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Global analysis of the techno-economic potential of renewable energy hybrid systems on small islands

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HIGHLIGHTS

- GIS analysis has identified approximately 1800 small island energy systems with significant renewable energy potential
- The global potential amounts to 7.5 GW of solar PV and 14 GW of wind power
- Total savings amount to 3.3% of GDP every year (up to 30% for less developed islands)
- The integration of these renewable energy sources would require 5.8 GWh of battery storage systems
- One of the main barriers for this deployment is the lack of regulation for independent power producers

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ABSTRACT

Globally, small islands below 100,000 inhabitants represent a large number of diesel based mini-grids. With volatile fossil fuel costs which are most likely to increase in the long-run and competitive renewable energy technologies the introduction of such sustainable power generation system seems a viable and environmental friendly option. Nevertheless the implementation of renewable energies on small islands is quite low based on high transaction costs and missing knowledge according to the market potential.

Our work provides a global overview on the small island landscape showing the respective population, economic activity, energy demand, and fuel costs for almost 1800 islands with approximately 20 million inhabitants currently supplied by 15 GW of diesel plants. Based on these parameters a detailed techno-economic assessment of the potential integration of solar PV, wind power, and battery storage into the power supply system was performed for each island. The focus on solar and wind was set due to the lack of data on hydro and geothermal potential for a global island study. It revealed that almost 7.5 GW of photovoltaic and 14 GW of wind power could be economically installed and operated on these islands reducing the GHG-emissions and fuel consumption by approximately 50%. In total numbers more than 20 million tons of GHG emissions can be reduced by avoiding the burning of 7.8 billion liters of diesel per year. Cost savings of around 9 USDct/kWh occur on average by implementing these capacities combined with 5.8 GWh of battery storage. This detailed techno-economic evaluation of renewable energies enables policy makers and investors to facilitate the implementation of clean energy supply systems on small islands. To accelerate the implementation of this enormous potential we give specific policy recommendations such as the introduction of proper regulations.

1. Introduction

Globally, the power generation sector faces two major challenges based on the use of fossil fuels: high emissions of greenhouse gases (GHG) and the finite nature of fossil fuels leading to price increases in the long-term perspective (IEA, 2015; IPCC, 2014). Especially small island developing states (SIDS) or small islands in general with mainly oil-based power generation suffer from high costs of electricity (IRENA, 2012). Furthermore they are particularly threatened by the impacts of GHG emissions induced climate change such as rise in sea level and weather extremes (IPCC, 2014).

With renewable energy technologies both challenges could be addressed. They currently offer a cost-effective and sustainable

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way of electricity supply for large scale systems as well as for small island energy supply systems. For our research we focus on renewable energies on islands for several reasons: Firstly, almost all small islands worldwide rely on expensive imports of fossil fuels for power generation. This burden can be alleviated by increasing the renewable energy share within the local power generation mix. Secondly, on most small islands solar and / or wind resources are abundantly available as local energy source. Thirdly, small islands can prove the technical and political feasibility of implementing high shares of renewable energies to serve as positive lighthouse examples for larger regions and countries.

Despite the obvious advantages of renewable energy systems on small islands their implementation is happening rather slowly. One major barrier is the missing knowledge about the existing techno-economic potential of renewable energy hybrid systems on these islands. Studies have been conducted analyzing single island countries or islands of different countries, but no comprehensive global analysis exists. This leads to wrong guidance from the political sector as well as to lack of interest from private project developers. Thus, it is important to conduct an analysis determining the techno-economic potential for all small islands of the world. This analysis can facilitate the implementation of renewable energies for project developers, private companies, and utilities by providing a pre-feasibility study showing the potential of solar photovoltaic (PV) and wind power at each island. In addition, it can strengthen policy makers in evidence based decisions for policies, regulatory frameworks, and measurements supporting the most attractive technology mix for their respective island or small island developing state.

Our analysis of the techno-economic renewable energy potential on small islands is driven by the overall research question:

- What is the techno-economic potential of renewable energies on small islands between 1000 and 100,000 inhabitants?

This is elaborated along the following sub-questions:

- Which methodologies have to be applied to detect the potential?
- What is the techno-economic optimized hybrid energy system for each island?
- Which policy implications can be derived to foster the detected potential?

To provide reliable answers to these questions we developed a novel methodology to assess up to 1800 small islands worldwide. First a geographic information system (GIS) analysis was performed to identify the location and size of each island combined with the relevant resource and load data for the simulations. To conduct the techno-economic optimization an electricity supply system model was created and applied reflecting the power generation of each island. This model is fed by input data derived from GIS analyses to assess the potential of renewable energies on small islands.

In the following sections these research steps are presented and explained. First, the theoretical background is described in Section 2 followed by the research methodology and an explanation of the energy system model, the GIS approach, and the input parameters in Section 3. Afterwards the results are presented and discussed in Section 4 to illustrate the global potential of renewable energies (RE) on small islands. The paper concludes with a summary of the results and policy implications in Section 5.

2. Practical and scientific relevance

As mentioned before island energy supply systems are receiving more and more attention with respect to implementing renewable energies. The research perspectives range from pure technological considerations to economic and socio-political implications. Within this section an overview on current research about renewable energies on islands and implementation projects is given. This is completed by identifying research gaps and future research needs.

In 1998 the comprehensive report on “Renewable Energy on small Islands” has been published (Jensen, 1998). It lists various islands where RE activities were taking place. The report underlines that even more than 15 years ago a special focus was laid on RE on small islands. Also the example of Greek islands and Pacific islands underlines the growing attention for RE on islands (Balaras et al. 1999; Yu and Tapling, 1997). Anyhow, the attention has been drawn away from island systems towards large scale on-grid applications for RE due to rising market opportunities based on feed-in tariffs, other incentives and more and more fully profitable investments (IEA-PVPS, 2015).

However, feed-in tariffs are currently becoming less attractive and large scale on-grid markets are structured more competitively. Consequently, global RE companies start to consider island energy supply systems as new business field. The recent decline in RE prices (IRENA, 2014) combined with volatility of diesel costs (EIA, 2014) makes RE systems on more and more small islands cost competitive compared to pure diesel systems. This is underlined by initiatives such as IRENA's SIDS lighthouse initiative[1] and AOSIS.[2] In addition, large technology providers and start-ups also focus on small islands as an attractive market for their renewable energy solutions. For example Siemens AG with its off-grid section and fleet control system, ABB AG with special devices on frequency control and stability, SMA Solar Technology AG providing specialized power electronics, and Younicos AG as an emerging company for battery solutions. All this indicates that the technology is ready and available for renewable-based energy supply on small islands.

In the scientific community the technological aspects of island energy supply systems have been discussed over decades. Among these issues are the combination of RE and conventional power generation technologies, energy storage technologies and demand side management. For instance, different storage options from batteries to hydrogen have been analyzed and tested. It can be stated that technological solutions to supply islands by renewable based energy systems widely exist and are described in the scientific literature (Kaldellis et al., 2009; Franzen et al. 2011). In addition, showcases of implemented RE projects on islands underline the potential and attractiveness of reducing fossil fuel based power generation and GHG emissions. Even though small islands and SIDS can only reduce a small amount of the global GHG emissions directly, they are able to send important signals to high polluting countries that high share renewable energy systems are technically, economically and politically feasible. On some Pacific islands PV projects target to convert the islands energy supply systems into 100% fossil fuel free supply systems, which is already achieved on Tokelau Islands.[3] On Graciosa, Azores, a combination of PV, wind power and batteries should enable the local utility “to switch off the diesel generator” (Franzen et al., 2011), whereas the coupling of energy demand for power and mobility could further reduce the cost (Hlusiak et al., 2012). Along these cases it becomes obvious that on different islands worldwide individual solutions to implement RE are chosen as for example listed by IRENA Global Renewable Energy Island Network (GREIN).[4] Anyhow, no comprehensive overview on the resource availability and on the local

[1] ⟨http://grein.irena.org/islandlighthouses.aspx⟩
[2] ⟨http://aosis.org/⟩
[3] ⟨http://www.sma.de/en/newsroom/current-news/news-details/news/3943-tokelau-becomes-the-worlds-first-100-solar-powered-country.html⟩
[4] ⟨http://grein.irena.org/⟩