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

Catherina Cader
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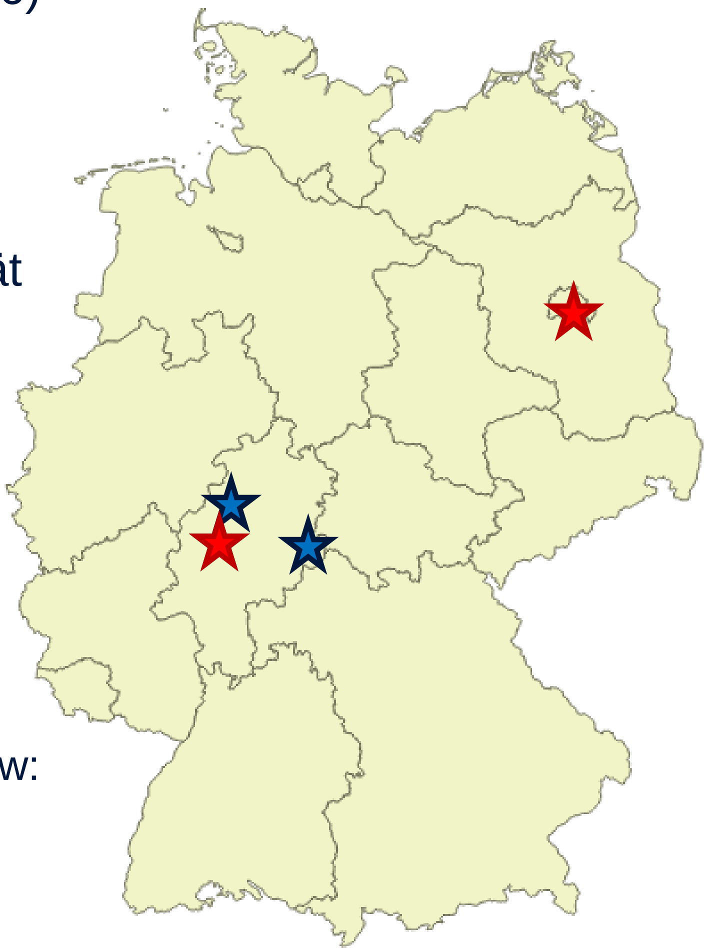
Introduction

- Catherina Cader, born in Fulda, Germany (1986)
- Bachelor *Environmental Management* Justus Liebig Universität Gießen (2007-2010)
- Masters *Physical Geography: Systems, Interactions and Processes* Philipps Universität Marburg, Exchange semester University of Pécs, Hungary (2010-2012)
- 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)



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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

Reiner Lemoine
Founder of the Reiner Lemoine Foundation

Scientific research for an energy transition towards 100 % renewable energies.

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Off-Grid Activities: Overview

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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

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Outline

- Introduction
- Objective
- Methods

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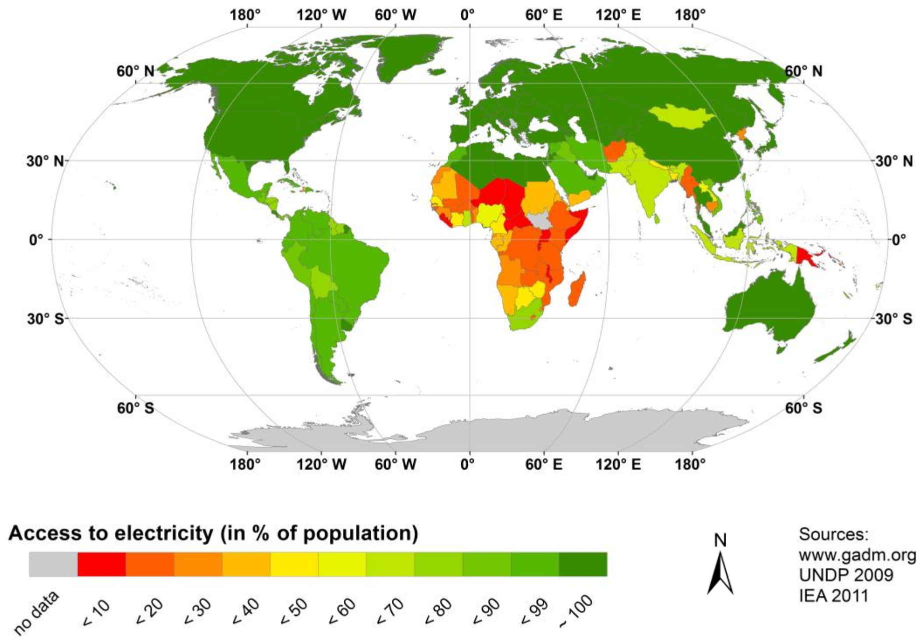
Introduction



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

	Rural	Urban	Total	Share of population
Developing countries	1,081	184	1,265	24%
Africa	475	114	590	57%
Developing Asia	556	62	628	18%
Latin America	23	6	29	6%
Middle East	16	2	18	9%
World	**1,083**	**184**	**1,267**	**19%**

Source: Number of people without access to electricity by region (million). World Energy Outlook 2012, International Energy Agency, 2012.

Status quo

- 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

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).

Low electricity access, high costs and outdated technology is prevailing

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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 CO_2 emissions

PV-Batterie SHS – Extreme Nord, Cameroon (Cader, 2014).

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

PV moduels – Extreme Nord, Cameroon (Cader, 2014).

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

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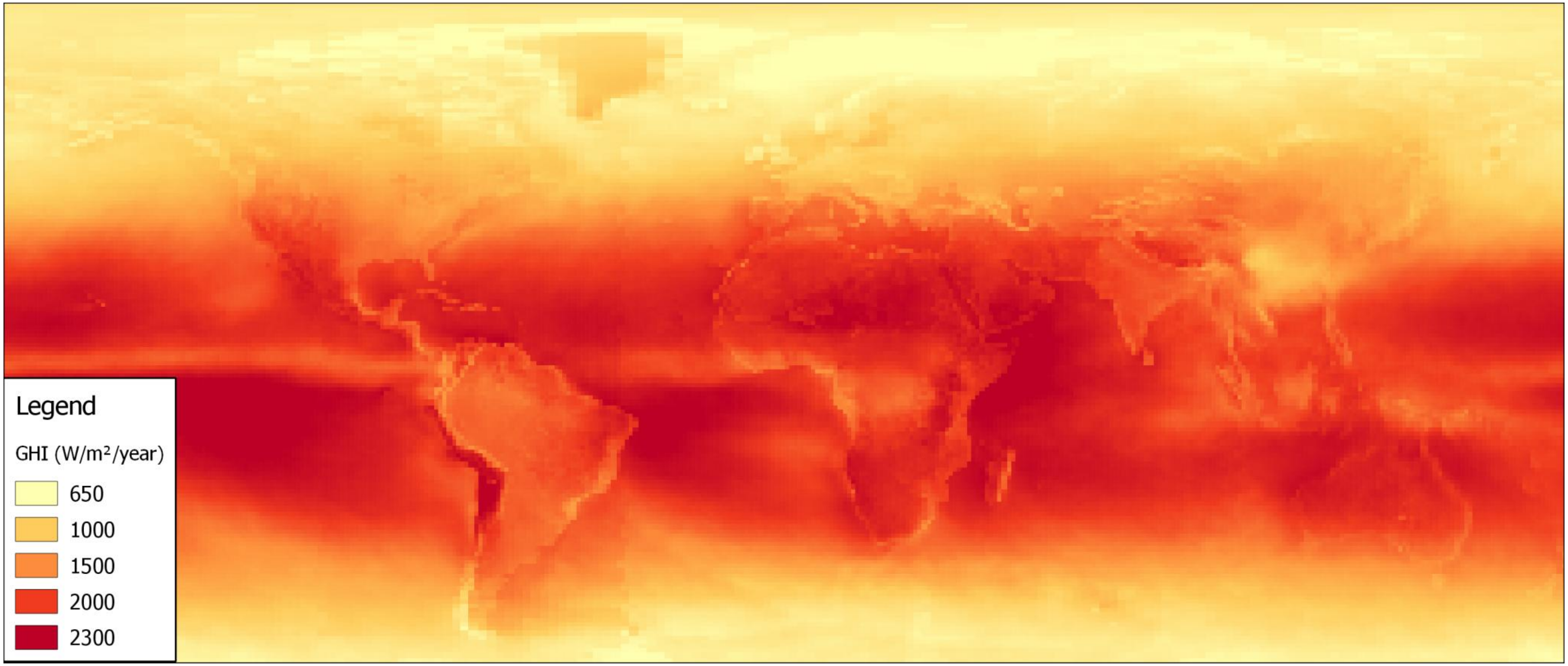
Global solar irradiation

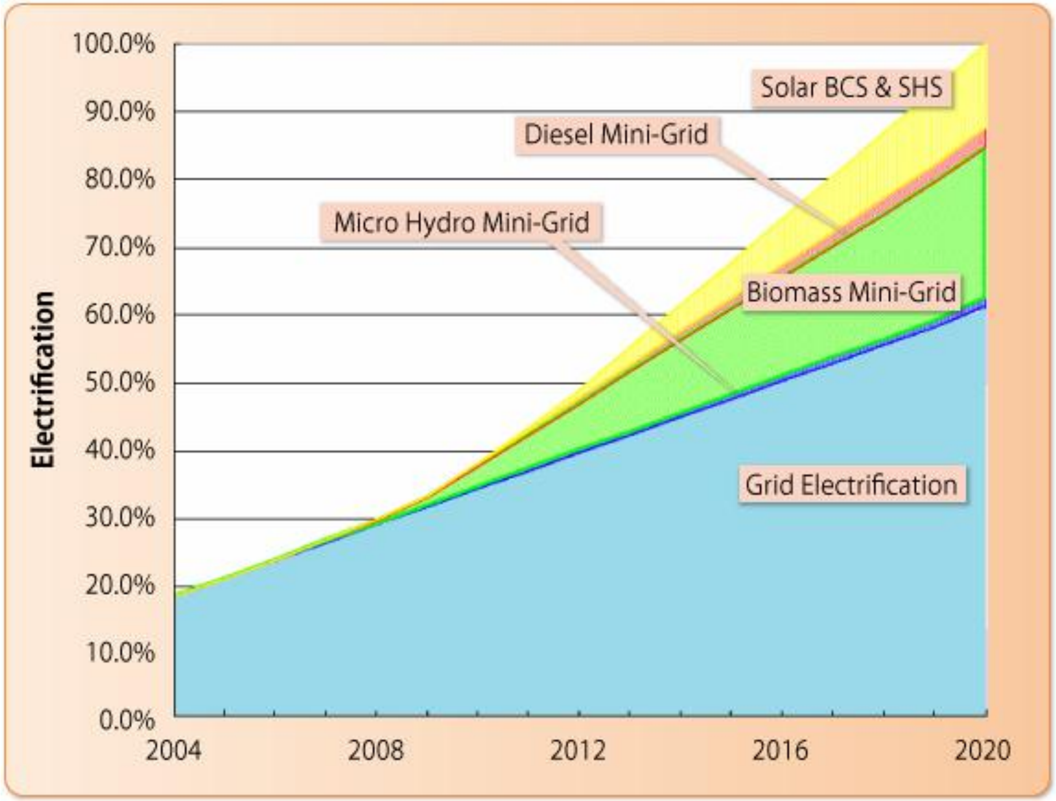
The sum of the global irradiance can be utilized for a first estimation of the PV potential.



Source: DLR Deutsches Zentrum für Luft- und Raumfahrt. Data provided by NASA, 2005.

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.Toch%20Sovanna%20-%20The%20Potential%20of%20Renewable%20Energy%20in%20Cambodia.pdf

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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)

Aim

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?

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Objective

Definition of influencing parameters:

	Advantage +	Disadvantage -
Grid extension	?	?
Decentral off-grid/ mini-grid solution	?	?

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Objective

Definition of influencing parameters:

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

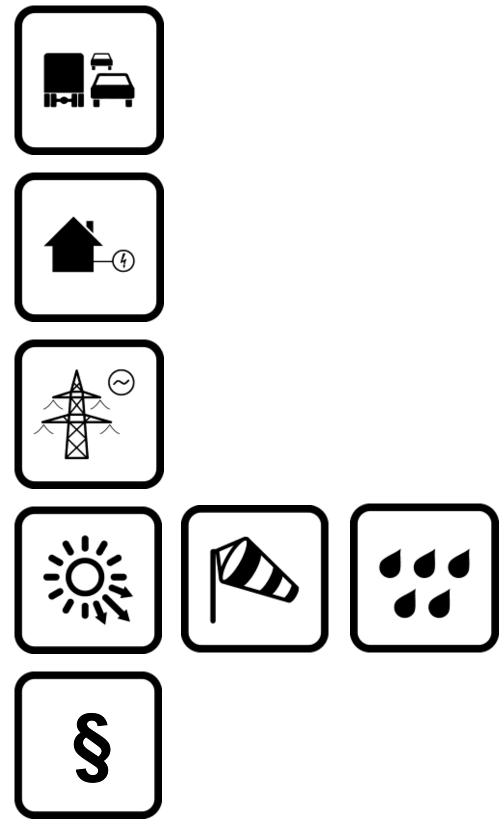
Research Approach - Methods

1. **Development of multi-criteria-catalog**
2. Evaluation of identified criteria by GIS analysis
3. Simulation of LCOE for off-grid solutions versus grid extension costs based on weighted criteria

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.

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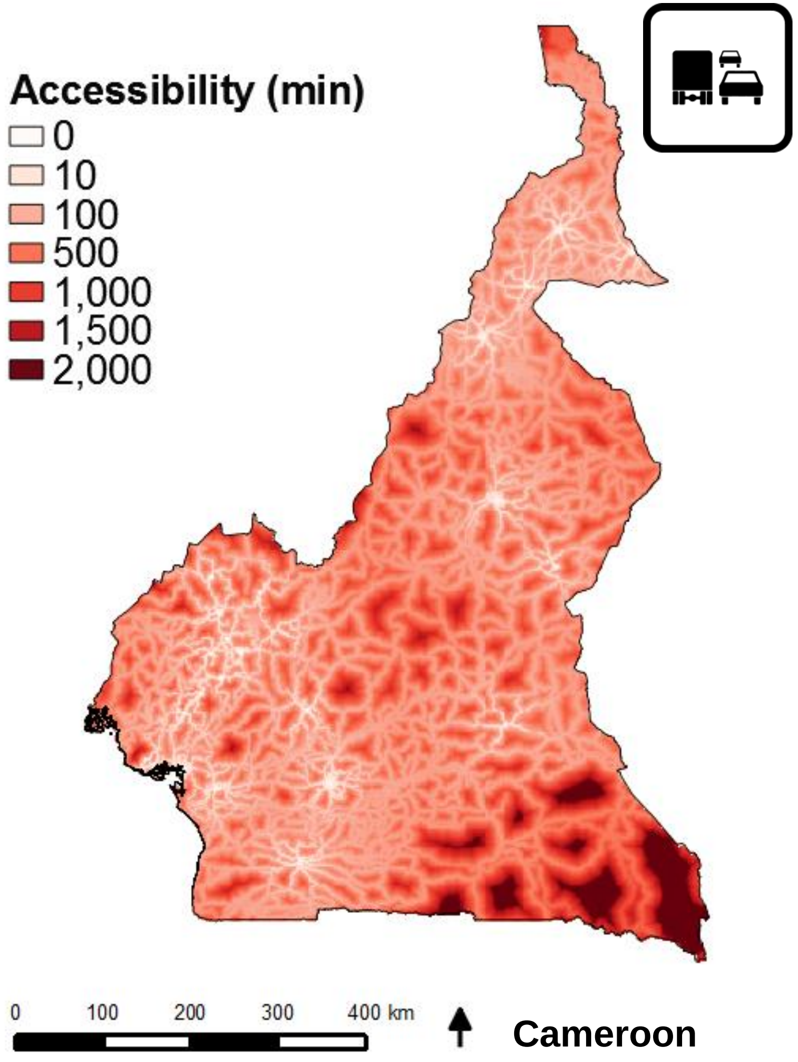
Remoteness

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



Sources:

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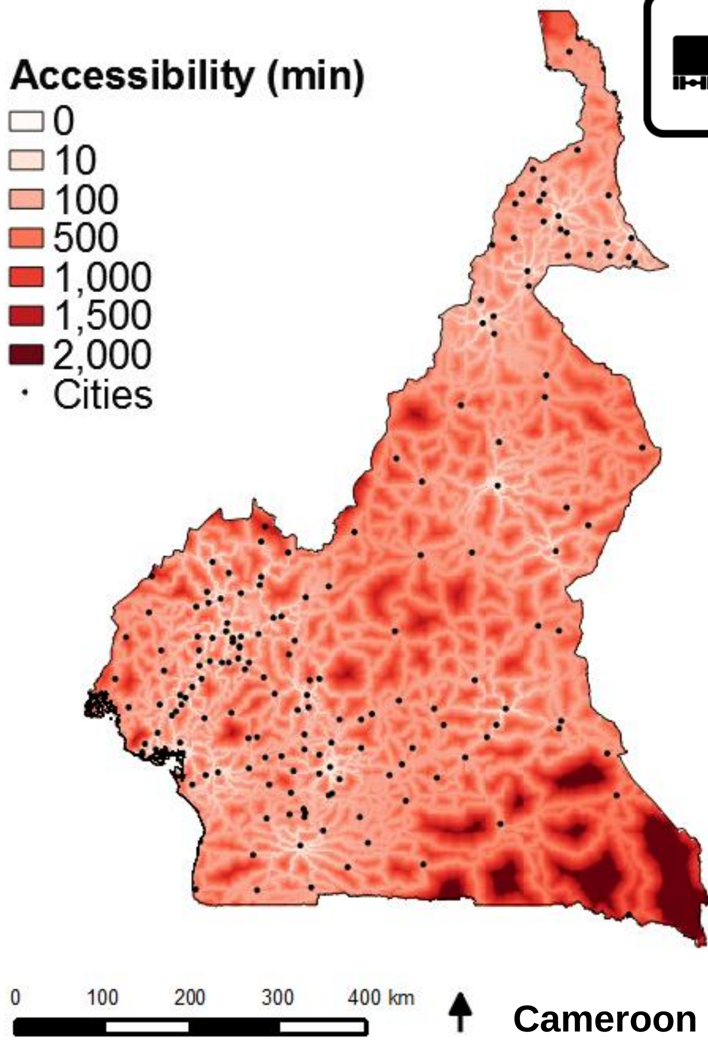

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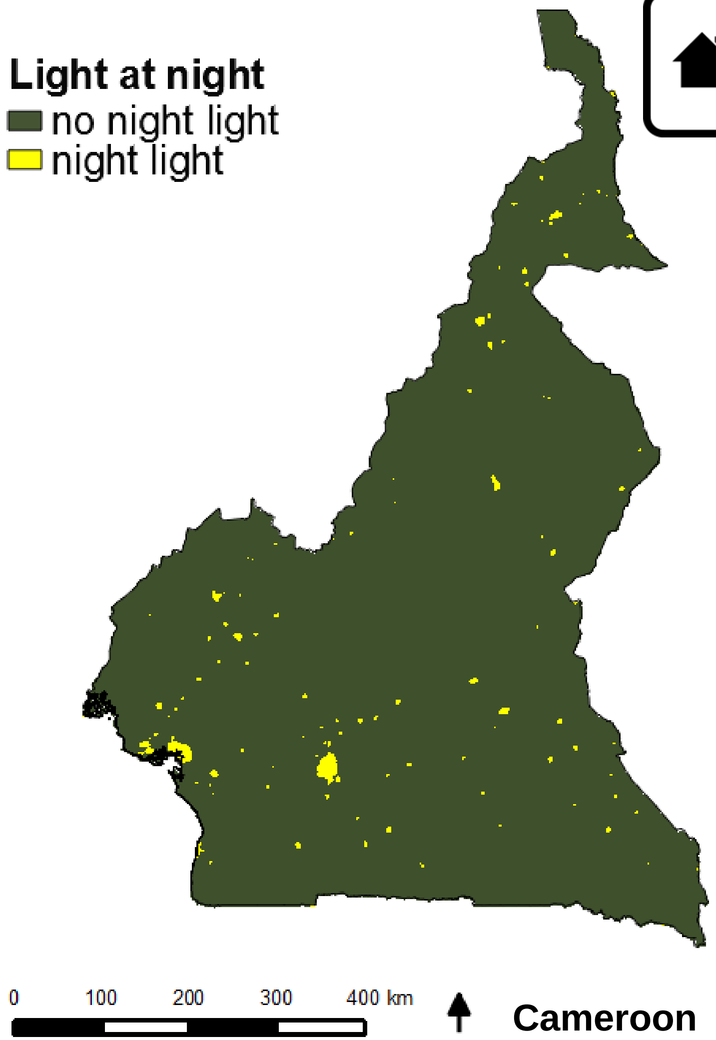
Electricity Demand

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



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- *Night Light Imagery,* version 4 DMSP-OLS Night Lights Time Series, NOAA National Geophysical Data Center, US Air Force Weather Agency, Boulder, Colorado. LandScan 2011™ *High Resolution global Population Data Set ,* copyright UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy.
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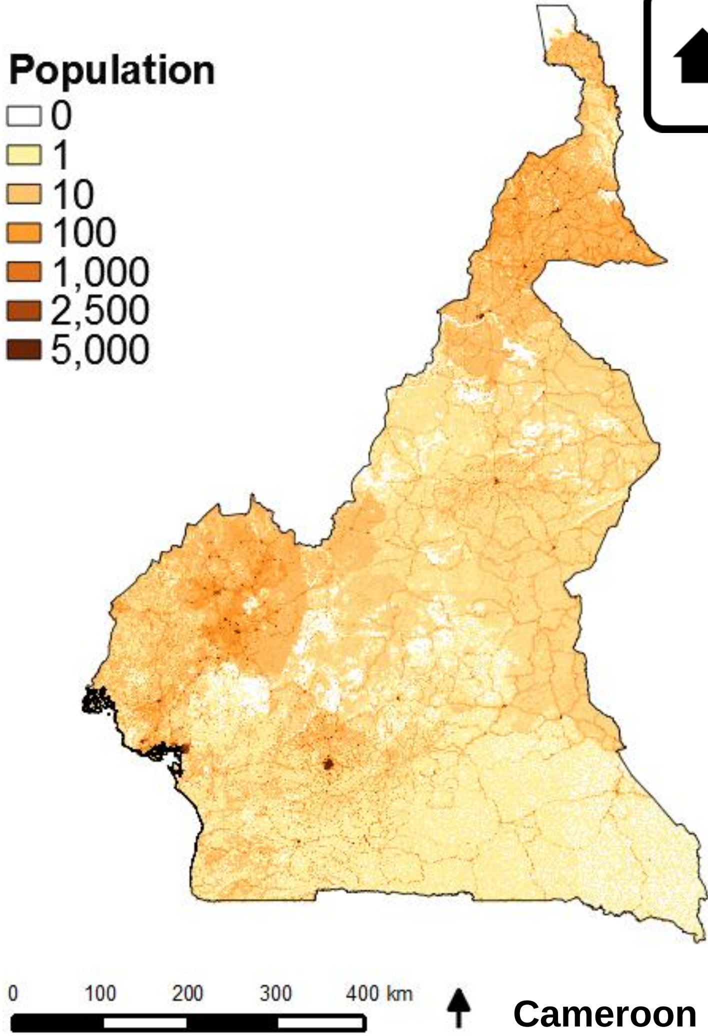

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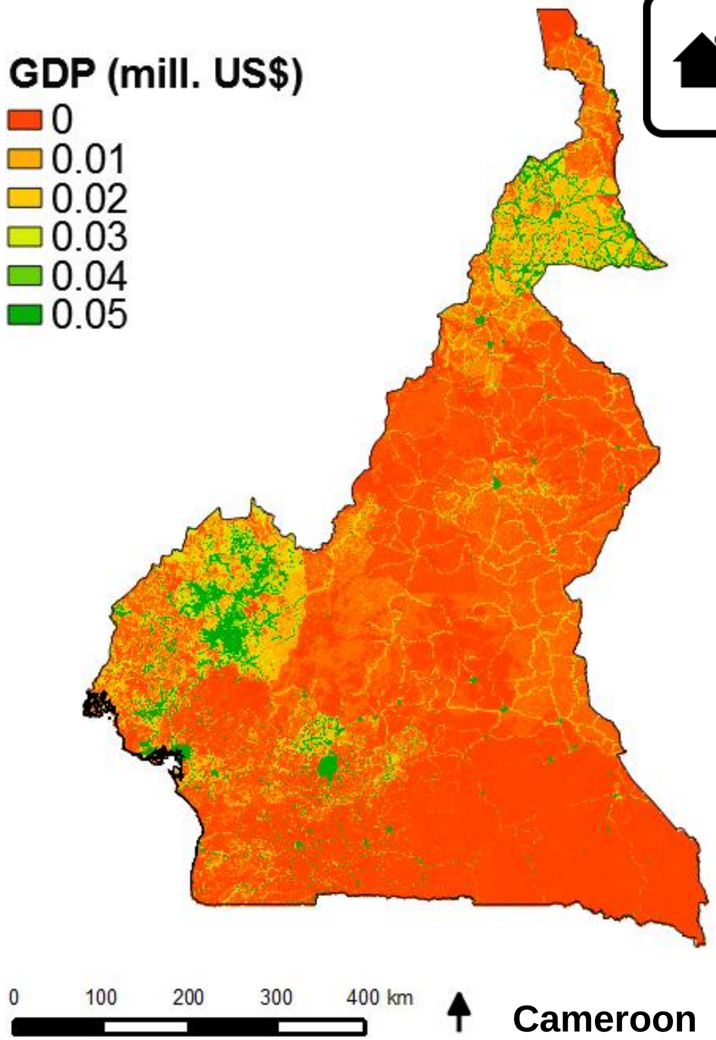

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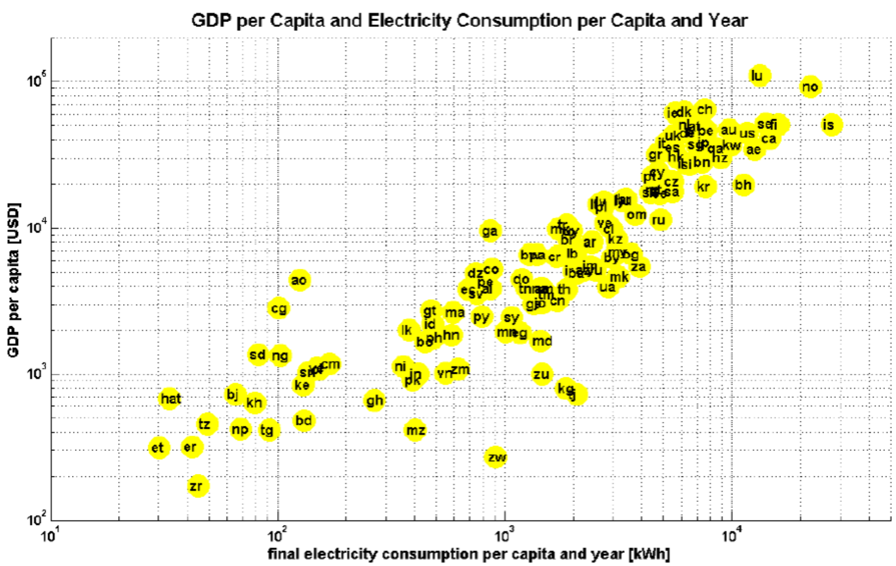
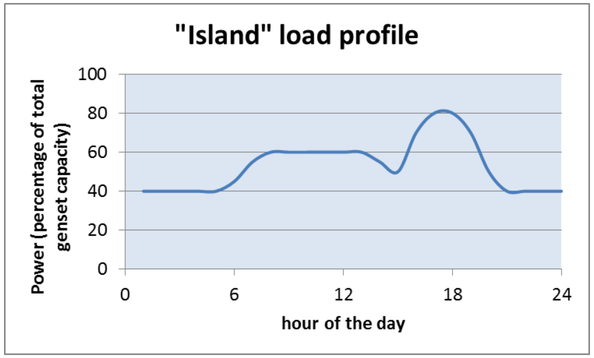
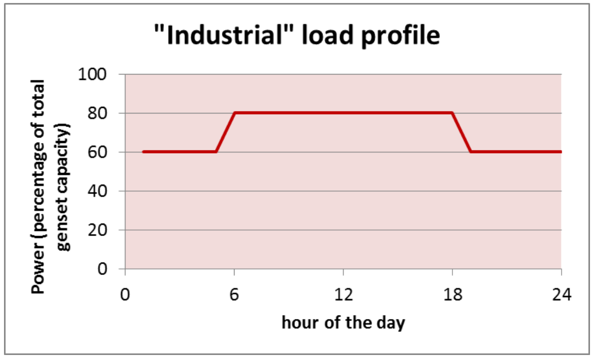




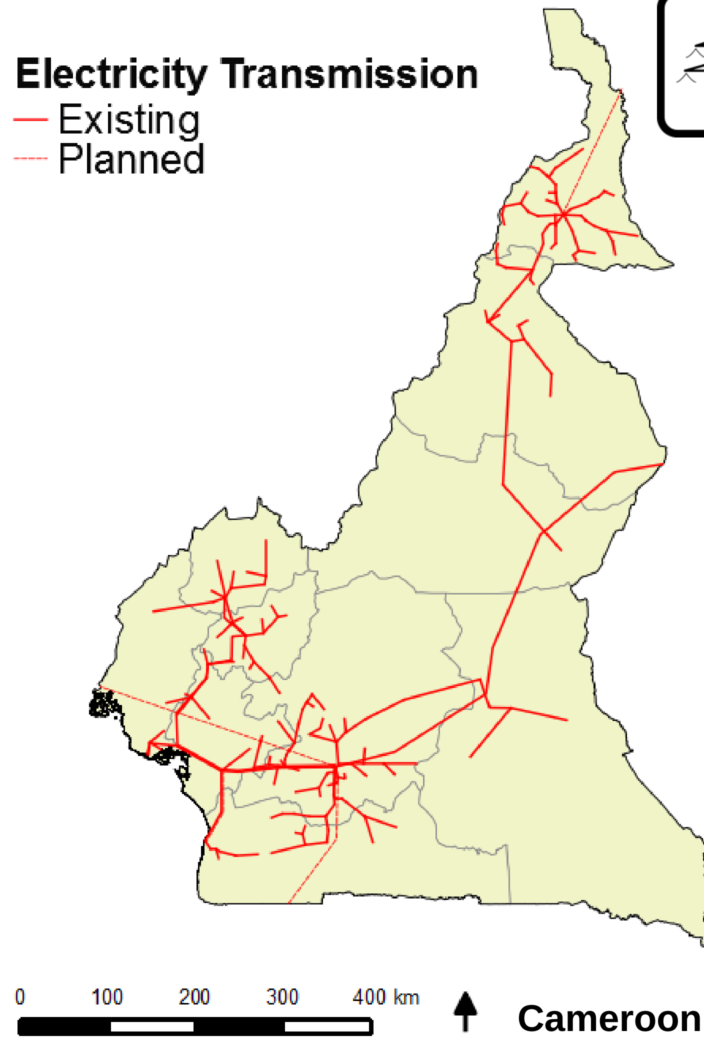
Typical rural/island load profile.



Typical industrial load profile.

Existing Electricity Generation and Transmission Schemes

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



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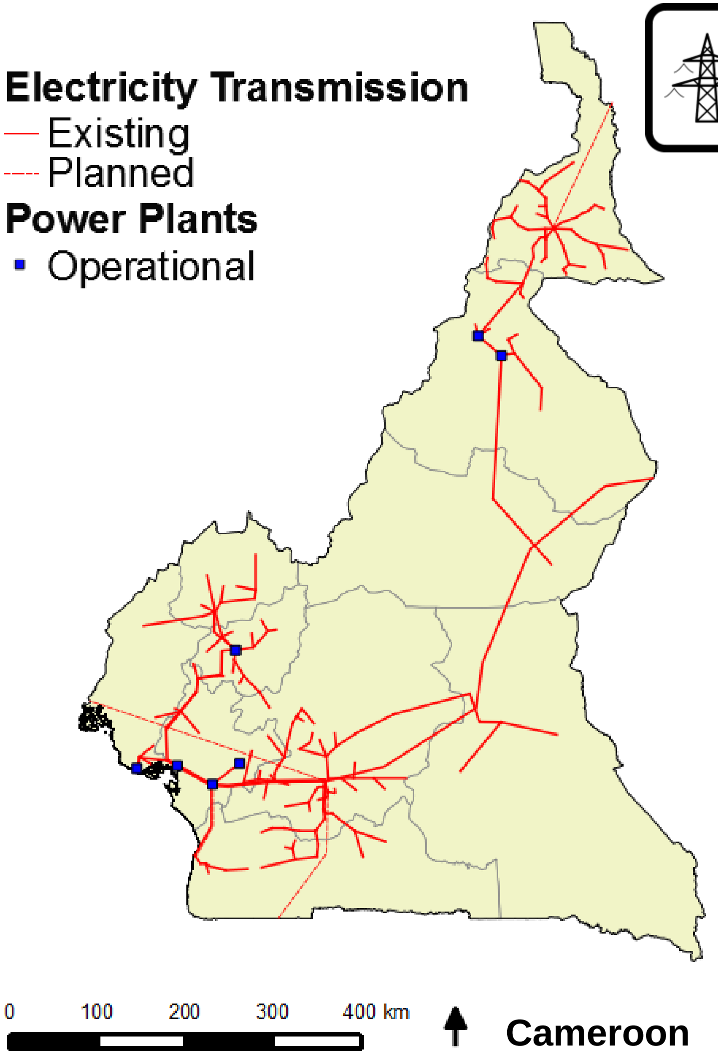

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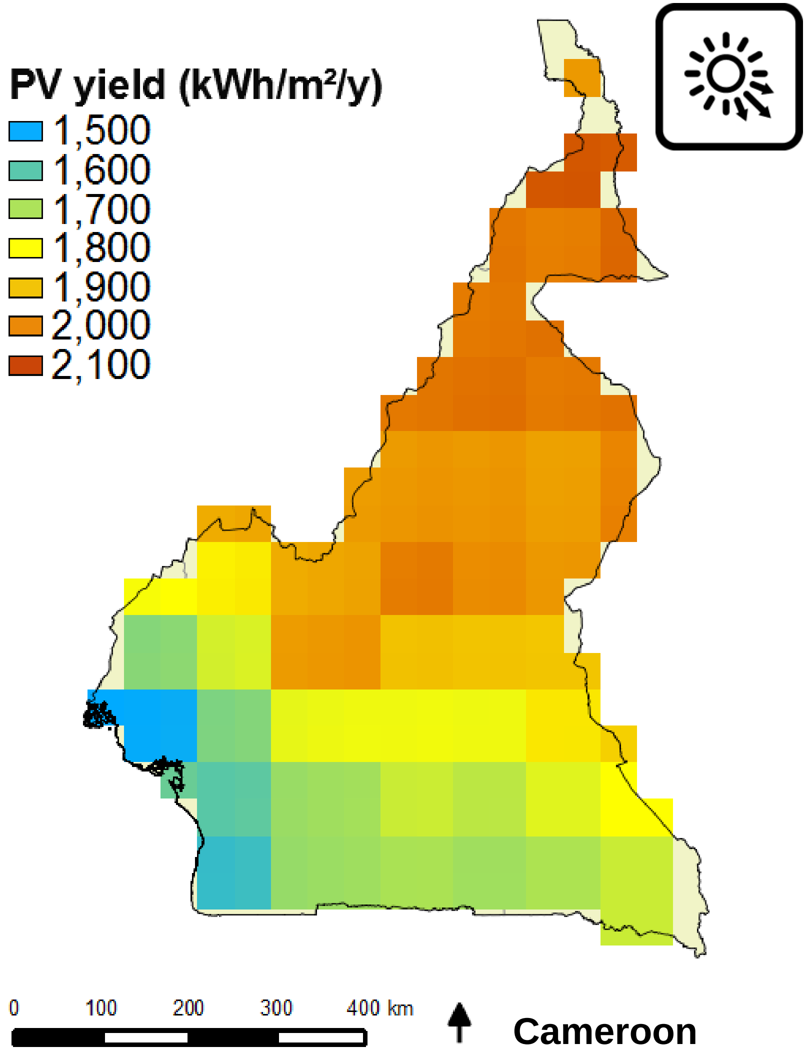
Natural Resource Assessment

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



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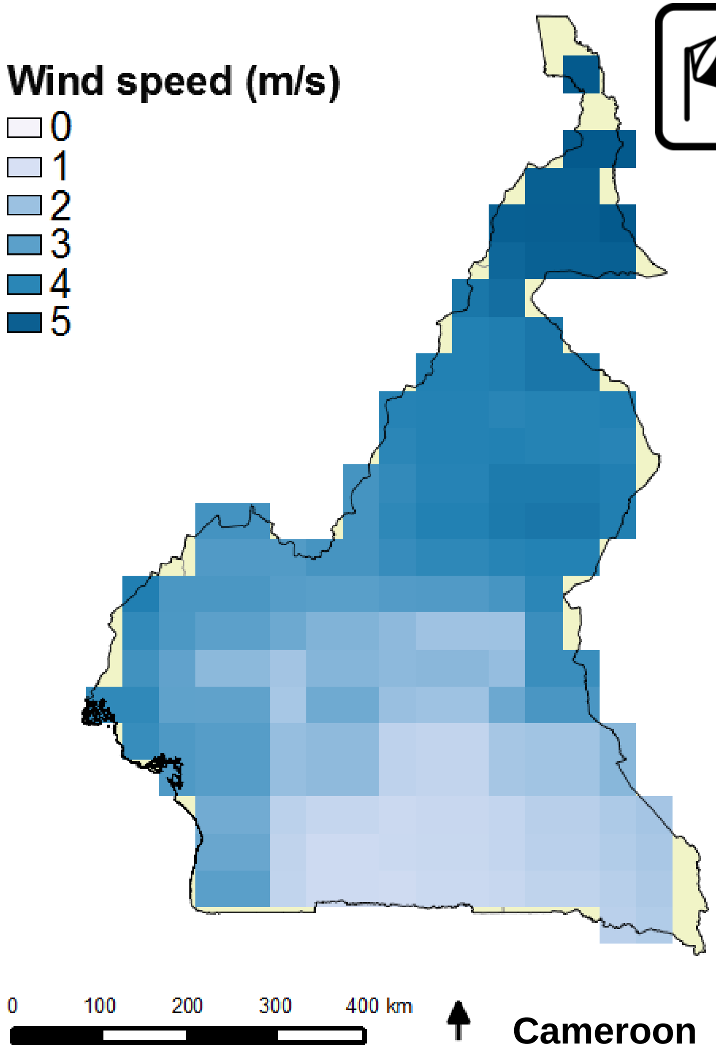

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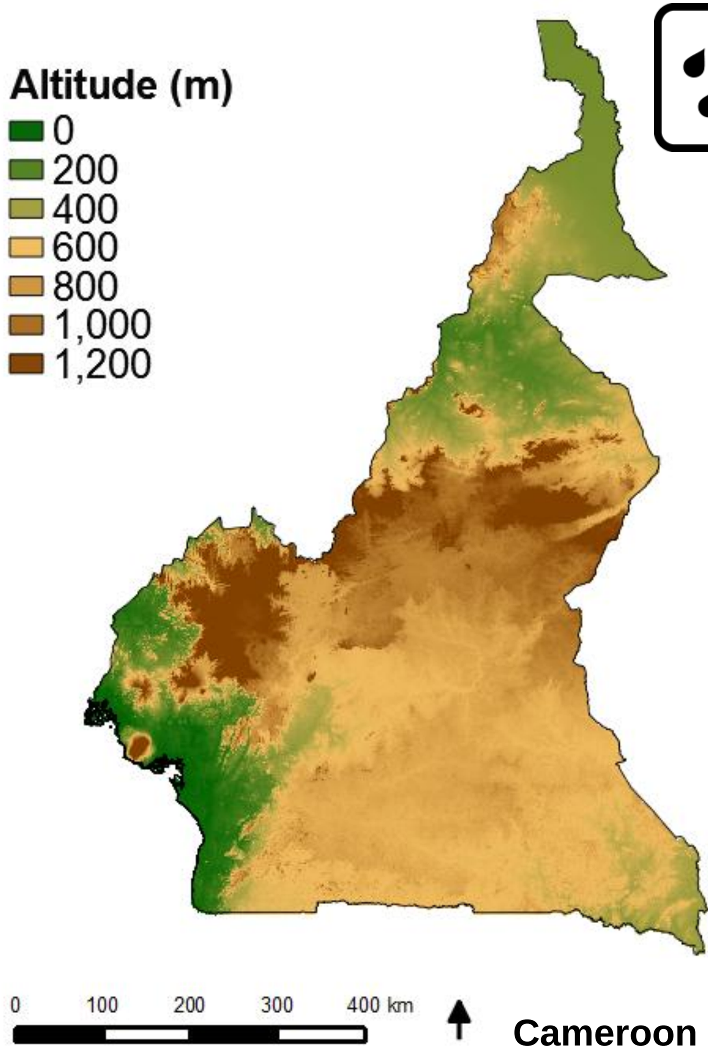

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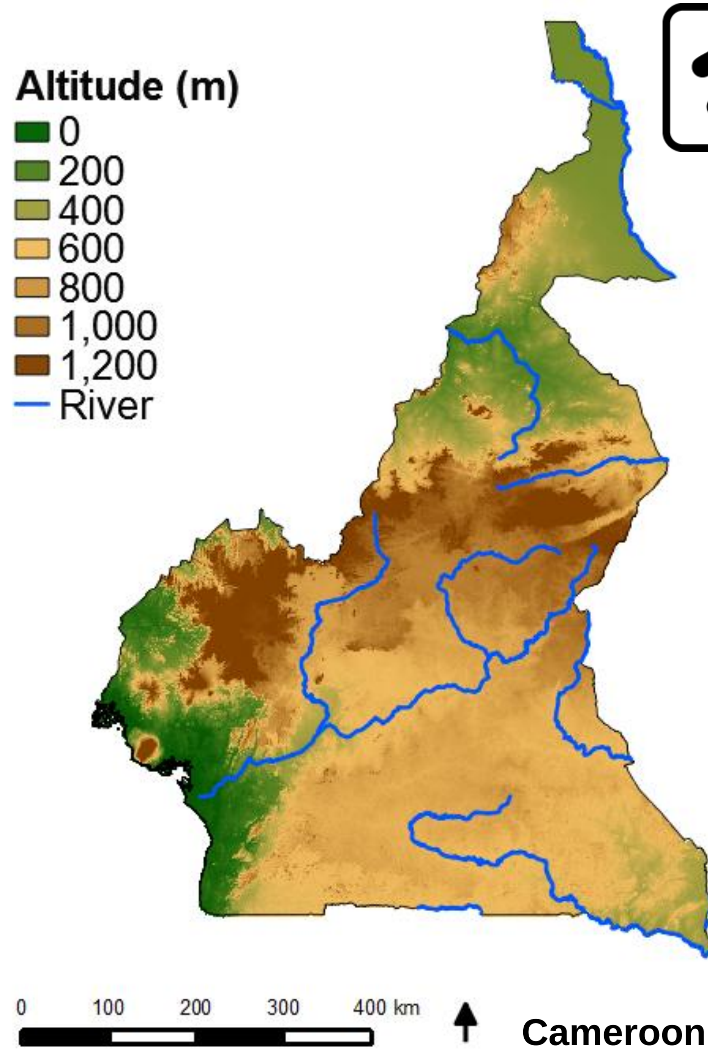

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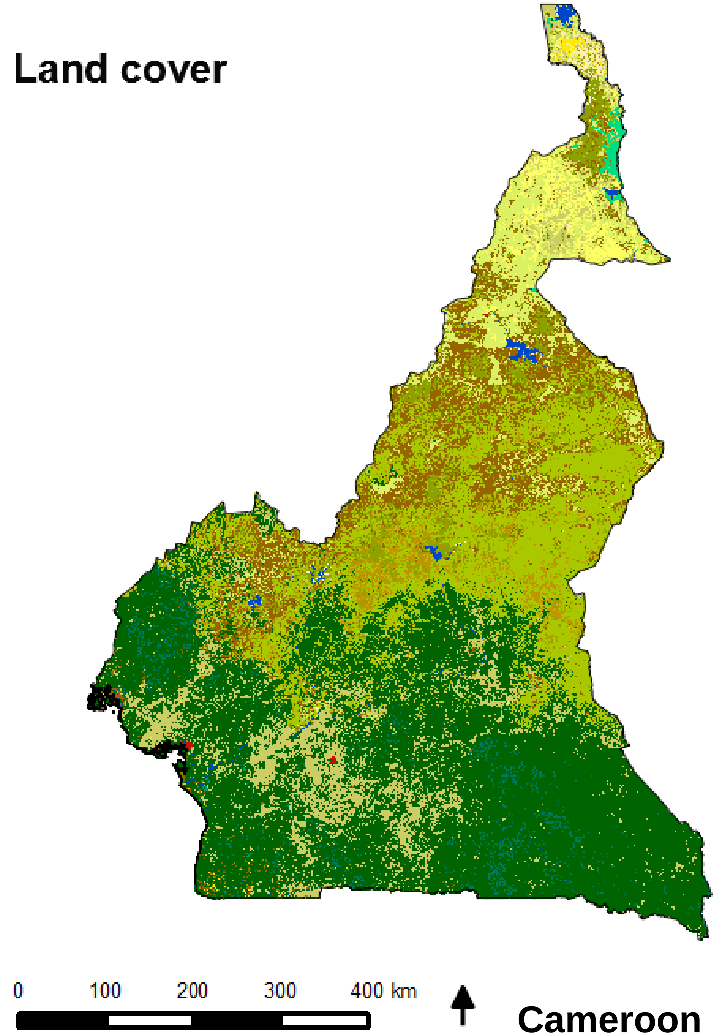

- Irrigated croplands
- Rainfed croplands
- Mosaic cropland
- Mosaic vegetation
- Broadleaved evergreen or semi-deciduous forest
- Broadleaved deciduous forest
- Needleleaved evergreen forest
- Needleleaved deciduous or evergreen forest
- Needleleaved deciduous or evergreen forest
- Mixed broadleaved 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

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Non-spatial Parameters

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- 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

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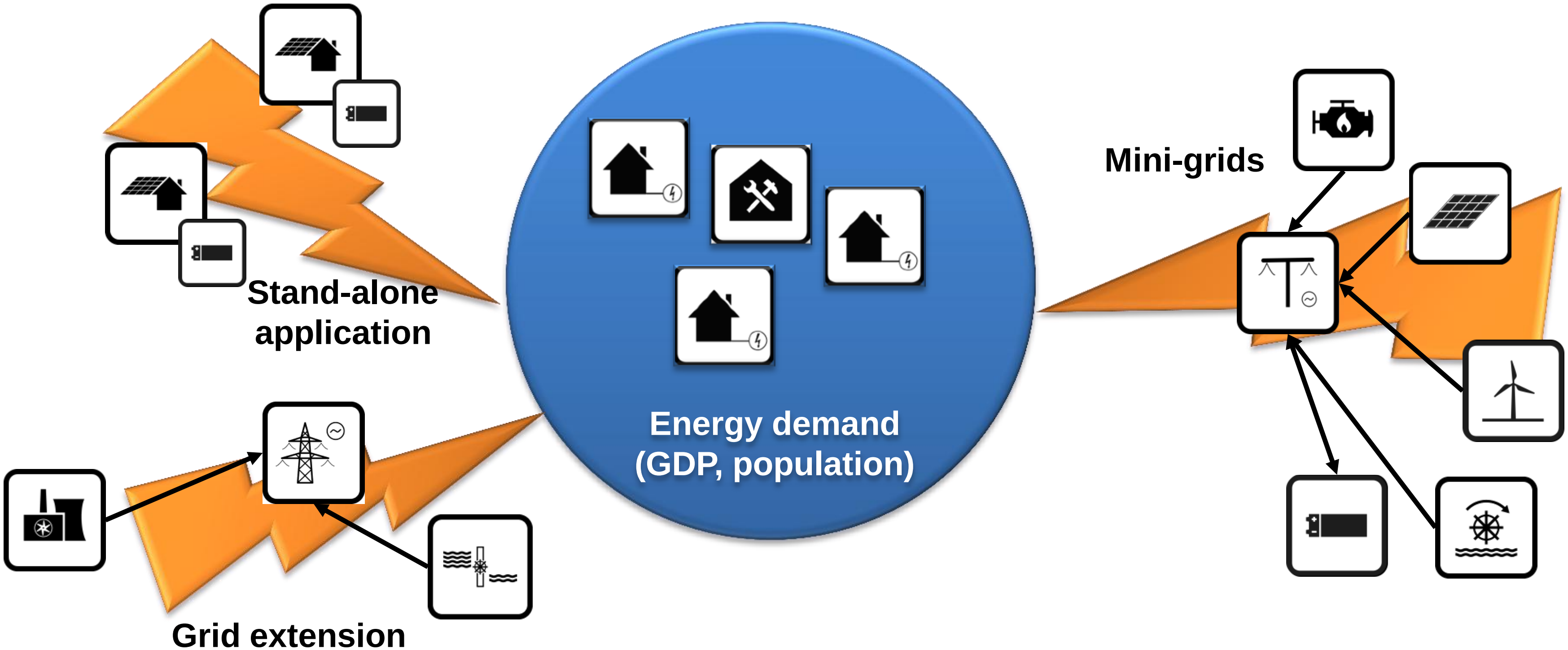
Outcome

- 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.

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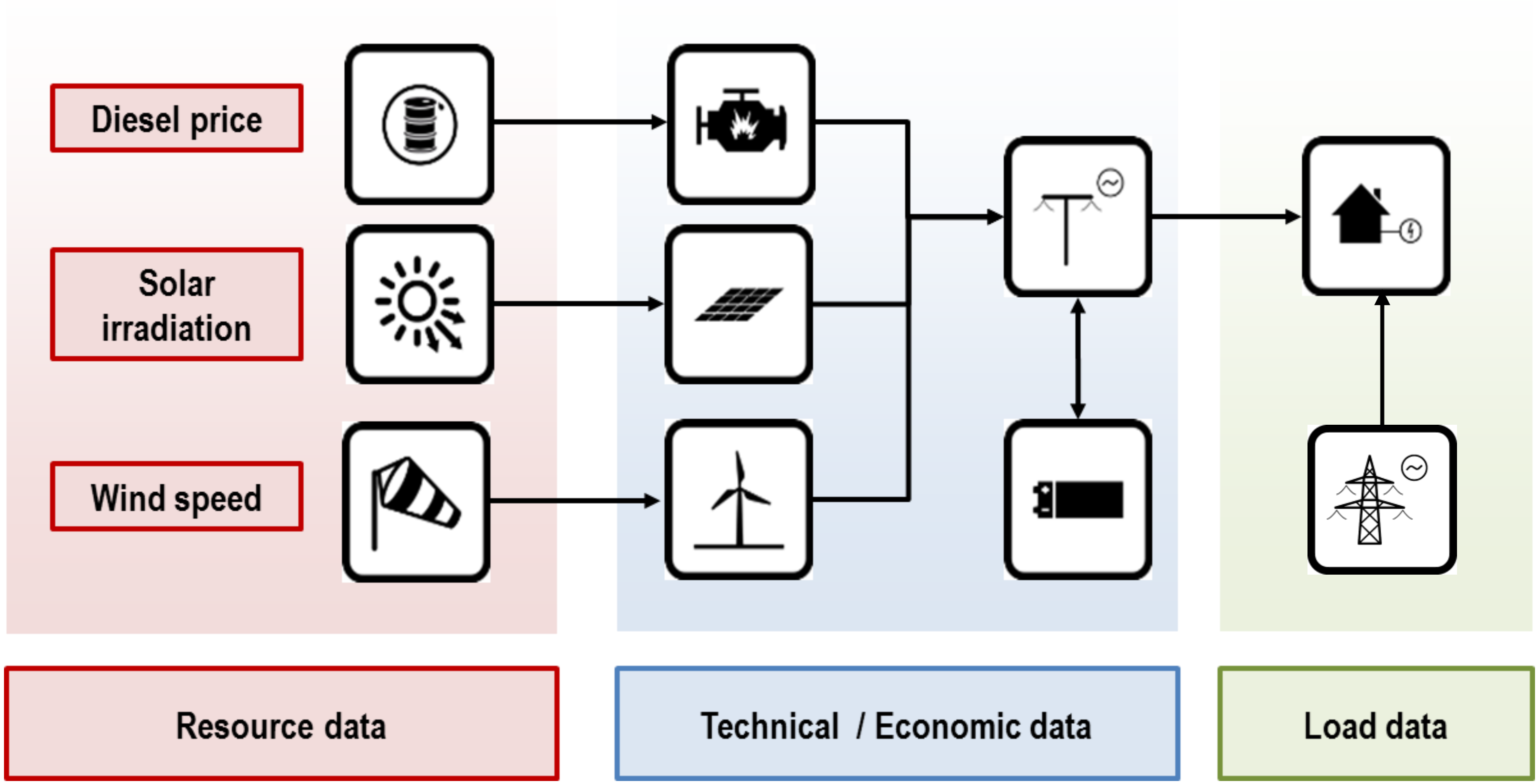
Energy Systems Modelling

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

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RE Hybrid Electrification options

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

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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)

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Stand der Forschung

- **Einzelfallbetrachtungen:**
  - Wo machen off-grid/mini-grid Systeme mit einem erneuerbaren Energieanteil Sinn?
- **Stromtrassenplanung**
  - Wo ist es auch geographisch-topoligischer Sicht am kostengünstigesten 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**

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