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Assessment of sustainable energy system configuration for a small Canary island in 2030

Henning Meschede[a,*], Michael Child[b], Christian Breyer[b]

[a] University of Kassel, Department of Sustainable Products and Processes (upp), Kurt-Wolters-Str. 3, 34125 Kassel, Germany
[b] Lappeenranta University of Technology, Skinnarilankatu 34, 53850 Lappeenranta, Finland

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ABSTRACT

Renewable energy systems can play a key role in sustainable energy supply. Because of the fluctuating electricity generation, storage technologies are needed to close the gap between demand and supply. Besides the electricity sector, the transport sector causes high energy demand. In this context, because of their remoteness, islands can be seen as blueprints for possible energy transition pathways. The objective of this paper is to analyse different principle concepts that come into question for a 100% renewable subtropical island from the distribution system operator's point of view. This perspective offers the possibility to account all system costs needed to transfer a centralised energy system into a 100% renewable one and to assume the macroeconomic costs of such a transfer. For the case of La Gomera the economic competitiveness of renewable energy, particularly solar PV and wind power, is shown. All evaluated sustainable scenarios lead to lower annual cost and primary energy demands than the business-of-usual (BAU) scenario based on the cost assumptions used in this study. The analysis underlines that the combination of different technologies will lead to the lowest primary energy demand and to the lowest annualised cost of 10.89 M€ for the entire island energy system, which is 37.2% lower than a BAU scenario.

1. Introduction

In 2015, the United Nations Framework Convention on Climate Change, 21st Conference of the Parties (COP 21) affirmed that the use of fossil fuels and their associated greenhouse gas emissions must be reduced to decrease the anthropogenic causes of climate change. Hereby, the utilisation of renewable energy systems (RES) in the electricity, heating, cooling and transport sectors can lead to significant reductions in this regard. In addition to environmental benefits, the utilisation of RES can also offer economic advantages, e.g. reduction of and therefore more independence from energy imports as well as lower levelised costs of electricity (LCOE) and lower total annual costs of the energy system.

Regarding the energy transition as well as possible utilisation and integration of RES, especially islands have an outstanding role as blue prints for transition pathways and demonstrators of new, innovative technologies or energy system designs [1]. Globally, more than 85,000 islands can be found, with approximately 13% of them are inhabited, accounting for a global population of around 740 million people [2]. Since the United Nations Conference on Environment and Development in 1992, many island communities have set objectives to become renewable energy islands and have tested currently established renewable energy (RE) resources like photovoltaic (PV) and wind turbines. For the last ten years, the number of programmes and initiatives to promote the energy transition on islands has been growing rapidly.

Islands are best suited for the utilisation of RE. On the one hand, many islands offer very good weather conditions [2]. On the other hand, the operation of the current energy systems, in many cases based on imported diesel fuel, leads to high LCOE and poor trade balances. For the Greek islands, LCOE between 0.26 €/kWh and more than 1 €/kWh can be found [3]. The average LCOE on the Canary Islands is about 200.5 €/MWh [4]. A global estimation of the huge economic potential of PV and wind turbines can be found in [5]. Utilising more domestic, renewable energy sources can aid in facilitating greater autonomy and self-reliance seen in other aspects of island life, but which is notably absent in their energy systems. It will also result in islands actively achieving more climate action in international efforts to mitigate climate change, something to which islands may show the greatest sensitivity due to the potential for rising sea levels.

A study of the island of Fuerteventura of the Spanish Canary Islands showed that greater energy self-sufficiency and a reduced carbon footprint could be achieved by means of wave and offshore wind energy [6]. However, not all of the Canary Islands share the same potentials for wave and offshore wind energy. The neighbouring island of La Gomera,

* Corresponding author.
E-mail address: meschede@upp-kassel.de (H. Meschede).

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Nomenclature

BAU	business-as-usual
C	annual costs
capex	capital expenditures
DSM	demand side management
BEV	battery electric vehicles
H_2	hydrogen
I	overnight investment costs
LCOE	levelized costs of electricity
μ-CHP	micro combined heat and power
opex	operation and maintenance expenditures
PE	primary energy
PtX	power-to-x
PV	photovoltaics
RE	renewable energy
RES	renewable energy system
$t_{Payback}$	armortisation time
V2G	vehicle-to-grid
WACC	weighted average cost of capital

for example, must look to other resources, such as solar and onshore wind power, if it is to achieve the same goals of energy self-sufficiency and climate action. In general, the overall uniqueness of islands that is often romanticised in popular culture must be extended into their energy systems.

Because of the intermittent nature of solar irradiation and wind, the electricity generation of RE cannot be fully controlled by increasing the generation at any time. Therefore, the demand-driven control of energy supply of fossil power plants may be challenging in energy systems with high shares of RE. To balance intermittent energy generation and the energy demand, different energy system designs have been tested for islands. Overviews of research and demonstration projects regarding renewable energy islands can be found in [7–9]. The reviews underline the interest in island energy systems on the one hand. On the other hand, Neves et al. [7] show that only a few projects aim to reach an advanced RE penetration of more than 80%, and that most projects are realised in very small communities with less than 10,000 inhabitants.

One possibility for integrating high shares of RE on islands is the utilisation of typical energy storage technologies like batteries and pumped hydro storage. For both technologies, Kaldellis et al. outline a technical and economic analysis for 33 Aegean islands (Greece) of different sizes [10]. Ma et al. evaluate RE, battery and pumped hydro storage concepts for a Chinese island [11,12]. The utilisation of different storage technologies for the Canary Islands (Spain) is evaluated by Sigrist et al. [13]. The authors underline the different applications of storage technologies like balancing frequency and voltage or to store electricity over the mid and long term.

Detailed concepts of using wind turbines and pumped hydro storage are also analysed for the island of El Hierro [14] and the island of Gran Canaria [15], both belonging to the Canary Islands. In 2014, a similarly designed system including wind turbines and pumped hydro storage was set in operation on El Hierro [16], aiming to increase the RE penetration to at least 60% [17]. A combination of PV, wind power and lithium-ion batteries is set up on the small island of Graciosa, belonging to the Azores (Portugal). The objective is to decrease the annual diesel fuel demand by 65% [18], and commissioning should be in summer 2018 [19].

Besides battery and pumped hydro storage, further energy transition pathways are analysed in the scientific literature. Hereby, Duić et al. analyse the utilisation of hydrogen for electricity generation and transport purposes [20]. The further development and demonstration of this concept was focused within the RenewIslands project [21]. The concept is transferred to several islands and evaluated by using the developed simulation tool H2RES [22–24]. Another approach for integrating hydrogen in the energy system of an island is presented by Karavas et al. [25]. Hereby, the focus is set on the control of all units of the entire energy system.

Erdinc et al. show that demand side management (DSM) and vehicle-to-grid (V2G) are topics of growing interest for the integration of RE since both measures allow the adjustment of the energy demand to the energy supply, and therefore have a potential to reduce system costs and increase RE penetration [8]. Neves et al. analyse the economic potential of flexible domestic hot water supply for the case of the island of Corvo (Azores/Portugal) considering solar thermal systems and heat pumps. They show, that on the one hand DSM will increase the annual electricity demand but on the other hand will lead to decreased LCOE [26]. Further studies on the economic potential of DSM are carried out for the island of Flores (Azores/Portugal) [27,28] and for the island of Gran Canaria [29]. In these studies, the DSM potential is formulated as a flexible amount of the annual electricity demand without explicit and quantitative analytical research of single measures or technical concepts. For the island of La Gomera, a study of Meschede and Wiegand the amount of flexible load within the hotel sector is quantified and technical pathways to implement DSM are presented [30].

The V2G concept involves using the batteries of battery electric vehicles (BEV) as mobile battery storage, since most of the time BEVs are not used for transport. The concept consists of two parts. First, it includes smart charging strategies to enable charging at times of electricity surplus to increase the utilisation of RE. Second, V2G allows a bidirectional electricity flow, so in times of insufficient energy supply of RE, the batteries of the BEV can be discharged to fill the gap between demand and supply. Zhang et al. report how smart charging of BEV can be used for valley-filling and to flatten load profiles [31]. Furthermore, several studies have suggested that widespread use of electric vehicles should be considered as efficient means of managing variable RE resources [32,33]. On an island scale, Arnhold et al. analyse the impact of V2G on the island of Graciosa (Azores/Portugal) [34]. The study shows a high energetic and environmental potential for V2G in comparison to power-to-methane mobility concepts; nevertheless, the economic potential is found to be lower under the employed cost assumptions. In addition, Sigrist et al. [35] compare V2G, DSM and stationary electricity storage systems for five prototype islands which represent almost 60 islands. They conclude, that different sizes of islands demand different smart grid initiatives. Detailed analysis of specific islands is not given.

To realise a 100% renewable energy system for islands, all energy sectors including electricity, heating, cooling and transport must be considered. Hereby, coupling of different sectors seems to enable high DSM potential [36,37]. Especially the recently growing utilisation of BEV promise high potential if V2G concepts are implemented. Amongst other transition pathways, Child et al. have analysed V2G scenarios for the Åland Islands (Finland). In addition to street vehicles they also include electrified marine transport in their scope. They show a high energetic and economic potential for V2G compared to other concepts [38]. A 100% renewable scenario is carried out for the Canary Islands by Gils and Simon [39]. Hereby, one focus is set on interconnections of the different islands to balance electricity demand and supply. Furthermore, the analysis includes also the heating, cooling and transport sectors of the Canary Islands. Smart charging of the BEV is included in the analysis but V2G (discharging of mobile batteries) is not considered in detail.

Regarding the reviewed literature there is still a lack of information on the comparison of different energy system concepts including V2G for subtropical islands, which show differences in renewable energy potential and energy demand compared to northern islands like the Åland Islands. Although some similarities between different islands can