none of the discussed technologies would be able to provide more that, with the exception of steam turbines, none of the discussed technologies could provide more that 20% of Knoydart's present electricity demand. Also, none of the technologies is currently available on a scale or degree of maturity that is feasible for Knoydart.

If this will be the case in future it would only be viable to purchase this unit if it runs for as many hours as possible per year and when it runs as CHP plants where the waste heat is used.

Running a CHP plant at more hours to generate more electricity and heat would imply that the technology competes with hydropower which will always generate electricity at lower cost thus, this option is not beneficial to the Foundation. Running a CHP unit would thus require a district heating system discussed in the following section.

Based on this background, it's evident that using biomass for generation of electricity is not really beneficial although it can be used for space heating. This could be done either by considering district heating in Inverie since there are a number of household and commercial units clustered in the area. Alternately, individual wood boilers for private buildings can be installed.

4.1.3 Small Biomass District Heating system

As a number of buildings in Inverie village are very close to each other, a small district heating system could be a viable option to supply about 7 buildings with heat from wood.

Further consultation regarding possibility of installing a larger wood boiler for district heating was done and the following views were obtained.

- Consultation with personnel from Knoydart foundation (Grant Holroyd) helped highlight the fact that considering a district heating system would imply changing some of the already existent heating systems in the various properties. This would not only be cumbersome in terms of obtaining consent from those connected to the grid but would also require considerable financial input to change the heating systems to allow for necessary installations.
- Additionally, a survey for 37 properties (household and businesses) done for the Knoydart community showed that at least 73% of the respondents were content with their existing heating system and not really willing to change to other heating systems either because their existing systems were still functional or because they had recently done installations thus didn't see the need to change their heating system.

Therefore, In reference to these views, although a small district heating systems seems to be a technically and economically viable technology, it didn't seem feasible.

4.1.4 Individual Wood Boilers for Space Heating in larger buildings

Consultation with Angela Williams from Knoydart Foundation indicated that the foundation intends to refurbish the existing bunkhouse and make at least 4 units that can be rented out for accommodation. A new bunkhouse is planned in the neighbourhood of the old one. Consideration of a wood boiler to cater for space and water heating was suggested. To estimate what capacity of boiler would be required for the bunkhouse, the heating demand for the facility was obtained. This was done based on literature.

Scottish Government estimates the average heating index for Scottish households as 250 $kWh/m^2/a$ (Renewable Heat Group, 2008). The bunkhouse covers an area of approximately 198m2 thus will require approximately 50000/a or around 17 tons of fuel wood per year, implying a wood boiler of 25 kW capacity will be required. This can be considerably lower if the old bunkhouse is brought to low energy standard when converted into flats. Considering the proximity of the new bunkhouse to the old one a common heating system for both buildings should be considered.

Boilers are generally located in a dedicated boiler room as with a conventional boiler and can be used as an individual system for both room heating and domestic hot water heating. For the bunk house, the 25 kW capacity log boiler can be installed to avail heat for the four single flats that will be existent after the refurbishment. Log boiler systems work best where heat is required over longer periods of time as the boilers are not as suited to frequent start up and shut down sequences. It's common for the boiler systems to be connected to an accumulator/ large hot water storage tank in order that the boiler can be lit once and the heat stored and subsequently used over a number of days before the boiler needs to be restarted

Based on cost comparison of various 25kW capacity wood log boilers, the proposed wood boiler will cost between 12,000£ and 16,000£. That does not include the cost of installing a water bound heating system.

4.2 New hydro options

Based on preliminary desktop studies conducted in Flensburg in 2012 and meetings with Knoydart Foundation personnel, four potential sites along **Allt A' Mhuilinn, Allt A' Mhogha, Scottas Burn** and **Loch Glaschoille** were identified. The Google earth image in Figure 21 shows the location of the sites.

Figure 21: The Google Map Image of Knoydart with four potential micro hydro sites

Source: Google Map ©

The potential micro and pico hydro generation of the selected locations was calculated. The calculation is based on low-flow data provided by Wallingford HydroSolutions Limited for Allt A' Mhuilinn and Allt A' Mhogha (Hydrosolutions, 2012), see Annex XV. The flow data for Scottas Burn and Loch Glaschoille is correlated based on low-flow data and the size of their catchment areas. However, it has to be mentioned that the accuracy of low flow data decreases with the decrease in size of the catchment area. (Hydrosolutions, 2012, Ledingham 2007). For all sites considered in this study, it is recommended to carry out at least one year of flow measurements and correlate them to the long-term data before taking an investment decision.

The study includes:

- identification of requirements for establishing hydro power plants by Scottish Environmental Protection Agency (SEPA)
- land profiling for the components (penstock, powerhouse, intake, forebay, tailrace) for each site, based on 2m contour maps and site visits
- carrying out initial design with respect to the hydro power potential of each sites,
- estimation of annual and seasonal power generation
- estimation of investment cost
- economic analysis for each of the sites.

4.2.1 Environmental Acceptability

The four selected rivers were assessed based on the Scottish Environment Protection Agency (SEPA) criteria and none of the rivers can be classified as baseline water bodies. This means that all these rivers have catchment areas of less than 10 km^2, and are considered small coastal burns.

The Environment Protection Officer of SEPA, was contacted and concurred with the group's findings regarding the environmental acceptability of the rivers considered.

All schemes are considered provisionally acceptable since there are no environmentally critical areas near the abstractions (intake). However, the general area where the rivers are located has been identified as 'potentially important but not yet surveyed' for bryophyte assemblages. The rivers would have to be surveyed by the Scottish National Heritage (SNH) to identify if the sites are `nationally/internationally important'.

Mitigation measures stated in the SEPA document "*Guidance for developers of run-of-river hydro power schemes*" aim to reduce impact on the water environment need to be incorporated when considering the development of the sites. The mitigation measures include protection of river flow, river continuity and sediment transport.

4.2.2 Allt A' Mhuilinn

4.2.2.1 Overview

This site was identified as the site with the highest hydro power potential (85 kW at 38% of the year). The site was inspected along river Allt A' Mhuilinn from the designated intake point down to the powerhouse as shown in Figure 22. The intake was selected due to its accessibility and to optimize the ratio of head and penstock length. A part of the penstock and the powerhouse would be located on private land. There is no alternative that avoids crossing private land. Table 2 shows a summary of the main design parameters.

Table 16: Design Summary for Allt A' Mhuilinn

Catchment Area	2.88 km^2
Intake	NG 176575.29, 801293.75
Gross Head	87 m
Head Loss	2.35 m
Net Head	84.65 m
Penstock Length	1007 m
Penstock Diameter	400 mm, 300 mm
Installed Capacity (full capacity available for 38 % of the year)	85.00 kW
Power House	NG 176123.65, 800425.82
Tail Race Length	16 m

Source: Author, 2013

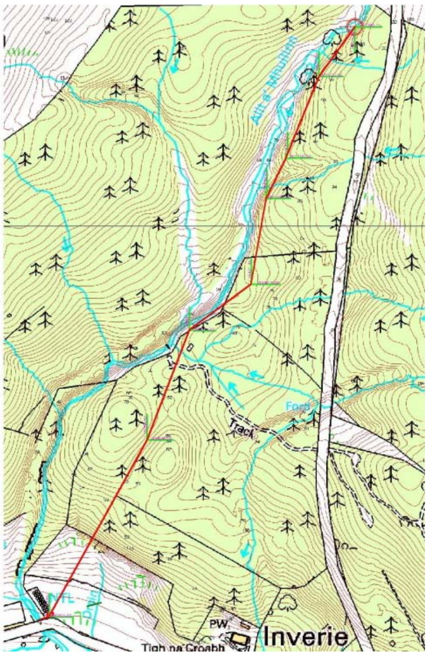


Figure 22: The Penstock, forebay, powerhouse and intake along Allt A Mhuilinn (2m contours)

Source: Ordnance Survey 1:10 000 raster, NextMap Britain 2m Contours, Author, 2013

Figure 23: The Catchment of site Mhuilinn

Source: Ordnance Survey 1:10 000 raster, Author, 2013

4.2.2.2 Hydrology

The annual percentile flow of Allt A' Mhuilinn is shown in Figure 24. As shown in Figure 24, the river has a flow range from 0.757m^3/s to 0.008m^3/s with Q90 flow of 0.018 m^3/s. In order to achieve the designed power, a design flow of 0.149 m3/s will be used and according to flow data, this design flow is fully available for 38% of the year. However, for the other percentiles, the flow is compensated (actual flow – Q90 flow) with respect to Q90 flow leaving 10% flow of water in the river at all time. The minimum flow available to produce the hydro power is 0.011 m^3/s.

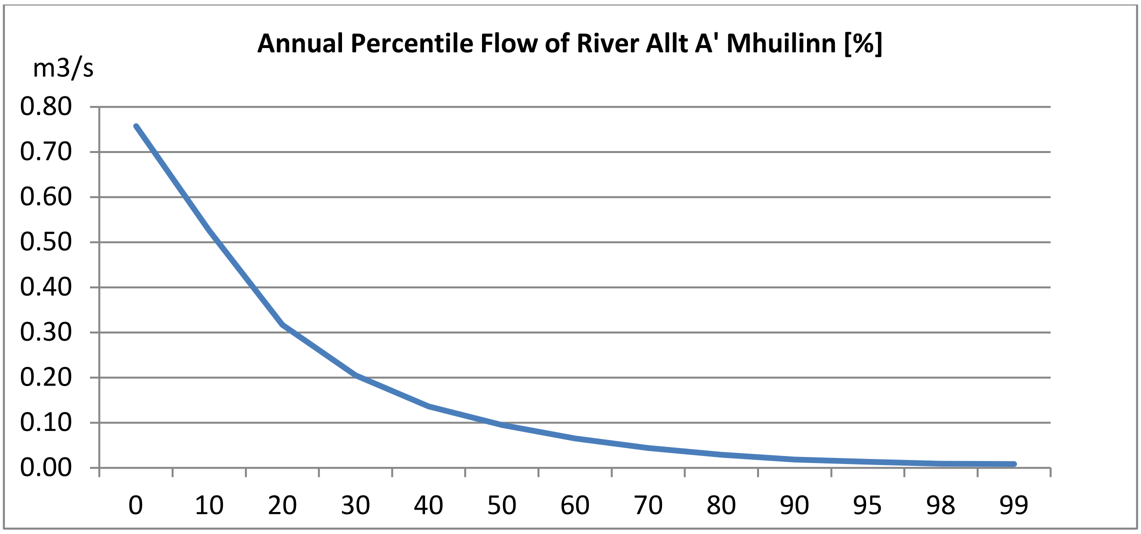


Figure 24. Annual Percentile Flow of River Allt A' Mhuilinn

Source: (Hydrosolutions, 2012), Author, 2013

4.2.2.3 Geomorphology and Penstock Design

From inspection of the site, the location and path of the penstock, forebay, powerhouse and tailrace are assigned. The bank of the river possesses rocky surfaces as shown in Figure 25 (Author, 2013). Therefore, the penstock installation should avoid excavation. The path proposed for penstock along the river is not very steep and road access is available near intake point and again near the powerhouse. Right next to the proposed location of the powerhouse, there is a transmission line passing by. In two different locations along the path of the penstock, there is currently a forest in close proximity that would make installation difficult but according to local community, the trees in that forest have reached maturity and will be cut down soon, hence, not registered as an issue. The exact bend of the penstock was calculated by ground profiling. In order to profile the ground, virtual ground was constructed by plotting the height from the contour lines along the penstock. The height of the ground above the sea level along the penstock was registered in an excel sheet to acquire the shape of land as shown in Figure 26.

Figure 25: One Rocky River Bank of Allt A' Mhuilinn with close proximity to forest

Source: Author, 2012

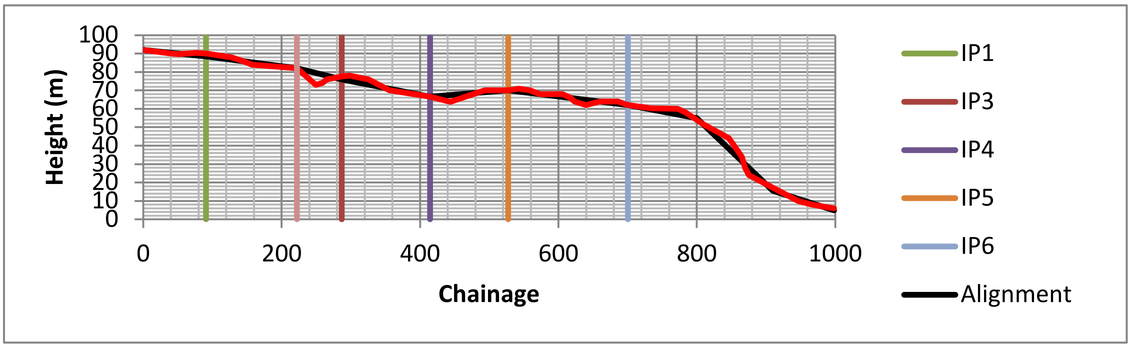


Figure 26: Longitudinal Sectional Land Profiling from intake point to powerhouse for Site Mhuilinn

Source: Author, 2013

According to the site survey and land profiling, the head of the hydro power potential is found to be 87 meters (Author, 2013). Utilizing the horizontal and vertical bends acquired from ground profiling, flow data, assumed efficiency of turbine and generator, the hydro power potential obtained was 85.00 kW. See detailed calculation in Annex XVI.

4.2.2.4 Turbine selection

Considering head and hydro power potential, a Pelton Multijet turbine was selected for this site. Large variation in flow throughout the year and high head made the selection appropriate. The calculation for the selection of the turbines is shown in Annex XVIII. The pipe with 400 mm and 300 mm diameters are selected by using Nomogram method. The summary of the technical design for this site is shown in Table 16.

4.2.2.5 Energy Output and Economic Analysis

The monthly energy production resulting from using this design is shown in Figure 27 below. The monthly energy potential in detail is further illustrated in Annex XX.

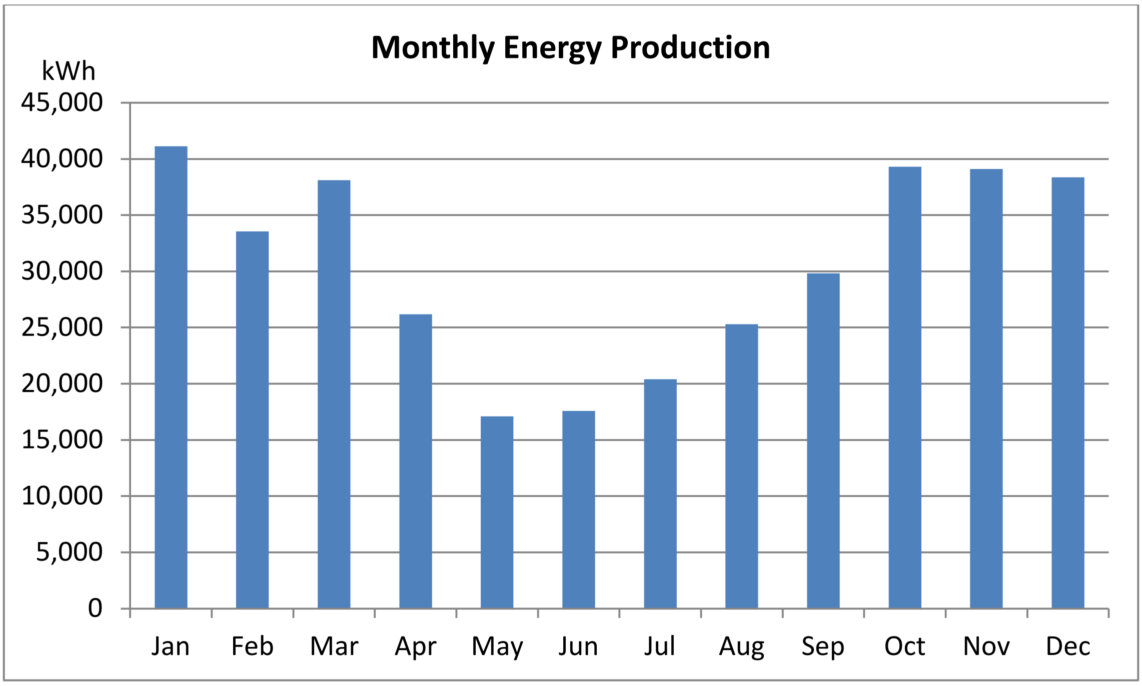


Figure 27: Energy Production from Mhuilinn

Source: Author, 2013

The expenditures and income of the proposed hydro plants are compared to determine the economic viability of the project options.

The investment cost was calculated based on cumulating costs for environmental surveys, construction costs for intake, penstock and powerhouse, equipment such as turbine and generator, design and supervision costs. Contingency costs of 8% of the total costs are also added to account for unforeseen expenses.

Costs are estimated based on the cost estimations and quotations for two small hydro power sites that were under development in 2012 in Jura (EEM, 2012). Costs are adjusted according to the size and design characteristics of the new hydro sites being considered.

Annual costs for Operation and Maintenance (O&M) are estimated based on current O&M costs of the existing hydro plant in Knoydart and adjusted according to size.

Based on the hydrologic data and technical design of the hydroplant, Allt a' Mhuilinn has an annual electrical output of 365.93 MWh. Electricity is assumed to be sold at a rate of 14 pence/kWh for the duration of the plant's lifetime of 50 years and an additional income from the generation tariff 19.6 pence/kWh for 20 years set by the government of the United Kingdom for generation plants with a capacity between 15 and 100 kW.

All cost and income calculations can be seen in detail in the Annex XXIV. If the plant sold off all its potential electricity generation, then the investment cost can be recovered in 5 years. The Net Present Value of the project would be £942,320 using an interest rate of 6.5% and the Internal Rate of Return of the project is 25.06%.

Table 17. Economic Feasibility Indicators for proposed Allt A' Mhuilinn hydro plant under Feed in Tariff Scheme

Allt A' Mhuilinn (under Feed in Tariff Scheme)	
Investment	£ 467,425
Annual maintenance cost	£ 5,000
Discount factor	6.5%
Electricity tariff	14 p/kWh
Generation tariff	19.6 p/kWh
Max. annual electricity generation	365.93 MWh
Max. capacity factor	0.49
Payback Period	5 years
Net Present Value	£942,320
Internal Rate of Return	25.06%

Source: Author

The values calculated above are based on the assumption that the generated electricity from the plant is all consumed. Calculations are also done to compute the amount of energy that should be sold to the customers for the project to be profitable. The hydro plant should be able to sell 109.36 MWh, 29.9% of the maximum annual energy produced, in a year for the Net Present Value to be zero, i.e. the project to recover all the investment cost. This value translates to 300 kWh per day or the hydro plant should operate at full capacity for 3.5 hours in a day and sell all of the energy generated to the customers.

The economic analysis was also done considering that the system will not be registered under the Feed in Tariff Scheme. At a rate of 14 pence/kWh, which is the current price of electricity in Knoydart, the economic feasibility of the proposed plant can be appreciated. The economic indicators are as seen in Table 18 below.

Table 18. Economic Feasibility Indicators for proposed Allt A' Mhuilinn hydro plant

Allt A' Mhuilinn	
Payback Period	18 years
Net Present Value	£200,277
Internal Rate of Return	9.8 %

Source: Author

In the case that the project is not registered under the Feed in Tariff scheme, the hydro plant should be able to sell 262.5 MWh, 71.7% of the maximum annual energy produced for the project to recover all the investment cost.

4.2.3 Allt A' Mhogha (White Gate)

According to observations of Knodart hydro staff members this site possesses the most consistent flow throughout the year. It is assumed that there are underground supplies from aquifers The low flow data acquired for this site do not show a considerably different flow characteristic than the other sites. Therefore regular flow measurements are recommended for this site to confirm or reject the observation of a more steady flow.

The site was inspected along Allt A' Mhogha from the designated intake point up to the tailrace as shown in Figure 29. This site was observed to be steep as shown in Figure 28. The intake shown in Figure 29 was selected due to its accessibility and to optimize the ratio of head and penstock length. This is the only site where the path of the entire project will be in the land owned by Knoydart Foundation (Knoydart Foundation, 2013). Table 19 shows a summary of the main design parameters.

Table 19: Detailed Design Summary for site Mhogha

Catchment Area	0.42 km^2
Intake	NG 177671.74, 800099.51
Gross Head	104 m
Head Loss	2.89 m
Net Head	101.11 m
Penstock Length	532 m
Penstock Diameter	150 mm
Installed capacity (full capacity available for 38% of the year)	15.00 kW
Power House	NG 177566.67, 799605.55
Tail Race Length	15 m

Source: Author, 2013

Figure 28: The Steep Nature of Site Mhogha

Source: Author, 2013

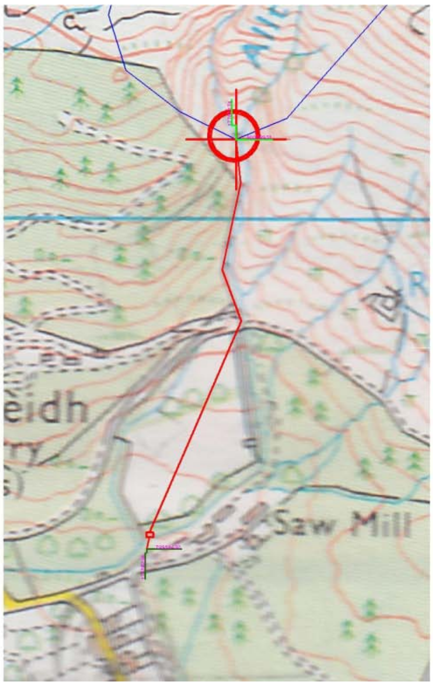


Figure 29: The Penstock, forebay, powerhouse and intake along Site Mhogha in 10m contour

Source: Ordnance Survey 1:10 000 raster, NextMap Britain 2m Contours, Author, 2013

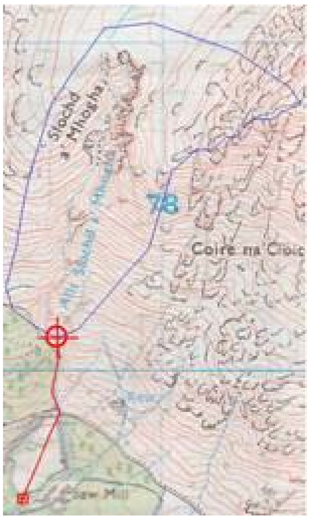


Figure 30: Catchment Area of site Mhogha

Source: Ordnance Survey 1:10 000 raster, 2012, Author, 2013

4.2.3.1 Hydrology

The annual percentile flow of the Allt A' Mhogha is shown in Figure 31. As shown in Figure 31, the river has a flow range from 0.114m^3/s to 0.001m^3/s with Q90 flow of 0.003 m^3/s (Hydrosolutions, 2012). On this site, actual flow measurement is conducted to try to find out the low flow during the dry season since there was no rain for the past two weeks and to find out thee flow consistency. From the flow measurement, the minimal flow is measured to be 0.008 m^3/s. This is 8 times the minimum flow in the LowFlows data.

In order to achieve the designed power, a design flow of 0.0224 m3/s will be used and according to flow data, the design flow is fully available 38% of the year. However, during the other percentile, the flow is compensated (actual flow – Q90 flow) with respect to Q90 flow leaving 10% flow of water in the river at all time. The minimum flow available to produce the hydro power is 0.002 m^3/s.

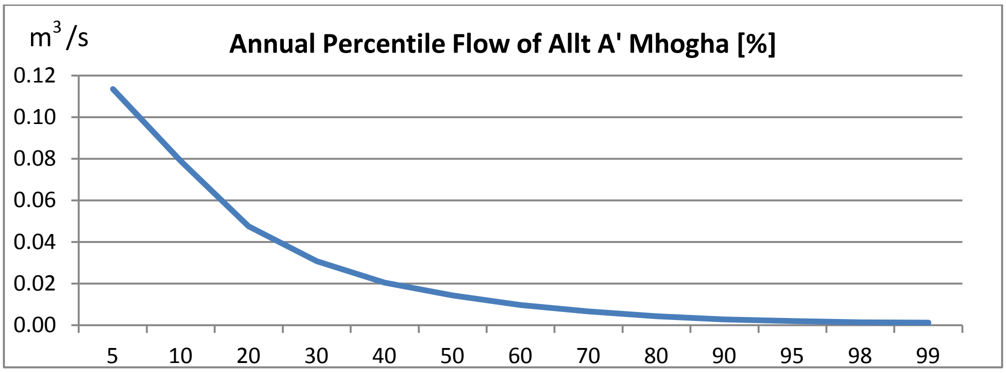


Figure 31: Annual Percentile Flow of Allt A' Mhogha

Source: Author, 2013

4.2.3.2 Geomorphology and Penstock Design

From inspection of the site, the location and path of the penstock, forebay, powerhouse and tailrace are assigned. The bank of the river possesses rocky surfaces as shown in Figure 28 and expected to be extremely difficult for excavation. In addition, there is one area where a road crosses through the path of penstock and the penstock must be definitely buried at that point. The road access along the penstock is possible at two points, i.e. in the midway of the penstock and near the powerhouse as shown in Figure 29.

The location of the powerhouse is close to the transmission line. However, part of the penstock is passing through the forest from the road crossing point till powerhouse. The exact bend of the penstock was calculated by ground profiling. In order to profile the ground, a virtual ground was constructed by plotting the height and length from the contour map along the penstock. The height of the ground above the sea level along the penstock was registered in an excel sheet to acquire the shape of land as shown in Figure 32.

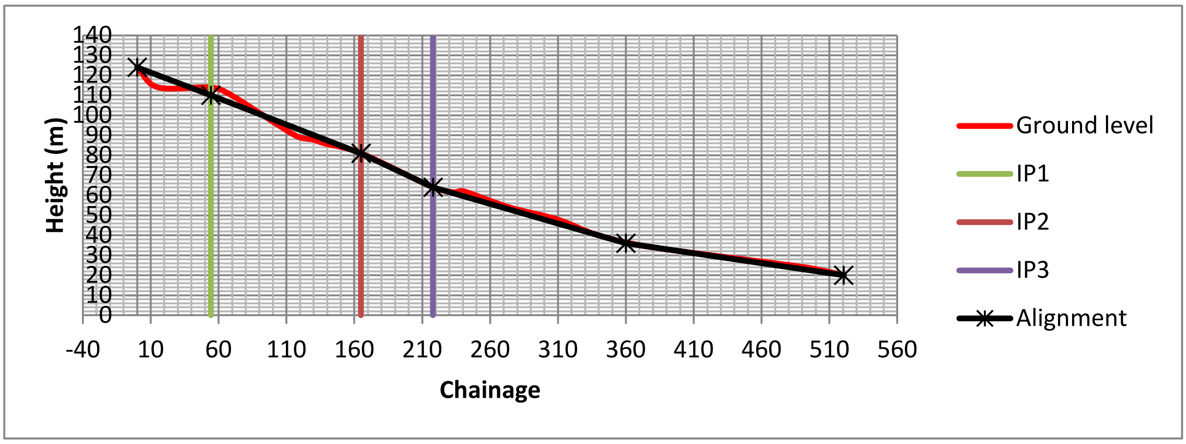


Figure 32: Longitudinal Sectional Land Profiling from intake point to powerhouse for Mhogha

Source: Author, 2013

According to the site survey and land profiling, the gross head of the hydropower was defined as 104 meters (Author, 2013). Utilizing the horizontal and vertical bends acquired from ground profiling, flow data, assumed efficiency of the turbine and generator, the hydro power potential was obtained as 15.00 kW. The detailed calculation is illustrated in Annex XVII.

4.2.3.3 Turbine Selection

Considering head and hydro power potential, a Pelton Single Jet Turbine was selected for this site. The high head and low flow indicate that the selected turbine is appropriate. The calculation for the selection of the turbine is shown in Annex XX. A penstock with 150 mm diameter is selected by using Nomogram method.

4.2.3.4 Energy Output and Economic Analysis

Based on this design, the monthly energy production is shown in Figure 33. The monthly energy production is further illustrated in Annex XX.

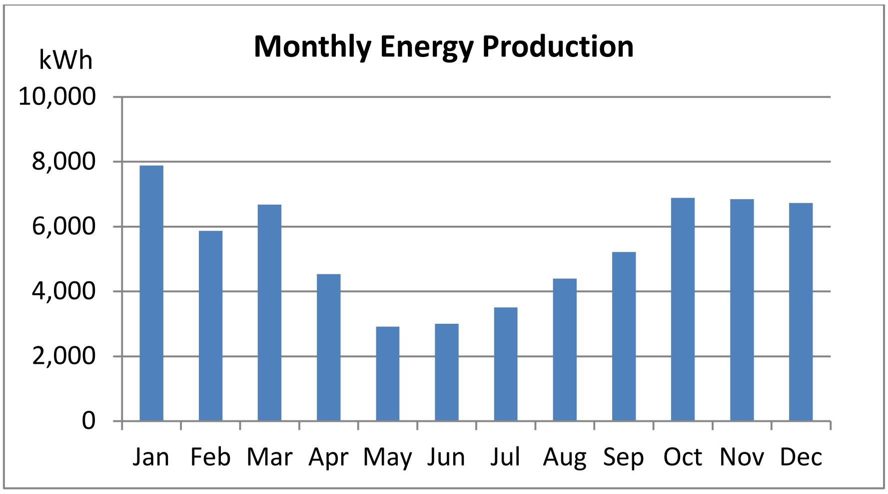


Figure 33: Energy Production from Mhogha

Source: Author, 2013

Allt A' Mhogha has an electric output of 64.48 MWh/a based on the hydrologic data and technical design of the hydro plant. Electricity is assumed to be sold at a rate of 14 pence/kWh for the duration of the plant's lifetime of 50 years and an additional income from the generation tariff of 21.9 pence/kWh for 20 years set by the government of the United Kingdom for generation plants with a capacity of 15 kW or less. All cost and income calculations can be seen in the Annex XXIV.

The project cannot recover the investment cost during its lifetime of 50 years. The Net Present Value of the project is -£ 56,033 using a discount rate of 6.5% and with 4.54% the Internal Rate of Return of the project is below the discount rate.

Table 20. Economic Feasibility Indicators for proposed Allt A' Mhogha hydro plant under Feed in Tariff Scheme

Allt A' Mhogha (under Feed in Tariff Scheme)	
Investment	£ 311,360
Annual maintenance cost	£ 2,500
Discount factor	6.5%
Electricity tariff	14 p/kWh
Generation tariff	21.9 kWh
Max. annual electricity generation	64.48 MWh
Max. capacity factor	0.49
Payback Period	>50 years
Net Present Value	-£ 56,033
Internal Rate of Return	4.54%

Source: Author, 2013

The economic analysis of the site was done taking into consideration that the system would not be registered under the Feed in Tariff Scheme. At the rate of 14 pence/kWh, which is the current price of electricity in Knoydart, the economic feasibility of the site can be appreciated as summarized in Table 21.

Table 21. Economic Feasibility Indicators for proposed Allt A' Mhogha hydro plant

Allt A' Mhogha	
Payback Period	>50 years
Net Present Value	-£ 202,121
Internal Rate of Return	(negative)

Source: Author, 2013

The Internal Rate of Return of the hydro plant for Allt A' Mhogha is negative if it is not registered under the Feed in tariff scheme.

4.2.4 Scottas Burn

In the preliminary desktop study conducted in Flensburg in 2012 the Scottas Burn was regarded as the second preference due to its hydro power potential (65.00kW, available for 37% of the year). Among all four sites, the Scottas Burn which is situated in a deep gorge has the poorest road access. The site was inspected along Scottas Burn from the designated intake point down to the powerhouse as shown in Figure 34. The intake shown in Figure 34 was selected to optimize the ratio of head and penstock length in accordance with geographical feasibility. A part of the penstock and the powerhouse would be located on private land. There is no alternative that avoids crossing private land. Table 22 shows a summary of the main design parameters.

Table 22: Detailed Design Summary for **Site Scottas Burn**

Catchment Area	1.30 km^2
Intake	NG 174428.99, 801468.87
Gross Head	145 m
Head Loss	3.395m
Net Head	141.60 m
Penstock Length	1022m
Penstock Diameter	300 mm and 250 mm
Installed capacity (full capacity available for 37% of the year)	65.00 kW
Power House	NG 174880.32, 800655.02
Tail Race Length	14.74 m

Source: Author, 2013

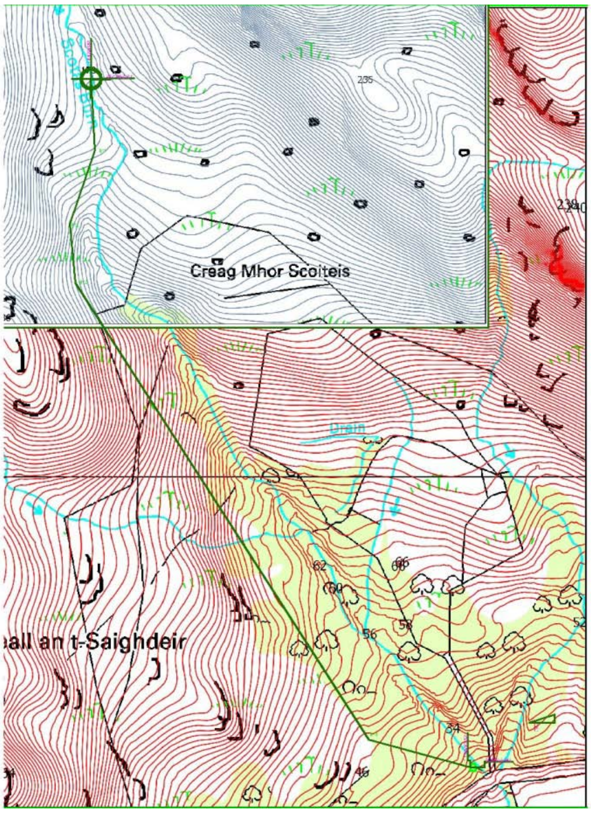


Figure 34: The Penstock, forebay, powerhouse and intake along site Scottas burn in 2m contour

Source: Ordnance Survey 1:10 000 raster, NextMap Britain 2m Contours,, Author, 2013

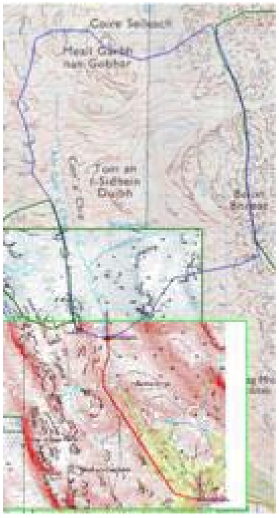


Figure 35: Catchment Area of site Scottas Burn

Source: Ordnance Survey 1:10 000 raster, NextMap Britain 2m Contours,, 2013, Author, 2013

4.2.4.1 Hydrology

The annual percentile flow of Scottas Burn is shown in Figure 36. As shown in Figure 36, the river has a flow range from 0.341m^3/s to 0.004m^3/s with Q90 flow of 0.008 m^3/s. In order to achieve the designed power, a design flow of 0.070 m3/s will be used and according to the flow data, the design flow is fully available 47% of the year. However, during the other percentile, the flow is compensated (actual flow – Q90 flow) with respect to Q90 flow leaving 10% flow of water in the river at all time. The minimum flow available to produce the hydro power is 0.005 m^3/s.

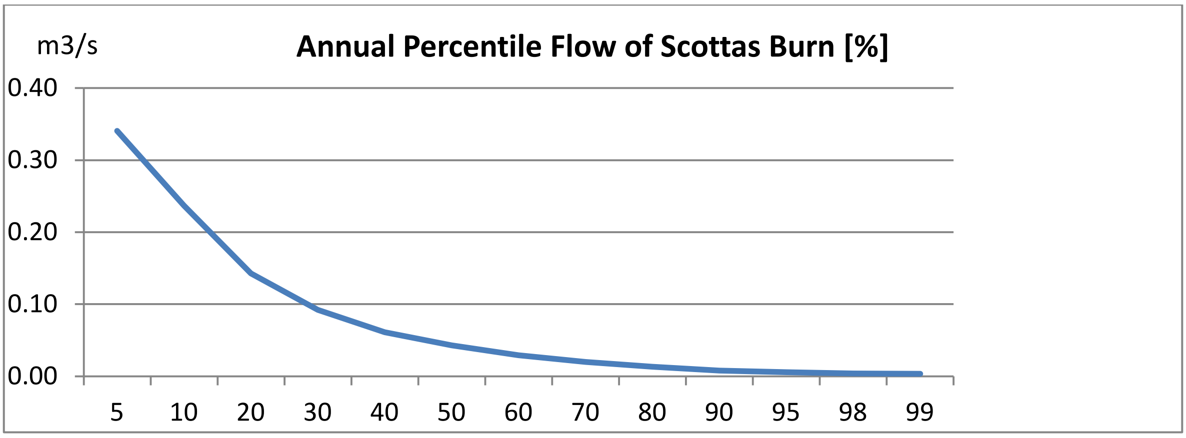


Figure 36: Annual Percentile Flow of Scottas Burn

Source: Author, 2013

4.2.4.2 Geomorphology and penstock design

From inspection of the site, the location and path of the penstock, forebay, powerhouse and tailrace are assigned. The bank of the river possesses rocky surface in some parts and soft soil surface in some part as shown in Figure 37(Author, 2013). Therefore, the penstock installation could be carried out with minimal excavation. A part of the path proposed for the penstock along the river has a mild slope and the rest has a gentle slope. Road access is only available near the powerhouse. A part of the path downstream near the power house passes through old forest. Right next to the proposed location of the powerhouse, there is a transmission line passing by. The exact bend of the penstock was calculated by ground profiling. In order to profile the ground, a virtual ground was constructed by plotting the height from the contour lines along the penstock. The height of the ground above the sea level along the penstock was registered in an excel sheet to acquire the shape of land as shown in Figure 38. The pipe of 300mm, 250mm and 225mm diameters are selected for the penstock using a nomogram.

Figure 37: One Example of River Scottas Burn location in deep gorge

Source: Author, 2013

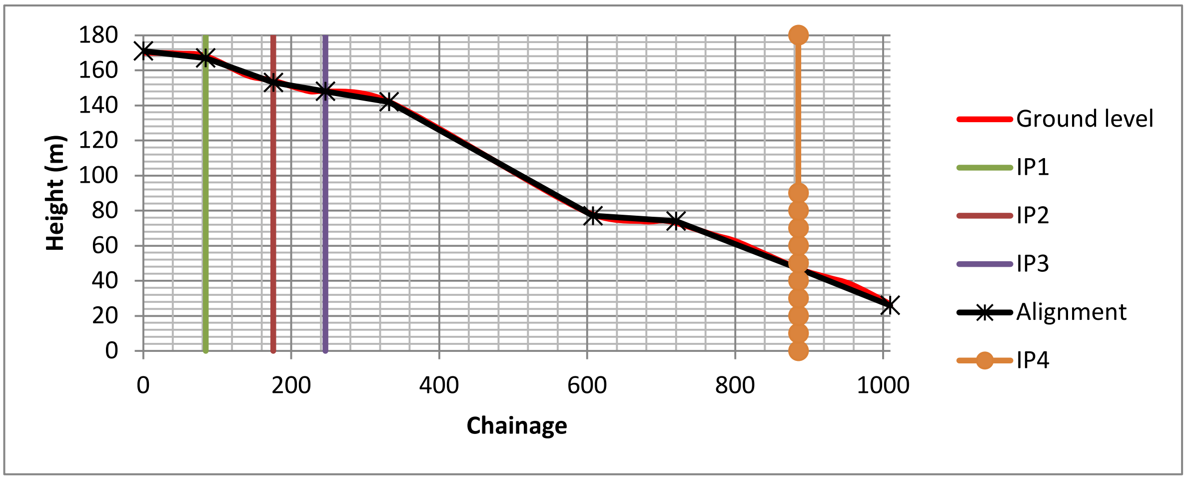


Figure 38: Longitudinal Sectional Land Profiling from intake point to powerhouse for Scottas Burn

Source: Author, 2013

According to the site survey and land profiling, the gross head of the hydro power potential is found to be 145 meters (Author, 2013). Utilizing the horizontal and vertical bends acquired from ground profiling, flow data, assumed efficiency of turbine and generator, the hydro power potential obtained was 65.00 kW. See detailed calculation in Annex XVII.

4.2.4.3 Turbine Selection

Considering head and hydro power potential, a Pelton Single Jet Turbine was selected for this site. The high head and low flow makes a Pelton turbine suitable. The calculation for the selection of the turbines is shown in Annex XVIII.

4.2.4.4 Energy Output and Economic Analysis

The monthly energy potential by using this design is shown in Figure 39 and the monthly energy potential in detail is illustrated in Annex XXII.

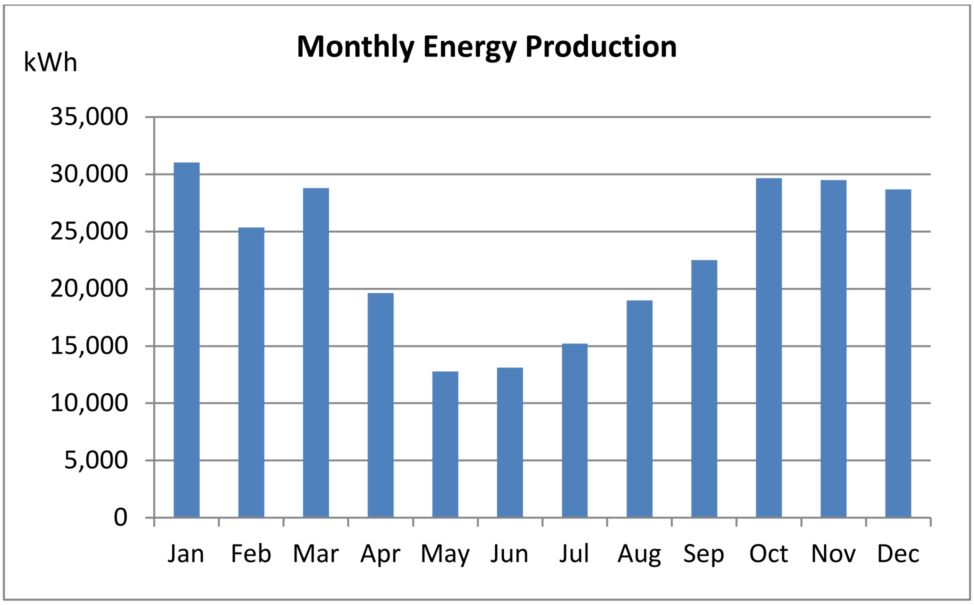


Figure 39: Energy Production for Scottas Burn

Source: Author, 2013

There are additional costs for the construction of the proposed Scottas Burn hydro plant due to difficulty to access the site. Helicopter lifts for the intake and penstock add to the investment cost for this site. All cost and income calculations can be seen in the Annex XXIV.

Scottas Burn has an electric output of 275.192 MWh based on the hydrologic data and technical design of the hydro plant. Electricity is assumed to be sold at a rate of 14 pence/kWh for the duration of the plant's lifetime of 50 years and an additional income from the generation tariff 19.6 pence/kWh for 20 years set by the government of the United Kingdom for generation plants with a capacity between 15 and 100 kW.

If the plant sold all of its generated energy, then the investment cost can be recovered in 7 years. The Net Present Value of the project is £594,718 using an interest rate of 6.5% and the Internal Rate of Return of the project is 18.86%.

Table 23. Economic Feasibility Indicators for proposed Scottas Burn hydro plant under Feed in Tariff Scheme

Scottas Burn (under Feed in Tariff Scheme)	
Investment	£ 454,605
Annual maintenance cost	£ 5,000
Discount factor	6.5%
Electricity tariff	14 p/kWh
Generation tariff	19.6 p/kWh
Max. annual electricity generation	275.19MWh
Max. capacity factor	0.48
Payback Period	7 years
Net Present Value	£ 594,718
Internal Rate of Return	18.86%

Source: Author

The values calculated above are based on the assumption that the generated electricity from the plant is all consumed. Calculations are also done to compute the amount of energy to be sold to the customers for the project to be profitable. The hydro plant should be able to sell 106.77MWh, 38.8% of the maximum annual production, for the Net Present Value to be zero. This value translates to 292.5 kWh per day or the hydro plant should operate at full capacity for 4.5 hours daily and sell all of the energy generated to the customers.

The economic analysis was also done considering that the system would not be registered under the Feed in Tariff Scheme. At a rate of 14 pence/kWh, which is the current price of electricity in Knoydart, the economic feasibility of the site can be appreciated and is summarized in Table 24 below.

Table 24. Economic Feasibility Indicators for proposed Scottas Burn hydro plant

Scottas Burn	
Payback Period	34 years
Net Present Value	£ 36,678
Internal Rate of Return	7.14 %

Source: Author

In the case that the project is not registered under the Feed in Tariff scheme, the hydro plant should be able to sell 256.3 MWh, 93.1% of the maximum annual energy produced for the project to recover all the investment cost.

4.2.5 Loch Glaschoille Run-off River scheme

The site is close to the river that passes through the Lagen Bridge. A part of the flow from the nearby river, where a plastic pipe is already placed, could be diverted to this site. Thus, the catchment area could be increased. This expansion of catchment area is considered in this project. The site was inspected from the designated intake point down to the powerhouse as shown in Figure 40. As there is no considerable inclination for the first 265m downstream from the existing dam at the loch, the intake for a run-off river scheme was selected further downstream. The intake shown in Figure 40 was considered as an optimization of head and penstock length. Using the Loch as storage would involve a longer penstock. This option is briefly discussed in chapter 4.2.6.

A part of the penstock and the powerhouse would be located on private land. There is no alternative that avoids crossing private land. Table 2 shows a summary of the main design parameters.

Table 25: Detailed Design Summary for Glaschoille

Catchment Area	0.77 km^2
Intake	NG 173890.92, 800495.73
Gross Head	68m
Head Loss	2.61m
Net Head	65.39m
Penstock Length	255m
Penstock Diameter	250 mm, 150 mm
Installed capacity (full capacity available for 41% of the year)	15.00 kW
Power House	NG 173920.80, 800254.38
Tail Race Length	10.76 m

Source: Author, 2013

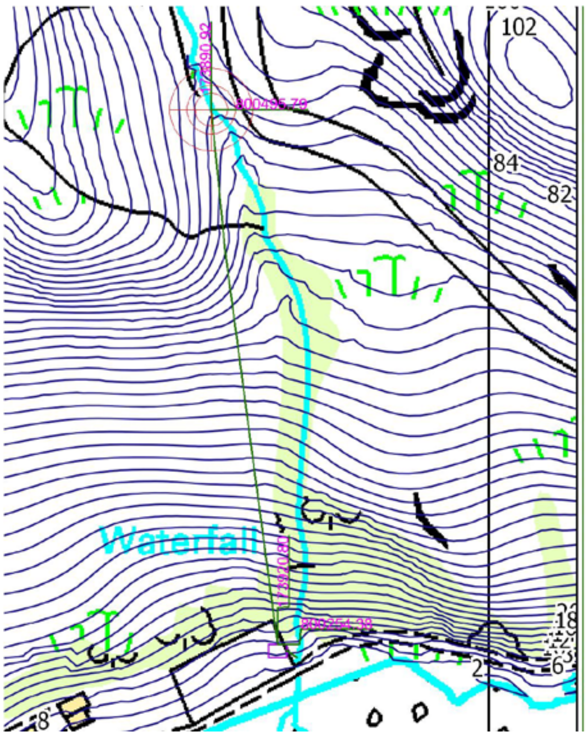


Figure 40: The Penstock, forebay, powerhouse and intake along Glaschoille in 2m contour

Source: Ordnance Survey 1:10 000 raster, NextMap Britain 2m Contours,Author, 2013

Figure 41: Catchment Area of Glaschoille

Source: Ordnance Survey 1:10 000 raster, NextMap Britain 2m Contours, 2012, Author, 2013

4.2.5.1 Hydrology

The annual percentile flow from Loch Glaschoille is shown in Figure 42. As shown in Figure 42, the site has a flow range from 0.201m3/s to 0.0002m3/s with Q90 flow of 0.005 m3/s . In order to achieve the designed power, a design flow of 0.035 m3/s will be used and according to the flow data, the design flow is fully available 41% of the year. However, during the other percentile, the flow is compensated (actual flow – Q90 flow) with respect to Q90 flow leaving 10% flow of water in the river at all time. The minimum flow available to produce the hydropower is 0.004 m3/s.

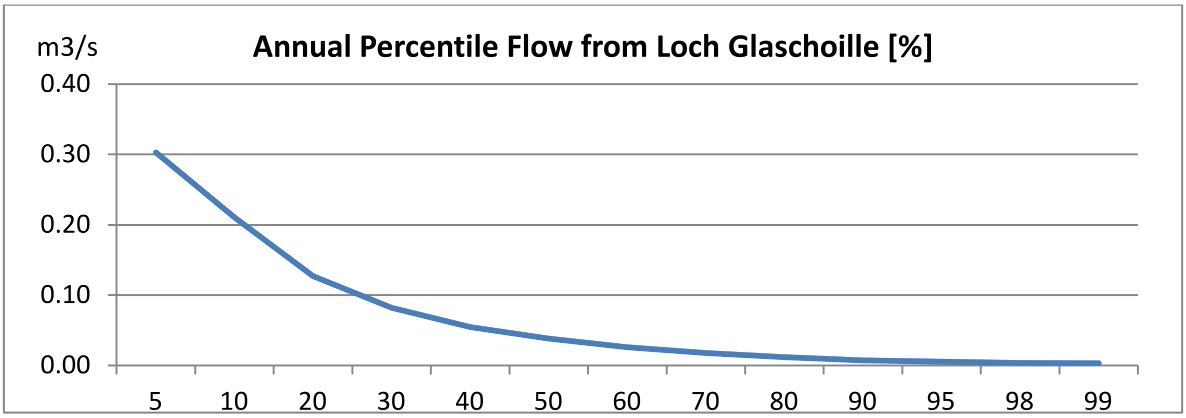


Figure 42:The Annual Percentile Flow from Loch Glaschoille with diversion of flow from the river nearby

Source: Author, 2013

4.2.5.2 Geomorphology and penstock design

From inspection of the site, the location and path of the penstock, forebay, powerhouse and tailrace are assigned. Since the intake point is taken further down from the loch, the intake point is situated in the deep gorge and from intake point till powerhouse is situated on rocky surface. The path of the penstock consists of steep ground and the transmission line is close to the proposed powerhouse location. There is no dense forest along the path of penstock, however, there are some plantations along the path and some include big trees. The exact bend of the penstock was calculated by ground profiling. In order to profile the ground, a virtual ground was constructed by plotting the height from the contour lines along the penstock. The height of the ground above the sea level along the penstock was registered in an excel sheet to acquire the shape of land as shown in Figure 44.

Figure 43: The Location of Loch Glaschoille

Source: Author, 2013

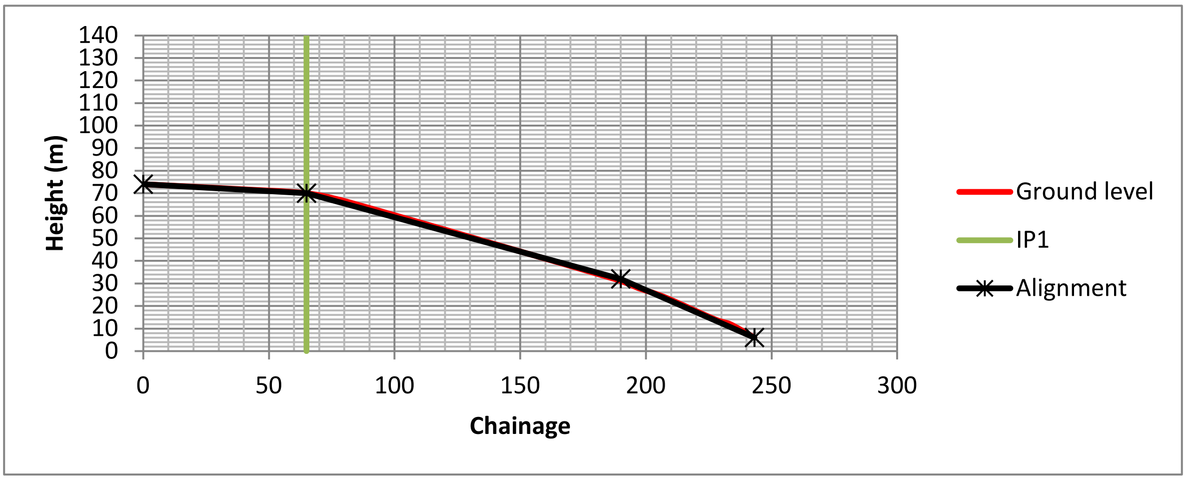


Figure 44: Longitudinal Sectional Land Profiling from intake point to powerhouse for Loch Glashoille

Source: Author, 2013

According to site survey and land profiling, the gross head of the hydro power potential was defined as 68 meters (Author, 2013). Since detailed flow data was not purchased for this site, the flow data for this site was calculated by correlating it with flow data of site Mhuilinn. This was done with respect to the ratio of average mean flow. Utilizing the horizontal and vertical bends acquired from ground profiling, together with flow data and assumed efficiency of turbine and generator, the hydropower potential obtained was 15.00 kW. See detailed calculation in Annex XXIII.

4.2.5.3 Turbine Selection

Considering head and hydropower potential, a Pelton Multi Jet Turbine was selected for this site. The calculation for the selection of the turbine is shown in Annex XVIII. Pipes with 250 mm and 150 mm diameters are selected by using Nomogram for the penstock. The summary of technical design for Loch Glaschoille is shown in Table 25.

4.2.5.4 Energy Output and Economic Analysis

The monthly energy potential by using this design is shown in Annex XXIII and the monthly energy potential in detail is illustrated in Figure 45.

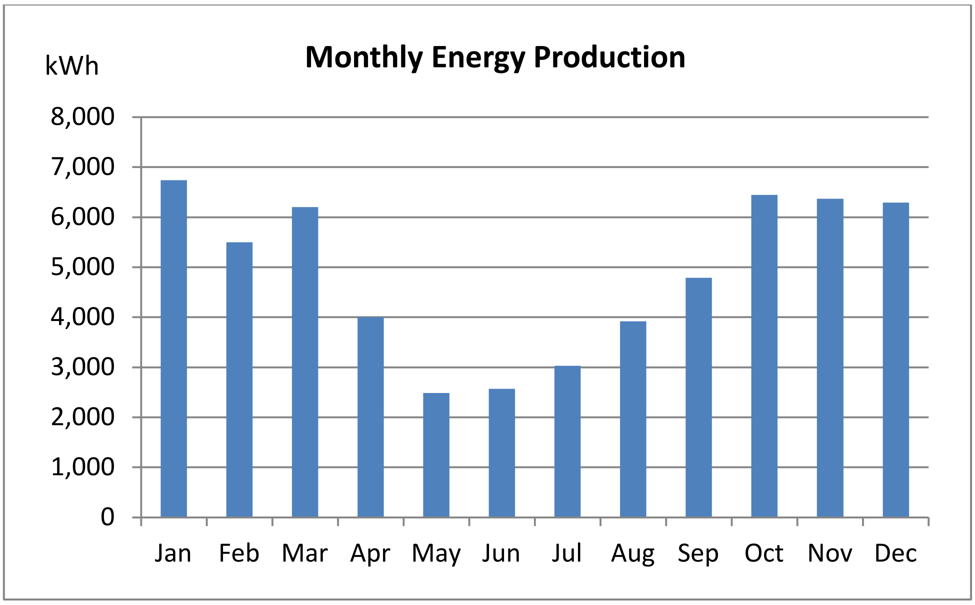


Figure 45: Energy Production for Loch Glaschoille

Source: Author, 2013

Loch Glaschoille has an electric output of 63.72 MWh/a based on the hydrologic data and technical design of the hydroplant. Electricity is assumed to be sold at a rate of 14 pence/kWh for the duration of the plant's lifetime of 50 years and an additional income from the generation tariff of 21.9 pence/kWh for 20 years set by the government of the United Kingdom for generation plants with a capacity of 15 kW or less. All cost and income calculations can be seen in the Annex XXIV.

The project cannot recover the investment cost during its lifetime of 50 years. The Net Present Value of the project is -£32,101 using a discount rate of 6.5% and with 5.27%. the Internal Rate of Return of the project is below the discount rate.

Table 26. Economic Feasibility Indicators for proposed Loch Glaschoille hydro plant under Feed in Tariff Scheme

Loch Glaschoille (under Feed in Tariff Scheme)	
Investment	£ 282,494
Annual maintenance cost	£ 2,500
Discount factor	6.5%
Electricity tariff	14 p/kWh
Generation tariff	21.9 p/kWh
Max. annual electricity generation	63.72 MWh
Max. capacity factor	0.48
Payback Period	>50 years
Net Present Value	-£ 32,101
Internal Rate of Return	5.27 %

Source: Author

The economic analysis was also done considering that the system would not be registered under the Feed in Tariff Scheme. At a rate of 14 pence/kWh, which is the current price of electricity in Knoydart, is applied, the economic feasibility of the site can be appreciated and is summarized in Table 27.

Table 27. Economic Feasibility Indicators for proposed Loch Glaschoille hydro plant

Loch Glaschoille	
Payback Period	>50 years
Net Present Value	-£ 176,478
Internal Rate of Return	(negative)

Source: Author

The Internal Rate of Return of the hydro plant for site Loch Glaschoille is negative if it is not registered under the Feed in tariff scheme.

4.2.6 Loch Glaschoillle-Storage Option

The site is unique due to the availability of water storage which could actually provide a portion of energy demand during peak hours or during outages of existing hydropower. A total volume of 63,281 cubic meters can be stored in the loch with the flow from the catchment area of the loch itself and from catchment area of Scottas Burn. It will be connected via a pipeline. With this volume of water, the loch would be able to provide 300kW with a design flow of 0.6m3/s for approximately 29 hours, (consideration of 300kW is based on peak demand and backup power required in 2032). The capacity factor is 5.83%. To use Loch Glaschoille as a storage the penstock would have to be extended to the existing dam with the length of 325m.

Table 28. Requirement for Storage Option

Total energy demand from storage	137,105.2 kWh
Transmission and Distribution Losses (11.67%)	16,000.18 kWh
Total Energy Needed From Storage	153,105.4 kWh
Capacity of Storage (Peak demand)	300 kW

Source: Author, 2013,

The total investment cost is roughly estimated at £850,000. Therefore, it is observed that the investment cost is too high and the capacity factor is too low. A storage option in Loch Glashoille is not economically feasible.

4.2.7 Expansion of Existing Hydro Power Plant

The existing hydro power plant could be expanded by the addition of another turbine connected to the same penstock. To check if the expansion is feasible, the following analysis was done

The availability of water flow was checked to identify if more flow could be redirected while maintaining 10% of original flow as compensation flow at all time. With more water flow, higher head losses can be expected. Therefore, theoretical head losses of additional hydro power were calculated and are shown in Table 29.

The calculations are based on flow data used for the refurbishment of the hydro scheme in 2002 (source). Unfortunately there are no reliable flow data available from the existing monitoring system due to technical problems in measuring the spillway and compensation flow. The calculations are also based on the assumption that the penstock losses of the existing penstock can be reduced down to its original design values. Additional flow to run a second turbine during peak time would increase the head loss to 23.95m, which is only acceptable if the head loss at the design flow of the main turbine can be reduced to its design head loss of 20.69m.

Table 29: Calculation of Additional Hydro Power Available for One Additional Turbine at Existing Hydro Power Site

Design Flow additional turbine	0.0098 m^3/s
Design flow main turbine	0.129 m3/s
Existing Penstock Diameter	295 mm plastic, 258 mm steel
Theoretical Penstock Loss (main turbine)	20.69 m
Theoretical Penstock Loss (both turbines)	23.95 m
Real flow if both turbines are running at full capacity	0.140 m3/s
Additional Hydro Power Available	20 kW (max)

Source: Knoydart Foundation, 2013, Author 2013

It was however noted that the additional power available would not be consistent throughout the year. The power output, however correlates with the existing load curve of the electricity demand in

Knoydart. The maximum monthly availability of additional hydro power is shown in Table 30 and Table 31..

Table 30: Maximum Availability of Additional Power from Existing Hydro Power

Month	Average available daily flow(m3)	m3/s	Main Turbine flow(m3/month)if the turbine runs at full capacity	design flow of main turbine (m3/s)	Proposed Design Flow for Main Turbine (m3/s)	proposed total designed flow of both turbines (m3/s)	Max availability of both turbines (%)	flow balance
January	16276.3	0.1884	11145.6	0.1290	0.130	0.140	100	0.0594
February	14850	0.1719	11145.6	0.1290	0.130	0.140	100	0.0429
March	12056.5	0.1395	11145.6	0.1290	0.130	0.140	100	0.0105
April	12069.1	0.1397	11145.6	0.1290	0.130	0.10	100	0.0107
May	9117.8	0.1055	11145.6	0.1290	0.130	0.140	75	-0.0235
June	10433.9	0.1208	11145.6	0.1290	0.130	0.140	86	-0.0082
July	11001.6	0.1273	11145.6	0.1290	0.130	0.140	91	-0.0017
August	12508.7	0.1448	11145.6	0.1290	0.130	0.140	100	0.0158
September	16429.6	0.1902	11145.6	0.1290	0.130	0.140	100	0.0612
October	19742.6	0.2285	11145.6	0.1290	0.130	0.140	100	0.0995
November	15728.8	0.1820	11145.6	0.1290	0.130	0.140	100	0.0530
December	20646.8	0.2390	11145.6	0.1290	0.130	0.140	100	0.1100

Source: Average Available Daily Flow by Knoydart Foundation, 2013, calculations by Author, 2013

Table 31: Additional Power Output from Existing Hydro Power Site

Month	hours	available flow	design flow	power	energy output (kWh)
January	744	0.053	0.0098	19.81	14739.31
February	672	0.037	0.0098	19.81	13312.93
March	744	0.005	0.0098	19.81	14739.31
April	720	0.005	0.0098	19.81	14263.85
May	744	0.000	0	0.00	0.00
June	720	0.000	0	0.00	0.00
July	744	0.000	0	0.00	0.00
August	744	0.010	0.0098	19.81	14739.31
September	720	0.055	0.0098	19.81	14263.85
October	744	0.094	0.0098	19.81	14739.31
November	720	0.047	0.0098	19.81	14263.85
December	744	0.104	0.0098	19.81	14739.31
	8760				129801.03

Source: Author, 2013

Installing a new turbine to the existing hydro plant could thus produce an extra 129.8 MWh. The total investment cost for adding a new turbine is estimated to be £ 130.000. If all generated electricity is sold, then the investment can be recovered in 10 years, the Net Present Value is £130,195, and the internal rate of return is 13%.

It is, however, strongly recommended to refurbish the spillway flow measurement, collect data on the available surplus flow for at least one year and correlate them to long term flow data before taking a decision.

4.2.8 Conclusions

According to the findings, site Allt a Mhuilinn is considered the best option to develop a new micro hydro plant. It has the largest electric potential with a design capacity of 85 MW and an annual electric production of 365.93 MWh. Allt a Mhuilinn also proved to be a sound economic investment as compared to the other three sites. The site has a Net Present Value of £942,320 and the investment would be recovered in 5 years given that all of its generated electricity is consumed by the consumers, which is presently not possible. A summary of technical and economic data for the four sites are given in Table 32.

Table 32. Summary of Technical and Economic Data of four sites

	Technical and Economic Details	
Allt a Mhuilinn	Capacity:	85 kW
	Annual Production:	365.93 MWh
	Total Investment Cost:	£ 467,425
	Payback Period:	5 years
	Net Present Value	£ 942,320
	Minimum MWh to breakeven	109.36 MWh
Allt a Mogha (White Gate)	Capacity:	15 kW
	Annual Production:	64.48 MWh
	Total Investment Cost:	£ 311,360
	Payback Period:	>50 years
	Net Present Value	- £56,033
Scottas Burn	Capacity:	65 kW
	Annual Production:	275.19 MWh
	Total Investment Cost:	£ 454,605
	Payback Period:	7 years
	Net Present Value	£594,718
	Minimum MWh to breakeven	106.77 MWh
Loch Glaschoille	Capacity:	15 kW
	Annual Production:	63.72MWh
	Total Investment Cost:	£ 282,494
	Payback Period:	>50 years
	Net Present Value	-£32,101

Source: Author, 2013

The values summarized in the table assume the project is registered under the Feed in Tariff Scheme.

It should be noted that additional costs that could be incurred due to construction on land not owned by the Knoydart Foundation are not included in the analysis. The economic indicators except for site Allt a Mogha (White Gate), which is owned by the Knoydart Foundation, will have to be adjusted according to negotiations with land owners.

Additionally, it is recommended that long term flow measurements on site Allt a Mogha are carried out to ascertain observations of Knoydart residents. They pointed out that there is constant and reliable flow in the river although this differs widely from flow that was measured by the group and flow data from Wallingford HydroSolutions.

For all sites which are considered for installation of a new hydro power plant flow measurement should be carried out over a period of at least one year as the reliability of the available low flows data is limited due to the size of the catchment areas.

4.3 Management of Energy Surplus

The energy system in Knoydart consists of the hydropower plant and the diesel generator which operates as a backup power source. During off-peak hours, there is excess energy that can be produced by the hydropower plant due to demand being less than the capacity of the scheme. In these instances, storage of energy could be useful as a backup during maintenance of the hydropower plant and outages to reduce the consumption of diesel fuel by the generator. Different options such as battery banks, hydrogen and heat storage systems can be considered to manage the surplus electricity.

4.3.1 Energy storage for management of the peak demand

Management of demand during peak hours is relevant to avoid undesired outages of electricity supply. As explained previously in chapter 3, the hydropower plant currently generates an annual average power of 105 kW and peak power of approximately 180 kW (30 minutes' average). When demand exceeds this peak power, the system shuts down. With growing demand, these events will occur more often.

Storage of electricity in battery banks could be a solution of supplying electricity during peak demand. Batteries are charged during off-peak hours to supply electricity during high demand. This configuration allows the system to deliver a more consistent electricity output, making better use of the hydro scheme. The parameters that should be taken into consideration when selecting the storage dimensions are: power during peak demand and the duration of the peaks. Unfortunately the monitoring system of the hydropower plant currently only delivers 30 minute averages of demand. Data from previous measurements (Senergy Econnect Limited, 2009, p. 12) indicate that the real peak varies by about +/-17%. Using the power data available, a simulation of electricity production for one day that had a high demand was conducted to determine the storage dimension. Following, the graph of Knoydart power consumption during 17th – 18th March 2009 from the Senergy report is shown.

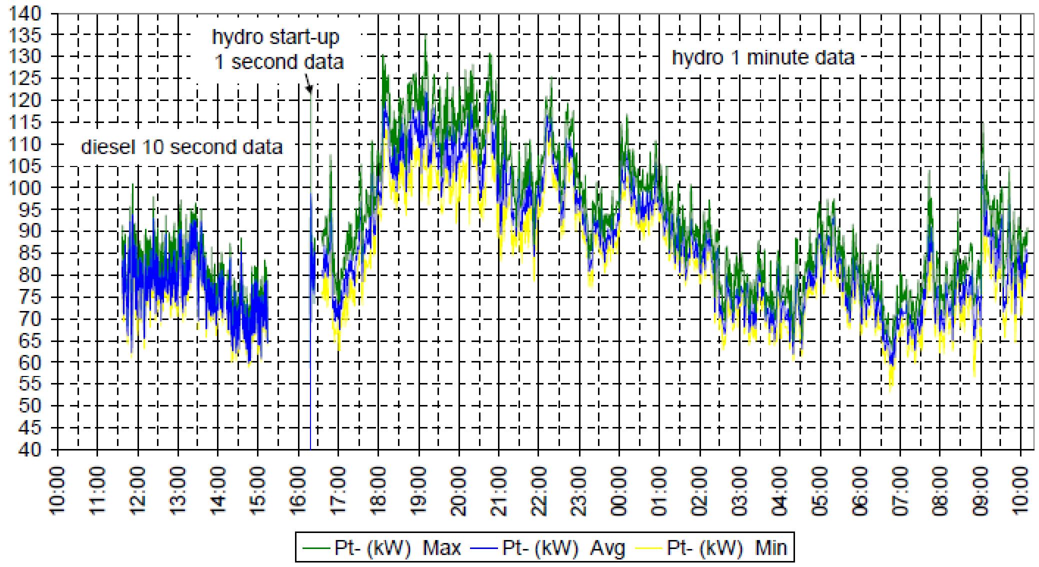


Figure 46: Knoydart Power Consumption 17-18 March 2009

Source: (Senergy Econnect Limited, 2009)

In the figure below a simulation of the electricity peaks is shown. Currently the hydropower plant can produce between 170 kW and 180 kW. Taking into consideration the results from the simulation, the electricity storage should deliver approximately 40 kW of power for 1 hour and requires a capacity of 100 Ah, considering 400 V of output. In this way, the power generation could reach up to approximately 220 kW, slightly below the peak power shown in the simulation. Regarding the duration of the peaks, only in extreme situations, these ones could last for more than 1 hour; thus, for the dimension of the battery bank only 1 hour duration has been considered to manage the peaks.

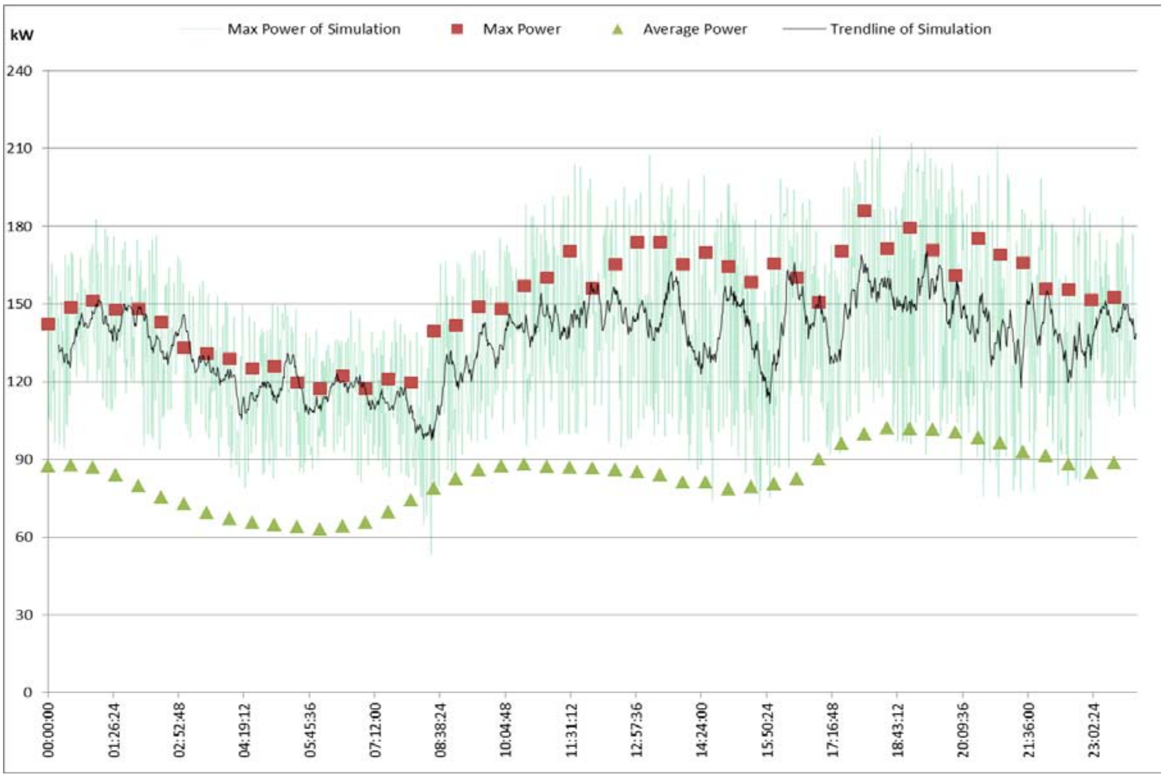


Figure 47: Simulation of the daily peak demand (extreme scenario)

Source: Author 2013

From the electricity storage technologies discussed as alternatives for Knoydart in the Pure Energy report (Pure Energy Centre Ltd., 2008, p. 33) Lithium Ion, Lead Acid and Flow batteries were analysed. The other alternatives, Sodium Sulphur and Sodium Nickel Chloride are technologies not yet mature; and although Nickel Cadmium is a mature technology, applications for renewable energy back up are still under development.

Lithium Ion (LiOn)

The Lithium Ion Battery is an energy storage device that uses lithium salt as electrolyte. The salt provides the ions required by the chemical reaction. Extensive use of lithium-ion batteries in electronic devices (e.g. laptop, cell phone, and camera) has increased its research and development over the last years. The scaling-up application of LiOn batteries has been successfully implemented for electrical vehicles (EVs) due to its advantage of relatively high energy and power density (Yang, et al., 2010).

The very high efficiency of nearly 95%, anticipated mass production, flexible discharge time (from seconds to weeks), easy monitoring of the state of charge, power capacities of up to tens of kW and long life are the main advantages of this technology. The lithium-ion battery also presents some disadvantages such as high cost (i.e. two times the cost of lead-acid battery) and an increasing temperature while charging and discharging at high current (IEA, 2011).

Lead Acid

Lead acid batteries technology dates from the 19th century and it is still presently used due to its capacity to deliver high power surges in a short period of time. Since the technology is about 140 years old, it is relatively lower in cost compared to other technologies. It operates by a chemical reaction between a lead plate (negative plate) and a lead oxide plate (positive plate) immersed in an electrolyte (sulphuric acid). The chemical reaction in the negative plate produces lead sulphate and 2 electrons (e-) and the reaction in the positive plate also produces lead sulphate and uses the 2e- produced in the negative plate to complete the reaction. This flow of electrons from one plate to the other one produces the current in the battery (Progressive Dynamics, 2013).

There are two main types of lead batteries: SLI Batteries (Starts, Light, and Ignition) and Deep Cycle Batteries. The former are used to store and deliver high power (kW) during short periods of time and the latter are used to store large amount of energy (kWh). For specific application in renewable energy, the appropriate type is the Deep Cycle Battery that can provide a steady supply of energy, while the generation of electricity is intermittent.

Lead batteries have the advantage of being a proven and simple technology due to the simplicity of their chemistry. In addition, they are mass produced in several sizes, shapes and storage capacity. This means that they are cheap and provide the best value for power. The current lead acid battery industry is the most developed in terms of infrastructure and can provide good service to the final user when needed. However, lead batteries are heavy and very large in size which makes them best suitable for stationary applications (Battery Council International, 2013).

Flow batteries

This is an energy storage device in which electrolytes are stored in two tanks outside the electrochemical cell. The battery generates electricity when the electrolytes flow and react with the electrodes in each cell. Flow batteries are rechargeable and last for a long time. Due to the use of external storage tanks, this system can be easily scaled up or down. If it is necessary to increase the capacity of the battery, the user only needs to add more electrolytes in the same tank or additional ones. They present power design flexibility, since the energy storage capacity is independent of the power rating. Also the stand-by losses of these batteries are low. The electrolyte can be stored for long durations without special requirements. The disadvantages of these batteries are: they cannot be moved easily, have to be assembled on site, and the chemical products used as electrolytes possess high toxicity.

There are mainly two types of flow batteries: zinc-bromide and vanadium redox. The main difference between the two is that in the latter vanadium is used in both electrolyte solutions. The advantage of having the same component as an electrolyte is avoidance of permanent damage if these solutions get mixed up (Electricity Storage Association, 2011).

In the following table, prices and technical data of each of these technologies are presented.

Table 33: Energy Storage Technologies Comparison for Peak Demand Management

	Lithium Ion	Lead Acid	Flow Batteries
Power Density [kW]	40	40	40
Life [cycles at full charge]	10,000	2,100	20,000
Operation Time [hours]	1	1	1
Capacity [kWh]	40	40	40
Rated power per unit [kW]	5.2	1.2	5.1
Quantity of units	8	34	8
Total system Weight [kg]	520	4182	10,400
Total system Volume [m^3]	0.60	2.52	38.4
Energy density [kWh/kg]	0.077	0.010	0.004
Batteries Price [£]	52,751.28	21,537.50	111,333.76
Cost of control system [£]	34,731.14	37,626.88	34,731.14
Total Price (£)	**87,482.42**	**59,164.38**	**146,064.90**
£/ kW	2,187.06	1,479.11	3,651.62
£/ Cycle	8.75	28.17	7.30
Assumed Lifetime [years]	10	10	10
Annual cost [£ / year]	9,316.88	6,301.01	15,555.91

Source: Author 2013 based on (Rolls Distribution, 2013), (Corvus Energy, 2013) and (Golden Energy Century Ltd. - GEC, 2013)

As shown in the above table Lead Acid batteries have the lowest cost per kW but Flow batteries have the lowest cost per cycle, making the latter ones a good option to be considered for the long term. It has to be considered that for the management of peak demand in Knoydart, the batteries would not have an extensive use; thus, the parameter to take into account in this case is the annual cost. These calculations have been done considering 10 years of lifetime for the batteries due to the manufacturers' warranty. Comparing these alternatives and taking into account the lifetime of the project mainly due to economic reasons Lead Acid batteries seem to be the best solution to manage the peak demand in Knoydart. In Annex I technical information of these batteries is presented. In Annex II the cash flow of the electricity sales considering the investment needed on this technology is shown. Battery storage would increase the available capacity of the hydropower scheme and its reliability; but at present cost of Diesel fuel and electricity, the high initial investment would not pay back during the lifetime of the project. Therefore, it is recommended to consider the alternative with the lowest investment. But as shown in Chapter 5 in a future scenario with a higher demand of electricity, this alternative might be a good option to manage the peaks and have a permanent supply of electricity.

The suggested place to locate the battery bank would be near the diesel power generator which is located at Inverie village. The batteries should be kept in a shed to protect the casing from adverse climate conditions. It is recommended to keep them in a ventilated shed, because when the batteries are charging they produce small amounts of explosive hydrogen. The controller, sensor and inverters should be placed close to the battery bank to avoid losses (Wind&Sun , 2008). In this case, the Lead Acid battery bank has an area of 5.44 m^2. The shed should have an approximate size of 15 m^2, considering area for the batteries, maintenance and control equipment, and also transit area.

Since peak load management on the supply side is always costly, no matter whether it takes place with batteries, other storage technologies, Diesel generators or additional renewable energy systems, it is recommended to analyze the root cause of the electricity peaks on the consumer side. An alternative that has been already explored in Knoydart is power load controllers (Senergy Econnect Limited, 2009). The recommendations in the Senergy report should be followed up. More accurate and reliable data on the extend of the peak load problem should be collected to identify the causes of the problem on the demand side, as recommended in chapter 3.4 of this report, and to act accordingly. The 1 minute measurement conducted by Senergy indicate that the automatic shutdowns of the hydro scheme might be caused only be a few large appliances.

4.3.2 Energy storage for management of the peak demand and outages

Larger electricity storage can be used as a solution to provide electricity when the hydro system is down and also to control the peaks when the system is operating. Usually the maintenance takes place once every two weeks for less than one hour. Besides, some major corrective maintenance occurs during longer periods for up to 8 hours. In order to avoid the use of the diesel generator, which represents a higher cost of electricity production, the same technologies as described in the previous chapter and hydrogen storage can be considered for this purpose.

Hydrogen

Hydrogen (H) is the most abundant and lightest chemical element in the universe. It is not an energy source; it is just an energy carrier. Hydrogen can be combined easily with other elements. It is possible to find it as part of different substances such as hydrocarbons, water, biomass and alcohols. The main industry around the hydrogen production is focused on getting it from cost effective sources such as hydrocarbons (fossil fuels or even biomass). Water as hydrogen source is becoming popular, but it requires big quantities of electricity.

One of the cleanest sources of hydrogen is through water electrolysis, splitting water into hydrogen and oxygen inside a device called "electrolyzer". The Water is then subjected to direct electric current and the result is hydrogen and oxygen separation. Different authors differ about the efficiency of this process, but the most accepted is between 50% and 70% (US DOE , 2012).

$$\mathbf{2H_2O + energy \rightarrow 2H_2 + O_2}$$
$$\mathbf{E_0 = -1.229\ V}$$

The main components required for water electrolysis are: (Bellona Foundation, 2002)

- *Electrolyte:* In this case the electrolyte is water. Its main characteristic is that it is "a substance containing free ions which are the carriers of electric current in the electrolyte. If the ions are not mobile, as in a solid salt then electrolysis cannot occur." (Bellona Foundation, 2002)
- *Direct current (DC) supply*: It is necessary to provide energy to discharge the ions in the electrolyte.

- *Two electrodes:* To conduct electricity through the electrolyte, it is necessary to have a physical interface between the electrical circuits. Electrodes of graphite, semiconductor materials and metal are widely used.

There are three main large industrial electrolysis processes:

- Alkaline electrolyzers: They use a liquid electrolyte, typically 25% potassium hydroxide solution. Some of them have an efficiency of over 80% (Bellona Foundation, 2002). Some companies such as "NHE" and "GHW" "(…) have developed compact electrolysis system that can produce hydrogen equivalent to the energy supply of a standard gasoline station. These electrolyzers operate under pressure, and the product is hydrogen under moderate pressure (30 Bar)" (Bellona Foundation, 2002).
- Polymer electrolyte membrane (PEM) electrolyzers: This electrolyzer utilizes polymer membranes as electrolytes (PEM). This technology comes from fuel cells development and can be found commercially. So far, its efficiency is lower than that of alkaline electrolyzers but some authors say that, after more development of this technology, its efficiency could reach 94% (Bellona Foundation, 2002). According to (Bellona Foundation, 2002) "PEM electrolyzers are best suited for small plants, especially plants with varying output, while alkaline electrolyzers are clearly an advantage in larger systems which are connected to the power grid".
- Steam electrolyzers: This process uses a ceramic ion-conducting electrolyte. Unfortunately, this technology is not yet available and is still part of laboratory work. So far, they have reached a very good efficiency (Bellona Foundation, 2002).

The dimension of the electricity storage has been calculated considering the power data from the year 2009-10[2], the only year for which a complete set of data was available (30 minutes' average). The following figure shows the extreme scenario of daily power generation. It is calculated considering the highest load within 30 minutes duration. The maximum power achieved in this period is slightly below 175 kW.

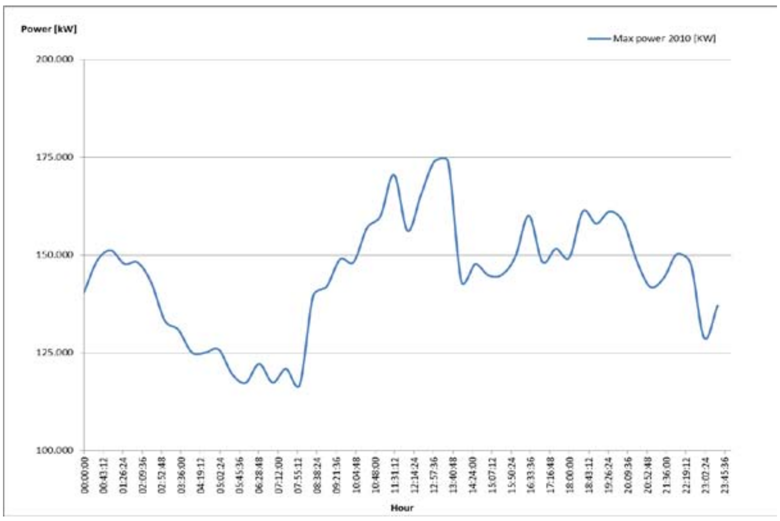


Figure 48: Extreme day scenario of highest load for the period 2009-10[3]
Source: Author 2013

[2] Power data (kW) from October 2009 until October 2010 obtained from the ABB device
[3] Power data (kW) from October 2009 until October 2010 obtained from the ABB device

The electricity storage should provide full supply of electricity at least during short outages of the hydropower plant. During 2009-10[4] the outages reached approximately 79 hours. This alternative will be focused on the maintenance operations that last less than 2 hours. Thus, for the dimensioning it has been considered 180 kW of power for 2 hours, including a safety margin. The table below shows the calculated annual hours of outages of the hydropower plant occurred during the period 2009-10[5] and the possible scenario considering that batteries will cover up to 2 hours the whole electricity supply when the hydropower system is not working. This scenario assumes that all outages that last less than 2 hours and the first 2 hours of all outages currently covered by the diesel generator (8 under the period analysed) will be covered by the batteries.

Table 34: Outages of the Hydropower Plant and fractions covered by the diesel generator and battery

	Outages of the Hydropower Plant 2009-10[6] (hours/year)	**Electricity generated during outage times** (kWh)	**Diesel consumption based on 2009-10 outages** (litres)
Current scenario			
Annual outages hours	79.0	6 546	1 850
Outages of less than 2 hours	14.5	1 202	340
Outages of more than 2 hours	64.5	5 345	1 510
New scenario with electricity storage			
Annual outages hours	79.0	6 546	1 136
Cover by the batteries (charged by hydro scheme)	30.5	2 527	–
Cover by the batteries (charged by diesel generator)	48.5	4 019	1 136

Source: Author 2013

For hydropower plant outages that last more than 2 hours, the Diesel generator can be used to recharge the batteries. In this way, better use of the diesel generator can be assured, obtaining its best efficiency while consuming less quantity of fuel. During 2010, the diesel generator produced nearly 6546 kWh, consuming circa 1849.5 litres of diesel. This results in an average efficiency of 36% while the efficiency at rated power is 41% (John Deere, 2002). Since the demand is always fluctuating, when the diesel generator supplies electricity directly to the grid, it does not work under optimal conditions. By using electricity storage the performance of the diesel generator can be improved up to 10% above its current performance. In the following table, the comparison of the electricity storage technologies can be observed.

[4] Idem
[5] Idem
[6] Idem

Table 35: Energy Storage Technologies Comparison for Management of the Peak Demand and Outages

	Lithium Ion	Lead Acid	Flow Batteries	Hydrogen
Power Density [kW]	180	180	180	180
Life [cycles at full charge]	10,000	2,100	20,000	50,000
Operation Time [hours]	2	2	2	2
Capacity [kWh]	360	360	360	360
Rated power per unit [kW]	5.2	1.8	5.1	5
Quantity of units	70	200	36	72
Total system Weight [kg]	4,550	24,600	46,800	5,976
Total system Volume [m^3]	5.18	14.80	172.80	17.28
Energy density [kWh/kg]	0.080	0.015	0.008	0.060
Unit Price [£]	461,573.70	186,782.08	563,627.16	773,813.81
Cost of control system [£]	34,731.14	37,626.88	34,731.14	0
Total Price (£)	**496,304.84**	**224,408.95**	**598,358.30**	**773,813.81**
£/kW	2,757.25	1,246.72	3,324.21	4,298.97
£/Cycle	49.63	106.86	29.92	15.48
Assumed Lifetime [years]	10	10	10	10
Annual cost [£/year]	52,856.47	23,899.55	63,725.16	82,411.17

Source: Author 2013 based on (Rolls Distribution, 2013), (Corvus Energy, 2013), (Golden Energy Century Ltd. - GEC, 2013) and (Horizons Fuel Cell Technologies, 2013)

In this case as well, it has been considered 10 years of lifetime of the batteries; and from the alternatives presented the Lead Acid battery bank has the lowest cost per kW, representing the most attractive option. For the Lead Acid battery bank the same general conditions detailed in the previous alternative applied for this option. The Lead Acid battery bank has an area of 32 m^2; therefore, the shed should have an approximate area of 42 m^2.

In order to determine the return of investment an economic analysis has been done (Annex III). The results of this analysis show that under the current conditions the investment cannot be recovered during the lifetime of the Project. Thus, for this option also the lowest investment should be considered to reduce economic impacts.

Finally we evaluated to install a battery bank in the “Foundation Bunkhouse” to be used as a pilot project. The regarding this project can be found in Annex V

4.3.3 Other options

Other options can be used to manage the electricity surplus apart from storing the energy in batteries. The other options being considered are thermal storage and electrical vehicles. To find out the possibilities of adopting these technologies, inquiries were included in the 38 questionnaires carried out.

4.3.3.1 Thermal Storage

Electrical Thermal Storage (ETS) is a technology commonly used to convert off-peak electricity to heat and store it for later use. The heat can be stored in diverse mediums; the most common are bricks (ceramics) and water, providing heat for 24 hours a day. In order to promote the use of this technology some utilities absorb part of the cost of the ETS system or it can be paid in differed payments included in the electricity bill (Greater Sudbury Hydro Inc, 2008).

The Flensburg utility has recently installed a large thermal storage of 28,000 m^3, resp.1000 MWh volume that uses peak electricity from wind energy to supply hot water to the local district heating system. Similar technologies are common in Danish district heating systems (Stadtwerke Flensburg GmbH, 2012).

Regarding the survey, from the 38 questionnaires, only 36 respondents answer to the question: "If it were possible, would you be interested to change your primary heating system to an electric boiler or electrical storage heaters?" 69% of the respondents said "no" and the remainders are willing to change.

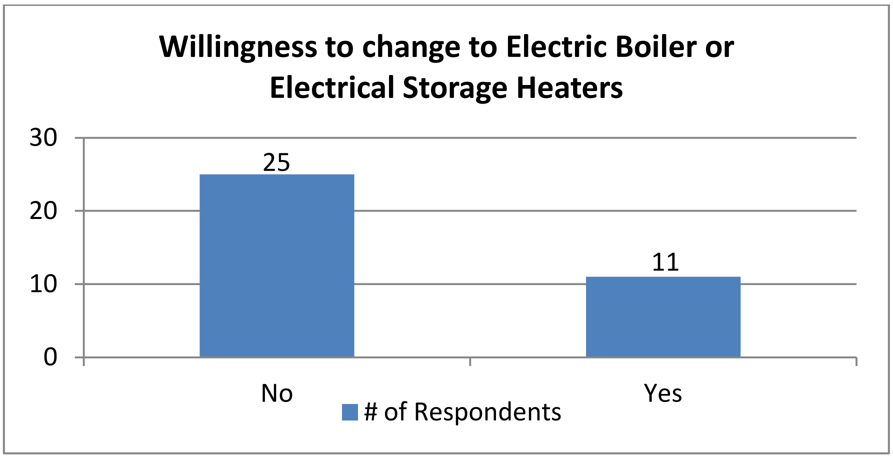


Figure 49: Willingness to change to Electric Boiler or Electrical Storage Heater

Source: Questionnaire Households Knoydart 2013

From the 25 respondents who are not willing to change to an Electrical Thermal Storage (ETS) only 20 gave an explanation. They mentioned the following reasons: 10 prefer other sources or technologies of heating, 6 expressed that either price of the ETS system or electricity was too high, 2 have it already installed and 2 respondents said that they do not own the property; therefore they are not able to take such a decision. From the 11 respondents who were willing to change only 9 expressed the reasons. They would agree to use electricity in combination with thermal storages mainly if there was a reduction in their heating bills (4 answers) or if electricity supply was reliable (3 answers) and because they do not like other technologies (2 answers). In the following sections these technologies and their applicability in Knoydart are further discussed.

- **Electric Boilers**

This technology uses water as a storage medium with a high efficiency It uses electrical elements from a total power between 2 kW and 12 kW to heat the water. The water is stored in a Domestic Hot Water (DHW) cylinder. The storage can be used to supply hot water to the dwelling or to use it in the Central Heating System for room heating. The size of the cylinder determines the amount of energy that can be stored. This system is easy to install, does not require much plumbing and can be programmed to be used only during off-peak time or with off-peak tariff (Trianco, 2012).

The storage capacity of this technology depends on the size of the DHW and the initial and final temperature of the water. Assuming that the temperature difference of the water is 30° C, 10 litres of water can store 0.4 kWh. The size of a hot water cylinder to supply heat for space heating and domestic hot water to an average size residential house would be in the range of 1500 -2000 liters. Some suppliers of this technology are Trianco, The Electric Heating Company, Thermaflow and Heatraesadia.[7]

- **Electrical Thermal Storage Heaters**

This technology works by storing energy in ceramic bricks. Electrical elements are used to heat the bricks during off-peak hours or during the programed time. Later, the heat is released as needed to provide heating comfort. The load of the ETS ranges from 1.32 kW to 10.8 kW for large applications. This technology can store energy from 13.5 kWh up to 40 kWh (Steffes Corporation, 2007-20012). When the system is fully charged, the maximum temperature that the bricks can store is 1400 °C. When used daily, the system rarely gets below 250 °C (Renovation Experts, 2012). Creda, Dealec and Dimplex[8] are some of the suppliers located in the United Kingdom.

Both technologies need to be sized considering the amount of off-peak hours available and the heat demand, and programmed in order to store enough energy to provide heating when needed, in most cases 24 hrs. Regarding differentiated tariffs, currently in Knoydart there is a night tariff. The cost of this tariff is approximately 0.07 ₤/kWh compared with 0.14 ₤/kWh which is the regular tariff. A higher implementation of this differentiated tariff and using timers can be promote the use of high power appliances such as water heaters, washing machines, dryers, pumps and others during off-peak hours. To measure the electricity used at off-peak time either a two-tariff meter or two separate meters are needed.

4.3.3.2 Electrical Vehicles

Being the reduction of fossil fuels a main objective of the community, it is important to encourage the use of vehicles with low CO_2 emissions. From the 37 responses of the 38 surveys carried out, it was found out that for regular transportation in Knoydart at least 8 cars, 27 four-wheel drive vehicles and 1 van are used. Also, there is one electric vehicle, an electric squad used mainly to provide transport services to the tourists. If it is considered that the 8 cars consume petrol and are driven 2 miles per day[9] and the other 28 vehicles consume diesel and are driven 8 miles per day in average[10] the total annual CO_2 emissions amounts to circa 32663 kg[11].The diesel generator currently produces approximately 12313 kg of CO_2 emissions per year[12]. There are different options of electric vehicles available in the market that can be used as an alternative to avoid the consumption of fossil

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[7] http://www.trianco.co.uk/products/aztec-electric-boilers; http://www.electric-heatingcompany.co.uk/index.php/products/; http://www.thermaflowheating.co.uk/; http://www.heatraesadia.com/

[8] http://www.dimplex.co.uk/products/domestic_heating/installed_heating/storage_heaters/index.htm; http://www.credaheating.co.uk/products/storage-heaters.htm; http://www.dealec.co.uk/acatalog/-Storage-Heaters.html

[9] Information based on the survey carried out

[10] Idem

[11] Considering for diesel vehicles 0.19354 CO_2 kg/km and for petrol vehicles 0.20864 CO_2 kg/km

[12] Considering 1.881 kg of CO_2 equivalent per kWh

fuels. These vehicles can be charged during off-peak hours in the residences and then be used during daytime. In this way, a better management of the energy surplus can be obtained and import of fossil fuel avoided.

To the question "Would you be interested in using an electric vehicle (car, motorbike, electric bicycle) for your daily use?" 52% of the respondents answer positively.

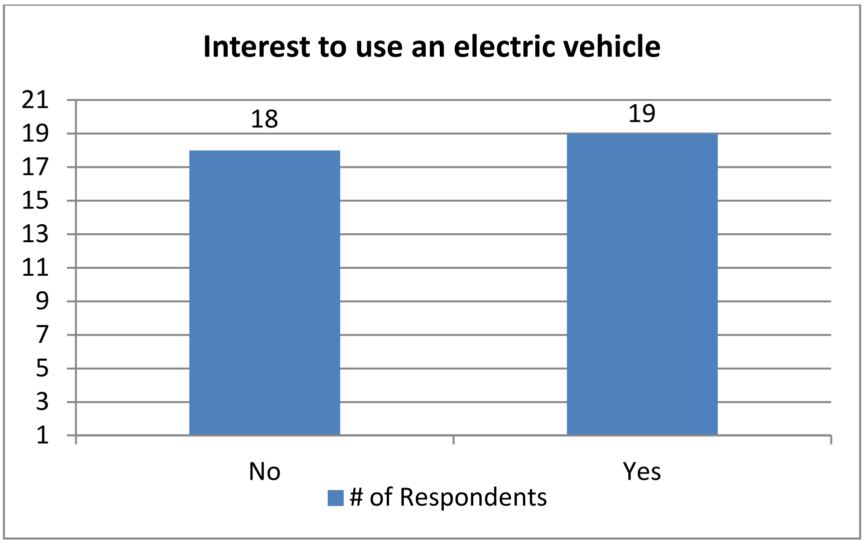


Figure 50: Interest to use an electric vehicle

Source: Questionnaire Households Knoydart 2013

The respondents mentioned that they will be willing to use electric vehicles under some conditions, like vehicles prices, performance and the presence of the needed facilities to charge them. They also declared that if the electricity price is cheaper than fossil fuels, they will be willing to use the electric vehicle. The interviewers who gave a negative response mentioned for example: the road conditions, the performance of the vehicles and not enough supply of electricity.

An option to introduce electric vehicles in Knoydart could be to start a small project hiring these vehicles to the tourists. For this purpose a charging station would have to be provided in Inverie village.

Electric car technologies are still in their early stages of development. Nevertheless, in the United Kingdom a large number of suppliers such as Renault, Nissan, Chevrolet, Vauxhall and Toyota[13] offer this kind of vehicles. As shown in the results of the survey, many people in Knoydart seem to be interested in the use of electric vehicles. Regarding the price of the electricity in comparison to the price of diesel, currently in Knoydart the electricity price is very attractive to consider electric cars as an option. Both, the prices of electricity and diesel are approximately 0.14 £/kWh but the efficiency of electrical motors is 4-5 times higher than the efficiency of an internal combustion engine,

[13] http://www.renault.co.uk/vans/model/kangoo-van-ze/product.aspx; http://www.dicksons-nissan.co.uk/new-cars/leaf/; http://www.chevrolet.co.uk/cars/volt; http://www.vauxhall.co.uk/vehicles/vauxhall-range/cars/ampera/index.html; http://www.toyota.co.uk/cgi-bin/toyota/bv/frame_start.jsp?id=CC2-Prius-Plug-landing

resulting in lower cost per mile. For a Renault Kangoo, for example, the fuel cost is around 0.01 £/mile for the electrical version compared to 0.05 £/mile for the diesel version.

For the following reasons electrical cars is an interesting option for Knoydart:

- Due to the isolated geographical situation most residents drive only short distances (8 miles/day for diesel vehicles according to our survey). Therefore the limited range of electrical cars would not be a problem.
- The hydropower scheme can provide cheap and environmentally friendly electricity at off-peak times and would make the residents less dependent on fuel imports.

However, there are some constraints:

- Some residents might need off-road vehicles for their daily duties. To our knowledge the only available electrical off-road vehicles are presently squads.
- Only licensed mechanics are allowed to do maintenance and repair work on the high voltage parts of electrical vehicles. For Renault, for example, the next licensed workshop is in Inverness. From Knoydart, this is beyond the mileage range of an electrical Renault Kangoo.
- To recharge the batteries in less than 3 hours with 415 V sockets a charging station is required. These stations are available only under contract with British Gas.

The following table compares the cost of an electrical car with its Diesel counterpart using the Renault Kangoo as an example.

Table 36: Cost comparison between diesel and electric Kangoo van

Vehicle	**Kangoo Van Diesel**	**Kangoo Van Electric**
Investment [£]	13250	17098
Depreciation and interest (static) [£]	1755,625	2265,485
Annual maintenance cost (considering trailer transport to Inverness once in a year for the electrical version) [£]	1000	1500
Fuel cost per mile[£]	0.05	0.01
Total annual cost without taxes and insurance, considering a lifetime of 10 years, considering 3000 miles/year	2905,625	3795,485

Source: Author based on (Renault UK, 2012)

An option to introduce electric vehicles in Knoydart could be to start a small project hiring electrical vehicles to the tourists. To minimise the risk this could be a small city car, only to be used on the tarmac road, such as the Renault Twizy. Table 37 shows a projection of the required income from hire to make such a project feasible.

Table 37: Summary of Pilot Project Economic Evaluation

Investment costs	
Vehicle cost [GBP]	£ 8,040.00
Charging Station [GBP]	£ 1,000.00
Total [GBP]	£ 9,040.00
Operation costs	
O&M [GBP / year]	£ 1,000.00
Electricity cost [GBP/kWh/year]	£ 0.14
Total Electricity expenses [GBP/year]	£ 60.48
Battery Lease [GBP]	£ 804.00
Commercial Terms	
Term [years]	10
Rent [days / year]	55
Rent [GBP / day]	£ 50.00
Total Rent [GBP/year]	£ 2,750.00

Source: Author based on (Renault UK, 2012)

The Twizy is a city car for two passengers. Two types of electric motors are available for this car: 4 kW (5 HP) with a top speed of 45 km/h (28 mph) and a 13 kW (17 HP) with a top speed of 80 km/h (50 mph). Prices range from £6,795 to £7,495 (Renault UK, 2013). The battery of the car is only available by leasing. Thus, Renault has developed a scheme were the two variables to fix the price are the number of years leasing the battery and the number of miles contracted. Renault UK takes care of the maintenance and replacement of the battery if needed. Prices may vary from one plant to another but the average hiring cost per month is £ 50 per battery. The great advantage of the Twizy is that it does not need any special equipment or infrastructure to be charged. It can be plugged in at any 230 V, 50 Hz socket supply. The battery can be fully charged in 3 ½ hours from 0% to 100% and does not suffer from the memory effect (Renault UK, 2012). The constraint in this case is that for maintenance operations that involve the electrical components, the vehicle must be transported to Glasgow, being necessary to hire a tow. In (Annex IV) the economic evaluation of the Twizy car with a range of 40 miles per charge has been analysed. Considering a total investment of £10904.48 and that the car could be rented at a price of £50 per day, if the car is rented 55 days per year, the investment could be recovered in approximately 10 years.

Also other electrical vehicles, as the electric squad currently available in the community, can solve some minor transportation problems in Knoydart. They can be used by the tourist companies to transport people and luggage. As well, it can be a solution for delivering orders and packages that arrive with the ferry (i.e. groceries). In the case of electric golf buggies, some suppliers as EZGO in the United States offer alternatives that can be used in all-terrain conditions. In the United Kingdom Ernest Doe & Sons Limited and Golf Buggies UK (Scotland)[14] have some kinds of electric golf buggies available. Regarding the all-terrain vehicles also known as "Quad", there are many options offered in

[14] http://www.ernestdoe.com; http://www.golfbuggiesuk.co.uk/

the United Kingdom. The suppliers of this technology in the United Kingdom are Verteci, Tramper and Honda[15].

Some other options that could be considered for personal use or as recreational vehicles include electric bikes, motorcycles and even the all-terrain vehicles, mentioned before. These vehicles can be an option for the tourists to travel around Knoydart, without using vehicles that consume fossil fuels and could also be an alternative for the inhabitants instead of using their cars.

5 FUTURE SUPPLY SCENARIOS

The main objective of this chapter is to propose different supply alternatives for different demand scenarios taking into account the existing renewable energy potential and the interest of Knoydart renewables to reduce the operation of the diesel generator. The base year for all scenarios is 2012 and based on sales and generation figures of Knoydart hydro the transmission and distribution losses are 11.67%. We propose different supply options for each demand scenario.

5.1 Sources and data assessment

Following the methodology that has been used for the sources assessment in the current electricity demand, we evaluate the sources used in the supply scenarios.

[15] http://www.verteci.com/industrial_electric_quads_and_atvs.asp; http://www.tramper.co.uk/prices.php; http://www.honda.co.uk/atv/

Table 38 Sources assessment

	Category	Quality	Source
Existing Hydro Power Plants			
Capacity	A	Good with uncertainties on peak capacity	Load Management advice for Knoydart (Shillitoe & Kemsley, 2009)
Availability	D	Uncertainties due to missing data of monitoring system	Group calculations
Capacity credit	D	Good	100%. Group assumptions
Electricity production	A	Reliable	Knoydart Renewables, half hourly data from data taker
Fixed O & M cost	C	Reliable	99.23£ per kW of production capacity (KNOYDART RENEWABLES LTD, January 2012, management account
Variable O& M cost	C	Reliable	34.27£ per MWh of production (KNOYDART RENEWABLES LTD, January 2012, management account)
New Hydro Power Plants			
Capacity	D	Well estimated	Calculations are presented in section 4.2 New hydro options
Availability			
Capacity credit			
Investment cost			
Life Time			
Maintenance cost			
Distribution			
Loses	D	Group calculations based on electricity generation and electricity bills from 2010	Group calculations based on electricity generation and electricity bills from 2010
Peak load shape (Average of 40 hr. interval)	A	Reliable	Own calculation based on (Knoydart Renewables, 2010), half hourly data from data taker.
Resources			
Annual yield	D	Group calculations	Group calculations
Import costs	C	(Shillitoe & Kemsley, 2009) Diesel cost according to Knoydart hydro	(Shillitoe & Kemsley, 2009) Diesel cost according to Knoydart hydro

Source: Authors, 2013.

5.2 Supply alternatives for low growth demand scenario

The low growth scenario assumes a population growth to 150 residents in 2032 and a growth of tourism by 1.7% annually. For the low growth demand scenario, the peak power requirement in

2032 will be 219.93 kW. Four different supply scenarios were modelled in order to meet the demand and the required power. The scenarios modelled are summarized in Table 39

Table 39 Supply alternatives for low growth demand scenario

		Capacity (kW)	Output (MWh)		Diesel Share (%)	
			2013	2032	2013	2032
1	Existing hydro and Diesel (status quo)	340	856.93	1136.77	0.57	0,68
2	Existing hydro, Diesel standby and Glaschoille Loch, Diesel reserve	195	856.93	1136.77	0.57	0.52
3	Existing hydro, Diesel standby and White Gate, Diesel reserve	195	856.92	1136.77	0.57	0.49
4	Existing Hydro, Diesel reserve and Battery 40kW	380	856.92	1136.77	0.57	1.03

Source: Authors, 2013. Modelled in LEAP software

We divide the capacity of diesel generator in diesel standby and diesel reserve. Diesel standby is used during maintenance of existing hydro while diesel reserve is used when the existing hydro cannot meet the demand. It is assumed a **synchronised** Diesel generator that supplies electricity during peaks and whenever the capacity of hydro plants is not sufficient. Upgrading the existing hydro has not been considered for the low demand scenarios, implying that the simulations are run with a hydro capacity of 180 kW.

The Table 39 shows that both options with new hydro power plants save Diesel, while the battery option does not save Diesel compared with an option where a synchronised Diesel is used as a reserve for peak loads. From the two hydro options the white gate is obviously the better one. Only the White Gate has been considered as an additional hydropower option in the further analysis.

The first scenario analysed is the status quo here, the existing hydro, the diesel standby and diesel reserve are used to meet the demand resulting in a capacity of 340 kW. It can be easily noted that the use of diesel increases from 4.92 MWh in 2013 to 7.7 MWh in 2032. Electricity generation from hydro has an annual average growth rate of 1.39%; in 2032 the total electricity generation is 1136.77 MWh from which 99% is generated by hydro.

Table 40 Electricity output of status Quo, low growth demand scenario in MWh

	2013	2015	2020	2025	2030	2032
Existing hydro	852.0011	879.3233	949.6816	1022.9239	1098.5064	1129.0854
Diesel reserve	0	0	0	0.2504	1.5659	2.7647
Diesel standby	4.9196	4.9196	4.9196	4.9196	4.9196	4.9196
Total	856.9208	884.2429	954.6012	1028.0939	1104.9919	1136.7698

Source: Authors, 2013. Modelled in LEAP software

In the third scenario White Gate generates 77.84MWh from a total of 1127.89 MWh. The capacity of the existing hydro together with White Gate is not enough to meet the demand on the last seven years of the simulation period. Due to this diesel reserve is required, however its contribution is lower compared to the status quo.

The option of using a battery bank with a capacity of 40 kW is considered in the fourth scenario. The purpose of this scenario is to manage the peak power demand. Here, unemployed hydro capacity is used to charge the batteries. Diesel is used for standby and as a reserve resulting in a capacity of 380 kW. The result of this scenario shows an increment in the use of diesel up to 1.03% of the total electricity generation and has no advantages compared to the status quo.

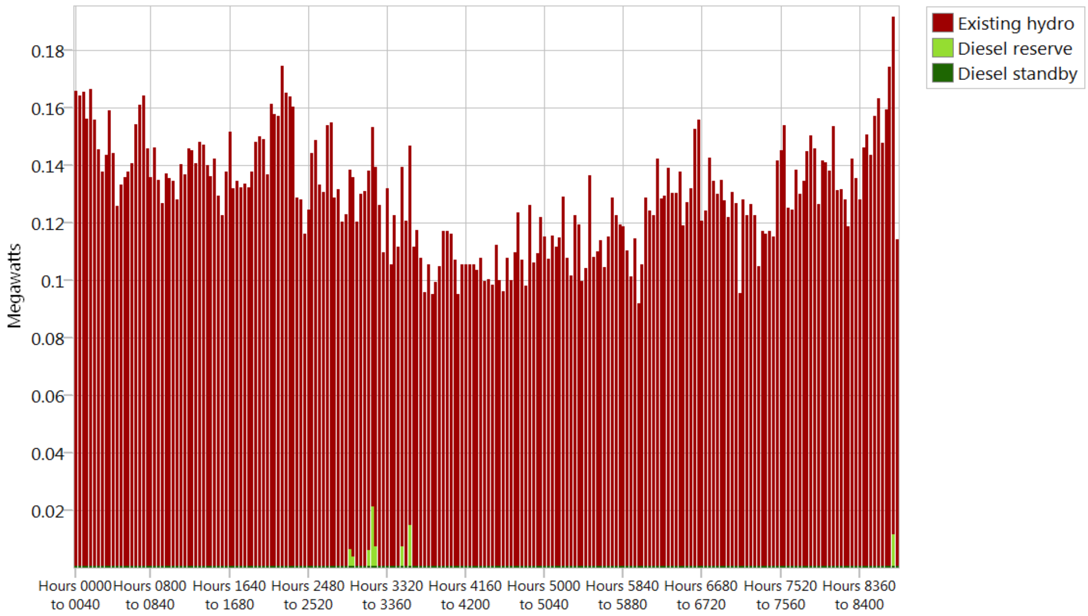


Figure 51 Average power dispatched in 2032, Low growth demand scenario. Status Quo.

Source: Authors, 2013. Modelled in LEAP software

The Figure 51 above shows the average power dispatched to meet the power requirements in 2032, here diesel reserve generation is mainly required in April and December. The maximum average power dispatched including the distribution losses is 213.96 kW. The electricity generation during status quo was 856.96 MWh and 1136.77 MWh respectively. The average power dispatched from White Gate and Battery are attached in Annex XXV. From the three options analysed above the status quo is the best one; the simulation shows that there is no unmet requirements and the diesel contribution is negligible.

5.3 Supply alternatives for medium growth demand scenario

This section presents the different supply alternatives for the medium growth scenario. This scenario assumes a population growth up to 185 residents in 2032 and a growth of tourism by 2.7% annually. For the medium growth demand scenario, the peak power requirement in 2032 will be 254.76 kW. Here four supply options were modelled and are summarized in Table 41.

Table 41 Supply alternatives for medium growth demand scenario

		Capacity (kW)	Output (MWh)		Diesel Share (%)	
			2013	2032	2013	2032
1	Existing 180kW and Diesel (*Status Quo*)	340	865.96	1353.73	0.57	2.60
2	Existing 250kW (*Hydro Refurbishment*) and diesel standby	250	865.96	1353.73	0.57	0.36
3	Existing Hydro 180kW and Mhuilinn and Diesel standby	265	865.76	1352.41	0.57	0.37
4	Existing Hydro 180kW and Scottas Burn and Diesel standby	245	865.96	1352.41	0.57	0.36

Source: Authors, 2013. Modelled in LEAP software

The Table 41 shows that options with new hydro power plants and hydro refurbishment save Diesel compared to the status quo. From the three hydro options, the hydro refurbishment is the best one followed by Mhuilinn and Scottas Burn.

In the status quo, there are no unmet requirements although there is a large contribution of diesel from 2019 till 2032. The diesel generation in 2032 is 30.303 MWh (see Table 42).

Table 42: Electricity output of status quo, medium growth demand scenario in MWh

	2013	2015	2020	2025	2030	2032
Existing hydro	861.0364	906.8988	1026.3183	1150.4804	1273.2289	1318.5102
Diesel reserve	0	0	0.2866	3.8524	17.9849	30.3028
Diesel standby	4.9196	4.9196	4.9196	4.9196	4.9196	4.9196
Total	865.956	911.8184	1031.5245	1159.2524	1296.1334	1353.7326

Source: Authors, 2013. Modelled in LEAP software

In the Hydro Refurbishment scenario, existing hydro with 250 kW capacity and diesel standby are considered. The standby diesel generator contributes 4.92MWh annually for standby generation. All other demand can be covered from the refurbished hydropower plant.

The second scenario is Mhuilinn, in which existing hydro of 180kW and Mhuilinn Hydro with capacity of 85kW were modelled. The Mhuilinn Hydro starts operation in 2020 with annual generation of 327.23MWh.

The third scenario considered for medium demand growth is the Scottas burn. This includes the existing hydro with a capacity of 180 kW and the Scottas burn hydro with a capacity of 65kW. The share of electricity generation from Scottas burn hydro in 2032 accounts for 17.6%.

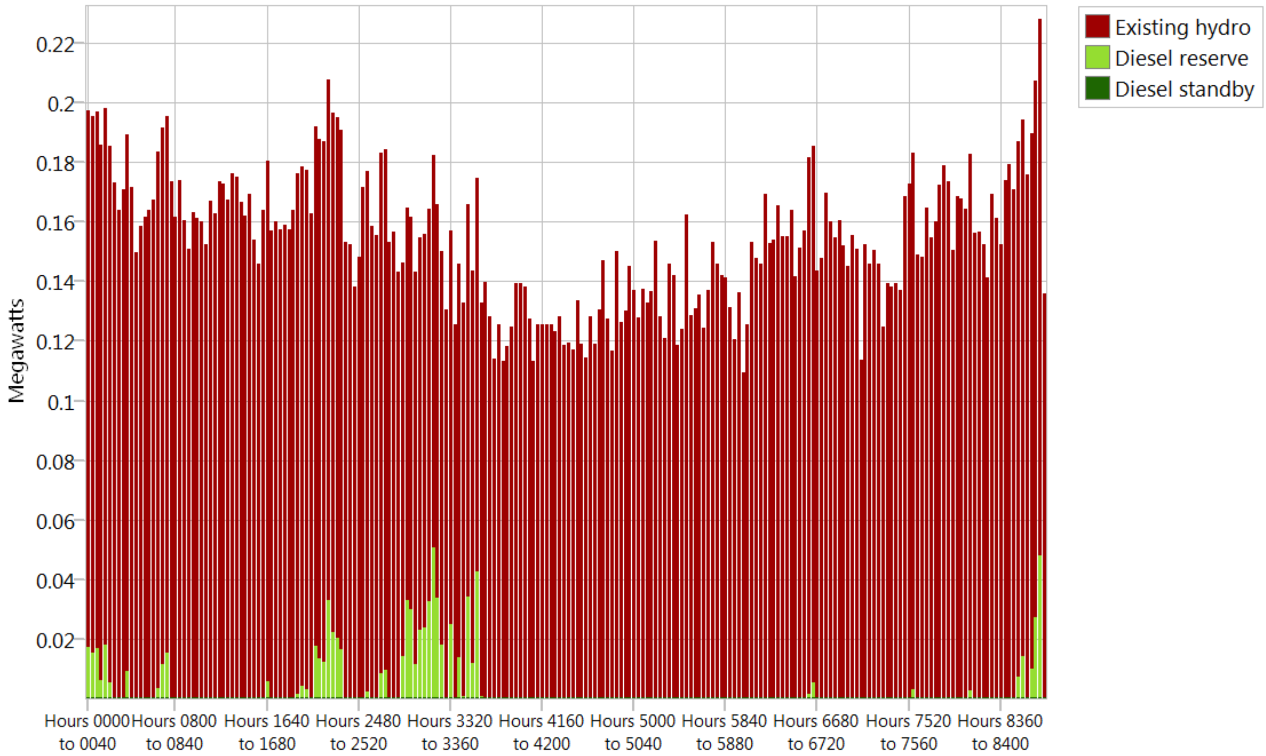


Figure 52 Average power dispatched in 2032, Medium growth demand scenario. Status Quo.

Source: Authors, 2013. Modelled in LEAP software

As shown in Figure 52, the maximum average power dispatched is 253.56kW on 2032. In the status quo scenario here diesel has major contribution in January, April and December. The average power dispatched from hydro refurbishment and Mhuilinn are attached in Annex XXV.

The comparison of the different options shows a clear advantage for the refurbishment/upgrading of the existing hydropower plant. Only if this is not possible a new hydropower scheme with Mhuilinn as first priority and Scottas burn as second priority should be considered.

5.4 Supply alternatives for high growth demand scenario

The high growth demand scenario assumes a population growth up to 220 residents in 2032 and a growth of tourism by 3.7% annually. For the high growth demand scenario, the peak power requirement in 2032 will be 297.19 kW. In this scenario four different supply alternatives are presented (see Table 43).

Table 43 Supply alternatives for high growth demand scenario

		Capacity (kW)	Output (MWh)		Diesel Share (%)	
			2013	2032	2013	2032
1	Existing Hydro 180 kW and Diesel (Status Quo)	340	874,660	1579,23	0,58	8,602
2	Hydro upgraded with 250kW, Mhuilinn 85kW and Diesel standby	495	874,460	1571,59	0,58	0,463
3	Hydro upgraded with 250kW, Scottas Burn 65kW and Diesel standby	475	874,661	1579,23	0,58	0,462
4	Hydro upgraded with 250kW and Large battery 180 kW	430	874,644	1576,97	0,58	0

Source: Authors, 2013. Modelled in LEAP software

It was assumed that new hydro power plants start operation in 2020, while the battery bank starts in 2016. In the Status Quo scenario, the existing hydropower plant has a capacity of 180 kW while in the other three scenarios it has a capacity of 250 kW (this is assumed to be the maximum power that the existing hydro can reach).

In the status quo scenario the diesel reserve starts generation from 2017 onwards due to the inability of the existing hydro to meet the increasing demand. Therefore, the share of diesel increases from 4.89 MWh in 2013 to 134.87 MWh in 2032, resulting in 8.6% of total electricity generation.

Table 44 Electricity output of status quo, medium growth demand scenario in MWh

	2013	2015	2020	2025	2030	2032
Existing hydro	869.74	933.63	1100.79	1269.13	1408.07	1444.37
Diesel reserve	0.00	0.00	1.65	17.10	79.82	129.95
Diesel standby	4.92	4.92	4.92	4.92	4.92	4.92
Total	874.66	938.55	1107.36	1291.15	1492.81	1579.23

Source: Authors, 2013. Modelled in LEAP software

The second scenario includes the upgraded hydro with a capacity of 250 kW and the new hydro Mhuilinn with 85 kW. Electricity generation from upgraded hydro generates 76.4% of the total electricity generation in 2032 while Mhuilinn generates 23.1%. The diesel standby generates the remaining 0.5%.

Considering the 65kW Scottas Burn in the third scenario, the total capacity including the upgraded hydro is 315kW. Electricity generation from the large hydro 81.02% of the total electricity in 2032 while Scottas Burn generates 18.52%. Diesel standby generates only 0.5%.

Finally, the fourth scenario with battery storage is presented. The purpose of this is to benefit from excess of energy produced by the existing hydro. Here, a battery bank of 180kW is modelled to manage outages for a maximum of 2 hours. The battery delivers 14.12 MWh in 2032. The last year of the simulation shows that 99.1% of the generation results from the hydro while only 1% is from the battery. This model shows that the battery was charged by the hydro only and is only used during outage times.

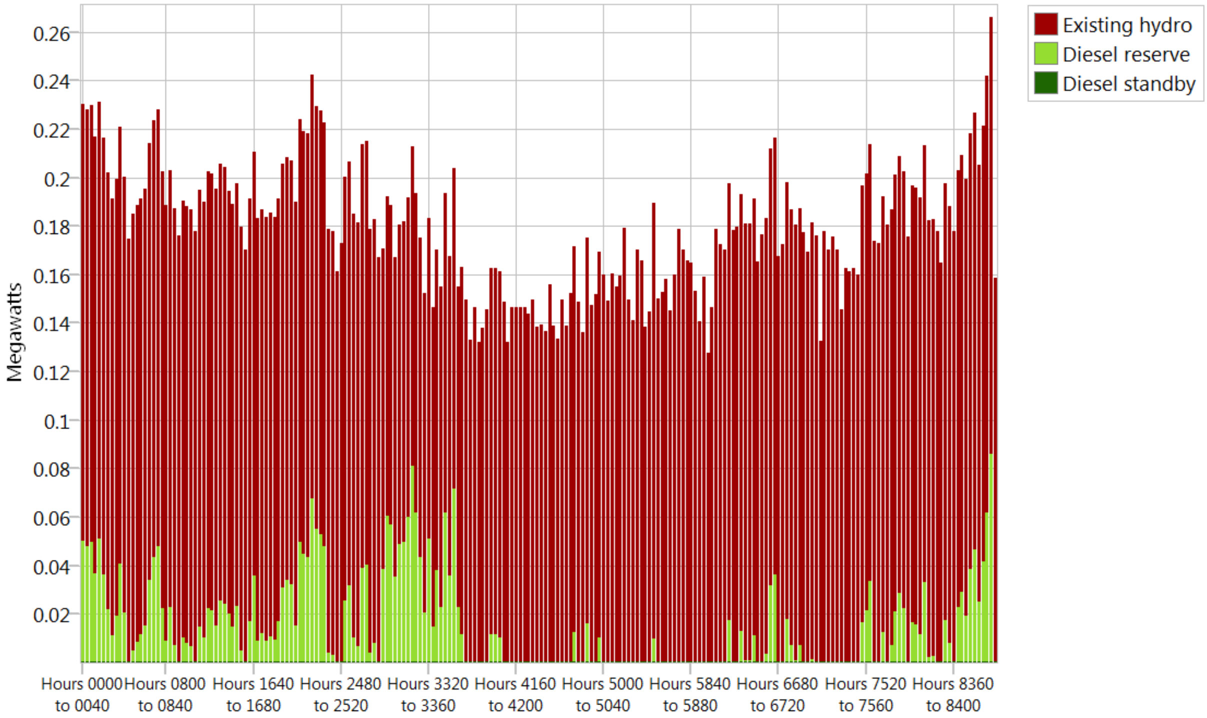


Figure 53: Average power dispatched in 2032, high growth demand scenario. Status Quo

Source: Own calculations with LEAP Software

The Figure 53 above shows the average power dispatched to meet the power requirements in 2032 in the status quo scenario. The maximum average power dispatched including the distribution losses is 297.19 kW peak power. Diesel generation is requires through the whole year. Peak power requirements of the other three scenarios are given in Annex XXV.

The comparison of the different options shows a clear advantage for the new hydropower schemes compared to the battery option. There is not a big difference between the two new hydropower options.

5.5 Scenario Comparison

The generation cost of electricity per megawatt-hour is used as an indicator to choose the best option from the economical point of view. First the status quo for the three demand scenarios is presented. The cost of generation per MWh in 2032 will be 125.06, 115.42 and 110.45 UK Pound for low, medium and high growth demand scenarios. Annual average growth of reference scenario is -1.26%.

The cost of generation per MWh for Existing hydro 250kW, Low Demand Scenario and Mhuilinn will be 128.9, 125.06 and 116.84 UK Pound in 2032. Annual average growth of reference scenario and Mhuilinn is -0.87% and -1.12% respectively.

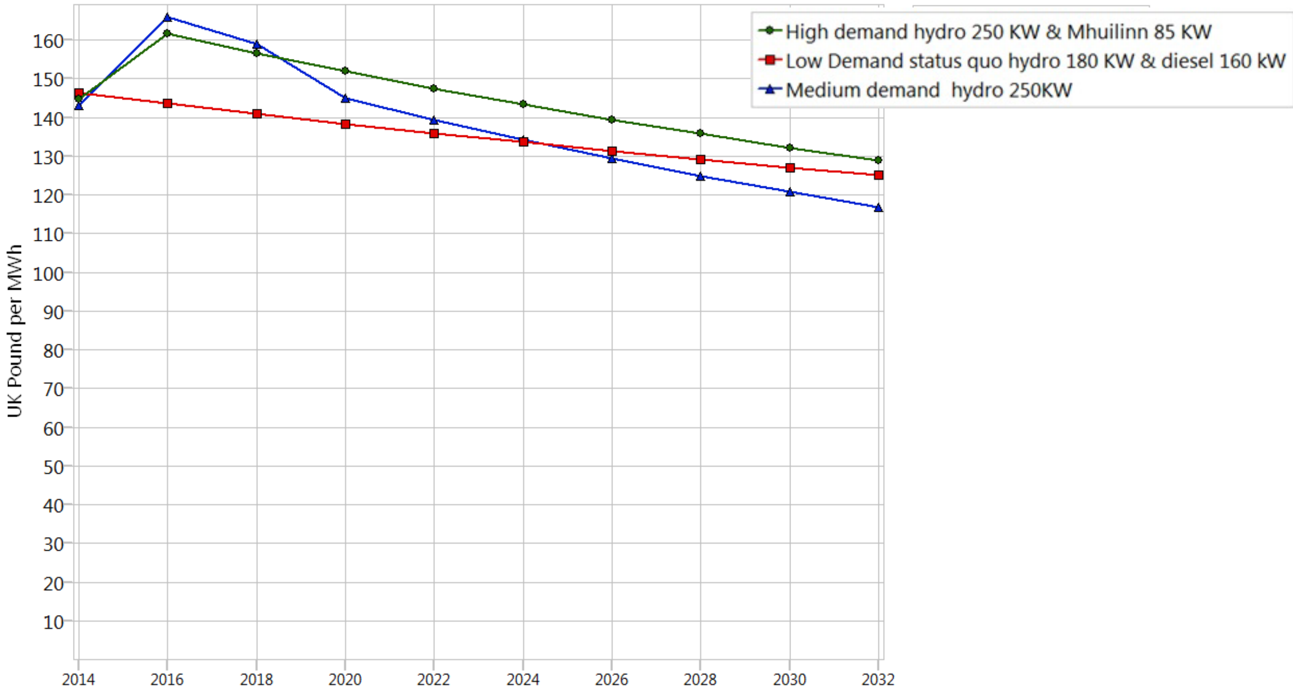


Figure 54: Cost of generation per MWh in low demand scenario with 180 kW hydro and 160 kW Diesel, medium demand scenario with 250 kW hydro and 160 kW Diesel, high demand scenario with 250 kW hydro, new hydro site 85 kW and Diesel 160 kW

Source: Own calculations with LEAP Software

Here all the scenarios are compared to appreciate which scenario is the most attractive in terms of electricity output. Figure 54 depicts that the electricity output trends are similar for all scenarios except Mhuilinn. It is important to note that the electricity demand compared to the different supply scenario options studied is too low. Based on this background, it is recommended that possible energy storage options are taken in to consideration to cater for the excess electricity. Alternatively additional load to use electricity during off peak period can be suggested.

6 CONCLUSIONS & RECOMMENDATIONS

In the modeling of the electricity system of Knoydart, the possible supply options are matched with the different demand scenarios.

In the medium growth demand (reference) scenario, when the electricity demand of Knoydart increases to 1,200 MWh in 2032, it is sufficient to refurbish the existing hydro power plant to be able to produce 250 kW. Refurbishing the hydro scheme entails eliminating the head losses along the penstock, which were identified to be the main cause of the lowered power output from the hydro power plant.

It is recommended to continuously monitor the following indicators:
(1) overall efficiency,
(2) rainflow and spillway flow and
(3) risk of vortexes.

It is also recommended to update the monitoring system to a new DT80M dataTaker and its related software to make the monitoring more user friendly and efficient. A data management team made up of three personnel should be formed.

Biomass energy systems such as wood boilers, gasifiers, and Combined Heat and Power (CHP) systems were considered but they are presently not available at a scale that is suitable for Knoydart. They would also require a centralized heat demand of considerable size that Knoydart does not have. The biomass resources of Knoydart is most fit for space and water heating.

Allt A' Mhogha (White Gate) is the only site that is entirely owned by the foundation. The impression of community members that it has more steady flow than other sides is not reflected in the available low-flow data. Therefore, although the site has only a small capacity according to our assessment, flow measurements should be carried out to confirm or reject the impression of a more steady flow.

Among the four assessed new hydro Allt A' Mhuilinn and Scottas burn are the most attractive ones with capacities of 85 kW and 65 kW respectively. However, the site conditions at Scottas burn are more difficult and lead to higher investment cost and therefore higher generation cost.

In the low growth scenario the share of Diesel generation is very low, even if the existing hydropower plant only generates electricity at a capacity of 180 kW.

In the medium growth scenario the best alternative is to upgrade the existing hydro plant to 250 kW. In this case no Diesel generation is required as reserve capacity for peak demand.

In the high growth demand scenario, when the electricity demand of Knoydart increases to 1,400 MWh in 2032, two new sites for a micro hydro power plant namely, Allt A' Mhuilinn 85kW and Scottas Burn 65kW, can add to the existing hydro plant of Knoydart. Economic indicators for Mhuilinn are better than for Scottas Burn. Hydro storage for Glaschoille Loch is not seen to be a feasible project because the investment cost would be too high and the capacity factor of the plant will be low as it will only be operated a few hours in a year during outages and maintenance of the existing hydro plant.

Implementation of load management programmes is recommended to reduce the load during peak times. Load management from the demand side can also manage excess electricity during off peak demand hours. It is recommended to follow up on implementation of load management measures from the demand side as stated in the Senergy Econnect report (Senergy Econnect Limited 2009).

Use of electricity storage technologies is an expensive option, considering the consumption of diesel fuel is still moderate. In the future, electricity storage technologies can be considered again once their prices go down. The use of electric vehicles is another option to make use of excess electricity during off peak demand hours. A pilot programme of renting electric vehicles to tourists can be carried out. Certain conditions such as proper maintenance and charging facilities must be present for this program to be feasible as well as improvement of road conditions.

7 BIBLIOGRAPHY

Stadtwerke Flensburg GmbH. (2012). Vorstellung Heizkraftwerk der Stadtwerke Flensburg GmbH. Flensburg: Stadtwerke Flensburg GmbH.

A. Dutta, M. T. (2011). *Process Design and Economics for Conversion of Lignocellulosic Biomass to Ethanol.* National Renewable Energy Laboratory.

Baris, K., & Dessie, F. (2012). *Biomass to Electricity generation & Technologies.*

Barrell, G. (2012). *Data Stratergy for Knoydart Renewables-Update December 2012.* Knoydart: Knoydart Foundation Ltd.

Battery Council International. (2013). *Lead Acid Batteries*. Retrieved 03 10, 2013, from http://batterycouncil.org/?page=Lead_Acid_Batteries#kinds

Bellona Foundation. (2002). *Hydrogen*. Retrieved 11 20, 2012, from http://www.interstatetraveler.us/Reference-Bibliography/Bellona-HydrogenReport.html

Biomass Energy, C. (2012, 09 12). *Types of system*. Retrieved 01 2013, from http://www.biomassenergycentre.org.uk: http://www.biomassenergycentre.org.uk/portal

BROWNSORT, P. A. (2009). *BIOMASS PYROLYSIS PROCESSES:PERFORMANCE PARAMETERS AND THEIR INFLUENCE ON BIOCHAR SYSTEM BENEFITS.* Edinburgh: University of Edinburgh.

Caledonia Energy Ltd. (1999). *Inverie Hydroelectric Scheme: Review Report for Highlands and Islands Enterprise.* Perth: Caledonia Energy Ltd.

Caledonian Energy Ltd. (1999). *Inverie hydroelectric scheme. Review report for Highlands and Islands enterprise.* Perth: Caledonian Energy Limited.

Corvus Energy. (2013, March 05). Request for Information.

Dixon, S. L. (1998). *Fluid Mechanics and Thermodynamics of Turbomachinery.* USA: Elsevier Science.

Doughty, D. H., Butler, P. C., Akhil, A. A., Clark, N. H., & Boyes, J. D. (2010). Batteries for Large-Scale Stationary Electrical Energy Storage. The Electrochemical Society.

EEM. (2012). *Assessment of Renewable Energy Technologies For the Sustainable Development of the Isle of Jura.*

Electricity Storage Association. (2011). *Storage Technologies: Batteries*. Retrieved January 2013, from Electricity Storage Association Web site: http://www.electricitystorage.org

Foundation, K. (2013, 03 7). *About Knoydart*. Retrieved 03 7, 2013, from http://www.knoydart-foundation.com/home/about-knoydart/

Gareth Mayhead, R. S. (2011). *Woody Biomass Fact Sheet: Pyrolysis of Woody Biomass.* University of Carlifonia.

Gimein, M. (2001). *Smart is not enough.* New York: Wiley.

Golden Energy Century Ltd. - GEC. (2013, March 5). Inquiry regarding Flow Batteries.

Gowans, I. A. (2000). *Report of an Inspection Under Section 10 of the ACT 0f Loch Bhraomisaig Reservoir.* Inspection Report under Reservoirs ACT 1975, Edinburgh.

Greater Sudbury Hydro Inc. (2008). *Electric Thermal Storage Heating*. Retrieved Dec 15, 2012, from http://www.sudburyhydro.com/programs_electric_thermal_storage_heating.htm

Harvey A., e. a. (1993). *Micro-Hydro Design Manual.* London: IT Publicatoins Ltd.

Heaps, C. (2012). Long-range Energy Alternatives Planning (LEAP) system. [Software version 2012.0037] . Somerville, MA, USA.: Stockholm Environment Institute. www.energycommunity.org.

Highlands and Islands of Scotland. (2010). *How energy is used in Scotland.* Retrieved 1 18, 2013, from HiEnergy, Highlands and Islands of Scotland: http://www.hi-energy.org.uk/Renewables/Why-Renewable-%20Energy/How-energy-is-used-in-Scotland.htm

Horizons Fuel Cell Technologies. (2013, March 05). Request for Information.

Hydrosolutions, W. (2012). Flow Estimates for Wulf Boie - University of Flensburg. *Low Flow Report*. Willingford Hydrosolution Limited.

IEA. (2011). *The Role of Energy Storage for Mini-Grid Stabilization.* Paris.

Initiative, C. W. (2006). *A guide to small-scale wood fuel (biomass) heating systems.* U.K: Coordinated Wood Fuel Initiative.

IRENA, I. R. (2012). *RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES.* IRENA.

John Deere. (2002, April 19). Engine Performance Curve. *Power Tech 6.8 L Engine Model 6068HF475*. John Deere.

John Duncanson Engineering Ltd. (n.d.). *Knoydart Hydro:Pipeline performance.* Ross-shire: John Duncanson Engineering Ltd.

Knoydart Foundation. (2011). *Knoydart visitor survey. Collation of results: Long version.* Knoydart.

Knoydart Foundation. (2012). *Knoydart Hydro Electric Power.* Retrieved November 20, 2012, from youtube: https://www.youtube.com/watch?v=yUxQu1h1DEE

Knoydart Renewables Limited. (2012). *Knoydart Renewables-the Next 10 years and beyond.* Briefing Report, Knoydart Foundation, Knoydart.

Kohler Power. (2013). *Kohler Power*. Retrieved 03 10, 2013, from http://www.kohlerpower.com/onlinecatalog/pdf/g6120.pdf

Ledingham, J. (2010). *Loch Bhraomisaig Hydrological Monitoring: Initial Data investigation and Recommendations.* Inverie.

Monroe, M. C. (2007). *Wood to energy outreach program: Biomass. .* Florida: University of Florida.

MyWeather. (2012). *Knoydart Climate Profile*. Retrieved 2012, from http://www.myweather2.com/City-Town/United-Kingdom/Highland/Knoydart/climate-profile

Pacific Northwest National Laboratory. (2007, 10). *Grid Friendly™ Appliance Project*. Retrieved 03 11, 2013, from http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17079.pdf

Penche, C. (1998). *Layman's handbook on how to develop a small hydro site.* Bruselas: European commision.

Progressive Dynamics. (2013). *Progressive Dynamics Battery Basics*. Retrieved 03 10, 2013, from http://www.progressivedyn.com/battery_basics.html

Pure Energy Centre Ltd. (2008). *Energy Analysis Overview.* Shetland: Pure Energy Centre Ltd.

Renault UK. (2012). *Z.E. CHARGING*. Retrieved December 15, 2012, from http://www.renault.co.uk/cars/model/twizy/zecharging.aspx

Renault UK. (2013). *Twizy - Price and Specifications*. Retrieved March 16, 2013, from http://www.renault.co.uk/cars/model/twizy/pricesandspecs.aspx

Renewable Heat Group, R. (2008). *Scotland's Renewable Heat Strategy:Recommendations to Scottish Ministers.* The Scottish Government.

Renovation Experts. (2012). *Off-Peak Heat and Water*. Retrieved Dec 15, 2012, from http://www.renovationexperts.com/off-peak-heat.asp

Rolls Distribution. (2013, March 05). Batteries for stand alone community.

Schröder, R., & Zanke, U. (2003). *Technische Hydraulik: Kompendium für den Wasserbau.* Springer.

Senergy Econnect Limited. (2009). *Load Management Advice for Knoydart.* Study, Northumberland.

Senergy Econnect Ltd. (2009). *Load management advice for Knoydart:A study of load management options.* Edinburgh: Senergy Econnect Ltd.

Shillitoe, F., & Kemsley, R. (2009). *Load management advice for Knoydart. A study of load management options.* Senergy. Alternative energy econnect. Edinburgh: Senergy.

Steffes Corporation. (2007-20012). *Choosing The Right System*. Retrieved December 15, 2012, from http://www.steffes.com/off-peak-heating/sizing.html

Storageheaters.com. (2013). *Economy 7 Electricity for Storage Heaters*. Retrieved 03 16, 2013, from http://www.storageheaters.com/economy-7-heaters.htm

The Engineering Toolbox. (2013). *Energy Storage in Water-kWh*. Retrieved 03 10, 2013, from http://www.engineeringtoolbox.com/energy-storage-water-d_1463.html

The Scottish Government. (2006, January). *Scottish Energy Study: Volume 1: Energy in Scotland: Supply and Demand. Scottish Energy Study: Volume 1.* Retrieved 03 19, 2013, from http://www.scotland.gov.uk/Publications/2006/01

The Scottish Government. (2009, 10 8). *Conserve and Save: Consultation on the Energy Efficiency Action Plan for Scotland.* Retrieved 3 18, 2013, from http://www.scotland.gov.uk/Publications/2009/10/16124856/3

The Sustainable Energy Authority of Ireland. (n.d). *Wood Energy Technologies and*. Retrieved 3 12, 2013, from SEAI website: http://www.seai.ie/Renewables/Bioenergy/Bioenergy_Technologies/Wood_Energy_Technologies_and_Technology_Standards.

Trianco. (2012, 03). *Trianco Vesatile Electric Heating Solutions*. Retrieved 03 10, 2013, from http://www.trianco.co.uk/uploads/20120411-Aztec%20Brochure%20Art.pdf

US DOE . (2012). *Hydrogen Production*. Retrieved 11 18, 2012, from http://www1.eere.energy.gov/hydrogenandfuelcells/production

Verojporn, Setta. (2011). *Technical and Economic Feasibility of Using Waste Wood as Biomass Fuel for Small Scale Boiler and CHP in Solway Precast, Scotland.* University of Strathclyde.

VisitScotland- Insight Department. (2011). *Tourism in Northern Scotland. Highlands & Islands, Abereden & Grampian, Orkney & Shetland Factsheet.*

Williams, A. (2013, 02 22). Knoydart foundation. Knoydart proprties. (J. Fernardo, Interviewer)

Wind&Sun . (2008, May 24). *Northern Arizona Wind & Sun*. Retrieved 03 10, 2013, from http://www.wind-sun.com/ForumVB/archive/index.php/t-2920.html

Yang, Z., Zhang, J., Kintner-Meyer, M., Lu, X., Choi, D., Lemmon, J. P., et al. (2010). *Electrochemical Energy Storage for Green Grid.* Washington: ACS Publications.

8 ANNEX

Annex I : Data Sheet of Lead Acid Batteries from Rolls Energy

(See Adobe Acrobat Document Attached)

Annex II: Economic Analysis of the peak demand management with Lead Acid as battery storage

(See Excel Document Attached)

Annex III: Economic Analysis of the management of the peak demand and outages with Lead Acid as battery storage

(See Excel Document Attached)

Annex IV: Economic Analysis for the pilot project of the Twizy Electric Car

(See Excel Document Attached)

Annex V: Pilot Project for battery System for the Bunkhouse

(See Excel Document Attached)

Annex VI: Questionnaire Results

(See Excel Document Attached)

Annex VII Verification of Power Data

The following table shows the results for a selected date 090909 in half hourly intervals.

	COMPARISON	
DATE	DATATAKER	ABB meter
	A/kWH Meter	Energy Demand kWh
09/09/2009	47	46
09/09/2009	45	39
09/09/2009	39	38
09/09/2009	39	37
09/09/2009	37	37
09/09/2009	36	36
09/09/2009	36	33
09/09/2009	33	31
09/09/2009	31	30
09/09/2009	30	26
09/09/2009	27	26
09/09/2009	26	27
09/09/2009	26	27
09/09/2009	28	29
09/09/2009	28	31
09/09/2009	31	33
09/09/2009	34	40
09/09/2009	40	43
09/09/2009	43	50
09/09/2009	50	46
09/09/2009	46	48
09/09/2009	49	38

	COMPARISON	
DATE	**DATATAKER**	**ABB meter**
	A/kWH Meter	**Energy Demand kWh**
09/09/2009	37	36
09/09/2009	37	41
09/09/2009	40	40
09/09/2009	40	36
09/09/2009	36	37
09/09/2009	37	37
09/09/2009	37	38
09/09/2009	38	36
09/09/2009	36	39
09/09/2009	39	40
09/09/2009	40	36
09/09/2009	36	34
09/09/2009	35	39
09/09/2009	38	39
09/09/2009	39	48
09/09/2009	49	49
09/09/2009	49	50
09/09/2009	49	42
09/09/2009	43	45
09/09/2009	45	46
09/09/2009	46	46
09/09/2009	46	44
09/09/2009	44	41
09/09/2009	40	39
09/09/2009	39	39
09/09/2009	39	44
	1855	**1852**

Source: Author, 2013

Annex VIII Efficiency Calculations with Decimals in Power and Flow

Date	flow meter (m^3 in 15 Min)	Real Efficiency	Eff lower limit (flow +0,49) (1)	Eff upper limit (flow-0,5) (2)	Eff lower limit (flow +0,49 and power -0,5) (1)	Eff upper limit (flow-0,5 and power + 0,49) (2)	flow plus 0,49 (1)	flow minus 0,5 (2)	l/sec	l/sec(1)	l/sec(2)	m3/sec	m3/sec (1)	m3/sec (2)	kWH Meter	kW	kW1	kW2
05/08/2007 05:45	**142**	0,638	0,636	0,640	0,635	0,641	142,400	141,500	157,778	158,222	157,222	0,158	0,158	0,157	6,000	**312**	**311,5**	**312,49**
05/08/2007 06:45	**142**	0,646	0,644	0,648	0,643	0,649	142,400	141,500	157,778	158,222	157,222	0,158	0,158	0,157	7,000	**316**	**315,5**	**316,49**
06/08/2007 06:45	**98**	0,687	0,685	0,691	0,683	0,692	98,400	97,500	108,889	109,333	108,333	0,109	0,109	0,108	7,000	**232**	**231,5**	**232,49**
02/08/2007 02:00	**101**	0,667	0,664	0,670	0,663	0,672	101,400	100,500	112,222	112,667	111,667	0,112	0,113	0,112	8,000	**232**	**231,5**	**232,49**

Source: Author, 2013

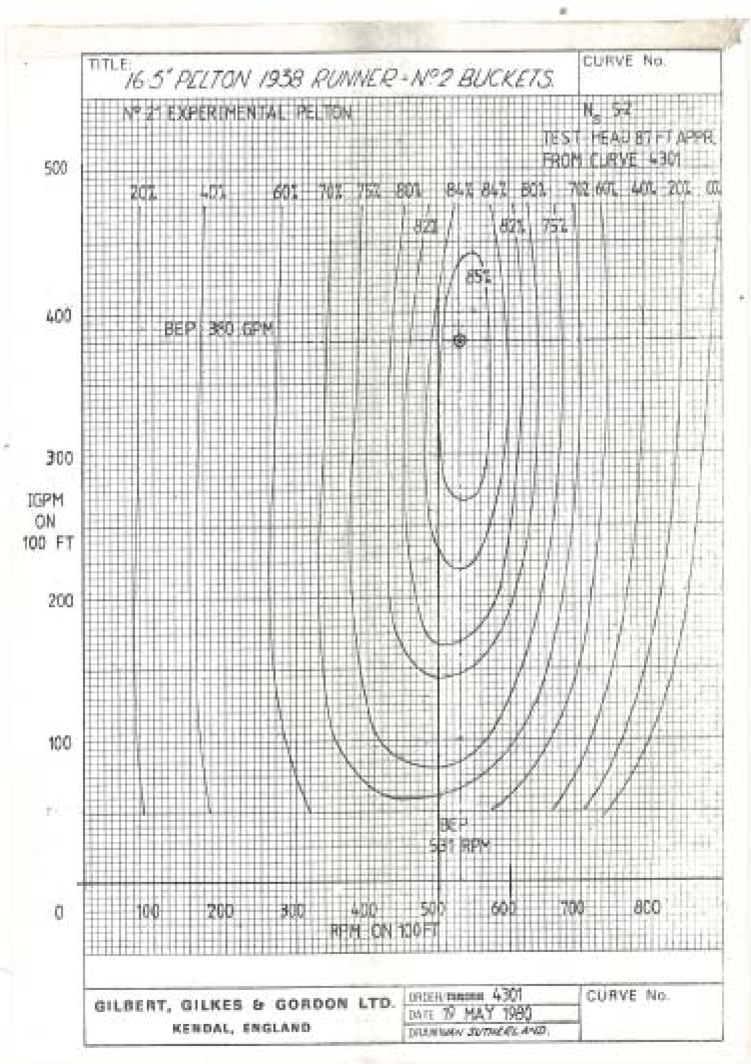
The real efficiency is within difference between:

0,663-0,692= 0,029

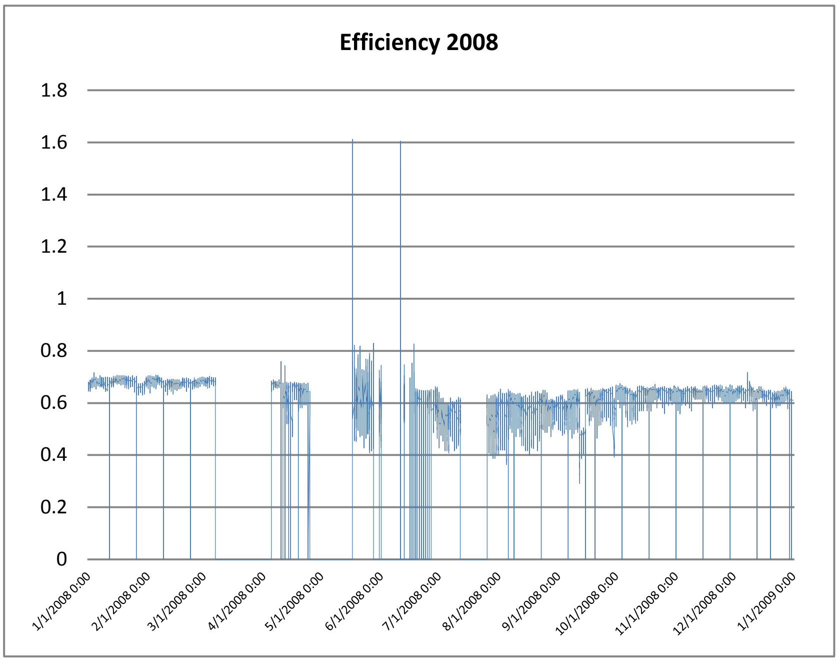
0,649-0,635=0,014

0,635-0,641 = 0,006

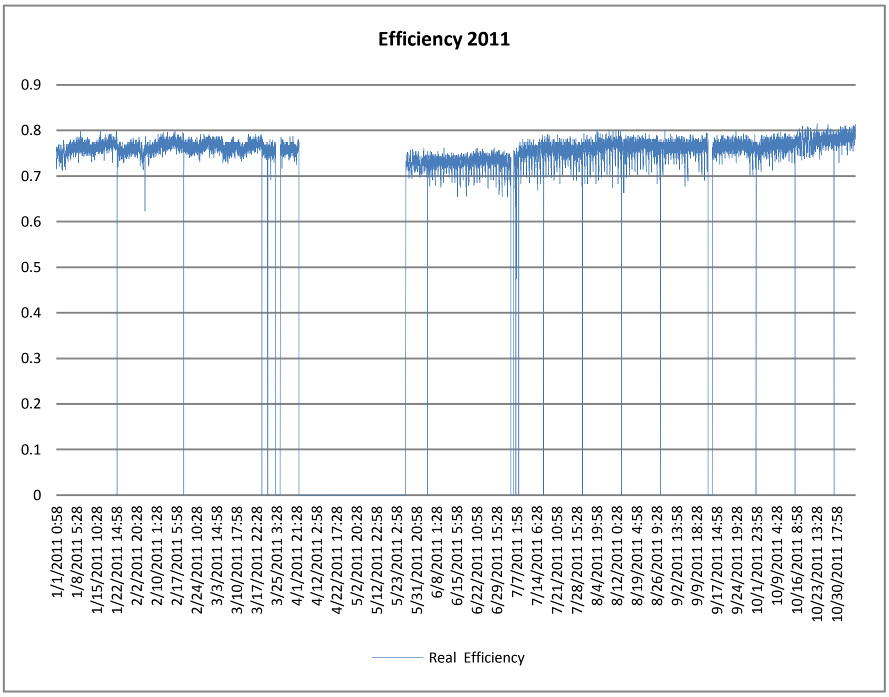
Annex IX Efficiency curve of Pelton turbine of Gilbert Gilkes & Gordon LTD.



Annex X: Overall Efficiency of 2008 and 2011



Source: Author, 2013

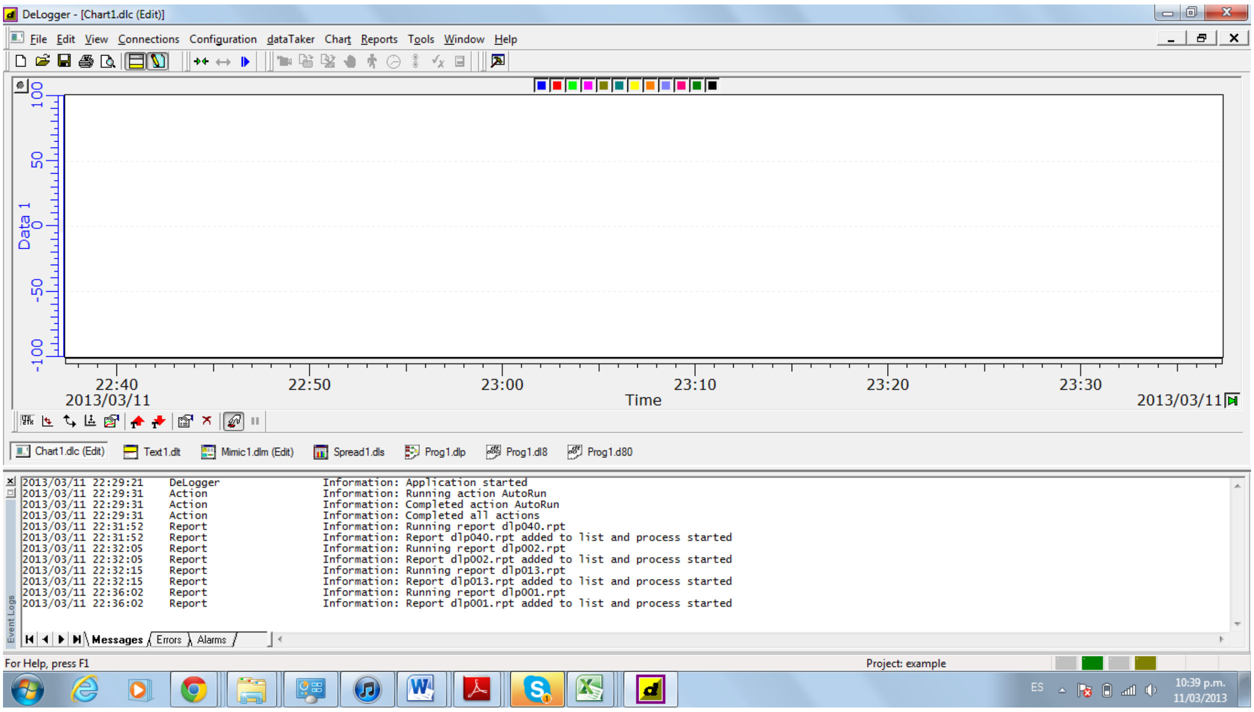


Source: Author, 2013

Annex XI Risk of Vortexes

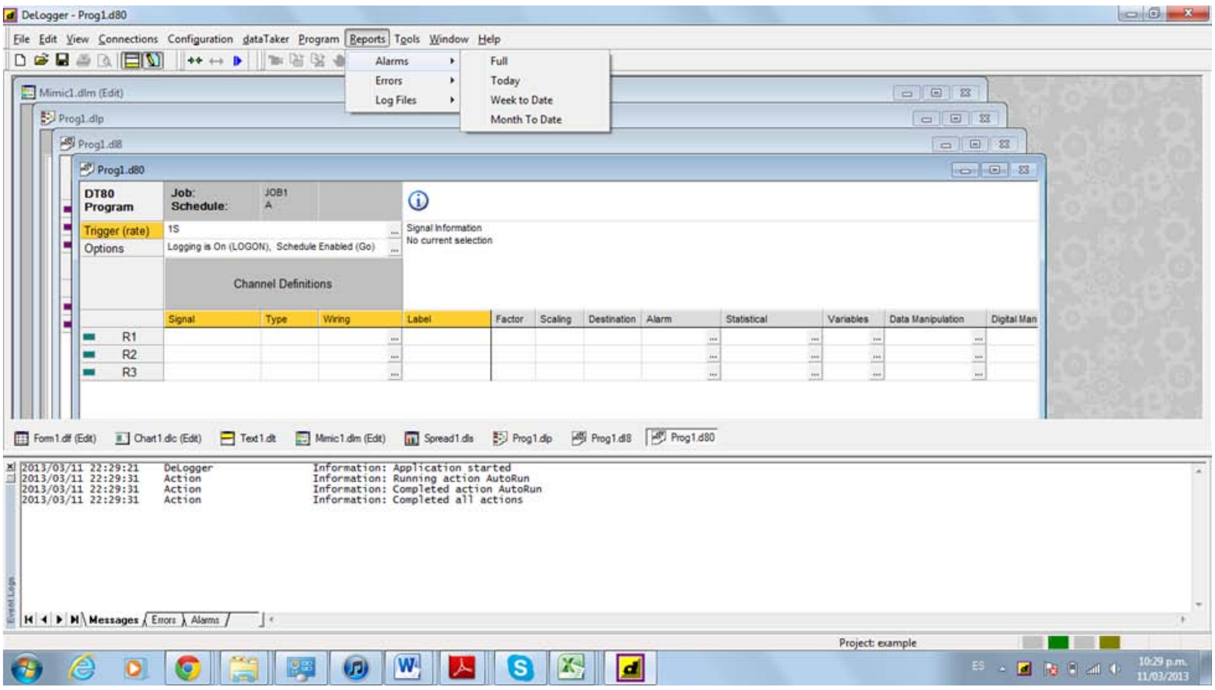
(excel file)

Annex XII DataTaker options



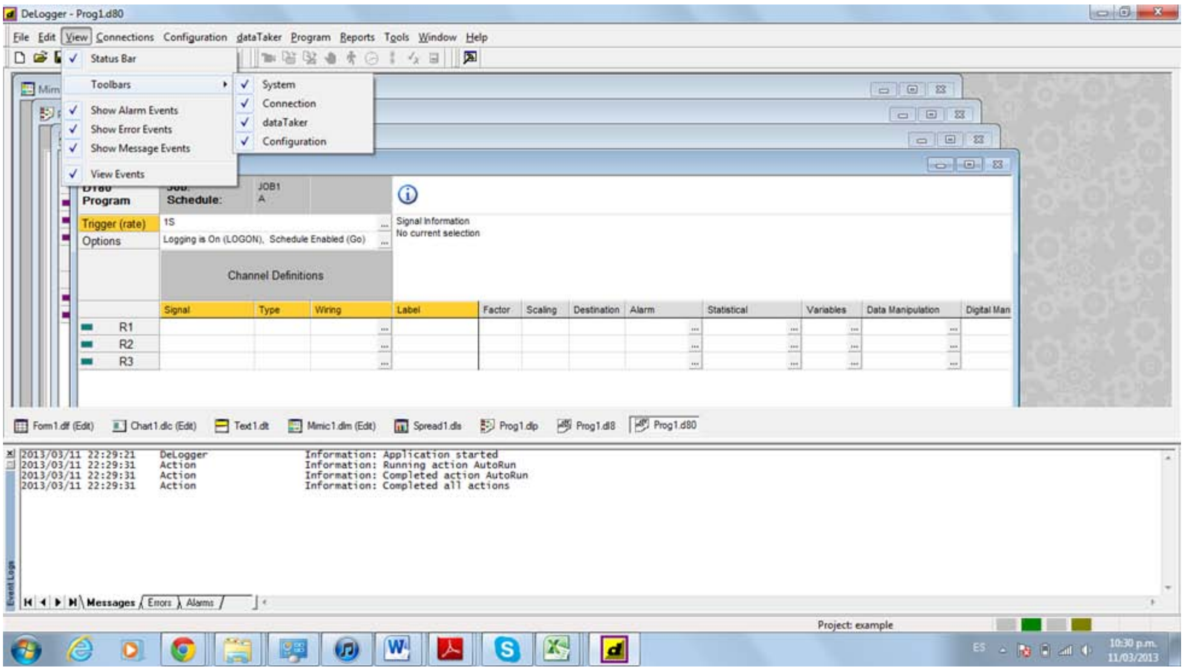
DataTaker Software – Chart Option

Source: DataTaker software



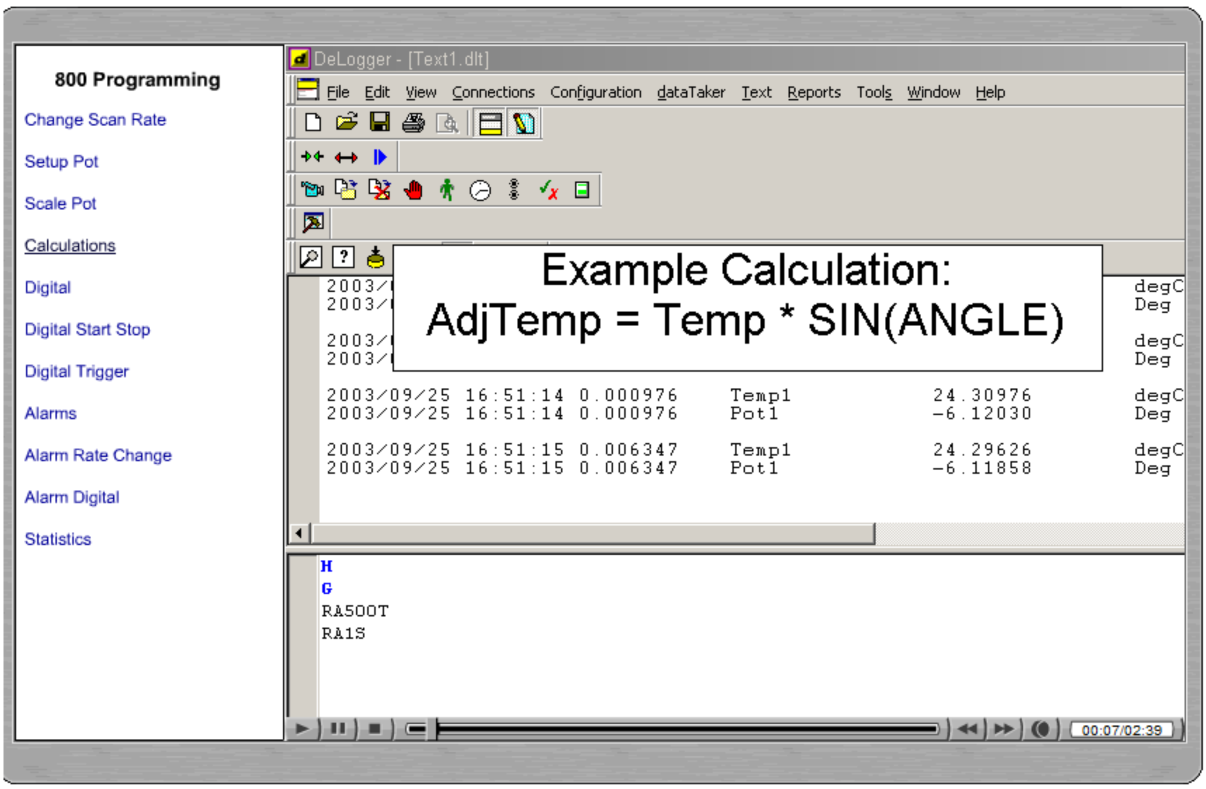
DataTaker Software – Alarm Option

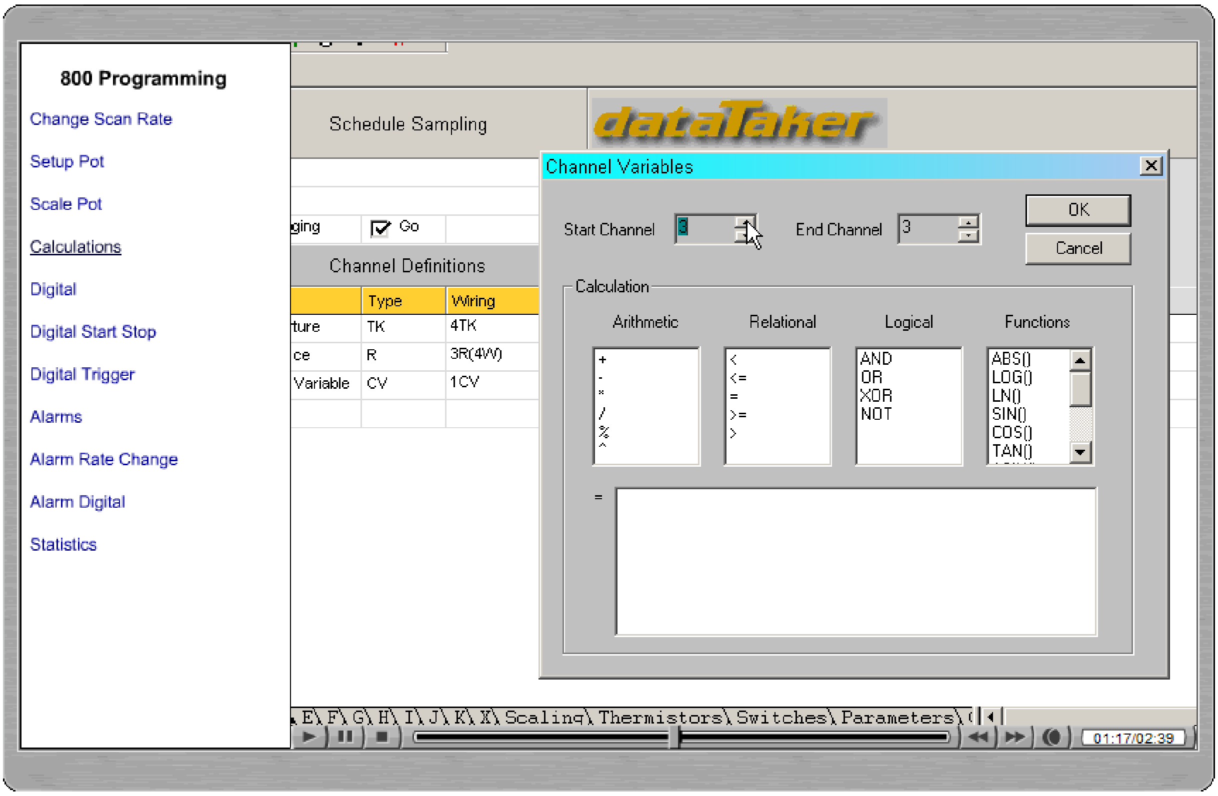
Source: DataTaker software

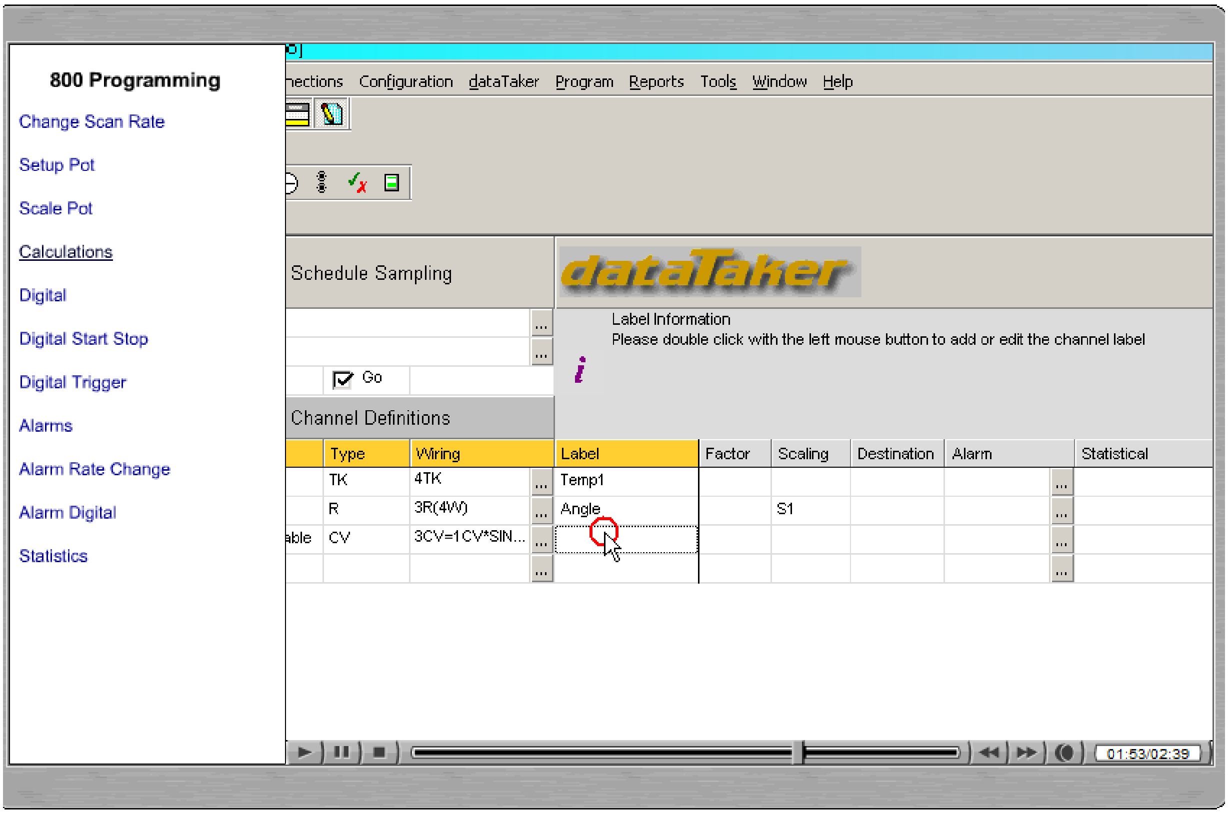


DataTaker Software – View Menu

Source: DataTaker software




800 Programming
Change Scan Rate
Setup Pot
Scale Pot
Calculations
Digital
Digital Start Stop
Digital Trigger
Alarms
Alarm Rate Change
Alarm Digital
Statistics
Schedule Sampling
dataTaker
Channel Variables
Start Channel
End Channel
OK
Cancel
Calculation
Arithmetic
Relational
Logical
Functions
AND
OR
XOR
NOT
ABS()
LOG()
LN()
SIN()
COS()
TAN()
Channel Definitions
Type
Wiring
01:17/02:39


800 Programming
Change Scan Rate
Setup Pot
Scale Pot
Calculations
Digital
Digital Start Stop
Digital Trigger
Alarms
Alarm Rate Change
Alarm Digital
Statistics
Configuration
dataTaker
Program
Reports
Tools
Window
Help
Schedule Sampling
dataTaker
Label Information
Please double click with the left mouse button to add or edit the channel label
Channel Definitions
Type
Wiring
Label
Factor
Scaling
Destination
Alarm
Statistical
TK
4TK
Temp1
R
3R(4W)
Angle
S1
CV
3CV=1CV*SIN...
01:53/02:39

Annex XIII: Quotation

omni INSTRUMENTS

Quotation 24066

Page	1
Customer no.	43301
Project	
Department	
Delivery method	UPS
Delivery terms	Freight charges paid by sender
Date of delivery	
Payment terms	Net 30 days
Currency	GBP
Date of quotation	12/03/2013
Valid until	12/04/2013

Knoydart Renewables Limited
Knoydart,
by Mallaig
Invernessshire
PH41 4PL
VAT no.

Our ref.	Steve Duncan
Your ref.	Jorge Núñez
Reference	

Product no.	Product description	Qty.	Unit price	Discount	VAT %	Total ex-VAT
DT80M	Data Electronics DT80M data logger, 16-48 analogue inputs	2.00	2,670.00	5.00%	20.00	5,073.00
	Datataker DT80 series stand alone data logger, mains or battery powered, with 5-15 analogue inputs (universal input type), 12 digital I/O, CAN bus serial input, USB memory up to 512 MB (50 million readings), Logging rates 25 Hz to 99 days. Unit has an internal memory of 10,000,000 readings. With integral 3G modem. Provides data download by FTP or email.					
CE4DMID001	MID Certified Energy Meter for three phase supplies	2.00	183.47	5.00%	20.00	348.59
	MID Certified Energy Meter for three phase supplies, 5 amp CT input with pulse KWh output. Suitable for submetering applications with pulse and RS485 Modbus outputs.					
DBP58800/5A	DBP58. Split core current transformer, range 0-800amps AC	6.00	22.46	5.00%	20.00	128.02
ENC-WMT-MED-DISP-UC1-G6-T8-A	Wall mount enclosure, ABS, IP 67	2.00	304.31	5.00%	20.00	578.19
	Wall mount enclosure, ABS, IP 67 fitted with accessories as listed below *Medium enclosure (max 8 connectors or 12 cable glands)* *DISP - Small Display fitted to ABS Enclosure* *1 bulkhead connector for USB connection* *6 cable glands fitted* *T8 - DIN rail terminal block, fitted, 8 terminals* *A - DIN rail mount power supply, 100-240 VAC, O/P 24v @ 2.5A*					
SYSTEMCONTROLLER2	Samsung Laptop (Windows 7 and OpenOffice)	1.00	605.00		20.00	605.00
SYSTEMSETUPNEW	System integration and setup	1.00	375.00		20.00	375.00
CARR UK STD	Next Day Standard Packing & Carriage	1.00	30.00		20.00	30.00

Annex XIV Excel data calculations Knoydart Hydropower plant

Annex XV: Flow Data of Allta A' Mhuilinn and Allt A' Mhogha from Wallingford Hydrosolutions

Allt A' Mhuilinn

Mean Flows	Flow (m^3/s)
Annual	**0.203**
January	0.320
February	0.276
March	0.255
April	0.136
May	0.094
June	0.094
July	0.102
August	0.142
September	0.195
October	0.262
November	0.265
December	0.295

Percentile	Flow (m^3/s)
5	0.757
10	0.526
20	0.317
30	0.205
40	0.136
50	0.095
60	0.065
70	0.044
80	0.029
90	0.018
95	0.013
98	0.009
99	0.008

Allt A' Mhogha

Mean Flows	Flow (m^3/s)
Annual	**0.023**
January	0.039
February	0.032
March	0.031
April	0.017
May	0.012
June	0.010
July	0.010
August	0.015
September	0.021
October	0.030
November	0.030
December	0.035

Percentile	Flow (m^3/s)
5	0.086
10	0.059
20	0.036
30	0.024
40	0.016
50	0.011
60	0.008
70	0.006
80	0.004
90	0.003
95	0.002
98	0.002
99	0.001

Annex XVI: Energy Potential for four sites with respective percentile low

Site Mhuilinn

Hours for Scale	Percentile	Hours	Cummulative Hours	Flow Site A Mhuilinn (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for 86 KW	Average with Compensation Flow (m^3/s) for 86 KW	Net Discharge Flow (m^3/s) for 86 KW	Ratio of Net Discharge to Design Flow	Power (kW) - Site A Mhuilinn	Energy Produced (kWh) - Site A Mhuilinn
0	0	0	0	0.757	0.149	0.739		0.73	85.16	0.00
876	10	876	876	0.526	0.149	0.508		0.73	85.16	74,599.14
1752	20	876	1752	0.317	0.149	0.299		0.73	85.16	74,599.14
2628	30	876	2628	0.205	0.149	0.187		0.73	85.16	74,599.14
3504	40	876	3504	0.136	0.118	0.118		0.58	67.44	59,078.51
4380	50	876	4380	0.095	0.077	0.077		0.38	44.01	38,551.23
5256	60	876	5256	0.065	0.047	0.047		0.23	26.86	23,531.27
6132	70	876	6132	0.044	0.026	0.026		0.13	14.86	13,017.30
7008	80	876	7008	0.029	0.011	0.011		0.05	6.29	5,507.32
7884	90	876	7884	0.018	0.000	0.000		0.00	0.00	0.00
8760	95	438	8322	0.013	0.000	0.000		0.00	0.00	0.00
	98	262.8	8584.8	0.009	0.000	0.000		0.00	0.00	0.00
	99	87.6	8672.4	0.008	0.000	0.000		0.00	0.00	0.00
	100	87.6	8760			0.000			Total	363,483.06

Site Mhogha

Hours for Scale	Percentile	Hours	Cummulative Hours	Flow Site B (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for XX KW	Average with Compensation Flow (m^3/s) for XX KW	Net Discharge Flow (m^3/s) for XX KW	Ratio of Net Discharge to Design Flow	Power (kW) - Site B Mhuilinn	Energy Produced (kWh) - Site B
0	5	438	438	0.114	0.0224	0.111		0.97	15.11	6,618.324
876	10	438	876	0.079	0.0224	0.076		0.97	15.11	6,618.324
1752	20	876	1752	0.048	0.0224	0.045		0.97	15.11	13,236.647
2628	30	876	2628	0.031	0.0224	0.028		0.97	15.11	13,236.647
3504	40	876	3504	0.020	0.018	0.018		0.77	11.94	10,459.315
4380	50	876	4380	0.014	0.012	0.012		0.50	7.79	6,825.146
5256	60	876	5256	0.010	0.007	0.007		0.31	4.76	4,165.998
6132	70	876	6132	0.007	0.004	0.004		0.17	2.63	2,304.595
7008	80	876	7008	0.004	0.002	0.002		0.07	1.11	975.021
7884	90	876	7884	0.003	0.000	0.000		0.00	0.00	0.000
8760	95	438	8322	0.002	0.000	0.000		0.00	0.00	0.000
	98	262.8	8584.8	0.001	0.000	0.000		0.00	0.00	0.000
	99	87.6	8672.4	0.001	0.000	0.000		0.00	0.00	0.000
	100	87.6	8760			0.000			Total	64,440.018

Site Scottas Burn

Hours for Scale	Percentile	Hours	Cummulative Hours	Flow Site C (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for XX KW	Average with Compensation Flow (m^3/s) for XX KW	Net Discharge Flow (m^3/s) for 86 KW	Ratio of Net Discharge to Design Flow	Power (kW) - Site C	Energy Produced (kWh) - Site C
0	5	438	0	0.341	0.070	0.333		0.75	65.16	28,539.51
876	10	438	438	0.237	0.070	0.229		0.75	65.16	28,539.51
1752	20	876	1314	0.143	0.070	0.135		0.75	65.16	57,079.02
2628	30	876	2190	0.092	0.070	0.084		0.75	65.16	57,079.02
3504	40	876	3066	0.061	0.053	0.053		0.57	49.43	43,298.51
4380	50	876	3942	0.043	0.035	0.035		0.37	32.25	28,254.11
5256	60	876	4818	0.029	0.021	0.021		0.23	19.69	17,246.02
6132	70	876	5694	0.020	0.012	0.012		0.13	10.89	9,540.35
7008	80	876	6570	0.013	0.005	0.005		0.05	4.61	4,036.30
7884	90	876	7446	0.008	0.000	0.000		0.00	0.00	0.00
8760	95	438	7884	0.006	0.000	0.000		0.00	0.00	0.00
	98	262.8	8146.8	0.004	0.000	0.000		0.00	0.00	0.00
	99	87.6	8234.4	0.004	0.000	0.000		0.00	0.00	0.00
	100	87.6	8322			0.000			Total	273,612.34

Site Glaschoille

Hours for Scale	Percentile	Hours	Cummulative Hours	Flow Site D (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for 15 KW	Average with Compensation Flow (m^3/s) for XX KW	Net Discharge Flow (m^3/s) for XX KW	Ratio of Net Discharge to Design Flow	Power (kW) - Site D	Energy Produced (kWh) - Site D
0	5	438	438	0.303	0.035	0.296		0.43	15.03	6,581.397
876	10	438	876	0.210	0.035	0.203		0.43	15.03	6,581.397
1752	20	876	1752	0.127	0.035	0.120		0.43	15.03	13,162.793
2628	30	876	2628	0.082	0.035	0.075		0.43	15.03	13,162.793
3504	40	876	3504	0.054	0.035	0.047		0.43	15.03	13,162.793
4380	50	876	4380	0.038	0.031	0.031		0.38	13.22	11,583.258
5256	60	876	5256	0.026	0.019	0.019		0.23	8.07	7,070.300
6132	70	876	6132	0.018	0.010	0.010		0.13	4.46	3,911.230
7008	80	876	7008	0.012	0.004	0.004		0.05	1.89	1,654.751
7884	90	876	7884	0.007	0.000	0.000		0.00	0.00	0.000
8760	95	438	8322	0.005	0.000	0.000		0.00	0.00	0.000
	98	262.8	8584.8	0.004	0.000	0.000		0.00	0.00	0.000
	99	87.6	8672.4	0.003	0.000	0.000		0.00	0.00	0.000
	100	87.6	8760			0.000			Total	76,870.713

Annex XVII: Detailed Hydro Power Calculation of four sites after Site Survey

Head and catchment calculation

Site	Head(m)
Mhuilinn	87
Mhogha	104
Scottas	145
Glaschoille	68

Catchment Area	km2
Mhuilinn	2.88
Mhogha	0.42
Scottas	1.30
Glaschoille	0.66

Flow and precipitation data for Alt a´ Mhuilinn

	Q (m3/s)	P(mm)
January	0.32	
February	0.276	
March	0.255	
April	0.136	
May	0.094	
June	0.094	
July	0.102	
August	0.142	
September	0.195	
October	0.262	
November	0.265	
December	0.295	
Sum		**2221**
Average	**0.203**	

Runoff-Coefficient: r = (Q*31536)/(P*A) = (114.58*31536)/(2920*2000) = 1.00

Determine the average flow for site A and site B

Qm Alt a´Mhuilinn= P*r*AA/31536 = 0.203
Qm Alt a´Mhogha = P*r*AB/31536 = 0.030
Qm Scottas Burn = P*r*AC/31536 = 0.091
Qm Loch Glashoille = P*r*AD/31536 = 0.054

The correlation data of monthly flows from all four rivers with respect to Allt A' Mhuilinn

	Q (m3/s)	Ratio Mhuilinn	Ratio Mhogha	Ratio Scottas	Ratio Glaschoille	QA Mhuilinn	QB Mhogha	QC Scottas	QD Glaschoille
January	0.32	1.00	0.15	0.45	0.23	0.320	0.047	0.144	0.073
February	0.276	1.00	0.15	0.45	0.23	0.276	0.041	0.124	0.063
March	0.255	1.00	0.15	0.45	0.23	0.255	0.038	0.115	0.058
April	0.136	1.00	0.15	0.45	0.23	0.136	0.020	0.061	0.031
May	0.094	1.00	0.15	0.45	0.23	0.094	0.014	0.042	0.021
June	0.094	1.00	0.15	0.45	0.23	0.094	0.014	0.042	0.021
July	0.102	1.00	0.15	0.45	0.23	0.102	0.015	0.046	0.023
August	0.142	1.00	0.15	0.45	0.23	0.142	0.021	0.064	0.032
September	0.195	1.00	0.15	0.45	0.23	0.195	0.029	0.088	0.045
October	0.262	1.00	0.15	0.45	0.23	0.262	0.039	0.118	0.060
November	0.265	1.00	0.15	0.45	0.23	0.265	0.039	0.119	0.061
December	0.295	1.00	0.15	0.45	0.23	0.295	0.043	0.133	0.067
Sum									
Average	0.203					0.203	0.030	0.091	0.046

Potential Calculation

	γ = g*ρ (KN/μ3)	**Q (m3/s)**	**Head**	**Eff.**	**Power (kW)**
Mhuilinn	9.81	0.203	87	0.5	86.63
Mhogha	9.81	0.030	104	0.5	15.26
Scottas	9.81	0.091	145	0.5	65.07
Glaschoille	9.81	0.054	68	0.5	18.00

Annex XVIII: Pipeline Selection and Head Loss

Project Site	Power (kW)	Head (m)	Discharge (m3/s)	K	5% HL(m)	Length(m)	ΔH (m/m)	Nomo Dia(mm)	Selected Dia(mm)	$H_L = (4^{10/3} * Q^2 L)/(\pi^2 k^2 D^{16/3})$	V = Q/A	ξ	$ξ*V^2/2g$	Total H_L	Difference	Remark	Net head
Mhuilinn	85	37.000	0.149	155.000	1.850	801.300	0.002	355.000	400.000	1.006	1.183	0.840	0.060	1.066	0.784	H_L< 5%	35.934
	85	50.000	0.149	155.000	2.500	205.970	0.012	255.000	300.000	1.200	2.104	0.380	0.086	1.286	1.214	H_L< 5%	48.714
		87.000				1007.270								2.352			84.648
Mhogha	15	104.000	0.022	155.000	5.200	532.140	0.010	130.000	150.000	2.794	1.258	1.180	0.095	2.889	2.311	H_L< 5%	101.111
		104.000				532.140								2.889			101.111
Scottas Burn	65	4.000	0.070	155.000	0.200	84.250	0.002	270.000	300.000	0.108	0.988	0.400	0.020	0.128	0.072	H_L< 5%	3.872
	65	25.000	0.070	155.000	1.250	249.420	0.005	225.000	250.000	0.847	1.423	0.220	0.023	0.870	0.380	H_L< 5%	24.130
	65	116.000	0.070	155.000	5.800	688.770	0.008	207.000	250.000	2.339	1.423	0.550	0.058	2.397	3.403	H_L< 5%	113.603
		145.000				1022.440						1.180		3.395			141.605
Glaschoille	15	4.060	0.035	155.000	0.203	65.100	0.003	192.000	210.000	0.140	1.009	0.300	0.016	0.156	0.047	H_L< 5%	3.904
		63.940	0.035	155.000	3.197	189.870	0.017	140.000	150.000	2.461	1.977	0.500	0.100	2.561	0.636	H_L< 5%	61.379
		68.000				254.970								2.717			65.283

Friction losses of bends site Mhuilinn	
Bend	ξ
inlet	0.3
14°	0.08
16°	0.08
43°	0.18
32°	0.12
16°	0.08
14°	0.08
Butterfly Valve	0.3

Friction losses of bends Site Scottas Burn		Friction losses of bends Site Mhogha		Friction losses of bends Site Glaschoille	
Bend	ξ	Bend	ξ	Bend	ξ
inlet	0.3	inlet	0.3	inlet	0.3
23°	0.1	18°	0.08	13°	0.08
25°	0.1	33°	0.12	9°	0.12
27°	0.12	44°	0.18	Butterfly Valve	0.3
12°	0.08	Butterfly Valve	0.3		
42°	0.18				
Butterfly Valve	0.3				

Annex XIX: Selection of Turbines for four sites

SN	Project	Power (P) KW	Net Head (h) m	Discharge m^3/s	RPM (n_{turb})	α Deg	$n_s = n_{turb}*1.2*P^{0.5}/h^{1.25}$	$n_q = n_{turb}*Q^{0.5}/h^{1.26}$	Turbine Dia D = sqrt(2gh)*cosα/(2p()n)	Name of Turbine	Remark
1	Site A	85	84.648	0.149	1500	0	64.634	2.253	0.259	Mult jet Pelton	
2	Site B	15	101.111	0.022	1500	0	21.743	0.698	0.284	Pelton single jet	
3	Site C	65	141.605	0.070	1500	0	29.708	0.811	0.336	Pelton single jet	
4	Site D	15	65.376	0.035	1500	0	37.501	1.508	0.228	Mult jet Pelton	

Annex XX: Total Monthly Flow Potential of Site Mhuilinn

Site A: Mhuilinn

Q90 0.018

January

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for 86 KW	Average with Compensation Flow (m^3/s)	Power (kW)	Energy Produced (kWh)	Avg
0	0	0	0.983	0.149	0.965	85.16	0.00	
10	74.4	74.4	0.766	0.149	0.748	85.16	6,335.82	
20	74.4	148.8	0.522	0.149	0.504	85.16	6,335.82	
30	74.4	223.2	0.372	0.149	0.354	85.16	6,335.82	
40	74.4	297.6	0.259	0.149	0.241	85.16	6,335.82	
50	74.4	372	0.173	0.155	0.155	88.59	6,590.95	
60	74.4	446.4	0.122	0.104	0.104	59.44	4,422.32	
70	74.4	520.8	0.082	0.064	0.064	36.58	2,721.42	3,426.59
80	74.4	595.2	0.053	0.035	0.035	20.00	1,488.28	
90	74.4	669.6	0.031	0.013	0.013	7.43	552.79	
95	37.2	706.8	0.020	0.000	0.002	0.00	0.00	
99	29.76	736.56	0.014	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	41,119.03	

February

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s)	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.876	0.149	0.858	85.16	0.00	
10	67.2	67.2	0.671	0.149	0.653	85.16	5,722.67	
20	67.2	134.4	0.440	0.149	0.422	85.16	5,722.67	
30	67.2	201.6	0.302	0.149	0.284	85.16	5,722.67	
40	67.2	268.8	0.208	0.149	0.190	85.16	5,722.67	
50	67.2	336	0.142	0.124	0.124	70.87	4,762.49	
60	67.2	403.2	0.099	0.081	0.081	46.29	3,110.98	
70	67.2	470.4	0.063	0.045	0.045	25.72	1,728.32	2,795.72
80	67.2	537.6	0.038	0.020	0.020	11.43	768.14	
90	67.2	604.8	0.025	0.007	0.007	4.00	268.85	
95	33.6	638.4	0.019	0.001	0.001	0.57	19.20	
99	26.88	665.28	0.013	0.000	0.000	0.00	0.00	
100	6.72	672		0.000	0.000	0.00	0.00	
						Total	33,548.69	

March

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s)	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.869	0.149	0.851	85.16	0.00	
10	74.4	74.4	0.609	0.149	0.591	85.16	6,335.82	
20	74.4	148.8	0.370	0.149	0.352	85.16	6,335.82	
30	74.4	223.2	0.260	0.149	0.242	85.16	6,335.82	
40	74.4	297.6	0.187	0.149	0.169	85.16	6,335.82	
50	74.4	372	0.135	0.117	0.117	66.87	4,975.10	
60	74.4	446.4	0.100	0.082	0.082	46.87	3,486.83	
70	74.4	520.8	0.073	0.055	0.055	31.43	2,338.72	3,176.77
80	74.4	595.2	0.049	0.031	0.031	17.72	1,318.19	
90	74.4	669.6	0.031	0.013	0.013	7.43	552.79	
95	37.2	706.8	0.023	0.005	0.005	2.86	106.31	
99	29.76	736.56	0.015	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	38,121.21	

April

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s)	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.461	0.149	0.443	85.16	0.00	
10	72	72	0.324	0.149	0.306	85.16	6,131.44	
20	72	144	0.199	0.149	0.181	85.16	6,131.44	
30	72	216	0.134	0.116	0.116	66.30	4,773.47	
40	72	288	0.099	0.081	0.081	46.29	3,333.20	
50	72	360	0.075	0.057	0.057	32.58	2,345.58	
60	72	432	0.057	0.039	0.039	22.29	1,604.87	
70	72	504	0.043	0.025	0.025	14.29	1,028.76	2,180.98
80	72	576	0.033	0.015	0.015	8.57	617.26	
90	72	648	0.023	0.005	0.005	2.86	205.75	
95	36	684	0.018	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.011	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
					0.000	Total	26,171.77	

May

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.366	0.149	0.348	85.16	0.00	
10	74.4	74.4	0.242	0.149	0.224	85.16	6,335.82	
20	74.4	148.8	0.132	0.114	0.114	65.16	4,847.54	
30	74.4	223.2	0.082	0.064	0.064	36.58	2,721.42	
40	74.4	297.6	0.054	0.036	0.036	20.58	1,530.80	
50	74.4	372	0.040	0.022	0.022	12.57	935.49	
60	74.4	446.4	0.030	0.012	0.012	6.86	510.27	
70	74.4	520.8	0.023	0.005	0.005	2.86	212.61	
80	74.4	595.2	0.018	0.000	0.000	0.00	0.00	1,424.50
90	74.4	669.6	0.013	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.011	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.008	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	17,093.95	

June

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.342	0.149	0.324	85.16	0.00	
10	72	72	0.235	0.149	0.217	85.16	6,131.44	
20	72	144	0.134	0.116	0.116	66.30	4,773.47	
30	72	216	0.088	0.070	0.070	40.01	2,880.54	
40	72	288	0.064	0.046	0.046	26.29	1,892.93	
50	72	360	0.045	0.027	0.027	15.43	1,111.07	
60	72	432	0.032	0.014	0.014	8.00	576.11	
70	72	504	0.023	0.005	0.005	2.86	205.75	
80	72	576	0.017	0.000	0.000	0.00	0.00	1,464.27
90	72	648	0.012	0.000	0.000	0.00	0.00	
95	36	684	0.009	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.007	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	17,571.30	

July

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.355	0.149	0.337	85.16	0.00	
10	74.4	74.4	0.255	0.149	0.237	85.16	6,335.82	
20	74.4	148.8	0.150	0.132	0.132	75.44	5,612.94	
30	74.4	223.2	0.102	0.084	0.084	48.01	3,571.87	
40	74.4	297.6	0.072	0.054	0.054	30.86	2,296.20	
50	74.4	372	0.051	0.033	0.033	18.86	1,403.23	
60	74.4	446.4	0.037	0.019	0.019	10.86	807.92	
70	74.4	520.8	0.026	0.008	0.008	4.57	340.18	
80	74.4	595.2	0.019	0.001	0.001	0.57	42.52	1,700.89
90	74.4	669.6	0.012	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.010	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.008	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	20,410.69	

August

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.524	0.149	0.506	85.16	0.00	
10	74.4	74.4	0.358	0.149	0.340	85.16	6,335.82	
20	74.4	148.8	0.222	0.149	0.204	85.16	6,335.82	
30	74.4	223.2	0.141	0.123	0.123	70.30	5,230.24	
40	74.4	297.6	0.096	0.078	0.078	44.58	3,316.74	
50	74.4	372	0.067	0.049	0.049	28.01	2,083.59	
60	74.4	446.4	0.047	0.029	0.029	16.57	1,233.15	
70	74.4	520.8	0.031	0.013	0.013	7.43	552.79	
80	74.4	595.2	0.023	0.005	0.005	2.86	212.61	2,108.40
90	74.4	669.6	0.016	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.012	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.007	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	25,300.75	

September

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.712	0.149	0.694	85.16	0.00	
10	72	72	0.497	0.149	0.479	85.16	6,131.44	
20	72	144	0.301	0.149	0.283	85.16	6,131.44	
30	72	216	0.205	0.149	0.187	85.16	6,131.44	
40	72	288	0.135	0.117	0.117	66.87	4,814.62	
50	72	360	0.094	0.076	0.076	43.44	3,127.44	
60	72	432	0.066	0.048	0.048	27.43	1,975.23	
70	72	504	0.044	0.026	0.026	14.86	1,069.92	
80	72	576	0.029	0.011	0.011	6.29	452.66	2,486.18
90	72	648	0.018	0.000	0.000	0.00	0.00	
95	36	684	0.012	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.008	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	29,834.17	

October

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.804	0.149	0.786	85.16	0.00	
10	74.4	74.4	0.605	0.149	0.587	85.16	6,335.82	
20	74.4	148.8	0.416	0.149	0.398	85.16	6,335.82	
30	74.4	223.2	0.312	0.149	0.294	85.16	6,335.82	
40	74.4	297.6	0.223	0.149	0.205	85.16	6,335.82	
50	74.4	372	0.158	0.140	0.140	80.02	5,953.12	
60	74.4	446.4	0.111	0.093	0.093	53.15	3,954.57	
70	74.4	520.8	0.074	0.056	0.056	32.01	2,381.25	
80	74.4	595.2	0.047	0.029	0.029	16.57	1,233.15	3,274.21
90	74.4	669.6	0.027	0.009	0.009	5.14	382.70	
95	37.2	706.8	0.020	0.002	0.002	1.14	42.52	
99	29.76	736.56	0.014	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	39,290.57	

November

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.818	0.149	0.800	85.16	0.00	
10	72	72	0.616	0.149	0.598	85.16	6,131.44	
20	72	144	0.418	0.149	0.400	85.16	6,131.44	
30	72	216	0.299	0.149	0.281	85.16	6,131.44	
40	72	288	0.210	0.149	0.192	85.16	6,131.44	
50	72	360	0.155	0.137	0.137	78.30	5,637.63	
60	72	432	0.112	0.094	0.094	53.72	3,868.15	
70	72	504	0.080	0.062	0.062	35.44	2,551.34	
80	72	576	0.055	0.037	0.037	21.15	1,522.57	3,257.75
90	72	648	0.037	0.019	0.019	10.86	781.86	
95	36	684	0.028	0.010	0.010	5.72	205.75	
99	28.8	712.8	0.017	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
					0.000	Total	39,093.05	

	Site A
Jan	41,119.03
Feb	33,548.69
Mar	38,121.21
Apr	26,171.77
May	17,093.95
Jun	17,571.30
Jul	20,410.69
Aug	25,300.75
Sep	29,834.17
Oct	39,290.57
Nov	39,093.05
Dec	38,376.34

December

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.949	0.149	0.931	85.16	0.00	
10	74.4	74.4	0.717	0.149	0.699	85.16	6,335.82	
20	74.4	148.8	0.472	0.149	0.454	85.16	6,335.82	
30	74.4	223.2	0.318	0.149	0.300	85.16	6,335.82	
40	74.4	297.6	0.218	0.149	0.200	85.16	6,335.82	
50	74.4	372	0.149	0.131	0.131	74.87	5,570.42	
60	74.4	446.4	0.101	0.083	0.083	47.44	3,529.35	
70	74.4	520.8	0.072	0.054	0.054	30.86	2,296.20	
80	74.4	595.2	0.047	0.029	0.029	16.57	1,233.15	3,198.03
90	74.4	669.6	0.027	0.009	0.009	5.14	382.70	
95	37.2	706.8	0.019	0.001	0.001	0.57	21.26	
99	29.76	736.56	0.012	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	38,376.34	

Annex XXI: Total Monthly Flow Potential of Site Mhogha

Site B: White Gate

Q90 0.003

January

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.147	0.0224	0.144	15.11	0.00	
10	74.4	74.4	0.115	0.0224	0.112	15.11	1,124.21	
20	74.4	148.8	0.078	0.0224	0.075	15.11	1,124.21	
30	74.4	223.2	0.056	0.0224	0.053	15.11	1,124.21	
40	74.4	297.6	0.039	0.036	0.036	24.18	1,799.24	
50	74.4	372	0.026	0.023	0.023	15.48	1,151.81	
60	74.4	446.4	0.018	0.015	0.015	10.32	767.87	
70	74.4	520.8	0.012	0.009	0.009	6.27	466.75	
80	74.4	595.2	0.008	0.005	0.005	3.34	248.43	657.46
90	74.4	669.6	0.005	0.002	0.002	1.11	82.81	
95	37.2	706.8	0.003	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.002	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	7,889.53	

February

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.131	0.0224	0.128	15.11	0.00	
10	67.2	67.2	0.101	0.0224	0.098	15.11	1,015.41	
20	67.2	134.4	0.066	0.0224	0.063	15.11	1,015.41	
30	67.2	201.6	0.045	0.022	0.042	15.11	1,015.41	
40	67.2	268.8	0.031	0.022	0.028	15.11	1,015.41	
50	67.2	336	0.021	0.018	0.018	12.34	829.56	
60	67.2	403.2	0.015	0.012	0.012	7.99	537.17	
70	67.2	470.4	0.009	0.006	0.006	4.35	292.38	
80	67.2	537.6	0.006	0.003	0.003	1.82	122.39	489.48
90	67.2	604.8	0.004	0.001	0.001	0.51	34.00	
95	33.6	638.4	0.003	0.000	0.000	-0.10	-3.40	
99	26.88	665.28	0.002	0.000	0.000	0.00	0.00	
100	6.72	672		0.000	0.000	0.00	0.00	
						Total	5,873.76	

March

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.130	0.0224	0.127	15.11	0.00	
10	74.4	74.4	0.091	0.0224	0.088	15.11	1,124.21	
20	74.4	148.8	0.056	0.0224	0.053	15.11	1,124.21	
30	74.4	223.2	0.039	0.0224	0.036	15.11	1,124.21	
40	74.4	297.6	0.028	0.022	0.025	15.11	1,124.21	
50	74.4	372	0.020	0.017	0.017	11.64	865.74	
60	74.4	446.4	0.015	0.012	0.012	8.09	602.25	
70	74.4	520.8	0.011	0.008	0.008	5.36	398.99	
80	74.4	595.2	0.007	0.004	0.004	2.93	218.32	556.35
90	74.4	669.6	0.005	0.002	0.002	1.11	82.81	
95	37.2	706.8	0.003	0.000	0.000	0.30	11.29	
99	29.76	736.56	0.002	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	6,676.24	

April

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.069	0.0224	0.066	15.11	0.00	
10	72	72	0.049	0.0224	0.046	15.11	1,087.94	
20	72	144	0.030	0.0224	0.027	15.11	1,087.94	
30	72	216	0.020	0.017	0.017	11.54	830.53	
40	72	288	0.015	0.012	0.012	7.99	575.54	
50	72	360	0.011	0.008	0.008	5.57	400.69	
60	72	432	0.009	0.006	0.006	3.74	269.56	
70	72	504	0.006	0.003	0.003	2.33	167.56	
80	72	576	0.005	0.002	0.002	1.32	94.71	378.03
90	72	648	0.003	0.000	0.000	0.30	21.86	
95	36	684	0.003	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.002	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
					0.000	Total	4,536.34	

May

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.055	0.0224	0.052	15.11	0.00	
10	74.4	74.4	0.036	0.0224	0.033	15.11	1,124.21	
20	74.4	148.8	0.020	0.017	0.017	11.33	843.16	
30	74.4	223.2	0.012	0.009	0.009	6.27	466.75	
40	74.4	297.6	0.008	0.005	0.005	3.44	255.96	
50	74.4	372	0.006	0.003	0.003	2.02	150.56	
60	74.4	446.4	0.005	0.002	0.002	1.01	75.28	
70	74.4	520.8	0.003	0.000	0.000	0.00	0.00	
80	74.4	595.2	0.003	0.000	0.000	0.00	0.00	242.99
90	74.4	669.6	0.002	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.002	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.001	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	2,915.92	

June

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.051	0.0224	0.048	15.11	0.00	
10	72	72	0.035	0.0224	0.032	15.11	1,087.94	
20	72	144	0.020	0.017	0.017	11.54	830.53	
30	72	216	0.013	0.010	0.010	6.88	495.40	
40	72	288	0.010	0.007	0.007	4.45	320.55	
50	72	360	0.007	0.004	0.004	2.53	182.13	
60	72	432	0.005	0.002	0.002	1.21	87.42	
70	72	504	0.003	0.000	0.000	0.00	0.00	
80	72	576	0.003	0.000	0.000	0.00	0.00	250.33
90	72	648	0.002	0.000	0.000	0.00	0.00	
95	36	684	0.001	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.001	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	3,003.99	

July

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.053	0.0224	0.050	15.11	0.00	
10	74.4	74.4	0.038	0.0224	0.035	15.11	1,124.21	
20	74.4	148.8	0.023	0.020	0.020	13.15	978.66	
30	74.4	223.2	0.015	0.012	0.012	8.30	617.31	
40	74.4	297.6	0.011	0.008	0.008	5.26	391.47	
50	74.4	372	0.008	0.005	0.005	3.14	233.37	
60	74.4	446.4	0.006	0.003	0.003	1.72	127.98	
70	74.4	520.8	0.004	0.001	0.001	0.61	45.17	
80	74.4	595.2	0.003	0.000	0.000	-0.10	-7.53	292.55
90	74.4	669.6	0.002	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.002	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.001	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	3,510.64	

August

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.079	0.0224	0.076	15.11	0.00	
10	74.4	74.4	0.054	0.0224	0.051	15.11	1,124.21	
20	74.4	148.8	0.033	0.0224	0.030	15.11	1,124.21	
30	74.4	223.2	0.021	0.018	0.018	12.24	910.91	
40	74.4	297.6	0.014	0.011	0.011	7.69	572.14	
50	74.4	372	0.010	0.007	0.007	4.76	353.82	
60	74.4	446.4	0.007	0.004	0.004	2.73	203.26	
70	74.4	520.8	0.005	0.002	0.002	1.11	82.81	
80	74.4	595.2	0.003	0.000	0.000	0.30	22.58	366.16
90	74.4	669.6	0.002	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.002	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.001	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	4,393.95	

September

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.107	0.0224	0.104	15.11	0.00	
10	72	72	0.075	0.0224	0.072	15.11	1,087.94	
20	72	144	0.045	0.022	0.042	15.11	1,087.94	
30	72	216	0.031	0.022	0.028	15.11	1,087.94	
40	72	288	0.020	0.017	0.017	11.64	837.81	
50	72	360	0.014	0.011	0.011	7.49	539.11	
60	72	432	0.010	0.007	0.007	4.65	335.13	
70	72	504	0.007	0.004	0.004	2.43	174.85	
80	72	576	0.004	0.001	0.001	0.91	65.57	434.69
90	72	648	0.003	0.000	0.000	0.00	0.00	
95	36	684	0.002	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.001	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	5,216.30	

October

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.121	0.0224	0.118	15.11	0.00	
10	74.4	74.4	0.091	0.0224	0.088	15.11	1,124.21	
20	74.4	148.8	0.062	0.022	0.059	15.11	1,124.21	
30	74.4	223.2	0.047	0.022	0.044	15.11	1,124.21	
40	74.4	297.6	0.033	0.022	0.030	15.11	1,124.21	
50	74.4	372	0.024	0.021	0.021	13.96	1,038.89	
60	74.4	446.4	0.017	0.014	0.014	9.21	685.06	
70	74.4	520.8	0.011	0.008	0.008	5.46	406.52	
80	74.4	595.2	0.007	0.004	0.004	2.73	203.26	573.61
90	74.4	669.6	0.004	0.001	0.001	0.71	52.70	
95	37.2	706.8	0.003	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.002	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	6,883.27	

November

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.123	0.0224	0.120	15.11	0.00	
10	72	72	0.092	0.0224	0.089	15.11	1,087.94	
20	72	144	0.063	0.0224	0.060	15.11	1,087.94	
30	72	216	0.045	0.022	0.042	15.11	1,087.94	
40	72	288	0.032	0.022	0.029	15.11	1,087.94	
50	72	360	0.023	0.020	0.020	13.66	983.52	
60	72	432	0.017	0.014	0.014	9.31	670.25	
70	72	504	0.012	0.009	0.009	6.07	437.12	
80	72	576	0.008	0.005	0.005	3.54	254.99	570.89
90	72	648	0.006	0.003	0.003	1.72	123.85	
95	36	684	0.004	0.001	0.001	0.81	29.14	
99	28.8	712.8	0.003	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
					0.000	Total	6,850.65	

	Site B
Jan	7,889.53
Feb	5,873.76
Mar	6,676.24
Apr	4,536.34
May	2,915.92
Jun	3,003.99
Jul	3,510.64
Aug	4,393.95
Sep	5,216.30
Oct	6,883.27
Nov	6,850.65
Dec	6,725.18

December

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.142	0.0224	0.139	15.11	0.00	
10	74.4	74.4	0.108	0.0224	0.105	15.11	1,124.21	
20	74.4	148.8	0.071	0.022	0.068	15.11	1,124.21	
30	74.4	223.2	0.048	0.022	0.045	15.11	1,124.21	
40	74.4	297.6	0.033	0.022	0.030	15.11	1,124.21	
50	74.4	372	0.022	0.019	0.019	13.05	971.14	
60	74.4	446.4	0.015	0.012	0.012	8.20	609.78	
70	74.4	520.8	0.011	0.008	0.008	5.26	391.47	
80	74.4	595.2	0.007	0.004	0.004	2.73	203.26	560.43
90	74.4	669.6	0.004	0.001	0.001	0.71	52.70	
95	37.2	706.8	0.003	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.002	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	

Annex XXII: Total Monthly Flow Potential of Site Scottas Burn

Site C: Scottas

Q90 0.008

January

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.442	0.07	0.434	65.16	0.00	
10	74.4	74.4	0.345	0.07	0.337	65.16	4,847.81	
20	74.4	148.8	0.235	0.07	0.227	65.16	4,847.81	
30	74.4	223.2	0.167	0.07	0.159	65.16	4,847.81	
40	74.4	297.6	0.117	0.070	0.109	65.16	4,847.81	
50	74.4	372	0.078	0.070	0.070	65.02	4,837.42	
60	74.4	446.4	0.055	0.047	0.047	43.66	3,248.03	
70	74.4	520.8	0.037	0.029	0.029	26.90	2,001.45	
80	74.4	595.2	0.024	0.016	0.016	14.75	1,097.68	2,585.21
90	74.4	669.6	0.014	0.006	0.006	5.54	412.06	
95	37.2	706.8	0.009	0.001	0.001	0.93	34.63	
99	29.76	736.56	0.006	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	31,022.50	

February

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.394	0.07	0.386	65.16	0.00	
10	67.2	67.2	0.302	0.07	0.294	65.16	4,378.66	
20	67.2	134.4	0.198	0.07	0.190	65.16	4,378.66	
30	67.2	201.6	0.136	0.070	0.128	65.16	4,378.66	
40	67.2	268.8	0.094	0.070	0.086	65.16	4,378.66	
50	67.2	336	0.064	0.056	0.056	52.03	3,496.68	
60	67.2	403.2	0.045	0.037	0.037	34.02	2,286.29	
70	67.2	470.4	0.028	0.020	0.020	18.94	1,272.94	
80	67.2	537.6	0.017	0.009	0.009	8.47	569.23	2,113.36
90	67.2	604.8	0.011	0.003	0.003	3.03	203.30	
95	33.6	638.4	0.009	0.001	0.001	0.51	17.20	
99	26.88	665.28	0.006	0.000	0.000	0.00	0.00	
100	6.72	672		0.000	0.000	0.00	0.00	
						Total	25,360.29	

March

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.391	0.07	0.383	65.16	0.00	
10	74.4	74.4	0.274	0.07	0.266	65.16	4,847.81	
20	74.4	148.8	0.167	0.07	0.159	65.16	4,847.81	
30	74.4	223.2	0.117	0.07	0.109	65.16	4,847.81	
40	74.4	297.6	0.084	0.070	0.076	65.16	4,847.81	
50	74.4	372	0.061	0.053	0.053	49.10	3,653.17	
60	74.4	446.4	0.045	0.037	0.037	34.44	2,562.41	
70	74.4	520.8	0.033	0.025	0.025	23.13	1,720.97	
80	74.4	595.2	0.022	0.014	0.014	13.08	973.02	2,399.52
90	74.4	669.6	0.014	0.006	0.006	5.54	412.06	
95	37.2	706.8	0.010	0.002	0.002	2.19	81.37	
99	29.76	736.56	0.007	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	28,794.24	

April

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.207	0.07	0.199	65.16	0.00	
10	72	72	0.146	0.07	0.138	65.16	4,691.43	
20	72	144	0.090	0.07	0.082	65.16	4,691.43	
30	72	216	0.060	0.052	0.052	48.68	3,505.17	
40	72	288	0.045	0.037	0.037	34.02	2,449.59	
50	72	360	0.034	0.026	0.026	23.97	1,725.77	
60	72	432	0.026	0.018	0.018	16.43	1,182.91	
70	72	504	0.019	0.011	0.011	10.57	760.68	
80	72	576	0.015	0.007	0.007	6.38	459.09	1,635.30
90	72	648	0.010	0.002	0.002	2.19	157.50	
95	36	684	0.008	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.005	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
					0.000	Total	19,623.56	

May

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.165	0.07	0.157	65.16	0.00	
10	74.4	74.4	0.109	0.07	0.101	65.16	4,847.81	
20	74.4	148.8	0.059	0.051	0.051	47.85	3,559.68	
30	74.4	223.2	0.037	0.029	0.029	26.90	2,001.45	
40	74.4	297.6	0.024	0.016	0.016	15.17	1,128.85	
50	74.4	372	0.018	0.010	0.010	9.31	692.54	
60	74.4	446.4	0.014	0.006	0.006	5.12	380.90	
70	74.4	520.8	0.010	0.002	0.002	2.19	162.75	
80	74.4	595.2	0.008	0.000	0.000	0.00	0.00	1,064.50
90	74.4	669.6	0.006	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.005	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.004	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	12,773.97	

June

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.154	0.07	0.146	65.16	0.00	
10	72	72	0.106	0.07	0.098	65.16	4,691.43	
20	72	144	0.060	0.052	0.052	48.68	3,505.17	
30	72	216	0.040	0.032	0.032	29.41	2,117.84	
40	72	288	0.029	0.021	0.021	19.36	1,394.02	
50	72	360	0.020	0.012	0.012	11.40	821.00	
60	72	432	0.014	0.006	0.006	5.96	428.93	
70	72	504	0.010	0.002	0.002	2.19	157.50	
80	72	576	0.008	0.000	0.000	0.00	0.00	1,092.99
90	72	648	0.005	0.000	0.000	0.00	0.00	
95	36	684	0.004	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.003	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	13,115.89	

July

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.160	0.07	0.152	65.16	0.00	
10	74.4	74.4	0.115	0.07	0.107	65.16	4,847.81	
20	74.4	148.8	0.068	0.060	0.060	55.38	4,120.64	
30	74.4	223.2	0.046	0.038	0.038	35.28	2,624.74	
40	74.4	297.6	0.032	0.024	0.024	22.71	1,689.81	
50	74.4	372	0.023	0.015	0.015	13.92	1,035.35	
60	74.4	446.4	0.017	0.009	0.009	8.05	599.05	
70	74.4	520.8	0.012	0.004	0.004	3.44	256.24	
80	74.4	595.2	0.009	0.001	0.001	0.51	38.09	1,267.64
90	74.4	669.6	0.005	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.005	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.004	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	15,211.73	

August

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.236	0.07	0.228	65.16	0.00	
10	74.4	74.4	0.161	0.07	0.153	65.16	4,847.81	
20	74.4	148.8	0.100	0.07	0.092	65.16	4,847.81	
30	74.4	223.2	0.063	0.055	0.055	51.61	3,840.16	
40	74.4	297.6	0.043	0.035	0.035	32.77	2,437.75	
50	74.4	372	0.030	0.022	0.022	20.62	1,533.98	
60	74.4	446.4	0.021	0.013	0.013	12.24	910.70	
70	74.4	520.8	0.014	0.006	0.006	5.54	412.06	
80	74.4	595.2	0.010	0.002	0.002	2.19	162.75	1,582.75
90	74.4	669.6	0.007	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.005	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.003	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	18,993.01	

September

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.320	0.07	0.312	65.16	0.00	
10	72	72	0.224	0.07	0.216	65.16	4,691.43	
20	72	144	0.135	0.070	0.127	65.16	4,691.43	
30	72	216	0.092	0.070	0.084	65.16	4,691.43	
40	72	288	0.061	0.053	0.053	49.10	3,535.32	
50	72	360	0.042	0.034	0.034	31.93	2,298.80	
60	72	432	0.030	0.022	0.022	20.20	1,454.34	
70	72	504	0.020	0.012	0.012	10.98	790.84	
80	72	576	0.013	0.005	0.005	4.70	338.45	1,874.34
90	72	648	0.008	0.000	0.000	0.00	0.00	
95	36	684	0.005	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.004	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	22,492.04	

October

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.362	0.07	0.354	65.16	0.00	
10	74.4	74.4	0.272	0.07	0.264	65.16	4,847.81	
20	74.4	148.8	0.187	0.070	0.179	65.16	4,847.81	
30	74.4	223.2	0.140	0.070	0.132	65.16	4,847.81	
40	74.4	297.6	0.100	0.070	0.092	65.16	4,847.81	
50	74.4	372	0.071	0.063	0.063	58.74	4,369.95	
60	74.4	446.4	0.050	0.042	0.042	39.05	2,905.22	
70	74.4	520.8	0.033	0.025	0.025	23.55	1,752.14	
80	74.4	595.2	0.021	0.013	0.013	12.24	910.70	2,470.94
90	74.4	669.6	0.012	0.004	0.004	3.86	287.41	
95	37.2	706.8	0.009	0.001	0.001	0.93	34.63	
99	29.76	736.56	0.006	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	29,651.26	

November

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.368	0.07	0.360	65.16	0.00	
10	72	72	0.277	0.07	0.269	65.16	4,691.43	
20	72	144	0.188	0.07	0.180	65.16	4,691.43	
30	72	216	0.135	0.070	0.127	65.16	4,691.43	
40	72	288	0.095	0.070	0.087	65.16	4,691.43	
50	72	360	0.070	0.062	0.062	57.48	4,138.51	
60	72	432	0.050	0.042	0.042	39.47	2,841.66	
70	72	504	0.036	0.028	0.028	26.06	1,876.57	
80	72	576	0.025	0.017	0.017	15.59	1,122.59	2,456.58
90	72	648	0.017	0.009	0.009	8.05	579.73	
95	36	684	0.013	0.005	0.005	4.28	154.15	
99	28.8	712.8	0.008	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
					0.000	Total	29,478.91	

	Site C
Jan	31,022.50
Feb	25,360.29
Mar	28,794.24
Apr	19,623.56
May	12,773.97
Jun	13,115.89
Jul	15,211.73
Aug	18,993.01
Sep	22,492.04
Oct	29,651.26
Nov	29,478.91
Dec	28,674.78

December

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.427	0.07	0.419	65.16	0.00	
10	74.4	74.4	0.323	0.07	0.315	65.16	4,847.81	
20	74.4	148.8	0.212	0.070	0.204	65.16	4,847.81	
30	74.4	223.2	0.143	0.070	0.135	65.16	4,847.81	
40	74.4	297.6	0.098	0.070	0.090	65.16	4,847.81	
50	74.4	372	0.067	0.059	0.059	54.97	4,089.47	
60	74.4	446.4	0.045	0.037	0.037	34.86	2,593.58	
70	74.4	520.8	0.032	0.024	0.024	22.71	1,689.81	
80	74.4	595.2	0.021	0.013	0.013	12.24	910.70	2,389.56
90	74.4	669.6	0.012	0.000	0.004	0.00	0.00	
95	37.2	706.8	0.009	0.000	0.001	0.00	0.00	
99	29.76	736.56	0.005	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	28,674.78	

Annex XXIII: Total Monthly Flow Potential of Site Glaschoille

Site D: Loch Glaschoille

Q90 0.007

January

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.226	0.035	0.219	15.03	0.00	
10	74.4	74.4	0.176	0.035	0.169	15.03	1,117.94	
20	74.4	148.8	0.120	0.035	0.113	15.03	1,117.94	
30	74.4	223.2	0.086	0.035	0.079	15.03	1,117.94	
40	74.4	297.6	0.060	0.035	0.053	15.03	1,117.94	
50	74.4	372	0.040	0.033	0.033	14.08	1,047.35	
60	74.4	446.4	0.028	0.021	0.021	9.04	672.68	
70	74.4	520.8	0.019	0.012	0.012	5.09	378.82	
80	74.4	595.2	0.012	0.005	0.005	2.23	165.77	561.36
90	74.4	669.6	0.007	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.005	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.003	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	6,736.36	

February

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.201	0.035	0.194	15.03	0.00	
10	67.2	67.2	0.154	0.035	0.147	15.03	1,009.75	
20	67.2	134.4	0.101	0.035	0.094	15.03	1,009.75	
30	67.2	201.6	0.069	0.035	0.062	15.03	1,009.75	
40	67.2	268.8	0.048	0.035	0.041	15.03	1,009.75	
50	67.2	336	0.033	0.026	0.026	11.02	740.29	
60	67.2	403.2	0.023	0.016	0.016	6.77	454.96	
70	67.2	470.4	0.014	0.007	0.007	3.22	216.09	
80	67.2	537.6	0.009	0.002	0.002	0.75	50.20	458.38
90	67.2	604.8	0.006	0.000	0.000	0.00	0.00	
95	33.6	638.4	0.004	0.000	0.000	0.00	0.00	
99	26.88	665.28	0.003	0.000	0.000	0.00	0.00	
100	6.72	672		0.000	0.000	0.00	0.00	
						Total	5,500.53	

March

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.200	0.035	0.193	15.03	0.00	
10	74.4	74.4	0.140	0.035	0.133	15.03	1,117.94	
20	74.4	148.8	0.085	0.035	0.078	15.03	1,117.94	
30	74.4	223.2	0.060	0.035	0.053	15.03	1,117.94	
40	74.4	297.6	0.043	0.035	0.036	15.03	1,117.94	
50	74.4	372	0.031	0.024	0.024	10.33	768.18	
60	74.4	446.4	0.023	0.016	0.016	6.87	511.06	
70	74.4	520.8	0.017	0.010	0.010	4.20	312.70	
80	74.4	595.2	0.011	0.004	0.004	1.83	136.39	516.67
90	74.4	669.6	0.007	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.005	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.003	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	6,200.07	

April

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.106	0.035	0.099	15.03	0.00	
10	72	72	0.075	0.035	0.068	15.03	1,081.87	
20	72	144	0.046	0.035	0.039	15.03	1,081.87	
30	72	216	0.031	0.024	0.024	10.23	736.29	
40	72	288	0.023	0.016	0.016	6.77	487.46	
50	72	360	0.017	0.010	0.010	4.40	316.83	
60	72	432	0.013	0.006	0.006	2.62	188.86	
70	72	504	0.010	0.003	0.003	1.24	89.33	
80	72	576	0.008	0.001	0.001	0.25	18.24	333.40
90	72	648	0.005	0.000	0.000	0.00	0.00	
95	36	684	0.004	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.003	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
					0.000	Total	4,000.77	

May

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.084	0.035	0.077	15.03	0.00	
10	74.4	74.4	0.056	0.035	0.049	15.03	1,117.94	
20	74.4	148.8	0.030	0.023	0.023	10.03	746.14	
30	74.4	223.2	0.019	0.012	0.012	5.09	378.82	
40	74.4	297.6	0.012	0.005	0.005	2.33	173.12	
50	74.4	372	0.009	0.002	0.002	0.94	70.27	
60	74.4	446.4	0.007	0.000	0.000	0.00	0.00	
70	74.4	520.8	0.005	0.000	0.000	0.00	0.00	
80	74.4	595.2	0.004	0.000	0.000	0.00	0.00	207.19
90	74.4	669.6	0.003	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.003	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.002	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	2,486.29	

June

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.079	0.035	0.072	15.03	0.00	
10	72	72	0.054	0.035	0.047	15.03	1,081.87	
20	72	144	0.031	0.024	0.024	10.23	736.29	
30	72	216	0.020	0.013	0.013	5.68	409.26	
40	72	288	0.015	0.008	0.008	3.31	238.63	
50	72	360	0.010	0.003	0.003	1.44	103.55	
60	72	432	0.007	0.000	0.000	0.00	0.00	
70	72	504	0.005	0.000	0.000	0.00	0.00	
80	72	576	0.004	0.000	0.000	0.00	0.00	214.13
90	72	648	0.003	0.000	0.000	0.00	0.00	
95	36	684	0.002	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.002	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	2,569.60	

July

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.082	0.035	0.075	15.03	0.00	
10	74.4	74.4	0.059	0.035	0.052	15.03	1,117.94	
20	74.4	148.8	0.035	0.028	0.028	11.81	878.38	
30	74.4	223.2	0.023	0.016	0.016	7.07	525.75	
40	74.4	297.6	0.017	0.010	0.010	4.10	305.36	
50	74.4	372	0.012	0.005	0.005	2.03	151.08	
60	74.4	446.4	0.009	0.002	0.002	0.65	48.23	
70	74.4	520.8	0.006	0.000	0.000	0.00	0.00	
80	74.4	595.2	0.004	0.000	0.000	0.00	0.00	252.23
90	74.4	669.6	0.003	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.002	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.002	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	3,026.73	

August

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.121	0.035	0.114	15.03	0.00	
10	74.4	74.4	0.082	0.035	0.075	15.03	1,117.94	
20	74.4	148.8	0.051	0.035	0.044	15.03	1,117.94	
30	74.4	223.2	0.032	0.025	0.025	10.92	812.26	
40	74.4	297.6	0.022	0.015	0.015	6.47	481.67	
50	74.4	372	0.015	0.008	0.008	3.61	268.62	
60	74.4	446.4	0.011	0.004	0.004	1.64	121.70	
70	74.4	520.8	0.007	0.000	0.000	0.00	0.00	
80	74.4	595.2	0.005	0.000	0.000	0.00	0.00	326.68
90	74.4	669.6	0.004	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.003	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.002	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
					0.000	Total	3,920.12	

September

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.164	0.035	0.157	15.03	0.00	
10	72	72	0.114	0.035	0.107	15.03	1,081.87	
20	72	144	0.069	0.035	0.062	15.03	1,081.87	
30	72	216	0.047	0.035	0.040	15.03	1,081.87	
40	72	288	0.031	0.024	0.024	10.33	743.40	
50	72	360	0.022	0.015	0.015	6.28	451.91	
60	72	432	0.015	0.008	0.008	3.51	252.85	
70	72	504	0.010	0.003	0.003	1.34	96.44	
80	72	576	0.007	0.000	0.000	0.00	0.00	399.19
90	72	648	0.004	0.000	0.000	0.00	0.00	
95	36	684	0.003	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.002	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	4,790.23	

October

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.185	0.035	0.178	15.03	0.00	
10	74.4	74.4	0.139	0.035	0.132	15.03	1,117.94	
20	74.4	148.8	0.096	0.035	0.089	15.03	1,117.94	
30	74.4	223.2	0.072	0.035	0.065	15.03	1,117.94	
40	74.4	297.6	0.051	0.035	0.044	15.03	1,117.94	
50	74.4	372	0.036	0.029	0.029	12.60	937.15	
60	74.4	446.4	0.026	0.019	0.019	7.96	591.87	
70	74.4	520.8	0.017	0.010	0.010	4.30	320.05	
80	74.4	595.2	0.011	0.004	0.004	1.64	121.70	536.88
90	74.4	669.6	0.006	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.005	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.003	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	6,442.50	

November

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharg	Average with	Power (kW)	Energy Produced	
0	0	0	0.188	0.035	0.181	15.03	0.00	
10	72	72	0.142	0.035	0.135	15.03	1,081.87	
20	72	144	0.096	0.035	0.089	15.03	1,081.87	
30	72	216	0.069	0.035	0.062	15.03	1,081.87	
40	72	288	0.048	0.035	0.041	15.03	1,081.87	
50	72	360	0.036	0.029	0.029	12.30	885.59	
60	72	432	0.026	0.019	0.019	8.05	579.88	
70	72	504	0.018	0.011	0.011	4.89	352.38	
80	72	576	0.013	0.006	0.006	2.43	174.65	530.56
90	72	648	0.009	0.002	0.002	0.65	46.68	
95	36	684	0.006	0.000	0.000	0.00	0.00	
99	28.8	712.8	0.004	0.000	0.000	0.00	0.00	
100	7.2	720		0.000	0.000	0.00	0.00	
						Total	6,366.67	

Jan	6,736.36
Feb	5,500.53
Mar	6,200.07
Apr	4,000.77
May	2,486.29
Jun	2,569.60
Jul	3,026.73
Aug	3,920.12
Sep	4,790.23
Oct	6,442.50
Nov	6,366.67
Dec	6,288.23

December

Percentile	Hours	Cummulative Hours	Flow (m^3/s) (Percentile)	Net Discharge Flow (m^3/s) for	Average with Compensation	Power (kW)	Energy Produced (kWh)	
0	0	0	0.218	0.035	0.211	15.03	0.00	
10	74.4	74.4	0.165	0.035	0.158	15.03	1,117.94	
20	74.4	148.8	0.109	0.035	0.102	15.03	1,117.94	
30	74.4	223.2	0.073	0.035	0.066	15.03	1,117.94	
40	74.4	297.6	0.050	0.035	0.043	15.03	1,117.94	
50	74.4	372	0.034	0.027	0.027	11.71	871.03	
60	74.4	446.4	0.023	0.016	0.016	6.97	518.40	
70	74.4	520.8	0.017	0.010	0.010	4.10	305.36	
80	74.4	595.2	0.011	0.004	0.004	1.64	121.70	524.02
90	74.4	669.6	0.006	0.000	0.000	0.00	0.00	
95	37.2	706.8	0.004	0.000	0.000	0.00	0.00	
99	29.76	736.56	0.003	0.000	0.000	0.00	0.00	
100	7.44	744		0.000	0.000	0.00	0.00	
						Total	6,288.23	

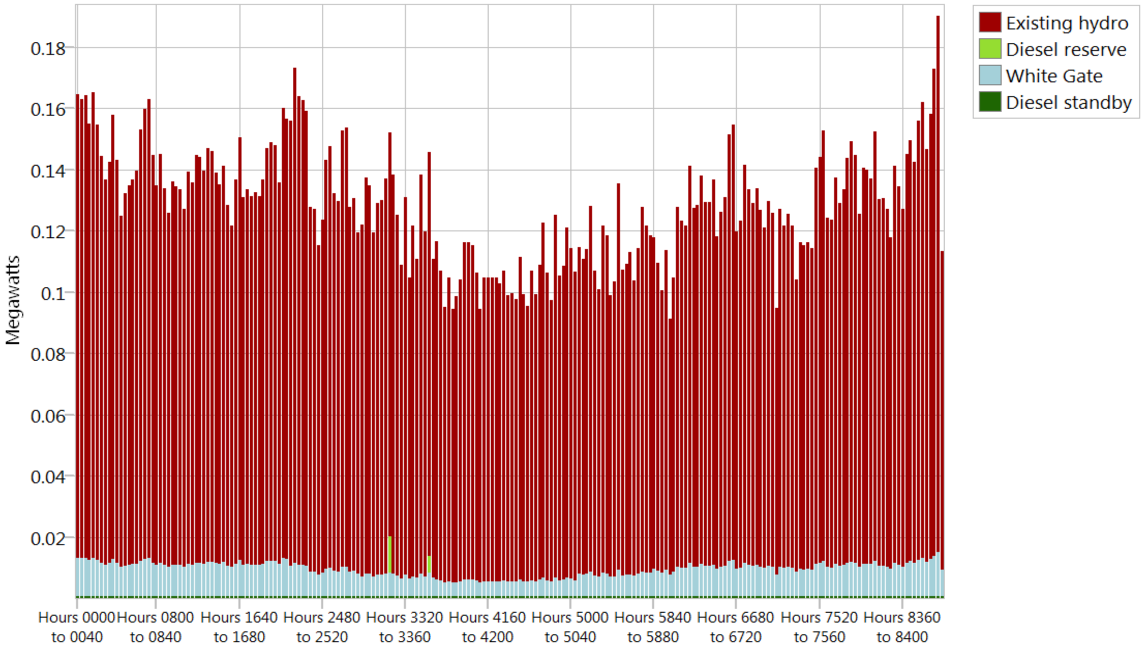
Assumptions for efficiency

Turbine efficiency: 0.8; Generator efficiency: 0.9; Transformer efficiency: 0.98

Annex XXIV: Summary of Costs and Revenues for the 4 proposed sites for a new Micro Hydo plant

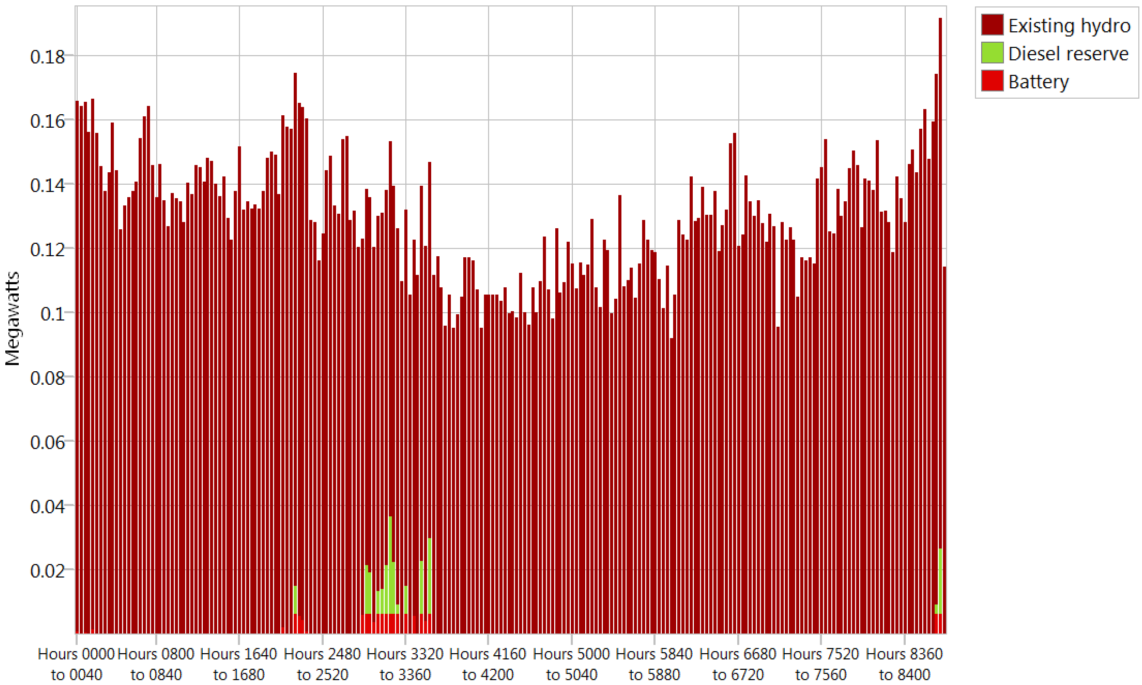
	Costs																	Revenues				
Site	Environmental Surveys	Intake	Heli Lift for Intake	Excavation	Penstock	HeliLift for Penstock	Penstock Fittings	Installation	Power House	Turbine & Generator	Grid Connection	Secondary Electrical & Controls	Engineering Design & Planning	Engineering Supervision	Sum of Costs	Contigency Costs 8%	Total Investment Cost	Annual Maintenance Cost	Energy Generated kWh / Year	Income £/year	Payback Period (Years)	IRR	NPV
Mhuillin	5,000	50,000	0	31,477	43,136	0	7,857	30,621	50,000	94,800	22,500	40,000	27,779	29,631	432,801	34,624	467,425	5,000	365,932	122,953	5	25.06%	£942,320
White Gate	5,000	50,000	0	16,629	7,471	0	4,151	16,177	50,000	38,350	22,500	40,000	18,396	19,622	288,297	23,064	311,360	2,500	64,476	23,147	>50	4.54%	-£56,033
Scottas Burn	5,000	50,000	3,750	31,951	15,070	12,985	7,975	31,082	50,000	94,800	22,500	40,000	27,009	28,809	420,931	33,674	454,605	5,000	275,192	92,465	7	18.86%	£594,718
Loch Glaschoille	5,000	50,000	0	7,968	3,580	0	1,989	7,751	50,000	38,350	22,500	40,000	16,660	17,771	261,569	20,925	282,494	2,500	63,721	22,876	>50	5.27%	-£32,101

Annex XXV: Average power dispatch for Future Supply Scenarios



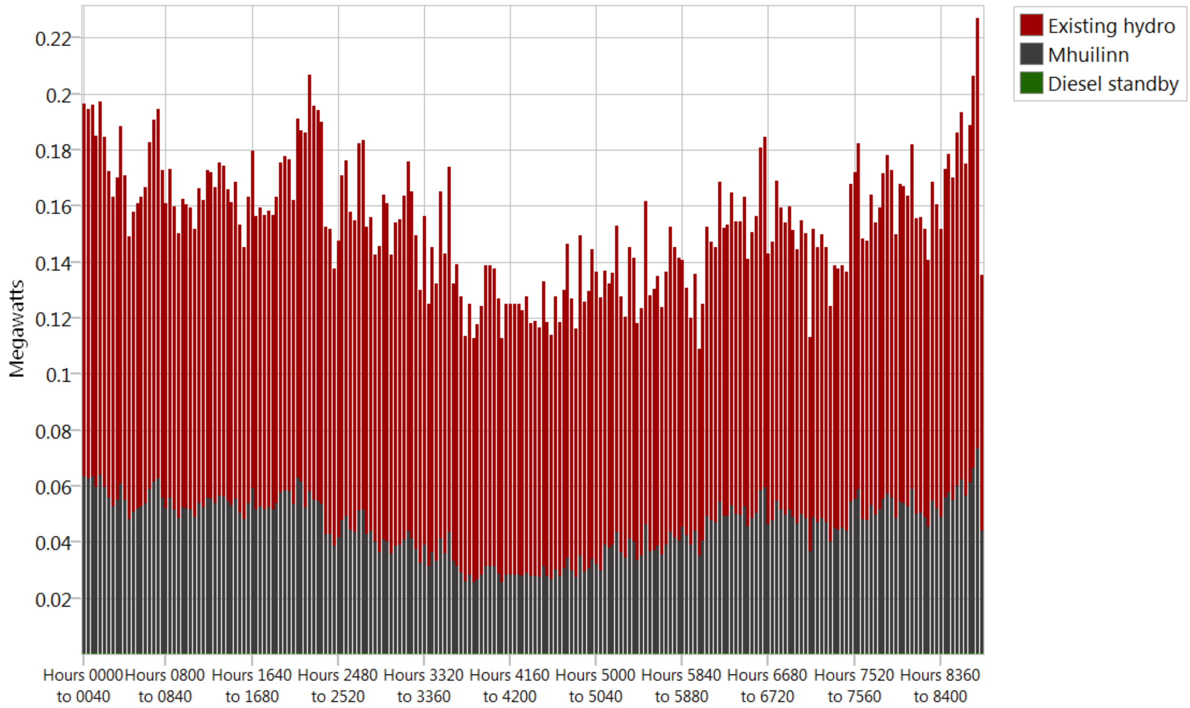
Average Power Dispatched of peak White Gate 15 kW or low demand scenario on Year 2032

Source: Authors, 2013. Modelled in LEAP software



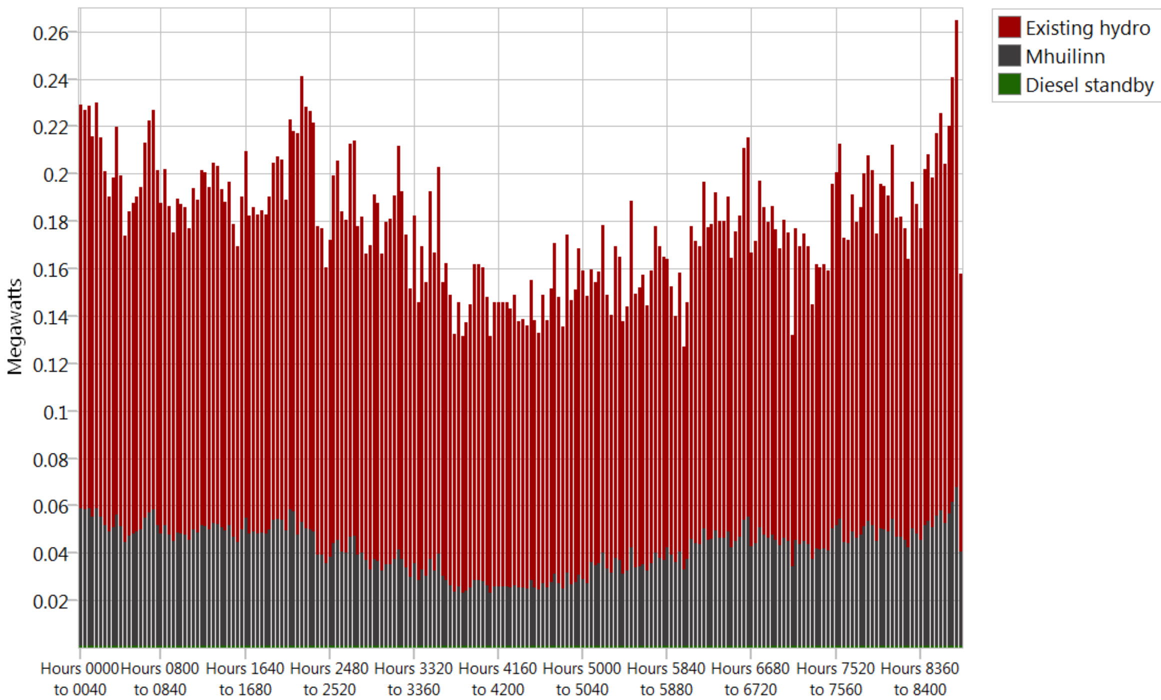
Average Power Dispatched of peak Battery 40kW for low demand scenario on Year 2032

Source: Authors, 2013. Modelled in LEAP software



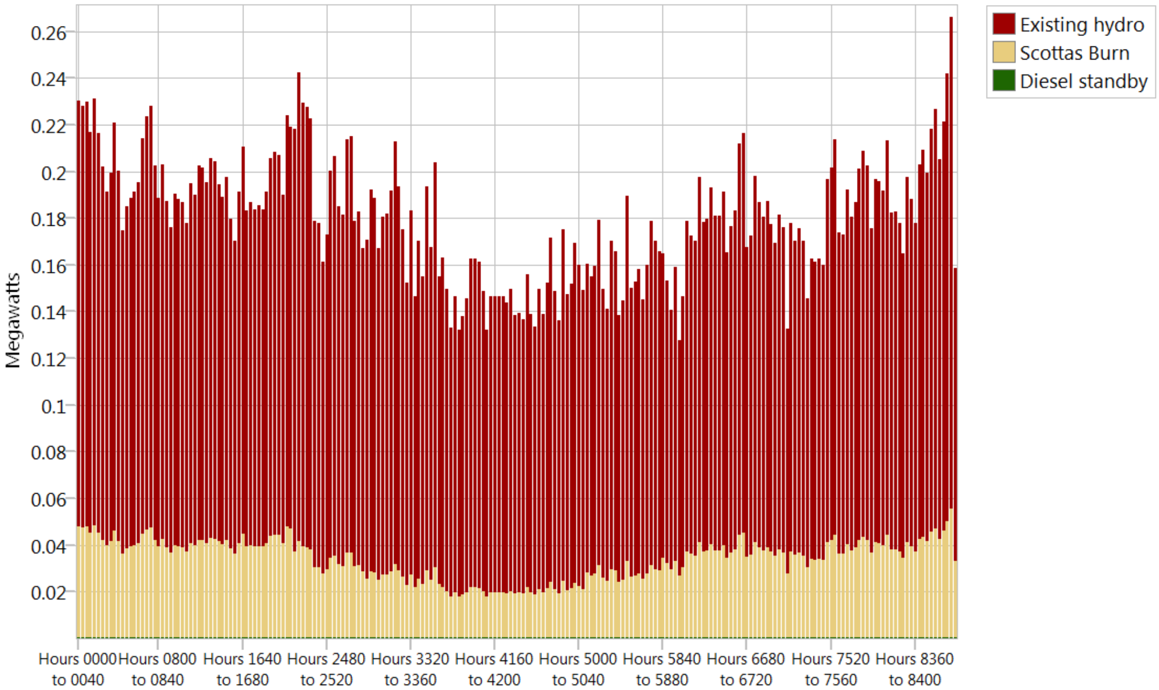
Average power dispatched on 2032 from Mhuilinn Scenario in kW

Source: Authors, 2013. Modelled in LEAP software



Average power dispatched on 2032 from Mhuilinn Scenario in the high growth demand

Source: Authors, 2013. Modelled in LEAP software



Average power dispatched on 2032 from Scottas in the high growth demand scenario

Source: Authors, 2013. Modelled in LEAP software