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Scotland's hydropower: Current capacity, future potential and the possible impacts of climate change

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ABSTRACT

To promote the transition towards a low carbon economy, the Scottish Government has adopted ambitious energy-related targets, including generating all electricity from renewable sources by 2020. To achieve this, continued investment will be required across a range of sustainable technologies.

Hydropower has a long history in Scotland and the present-day operational capacity of ~1.5 GW already makes a substantial contribution to the national energy budget. In addition, there remains potential for ~500 MW of further development, mostly in the form of small to medium size run-of-river schemes.

Climate change is expected to lead to an intensification of the global hydrological cycle, leading to changes in both the magnitude and seasonality of river flows. There may also be indirect effects on water flows, such as changing land use, enhanced evapotranspiration rates and an increased demand for irrigation, all of which could affect the water available for energy generation.

In this paper we describe Scotland's currently installed hydropower capacity and present a review of the scope for future development. We also review the potential impacts of climate change, highlighting possible adaptation measures as well as key factors likely to determine financial viability over the coming decades. We present a summary of the present state of knowledge regarding the resilience of Scotland's hydropower resource to a changing climate, and identify key areas where further research is required.

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Contents

Abbreviations: BFI, Base Flow Index; DECC, Department of Energy and Climate Change; FDC, Flow Duration Curve; FIT, Feed-in Tariff; GIS, Geographic Information System; NPV, Net Present Value; NSHEB, North of Scotland Hydroelectric Board; OS, Ordnance Survey; RoR, Run-of-River; ROC, Renewables Obligation Certificate; SAAR, Standard Average Annual Rainfall; SEPA, Scottish Environmental Protection Agency; SNH, Scottish Natural Heritage; UKCP09, UK Climate Projections, 2009; WFD, Water Framework Directive; WG, Weather Generator

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1. Introduction and scope

The Scottish Government has set ambitious targets for renewable energy generation, with a commitment to produce 100% of gross annual electricity consumption[1] from renewable sources by 2020 [1]. An interim target of 31% by 2011 has already been met and progress is being made towards a new interim target of 50% by 2015 [2].

Hydropower is already an important component of Scotland's energy mix, accounting for one third[2] of the total renewable energy generated in 2012 [3]. Existing hydropower installations can be broadly categorised into two types: "run-of-river" (RoR) sites, which require little or no infrastructure for water storage, and "impoundment" schemes, which involve the construction of substantial dams. While the potential for additional large scale impoundment schemes in Scotland is thought to be limited [4,5], there is considerable scope for the development of further small to medium sized installations, particularly of the RoR type. Such developments have the potential to make a valuable contribution to Scotland's renewable energy targets, especially as hydropower technology is mature and the resource is generally considered to be less variable than alternatives such as wind.

Climate change is expected to lead to an intensification of the global hydrological cycle, leading to changes in both the magnitude and seasonality of river flows [6]. Climate change may also have indirect effects, for example by leading to changes in land capability [7], which may in turn affect land use and consequently water resources. Furthermore, land use adaptation aimed at mitigating climate change, such as the large scale afforestation outlined in the Land Use Strategy for Scotland [8], may affect the water balance, changing evapotranspiration rates and thereby altering runoff patterns.

Changing flow regimes have the potential to affect the energy output (and therefore financial viability) of hydropower production in Scotland. This is likely to be especially true for RoR installations, which lack the storage capacity necessary to buffer changes to seasonal discharge patterns. Existing schemes, designed primarily for optimum efficiency under the present-day climate, may therefore operate with reduced efficiency in the future and may benefit from upgrading. Similarly, it is possible that new schemes will need to consider future water availability, as well as the historic flow record, when performing site feasibility studies.

There is a substantial body of peer-reviewed literature describing methods for identifying new hydropower sites, as well as assessing the potential impacts of climate change on energy output. This is supplemented by a large volume of "grey" literature – primarily consultancy reports and industry guidelines – which are also highly relevant. While most of the material is focussed on areas outside of Scotland, a number of papers specifically consider the Scottish context.

[1] Gross annual consumption is defined as electricity generated, plus imports, minus exports (and including losses).

[2] This figure excludes energy generated from pumped storage.

The aims of this review are as follows:

i. To provide a brief overview of the historic development of hydropower in Scotland, and to place this in context with other renewables development to date (Section 2).
ii. To review the literature describing the potential for new hydropower development in Scotland (Section 3).
iii. To review the literature concerning the possible effects (both direct and indirect) of climate change on hydropower generation. Studies focussing on the Scottish context will be considered in detail (Section 4).
iv. To identify knowledge gaps and future research priorities relating to the potential impacts of climate change on Scottish hydropower (Section 5).

2. Currently installed capacity

2.1. The development of hydropower in Scotland

The first large scale hydropower schemes in Scotland were built in Kinlochleven (1909) and Lochaber (1929) to provide energy for the aluminium industry. The first public supply schemes were designed to provide peak power to Glasgow and were built in the Galloway and Lanark areas during the 1920s and 1930s. After the Second World War, the electrification of the Highlands became a Scottish policy priority and the publicly owned North of Scotland Hydroelectric Board (NSHEB) was formed to oversee development work. Between its creation in 1943 and the late 1960s, NSHEB supervised the construction of some 60 different hydropower schemes, with a total capacity of around 1.2 GW [5].

Between 1963 and 2000, very little hydropower development took place (Fig. 1), reflecting the opinion that, "*the work done in the 1940s, 1950s and 1960s […] was almost totally successful in fulfilling the potential for hydroelectricity in Scotland*" [4]. Since 2000, the rate of development has increased once more, most notably with the commissioning of Scottish and Southern Energy's 100 MW impoundment scheme at Glendoe in 2008. Small scale RoR hydropower has also become popular in recent years, particularly following the introduction in early 2010 of the Feed-in Tariff (FIT), which incentivises small-scale ($<$ 5 MW) renewable energy developments by guaranteeing minimum sales prices for the electricity generated [9].

The resurgence of interest in RoR hydropower in Scotland has taken place against a background of "*…often competing, but sometimes complementary, policy discourses*" [10]. For example, small scale hydropower development may help to meet renewable energy and carbon emissions targets while also offering opportunities for diversification and employment in rural communities. According to [11], RoR hydropower could create up to 1400 new jobs in rural Scotland by 2020. On the other hand, alterations to the flow regime such as depleted river reaches and loss of weir-pool habitat may adversely affect fish populations [12], which may in turn lead to downgrading of water body status under the Water Framework Directive (WFD).

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