Department of Mechanical and Aerospace Engineering

Investigating Potential Reinstatement of Historic Micro-Hydro Sites

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Signed: Date: 23rd August 2019

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On a personal note I'd like to thank my family; Julia, Evelyn and Toby, for their patience and support.

Lastly, I'd like to dedicate this piece of work to Sandy Taylor (1922 – 2015), former resident of the case study site and renown jazz pianist. With thanks for his stories, and recognition of his humour and enthusiasm.

Abstract

This report presents an investigation into a collection of novel hydropower schemes. Starting with a comprehensive literature review, the investigation continues with a case study and a regional survey identifying similar application sites.

Specifically, this project is interested in retrofitting modern micro-hydropower technology into disused, historic watermill sites within the Loch Lomond and The Trossachs National Park in Scotland. The topography of the national park is particularly suitable for the capture of hydropower. The reuse of historic civil engineering, even if in a state of disrepair, offers the potential to realise overall cost savings and minimise additional impacts from developments.

The literature review investigates past, present and future application of hydropower in Scotland, and continues with a study of regional and national incentives and regulation. The results of previous investigations into the potential hydropower output, both of Scotland and of the national park, are discussed. Through this activity it was revealed that these studies have either ignored micro-hydro schemes or acknowledged deficiencies in their results for this size of system.

The findings of a comprehensive case study are presented. A combination of on-site surveying, credible source data and commercial software have been employed to present a complete assessment of the potential power output, expected annual energy yield and greenhouse gas savings. Other challenges and benefits of the scheme are also discussed.

Using the case study as a model, historic mapping data was surveyed to identify similar historic mill sites within the national park. These sites were then assessed for viability of similar schemes. A combined installed renewable electricity capacity of 1 MW has been identified, adding around 6.4 GWh annually to Scotland's energy system. Crucially, the identified developments minimise environmental impact and are very likely to be acceptable to the park authority.

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1.0 Introduction

1.1. Problem Definition

It is widely accepted that climate change must be addressed, and that burning fossil fuels is a significant contributor to this phenomenon. Scotland has set (and so far, met) aggressive targets for increasing the proportion of energy generated through renewable means, thereby decreasing energy generation through fossil fuels. However, electricity is a displacement system, demand and supply must match in real time. Most renewable electricity generation technologies are reliant on natural resources (e.g. wind, sun, and precipitation) which, while often predictable, are not as easy to control as traditional energy generation technologies. A good blend of utilisation of resources, technologies and locations reduces the impact of a single source becoming unavailable. This raises the grid's renewables saturation point and reduces reliance on fossil fuels to maintain reliability. Hydropower is one renewable resource that generally tracks seasonal demand, and Scotland has a reputation for its rainfall. However, in recent years the increase in wind and solar power installations in Scotland has been much greater than that of hydropower.

Large numbers of historic watermill sites exist throughout Scotland. Despite perhaps becoming obsolete with the availability of cheap fossil fuels, and then cheap electricity, these schemes were often well designed, enabling considerable energy extraction from their watercourses.

The visual and environmental impacts of new renewable installations are often significant barriers to development. For example, objections to windfarms visible from otherwise wild spaces. The reuse of historic civil engineering could minimise additional impacts and present a worthwhile cost saving.

1.2. Aim

This project will investigate practical, modern retrofitted installations for embedded generation of electricity using historic, disused watermill sites. Installations should be cost effective and cause minimal environmental impact. Environmental impact assessment and cost-benefit analysis (with feed-in tariffs having been discontinued in April 2019) will influence design. Community supply via local microgrids will be assessed.

1.3. Objectives

- To develop an example site in detail as a case study
- To assess the scope for replication of the case study across a defined region
- To assess the cumulative impact from a program of similar schemes

1.4. Outline of Methodology

Through a comprehensive literature review, covering relevant regional and national context, and technological challenges, a gap in previous studies has been identified.

On-site measurements, credible external data and established assessment techniques have been employed to examine a case study site. National and local authority guidance, and a SEPA tool have been used to predict regulatory acceptance. HOMER Pro and Merit software have been applied. These were used to analyse the local community demand and how it can be matched with generation, and for financial analysis of the scheme. Internationally recognised good practice has been employed to identify key considerations for impact analysis.

To assess regional relevance, historic mapping data has been examined to identify similar, suitable application sites. Cumulative impacts were identified, and site visits to a proportion of the identified sites aided assessment of viability as a whole. The combined potential output from the schemes has then been compared with other renewable generations of a similar size.

1.5. Structure of this Report

Section 2.0 outlines the literature review, with discussion of relevant academic resources supplemented with relevant local and government policy.

Section 3.0 details the case study performed with discussion of the results.

Section 4.0 discusses how the learnings from the case study might be applied to similar locations in a wider geographical area and the impact on the grid.

Section 5.0 concludes the project.

2.0 Literature Review

2.1. Hydropower in Scotland

> "The world's leading scientists and governments have stated flatly, 'warming of the climate system is unequivocal' and a 'settled fact' [with] such a high degree of certainty … because of the vast and growing amount of evidence pointing to such a conclusion." (Romm, 2018).

To address this, a rapid decline of "global emissions of carbon dioxide and other greenhouse gas (GHG) pollutants" is required, brought about by a reduction in energy consumption and switch to low carbon generation. With this attitude, the Scottish government has set targets including "renewable sources to generate the equivalent of 100% of Scotland's gross annual electricity consumption by 2020. Scotland has already met the 2015 50% interim target." (gov.scot, 2018). To achieve its objectives, Scotland is amid a transformation from a traditional electricity distribution model of few large generators supplying many loads, towards a future model of very diverse, embedded generation, with many generators (see section 2.2 below).

In the decade between 2006 and 2016, electricity consumption in Scotland fell steadily by a total of 20% (GOV.UK, 2019a). A reduction in demand may be attributed to many effects, such as efficiency improvements and reduced industry, but false accounting is also a factor with the increase of domestic microgeneration which is able to both provide electricity locally and export electricity to the grid without proper account. It may be hoped that demand will continue to fall but the government also has targets for reduced emissions from transport and heat which will likely require electrification of large parts of these sectors of energy use and rapidly increase Scotland's electricity

Scotland has a long history of employing hydropower, with definitive evidence of water powered mills dating from the 14th century and signs that hydropower was in use long before this (Shaw, 1984). The use of hydropower to generate electricity in Scotland began towards the end of the 19th century. Scotland developed large 'big-dam' schemes in the 1950s and 60s, with significant visual and environmental impact. A dam at Loch Tarsan is pictured in Figure 1 overleaf. "Small scale [run-of-river] hydropower has also become popular in recent years, particularly following the introduction in early 2010 of the Feed-in Tariff" (Sample, et al., 2015)

Figure 1: Author's photograph of one of two dams built in 1953 creating Loch Tarsan on the Cowal Peninsula, a 12,500,000 m^3 reservoir (Argyll and Bute Council, 2014) feeding Striven power station

Today hydropower accounts for 15% of Scotland's renewable electricity capacity, and 19% of Scotland's renewable electricity generation. Scotland's hydropower generation currently meets 20% of Scotland's total electricity demand (GOV.UK, 2019a). Scotland's small-scale hydro capacity more than doubled between 2010 and 2017 with no significant increase in 2018-19. Large-scale hydro currently represents 81% of Scotland's installed hydro capacity with no increase since the opening of the 100 MW Glendoe scheme in 2009 (GOV.UK, 2019b). However, Scotland does have plans to significantly increase large-scale hydro capacity. In 2013, Scottish and Southern Energy plc (SSE) gained planning approval for a new hydropower scheme at Coire Glas, north of Fort William (SSE, 2019). Rated at 600 MW with storage of up to 30 GWh, this scheme would be Scotland's largest. Construction has not yet started, and SSE are currently seeking approval to increase the size of the scheme to 1,500 MW. In 2016, Scottish Power Ltd. announced plans to double the output of their Cruchan scheme on Loch Awe creating an additional 400 – 600 MW of capacity with new dams to increase the storage capacity and a new cavern within the mountain (ScottishPower, 2016).

However, this may change with the sale of Cruchan power station to Drax Group plc earlier this year. Hamilton-based firm Intelligent Land Investments Group have plans for three 400 MW pumped hydro schemes in Scotland, one of which named ‘Red John’ on the eastern shores of Loch Ness would have storage capacity of 2.4 GWh (ILI Group, 2017).

Several studies have been executed to assess the available hydropower resource in Scotland. Most notably, in 2008 a Scottish Government commissioned report by Forrest et al. (2008) calculated a theoretical maximum hydro potential, then used a GIS-based computer model (“Hydrobot”) to identify and assess all likely hydro configurations in Scotland. The study identified and included data from all existing large schemes and avoided affecting these with new proposals. All lengths of river were assessed for run-of-river schemes and the optimal configurations were identified by the software. Constraints with the most impact were identified and incorporated, from grid connections to planning and environmental concerns, and financial viability. In total, 36,252 schemes were identified but only 3% of these were considered financially viable giving “an annual energy output of 2.77 TWh” – potentially meeting an additional 8% of Scotland’s current total electricity demand. Forrest’s assessment shows that most viable schemes were between 100 kW and 5 MW in size. Only 6 of the 1,019 identified viable schemes were micro-hydro. Through sensitivity analysis, the study shows that with more favourable financial terms up to 1,422 Scottish micro-hydro schemes may be viable and argues that even this number may still be pessimistic.

Forrest and Hydrobot were involved in further studies in 2009 and twice in 2012 (Sample, et al., 2015). These studies followed the introduction of feed-in tariffs (see section 2.3 below) and showed how this support mechanism had a dramatic effect on increasing the potential capacity of hydropower in Scotland, including a marked improvement in viability of micro-hydro. The 2009 study increase the overall potential capacity by 83%, with an increase in the number of micro-hydro schemes from 6 to 4,419. This number was reduced twice in the subsequent 2012 studies. Firstly, cumulative ecological impacts of widespread run-of-river schemes were added to the models, and secondly through manual validation of a proportion of the identified schemes.

2.2. Embedded Generation

Changing the grid from a traditional model, with large power stations and power flowing in one direction, towards a model of increasingly diverse energy supply sources and generator sizes, brings many benefits and challenges that must be addressed. Embedded (or distributed) generation involves the connection of many, smaller generators connected directly to the distribution network, causing power to potentially flow in both directions along power lines. A popular example, often quoted, is a suburban street with many PV installations generating during the day while all residents are away at work.

Allowing many smaller generators onto the grid brings benefits such as access to a wider range of types and locations of energy sources, including renewables. Security of supply may be increased by reducing reliance on a handful of large suppliers. Long-distance transmission and distribution costs and losses may be reduced by physically siting supplies nearer to demands.

Challenges of distributed generation include likely voltage rises, thermal ratings being exceeded and fault level rises (Forrest, et al., 2008). Power quality may also be affected e.g. flicker, voltage imbalance or harmonics (Jenkins & Strbac, 1995). Issues from voltage rises are particularly likely where connections are made to lower voltage levels, such as 11 kV lines in rural areas. This issue may be counteracted through “primary substation voltage reduction, reactive power import, autotransformers installation, conductor upgrading, and generation constraints” (Masters, 2002).

The Scottish Government, working closely with the UK Government and Ofgem, has an “Energy Strategy” aiming to transition the electricity and gas networks in Scotland. The strategy aims to support “an inclusive transition to a decarbonised energy system, a whole system approach across heat, transport and electricity, and smarter, local energy models” (gov.scot, 2019a).

2.3. Support Mechanisms

To encourage renewable energy installations, the UK government has a history of financial incentive schemes. Until recently, the main schemes were Renewables Obligation (RO), and the Renewable Energy Feed-In Tariff (REFIT).

“The RO is one of the main support mechanisms for large-scale renewable electricity projects in the UK” (Ofgem, 2019a). RO required licensed electricity suppliers to obtain a defined portion of their supply from renewable sources. No subsidies were provided, the customer baring the additional costs incurred. RO Certificates (ROCs) may be traded, or exemption may be purchased. The RO closed to new generating capacity in 2017 but continues to be enjoyed by existing installations.

REFIT was aimed at smaller renewable installations, up to 5 MW. Licensed electricity suppliers are required to pay a set rate (the FIT element) for each unit of electricity generated and a further rate for each unit exported to the electricity grid. REFIT rates were adjusted periodically and closed to new generators in April 2019. Existing generators were guaranteed payments for 20 years with increases linked to the Retail Price Index (RPI). Figure 2 shows the FIT and export payments that are being paid to micro-hydro generators today based on their accreditation date (Ofgem, 2019b). The total tariff line acts as an upper limit, assuming all electricity is exported, which would not normally be the case.

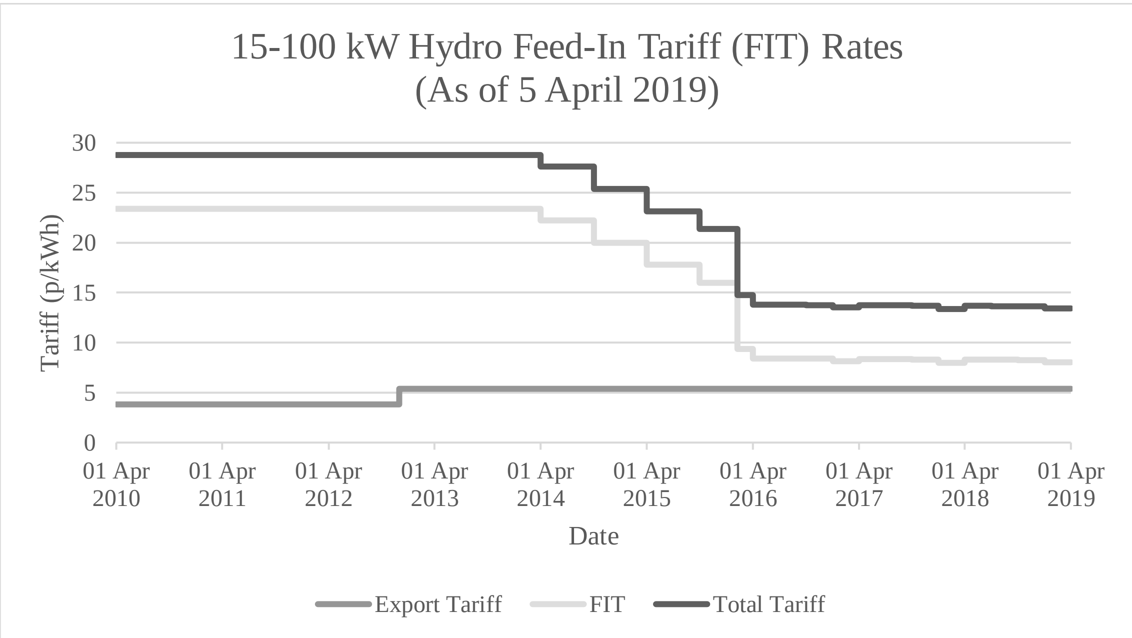


Figure 2: Feed-in tariff rates for micro-hydro. Tariffs are adjusted using the RPI, chart shows tariff available today, based on install date. Data from Ofgem (2019b)

Avochie Estate Micro-Hydro by Milltown of Rothiemay in Moray is a 59 kW Archimedes’ screw installed in 2014 beside a historic mill site (Renewable Energy Foundation, 2019a). This micro-hydro scheme averages 260 MWh per year, currently worth £72,000 per year in FIT and export payments (260,000 kWh×27.6 p). This scheme may not have been viable prior to 2010 or at the present time.

In 2020, a new support mechanism will be available for renewables rated up to 5 MW. Smart Export Guarantee (SEG) will provide for payments for all electricity exported to the grid. Larger licenced energy suppliers will be required to provide at least one export tariff which must always be above 0 p/kWh. Smart meters must be employed for accurate accounting (GOV.UK, 2019c). To date, only one fixed export tariff has been announced, Octopus Energy offer 5.5 p/kWh (Solar Trade Association, 2019) which is marginally greater than the current export tariff element provided by REFIT. At this level, SEG is effectively removing the FIT element and maintaining the export element of REFIT.

The reduction and then loss of FIT is likely to have been a significant influence on the reduction of new, small-scale hydro installations in Scotland. Unless suppliers compete for generators through their SEG tariffs, it is unlikely that SEG will act as a significant incentive for new hydro.

2.4. Regulation

In Scotland, regulation of renewable energy is managed by the Scottish Government, local authorities and the Scottish Environmental Protection Agency (SEPA). The Scottish Government has responsibility for any applications above 50 MW generating capacity, with the relevant local authority as a statutory consultee. Below 50 MW, the relevant local authority has responsibility. This is the Loch Lomond and The Trossachs National Park Authority (LLTNPA) for the case study below.

With relevance to hydropower, SEPA regulate water abstraction and discharge, river engineering works and waste management. Licences may also be required from Scottish Natural Heritage (SNH) and/or the Forestry Commission for protected species and felling activities respectively.

2.4.1. Local Planning

LLTNPA recognises the need for renewable energy generation within the park to "promote the sustainable use of the natural resources of the area" (LLTNPA, 2019a). Their planning policy favours run-of-river hydropower schemes over large-scale solar farms, wind farms and big-dam hydro for minimal environmental and visual impact (LLTNPA, 2019b). The park authority's guidance on planning for renewable energy declares that "Small scale run-of-river technology is considered to be the most compatible to the National Park's geography and special qualities" (LLTNPA, 2016). Other notable concerns include loss of cultural and historic heritage. The guide also includes a survey of potential run-of-river hydro sites within the park and calculates that "Cumulatively the National Park may have the technical potential to generate approximately 73 MW from small scale run-of-river schemes". They note that schemes likely to be sized under 50 kW were ignored in this survey, deciding that they would likely not be financially feasible. Figure 3, overleaf, shows the sites identified by the authority's survey.

A survey of recent planning applications for renewable energy installations within the National Park shows their policy and guidance being implemented. Between the start of 2017 and the first half of 2019:

- No wind or solar farm applications have been proposed
- Four roof top PV arrays gained planning approval (it should be noted that many more small-scale PV arrays will have automatically been permitted without planning applications through Permitted Development Rights)
- No big-dam hydro applications were submitted, one minor big-dam amendment was approved for a relatively small reservoir (raising the Arivurichardich reservoir dam height by 300 mm)
- Numerous run-of-river schemes were approved, including:
    - Five new applications,
    - Five amendments to existing applications and
    - One renewal of a previous application

It was also noted that all the new hydro planning applications surveyed were at new sites, none were reinstating existing hydropower schemes.

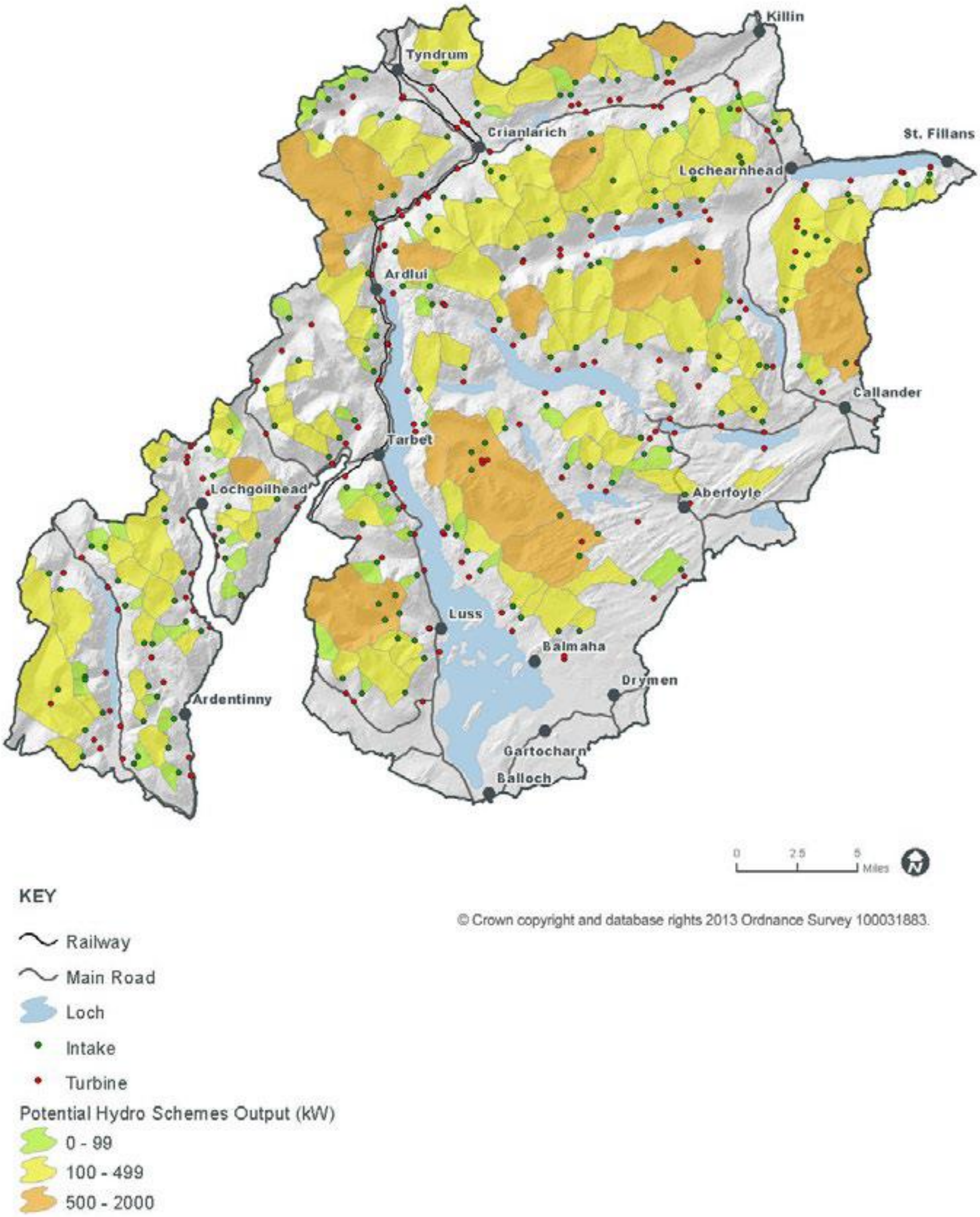


Figure 3: Technical assessment of potential run-of-river hydropower schemes with installed capacity between 15kw and 2MW (LLTNPA, 2016)

2.4.2. SEPA

SEPA is "Scotland's principal environmental regulator, protecting and improving Scotland's environment" (SEPA, 2019a). As a Scottish Government body, SEPA is responsible for ensuring that the environment and human health are protected, and ensuring sustainable use of natural resources.

Run-of-river hydro schemes require authorisation from SEPA under the Water Environment (Controlled Activities) Regulations 2011 (CAR) (SEPA, 2019b). Consents cover both water extraction from the river to feed the turbines and discharge back to the river from the tailrace. The CAR assessment must consider the water quality, hydrology and ecology of the water course. CAR also considers the cumulative impacts from all schemes on the same water course.

SEPA provide significant support for small hydropower schemes, including a comprehensive developer guide and a web-based screening tool to enable developers to quickly and cheaply obtain an idea of acceptability for a proposed scheme.

2.4.3. Electricity Networks Association (ENA)

Any generation greater than 16A per phase (3.68kW) must comply with Engineering Recommendation G99 in order to connect to the grid (Energy Networks Association, 2019). G99 is published by the ENA but connections are managed by the relevant Distribution Network Operator (DNO). G99 supersedes, and greatly extends G59 in response to the increasing capacity of embedded generation and associated increased risk of grid destabilisation. Equipment and installers must be certified by the Microgeneration Certification Scheme (MCS). For installed capacity below 50 kW (three phase) G99 compliance may be met through a simplified process which involves submitting details of the equipment and installers. Over 50 kW capacity will require the DNO to carry out system studies to assess the connection. These studies include investigating the cumulative impact of multiple generators concentrated in one area of the grid. Forrest (2008) calculates that up to 1,000 kW may be acceptable on each 11 kV line dependant on distance from the nearest 33 kV substation.

2.5. Literature Review Discussion

Scotland's climate and landscape lend themselves well to energy generation through hydropower and this has been exploited for many centuries, though most significantly within the last 100 years. National and regional studies have identified widely varying quantities of potential additional hydro resource. Micro sized schemes gave the most dramatic variation in estimates. The introduction, reduction and cessation of the REFIT support mechanism had a striking effect on the viability of smaller run-of-river schemes. In addition to financial influences, viability is also affected by regulation and by the ability to provide a load for the generated electricity, normally the national grid.

3.0 Case Study: Dumfin Sawmill

3.1. Site Description

Dumfin Sawmill is situated in Argyll and Bute, Scotland, and within the Loch Lomond and Trossachs National Park. The site is on Fruin Water at the small community of Dumfin, between the towns of Helensburgh and Balloch. Figure 4 shows the site's location within the UK and Scotland, and the surrounding area including Glasgow, Loch Lomond and the Firth of Clyde.

Figure 4: Case study location within UK and local area (Google Earth)

Dumfin is a small, rural community of six households, two holiday cottages, a working farm, and a restaurant with a small rare breed petting zoo. There is no mains gas to the area, heating being provided by oil, coal, wood and electric heating (including one air source heat pump (ASHP)).

Dumfin Sawmill is listed as a "charcoal mill for chemical purposes" in the Dunbartonshire OS Name Books (1860), there are mill stones remaining at the site presumed from this activity. A former resident, Mr Sandy Taylor, was born at the mill in 1922, lived almost his entire life at the mill, moving to sheltered housing in 2012, where he died in 2015 aged 92. In casual conversation, Mr Taylor remembered his grandfather managing the mill and his father converting it for milling timber, which involved building a large retaining wall and saw bed. As a sawmill, tree trunks were rolled from lorries to the saw bed, which passed back and forth over a large circular saw. In addition to the main saw, several small attached workshops contained equipment powered by the waterwheel. A small dam allowed the plant to operate with a degree of dispatchability. Gates at both ends of the lade were opened in the morning and closed at the end of the day. (A 'lade' is Scots for "a water channel, especially one conveying water to a mill-wheel, a mill-race" (SLD, 2019), sometimes also called a 'headrace' or 'leat'.) At times of low flow, the gates required closing during the day to allow the water retained by the dam to replenish and restore working pressure at the wheel. For a time in the early 20th century, a generator was also coupled to the wheel and a battery array was installed to provide electrical power to the main house and workshop. The batteries were maintained by Mr Taylor's cousin, and ceased use during the Second World War, from which he did not return. After the war, the house and workshop were connected to the national grid. The sawmill operation ended during the 1970s following severe storm damage to the lade and workshops and no milling has taken place at the site since.

Figure 5 shows an extract from an Ordnance Survey map published in 1862. At this section, the Fruin Water flows from west to east.

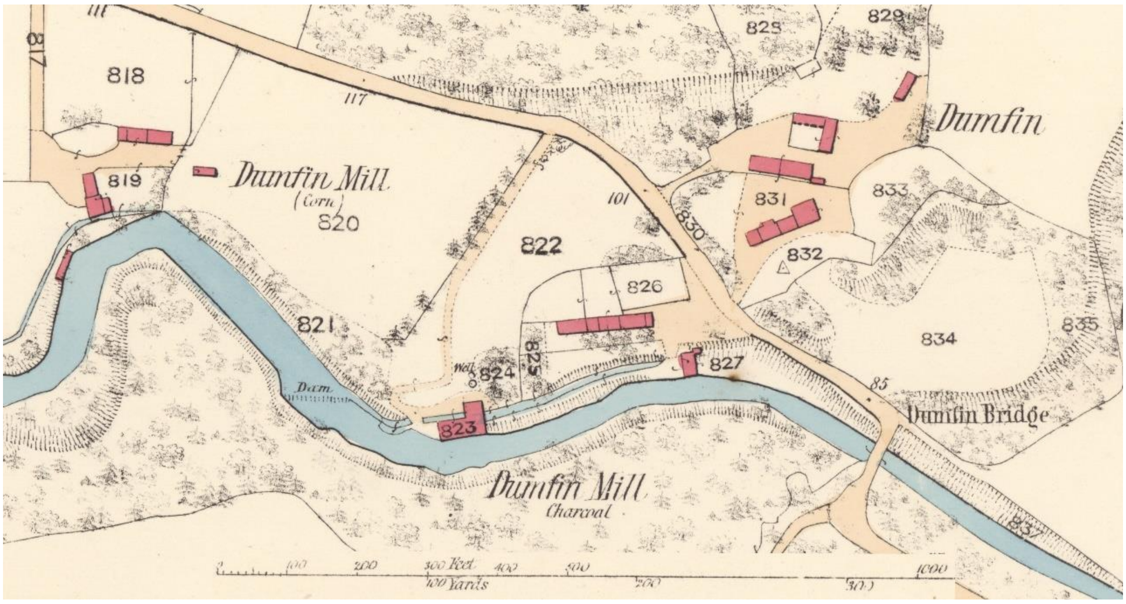


Figure 5: Case study location plan (OS, 1862)

Of the mill buildings numbered 823 and 827, only the foundations remain. Presumably they were demolished to enable reuse of the stone. The saw bed is situated just north of the building numbered 827. A short dam creates a low head and water storage, a 140 m lade channels the water to where a breastshot waterwheel was situated just before the building numbered 827. The dam and lade are in a state of disrepair. The neighbouring Dumfin Mill (Corn) is also disused. Dumfin Bridge to the East was removed in the 1990s.

Figure 6 shows a wood engraving included in an 1864 guide of the local area. The view is drawn from Dumfin Bridge, showing building 827 and the stepped roof of the house, stables and workshop behind. The engraving illustrates the size and flow of the river, although both banks are now far more overgrown.

Figure 6: Case study river and mill building, wood engraving (Battrum, 1864)

Fruin Water's catchment consists mainly of the area between the hills surrounding Glen Fruin. Auchengaich Reservoir is situated at the head of Glen Fruin. It was built in the 1940s, with volume of up to 250,000 m^3 and provides domestic water to the local area (Argyll and Bute Council, 2014). The reservoir significantly impacts the case study catchment area. Fruin Water drains into Loch Lomond. Loch Lomond in turn drains via the River Leven to the River Clyde Estuary, the Firth of Clyde and then on to the Atlantic Ocean.

3.2. Retrofit Process

A methodical approach to installation of a new generating scheme is required to ensure the full potential of a site is realised, and that viability of the scheme is recognised as early in the process as possible. Published micro-hydro planning and installation guides from Elliot (2014) and the British Hydropower Association (2012) have been used extensively throughout this section.

The key metrics required to assess viable power output are head and flow. With these, power output over the course of a year can be calculated and modelled. A load from the local community has also been modelled for comparison.

3.2.1. Site Assessment

3.2.1.1.Physical Layout

The layout of the site was measured physically on site, and by using high resolution, high accuracy OS mapping data for larger dimensions.

Figure 7: Author's photograph of the case study weir in spate conditions

The dam (or weir), shown above in Figure 7, is set at an angle of 40° relative to the direction of the flow of the river, is approximately 30 m wide and around 1 m high on the upstream side and around 2 to 3 m high on the downstream side. The dam retains a small body of water with an approximate surface area of 1,500 m^2 and approximate volume of 1,100 m^3. A small fish pool is situated behind and to one side of the dam, with a retaining wall perpendicular to the dam, 10 m in length, 1 m below the top of the dam. At the other end of the dam is a gap where the lade should start. The lade gap is 1.8 m wide when measured perpendicular to the lade and 1.1 m high.

The lade is horizontal and 140 m in length from the dam to the gate above the wheel well, with two slight bends along its length. After desilting and allowing for reasonable freeboard, the lade will give a consistent water height of 0.9 m, with a cross-sectional area ranging between 1.1 and 2.2 m^2. Using the equation for rectangular notches in thin plate weirs ($Q = 1.8(L - 0.003)h^{3/2}$), this suggests a maximum flow rate of 1.84 m^3/s. With a Manning's value of 0.0165 for concrete with rough joints, Manning's Equation for uniform flow in open channels gives a velocity of 1.67 m/s and a slope of 2.90×10^{-3} m/m is required, or around 3 mm drop for every linear metre.

The wheel well is 1.6 m wide and sits 2 m below the expected water level in the lade and around 6 m below the yard for vehicular access behind a stone retaining wall. The saw bed is situated at the top of this wall. The wall and overgrown nature of the wheel location and tailrace can be seen overleaf in Figure 8.

Several trees will require removal to enable access to the wheel well and ensure stability in the retaining wall above. Shrubs and small trees will also require removal along the length of the lade. The lade and dam will need desilting. Access for dam and lade maintenance is currently limited to a small footpath. A more substantial path would be beneficial. A set of steps for pedestrian access to the wheel well will be required for installation and maintenance, but transport and crane access is straightforward.

A medium voltage 11 kV step down transformer is situated 100 m northeast of the wheel well and would provide an ideal location for grid connection and boundary for a microgrid.

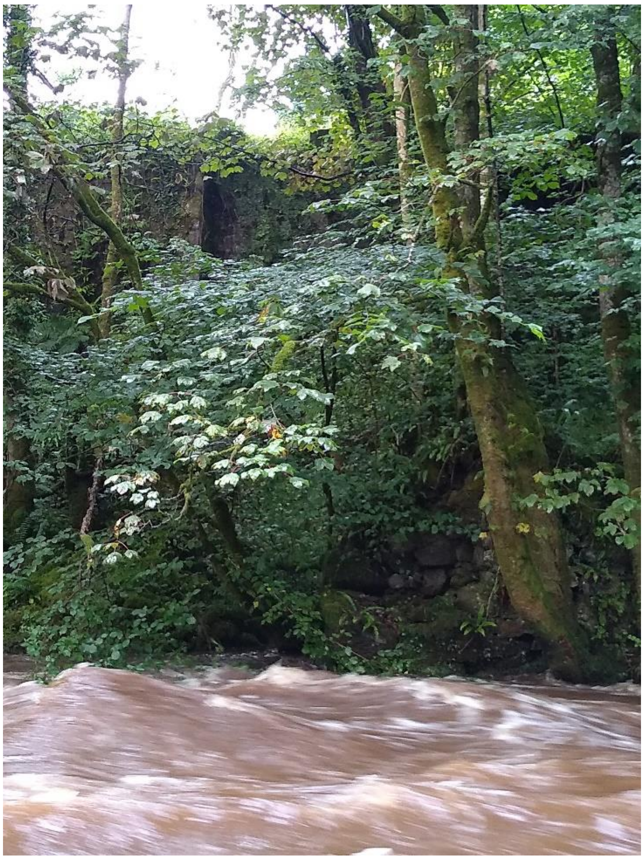


Figure 8: Author's photograph of the case study wheel location and tailrace, the stone at the bottom of the tree to the left is the foundations of the main building shown in Figure 6

3.2.1.2.Head

The available head was measured on site using a surveyor's dumpy level and staff. The difference in height between the expected water level in the lade channel (allowing for reasonable freeboard) and the typical water level of the river at the outflow was measured as 5.1 m.

3.2.1.3.Flow

Actual flow data would ideally be measured at the site over a significant time period. However, gauged mean daily flow data at Luss Water, for the years 1976 to 2017 is available from the National River Flow Archive (2019). The measuring authority providing this data was SEPA, a very credible source. Luss Water is two valleys north of Fruin Water, and has a similar size catchment area, similar landscape, land use and vegetation. Luss Water flow data was scaled by catchment area for use in this assessment.

Firstly, to measure the catchment area for Fruin Water at Dumfin Sawmill, the 1:25,000 scale OS map was marked with the boundary, using the hill peaks and contour lines as a guide. The catchment of the reservoir at the head of Glen Fruin was discounted, and the area was terminated at the site of the dam. Next, the area was transferred to an electronic map (Google Maps) using an Area Calculator Tool from Daft Logic (2019) to give a total area. The plotted shapes were then exported as a Keyhole Markup Language file and imported into Google Earth to be visualised in 3D with OS mapping overlay to ensure the areas were plotted correctly. Errors were discovered in the plot to the north west, and the process was repeated with corrections. Figure 9 and Figure 10 show both 2D and 3D representations of the plotted catchment area with Dumfin Sawmill located to the southeast of the maps. The catchment of the reservoir has been fully discounted, but it should be recognised that not all water will be extracted, and a quantity will overspill into the greater catchment area.

Figure 9: Case study catchment area plotted in Google Earth with OS mapping overlay. (The yellow shaded area represents the catchment area of the reservoir, the blue shaded area represents the catchment area of Fruin Water utilised at Dumfin Sawmill.)

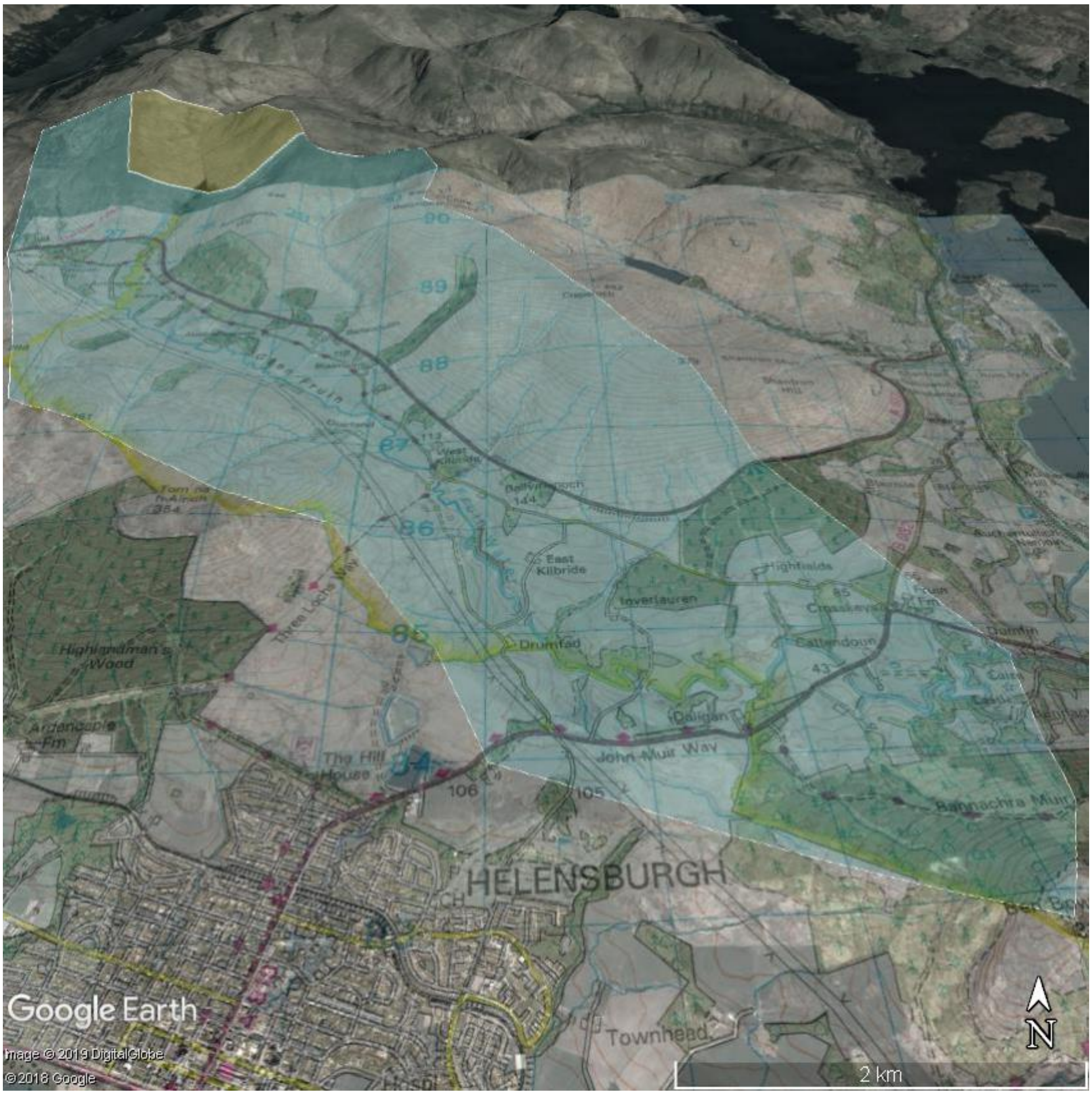


Figure 10: Case study catchment area, as shown in Figure 9, with terrain and 45° tilt.

The total plotted catchment area was measured at 42.9 km², less 3.4 km² for the catchment of the reservoir, gives a net catchment area for use at the mill site of 39.5 km². Luss Water has a catchment area of 35.3 km^2, therefore the flow data from Luss Water was scaled by 39.5 / 35.3 to provide representative data for Fruin Water. Figure 11 shows the daily mean flows in 2016 for Luss Water and Fruin Water. The data shows distinct variability throughout the year, with seasonal variance.

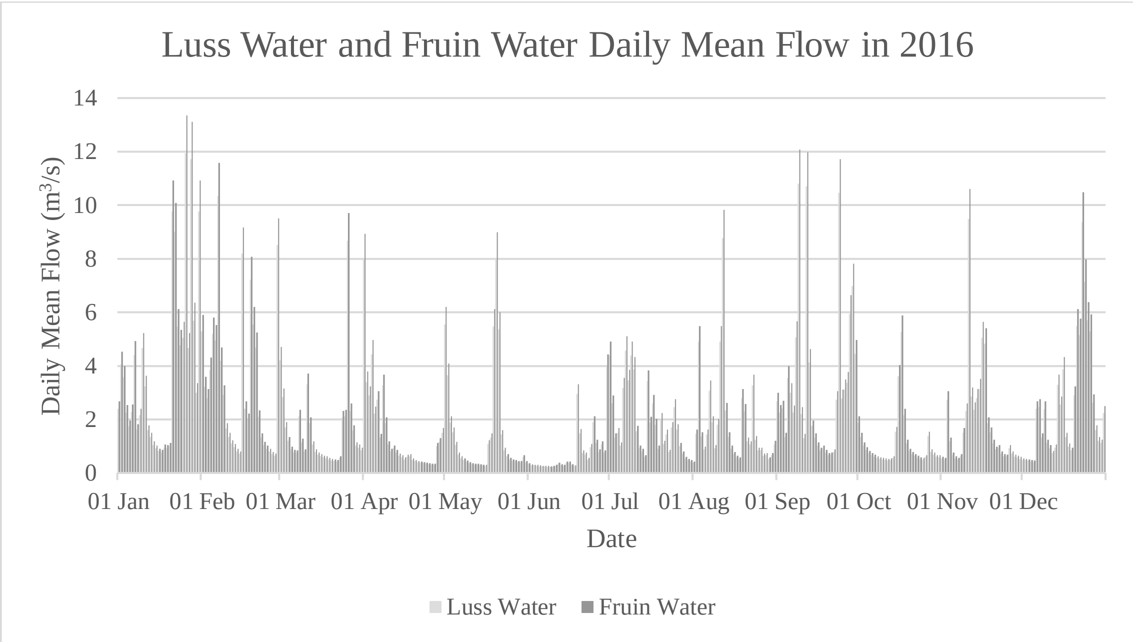


Figure 11: Daily mean flow in 2016 (the latest year a complete data set is available) for Luss Water and scaled for Fruin Water at the case study site

Figure 12 shows the flowrate percentage exceedance chart for the modelled intake, using the data from Luss Water in 2016. The curve shows the percentage of the year that the flow rate was greater than the values on the y axis.

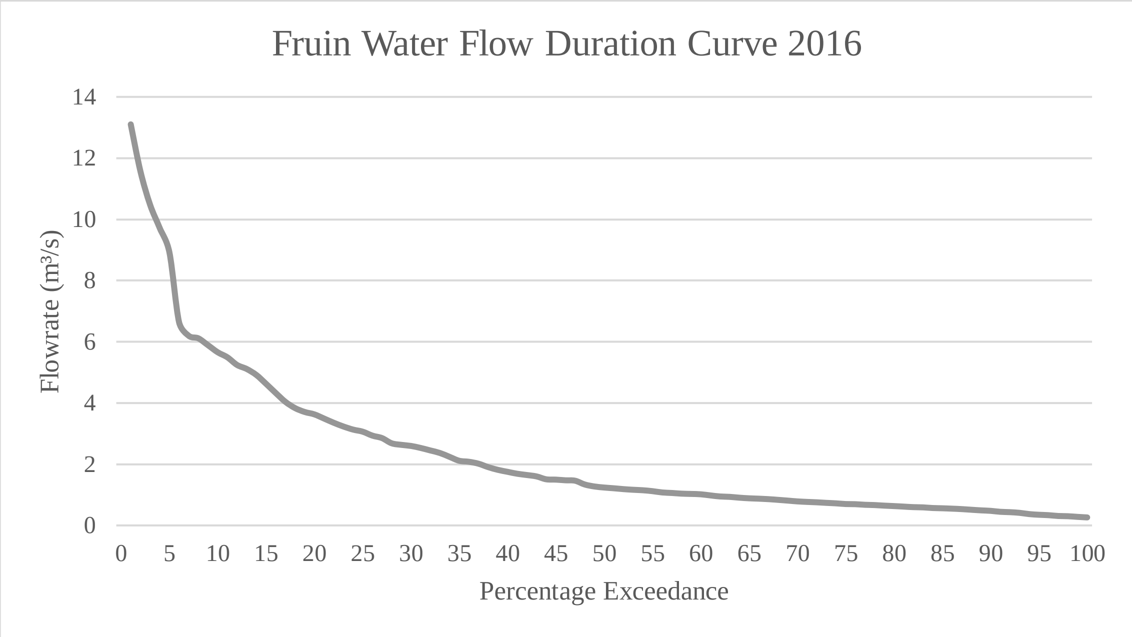
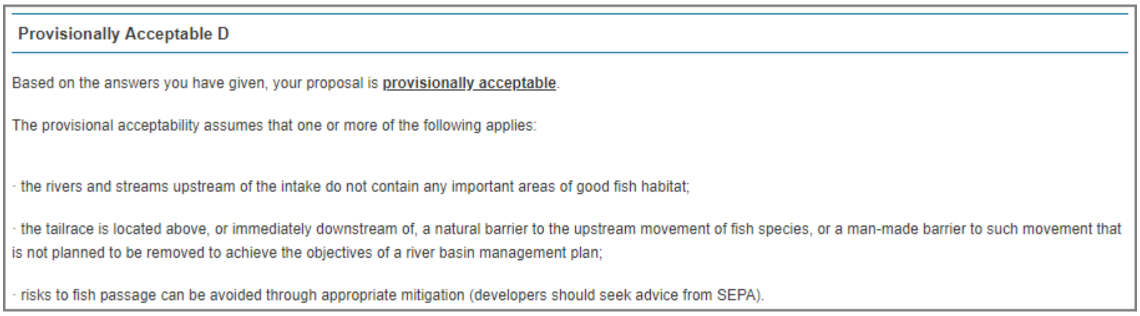


Figure 12: Case study modelled intake flow duration curve for 2016

3.2.2. SEPA Screening

Results from the site assessment were used in the SEPA "Run Of River Hydro Power Screening" tool. Provisional SEPA acceptance is shown in Figure 13.


Provisionally Acceptable D

Based on the answers you have given, your proposal is **provisionally acceptable**.

The provisional acceptability assumes that one or more of the following applies:

· the rivers and streams upstream of the intake do not contain any important areas of good fish habitat;

· the tailrace is located above, or immediately downstream of, a natural barrier to the upstream movement of fish species, or a man-made barrier to such movement that is not planned to be removed to achieve the objectives of a river basin management plan;

· risks to fish passage can be avoided through appropriate mitigation (developers should seek advice from SEPA).

Figure 13: Case study SEPA provisional screening outcome

3.2.3. Initial Design

Based on the detailed site assessment, key design limitations and priorities have been identified, applicable turbines compared, and an initial design proposal has been drawn up in order to meet these priorities.

3.2.3.1.Limitations

The lade has been identified as the limiting factor on flowrate. The maximum lade flow may be used for turbine sizing. It has been calculated that a turbine sited at the weir utilising all available water would likely capture less energy than a smaller turbine sited at the existing wheel well using only the water channelled along the lade. This difference is due to the influence of the head available. Example scenarios may be seen in Table 1.

Table 1: Comparison of annual energy capture from two different turbine locations using turbines sized to the available head and flow at those sites, and both using an example overall efficiency of 65%

	Turbine at End of Lade	Turbine at Weir
Head:	5.1 m	2.5 m
Turbine Rating:	60 kW	200 kW
Energy Capture:	350 MWh/year	320 MWh/year
Capacity Factor:	67%	18%

The limiting factor of the lade also drastically reduces the variability of the river flow. Looking at the chart in Figure 12 it can be seen that if 1.84 m3/s (the maximum flow of the lade calculated in section 3.2.1.1) is extracted via the lade, this will leave the weir over-topping 38% of the time, and most importantly during spate conditions when fish are most likely to attempt to swim up the river. Access to the original wheel site is far easier than access to the weir, therefore operations at the weir should be minimised. These limitations suggest that the original layout should be retained, and the new turbine should be installed in the location previously used for the water wheel.

3.2.3.2.Priorities

The main priority for the site is to maximise renewable energy capture.

Secondary to this is a desire to minimise environmental impact by ensuring minimal additional civil engineering. The existing civil engineering has already created an impact on the river and surrounding area. Therefore, the existing layout should be utilised as far as possible with additional civil engineering avoided.

Noise pollution must be considered, as domestic housing is sited within 40 m of the proposed turbine site. However, there is already noteworthy noise output from the existing river turbulence, and a baseline should be taken for assessment of additional pollution.

The river is valued for salmon and trout fishing. Fish passage requires frequent overspill at the dam, therefore either a turbine that allows fish to pass or suitable screening should be employed.

3.2.3.3.Applicable Turbines

Having low head and high flow, a limited choice of turbines is appropriate for the site.

Reaction turbines are generally more appropriate than impulse turbines for low head sites. Specifically, for the case study site, this class of turbines would include axial flow (e.g. Kaplan) or crossflow turbines. The axial flow turbine works in a similar way to a propeller in reverse, positioned in a tube. The crossflow turbine is cylindrical in shape, which allows for simple variation in power rating through varying the length. Both use the flow of the water over runner surfaces for turning motion and have the potential for high efficiency. Screening for fish and debris would be required.

An Archimedes' screw would also be appropriate. Here, the weight of the water is used to turn the machine. Archimedes' screws have been shown to be capable of good efficiency and simplify the challenge of enabling fish passage, as they can pass through the screw unharmed. Noise might be an issue, as the screw sits within the water at the outlet and excessive splashing can occur.

Another option is the reinstatement of a traditional wheel. As with the screw, the weight of the water is the driving force. As a traditional technology, this could arguably be more aesthetically pleasing, but would likely be far less efficient than the options above and be a larger burden on repair and maintenance.

3.2.3.4.Proposal

Relevant observations and calculations discussed above suggest that the original scheme, designed and realised by millwrights, has already employed the site layout to its full potential. The new scheme should include restoration of the weir and lade, but with a modern turbine sited within the existing wheel well.

3.2.4. Power Output and Energy Capture

The available head and maximum flow of the lade channel and an assumed overall efficiency of 65% (Elliott, 2014) may be used to approximate the maximum power and therefore the maximum rating of the required turbine:

$$P_{max} = \eta g Q h$$
$$P_{max} = 0.65 \times 9.81 \times 1.84 \times 5.1$$
$$P_{max} = 59.8\ kW$$

Flow data from 2016, obtained as described in section 3.2.1.3, was then used in an Excel spreadsheet to estimate the potential energy capture over a full year. With a 60 kW turbine, 355 MWh per year is predicted with a capacity factor of 67%. Reducing the size of the turbine slightly to 50 kW would allow for up to 15% friction losses through the intake and simplify grid connection using G99 regulations. This would reduce energy capture to around 319 MWh per year and increase the capacity factor to 73%.

The installation of a 50 kW turbine using flow of up to 1.54 m^3/s, as shown overleaf in Figure 14, will result in overspill at the weir 43% of the time, and most importantly for fish passage, overspill will always occur when the river is in spate. Maximum flowrate for a large proportion of time enables the exceptionally high capacity factor of the scheme. However, the turbine will not be running at full capacity 57% of the time. Dependent on turbine employed, a variable speed controller may be required to compensate for the reduction in flowrate. The minimum power output will be around 8 kW.

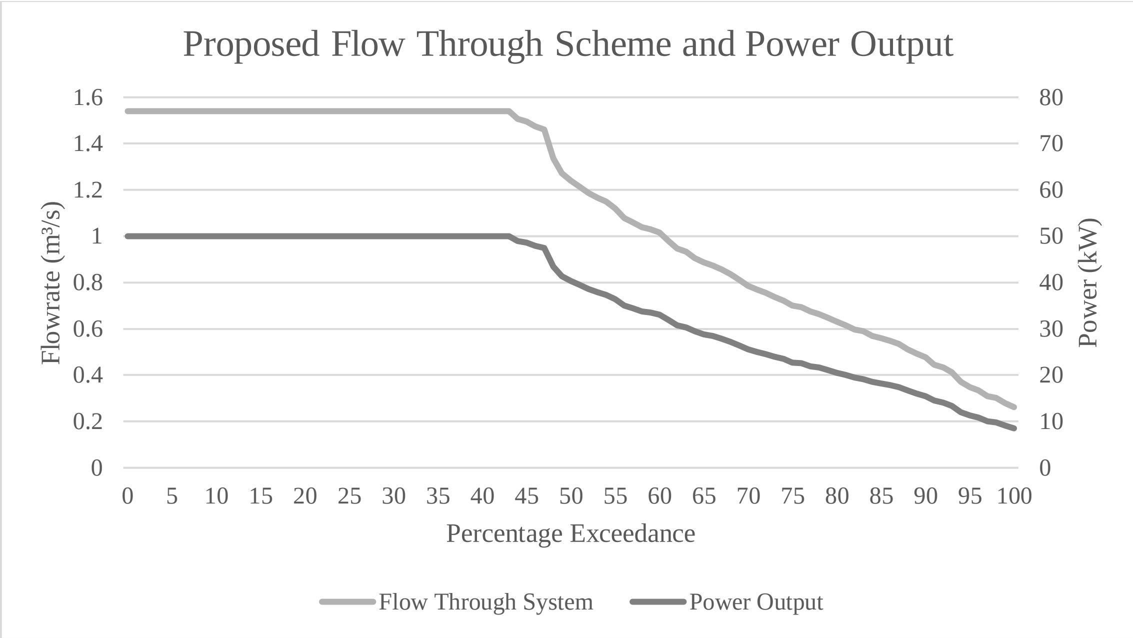


Figure 14: Case study proposed flow through scheme (primary axis) and power output (secondary axis) at 65% overall efficiency using 2016 flow data and 50 kW turbine

For comparison, a run-of-river hydro scheme was installed in Glen Douglas (three valleys north of the case study site) in 2010 (Renewable Energy Foundation, 2019b). Inverbeg Hydro Scheme has a 1 MW turbine, producing between 2,500 MWh and 4,200 MWh each year from a smaller catchment area. It has a capacity factor of between 28% and 46%, which is relatively low for a hydro scheme. The vast difference in power and energy capture from this scheme and from the proposed case study can be explained by the difference in available head, the influence of which can easily be seen in the equation above. Inverbeg has a head of around 55 m, compared with only 5.2 m at Dumfin Sawmill.

3.2.5. Microgrid

With electricity exports from the scheme likely to attract around 5.5 p/kWh under SEG, and electricity in the local area being bought for around 15 p/kWh, it would be sensible to attempt to utilise the electricity generated directly. If the scheme were a community owned and managed project, a microgrid could also be developed to extend to the local community. The grid connection point at the MV transformer nearby would be a sensible boundary for the microgrid. Using the local community audit described in section 3.1, representative annual demand profiles were generated using HOMER Pro (v3.13.1 from HOMER Energy LLC).

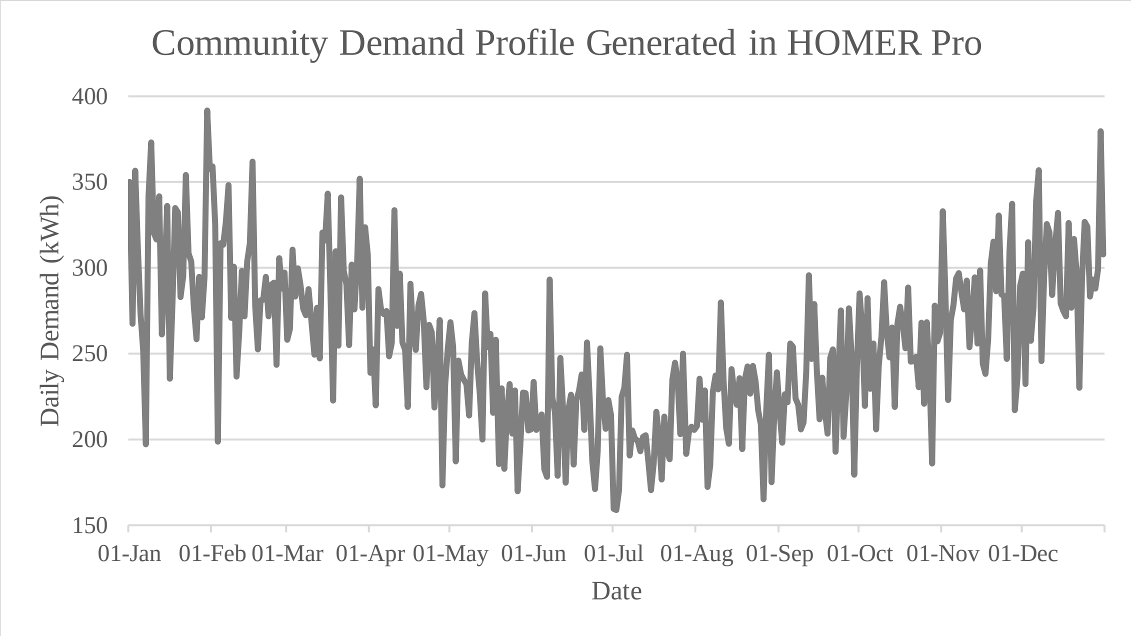


Figure 15: Case study community demand profile

The generated daily community demand profile for the year is shown in Figure 15. Total representative energy demand for the community is 93.4 MWh per year, with power averaging 10.7 kW and peaking at 38 kW.

Although not included in this modelling, a degree of dispatchability using storage behind the weir could be employed with an automated gate within the lade. Demand-side management could also be employed to activate and deactivate non-time sensitive demands (e.g. water and space heating) according to the available power from the hydro scheme. These two enhancements would reduce exports and imports, reducing the impact of variability on the national grid.

3.3. Demand-Supply Matching

The energy generated by the hydro scheme has been calculated in section 3.2.4 as 319 MWh per year. In section 3.2.5 it has been calculated that the local community could utilise up to 29% of this supply, with an energy demand of 94 MWh. As electrical energy must be consumed and generated at the same rate, either generation will need to be slowed, or an additional load must be introduced to consume the 61% excess supply. In addition, some form of energy storage is required to charge with surplus supply and discharge at times of excessive demand. A connection to the national grid meets both requirements. Figure 16, overleaf, shows the power output from the hydro plotted over the range of daily power demand – that is the lowest to highest average hourly power demand each day.

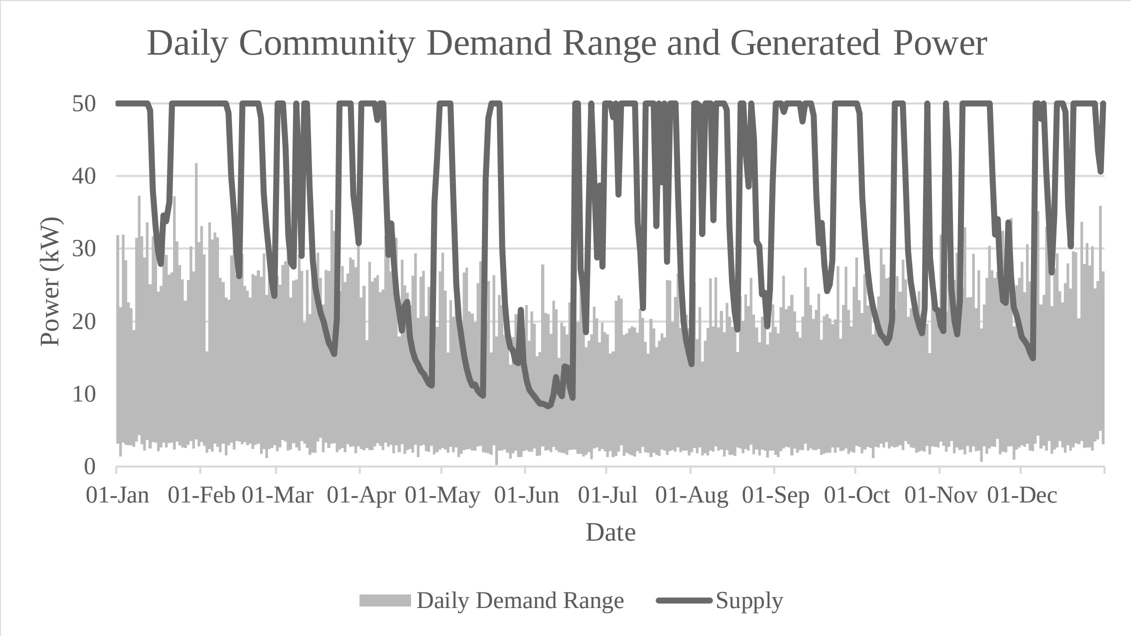


Figure 16: Case study daily power demand range and supply

For representative supply data, the 2016 river flow data has continued to be used as an example year. Similar peaks and troughs are shown at various times in other years. To take an average over several years of flow data would present a smoothed supply plot which would not be truly representative.

It is clear from the chart above that supply exceeds demand for most of the year. However, there are times, notably in June, where supply is restricted, and demand exceeds supply. The supply and demand profiles were imported into Merit (v3.36 from the Energy Systems Research Unit) to calculate the matching of demand and supply. Merit calculates:

- The community would utilise 91.8 MWh directly from the hydro scheme – 98% of demand is met
- The community would need to buy 1.45 MWh from the grid – less than 2% of demand
- The scheme would export 226 MWh to the grid – 71% of generation

It is also clear that the scheme will change the community to a net exporter of energy. They will regularly export far more power than the community currently consumes. As discussed in section 2.4.3 above, this is unlikely to excessively stress the local transmission network.

3.4. Impact Assessment

Following International Association for Impact Assessment (IAIA) good practice, environmental impact was considered throughout the feasibility and design process detailed above.

The visual impact of the case study scheme is likely to be similar to that at Keithick, Perthshire shown in Figure 17.

Figure 17: Photograph of 35 kW Archimedes' screw at Keithick, Perthshire, reproduced with permission (MannPower, 2015)

The main considerations for an impact assessment of the case study site are listed below.

3.4.1. Positive Impacts

Although a relatively small generator is employed, significant renewable energy generation will be achieved.

GHG saving of 46 tCO_2e/year (tonnes of CO_2 equivalent per year) when compared with the predicted carbon intensity of current generation on the UK grid (144 gCO_2e/kWh (GOV.UK, 2019d)). This saving will reduce over time as the grid continues to be de-carbonised.

The environmental damage from civil engineering (weir and lade) has already taken place at the site. The scheme extends the lifetime of the civil engineering and represents a saving when compared with other undeveloped scheme sites.

Reinstatement of the salmon pool will aid the passage over the dam for migratory fish (mainly salmon and trout). Atlantic salmon is a SNH protected species (Scottish Natural Heritage, 2019).

An improvement of the visual appearance of the stretch of river is expected with annual maintenance.

3.4.2. Adverse Impacts

A minor impact from additional noise pollution is anticipated.

Minor or negligible environmental impact on the following species is expected (species marked with an asterisk are SNH protected species, which incorporate European Protected Species (EPS) and The Birds Directive (Scottish Natural Heritage, 2019)):

- Birds*: including heron and many common garden birds
- Mammals: bats*, mink, pine marten*, bank voles, deer*
- Trees: various native species, mainly ash, beech and sycamore
- Common mosses, ferns and lichen

Installation of a modern turbine in place of the historic wheel may incur minor or negligible loss of cultural and architectural heritage.

3.4.3. Mitigations

As noted, the existing salmon pool should be reinstated and maintained.

Fish screening at the intake may be required.

Tree and environment loss could be compensated for within the area.

3.5. Financial Assessment

Estimates of total installation costs for a 100 kW low head hydro range from £250,000 – £500,000, and in addition £4,000 – £6,500 annually for running costs (British Hydropower Association, 2012). SEPA (2018) estimates costs of £200,000 for installation of the same system. Reuse of civil works should reduce the cost significantly compared with a greenfield site. Mann Power Hydro Ltd. is a supplier of hydro equipment and consultancy with considerable experience across the UK. A discussion of the project with a representative from the company resulted in an advisory costing of £130,000 for all required equipment. Based on these estimates, indicative estimates of £200,000 for installation and £5,125 for yearly running cost have been used for the financial analysis.

The Scottish government's Community and Renewable Energy Scheme (CARES) offers significant funding for community projects (gov.scot, 2019b):

- Enablement grants of up to £25,000 towards non-capital start-up costs
- Development loans covering up to 95% of all costs up to construction completion. The loan is unsecured, and the fixed interest rate is 10% p.a.
- Home Energy Scotland Loans of up to £2,500. The loan is interest free but has an administrative fee of 1.5% (£37.50)

HOMER Pro has been used to assess financial viability. Based on the estimates and values above, nominal discount rate was set at 10%, with expected inflation at 2% giving an annual real interest rate of 8%. Income from exported energy has been set at 5.5 p/kWh from SEG (as discussed in section 2.3). Cost of electricity from the grid has been set at 15 p/kWh. For the hydro scheme, installation costs have been set at £175,000, and yearly running cost at £5,125.

The hydro scheme alone, exporting through SEG and without the community microgrid attached, would have a net present cost (NPC) of £42,000, and would therefore be unable to pay back the capital costs within 25 years.

Adding the microgrid gives the project financial viability, with indicative Internal Rate of Return (IRR) at 11.2%, a Return on Investment (ROI) of 8%, and a payback within 8.3 years. The scheme has an NPC of £99,000 over 25 years. Compared with the NPC of continuing to use grid electricity at £152,000, the scheme represents a saving of £53,000. Figure 18 shows the cumulative nominal cash flows of the hydro scheme with microgrid and the community continuing to use grid electricity without implementing the scheme.

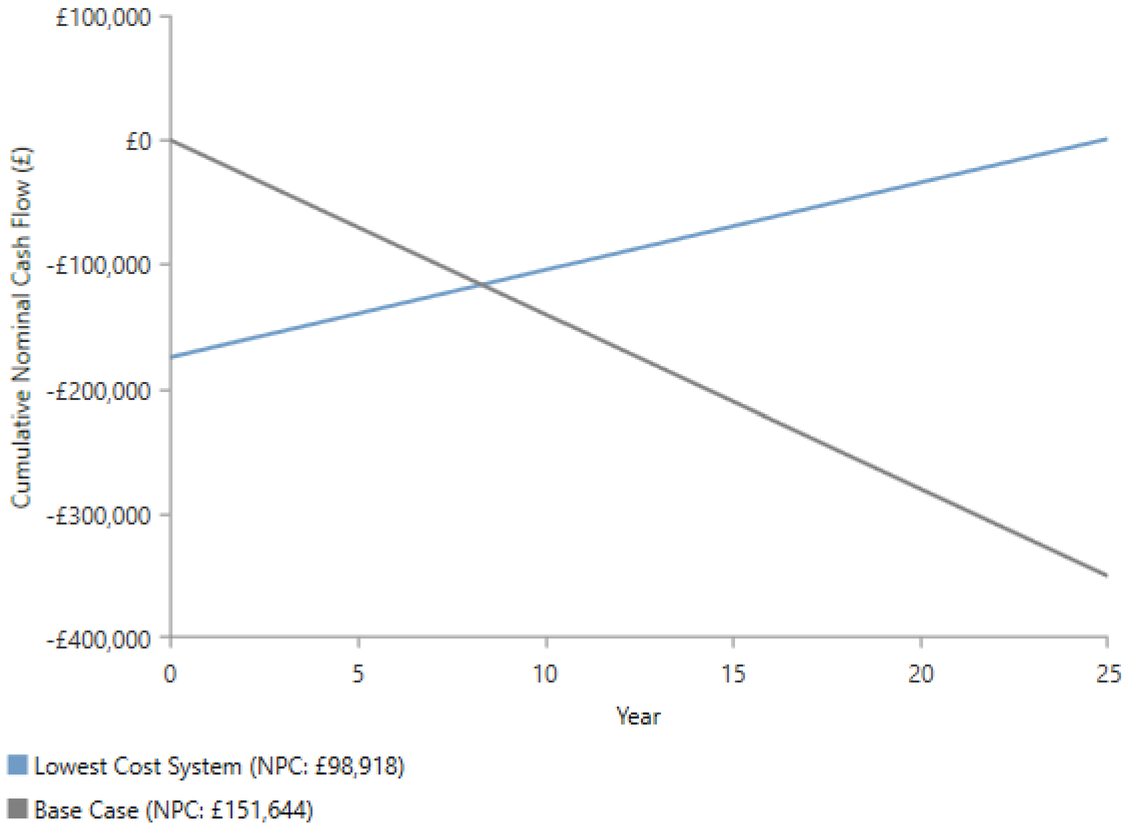


Figure 18: Case study financial comparison from HOMER Pro. Comparing implementing the hydro scheme with microgrid (blue line) with the local community continuing to purchase energy from the grid (grey line) over 25 years

If FITs were still available at their 2019 rates, the scheme would reach payback within 8.6 years, or 6.6 years utilising the microgrid. At FITs original 2010 rates the scheme would generate £86,000 gross profit per year with payback within 2 years.

3.6. Case Study Discussion

The case study has shown that a historic, disused water mill site may be reinstated with a modern hydropower turbine for embedded generation. Further, the case study has shown that the reinstatement can be carried out in a logical and straightforward manner, with minimal additional civil engineering and minimal adverse environmental impacts. Ensuring that the reinstatement is financially viable has become more challenging with the loss of targeted government support mechanisms. Using a community owned microgrid to utilise the generated power locally gives the scheme a reasonable payback period because the value of the electricity is increased. The impact on the power quality of the national grid has also been minimised.

While offsetting construction costs by utilising local consumption, it is important to ensure honesty on exactly what is being powered. MacKay (2008) discusses the following disingenuous example:

> "Glendoe [Hydropower Station] has been billed as "big enough to power Glasgow." But if we share its 180 GWh per year across the population of Glasgow (616 000 people), we get only 0.8 kWh/d per person. That is just 5% of the average electricity consumption of 17 kWh/d per person. The 20-fold exaggeration is achieved by focusing on Glendoe's peak output rather than its average, which is 5 times smaller; and by discussing "homes" rather than the total electrical power of Glasgow…. The "home" covers the average domestic electricity consumption of a household, only. Not the household's home heating. Nor their workplace. Nor their transport. Nor all the energy-consuming things that society does for them."

The microgrid discussed above assumes normal home electricity consumption and includes space and water heating, without electrified transport. It was not possible to assess the use at the working farm identified in the community in section 3.1.

In a similar vein, while discussing CO_2 and other GHG savings, it is important to note that the grid, the alternative source of electricity at the case study site, is experiencing continuous de-carbonisation. Figure 19, overleaf, shows the UK government predictions of future grid carbon intensity. The continued decline reflects predicted increases in renewable generation and reduction in fossil fuelled generation. The fall between 2017 and 2018 predictions is due to higher than predicted renewable generation and early closure of coal fired power stations in this time. While per unit intensity is predicted to fall, overall emissions from grid generation are likely to increase as electricity demand increases in future years through electrification of transport and heat.

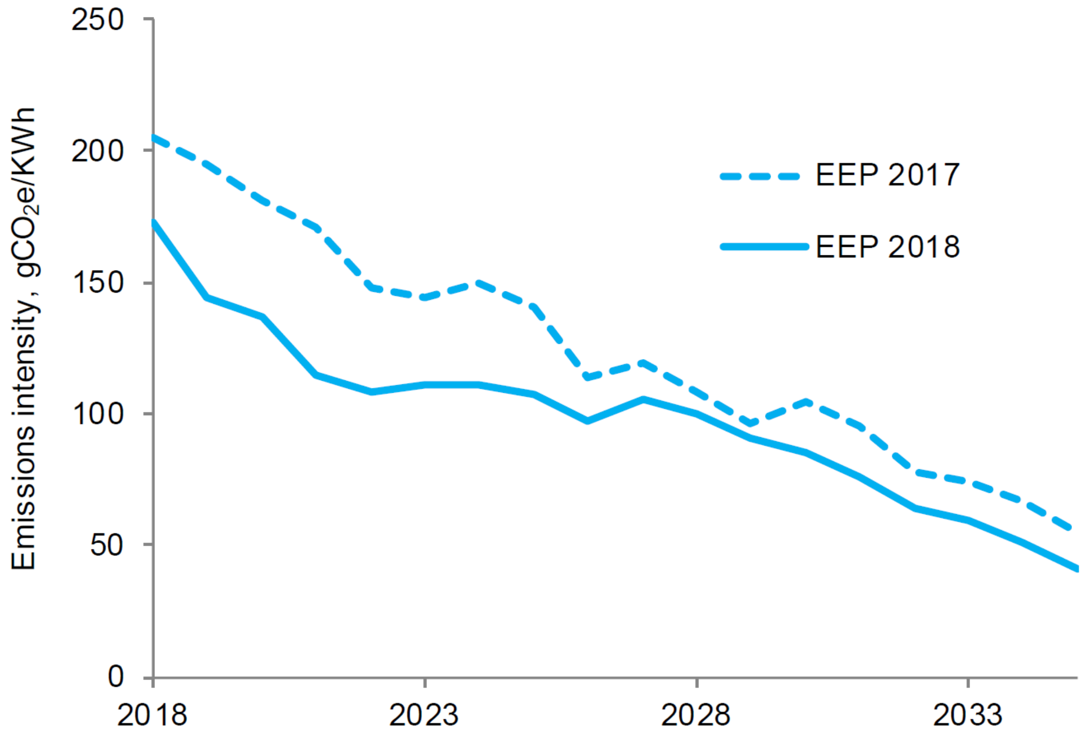


Figure 19: Power sector emissions intensity in EEP (Energy and Emissions Projections) 2017 and 2018. Measured in grams of CO_2 equivalent per kWh electricity generated on the national grid (GOV.UK, 2019d)

Based on this data, CO_2 savings through clean generation at the case study site will reduce significantly in future years from the predicted 46 tCO2e in 2019-20. However, the predicted decline is only possible through increased renewable generation capacity such as the proposed scheme. The scheme and similar schemes are contributing to the reduction in grid emissions intensity. Embedded emissions from construction and installation of the project should also be considered, but it could be argued that these would equally be present in equivalent non-renewable power plants.

3.6.1. Methodology

The case study has developed a model hydropower scheme which could then be replicated at similar sites. Adjustments to the model may be required to accommodate different flow rates and heads. The methodology developed through the case study consists of the following:

1. Identification of the site
2. Site assessment (including head and annual flow)
3. Initial design
4. Calculation of power output and energy capture
5. Production of microgrid demand profiles
6. Demand-supply matching
7. Impact and financial assessments

Working through each of the above, an assessment of predicted viability at the case study site has been achieved. The next section will consider how this can be applied to other sites.

4.0 Regional Relevance

4.1. Objective

A model micro-hydro scheme utilising a historic mill site has been developed through the case study in section 3.0.

This section attempts to estimate the potential of, and impact from, a programme of replicating the model across the Loch Lomond and The Trossachs National Park (LLTNP).

LLTNP is the fourth largest national park in the UK, covering 2.4% of the area of Scotland. The park sits partly within four Scottish council areas: Argyll and Bute, Perth and Kinross, Stirling and West Dunbartonshire. Historically, these counties were named Argyll, Dunbartonshire, Perthshire and Stirlingshire, and there have been some border changes between them since. The four counties combined cover nine times the area of the national park and a fifth of the area of Scotland.

The model is specific to the case study site: a 5.2 m head and 9,800 m^3 annual water flow through the system. Questions that must be addressed include:

- How many other potential sites exist?
- How should the model be scaled for other sites? Can it be replicated directly?
- What cumulative effects must be recognised and mitigated?
- What is the total and realistic impact from the whole programme?

4.2. Benefits

The obvious main benefit of a programme of developing renewable generators is the clean power generated. In addition, significant global, national and local benefits may be realised.

4.2.1. Global Benefits

Humankind's awareness and acceptance of climate change and its causes is increasing. Development of renewable power generators contributes to a reduced reliance on fossil fuels and a reduction in GHG emissions without impacting lifestyle.

4.2.2. National Benefits

Scotland has an ambitious target to increase renewable capacity by 2020. Although one small scheme may not make an impact on a national scale, collectively a program of small generators would contribute towards meeting this target. In addition, Scotland aims to increase electrification of heat and transport, which will likely require increased supply.

Large generators enjoy significant economies of scale when compared to small generators. However, many small generators would provide significant security of supply. For example, should one generator be taken offline for repair or maintenance. Cumulatively, the environmental and visual impact of many small generators spread across the nation is likely to be far less damaging compared with one large scheme (see photograph of Loch Tarsan in Figure 1).

A programme of similar schemes will provide opportunities for significant economies of scale. For example, reuse of scheme design, fabrication tooling and installation methods. Further, optimisation from scheme to scheme should be pursued as different challenges and opportunities arise with each site.

4.2.3. Community Benefits

The programme targets previously developed sites, reusing existing civil engineering. The community should expect minimised additional impact from any further civil engineering. In addition, regulation may force work to be carried out to improve the sites, enabling fish passage over derelict weirs, as an example.

The programme would provide opportunity for developing local employment and expertise, especially in civil engineering, fabrication, installation, and service and maintenance.

Community involvement should be encouraged during planning, financing and operation of the scheme. A relatively cheap local electricity supply may encourage further electrification of heat and transport, reducing localised pollution.

4.3. Identifying Suitable Sites

One of the main tenets of this project's aim was to avoid greenfield development by reusing existing historic mill sites. Identifying and screening candidate locations presents a major challenge, but this is required to enable a picture of the overall impact from a collection of similar generators.

4.3.1. Assessment Approaches

Evaluation of the hydro potential of a site would usually start with a predetermined reach of river, for example, a landowner looking at ways to develop part of their estate. A very simplistic approach to a wider survey could be to obtain lists of Scottish rivers, identify their lengths and descents, then calculate the number of possible schemes for each river. The catchment, and therefore flowrate for each scheme along a river, would differ and suitable recovery would be required between schemes. Calculations of power output would have to take these differences into account. Historic Scottish estates were the likely instigators of many mills and, in the early 20th century, electricity generating schemes. To specifically assess historic sites, assumptions could be made on likely uses and locations of these schemes based on the sizes of the estates.

Previous studies of national hydropower potential have used various means for identifying all suitable sites. The Salford study, in 1989, simply requested information from electricity generating boards and councils in Scotland (Forrest, et al., 2008). In 1993 and 2001, later studies expanded on this by visiting the most promising of the sites previously identified. Forrest et al., and later studies, have developed software to automate identification of suitable sites directly from GIS data (Sample, et al., 2015). While researching the history of water power in Scotland, Shaw (1984) used the first Ordnance Survey maps, surveyed between 1846 and 1870 to compile distributions of different types of mills. With this method, Shaw counted many thousands of mills across Scotland, including over 700 sawmills.

4.3.2. Approach Employed

To identify water courses with historic mill sites, rather than greenfield sites, Shaw's approach of scanning historic OS maps was employed for this project. Unfortunately, Shaw did not publish his lists of identified water mill sites. However, the historic OS maps have been digitised and are available online from the National Library of

Scotland. In addition, the OS Name Books, collated in the mid-19th century, have also been digitised and transcribed and are also available online. These name books describe place names and building names surveyed for the first edition OS mapping.

OS maps covering the park were identified by comparing the sheets to a modern map of the park. Where maps were on the borders of the park, or between counties, and contained small portions of the park, these were manually searched and discounted if no mill sites were found. A total of 48 six-inch maps were identified covering the park, these are listed in Appendix A.

There is no direct link between the maps and the OS name books. The descriptions of each were used to cross reference and 28 name books were identified. These are listed in Appendix B. Regrettably, some of the Perthshire OS Name Books were destroyed during the Second World War, including Balquhidder and Killin. At the time, nearly all of the north-eastern half of the park was within Perthshire. The proportional difference between the identified OS maps and name books available for the park is stark. 46% of the identified OS maps are within Perthshire, yet only 21% of the name books are available for the same area. The numbers suggest it’s possible that a further 13 relevant name books are missing.

The identified name books were then searched with the keywords ‘mill’, ‘dam’, ‘weir’, ‘lade’ and ‘wheel’, although only ‘mill’ and ‘dam’ gave useful results. Each hit was then manually checked using the descriptions in the name books then cross referenced with appropriate maps. Each site was checked both on historic and current maps to ensure its situation within the park, reasonable layout of the mill site and that a hydropower retro fit development might still be physically possible.

4.3.3. Identified Sites

A total of 24 mills were identified using the approach outlined above, including four sawmills. With sections of the park boundary being defined by watercourses, five of the identified sites are on the border of the park. As discussed, Shaw discovered thousands of mills in Scotland, including over 700 sawmills, using a similar method. The park covers 2.4% of the area of Scotland. It should be expected that over 100 mills, including around 17 sawmills, would be in the park, suggesting these results are disappointing. Only three sites were found in Perthshire and none were found in the northern half of the park, suggesting the missing name books had a significant impact on these results. A further five mills, known to the author, were added to the results in that area (at Killin, near Balquhidder and near Callander). The 29 target sites are shown in Figure 20.

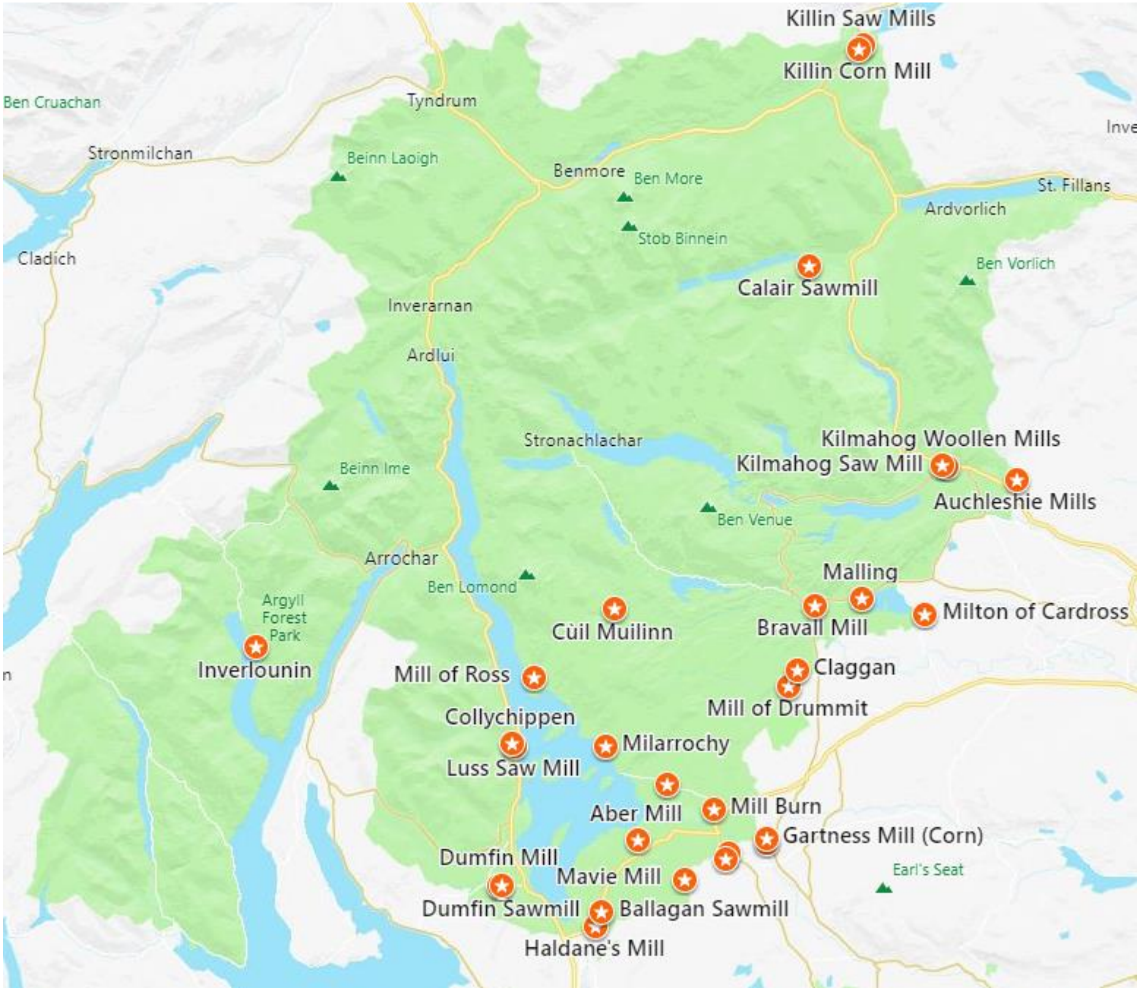


Figure 20: Identified target mill sites, the green area is the national park (Bing maps © 2019 Microsoft, map available at https://binged.it/2KDnpG3)

4.3.4. Validation

Eleven of the identified sites were visited to attempt visual confirmation of suitability. It was difficult to gain access to many areas of several sites, sometimes limited to viewing the appropriate watercourse from a road bridge and having to estimating the height differences in the local landscape. Lower flow rates in the source watercourses than the case study site might be addressed by extracting a greater proportion of the water. Ideally, a more detailed site assessment, with physical measurements, would be carried out to fully verify the collective potential.

Near Drymen, Mill Burn has a lower flow rate than the case study site, but enjoys a greater head to counter this. However, there is no obvious evidence of the former mill's civil engineering. Further along the road towards Balmaha, Buchanan Mills (pictured in Figure 21) has been converted to residential use and looks to have reasonable flow and head. The wheel on display is smaller than that at the case study site, but two mills were previously supported on this site.

Figure 21: Author's photograph of Buchanan Mills near Drymen

Milarrochy is a residential property. The source and tailrace were found and suggest a much lower flow rate through the mill.

Ballagan Saw Mill near Balloch is now an agricultural supplies store, and Aber Mill near Gartocharn is also a residential property. Both seem to retain their former layout and have good head and reasonable flow.

Haldane's Mill, near Balloch, and Croftamie Mill have residential housing built on and around their sites, which would present a challenge for retrofit. Croftamie Saw Mill, and Mavie Mill nearby, could not be seen. However, Catter Burn, on which they sit, has very good flow and modern maps suggested that both seem to retain much of their former civil engineering.

Next door to Dumfin Sawmill, Dumfin Mill is in a similar state of disrepair. The lade still exists but is dry and the mill building has been removed. Instead of a weir, the mill's lade channels water either side of a set of waterfalls, giving a very similar head to that of the case study site. The flow rate is slightly lower because the catchment is slightly smaller, with a small tributary joining the river between the two mills. Two hydro schemes in proximity, create two major challenges; water power recovery and electrical load. Despite being within 300 m of each other, there is still a sufficient altitude drop between the mills to enable sufficient recovery in the river between the two schemes. The G99 regulations allow multiple low powered generators to connect to the same low voltage network. However, the microgrid modelled in the case study could only be included once, possibly affecting financial viability. Four other pairs of the target mills have similar proximity issues that will need to be accounted for.

Near Luss, Collychippen and Luss Saw Mill have similar flow to the case study (N.B. the case study river flow was modelled on Luss Water). These sites seem to have a significantly lower head, but they could extract a greater quantity of water to maintain similar power.

The mills at Killin enjoy significantly greater flow than the case study site. Similar or greater extraction via the mill lades would easily be achieved, and a similar head is available. Situated within a more populous area suggests local use of all the generated energy would be likely, reducing impact on the grid and aiding financial viability of the schemes. As with many locations within the park, Killin is a popular tourist village but this does not necessarily indicate that a small hydropower scheme or two would be rejected. It must be hoped that an installation would be carried out sensitively and could perhaps be deemed as an additional village attraction.

While grid capacity constraints are less likely to affect smaller projects, cumulative projects may cause issues. Scottish and Southern Electricity Networks (SSEN), the DNO covering the national park, shares their grid constraint status online. The area covering the park is shown in Figure 22 overleaf.

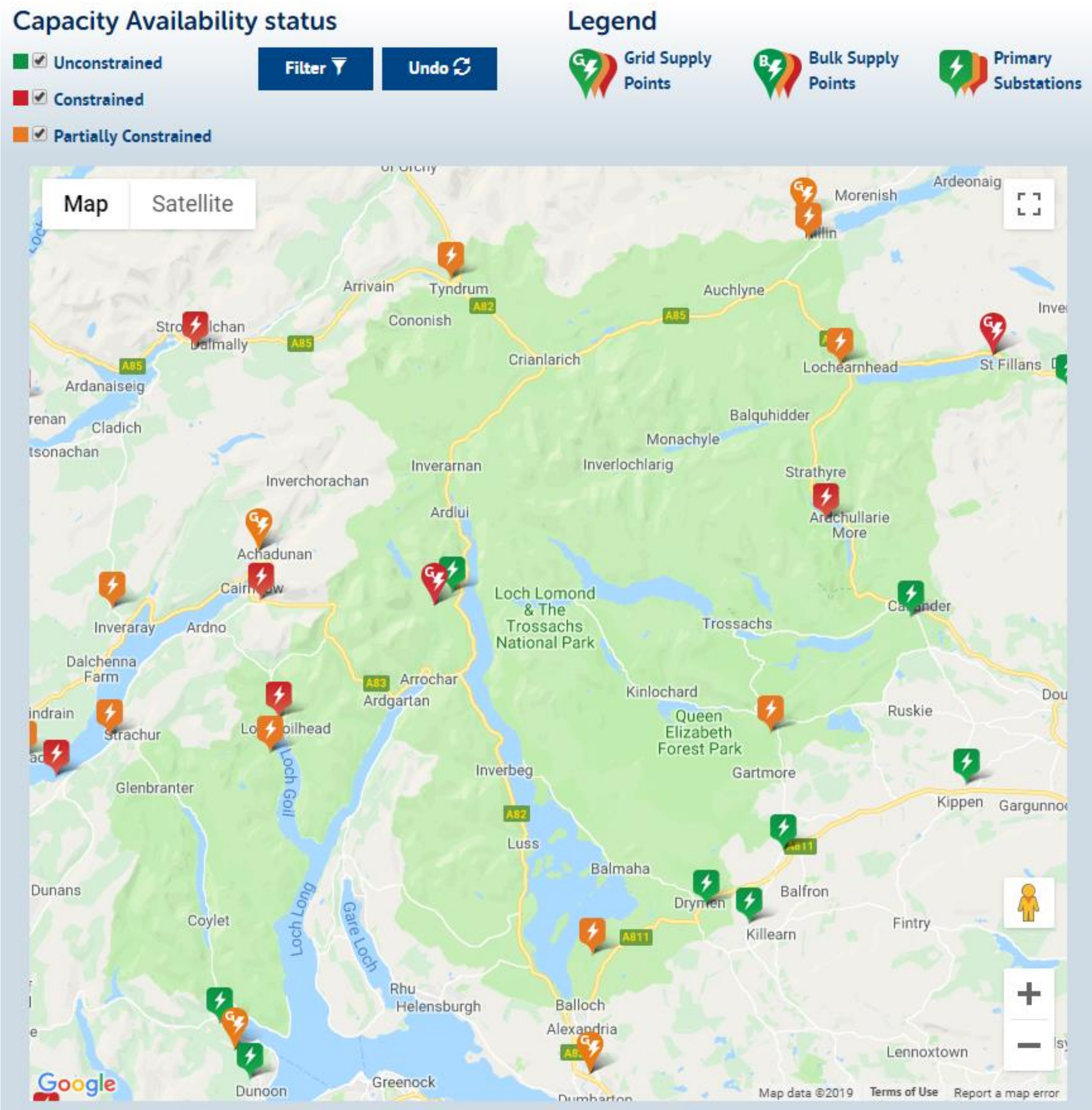


Figure 22: SSEN generation availability map. The green area is the national park (Scottish and Southern Electricity Networks, 2019)

Comparing the map screenshots in Figure 20 and Figure 22, one site (Inverlounin near Lochgoilhead) is near a constrained substation which could restrict additional generation at the site.

Ideally all target sites would be visited and properly assessed for viability. However, informal visits suggest reasonable viability of around three-quarters of the identified sites. The differing flows at some sites suggest different types of turbines may be appropriate.

4.4. Results

If three quarters of the 29 identified sites were developed in the same manner as the case study site, allowing for slightly less flow at some sites, a total installed capacity of around 1 MW would be achieved. At this level, collective generation of around 6.4 GWh/year would be achieved, with a GHG saving of around 1,000 tCO2e/year against current grid generation.

For comparison, Figure 23 shows construction of a 1.5 MW windfarm in 2015 at Easter Melrose in Aberdeenshire (Aberdeenshire Council, 2012). The farm consists of three 500 kW wind turbines and produces an annual quantity of energy similar to that of the proposed hydro schemes collectively (Renewable Energy Foundation, 2019c). The farm's capacity factor of around 50% is particularly impressive for on-shore wind. With a maximum height of 77 m, the turbines have a significant impact on the landscape. A similar scheme would be very unlikely to be accepted by the park authority as being appropriate.

Figure 23: Photograph of construction of one of three 77 m wind turbines at Easter Melrose, Aberdeenshire (© Orkney Sustainable Energy Ltd. 1995 – 2019)

Another comparison may be made with the 1 MW run-of-river hydro scheme at Inverbeg, discussed previously and pictured in Figure 24. Inverbeg has a similar installed capacity to the collection of proposed schemes, but, with a lower capacity factor, it produces less energy. Although the scheme holds a substantial area of water behind a small dam, the intake is along the top of the spillway enabling simple screening, and there is secondary pool to allow fish passage. During construction, considerable civil engineering was required, including the small dam, burial of around 1,600 m of pipe, and a turbine house. Following reconstruction, however, the scheme has a similar visual impact to that of maybe three or four of the proposed schemes combined. LLTNPA has approved several similar schemes in the past decade.

Figure 24: Author's photograph of the intake and fish pool at Inverbeg hydro scheme in Glen Douglas.

4.5. Discussion

The number of potential sites identified by the regional survey is disappointing when compared to Shaw’s historic survey. This was partly caused by missing source data for part of Perthshire, but despite this, a higher number of sites were expected from the source used. In addition to this limitation, sites developed after the OS survey in the mid-19th century will not have been detected: estate hydropower schemes developed in the early 20th century for example. To either identify missing sites, or to confirm the results above, a new survey method should be developed and carried out. Despite the low number, the identified sites show a higher level of potential than expected. This would be both in terms of power available and access to the original civil engineering.

While it may be possible to replicate the model case study directly at some sites, the site survey showed that a degree of scalability would most likely be required in order to utilise each site to its optimum. This could be achieved in several ways, most simply by varying the length of a crossflow turbine, or that of an Archimedes' screw. A different turbine technology may be appropriate at sites with a significantly higher head. The cost and benefit of a significant change, such as this, should be investigated further.

Issues requiring consideration through an impact assessment were identified within the case study. These issues related to a single site. The identified sites are reasonably well distributed throughout the southern half of the national park, with up to two sites sometimes in proximity on the same watercourse. This wide distribution limits cumulative impacts. Two cumulative impacts have been identified. The schemes will cause a loss of industrial heritage, as existing engineering is reused and built upon. If deemed significant, this could be mitigated through documentation prior to development and by not developing one or more important sites of historic interest. Secondly, there is a slight possibility that the pairs of sites in proximity may stress the local electricity transmission network if a microgrid cannot utilise a significant portion of the cumulative generation. In this case, financial viability would also be affected, and this may cause only one or other of the sites being developed.

5.0 Conclusions

This project has investigated the potential renewable energy generation available through retrofit of historic mill sites with modern hydropower turbines.

A case study site was identified and comprehensively developed using credible data and methodology. The site shows potential for useful generation rated at 50 kW. A relatively high capacity factor is achievable by not being reliant on extracting all the water, enabling the turbine to run at full capacity 43% of the year. Channelling the extracted water along a lade creates a larger head, countering the effect of this loss of flow. The case study was validated against another local hydro scheme, albeit with a much larger head and installed capacity.

Challenges of embedded generation may be addressed through development of local microgrids to enable local utilisation of the generated energy. The case study showed how nearly all the local community's energy demand could be satisfied by one turbine. Significant exports to the grid would also occur.

Relevant regulation, both nationally and from within the LLTNP, is supportive of small hydro schemes. This has been demonstrated with several new developments within the park in recent years. It has been shown how impacts from the case study scheme may be mitigated or minimised.

The incremental decrease and then loss of the government's REFIT renewable energy support mechanism has been a setback to potential small embedded generators. Despite this, the case study scheme should be financially viable. This would only be achieved by including the development of a microgrid, saving on the middle men costs of energy imported into the community. It will be interesting to see what SEG brings, and whether export prices can be improved under this incentive.

A survey of historic mill sites within the LLTNP has been carried out, identifying sites with the potential for a modern hydropower retrofit installation. A portion of the identified sites were validated through informal visits. The number of identified sites was less than expected, and deficiencies in the survey method have been identified. Significant proportion of the identified sites showed potential for replication of the case study model. This new generation was compared with that of a similar sized windfarm outside the national park, and a hydro scheme within the park. A number of small schemes with low cumulative environmental impact contrast with larger schemes with significant impacts.

Collectively, new generation installed capacity of 1 MW has been identified by this project. This new generation is from sites not previously considered and adds to the 73 MW identified by the LLTNPA and to the outputs from national surveys. If implemented, 6.4 GWh/year would be generated. The energy generated at these sites would represent a saving of around 1,000 tCO2e/year of GHG when compared with the current carbon intensity of the national grid. These schemes would contribute towards the Scottish government's renewables targets.

5.1. Further Work

Firstly, at the case study site, it would be interesting to assess the scope and influence of dispatchability from the small body of water being retained by the weir. Demand-side management could also be assessed within the community microgrid. For example, by automating domestic heating to only operate during times of surplus generation. Controlling the water flow (and therefore energy output) and controlling some of the community energy loads, 100% of the community energy demand could potentially be met without any supplementary energy storage.

Secondly, a repeat of the regional survey, using a different data source would be beneficial.

Thirdly, each site identified should be fully assessed for optimal generation potential. The case study model could then be adjusted to meet the needs of all sites, and a one-size-fits-all approach could be compared with bespoke development at each site. A compromise, with a model scheme that allows for cost effective adjustments, could then be developed and added to this comparison.

6.0 References

Aberdeenshire Council, 2012. *Planning – Application Summary APP/2011/2473.* [Online]
Available at: https://upa.aberdeenshire.gov.uk/online-applications/caseDetails.do?caseType=Application&keyVal=ZZZWU4CAXE726
[Accessed 01 08 2019].

Argyll and Bute Council, 2014. *Reservoirs Act 1975 Public Register.* [Online]
Available at: https://www.argyll-bute.gov.uk/sites/default/files/reservoirs_act_public_register_14_8_8.pdf
[Accessed 01 07 2019].

Battrum, W., 1864. *Battrum's Guide to Helensburgh and Neighbourhood.* 1st ed. Helensburgh: William Battrum.

British Hydropower Association, 2012. *A Guide to UK mini-hydro development v3.0,* British Hydropower Association: Available at http://www.british-hydro.org/micro-hydro-guide/.

Daft Logic, 2019. *Google Maps Area Calculator Tool.* [Online]
Available at: https://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm
[Accessed 01 07 2019].

Dunbartonshire OS Name Books, 1860, 1860. *Scotlands Places.* [Online]
Available at: https://scotlandsplaces.gov.uk/digital-volumes/ordnance-survey-name-books/dunbartonshire-os-name-books-1860/dunbartonshire-volume-13/46
[Accessed 15 07 2019].

Elliott, C., 2014. *Planning and Installing Micro-Hydro Systems.* 1st ed. Abingdon: Routledge.

Energy Networks Association, 2019. *Connection of Generation > 3.68kW (G99).* [Online]
Available at: http://www.energynetworks.org/electricity/engineering/distributed-generation/engineering-recommendation-g99.html
[Accessed 01 07 2019].

Forrest, N. et al., 2008. *Scottish hydropower resource study,* s.l.: Scotland: Hydro Sub Group of the Forum for Renewable Energy Development in Scotland.

gov.scot, 2018. *Renewable Energy.* [Online]
Available at: https://www2.gov.scot/renewableenergy
[Accessed 01 07 2019].

gov.scot, 2019a. *A vision for Scotland's electricity and gas networks,* Edinburgh: The Scottish Government.

gov.scot, 2019b. *Policy: Renewable and low carbon energy, local and small-scale renewables.* [Online]
Available at: https://www.gov.scot/policies/renewable-and-low-carbon-energy/local-and-small-scale-renewables/
[Accessed 01 08 2019].

GOV.UK, 2019a. *Total final energy consumption at regional and local authority level.* [Online]
Available at: https://www.gov.uk/government/statistical-data-sets/total-final-energy-consumption-at-regional-and-local-authority-level
[Accessed 11 07 2019].

GOV.UK, 2019b. *Energy Trends: UK renewables.* [Online]
Available at: https://www.gov.uk/government/statistics/energy-trends-section-6-renewables
[Accessed 11 07 2019].

GOV.UK, 2019c. *Digest of UK Energy Statistics (DUKES) 2019,* s.l.: Department for Business, Energy & Industrial Strategy.

GOV.UK, 2019d. *Updated Energy and Emmissions Projections 2018.* [Online]
Available at: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018
[Accessed 01 07 2019].

ILI Group, 2017. *Red John Pumped Storage Hydro Scheme.* [Online]
Available at: www.redjohnpsh.co.uk
[Accessed 01 07 2019].

Jenkins, N. & Strbac, G., 1995. *Effects of small embedded generation on power quality.* Coventry, UK, IET.

LLTNPA, 2016. *Supplementary Planning Guidance Renewable Energy.* [Online]
Available at: http://www.lochlomond-trossachs.org/wp-content/uploads/2016/07/SPG-Adopted-Plan-Renewable-energy-SPG.pdf
[Accessed 01 07 2019].

LLTNPA, 2019a. *Our vision & aims.* [Online]
Available at: https://www.lochlomond-trossachs.org/park-authority/what-we-do/our-aims-values/
[Accessed 01 07 2019].

LLTNPA, 2019b. *Run-of-river hydro schemes in the National Park.* [Online]
Available at: https://www.lochlomond-trossachs.org/planning/blog/rainy-days-great-run-river-hydro-schemes-national-park/
[Accessed 01 07 2019].

MacKay, D. J. C., 2008. *Sustainable Energy – without the hot air.* UIT Cambridge: Available free online from www.withouthotair.com.

MannPower, 2015. *Keithick.* [Online]
Available at: http://www.mannpower-hydro.co.uk/project/keithick/
[Accessed 01 07 2019].

Masters, C. L., 2002. Voltage rise: the big issue when connecting embedded generation to long 11 kV overhead lines. *Power Engineering Journal,* 16(1), pp. 5-12.

National River Flow Archive, 2019. *85004 - Luss Water at Luss.* [Online]
Available at: https://nrfa.ceh.ac.uk/data/station/meanflow/85004
[Accessed 01 07 2019].

Ofgem, 2019a. *About the RO.* [Online]
Available at: https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro
[Accessed 01 07 2019].

Ofgem, 2019b. *Feed-In Tariff (FIT) rates.* [Online]
Available at: https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates
[Accessed 01 07 2019].

OS, 1862. *Dumbartonshire XIII.15 (Luss), 25 inch to the mile, 1st edition. Reproduced with the permission of the National Library of Scotland.* Southampton: Ordnance Survey.

Renewable Energy Foundation, 2019a. *G01644HYSC: Avochie Estate Micro-Hydro.* [Online]
Available at:
https://www.ref.org.uk/generators/view.php?regoid=G01644HYSC&returnurl=
[Accessed 01 08 2019].

Renewable Energy Foundation, 2019c. *G02382NWSC: Easter Melrose.* [Online]
Available at:
https://www.ref.org.uk/generators/view.php?regoid=G02382NWSC&returnurl=
[Accessed 01 08 2019].

Renewable Energy Foundation, 2019b. *R00144SESC G01456HYSC : Inverbeg Hydro Scheme.* [Online]
Available at:
https://www.ref.org.uk/generators/view.php?rid=R00144SESC&returnurl=
[Accessed 01 08 2019].

Romm, J., 2018. *Climate Change: What Everyone Needs to Know.* 2nd ed. New York: Oxford University Press.

Sample, J. E., Duncan, N., Ferguson, M. & Cooksley, S., 2015. Scotland's hydropower: Current capacity, future potential and the possible impacts of climate change. *Renewable and Sustainable Energy Reviews,* 52(December 2015), pp. 111-122.

Scottish and Southern Electricity Networks, 2019. *Generation availability map.* [Online]
Available at: https://www.ssen.co.uk/generationavailability/
[Accessed 01 08 2019].

Scottish Natural Heritage, 2019. *Safeguarding protected areas and species.* [Online]
Available at: https://www.nature.scot/professional-advice/safeguarding-protected-areas-and-species
[Accessed 01 07 2019].

ScottishPower, 2016. *Scottishpower Concludes Feasibility Study for Cruachan Expansion.* [Online]
Available at:
https://www.scottishpower.com/news/pages/scottishpower_concludes_feasibility_study_for_cruachan_expansion.aspx
[Accessed 01 07 2019].

SEPA, 2018. *Water Use Supporting Guidance (WAT-SG-74) Sector-specific Guidance: Hydropower v3.0,* s.l.: SEPA.

SEPA, 2019a. *SEPA: Our role.* [Online]
Available at: https://www.sepa.org.uk/about-us/our-role/
[Accessed 01 07 2019].

SEPA, 2019b. *The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended) - A Practical Guide,* Edinburgh: SEPA.

Shaw, J., 1984. *Water Power in Scotland 1550-1870.* Edinburgh: John Donald.

SLD, 2019. *Dictionary of the Scots Language: LADE.* [Online]
Available at: https://www.dsl.ac.uk/entry/snd/lade
[Accessed 01 08 2019].

Solar Trade Association, 2019. *Smart Export Guarantee.* [Online]
Available at: https://www.solar-trade.org.uk/resource-centre/advice-tips-for-households/smart-export-guarantee/
[Accessed 01 07 2019].

SSE, 2019. *COIRE GLAS HYDRO SCHEME.* [Online]
Available at: http://sse.com/whatwedo/ourprojectsandassets/renewables/CoireGlas/
[Accessed 01 07 2019].

Appendix A – List of First Edition OS Maps Covering the Loch Lomond and The Trossachs National Park

Sheet Name and URL	**Dates**
Argyllshire, Sheet CXXXIV (includes: Lochgoilhead And Kilmorich) https://maps.nls.uk/view/74427420	Survey date: 1870 Publication date: 1874
Argyllshire, Sheet CXXXV (includes: Arrochar; Buchanan; Lochgoilhead And Kilmorich) https://maps.nls.uk/view/74427421	Survey date: 1870 Publication date: 1874
Argyllshire, Sheet CXLI (includes: Strachur) https://maps.nls.uk/view/74427427	Survey date: 1866 Publication date: 1870
Argyllshire, Sheet CXLII (includes: Lochgoilhead And Kilmorich) https://maps.nls.uk/view/74427428	Survey date: 1866 Publication date: 1869
Argyllshire, Sheet CLII (includes: Dunoon And Kilmun; Kilmodan; Strachur) https://maps.nls.uk/view/74427437	Survey date: 1865 Publication date: 1870
Argyllshire, Sheet CLIII (includes: Lochgoilhead And Kilmorich; Rhu) https://maps.nls.uk/view/74427438	Survey date: 1866 Publication date: 1869
Argyllshire, Sheet CLXIII (includes: Dunoon And Kilmun; Inverchaolain; Kilmodan; Strachur) https://maps.nls.uk/view/74427447	Survey date: 1865 Publication date: 1869
Argyllshire, Sheet CLXIV (includes: Dunoon And Kilmun; Lochgoilhead And Kilmorich; Rosneath) https://maps.nls.uk/view/74427448	Survey date: 1865 Publication date: 1869
Dumbartonshire, Sheet III (Inset Sheet V) (includes: Arrochar; Lochgoilhead And Kilmorich) https://maps.nls.uk/view/74426605	Survey date: 1860 Publication date: 1864
Dumbartonshire, Sheet IV (includes: Arrochar; Buchanan; Callander) https://maps.nls.uk/view/74426606	Survey date: 1860-64 Publication date: 1865-67

Sheet Name and URL	**Dates**
Dumbartonshire, Sheet VI (includes: Arrochar; Buchanan; Lochgoilhead And Kilmorich) https://maps.nls.uk/view/74426607	Survey date: 1860 Publication date: 1864
Dumbartonshire, Sheet VIII (includes: Arrochar; Buchanan; Luss) https://maps.nls.uk/view/74426609	Survey date: 1860-65 Publication date: 1864-73
Dumbartonshire, Sheet IX (includes: Lochgoilhead And Kilmorich; Rhu; Rosneath) https://maps.nls.uk/view/74426610	Survey date: 1860 Publication date: 1865
Dumbartonshire, Sheet X (includes: Luss) https://maps.nls.uk/view/74426611	Survey date: 1860 Publication date: 1864
Dumbartonshire, Sheet XIII (includes: Luss; Rhu) https://maps.nls.uk/view/74426614	Survey date: 1860 Publication date: 1864
Dumbartonshire, Sheet XIV (includes: Buchanan; Kilmaronock) https://maps.nls.uk/view/74426615	Survey date: 1860 Publication date: 1865
Dumbartonshire, Sheet XVII (includes: Bonhill; Cardross; Luss; Rhu) https://maps.nls.uk/view/74426618	Survey date: 1860 Publication date: 1865
Dumbartonshire, Sheet XVIII (includes: Bonhill; Dumbarton; Kilmaronock) https://maps.nls.uk/view/74426619	Survey date: 1860 Publication date: 1864
Perthshire, Sheet LXXVII (includes: Glenorchy And Inishail; Killin) https://maps.nls.uk/view/74428156	Survey date: 1864 Publication date: 1867
Perthshire, Sheet LXXVIII (includes: Glenorchy And Inishail; Killin) https://maps.nls.uk/view/74428157	Survey date: 1864 Publication date: 1867
Perthshire, Sheet LXXIX (includes: Killin) https://maps.nls.uk/view/74428158	Survey date: 1864 Publication date: 1867

Sheet Name and URL	Dates
Perthshire, Sheet LXXX (includes: Balquhidder; Comrie; Kenmore; Killin) https://maps.nls.uk/view/74428159	Survey date: 1861 Publication date: 1867
Perthshire, Sheet LXXXIX (includes: Glenorchy And Inishail; Killin) https://maps.nls.uk/view/74428168	Survey date: 1864 Publication date: 1867
Perthshire, Sheet XC (includes: Killin) https://maps.nls.uk/view/74428169	Survey date: 1864 Publication date: 1867
Perthshire, Sheet XCI (includes: Balquhidder; Killin) https://maps.nls.uk/view/74428170	Survey date: 1864 Publication date: 1867
Perthshire, Sheet XCII (includes: Balquhidder; Comrie; Killin) https://maps.nls.uk/view/74428171	Survey date: 1862 Publication date: 1867
Perthshire, Sheet XCIII (includes: Comrie) https://maps.nls.uk/view/74428172	Survey date: 1861 Publication date: 1867
Perthshire, Sheet CI (includes: Arrochar; Killin; Lochgoilhead And Kilmorich) https://maps.nls.uk/view/74428180	Survey date: 1860-71 Publication date: 1864-74
Perthshire, Sheet CII (includes: Arrochar; Balquhidder; Callander; Killin) https://maps.nls.uk/view/74428181	Survey date: 1860-64 Publication date: 1865-67
Perthshire, Sheet CIII (includes: Balquhidder; Callander) https://maps.nls.uk/view/74428182	Survey date: 1864 Publication date: 1866
Perthshire, Sheet CIV (includes: Balquhidder) https://maps.nls.uk/view/74428183	Survey date: 1862 Publication date: 1866
Perthshire, Sheet CXII (includes: Aberfoyle; Arrochar; Buchanan; Callander) https://maps.nls.uk/view/74428191	Survey date: 1863 Publication date: 1866
Perthshire, Sheet CXIII (includes: Aberfoyle; Balquhidder; Callander) https://maps.nls.uk/view/74428192	Survey date: 1863 Publication date: 1866

Sheet Name and URL	Dates
Perthshire, Sheet CXIV (includes: Balquhidder; Callander) https://maps.nls.uk/view/74428193	Survey date: 1862 Publication date: 1866
Perthshire, Sheet CXV (includes: Callander; Comrie; Kilmadock; Muthill) https://maps.nls.uk/view/74428194	Survey date: 1862-63 Publication date: 1866
Perthshire, Sheet CXXII (includes: Aberfoyle; Callander) https://maps.nls.uk/view/74428201	Survey date: 1863 Publication date: 1866
Perthshire, Sheet CXXIII (includes: Aberfoyle; Callander; Port Of Menteith) https://maps.nls.uk/view/74428202	Survey date: 1862-63 Publication date: 1866
Perthshire, Sheet CXXIV (includes: Callander; Kilmadock; Port Of Menteith) https://maps.nls.uk/view/74428203	Survey date: 1862-63 Publication date: 1866
Perthshire, Sheet CXXIX (includes: Aberfoyle; Buchanan; Drymen) https://maps.nls.uk/view/74428208	Survey date: 1862-63 Publication date: 1866
Perthshire, Sheet CXXX (includes: Drymen; Port Of Menteith) https://maps.nls.uk/view/74428209	Survey date: 1862 Publication date: 1866
Stirlingshire, Sheet I (inset IA) (includes: Arrochar; Killin; Lochgoilhead And Kilmorich) https://maps.nls.uk/view/74430854	Survey date: 1861 Publication date: 1865
Stirlingshire, Sheet II (inset IIA) (includes: Aberfoyle; Balquhidder; Buchanan; Callander; Killin) https://maps.nls.uk/view/74430855	Survey date: 1861 Publication date: 1865
Stirlingshire, Sheet IV (includes: Aberfoyle; Buchanan) https://maps.nls.uk/view/74430857	Survey date: 1861-3 Publication date: 1865-6
Stirlingshire, Sheet VI (includes: Buchanan; Drymen) https://maps.nls.uk/view/74430858	Survey date: 1860-3 Publication date: 1864-6

Sheet Name and URL	**Dates**
Stirlingshire, Sheet VII (includes: Aberfoyle; Drymen; Port Of Menteith) https://maps.nls.uk/view/74430859	Survey date: 1860 Publication date: 1865
Stirlingshire, Sheet XIII (includes: Buchanan; Kilmaronock; Luss) https://maps.nls.uk/view/74430863	Survey date: 1860 Publication date: 1865
Stirlingshire, Sheet XIV (includes: Buchanan; Drymen) https://maps.nls.uk/view/74430864	Survey date: 1861 Publication date: 1865
Stirlingshire, Sheet XX (with inset of sheet XIX) (includes: Bonhill; Drymen; Killearn; Kilmaronock; Luss) https://maps.nls.uk/view/74430869	Survey date: 1861 Publication date: 1865

Appendix B – List of OS Name Books Covering the Loch Lomond and The Trossachs National Park

The following name books are available from:
https://scotlandsplaces.gov.uk/digital-volumes/ordnance-survey-name-books

Name	Contents
Argyll volume 04	Parishes of Dunoon, and Kilmun and Inverchaolain
Argyll volume 07	Parish of Inverchaolain
Argyll volume 18	Parish of Kilmodan
Argyll volume 20	Parish of Kilmorich
Argyll volume 55	Parishes found on OS 6-inch map sheets CXXXIII, and CXXXIV
Argyll volume 80	Parishes found on OS 6-inch map sheets CXXVI, CXXXV, CXLIII, CLII, CLIII, CLXIII, and CLXIV
Argyll volume 81	Parishes found on OS 6-inch map sheets CXLI, CXLII, CLI, CLXI, CLXII, and CLXXII
Dunbartonshire volume 01	Parish of Bonhill
Dunbartonshire volume 02	Parish of Arrochar
Dunbartonshire volume 03	Parish of Arrochar
Dunbartonshire volume 04	Parish of Bonhill
Dunbartonshire volume 06	Parish of Cardross
Dunbartonshire volume 07	Parish of Dumbarton
Dunbartonshire volume 08	Parish of Dumbarton
Dunbartonshire volume 09	Parish of Kilmaronock
Dunbartonshire volume 13	Parish of Luss
Dunbartonshire volume 16	Parish of Roseneath
Dunbartonshire volume 17	Parish of Row
Dunbartonshire volume 18	Parishes of Dumbartonshire, including Arrochar, Bonhill, Cardross, Dumbarton, New Kilpatrick, Kilmaronock, Luss, Roseneath, Row, Old Kilpatrick, Kirkintolloch, Kilsyth, Cumbernauld, and Dryman
Perthshire volume 02	Parish of Aberfoyle

Name	**Contents**
Perthshire volume 12	Parish of Callander
Perthshire volume 23	Parishes of Dull, Fowlis Wester, Crieff, Fortingall, Weem, Monzie and Kenmore
Perthshire volume 37	Parish of Kilmadock
Perthshire volume 62	Parishes of Muthill, Monzievaird and Strowan
Perthshire volume 69	Parish of Port of Menteith
Stirlingshire Volume 06	Parish of Buchanan
Stirlingshire Volume 09	Parish of Drymen
Stirlingshire Volume 15	Parish of Killearn