Mini-Grids for Off-Grid Energy Supply – Global Potential for Rural Electrification and Islands

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International Workshop on Replication and Scaling-up of Decentralised Off-grid Electrification in Developing Countries
Leicester, 11th July 2013

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Research focuses:

- Integrated energy systems
  - Optimization of energy systems
  - Energy transition processes
  - Off-grid energy systems
- Mobility with renewable energies
  - Integration of renewable energies into e-mobility
- Renewable energy technology
  - Small wind power

Reiner Lemoine
Founder of the Reiner Lemoine-Foundation

Scientific research for an energy transition towards 100% renewable energies

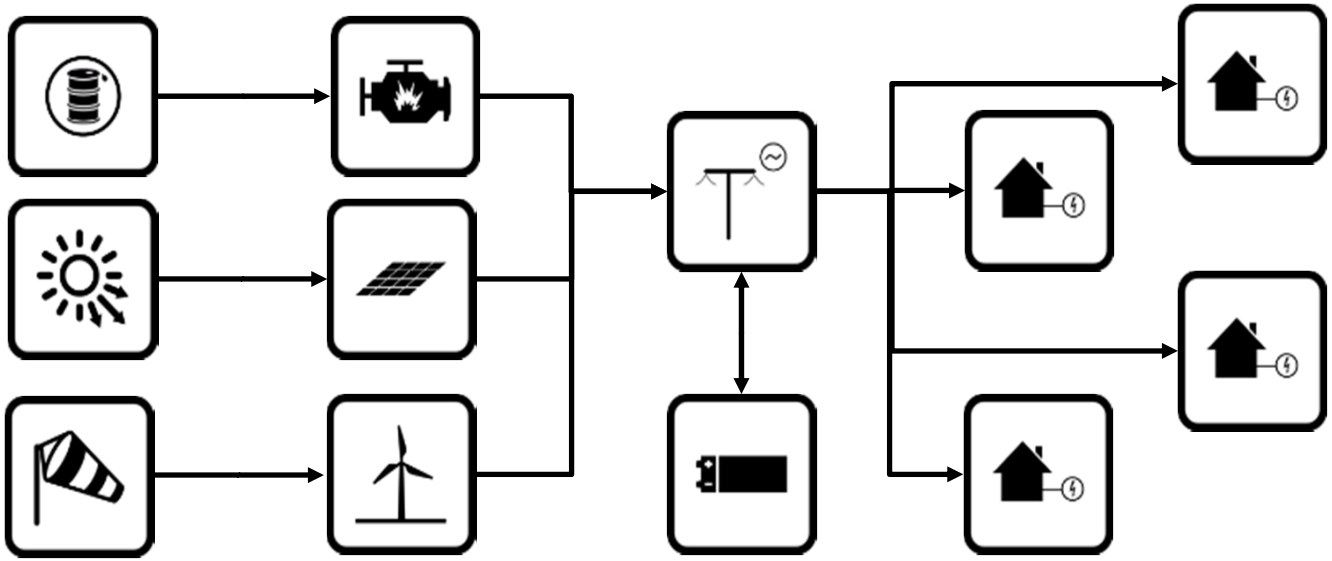
Outline

- Introduction: Mini-Grids
- Rural Electrification
- Island Energy Supply
- Summary + Discussion

Definition Hybrid Mini-Grid

A **hybrid Mini-Grid** combines at least two different kinds of technologies for power generation and distributes the electricity to several consumers through an independent grid.

Thus, the mini-grid is supplied by a mix of renewable energy sources and a genset, generally supplied with diesel, used as a back-up.



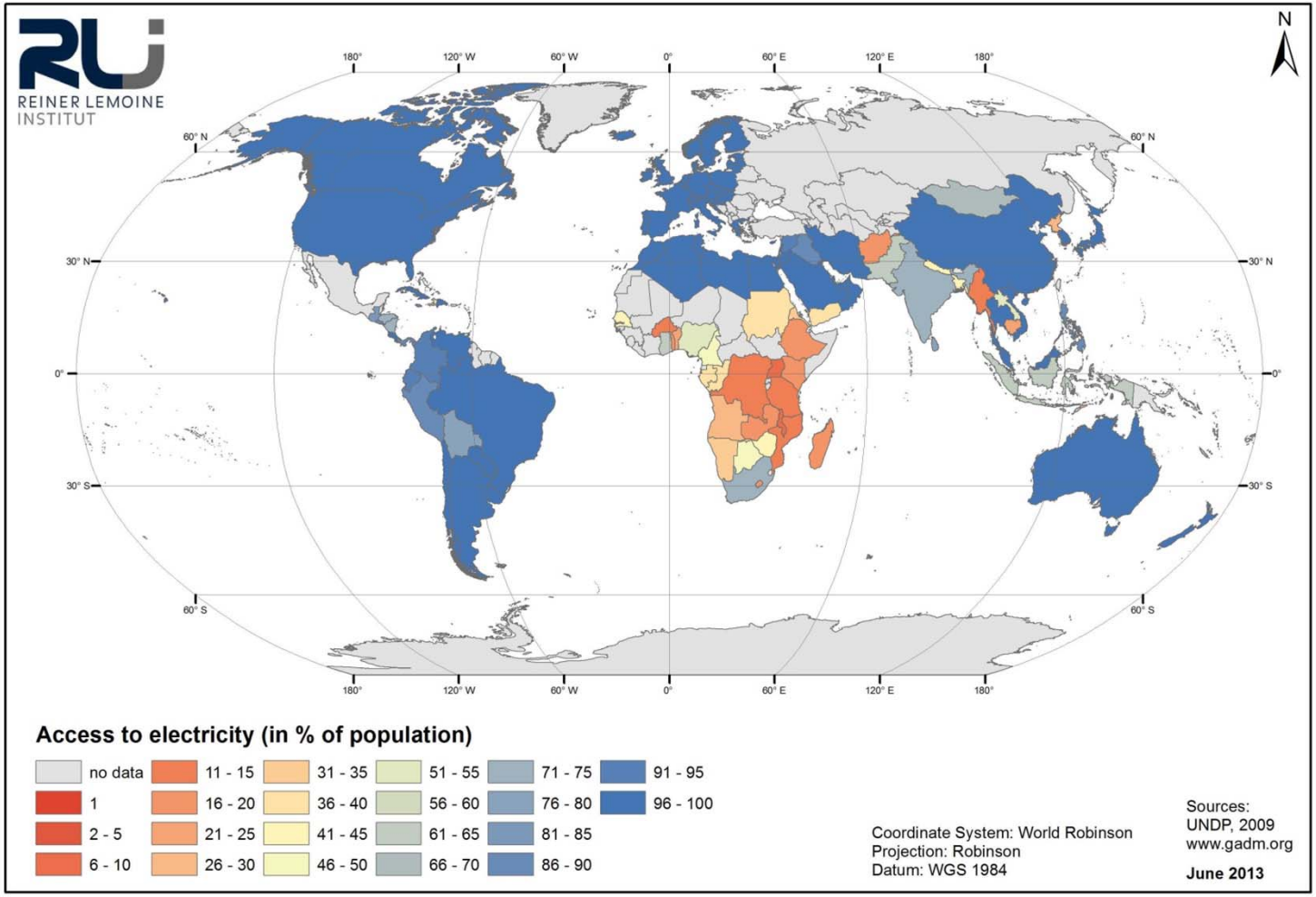
Specific Applications for Hybrid Mini-Grids

- Enable power supply for non-electrified areas
- Support pico-electrified (solar home systems) areas
- Ensure quality of supply in on-grid areas
- Substitute diesel-only Mini-Grids

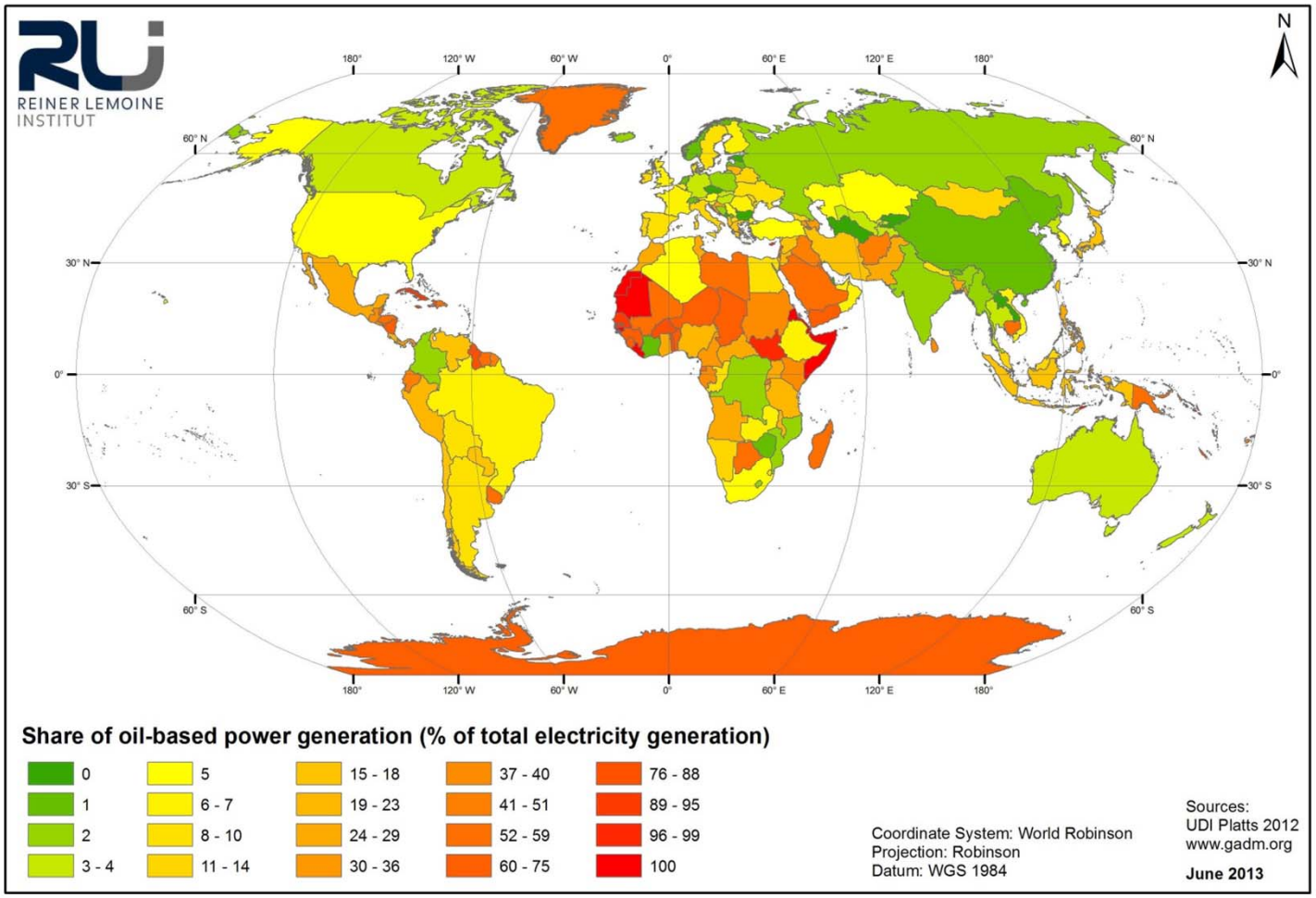
Rural electrification

Islands

1.3 Billion People without Access to Electricity



Diesel-Grids Worldwide



The higher the diesel share the more local diesel-grids can be expected.

Outline

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- Rural Electrification
  - Un-Electrified and Pico-Electrified Regions
- Island Energy Supply
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PV-based Mini-Grids for Electrification in Developing Countries

(published at
http://www.sma-stiftungsverbund.de/de/downloads/elektrifizierung-netzferner-regionen.html)

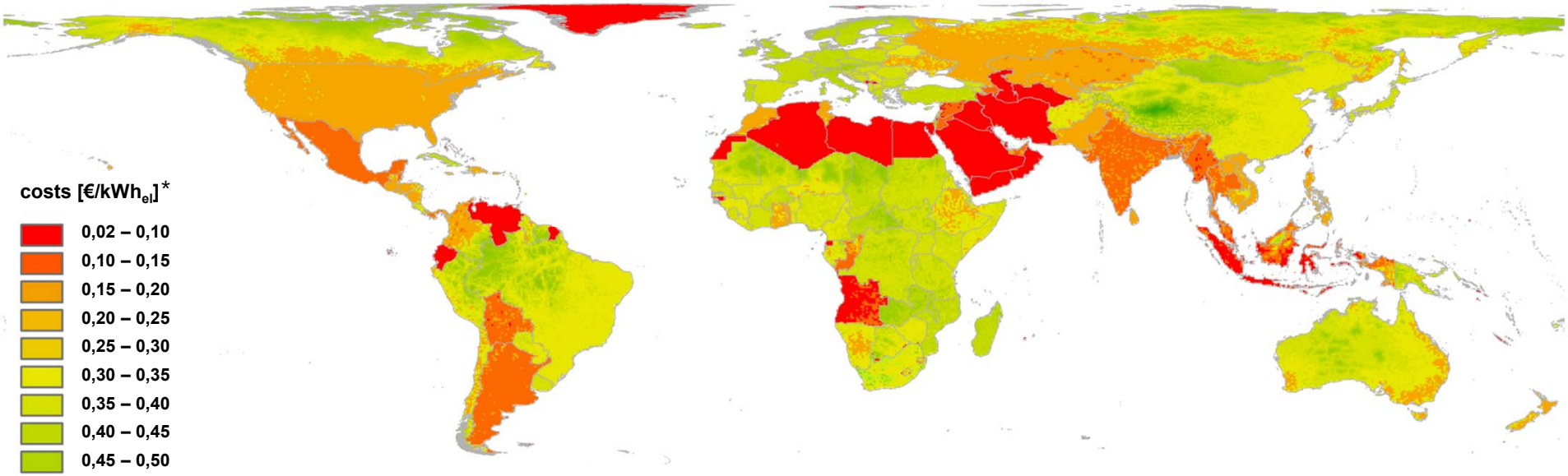
Geodata-Referenced Cost Analyses

- Hybrid Mini-Grids compete with grid extension and **pure diesel-grids**.
- Increasing **distance to large trade routes** leads to high transport costs for diesel.
- Abundant **renewable resources (solar)** favor hybrid Mini-Grids.
- According to local resource data (diesel and renewable) **cost-optimized** hybrid Mini-Grids for every location can be calculated worldwide.

National diesel price + **Road network** + **Solar irradiation** = **Cost-optimized hybrid mini-grid**

Source:
PV-based Mini-Grids for Electrification in Developing Countries, Ch. Breyer et al., 2012. study on behalf of SMA Stiftungsverbund

Local Diesel Power Generation Costs



costs [€/kWh$_{el}$]*

- 0,02 – 0,10
- 0,10 – 0,15
- 0,15 – 0,20
- 0,20 – 0,25
- 0,25 – 0,30
- 0,30 – 0,35
- 0,35 – 0,40
- 0,40 – 0,45
- 0,45 – 0,50
- 0,50 – 0,75
- 0,75 – 1,00
- 1,00 – 1,25
- 1,25 – 1,50
- 1,50 – 1,75
- 1,75 – 2,00
- 2,00 – 2,25

* 1 l diesel corresponds to approx. 3 kWh$_{el}$

- Subsidization and taxation of diesel have strong effects on costs (e.g. MENA-region).
- Transportation costs affect mainly remote rural areas or islands (e.g. outback of Australia, Himalaya region, Caribbean)

model based on: *Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension*, Szabo S. et al., Environ. Res. Lett., 6, 034002 (2011).

Source:
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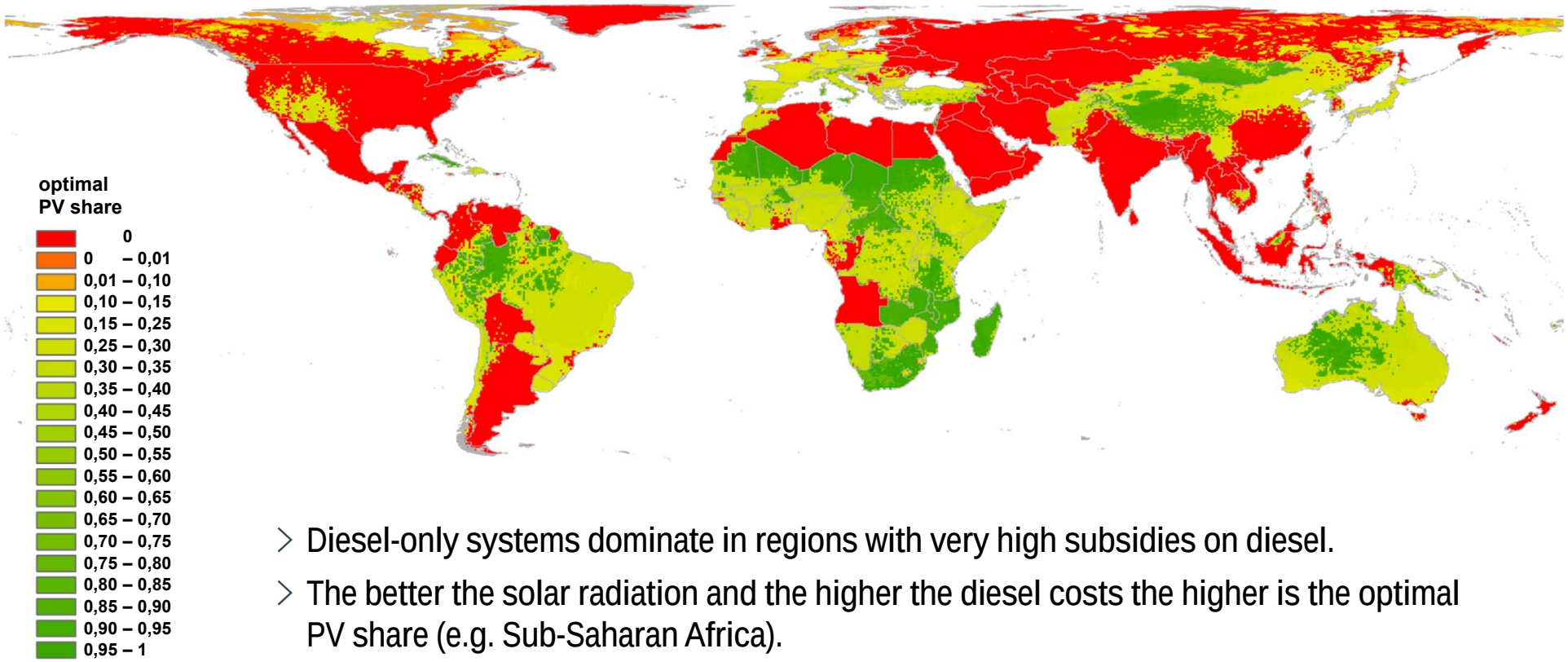
Optimal PV Share of PV-Battery-Diesel System

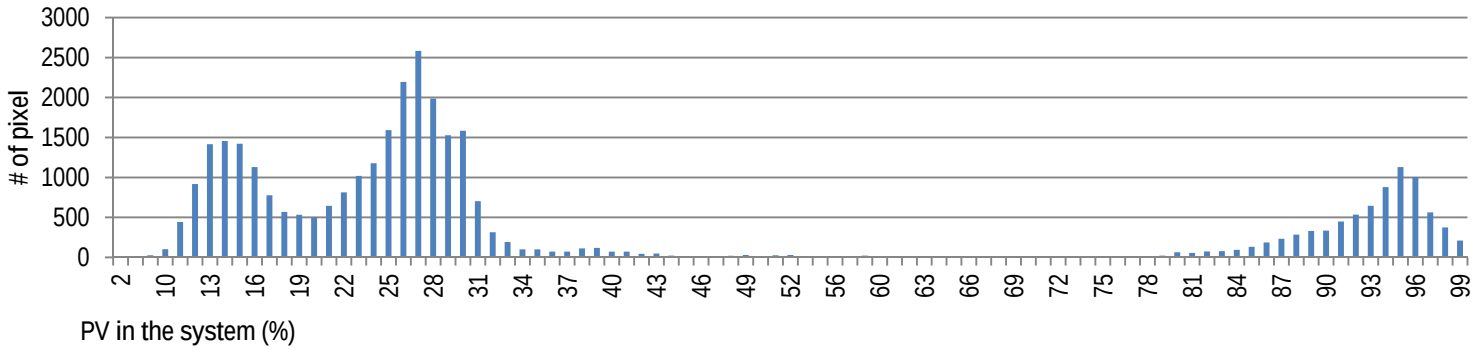


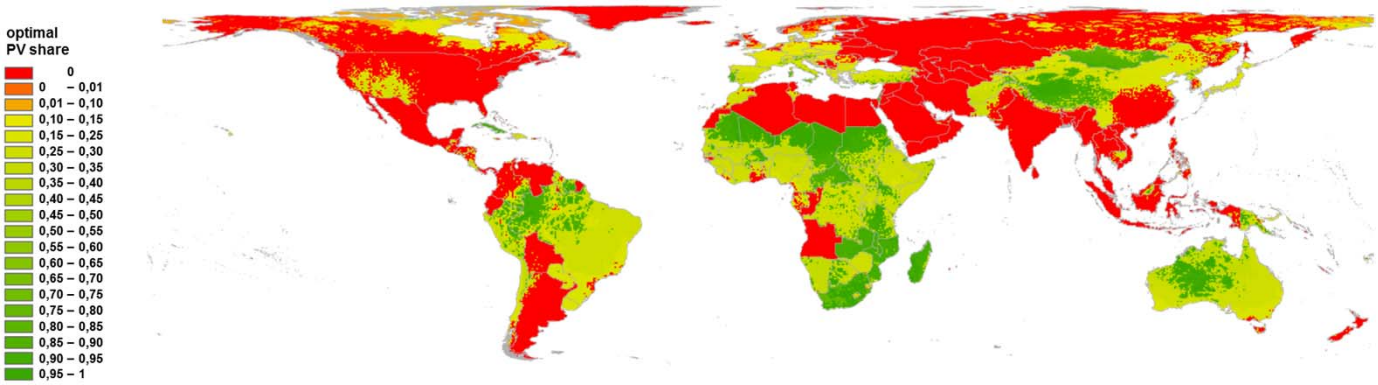
- Diesel-only systems dominate in regions with very high subsidies on diesel.
- The better the solar radiation and the higher the diesel costs the higher is the optimal PV share (e.g. Sub-Saharan Africa).

Source:
PV-based Mini-Grids for Electrification in Developing Countries, Ch. Breyer et al., 2012. study on behalf of SMA Stiftungsverbund

Statistic distribution of values

- The first step of hybridization with PV reaches PV shares of 10 to 30 %.
- In areas where use of batteries is profitable, also evening- and night-hours can mostly be covered by PV, i.e. >85 % PV share.





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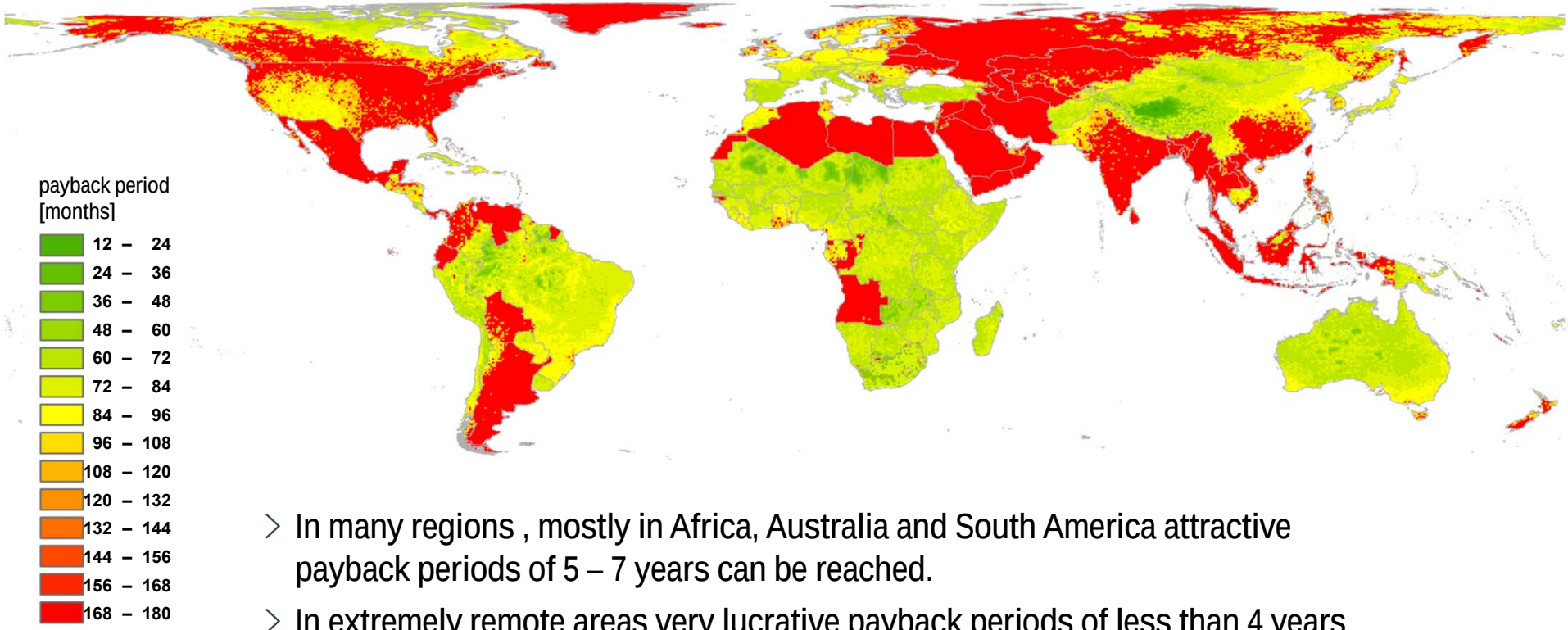
Global: PV Mini-Grids Payback Period



- In many regions , mostly in Africa, Australia and South America attractive payback periods of 5 – 7 years can be reached.
- In extremely remote areas very lucrative payback periods of less than 4 years arise for PV Mini-Grids.

Source:
PV-based Mini-Grids for Electrification in Developing Countries, Ch. Breyer et al., 2012. study on behalf of SMA Stiftungsverbund

Comparative Country Ranking for Rural Electrification

Used criteria and weighting factors:

40 % **A: „Market potential“**

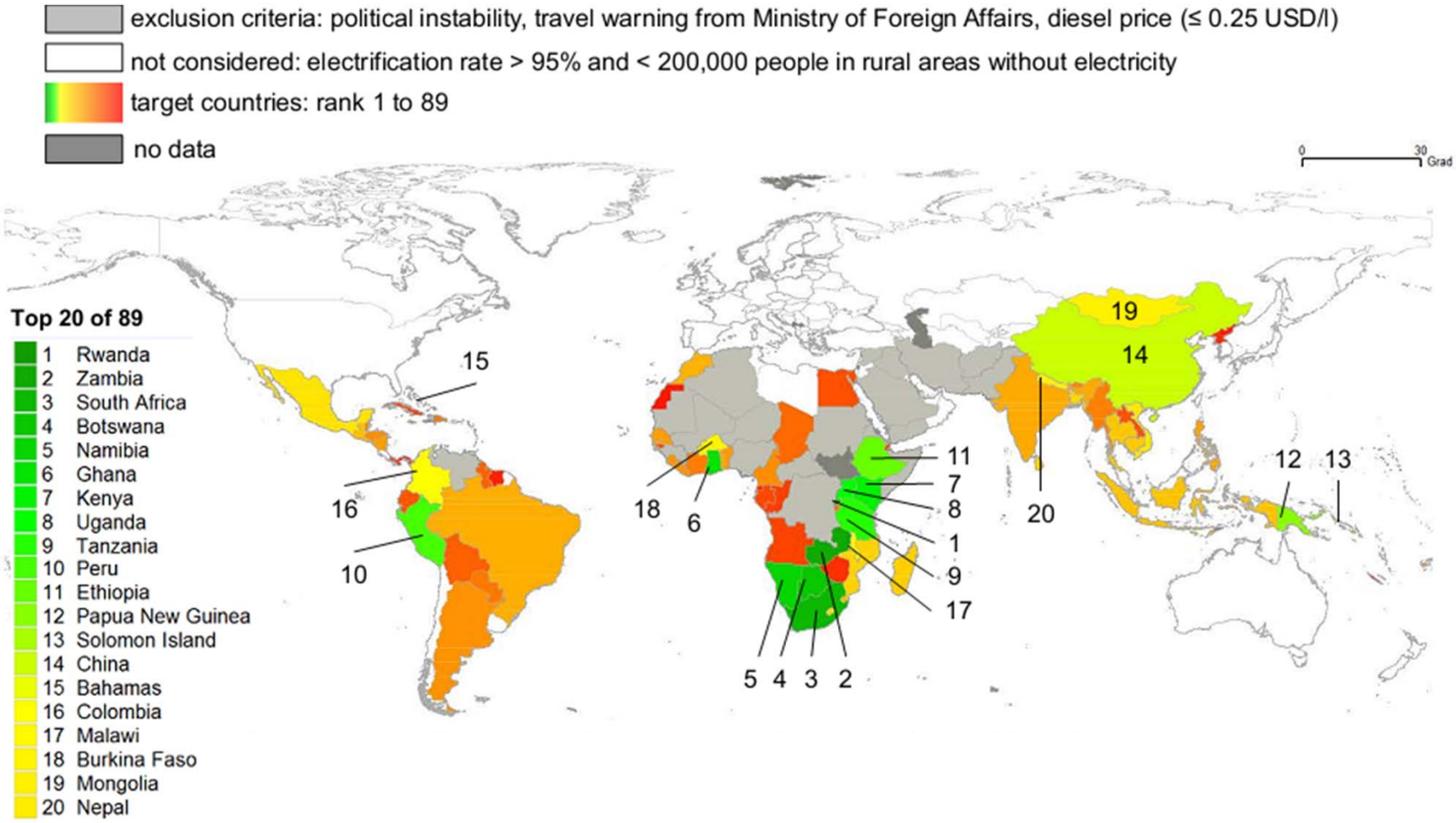
- 30 % • Electrification rate [worldbank, IEA, UNDP]
- 50 % • Rural population without access to electricity [calculated]
- 20 % • Dieselprice [worldbank]

60 % **B: „Political and financial framework“**

- 15 % • Political stability [worldbank]
- 20 % • Corruption index [transparency Int.]
- 15 % • Inflation rate [worldbank]
- 50 % • Ease of doing business index [worldbank]

Source:
PV-based Mini-Grids for Electrification in Developing Countries, Ch. Breyer et al., 2012. study on behalf of SMA Stiftungsverbund

Results of Comparative Country Ranking



Source:
PV-based Mini-Grids for Electrification in Developing Countries, Ch. Breyer et al., 2012. study on behalf of SMA Stiftungsverbund

Conclusion of Study

- With high local diesel prices and abundant renewable energy sources in rural areas hybrid Mini-Grids become competitive.
  - Middle and South Africa
  - Middle Latin America
  - Mountainous Asia
  - Caribbean and Pacific islands

- Good political and financial environment combined with high electrification needs are identified especially in South and East Africa.

Source:
PV-based Mini-Grids for Electrification in Developing Countries, Ch. Breyer et al., 2012. study on behalf of SMA Stiftungsverbund

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  - Diesel Mini-Grids
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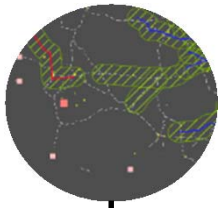
Methods: Localization of Diesel Mini-Grids

Global spatial information on country areas

Information on power plant inventory and locations from Platts database

Spatial extension of transmission grid



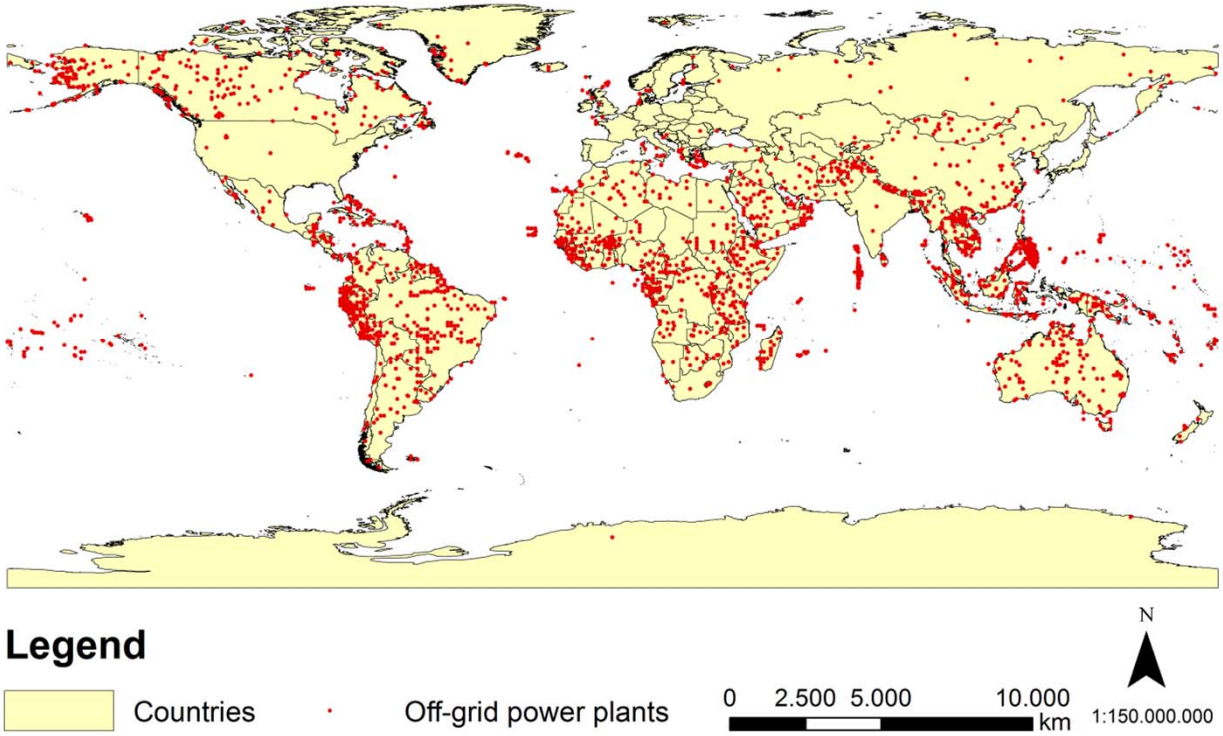
Extraction of 50 km buffer zone

Determination whether a power plant operates **on-grid** or **off-grid**

Hybrid Mini-Grids
Philipp Blechinger ► philipp.blechinger@rl-institut.de

Source:
P. Bertheau: „Analysis of diesel-based mini-grids for enabling the implementation of renewable energies", Master's Thesis

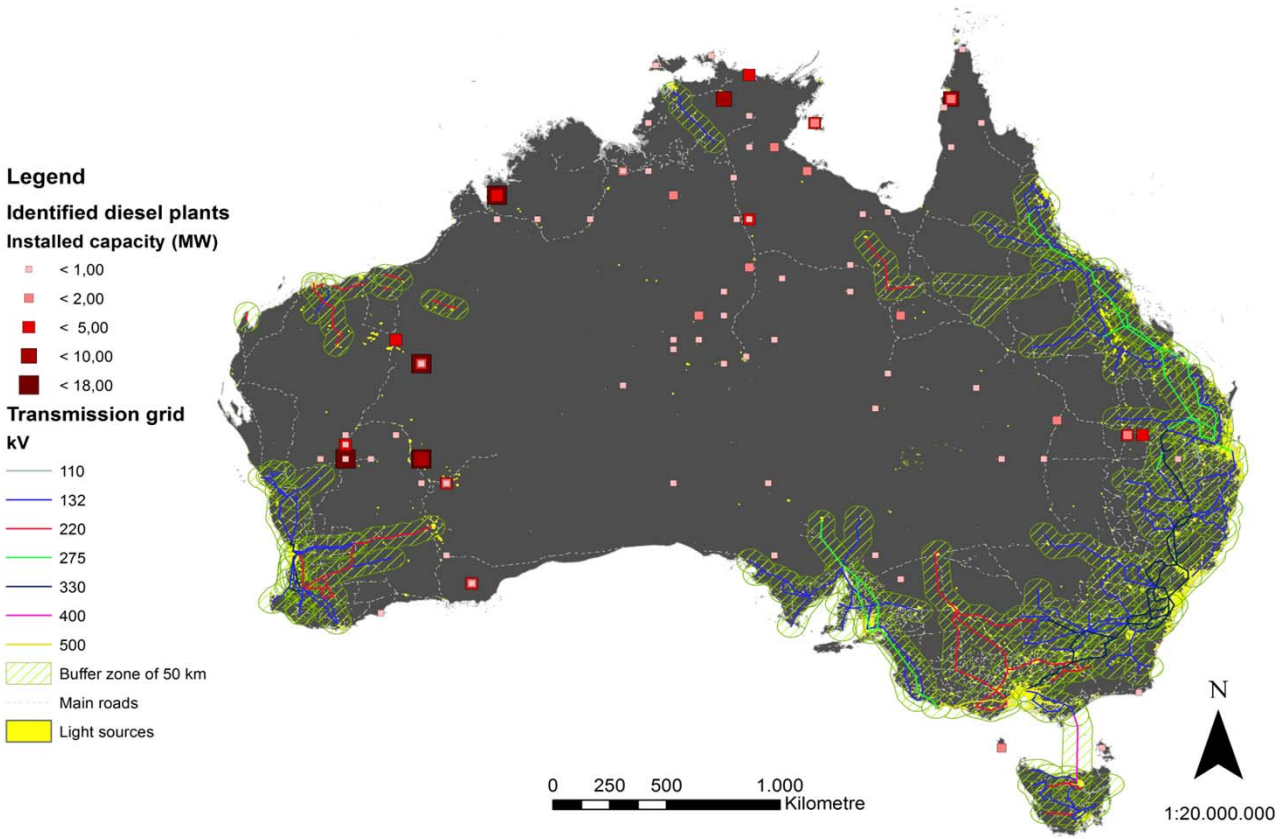
Deriving Global Capacity



Global Diesel Mini-Grid capacity of minimum 20 GW

Source:
P. Bertheau: „Analysis of diesel-based mini-grids for enabling the implementation of renewable energies", Master's Thesis

Case Study Australia



Identified off-grid capacity: appr. 500 MW
Main purposes: Mining-supply and remote villages

Source:
P. Bertheau: „Analysis of diesel-based mini-grids for enabling the implementation of renewable energies", Master's Thesis

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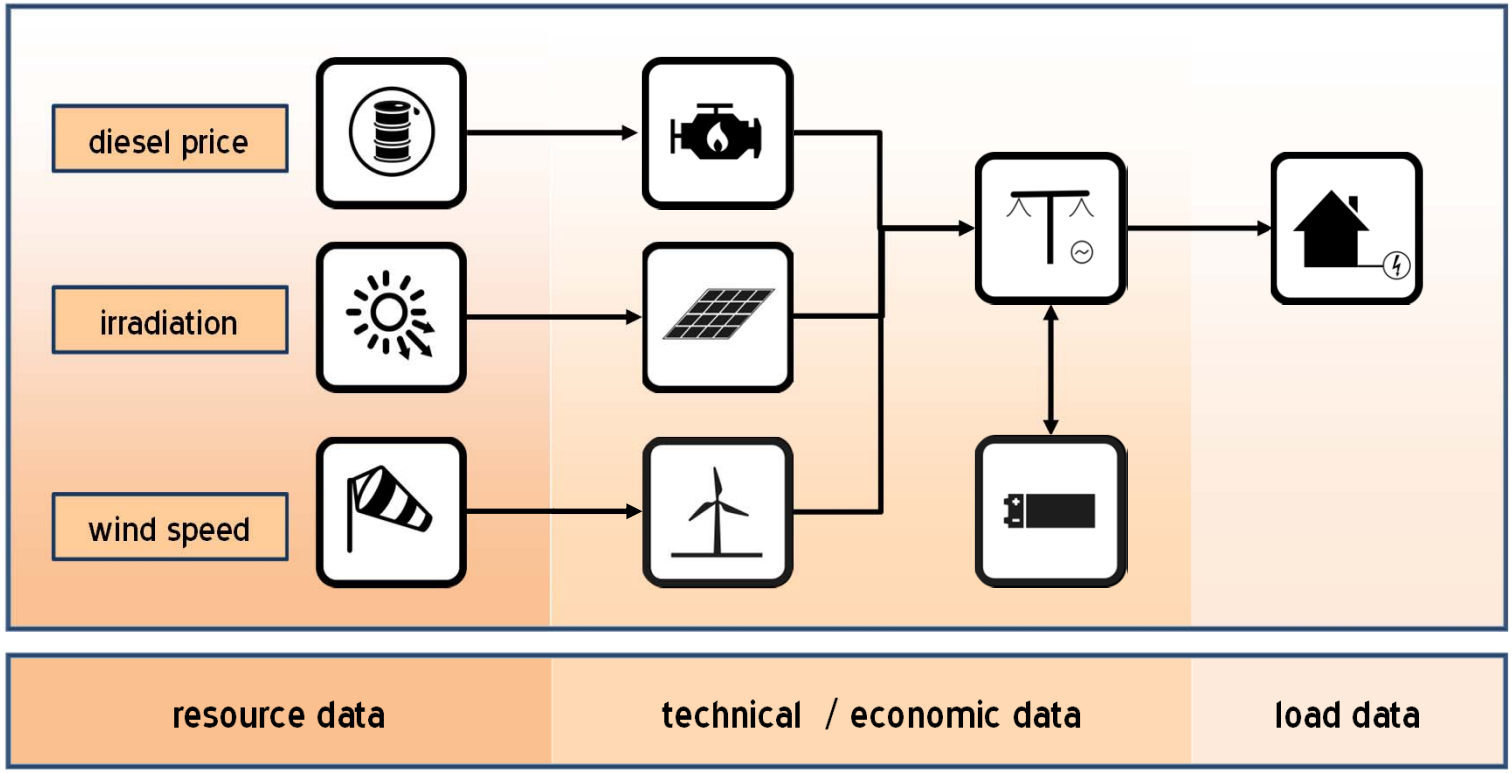
Islands are very Attractive Markets for RE

"An island is a naturally formed area of land, surrounded by water, which is above water at high tide"

Source: United Nations Convention on the Law of the Sea Part VIII, Article 121

Small islands are mainly powered by diesel power plants

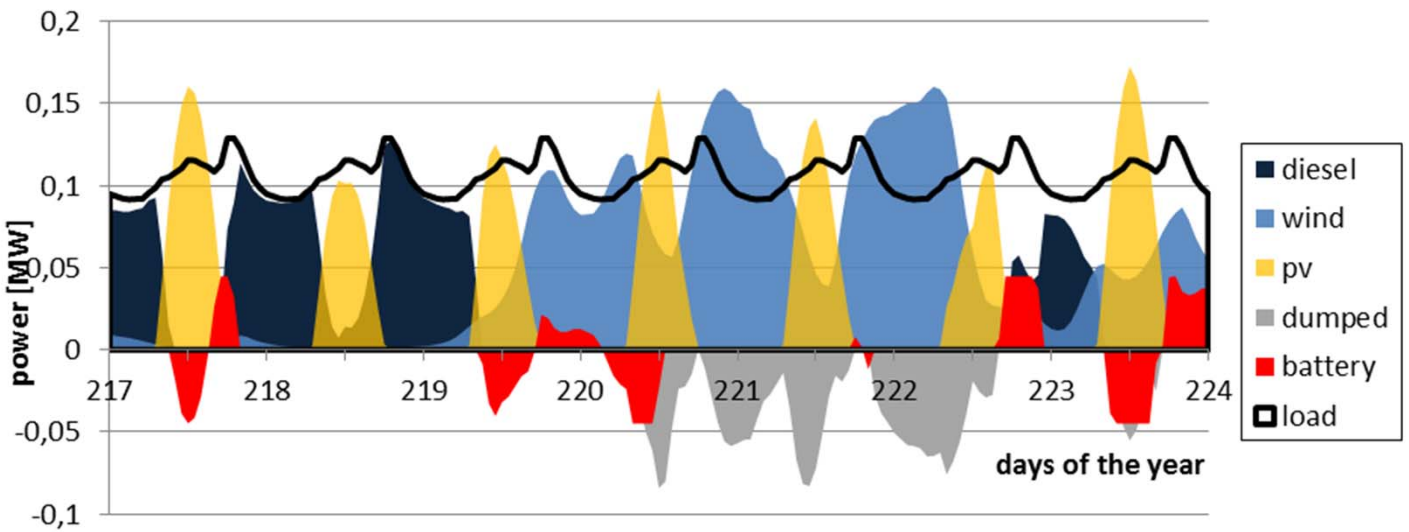
Simulation Example for RE Implementation on Islands



Techno-economic optimization in hourly timesteps.

- Limitations: Grid/frequency stability is not reflected, diesel genset is operating at constant efficiency, perfect foresight is assumed

Energy Flow Diagram



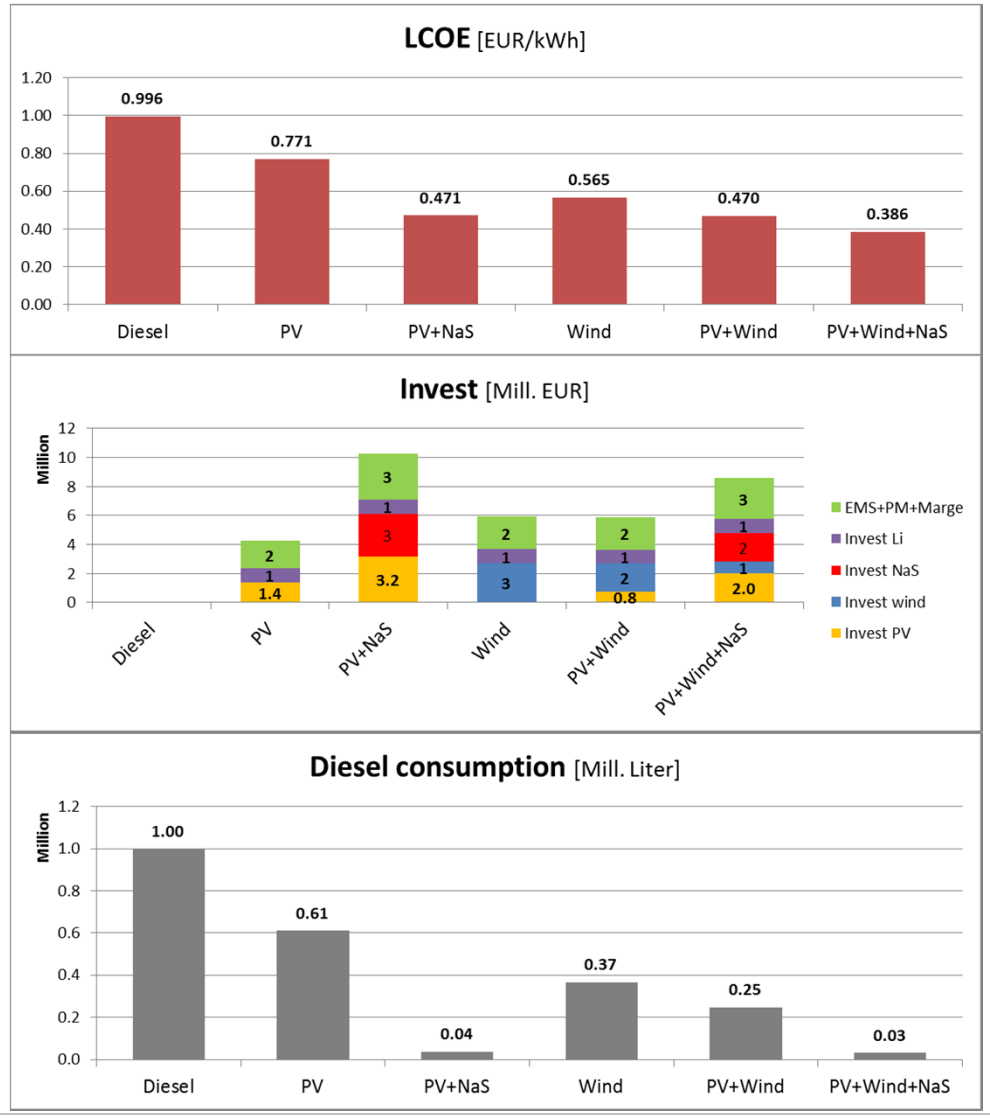
Load is met in every hour of the year by cumulated power generation of wind, pv, and diesel and by battery discharge.

Economic Results for Sample Island

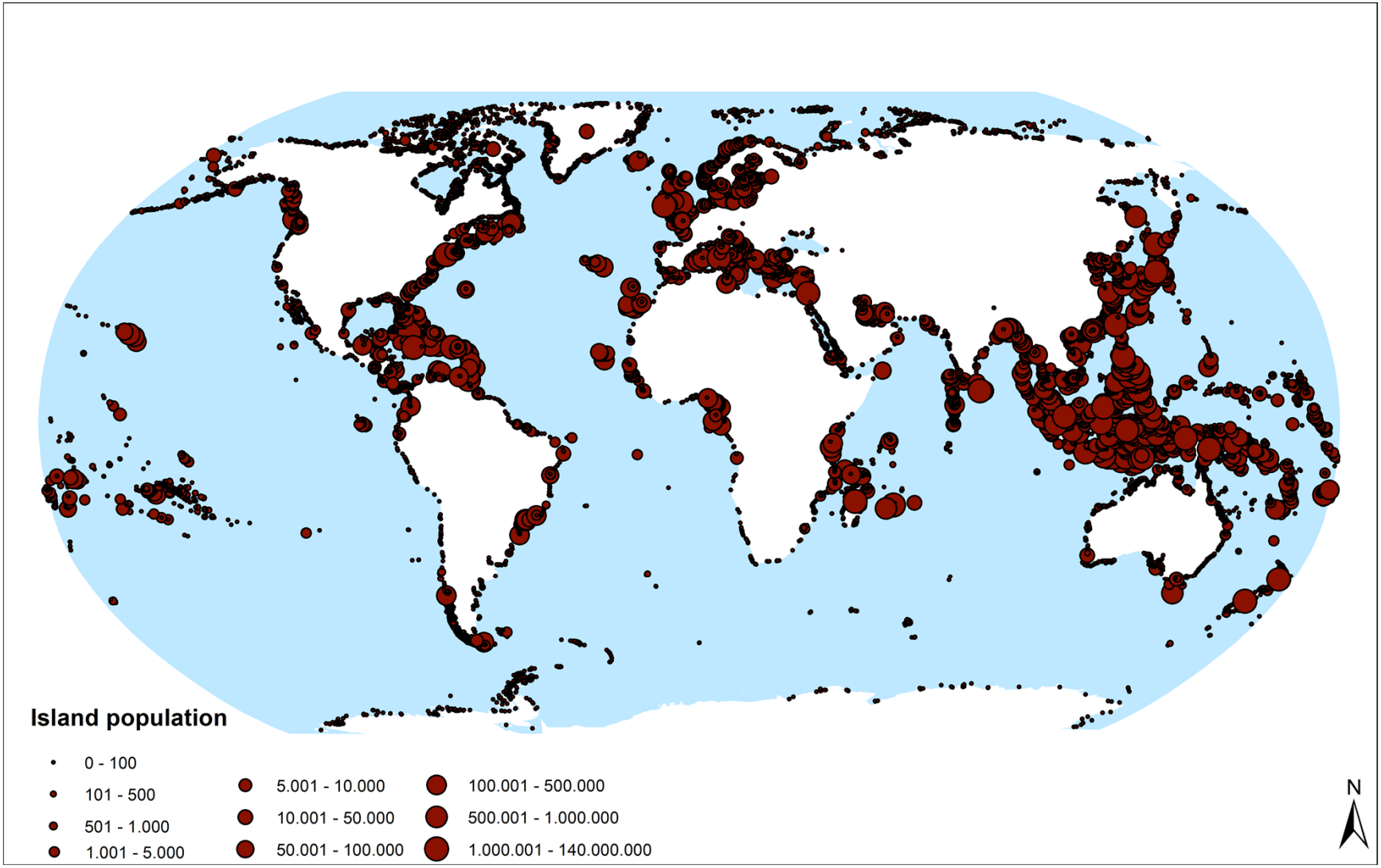
Savings potential and added value of the single technologies

Investment shares of the different technologies

Diesel and CO_2 reduction potentials.



Global Island Landscape



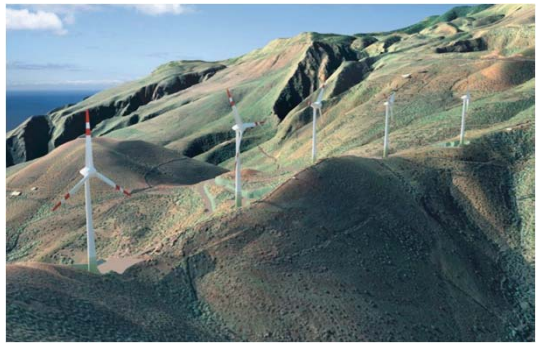
Global Island Distribution

- 11% of the global population lives on islands.
- Islands with fewer than 1 million inhabitants represent a cumulated market potential of 65 million people (equals 0.9% of global population).
- Appr. 2,000 islands between 1,000 and 100,000 inhabitants are identified, which can be considered as natural Mini-Grids

=> Huge potential for hybrid Mini-Grids!

Existing Island RES Projects

- Best-practice examples:
  - El Hierro (Canary Islands) - wind/hydro (PHS)
  - Ikaria (Greece) - wind/hydro (PHS)
  - Tokelau (Pacific) - PV/diesel
  - *Graciosa (Azores) - wind/PV/diesel (NaS)*



El Hierro: 11.5 MW wind, 11.32 MW hydro, 11.36 MW diesel (Backup)

Graciosa (planned): 9 MW wind, 1 MW PV, 4.2 MW diesel (Backup), 3 MW NaS battery

Ikaria: 4.5 MW wind, 2.73 MW hydro, 1.04 MW PV, 15.85 MW diesel

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Summary

Only few hybrid Mini-Grids are installed globally

- Even fewer operate sustainable and profitable

Huge potential in all four fields of application for hybrid Mini-Grids!

Challenges:

- Identification of market region
- Political / regulatory constraints
- Optimization of configuration
- Applying the best fitting operating / business model

Thank you!

And special thanks to the RLI off-grid team for providing the presented information

Contact:

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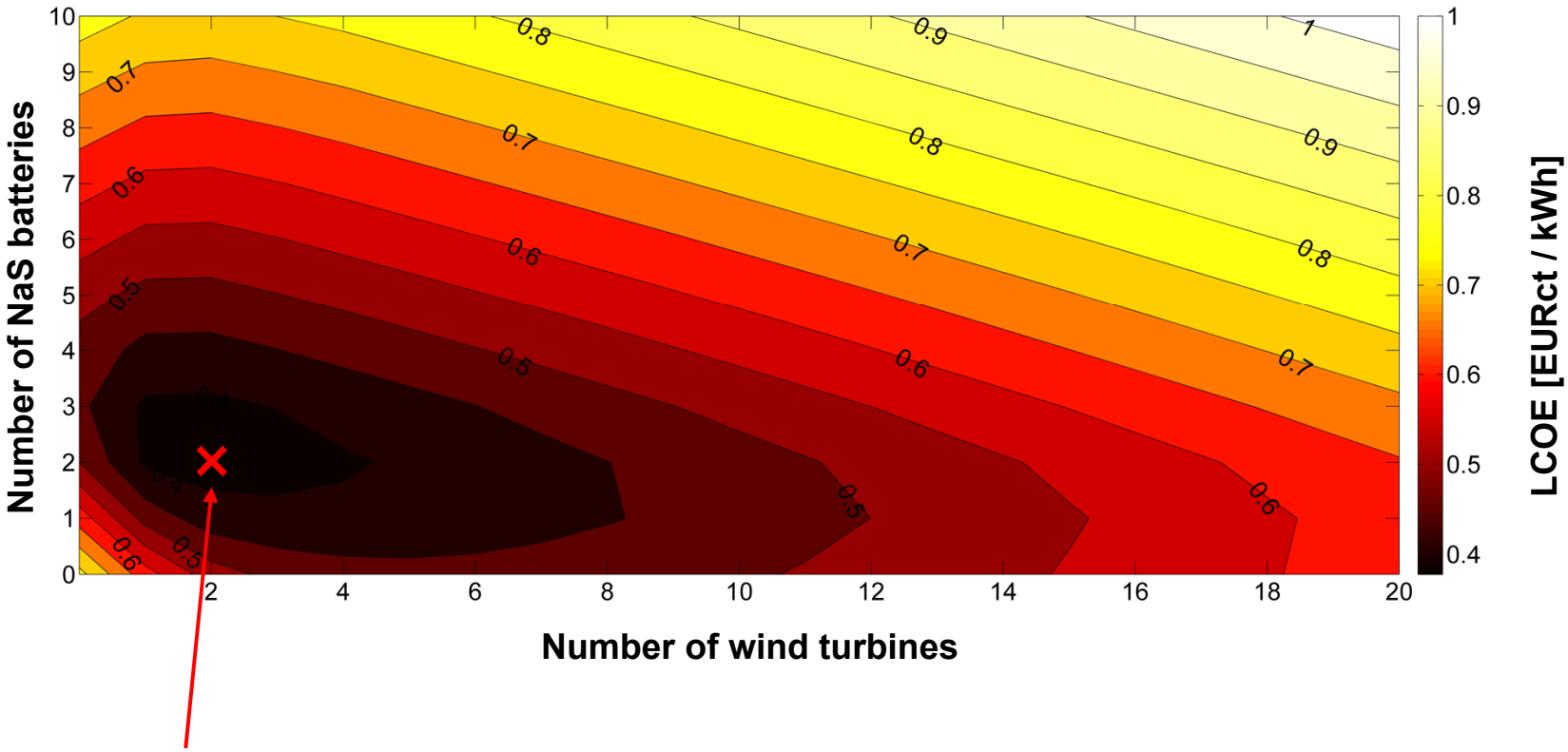
- Robert Seguin: robert.seguin@rl-institut.de

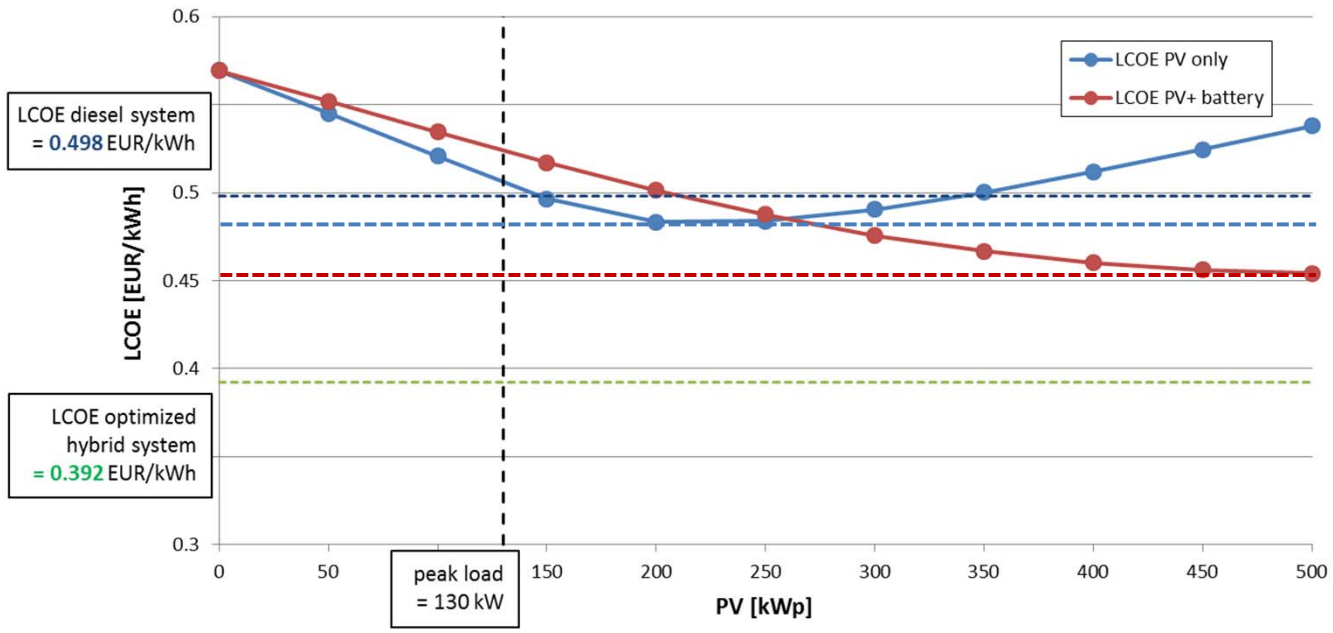
Backup

Sensitivity Analysis for Example Island



Optimized system: 1857 kW PV, 2 wind turbines, 2 NaS batteries → LCOE = 0,377 EURct / kWh

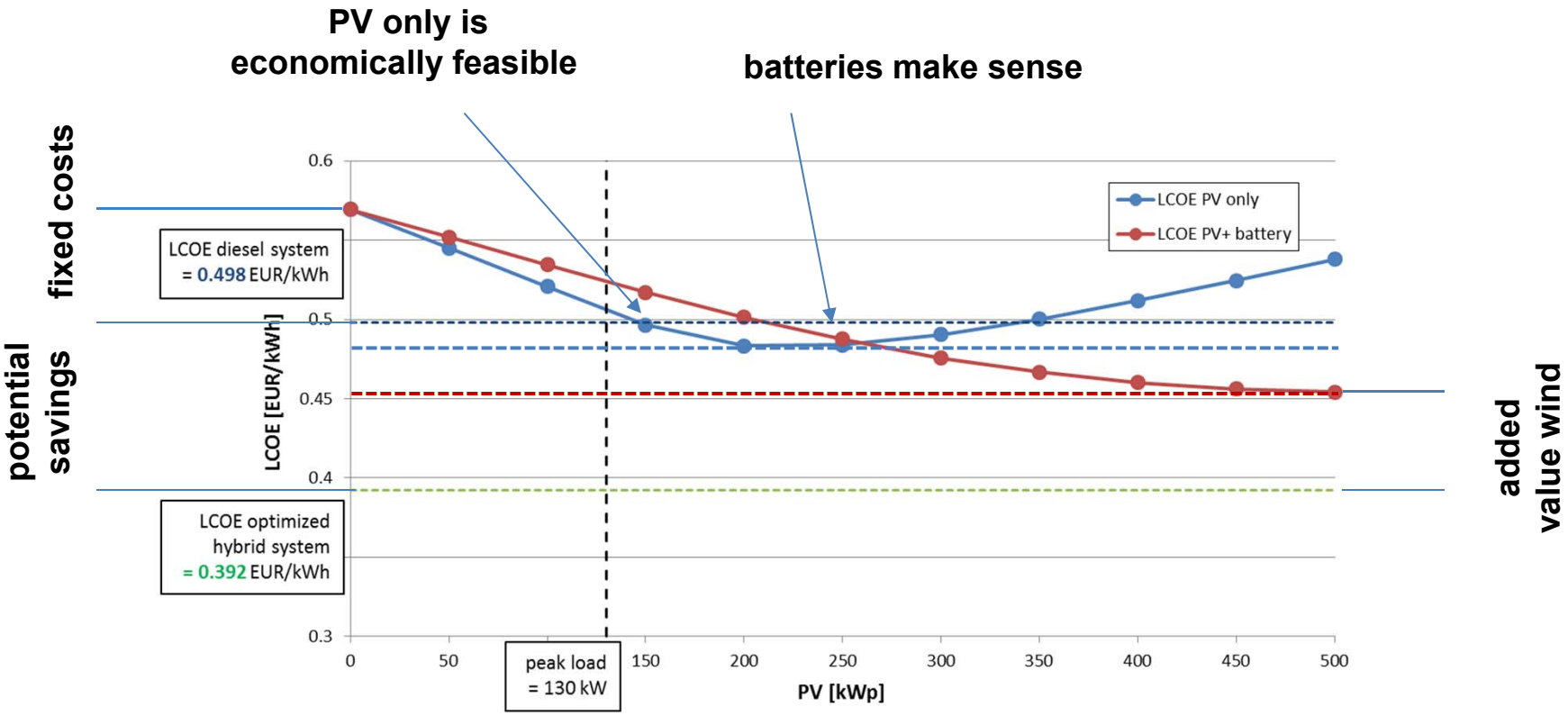
Implementation Strategies



→ Diesel only
+ PV
+ PV + bat.

→ full hybrid system

Implementation Strategies



The numbers are different for every mini-grid and imply different RES implementation strategies.