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Integration of transport and energy sectors in island communities with 100% intermittent renewable energy sources

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ABSTRACT

Islands' energy systems present a challenge in energy planning due to a limited amount of resources which could be used to make islands self-sufficient and sustainable. This paper presents a novel approach for defining energy system of a carbon neutral island which utilizes only intermittent renewable energy sources in combination with vehicle-to-grid concept as a demand response technology, where marine transportation has also been taken into account. Integration of power, heating, cooling and transport sectors has been modelled by using EnergyPLAN tool, i.e. its updated November 2017 version which is capable of simulating vehicle-to-grid operation in mentioned conditions. Power supply capacities have been selected not by using scenario analysis but by implementing an optimization procedure based on series of simulations in EnergyPLAN tool. In order to choose the most suitable power supply system configuration, two boundary conditions have been defined. Firstly, only solar and wind capacities must be utilized. Secondly, total electricity import and export must be balanced, i.e. the island has to be CO_2 neutral. In order to validate the approach, Croatian Island of Korčula has been used as the case study. 2011 has been selected as the base year for which final energy consumption has been calculated. The final simulation year was set to 2030 in which optimal capacities are installed. It has been shown that configuration with 40 MW of wind and 6 MW of installed solar capacities presents the least cost solution, while 22 MW of wind in combination with 30 MW of installed solar capacities provides the lowest amount of total electricity import and export. Analysis of the vehicle-to-grid share reduction has shown increase in total import and export in both cases, while transmission peak loads have not been influenced.

1. Introduction

A large majority of island communities are traditionally experiencing difficulties in terms of energy supply and energy security associated with a high dependency on imported fossil fuels. Growing concerns about climate change and increasing profitability of renewable based energy technologies contribute to higher shares of the renewable energy source (RES) utilization on a number of islands. Lately, a step forward in the endeavour to achieve energy self-sufficient islands has become integration of power sector with energy demand of domestic heating, cooling, fuels for transport or larger, commercial demand.

On the one hand, islands have a significantly unexploited potential for sustainable development while on the other, they are among the most vulnerable areas to experience a variety of impacts of climate change on their local ecosystem and livelihoods. Both have been recognised and acknowledged by several initiatives targeting sustainable development on islands. The International Renewable Energy Agency actively supports small island developing states (SIDS) into their renewable energy transition since 2011 [1] and coordinates the worldwide SIDS Lighthouse Initiative launched at the 2014 Climate Summit [2]. The SIDS Initiative supports energy transformation on islands from fossil-fuel based power systems enabling smart deployment of renewable energy in power, heating, cooling and transportation sectors. The European Union (EU) developed two strategies to treat climate change and sustainable development on islands under the same umbrella, namely Clean Energy for EU Islands [3] and Smart Island Initiative [4]. The latter represents a bottom-up initiative tackling climate change and supporting sustainable economic growth through a holistic approach by exploiting synergies between sectors, thus directly addressing the circular economy. Initiatives seek to gather European islands by developing a common method for the clean energy transition focusing on smart islands principles. Some researchers are also developing tools

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which could facilitate the integration of sustainable energy on islands, such as the one shown in [5].

In renewable energy planning, various options of resource and technology combinations can be applied on islands resulting in different technical and economic feasibilities. N. Duić et al. [6] developed the RenewIslands methodology specially designed to enable the assessment of alternative scenarios for energy and resource planning. The methodology supports renewable energy scenarios design through a systematic and comprehensive approach divided into four steps, namely analysis of needs, available resources, appropriate technologies and creation of scenarios. Moreover, the methodology is applied to several islands and evaluated by a computer tool called H2RES designed as a support for an island energy system modelling with the RenewIsland methodology [7–9]. H2RES was used in [8] to show how the integration of a desalination plant can support higher penetration of renewable energy sources reaching up to 72% renewable energy source production in 2020. Apart from using tools specifically designed for the islands systems, tools for different area sizes have proven successful in modelling island systems. The EnergyPLAN tool designed for national or regional energy planning was used in a number of case studies, i.e. La Gomera (Spain) [10], Thai island Wang-an (Taiwan) [11], Vis, Lastovo, Korcula [12], Mljet [12,13] and Hvar [14] (Croatia) while the HOMER tool developed for local community and single project energy systems has been applied on island systems such as Agios Efstratios (Greece) [15], St. Martin (Bangladesh) [16], Prince Edward (Canada) [17] and Vis (Croatia) [18]. The comparison of different tools for modelling the energy system on islands given in D. Neves et al. [19] highlighted the importance of the demand response to improve energy systems performance.

A rapid development of sustainable energy technologies along with favourable conditions for the exploitation of RES on a number of islands results in cost effective utilization of renewable energy in comparison to the solutions based on fossil fuels. A number of studies provided feasibility analysis of either individual technologies or their combinations and proposed novel methodologies and tools especially designed for the islands. The results of techno-economic analysis of different energy storage systems to support RES energy generation on islands showed financially viable electrification solutions [20]. P. Blechinger et al. [21] performed a techno-economic assessment of almost 1800 small islands proving the high market potential for the solar PV, wind power and battery storage systems. The economic feasibility of high wind energy share at island level was shown in [22]. The study is of particular interest for designing a cost-effective system to support a national energy strategy with a high RES share. The analysis of the combination of different desalination and solar technologies in a stand-alone microgrid with high RES penetration resulted in lower overall cost comparing to the fossil fuel based solutions [23]. Moreover, solutions such as a demand response strategy for a domestic hot water system in RES based microgrids proved to be a beneficial solution to reduce peak load and cost increase [24]. In [25], Anoune et al. analysed the importance of the optimization sizing technique to achieve maximum power reliability and the minimum system cost of a hybrid renewable energy system. A methodology for an assessment of the wind potential and costs on islands was presented in [26] while [27] presented a methodology for the economic assessment of roof PV systems. Schallenberg-Rodriguez presented a method for techno-economical potential of PV installation on the roof with the case study of the Canary Islands [28], while Reinsberger and Posch presented main drivers and barriers for PV projects [29]. In order to support short and long-term RES energy planning scenarios F. Guzzi et al. [30] designed a tool for economic assessment and support in investment planning. Economic assessment for integration of solar and geothermal energy for an island system which simultaneously produces electricity, thermal and cooling energy, including fresh water has been studied in [31].

Modelling renewable energy systems for self-sufficient islands requires special attention to be placed on the balancing of the renewable energy generation. Different energy systems have been designed in order to balance the variable nature of electricity generation from solar and wind. The great overview of island energy systems which proves the interest in renewable energy system designs can be observed in reviews [32,33] and [34]. A high share of renewable energy sources can be achieved by utilising typical energy storage technologies such as batteries and hydro storage. Marczinkowski et al. [35] analysed technical feasibility of PV systems coupled with batteries on the case of two approaches for a consumers' involvement in the smart island energy systems development. Both solutions, batteries at the residential households and the communal battery, showed to have a great potential for the implementation if the technological specifications are well coordinated and controlled. A cost benefit analysis of photovoltaic generators and the appropriate energy storage solution, namely batteries or hydro storage was performed for 33 Aegean islands (Greece) of different sizes [36]. Both storage technologies were also evaluated in [37] and [38] for a remote island in Hong Kong. Furthermore, the integration of hydrogen as a balancing option for the island energy transition was analysed in [39].

Moreover, coupling of different sectors represents a successful approach to enable high levels of variable renewable energy sources [40]. Such integration can best be achieved through a smart energy system which enables to detect and utilize synergies between different sectors [41]. Smart energy systems thus provide a better management of variable renewable energy generation as well as their higher penetration. With a special focus on the transport sector, B.V. Mathiesen et al. [42] showed that 100% renewable energy system is technically feasible by applying the smart energy system approach. Based on the analysis of the several aspects and constraints of the high RES shares on the islands, G. Notton [43] has emphasized that optimal energy management throughout the smart grid approach is inevitable to fully accomplish islands' renewable energy development. The polygeneration system, combining electricity and water supply systems, as well as heating and cooling supply was investigated in the case study of Pantelleria island (Italy) [31]. The research showed that the polygeneration approach can fulfil the water demand of the community and supply significant amounts of electricity, heating and cooling. The importance of RES integration and storage technologies, together with energy savings and energy efficiency improvements in energy production was highlighted for the case of an island of Hvar (Croatia) [14].

Integration of various sectors and energy types can often be observed in modelling of 100% renewable energy systems since for the achievement of such systems all the energy sectors, including electricity, heating, cooling and transport must be considered. However, number of studies aimed at achieving 100% renewable energy supply took into account only power sector [11,15,17,44–46]. A feasibility study for replacement of diesel-generators with renewable energy technologies for the case of small Greek island was carried out in [15]. Due to the extreme seasonal variations in energy consumption caused by tourism industry, D. Thomas et al. [15] envisaged enormous capacity of solar and wind as well as battery storage for the case of nearly 100% renewable energy system. Moreover, they highlighted potential technical difficulties of reaching 100%, namely maintaining stable voltage and frequency in the grid. N. Maïzi et al. [44] outlined technical constraints and the need for the transmission grid reinforcement for higher integration of variable renewable energy sources in the power mix. Fully renewable power supply for the year 2030 was developed for the case of Reunion island (France, Indian Ocean) [45] prioritising biomass as the most feasible solution. Therefore, biomass represented more than 50% of total electricity generation in 2030. Variability of renewable energy generation and mismatches in the demand and production were discussed in [11] showing that 100% renewable electricity can be achieved through the deployment of storages. Storage technology was envisaged, on the one hand to store electricity surplus while on the other to provide electricity during generation deficit. Hybrid hydrogen renewable energy system for a remote island area