Comparison of Off-Grid Electrification versus Grid Extension: Influencing Parameters and The Role of Renewable Energies from a Geographic Point of View

Catherine Cader
November 21st, 2014
Bonn, Jahrestagung 2014 „EnergieGeographien in internationaler Perspektive“
Introduction

- Catherina Cader, born in Fulda, Germany (1986)
- Bachelor *Environmental Management* Justus Liebig Universität Gießen (2007-2010)
- Researcher in the Off-Grid Team, Reiner Lemoine Institut, Berlin (from 2012)
- Scholarship, PhD candidate (from 2014): Comparison of Off-Grid Electrification versus Grid Extension: Influencing Parameters and the Role of Renewable Energies from a Geographic Point of View: Uni Gießen, Supervisors: Prof. Dittmann, Prof. Winker
- Field research Cameroon (01/2014)
Research Groups

- Off-grid energy systems
- Integrated energy systems
  - Optimization of energy systems
  - Analysis of energy transition scenarios
- E-mobility
  - Integration of renewable energies into e-mobility concepts
- Renewable energy technology
  - Small wind power

Managing Director: Dr. Claus Beneking

**Scientific research for an energy transition towards 100% renewable energies.**
Off-Grid Activities: Overview

Main focus areas

• Simulation of Hybrid Mini-Grids
• GIS-based Analyses
• Evaluation of Socio-Economic Context
• Market Potential Assessment / Feasibility Studies
• Global Rankings of Attractiveness for Renewable Energies
• Cooperation with Private and Public Partners
Comparison of Off-Grid Electrification versus Grid Extension

catherina.cader@rl-institut.de

November 21st, 2014

Outline

• Introduction
• Objective
• Methods
Comparison of Off-Grid Electrification versus Grid Extension

catherina.cader@rl-institut.de

November 21st, 2014

Introduction

- No or insufficient access to electricity in many remote rural region
- High costs for diesel fuel and kerosene and environmental impact

<table>
<thead>
<tr>
<th>Region</th>
<th>Rural</th>
<th>Urban</th>
<th>Total</th>
<th>Share of population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing countries</td>
<td>1,081</td>
<td>184</td>
<td>1,265</td>
<td>24%</td>
</tr>
<tr>
<td>Africa</td>
<td>475</td>
<td>114</td>
<td>590</td>
<td>57%</td>
</tr>
<tr>
<td>Developing Asia</td>
<td>556</td>
<td>62</td>
<td>628</td>
<td>18%</td>
</tr>
<tr>
<td>Latin America</td>
<td>23</td>
<td>6</td>
<td>29</td>
<td>6%</td>
</tr>
<tr>
<td>Middle East</td>
<td>16</td>
<td>2</td>
<td>18</td>
<td>9%</td>
</tr>
<tr>
<td>World</td>
<td><strong>1,083</strong></td>
<td><strong>184</strong></td>
<td><strong>1,267</strong></td>
<td><strong>19%</strong></td>
</tr>
</tbody>
</table>

Comparison of Off-Grid Electrification versus Grid Extension

catherina.cader@rl-institut.de

November 21st, 2014

- Insufficient power generation facilities in many regions
- Expensive power generation costs (high levelized costs of electricity)
- Outdated infrastructure
- Unreliable grid electricity access
- Dependence on fossil fuel imports

Low electricity access, high costs and outdated technology is prevailing

Mobile diesel power generation plant – Siquijor Island, Philippines (Bertheau, 2013).

Energy kiosk – Extreme Nord, Cameroon (Cader, 2014).

Small diesel generator to power little energy kiosks – Extreme Nord, Cameroon (Cader, 2014).
Future outlook

- Increasing demand for electricity in the coming years, especially in developing countries
  - Shortage of fossil resources
  - Price increase of fossil resources
  - Pollution and CO₂ emissions

- Access to electricity is crucial for
  - Education
  - Health
  - Economic development

High potential of decentralized renewable energy sources
Wind – Solar – Hydro – Biomass

PV-Batterie SHS – Extreme Nord, Cameroon (Cader, 2014).
PV moduels – Extreme Nord, Cameroon (Cader, 2014).
The sum of the global irradiance can be utilized for a first estimation of the PV potential.

Open questions

- Where is an unmet demand for electricity?
- Where are renewable resources?
- Where are expensive fossil fuels used for electricity generation?
- Which regions are viable for a decentralized electricity generation compared to central generation with transmission and distribution lines?
- Where does sufficient energy infrastructure exist?

Village electrification plan for Cambodia. Source: http://www.eria.org/events/5.%20Mr.%20Toch%20Sovanna%20The%20Potential%20of%20Renewable%20Energy%20in%20Cambodia.pdf
Objective

Off-Grid Electrification Today and in Future - Influencing Parameters and The Role of Renewable Energies From a Geographic Point of View

→ Where and how can off-grid regions be supplied with electricity by small-scale hybrid systems with renewable energies?

→ What are the advantages and disadvantages of decentralized power supply compared with a central electricity generation?

→ Where are decentralized solutions still viable with a progression of the future grid development and why? (economically, politically, socially)
Decision support tool for the design of development plans for electricity:

→ Which regions should be supplied decentrally, where is grid extension the better option
  • Through economical benefits
  • Through a simpler realizability
  • Through technical feasibility

→ How important are renewable energies in this regard?
## Objective

### Definition of influencing parameters:

<table>
<thead>
<tr>
<th></th>
<th>Advantage +</th>
<th>Disadvantage -</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid extension</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Decentral off-grid/mini-grid solution</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

**Advantage +**
- Günstige Stromerzeugung durch große Kraftwerke und Economy of Scale
- Zentrale Organisationsstruktur
- Viele Menschen können gleichzeitig davon profitieren

**Disadvantage -**
- Lange komplexe Planungsprozesse (wo genau verlaufen die Netze?)
- Hohe Investitionen
- Begrenzte Mitgestaltungsmöglichkeiten

**Decentral off-grid/mini-grid solution**
- Durch Kleinskaligkeit einfach zu planen und geringer Investitionen möglich
- Schnellere Umsetzung
- Weniger Menschen erreicht
- LCOE können sehr unterschiedlich sein
- Je nach Region begrenzte Ressourcenverfügbarkeit
### Objective

**Definition of influencing parameters:**

<table>
<thead>
<tr>
<th>Advantage +</th>
<th>Disadvantage -</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid extension</strong></td>
<td><strong>Long, complex planning processes (where exactly will the grid be planned/extended?)</strong></td>
</tr>
<tr>
<td>• Cheap central electricity generation through economies of scale</td>
<td>• High initial investments</td>
</tr>
<tr>
<td>• Central organization</td>
<td>• Limited influence of single stakeholder</td>
</tr>
<tr>
<td>• Many people can profit at the same time</td>
<td>• Connection fees</td>
</tr>
<tr>
<td><strong>Decentral off-grid/ mini-grid solution</strong></td>
<td><strong>Many successful independent projects are needed</strong></td>
</tr>
<tr>
<td>• Easy planning and smaller initial investment needed</td>
<td>• LCOE can vary significantly</td>
</tr>
<tr>
<td>• Faster realization of projects</td>
<td>• Dependence on local resources</td>
</tr>
<tr>
<td>• Resources can be used locally</td>
<td>• Large scale projects are often subsidized, small projects are not</td>
</tr>
<tr>
<td>• Regional independence</td>
<td>• Comparably high costs (LCOE and upfront costs)</td>
</tr>
<tr>
<td>• Also very remote locations can profit</td>
<td></td>
</tr>
</tbody>
</table>
Research Approach - Methods

Multi-criteria catalog is developed to distinguish advantages and disadvantages of on- and off-grid electricity supply.
Key Criteria

• Remoteness
• Electricity Demand
• Existing Electricity Generation and Transmission Schemes
• Natural Resource Assessment
• Non-Spatial Parameters

⇒ Examples of the most important spatial criteria are mapped along the example of Cameroon.
Remoteness

- Travel time to the next city with more than 50,000 inhabitants
- Distribution of towns and villages
- Urban / rural area distinction

Sources:
- Nelson, A., Estimated travel time to the nearest city of 50,000 or more people in year 2000, Global Environment Monitoring Unit - Joint Research Centre of the European Commission, Ispra, Italy, 2008.
Remoteness

- Travel time to the next city with more than 50,000 inhabitants
- Distribution of towns and villages
- Urban / rural area distinction

Sources:
- Nelson, A., Estimated travel time to the nearest city of 50,000 or more people in year 2000, Global Environment Monitoring Unit - Joint Research Centre of the European Commission, Ispra, Italy, 2008.
Electricity Demand

- Electricity access
- Population density
- GDP
- Tourism/industry

Sources:
Electricity Demand

- Electricity access
- Population density
- GDP
- Tourism/industry

Sources:
Electricity Demand

- Electricity access
- Population density
- GDP
- Tourism/industry

Sources:
- Nelson, A., Estimated travel time to the nearest city of 50,000 or more people in year 2000, Global Environment Monitoring Unit - Joint Research Centre of the European Commission, Ispra, Italy, 2008.
Electricity Demand

- Electricity access
- Population density
- GDP
- Tourism/industry

Typical rural/island load profile.

Typical industrial load profile.

Comparison of Off-Grid Electrification versus Grid Extension
catherina.cader@rl-institut.de
Existing Electricity Generation and Transmission Schemes

- Transmission line course
- Quality of service (load shedding, limited supply)
- Transport losses
- Central electricity generation plants (capacity, type)

Sources:
- UDI World Electric Power Plants Data Base (WEPP), Platts 2012.
- Africa Infrastructure Knowledge Program, http://www.infrastructureafrica.org (accessed 30.03.14)

Cameroon

Electricity Transmission
- Existing
- Planned
Existing Electricity Generation and Transmission Schemes

- Transmission line course
- Quality of service (load shedding, limited supply)
- Transport losses
- Central electricity generation plants (capacity, type)

Sources:
- UDI World Electric Power Plants Data Base (WEPP), Platts 2012.
- Africa Infrastructure Knowledge Program, http://www.infrastructureafrica.org (accessed 30.03.14)

Comparison of Off-Grid Electrification versus Grid Extension
catherina.cader@rl-institut.de

November 21st, 2014
Natural Resource Assessment

- Solar irradiation
- Wind speed
- Hydro power potential (Digital elevation model (DEM) + rivers)
- Land cover

Sources:
- NASA & Deutsches Zentrum für Luft- und Raumfahrt (DLR)
- GlobCover 2009 ESA
• Solar irradiation
• Wind speed
• Hydro power potential (Digital elevation model (DEM) + rivers)
• Land cover

Sources:
• NASA & Deutsches Zentrum für Luft- und Raumfahrt (DLR)
• GlobCover 2009 ESA
Natural Resource Assessment

- Solar irradiation
- Wind speed
- Hydro power potential (Digital elevation model (DEM) + rivers)
- Land cover

Sources:
- NASA & Deutsches Zentrum für Luft- und Raumfahrt (DLR)
- GlobCover 2009 ESA
Natural Resource Assessment

- Solar irradiation
- Wind speed
- Hydro power potential (Digital elevation model (DEM) + rivers)
- Land cover

Sources:
- NASA & Deutsches Zentrum für Luft- und Raumfahrt (DLR)
- GlobCover 2009 ESA
Natural Resource Assessment

- Solar irradiation
- Wind speed
- Hydro power potential (Digital elevation model (DEM) + rivers)
- Land cover

Sources:
- NASA & Deutsches Zentrum für Luft- und Raumfahrt (DLR)
- GlobCover 2009 ESA
- Natural Resource Assessment Cameroon
- Solar irradiation
- Wind speed
- Hydro power potential (Digital elevation model (DEM) + rivers)
- Land cover

Legend:
- Irrigated croplands
- Rainfed croplands
- Mosaic cropland
- Mosaic vegetation
- Broadleaved evergreen or semi-deciduous forest
- Broadleaved deciduous forest
- Needleleaved evergreen forest
- Needleleaved deciduous or evergreen forest
- Needleleaved deciduous or evergreen forest
- Mixed broadleaved and needleleaved forest
- Mosaic forest or shrubland
- Mosaic grassland
- Shrubland
- Herbaceous vegetation
- Sparse vegetation
- Broadleaved forest regularly flooded
- Broadleaved forest or shrubland permanently flooded
- Grassland or woody vegetation on regularly flooded or waterlogged soil
- Artificial surfaces and associated areas
- Bare areas
- Water bodies
- no data
Non-spatial Parameters

- Policy structures (e.g. electrification objectives, renewable energy targets)
- Investment incentives (e.g. PPAs)
- Ownership structure of power plants and transmission line infrastructure, utilities, and regulation authorities
- Attractiveness for investors (e.g. ease of doing business index, corruption index)
- Financial parameters
• A spatial approach is necessary to understand the dynamics between energy demand clusters, resources, distances to overcome etc.

• Only with this knowledge it is possible to assess the most economical strategy to provide electricity to rural non-supplied areas.

The spatially distributed nature of renewable energy resources calls for their local usage, especially for remote, small clusters of electricity demand.
Outlook: Electrification strategies

GIS Analysis, Energy system modelling and grid extension modelling allow an estimation of costs for rural electrification, to thereby suggest a local and environmental specific solution.
Energy Systems Modelling

For a given set of input parameters (resources, technical characteristics, load data, …) a cost optimized hybrid configuration is calculated (PV, wind, diesel, battery).

The model is developed in house and is modular, fast, and highly automatable.
Thank you!
Appendix
## RE Hybrid Electrification options

<table>
<thead>
<tr>
<th>Category</th>
<th>Unit</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel only</td>
<td>EUR/kWh</td>
<td>Detailed modelling</td>
</tr>
<tr>
<td>Single RE technologies (PV, wind)</td>
<td>EUR/kWh</td>
<td>Detailed modelling</td>
</tr>
<tr>
<td>Hybrid Mini-Grids (LCOE) (Solar, wind, battery, diesel)</td>
<td>EUR/kWh</td>
<td>Detailed modelling</td>
</tr>
<tr>
<td>Optimized solution: capacities, RE share, diesel consumption</td>
<td>kW of each technology</td>
<td>Optimization</td>
</tr>
<tr>
<td>Optimized solution: RE share</td>
<td>%</td>
<td>Optimization</td>
</tr>
<tr>
<td>Optimized solution: diesel consumption</td>
<td>liter/year</td>
<td>Optimization</td>
</tr>
<tr>
<td>Solar-Home-Systems (LCOE)</td>
<td>EUR/kWh</td>
<td>Detailed modelling</td>
</tr>
<tr>
<td>Electricity demand</td>
<td>kWh/year</td>
<td>Detailed modelling</td>
</tr>
<tr>
<td>Distance to grid</td>
<td>km</td>
<td>GIS analysis</td>
</tr>
<tr>
<td>Nightlights (access to electricity)</td>
<td>yes/no</td>
<td>GIS analysis</td>
</tr>
<tr>
<td>Cost of grid extension</td>
<td>EUR/km</td>
<td>Detailed modelling / GIS analysis</td>
</tr>
</tbody>
</table>
Historical Diesel Price Increase

Diesel price history (excluding taxes)

Quelle: U.S. Energy Information Administration

**Average 2012:** 3,1 USD / gal = 0,63 EUR / l (@ 1 EUR = 1,30 USD)
Stand der Forschung

- Historische & aktuelle Betrachtungen:
  - Idee eines universellen globalen Netzes („Supergrid“)
  - Nationale Netze auf Länder und Verbundebene
  - Desertec-Approach (Transport von EE)
  - Mini-Grid Approach (dezentrale Erzeugung & Verbrauch remote Village-Ebene)
  - Offgrid-Approach (dezentrale Erzeugung & Verbrauch Haushaltsebene)
• **Einzelfallbetrachtungen:**
  – Wo machen off-grid/mini-grid Systeme mit einem erneuerbaren Energieanteil Sinn?

• **Stromtrassenplanung**
  – Wo ist es auch geographisch-topologischer Sicht am kostengünstigsten Stromtrassen zu planen? Was bedeutet das für die Definition von off-grid Gebieten
  – Welche Rolle spielt die Entlegenheit von Regionen

• **Entwicklungspläne und Policies**
  – Gewisse Targets werden gesetzt, ohne fundiertes Hintergrundwissen über Einflussgrößen und Parameter zu besitzen

• **Forschung zu hybriden dezentralen Systemen**