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Benchmarking island power systems: Results, challenges, and solutions for long term sustainability

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ABSTRACT

Islanded power systems face unique challenges in the future in environmental, economic and social sustainability. Their high reliance on oil-fired generation leads to a carbon intensive power generation profile and consequently high costs to final energy consumers, hindering the economic development of islands. A detailed benchmarking exercise of islanded systems has been undertaken in collaboration with a group of islanded power systems under the auspices of EURELECTRIC, the association for European Power Companies. Results from this benchmarking survey of 28 different islands are presented, identifying the challenges of the current status quo, particularly in regard to generation profile and emissions. Four islands are taken for detailed study, in order to identify solutions to some of the energy challenges faced by island systems, with a focus on interconnection, renewables development and energy storage. The potential for implementing the latter technologies is positive and provides a partial solution to the challenges of islanded systems but the current costs of some innovative energy technologies, e.g. energy storage, still implies that it is not necessarily possible at present to invest in these technologies without non-market subsidies. However, islands are found to be excellent locations for pilot projects on new energy technologies due to their inherent advantages of small size and vertical integration of local power companies. Furthermore, strong communities imply that it is easier to engage with end consumers when promoting new concepts for electricity supply.

1. Introduction

1.1. Background and purpose of study

Islanded power systems make an interesting topic of study not only because of their unique challenges of isolation and socioeconomic conditions, but also their potential to visualise an entire power system on a small scale. Their small scale also offers considerable opportunity to install, commission and evaluate new power technologies quickly and effectively. While there is a wide body of literature considering the situation of and possible energy projects for individual small islands, there appear to be very few studies comparing a range of different island systems in different climatic, geographical and technological settings (some of the relatively few existing multi-island studies are limited to single technologies or geographic situations e.g. for non-interconnected islands [1], covering only Greek islands [2], covering different Canary islands for wind-hydro systems [3], PV in different islands [4], storage in different islands [5]). The purpose of this paper is to use a wide range of data collected from island power companies, covering a total of 28 islands, to compare the different island systems, identify reasons for their differences and analyse the key challenges that the systems face. Furthermore, solutions to meet these challenges are identified, particularly, in reference to a more detailed study of four islands taken from the wider benchmarking analysis: Malta, Isle of Man, Jersey and Terceira (Azores). This project has been undertaken in collaboration with a group of islanded power systems under the auspices of EURELECTRIC, an association for European Power Companies. The full range of datasets from this project were only made available internally in EURELECTRIC, this paper covers a restricted dataset but with an extensive analysis of the implications of the data, together with the detailed study of the four mentioned case study islands.

1.2. Scope of study

The EURELECTRIC Network of Experts on Islands Systems (NEIS) is tasked both with promoting legislation appropriate for islanded systems at the European level and providing a platform for sharing best

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practice between island energy companies. The NEIS Group composes representatives from island energy companies across the EU but also from islands within the European geographical area which are not actually part of the EU (e.g. British Channel Islands, Isle of Man). Islands in the Pacific, the Indian Ocean and the Caribbean are also part of the group due to very strong relational and political ties with European countries. The islands are divided in this paper into two categories as follows:

- Large islands: > 100 GW h of electricity supplied
- Small islands: 10–100 GW h of electricity supplied

The primary data analysed for this study is for the period 2009–2011 (2012 for some datasets). The scope is limited to this period for reasons of confidentiality and data availability. Where possible, the qualitative analysis is updated to the present time with relevant issues identified, which may have significantly changed the data since this period, although in most cases there have not been radical changes which would have affected the data. For the case study islands in Section 5, the analysis has been updated comprehensively in collaboration with the island company representatives. All data presented in the included figures and tables have been gathered through the benchmarking survey of the islands, unless mentioned otherwise.

The key objective of this paper is to identify best practice in island energy systems for addressing the three elements of sustainability – economic, social and environmental. In islanded system these elements are represented by issues such as high energy costs, issues with system reliability (in some islands), and relatively high specific greenhouse gas emissions. This paper considers existing technologies and practices for resolving these issues, together with some insight into future technologies which have not been implemented on any of the islands considered here.

1.3. Research background

This article adds to the current body of research on islanded energy system which to date has largely looked at individual islands as case studies and specific energy issues related to islanded systems. In general, existing literature includes islands in a theoretical sense, but often with limited reference to the actual state of existing island energy systems. By using existing literature, we refer to a number of relevant studies of energy systems on islands, many of which concern the islands included in this study. These existing studies have been categorised in the following sub-sections.

1.3.1. Increasing the share of renewables on islands

A large body of work has modelled the potential for 100% renewable electricity systems on islands such as that for the Madeiran island of Porto Santo [6] and the Croatian island of Hvar [7]. These studies use the RenewIsland model, a specific model developed for modelling high shares of renewables on islands, which is described in [8] and [9]. A number of studies have also pointed out the particular benefits of developing renewables on islands. The benefits generally identified include promoting energy independence, security of supply, and, in reducing dependence on high cost oil imports, supporting the development of island economies towards a self-sufficient and sustainable economy [6,10–12].

Concerning geographical coverage of the islands referred to in this study, we point to some exemplar studies. For the French island territory of Réunion, a number of studies have considered renewables developments on the island; including a summary of major investments in RES technologies on Réunion [13] and the potential for different forms of ocean energy on the island [14]. For the densely populated island of Malta, the spatial challenges to renewable energy implementation on island systems have been considered [15]. The issue of high population density is a condition not unique to Malta, but also to other islands covered by this study such as Jersey, Guernsey and Mauritius, as shown in Table 2. The development of renewables on the four case study islands is considered in Section 5.3.3.

1.3.2. Interconnecting to mainland systems

Whether to build an interconnection to mainland systems is an important consideration for many small island systems. At the cost of an often very significant capital investment, connecting islands to mainland power systems can significantly reduce the costs of electricity supply. Several techno-economic analyses have investigated relatively positive cases for interconnection, e.g. for several Greek islands and for Malta [2,16]. However, interconnection can be uneconomic in very small islands where the high capital cost of interconnection is not sufficiently compensated by the low power consumption of the islands and consequent low revenues from electricity sales. In the case of these very small islands, reduced electricity production costs may be better realised by use of renewables, as shown in studies such as that for the island of Kythira in Greece [17]. Indeed, the range of studies indicated in Section 1.3.1 are indicative that in view of the reducing costs of renewable energy systems (and complementary storage systems), the case for new island interconnections is becoming weaker. The question of interconnection in reference to the four case study islands is considered in Section 5.2.4.

1.3.3. Assessing the potential for storage in islanded systems

Assessing the use of energy storage in small island systems has attracted a significant body of research. Studies consider the possibility of applying different storage technologies e.g. batteries [18,19], pumped hydro [3,20] and hydrogen [20,21]; the latter often in combination with other direct uses of hydrogen in e.g. transport. These referenced studies have primarily focused on the use of storage for balancing variable renewable electricity (VRE) generation, primarily in non-interconnected islands, using relevant models such as the RenewIsland referenced in Section 1.3.1 [8,9], or in the case of hydrogen-based systems, the H2RES model [22]. Relatively few of these studies refer to examples where storage has actually been implemented on islands, although there are exceptions such as studies on the Canarian island of El Hierro, where a pumped hydro storage in combination with wind and PV has now been implemented [3,23]. The lack of commercial implementation to date is primarily the result of the high costs of such systems. However, the cost of storage technologies has fallen significantly in recent years, especially for batteries (and the complementary RES technologies), (see e.g. [24,25]), making the systems more feasible. The application of storage on the islands considered in this study is discussed in detail in Section 5.2.2.

2. Islanded power systems studied

2.1. Introduction to islands

According to the European Commission, there are over 600 inhabited islands in the European Union [26]. These islands have a population of over 21 million, representing around 4.3% of the European population [26]. The islands represent 2.4% of the European Domestic Product, and a more significant proportion of the tourism economy. These values do not strictly represent the islands covered in this survey, since the NEIS group has only partial coverage of EU islands (see Fig. 1), although as mentioned above, it does also include islands that are geographically part of Europe but not members of the EU and also islands outside of Europe but with strong political ties to Europe (e.g. French Polynesian islands in the Pacific, see Fig. 2, and French Caribbean islands and territories, see Fig. 3).

In political terms, islands are distinct from the mainland European context, as is evident by the different policy advocate groups of islands promoting their special circumstances; at least two exist purely in the energy sector – NEIS itself and Islenet, the European Islands Network