GLOBAL PV AND WIND POWER POTENTIAL OF SMALL ISLAND HYBRID MINI-GRIDS

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Motivation:
Renewable based hybrid mini-grids have been proven to be a sustainable and cost-effective solution to electrify remote regions [1], [2], [3]. Many case studies have been conducted globally for rural electrification and small islands [4], [5], [6]. Even though single islands are understood quite well the big picture of the global island land-scape is missing.
To target the existing potential for PV and wind power on small islands it is essential to understand the different conditions in different regions worldwide. Main influence on the potential has the local load profile, the diesel price for power generation, and solar and wind resources.
This work uses these data as a base for simulating the techno-economic optimized renewable energy potential on each small island (1,000 to 100,000 inhabitants) worldwide to assess the local market potential for hybrid mini-grids. The assessment should help companies and organizations to identify the most attractive island region for their hybrid mini-grid solutions.

Approach and Methodology:
First of all the small islands are detected globally by geographic information system (GIS) tools. For each island the population, local gross domestic product (GDP), electricity consumption (based on GDP) and local diesel costs are taken from the following data bases [7], [8], [9].
To calculate the least-cost hybrid technology combination for each island a Reiner Lemoine Institut (RLI) developed simulation tool based on Matlab is used. This model simulates an energy system in hourly time steps over one reference year regarding the fossil and renewable resources and technical, economic and load data. The considered components are diesel gensets, photovoltaics, wind turbines, battery storage, and one overall load (cf. Fig. 1). Fed by global input parameters for each island between 1,000 and 100,000 inhabitants the tool optimizes PV, wind power and battery sizes.

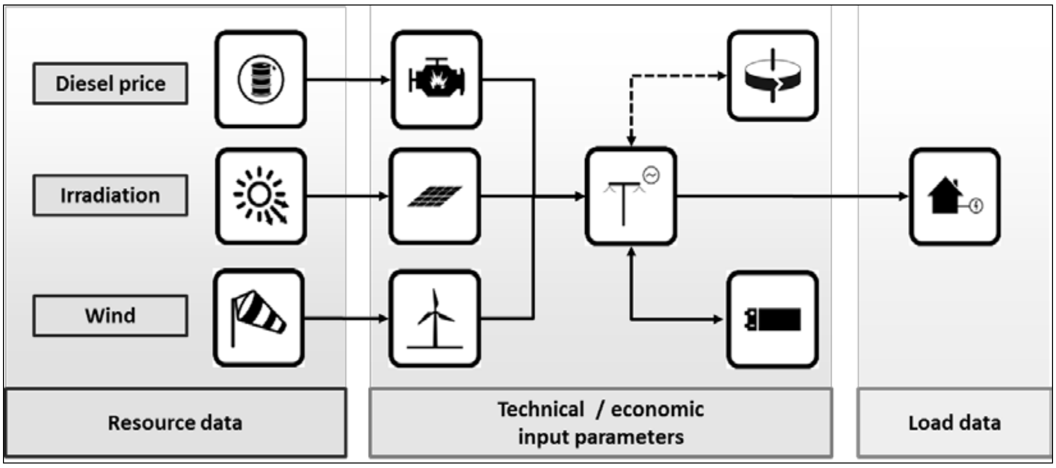

Figure 1: Simulation model of island's energy supply system.

Resource data: Diesel price (0.63 EUR/l, 3 % annual increase, transportation costs by traveltime [10], [9]), solar irradiation and wind speed by DLR Deutsches Zentrum für Luft- und Raumfahrt. Original data provided by NASA.
Technical: Diesel (efficiency: 25 to 35 %), Battery (round cycle efficiency: 85 %, lifetime: 10 yrs, c-rate: 1:6 kW/kWh), Flywheel (30 % of total renewable capacity, just considered in economics).
Economic: Capital expenditures - Capex (Diesel: 0 EUR/kW, PV: 2,000 EUR/kWp (high costs according to small market size and high transportation efforts), Wind: 1,250 to 1,500 EUR/kW (smaller turbine), Battery: 250 EUR/kWh, Flywheel: 1,000 EUR/kW), Operational expenditures - Opex (Diesel 0 EUR/kW*yr, PV: 2 % of Capex/yr, Wind: 2.5 % of Capex/yr, Battery: 10 EUR/kWh*yr, Flywheel: 0 EUR/kW*yr), Weighted average cost of capital - WACC (7 %), Project lifetime: 20 yrs (conservative approach due to difficult maintenance on islands, wind and PV plants last usually longer than 20 years).
Load: According to GDP, location, and tourism factor (number of overnight stays per year, derived from country level [11]) of island.

Results:
The results of the GIS analysis for small islands are shown in Fig. 2 and Tab. 1. The map in Fig. 2 illustrates the global distribution of small islands and indicates the yearly electricity consumption.

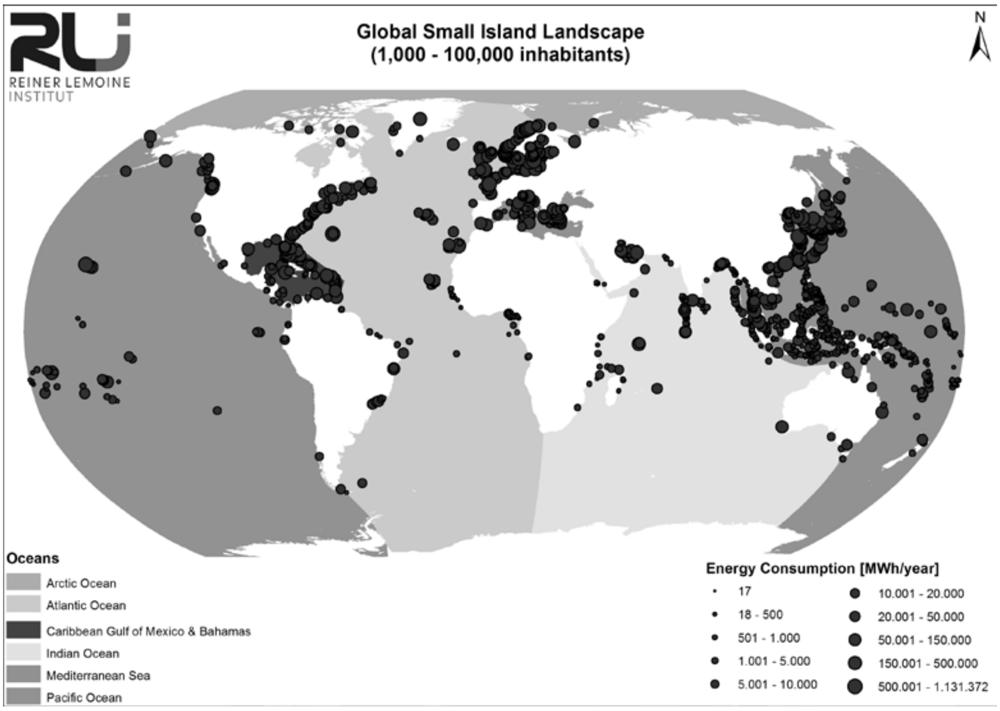

Figure 2: Global map of islands – energy consumption of small islands is highlighted.

It can be seen that both in number of islands and in population the Pacific region reaches the highest values. In addition to the geographic and economic information the local power generation costs for diesel are calculated. With an average efficiency of 30 % the diesel power generation costs range from about 32 to 39 EURct/kWh for the different regions. This reveals already a high cost reduction potential by hybridization of these diesel mini-grids via renewable energies.

Table 1: Overview on global small island landscape (1,000 to 100,000 inhabitants).
Regions: Atlantic and Arctic Ocean, Caribbean plus Gulf of Mexico and Bahamas, Indian Ocean, Mediterranean Sea, Pacific Ocean.

Region	Number of Islands	Population (av.)	Population (sum)	GDP (av.) [EUR/cap]	El. cons. (sum) [GWh/year]	El. cons. (av.) [MWh/year]	LCOE Diesel only (av.) [EURct/kWh]
Atl. + Arct. Oc.	416	9,985	4,150,000	18,200	18,270	43,930	36.6
Caribbean +	105	16,160	1,700,000	14,600	5,730	54,550	34.2
Indian Ocean	232	12,210	2,830,000	2,960	2,240	9,670	38.0
Mediterr. Sea	104	10,540	1,100,000	23,500	3,680	35,390	33.2
Pacific Ocean	1,199	9,690	11,620,000	8,660	22,770	18,990	39.3
Total	**2,056**	**10,410**	**21,400,000**	**14,300**	**52,690**	**25,630**	**38.0**

In the following the hybridization potential of these diesel based island grids by PV, wind power and batteries is revealed. For each island the configuration of a hybrid mini-grid is techno-economically optimized as described in the previous chapter. PV and wind power combined with batteries extend the diesel systems and mostly reduce the LCOE. According to different local conditions the most economic configurations change very much in different regions.

Photovoltaics
Fig. 3 illustrates the optimized PV configuration on a world map. It can be seen that most of the PV potential compared to the overall energy consumption (cf. Fig. 2) is found in tropical and sub-tropical regions. The higher the distance to the equator is the lower is the PV potential, even though the PV sizes seem small in the Pacific region due to small island sizes. Nevertheless, on almost all islands PV is economically feasible only the share within the energy supply system differs.

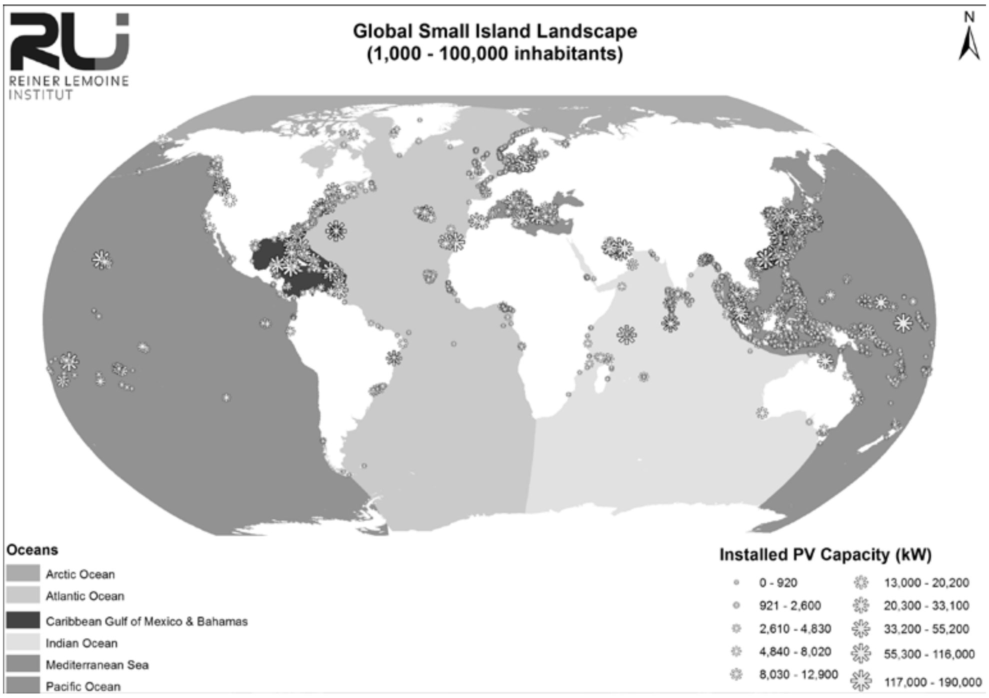

Figure 3: Global map of islands – PV capacity for techno-economic optimized configuration is highlighted. Ranging from 0 to 190 MW for single islands

Wind power

After indicating the interesting spots for PV the wind power potential on small islands is shown in Fig. 4. The distribution of wind power is quite different compared to the PV installations. Mostly in the northern hemisphere high wind potential can be found.

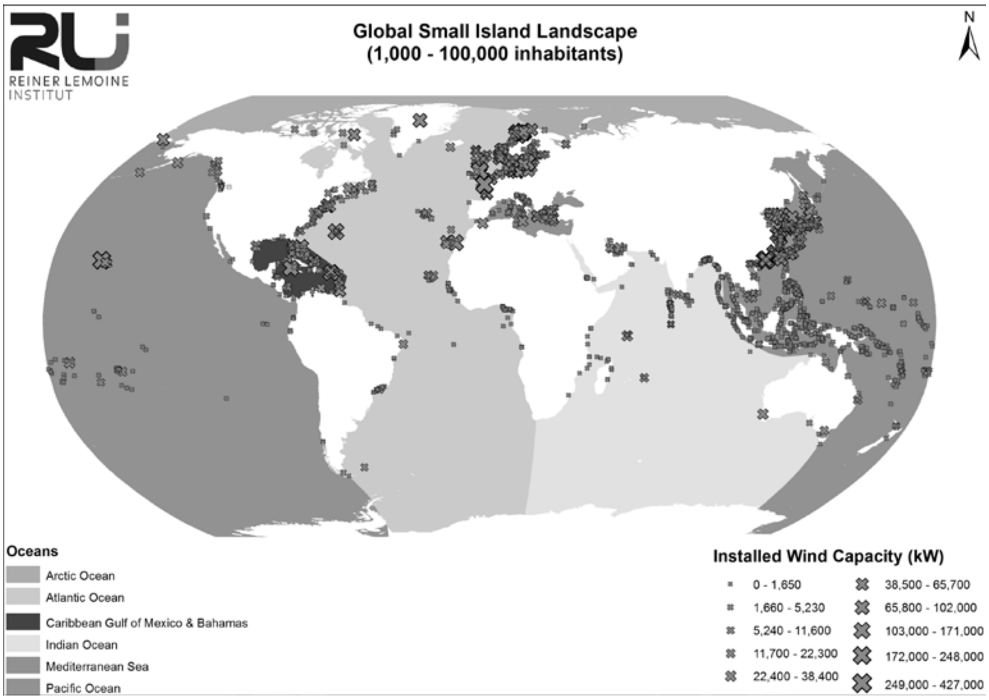

Figure 4: Global map of islands – Wind power capacity for techno-economic optimized configuration is highlighted. Ranging from 0 to 427 MW for single islands.

Battery power

As third component of a hybrid mini-grid potentially installed battery power is illustrated in Fig. 5. The energy storage potential highly correlates with the PV potential. More details on the influence of batteries within hybrid mini-grids can be found in [12].

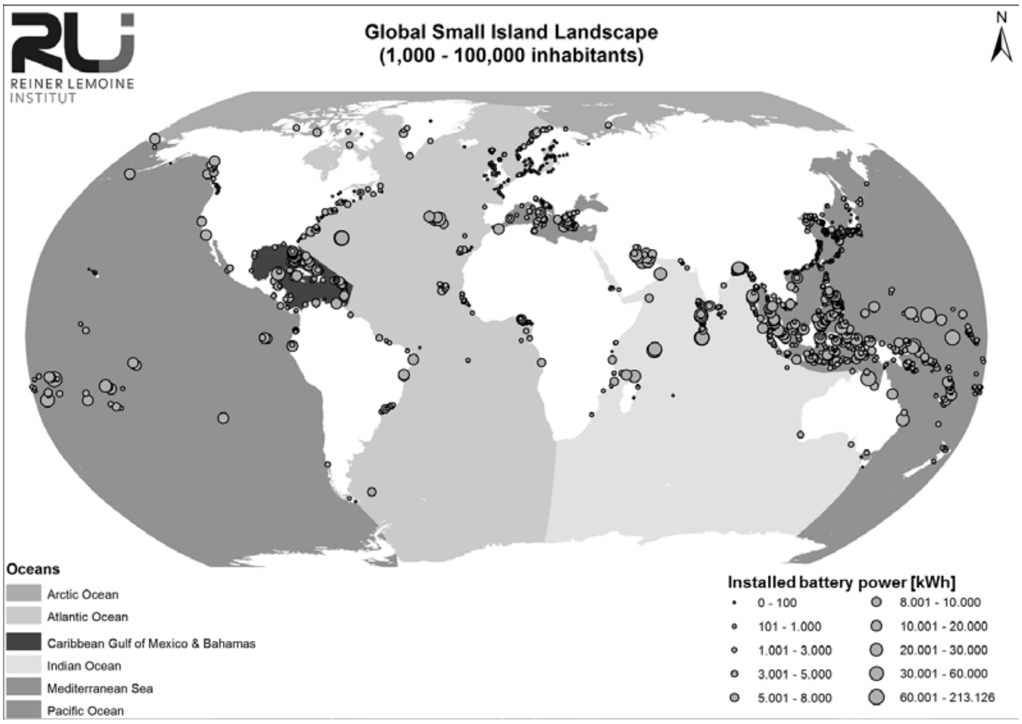

Figure 5: Global map of islands – Battery capacity for techno-economic optimized configuration is highlighted. Ranging from 0 to 213 MWh for single islands

Comparison

Overall, RE are very attractive on small islands. The RE share ranges from 55 to 80 percent in the economically optimized configurations (cf. Tab. 2). In regions with high PV and battery share, the highest overall RE share is reached, which is true for the Mediterranean and Pacific Ocean region. Wind technologies are favorable in the Atlantic and Arctic Ocean, but due to lower PV yields the optimized RE share is not higher than 58 %. For the Caribbean and Indian Ocean region the amount of battery is quite low. The natural resources fit quite well to the load curves and 55 to 65 % RE share are the techno-economic optimum without using high storage capacities. Especially in the Indian Ocean very high LCOE reductions are reached.

By introducing REs an average LCOE reduction of approx. 10 EURct/kWh is accomplished for all small islands. Looking at Fig. 6 reveals the LCOE reduction by REs for each island. The smaller and the more remote one island is, the higher is the LCOE reduction. This means, economically most attractive island systems are small and hard to reach which leads to difficulties in the business implementation. Investors have to choose between highest LCOE reductions, remoteness and market size.

Table 2: Results of techno-economic optimization of energy supply systems for global small island landscape (1,000 to 100,000 inhabitants).
Regions: Atlantic and Arctic Ocean, Caribbean plus Gulf of Mexico and Bahamas, Indian Ocean, Mediterranean Sea, Pacific Ocean.

Region	**PV** **(sum)** [MWp]	**Wind** **(sum)** [MW]	**Battery** **(sum)** [MWh]	**LCOE optimized system (avg.)** [EURct/kWh]	**LCOE reduction (avg.)** [EURct/kWh]	**RE share** **(avg.)** %
Atl. + Arct. Oc.	1,125	5,267	930	25.9	10.7	0.58
Caribbean +	605	762	230	25.5	8.7	0.55
Indian Ocean	992	1,186	360	23.9	14.1	0.65
Mediterr. Sea	731	259	1,240	27.7	5.5	0.80
Pacific Ocean	4,034	4,836	2,550	28.1	11.2	0.71
Total	**7,502**	**12,250**	**5,310**	**28.4**	**9.6**	**0.71**

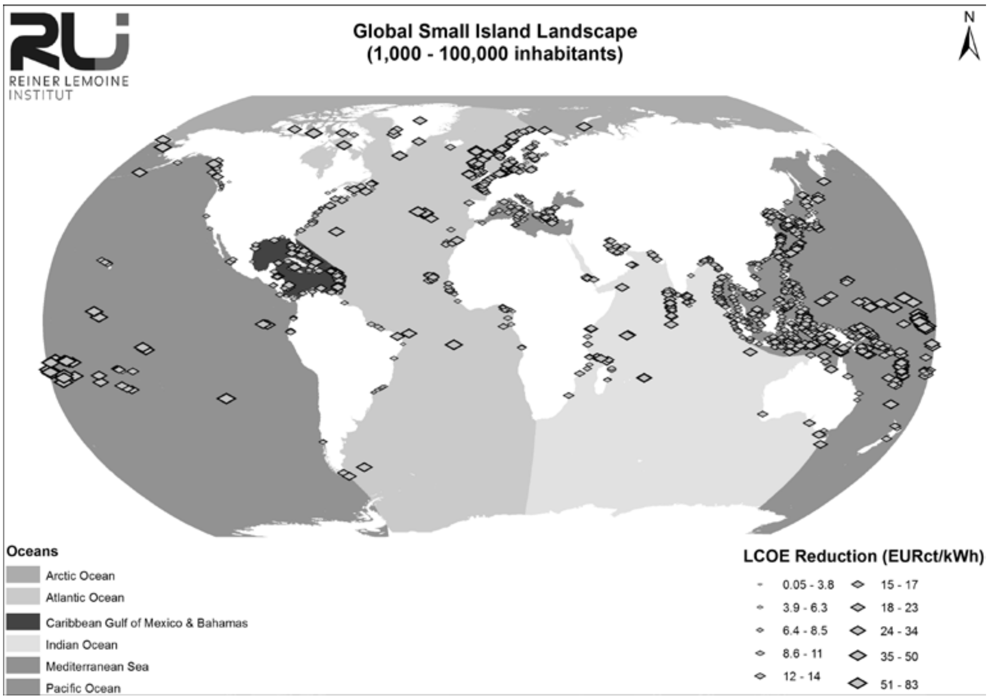

Figure 6: Global map of islands – LCOE reduction for techno-economic optimized configuration is highlighted. Ranging from 0 to 83 EURct/kWh for single islands.

Scientific innovation and relevance:

As aforementioned in the motivation this works supports the global roll out of small islands hybrid mini-grids. To develop a strategy for their off-grid businesses companies need to understand the island landscape better according to size, electricity demand, diesel costs and renewable resources. In opposite to other publications [3], [4], [5], [6] it is not based on just one region or single islands, but compares all small islands worldwide.

Without any subsidies, 70% RE can be economically viable on small islands due to expensive current diesel based power generation. Thousands of megawatts of PV and wind power could be installed if these potentials are being tapped.

Acknowledgement

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