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Geographic, technological and economic analysis of isolated diesel grids

Assessment of the upgrading potential with renewable energies for the examples of Peru, the Philippines and Tanzania

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I. Abstract

Diesel generators contribute to a large share of power generation in developing countries like Peru, the Philippines and Tanzania. This leads to high costs for electricity and causes harmful air pollution. In contrast to that renewable energies can provide affordable and environmentally sound power. This paper indicates that a potential of at least 500 MW is available for upgrading isolated diesel grids to hybrid grids. A geographic analysis is developed in order to localize isolated diesel grids. Furthermore, detected diesel grids are analyzed in terms of installed capacity, operators and purpose of supply. The methodology presented in this paper enables to reveal the huge potential that retrofitting isolated diesel grids provides for the introduction of renewable energies.

II. Introduction and Research objectives

Electricity is mainly supplied by distributed diesel generators in remote areas of many developing countries [1]. This extensive use of diesel generators is based on little initial costs, high availability on world markets, flexibility of power supply and ease of installation [2]. However, they include disadvantages as power generation is dependent on diesel fuel supply. Expenditures for fuel make up more than 80% of the total generation costs [3]. Thereby, electricity costs are largely determined by diesel retail prices and in this way subjected to crude oil price volatility. Depending on the remoteness of a location, transport costs can comprise a significant share of electricity costs, especially when supplying remote islands [4]. Furthermore, the use of diesel generators has detrimental environmental effects [2]. They contribute to climate change by greenhouse gas emissions and beyond they can cause respiratory diseases and cancer by the emission of air pollutants, especially particulate matter [5].

The expansion of existing diesel grids with renewable energy systems (RES) would significantly reduce the electricity costs and the emission of air pollutants [6]. So far, the required high initial investments prevented renewable energies from being introduced on a larger scale. Instead, more “affordable” diesel generators were favored even though resulting in higher power generation expenses over time [7]. Retrofitting diesel grids with renewable energies is already economically viable and will become even more viable in many locations when taking into account that fossil fuel prices are projected to increase [8], while costs for renewable energies are decreasing [7] [9] [10] [11] and are already on a comparably low level [12]. In some areas it is already feasible to integrate RES in existing isolated diesel grids under current technological conditions [13]. For the integration of RES it is advantageous to use the preexisting technical, economic and financial infrastructure from isolated diesel grids.

Even though it seems economically and ecologically very attractive to extend or substitute isolated diesel grids by RES, only little in-depth information can be found in the scientific literature. Isolated diesel grids are often stated as very important for decentralized energy supply, [14], [15] & [13] but no detailed information (e.g. on capacity or operators) is provided. Substantial characteristics of isolated diesel grids and barriers for the introduction of RES remain unclear. Within this study isolated diesel grids in Peru, the Philippines and Tanzania are analyzed in terms of location, size, purpose of supply, and ownership.

III. Approach and Methods

Three countries are selected for this study: Peru, the Philippines and Tanzania. Each is located on a different continent and characterized by specific geographic conditions. Distributed generation is important in areas not covered by the main transmission grid. Main limiting factors for not extending the grid are the topography in Peru, the insular distribution in the Philippines and lacking economic viability in Tanzania. Furthermore they are characterized by high expenditures for fossil fuel imports, low electricity consumption and a high share of people living in rural areas (Tab. 1).

All three countries are developing countries, but it is possible to distinguish them according to the indicators in Tab. 1. Peru appears to be the most developed country with highest gross domestic product (GDP) per capita, highest electricity consumption and lowest rural population rate. The Philippines achieve only less than half of the values of Peru and Tanzania lags far behind with lowest GDP per capita, electrification rate, electricity consumption and highest rural population and expenditures for oil imports. This coincides with the World Bank income levels that differ in Peru as “higher middle income”, the Philippines as “lower middle income” and Tanzania as “low income” [16].

Table 1: Key parameters for the surveyed countries [16] [17] [18]: Total population of each country in thousands; Gross domestic product per capita in USD; people with access to electricity in percent of total, part of the population living in rural areas in percent of total, electricity consumption per capita in kWh, expenditures for crude oil imports in percent of GDP.

Country	Total population (1000 pp) [17]	GDP (USD per capita) [17]	Electrification rate (%) [16]	Rural population (%) [16]	Electricity consumption (kWh per capita) [16]	Expenditures for oil imports (% of GDP) [18]
Peru	29,549	10,200	85.7	22.7	1,135	3.1
Philippines	103,755	4,100	89.7	51.1	593	5.7
Tanzania	46,912	1,500	13.9	73.2	85	12.9

The first objective of this work is to localize and determine off-grid power generating facilities in the three relevant countries. This is executed as a geospatial analysis using ESRI ArcGIS 2010[1]. Operating power plants are extracted from the UDI World electric power plant database and visualized [1]. The database provides information on 40 different categories for each plant. For this study data on unit, plant, operator, capacity, fuel type, status, city, and geographic location are relevant.

Additionally, national electricity transmission grids are digitalized according to grid maps for Peru and the Philippines [19]. For Tanzania existing geospatial data are taken from the African Development Bank [20]. The aforementioned information on plants and distribution grid are included into ArcGIS 2010. The crucial information for defining a power generation plant as off-grid or on-grid is the distance to the main transmission grid. Isolated plants are localized by adding a buffer zone of 50 kilometers around the transmission grid and excluding all plants within this area [21]. The remaining plants outside the buffer zone (with a distance of 50 km to the main transmission grid) are identified as isolated off-grid plants. In the Philippines plants are also identified as off-grid plants if they were located

[1] ESRI ® Arc Map™ 10.0

within the 50 km buffer zone but on an island without connection to one of the main grids (Fig. 2). Finally, for further analysis only oil-fired plants are considered (Fig. 1, Fig. 2 and Fig. 3).

Apart from the identification of off-grid diesel plants the objective is to investigate the size classes found during the first analysis for characterizing typical diesel mini-grids for each country. The size classes of the identified isolated diesel plants are statistically analyzed by applying SPSS 15.0[2]. A descriptive statistical analysis is conducted and the sample is illustrated in a box plot (Fig. 5) and the main statistical parameters are calculated.

The last objective is to determine the types of operators running a diesel mini-grid and the purpose of supply for estimating whether an upgrade with RES is feasible or not. Operators are assigned to localized isolated diesel generators found in the previous research step by extracting the information from the UDI World electric power plant database. The types of operators (private – state owned) and purposes of supply are allocated according to literature review. The proportion of installed capacity and number of plants are calculated with SPSS 15.0.

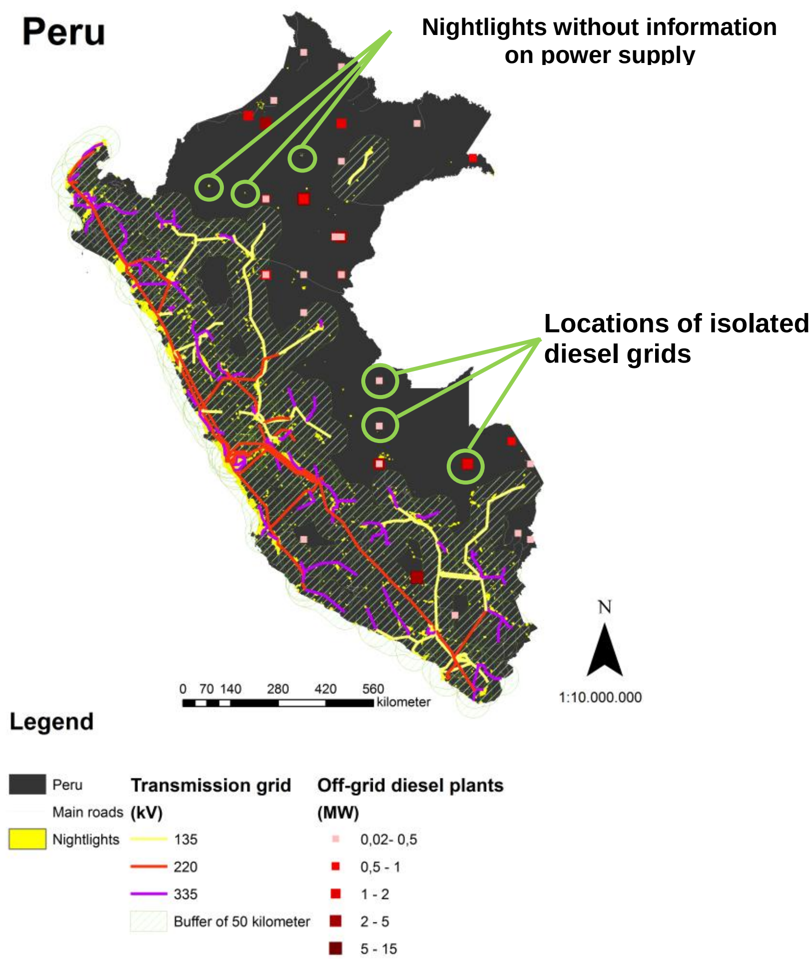

Figure 1: Peru - Diesel mini-grids, nightlights and national transmission grid

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[2] IBM ® SPSS™ 15.0 for Windows Evaluation Version

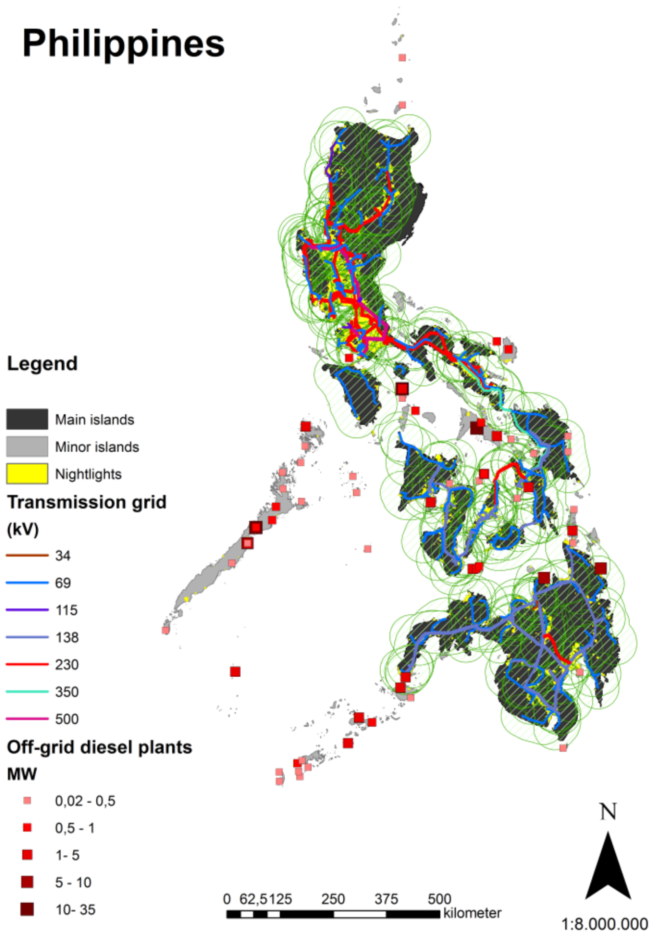

Figure 2: Philippines - Diesel mini-grids, nightlights and national transmission grid

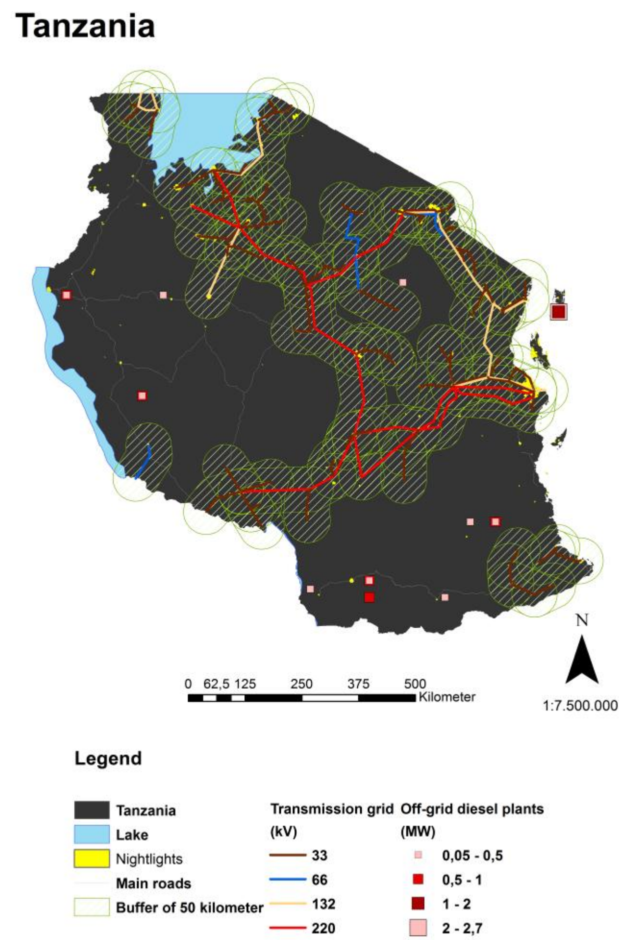

Figure 3: Tanzania - Diesel mini-grids, nightlights and national transmission grid

IV. RESULTS

The results demonstrate the heterogeneity of off-grid diesel power generation amongst the three surveyed countries. Tab. 2 lists the most important parameters for each country. The most isolated diesel grids, generators and highest installed off-grid diesel capacity are found in the Philippines, followed by Peru and Tanzania. The higher values identified in the Philippines probably are due to the overall higher population compared to the two other countries (Tab. 1) but as well related to the insular distribution of the country that makes distributed power generation even more important. Peru ranks second in terms of installed capacity and number of mini-grids. Here, distributed generation is crucial for remote areas that are very difficult to access. Tanzania has the lowest capacities. However, distributed generation is very important to enable electricity access because economic impacts prevent the extension of the main grid.

Overall, an installed diesel off-grid capacity of 501.5 MW is detected. Nevertheless, it is assumed that a much higher number of diesel generators are installed. Light sources visualized according to night satellite images indicate that there is even more off-grid capacity (Fig 1, Fig. 2, Fig. 3), which is potentially supplied by diesel generators. These are plants, that are operated by individuals or small and medium-sized enterprises and could not be considered within this study due to the lack of proper data.

Table 2: Key parameters of the diesel-based off-grid sector: Diesel off-grid capacity in megawatt, number of identified diesel plants, number of identified diesel mini-grids, number of operators

Country	Diesel-based off-grid capacity (MW)	Localized isolated diesel plants	Localized isolated diesel grids	Operators
Peru	105	50	29	17
Philippines	374.5	222	108	46
Tanzania	22	28	12	4

A higher number of operators in relation to the number of detected plants indicate a more liberalized electricity sector that allows private investment and private plant ownership. In fact, private companies comprise the major share of installed diesel capacity in Peru and the Philippines with 65 % and 52.8 %, respectively. On the contrary the diesel off-grid sector of Tanzania is totally dominated by two state-owned utilities with 98.2 % (Fig.4).

A high variety is reflected by the purposes of electricity supply: Whereas isolated diesel grids mainly contribute to the supply of mining locations in Peru, they are contributing to basic power supply for remote villages in Tanzania. On the Philippines off-grid supply has various purposes but a high share contributes to productive use (manufacturing & mining) (Fig. 4.).

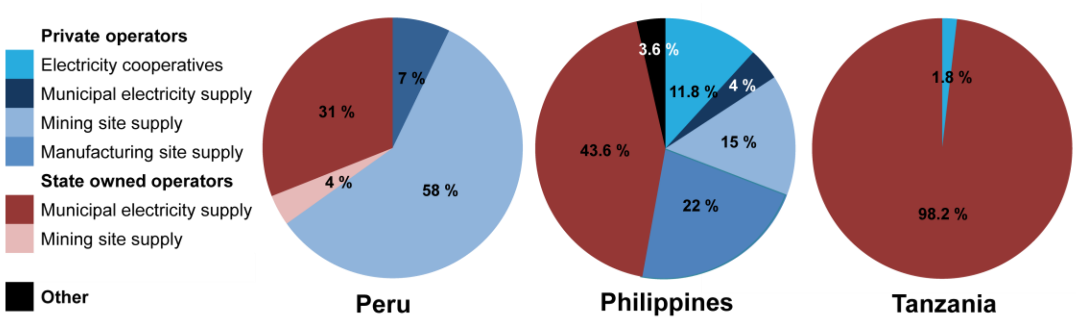

Figure 4: Type of operators and purpose of off-grid power supply in Peru, the Philippines and Tanzania

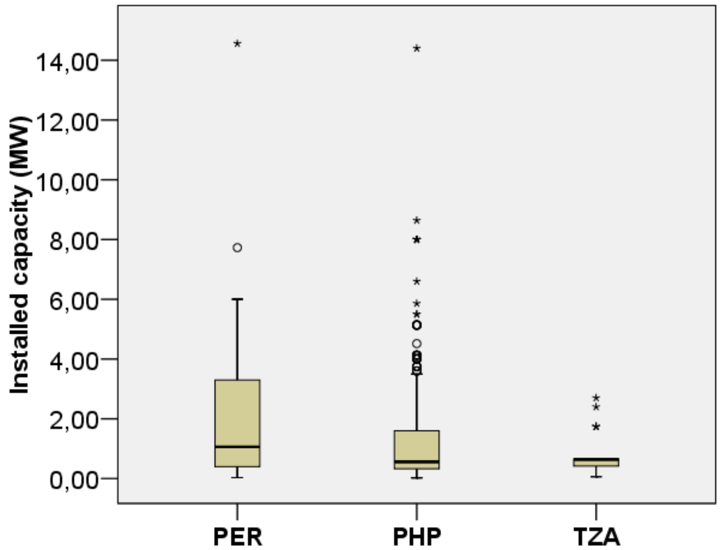

Figure 5: Boxplot showing the distribution of off-grid diesel generator sizes in Peru, the Philippines and Tanzania

Table 3: Key findings of the generator size analysis: Quantity of data cases, median of data cases, minimum of data cases, maximum of data cases

Country	N	Median (MW)	Minimum (MW)	Maximum (MW)
Peru	50	1.06	0.03	14.5
Philippines	222	0.56	0.02	16.0
Tanzania	28	0.64	0.06	2.7

Diesel generators have a comparable capacity in Tanzania and the Philippines with a median of 0.64 MW and 0.56 MW, respectively. In Peru generators are slightly larger which is indicated by a higher median of 1.06 MW (Tab. 3). Large ranges are found for Peru and the Philippines with minimum sizes from 20 kW up to 16 MW (Tab. 3).

In Peru, generator sizes show the largest variety (Fig. 5) making it impossible to determine one typical diesel mini-grid system representing the predominant application on the ground. When taking into account the proportion per size classes it becomes obvious that two different system types are prevailing in Peru (Fig. 6). Diesel generators with capacities up to 500 kW constitute the first peak with 34 % of all localized generators. Fewer generators are found in the two following sizes classes from 500 kW to 2 MW. The second peak is found within a capacity from 2 to 5 MW. The smaller grids supply power to remote villages far away from the main grid and are operated mainly by state owned utilities as indicated in Figure 4. The purpose of the largest systems is to supply remote mining sites. Here, several generators with more than one megawatt installed power are comprised for power supply. These mini-grids are mainly operated by private companies and in many cases by the mining company itself (Fig. 4).

The majority of diesel generators on the Philippines are aggregated within a small range of 400 kW 1.5 MW. However, the sample shows some outliers and extremes (Fig. 5). This is due to the variety of purposes that distributed diesel power generation is applied for on the Philippines (Fig. 4). Nevertheless, generators up to one MW make up by far the most generators found on the Philippines (Fig. 6). Thus, it is assumed that the prevailing system is a mini-grid that supplies power on remote islands. The smallest diesel grids comprise only some tens of kilowatt on remote islands but on larger islands with more productive use of electricity diesel mini-grids reach capacities of more than 20 MW. However, diesel mini-grids are slightly smaller than in Peru.

In Tanzania diesel power systems are utilized for supplying remote villages with an average population of 40,000 inhabitants. The majority of mini-grids are operated by the main electricity utility of the country, TANESCO. A typical system consists of two to three diesel generators with a capacity of around 600 kW each. Besides of insufficiency to generate enough power these systems are often malfunctioning due to overload and bad management.

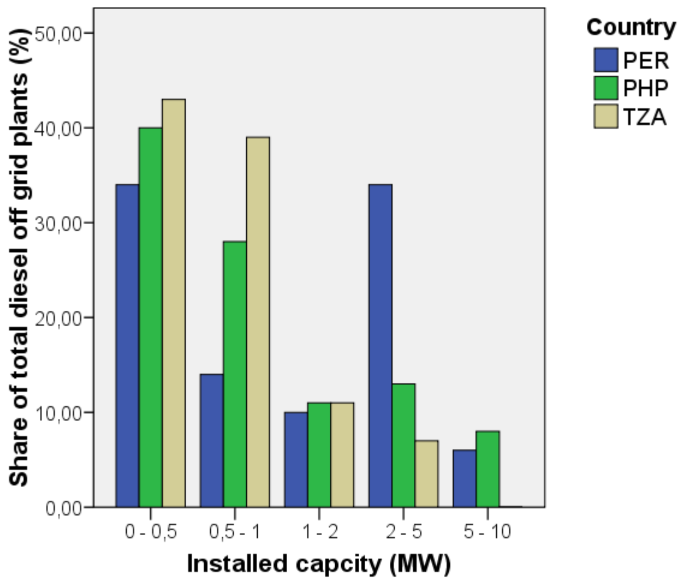

Figure 6: Proportion of diesel generators (%) per size class (MW) for Peru, the Philippines and Tanzania

V. Conclusion

Off-grid diesel power generation in the surveyed countries has various purposes and by that different customer groups. Consequently, location-based RES solutions and custom-tailored business models for upgrading off-grid diesel mini-grids are necessary. Nevertheless, it is possible to give indications for the injection of RES into remote grids in each of the three countries.

In Peru it is reasonable to design two customized business models. The first one should focus on the mining sector and private operators. Due to the high installed diesel capacity at mines, an upgrade of the existing off-grid diesel power generation by RES is possible as a first step. The second one should focus on municipal power supply for remote villages that is currently provided by state-owned utilities. Here, less capacity is installed and thereby the market potential for RES is smaller. However, an injection of RES could imply many benefits for the Peruvian government by reducing generation costs, enabling larger electricity access and dispense the need for fuel purchase and transport.

Off-grid electricity is essential for an insular state like the Philippines. Business models adjusted to population and electricity demand for a range of island sizes should be developed. In terms of financial viability it would be advantageous to focus on productive users, who consume up to at least 37 % of the diesel off-grid power. Thus, the facilities of small and medium sized enterprises and electricity cooperatives should be targeted for an upgrade with RES. Afterwards, a further escalation of electricity supply based on these facilities is reasonable.

State owned companies dominate the off-grid electricity generation and distribution in Tanzania. Hence, the utilities should be directly targeted with the business models. Business models should include renewable energy mini-grid solutions for the wider distribution of electricity in the remote areas of Tanzania. Furthermore, the cost saving potential of hybrid mini-grids should be worked out for a country like Tanzania that is spending a high share of its GDP for fossil fuel imports.

Overall a potential of at least 500 MW installed exists for the three exemplary countries, which can be seen as a great market potential for upgrading isolated diesel grids by renewable energies. Furthermore, a population of more than 14 million lives offside (more than 50 km distance) the main grid in the three countries. Retrofitting existing diesel grids with RES can contribute to a higher quality of power supply and widen electricity access and by that trigger sustainable development in the three countries. By applying the aforementioned business models, investors can start implementing RES due to their competitiveness in diesel-based mini grids.

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