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# Geographic, technological and economic analysis of isolated diesel grids to assess the upgrading potential with renewable energies A case study of Tanzania

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**Abstract**

In Tanzania off-grid electricity is mainly supplied by diesel generators. This causes harmful air pollution and leads to high power generation cost. Contrary to that renewable energies can provide affordable and environmentally sound power. This paper indicates that a potential of at least 22 MW is available for upgrading isolated diesel grids to hybrid grids. The electricity is supplied by state-owned utilities and private cooperatives, representing two contrary business models. 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 tariff structure. With rising fuel prices, it is expected that upgrading with renewable energies will become the most competitive option for rural areas of Tanzania.

**Keywords:** hybrid grids, rural electrification, off-grid supply, geospatial analysis

## Introduction

### Isolated diesel grids

Electricity is mainly supplied by distributed diesel generators in remote areas of many developing countries (Platts, 2009). This extensive use of diesel gensets is based on little initial costs, high reliability and ease of installation (ESMAP, 2007). But they include disadvantages as electricity costs are high due to expensive fossil fuel imports and high transportation costs (Breyer et al., 2011). Furthermore, diesel generators contribute to local and global environmental pollution (ESMAP, 2007).

The expansion of existing diesel grids with renewable energy systems (RES) could significantly reduce the electricity costs and the emission of air pollutants (Dekker et al., 2012). So far, the required high initial investments prevented renewable energies from being introduced on a larger scale. Instead of that more “affordable” diesel generators were favored even though resulting in higher power generation expenses over time (IEA-RETD, 2012).

Taking into account that fossil fuel prices are projected to increase (IEA, 2011) while costs for renewable energies are decreasing (IEA-RETD, 2012) and are already competitive with diesel-based generation (Schleicher-Tappeser, 2012), retrofitting diesel grids with renewable energies will become economically viable in many locations. It is already feasible to integrate RES in existing isolated diesel grids under current technological conditions (ARE, 2011). For this integration the preexisting technical, economic and financial infrastructure can be used.

Even if it seems economically and ecologically very attractive to extend or substitute isolated diesel grids by RES, only few information can be found in the scientific literature about this. Isolated diesel grids are often stated as very important for decentralized energy supply, (Zerriffi, 2011), (Brent & Rogers, 2010) & (ARE, 2011) 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 these topics are analyzed, as it is crucial to understand the diesel power generation to successfully implement the new RES.

### Case study country - Tanzania

Tanzania is chosen as case study country because it is representative for the situation in a number of African countries: Insufficient energy supply impedes economic development in rural areas, although renewable energy sources are abundant (BEST-AC, 2012).

The east African country comprises an area of 947,300 km² with a population of 46 million (CIA, 2012). It is one of the world’s poorest economies with a GDP of 528 USD per capita (World Bank, 2011) and an electrification rate of only 11%, that even falls below 2 % in rural areas (Rickerson, 2012).

The total installed power capacity in Tanzania adds up to 1,185 MW, which is supplied mainly by hydro followed by gas and oil power sources (Platts, 2009). Electricity is distributed by a transmission grid of 3,800 kilometers, which covers the country from the north-west to the south-east, representing the most prosperous and populated regions (ADB, 2012). Areas not covered by the main transmission grid are supplied by isolated diesel grids.

Tanzania lacks domestic oil resources, therefore fossil fuels need to be imported. The annual expenditures for crude oil imports add up to 6.5 % of the GDP (IRENA, 2010). Moreover, electricity costs in rural areas are increased by high transportation costs resulting in a low overall access to electricity. Despite all these unfavorable conditions, Tanzania has been ranked among the top 10 countries in the world for establishing sustainable business models for RES-based mini-grids (Gerlach A.-K. et al., 2013).

Although the injection of RES is challenging due to the complexity of management systems, lack of investment resources and lack of technical knowledge (GVEP, 2011), it could reduce electricity costs and improve the quality of supply. By that it is possible to relieve Tanzania's national budget, to enable economic growth and to increase the electricity access in rural areas.

## Research Objectives

As aforementioned, it is crucial to analyze the current diesel power generation system to find proper ways of extending or substituting them by RES. Doing this, our paper focuses on the following three research objectives:

1. Localization of isolated diesel grids
2. Analysis of isolated diesel generator size
3. Analysis of isolated diesel grid operators

Research objectives are worked on in the presented order above. First, it is necessary to localize and identify isolated diesel grids. Based on these outcomes the size structure is analyzed. Finally, operators and operating models are studied and associated to the outcomes of research objective 1 and 2.

## Methods

### Prearrangement of the data base

Required information on diesel power plants in Tanzania are extracted from the UDI World electric power plant database (Platts, 2009). 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. Plants are considered for further investigation, if the primary fuel type is diesel and the plants are stated as operating. Nevertheless, it is assumed that a much higher number of diesel generators are installed. These are plants, that are operated by individuals or small and medium-sized enterprises. Although these plants probably reflect a high potential for the upgrade with RES, they are not considered within this study due to the lack of proper data.

### Localization of isolated diesel plants

The localization of off-grid diesel plants is executed as a geospatial analysis using ESRI ArcGIS 2010[1]. The prearranged data from the UDI World electric power plant database is visualized in ArcMap 2010. Additionally, the national electricity transmission grid is included according to existing geospatial data taken from the African Development Bank (ADB, 2012). Isolated diesel plants are localized by adding a buffer zone of 50 kilometers around the transmission grid and excluding all plants within this area (Szabó, 2011). The remaining diesel plants outside the buffer zone are identified as isolated off-grid plants (Fig. 1).

### Analysis of isolated diesel generator size

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. 2) and main statistical parameters are calculated.

### Analysis of isolated diesel grid operators

Operators are assigned to localized isolated diesel generators in the previous research steps 1 and 2. The proportion of installed capacity and number of plants is calculated with SPSS 15.0. Further information on tariff structure, financial performance, technical performance and purposes of electricity supply is extracted from literature review.

## Results

### Localization of isolated diesel plants

In total, 28 isolated diesel generators were identified in eleven different locations (Fig.1 – dashed green boxes). Thus, it is assumed that each location represents an isolated diesel grid. The accumulated installed capacity of all isolated diesel grids is 21.8 MW. Six isolated diesel grids are located in the southern part, three in the western part, one in the central part of Tanzania and one on the island of Pemba (Fig.1).

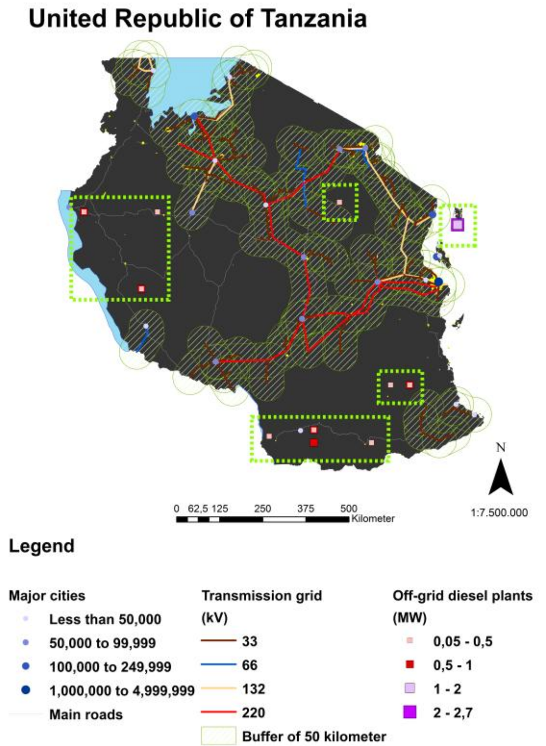


**Figure 1**: Isolated diesel grids in Tanzania.

[1] ESRI ® Arc Map™ 10.0

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

## Analysis of isolated diesel generator size

More than two thirds of the identified diesel plants have an installed capacity between 0.3 and 0.7 MW. The median of the sample is 0.65 MW. The range is 2.64 MW, with a minimum capacity of 0.06 MW and a maximum capacity of 2.7 MW (Fig. 2).

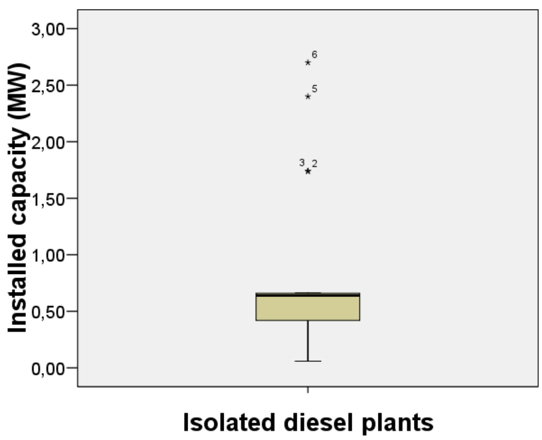


**Figure 2:** Boxplot of isolated diesel generators in Tanzania. Diesel plant parameters in the boxplot: N: 28, Median (MW): 0.65, Average (MW): 0.74, Maximum (MW): 2.7, Minimum (MW): 0.06.

## Analysis of isolated diesel grid operators

Four different operators, categorized in state-owned utilities and private cooperatives, run isolated grids. State owned utilities are the Tanzania Electric Supply Company (TANESCO) and the Zanzibar Electricity Corporation (ZECO). The two private electricity cooperatives are operating in the rural towns of Urambo and Mbinga.

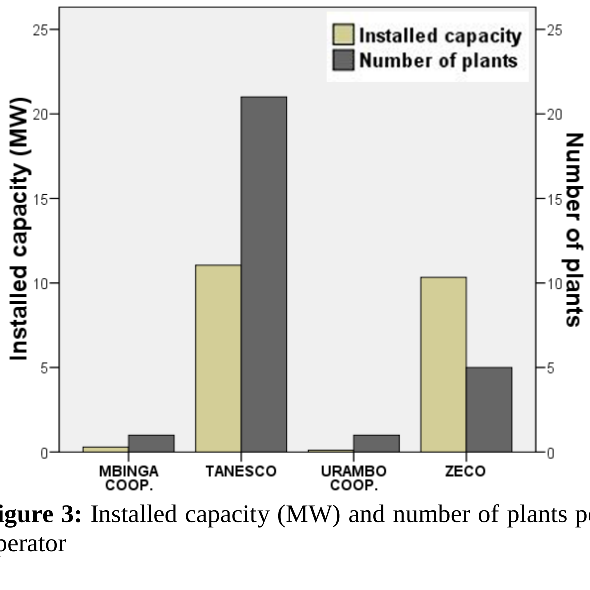


**Figure 3:** Installed capacity (MW) and number of plants per operator

**Table 1:** Isolated diesel grid operators

| Operator | Number of plants | Installed capacity (MW) | Organization type |
|---|---|---|---|
| TANESCO | 21 | 11.05 | state-owned |
| ZECO | 5 | 10.33 | state-owned |
| Urambo coop. | 1 | 0.11 | private |
| Mbinga coop. | 1 | 0.29 | private |

TANESCO comprises the majority of installed capacity with 11.05 MW, followed by ZECO with 10.33 MW. The two cooperatives have a minor proportion of installed capacity in the Tanzanian off-grid sector (Tab. 1 and Fig. 3).

The comparison of electricity retail prices for off-grid mini-grids detects huge differences among the operators. TANESCO charges 0.03 USD/kWh[3], whereas almost the tenfold price is charged by the Urambo electricity cooperative (Tab. 2). As a state-owned utility TANESCO's electricity tariff is subsidized by the government, leading to a loss of 0.42USD per generated kilowatt hour (Tab. 2). These losses accumulate to a deficit of approximately 36 million USD annually (Eberhard, 2010).

**Table 2:** Tariff structure of isolated diesel grid operators[4]

| Operator | Tariff (USD/kWh) | Generating costs (USD/kWh) | Financial performance (USD/kWh) |
|---|---|---|---|
| TANESCO | 0.03 | 0.45 | **-0.42** |
| ZECO | 0.06 | 0.45 | **-0.39** |
| Urambo coop.[5] | 0.28 | 0.15 | **0.13** |
| Mbinga coop. | N/A | 0.15 | N/A |

The calculation of levelized cost of electricity (LCOE) indicates, that RES are already cost-effective compared to diesel generators. The introduction of photovoltaic systems (PV) bears the potential for savings of 0.18 USD per kilowatt hour (Tab. 3) despite the fact that PV initial cost are exceptionally high due to rather unfavorable business conditions (World Bank & IFC, 2012). In addition capital expenditures are not considered in the calculation of diesel LCOE, which would make PV even more attractive.

**Table 3:** LCOE Diesel vs. RES; input parameters for calculation: PV –Yield/annum: 1,600 kWh/kWp, Capex: 3,250 USD/kWp, Opex: 32.5 USD/kWp, IRR: 0.2, IRL: 0.18, ER: 0.2, Inflation rate: 0.11. Diesel – Fuel costs: 1.36 USD/liter, Capex: 0 USD/kWh, Opex: 0.04 USD/kWh.

| | PV | Diesel | Cost advantage RES |
|---|---|---|---|
| LCOE (USD/kWh) | 0.27 | 0.45 | **0.18** |

## Discussion

The developed methodology is applicable for the localization of isolated diesel grids in general and used here for the case of Tanzania (Breyer, 2012). A potential of 22 MW installed capacity is detected, that offers great economic and ecological potential for an upgrade, especially with regard to the advancing diesel parity of RES (Schleicher-Tappeser, 2012). However, insufficient data and oversizing of the buffer zone probably might lead to the overlook of isolated grids. For Tanzania the installed capacity of all operating isolated diesel grids is stated 30 MW as opposed to the 22 MW detected (Eberhard, 2010).

[3]Domestic Low Usage Tariff up to 50 kWh
[4] Exchange rate: 1 USD = 1,596.33 TZS
[5] Parameters refer to the situation in 2005 (Ilskog et al., 2005)

Isolated diesel grids provide electricity in structurally weak and remote areas. Here, a low population density, low electricity demand and low income are major constraints for an extension of the main transmission grids. This assumption is validated by the results: Isolated diesel grids where predominantly localized in the poorest areas of Tanzania. As these grids are located close to population centers, it is assumed that they supply power for public, domestic and small productive use.

TANESCO and ZECO comprise the majority of installed capacity and the most diesel generators. Thus, it is important to concentrate on isolated grids of the two state-owned utilities for achieving an improved implementation of RES. Both utilities charge low electricity tariffs due to high subsidies. This results in an unsustainable business model, which leads to a deficit in Tanzania's national budget. The inclusion of RES could reduce the losses of this business model. However, for a sustainable electricity supply and the introduction of RES with the help of private investors, it is necessary to correlate tariffs to real generation costs.

The isolated diesel grids run by the electricity cooperatives hold only a minor proportion of the off-grid sector. However, a much larger number of diesel generators are likely operated informally by individuals and communities, which might contribute a significant share to the power generation. Hence, power generation apart from state-owned utilities presents an interesting business model, as it succeeded in setting cost-reflective tariffs, reducing the costs of operation and maintenance and improving the willingness to pay for electricity services (Marandu, 2002).

With the introduction of a framework for renewable energy small power projects in 2003 (EWURA, 2011), an important precondition for private and cooperative investment in the distributed electricity sector was created. Nevertheless, the framework failed in incenting renewable energy projects in remote areas. For a successful implementation of RES in existing isolated grids it is necessary to improve the framework in one crucial term: A clear regulation regarding the control, management and ownership of hybrid grids upgraded from former diesel grids is required. If this condition is met, the upgrade of the existing isolated diesel grids can improve the reliability of electricity supply. Furthermore, it is possible to increase the capacity of isolated grids and enable a higher electricity access in rural areas.

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