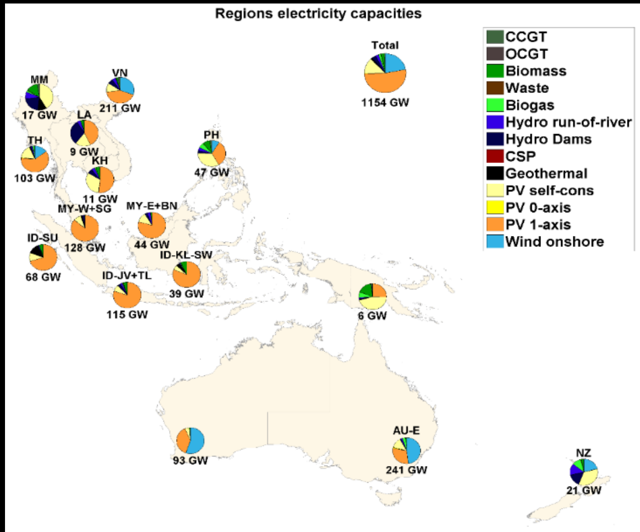

Solar Energy in Development Cooperation
A view on local demand

Christian Breyer
Professor for Solar Economy, LUT

Seminar of Technology for Life and Kepa on
Solar Energy in Development Cooperation
Helsinki, November 4, 2015

Agenda

- Overview
- Solar Home Systems/ pico SHS
- PV upgrades for diesel grids
- Country ranking business models
- Role of batteries: case of Tanzania
- Solarkiosk: catalyst for electrification
- Islands: on-grid but off-grid
- 100% RE for the case of South-East Asia
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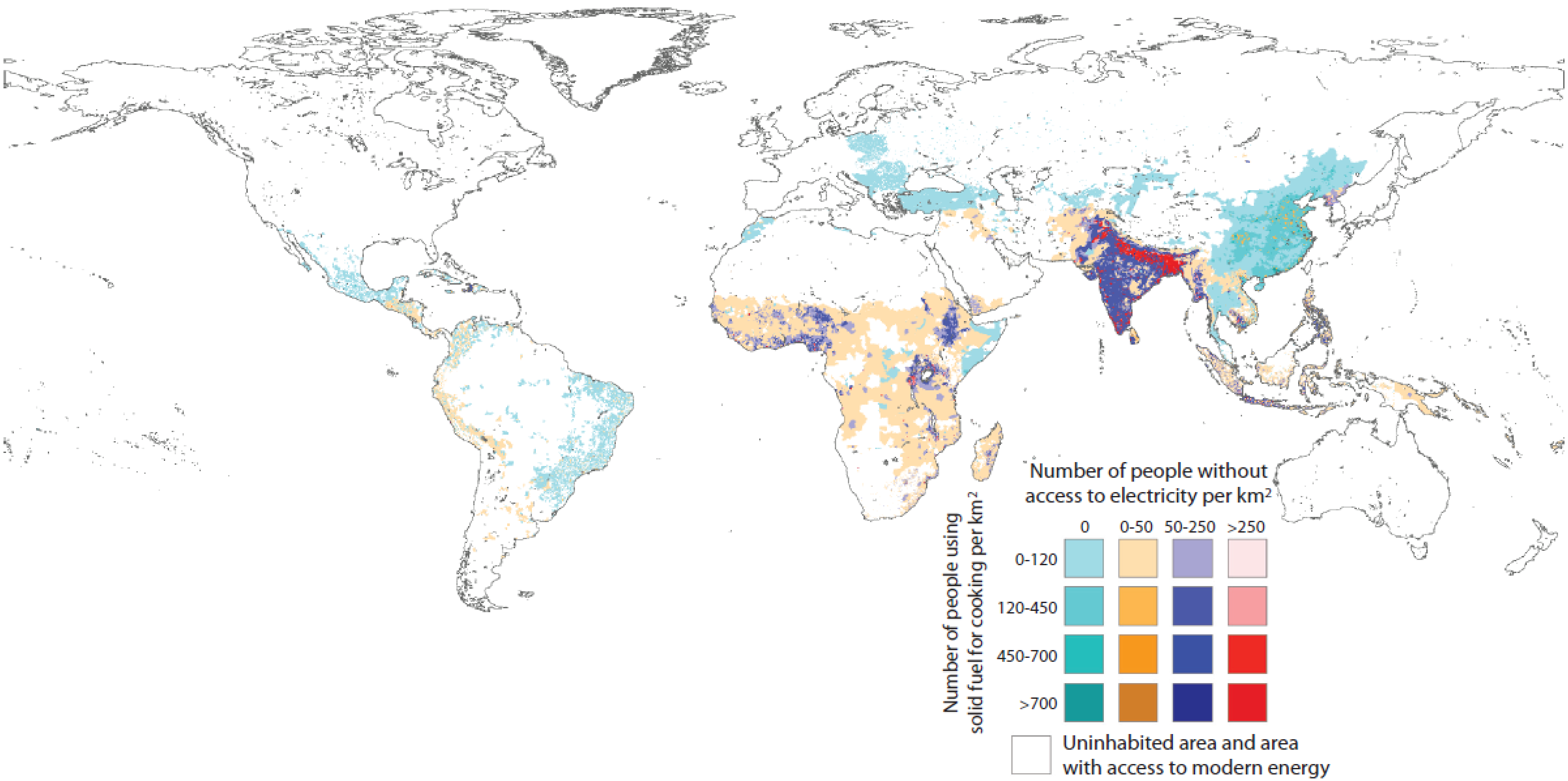
People without access to electricity

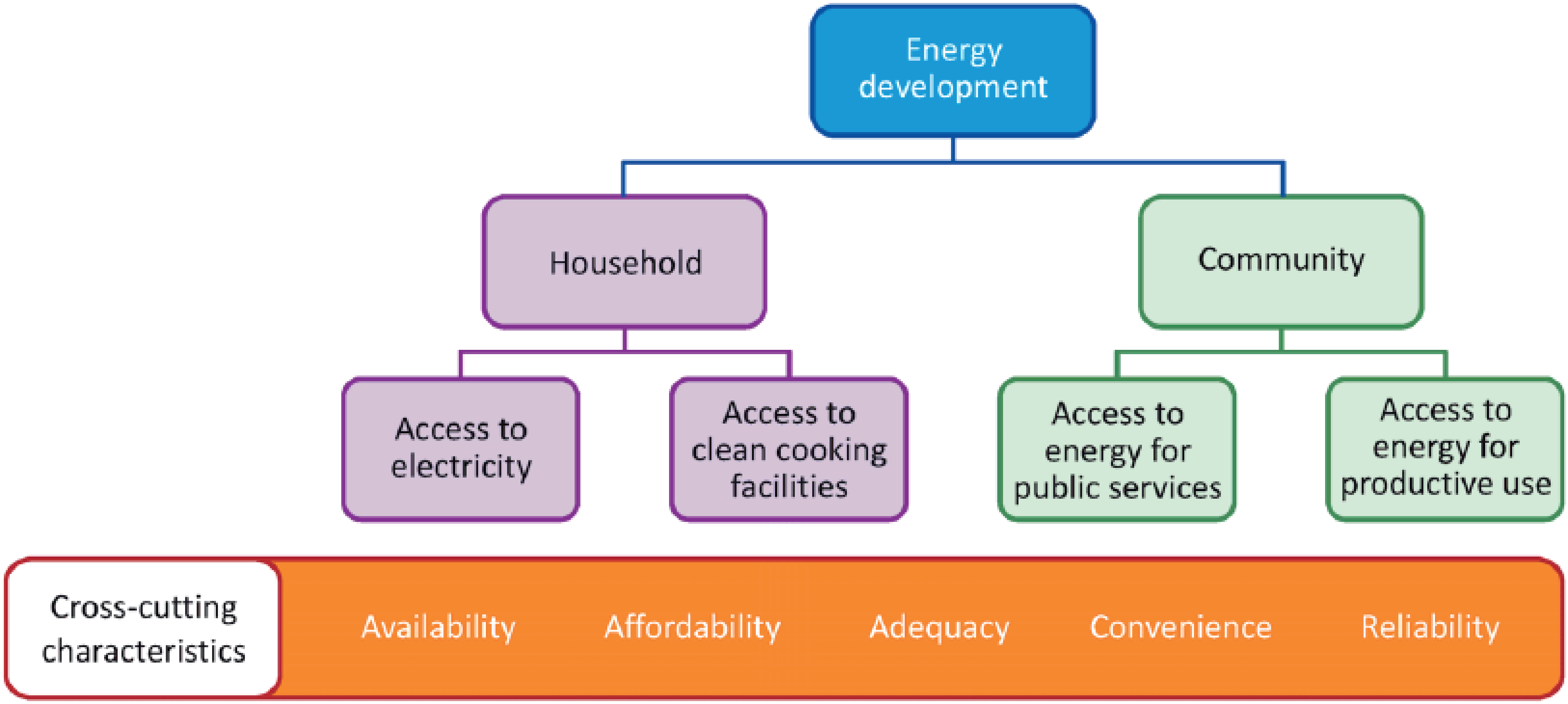


Density of population lacking access to modern energy carriers in 2005. Colored areas show people per km² without access to electricity and those that use solid fuels for cooking, e.g., dark blue and red areas show where people do not have access to electricity and cook predominately using solid fuels.

Christian Breyer ► christian.breyer@lut.fi

source: IIASA, 2012. Global Energy Assessment (GEA)

Energy development framework



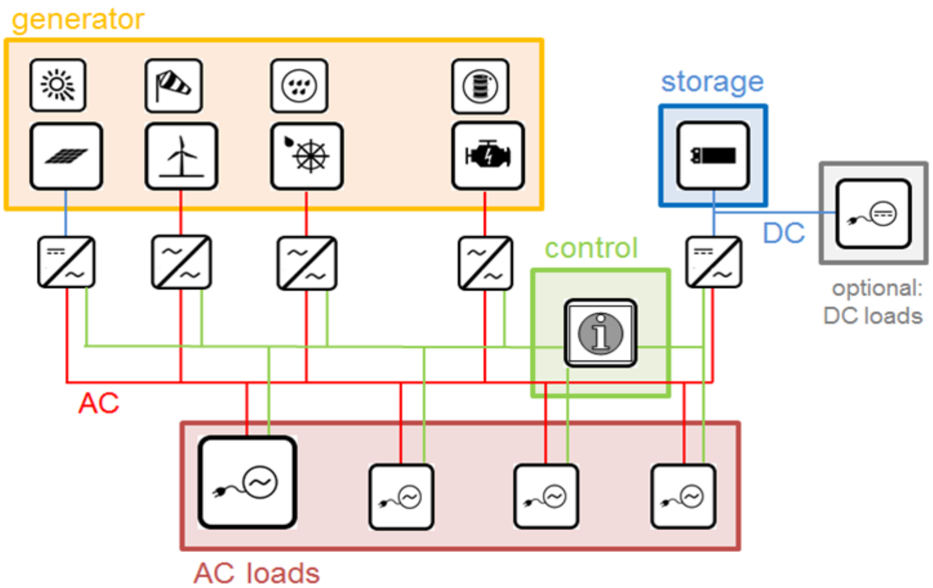
source: IEA, WEO 2012

PV: Basis for decentralised energy supply

Advantages of PV for decentralised sites

- cost-effective
- modular expandable
- wear-free technology
- solar energy available everywhere
- easy installation

picture: Sunlabob Renewable Energy Ltd.



Possible systems:

solar home systems (5 – 250 Wp)

- are suitable for very small energy needs
- are linked with small capital costs

mini-grids (kW – MW)

- are flexibly expandable
- higher power enables supply of commercial usage, hospitals, villages etc.

source: Breyer Ch., Gaudchau E., Gerlach A.-K. et al., 2012. PV-based Mini-Grids for Electrification in Developing Countries, study on behalf of cdw Stiftungsverbund

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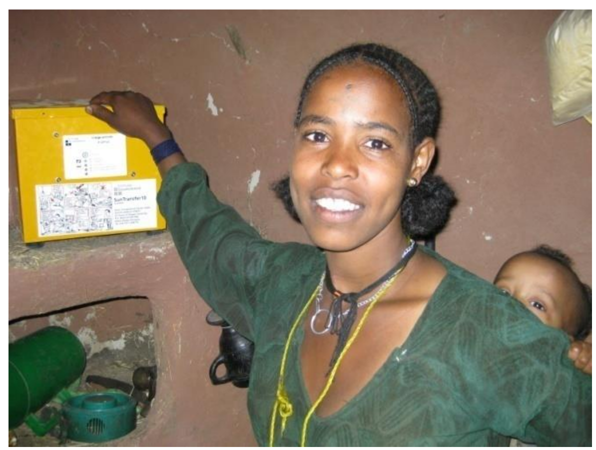
Solar Home System (SHS) in Ethiopia



see: www.solar-energy-foundation.org

source: Breyer Ch., Schützeichel H., et al., 2009. Electrifying the Poor: Highly Economic Off-Grid PV Systems in Ethiopia, 24th EU PVSEC, Hamburg

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fosera – high efficiency products for the poor

fosera®

fosera SCANDLE & BOP

use the energy

fosera SCANDLE

- Portable and Versatile
- Robust design allows multiple functions with one device: as a hanging lamp, wall lamp, ceiling lamp, ambience light, or portable torch.
- Ultra efficient, long-lasting LED lights.
- The SCANDLE can power radios and charge cell phones.
- After each full charging in the sun, the battery lasts up to 70 hours in dimmed mode.

fosera BOP

- The fosera BOP+ has one Outlet that is able to power several fosera applications.
- The robust and flexible design allows the device to be used in many ways; as a wall lamp, ceiling lamp or ambience light.
- After each full charging, the battery offers up to 50 hours of light in the dimmed mode.
- Nightlight function: light switches automatically on at night.

Brilliant solar lanterns with extremely long lifespan

Both the fosera SCANDLE and the fosera BOP can be combined with a fosera Pico-Solar Home System by Plug & Play connection.

They can be charged with a small separate PV module or over the PSHS.

fosera PSHS & LSHS

feel the energy

fosera PSHS

- Pico Solar Home System for domestic use
- Unique, modular PSHS extension: the system can grow with demand
- Easy to install
- Can charge cellphones

Unique Modular Concept

- Both the fosera PSHS and LSHS allow up to four different loads to be connected at one time.
- If demand grows, the fosera system can grow as well.
- This parallel connection is very simple; by plugging in one connector cable the additional fosera power pack will work perfectly.

fosera LSHS

- The fosera Li-ion Solar Home System is an autonomous and mobile energy system that is capable of powering several 12 V loads.
- The LSHS can power a TV or a small computer and several lamps.

Product features

enjoy the energy

Multiple Applications

- Efficient appliances can be connected to all fosera systems including table lamps, fans, radios, phone chargers, fairy lights etc.
- fosera engineers are constantly expanding the product range.

USB Outlet

- The PSHS is also available with a USB plug for the universal use of charging devices such as mobile phones and MP3 players.

Innovative Battery Technology

- fosera uses only new, high-quality lithium-iron-phosphate battery technology, to store energy.
- This technology allows long battery lifetime of five to ten years, lasting up to three times longer than conventional battery technologies on the market.

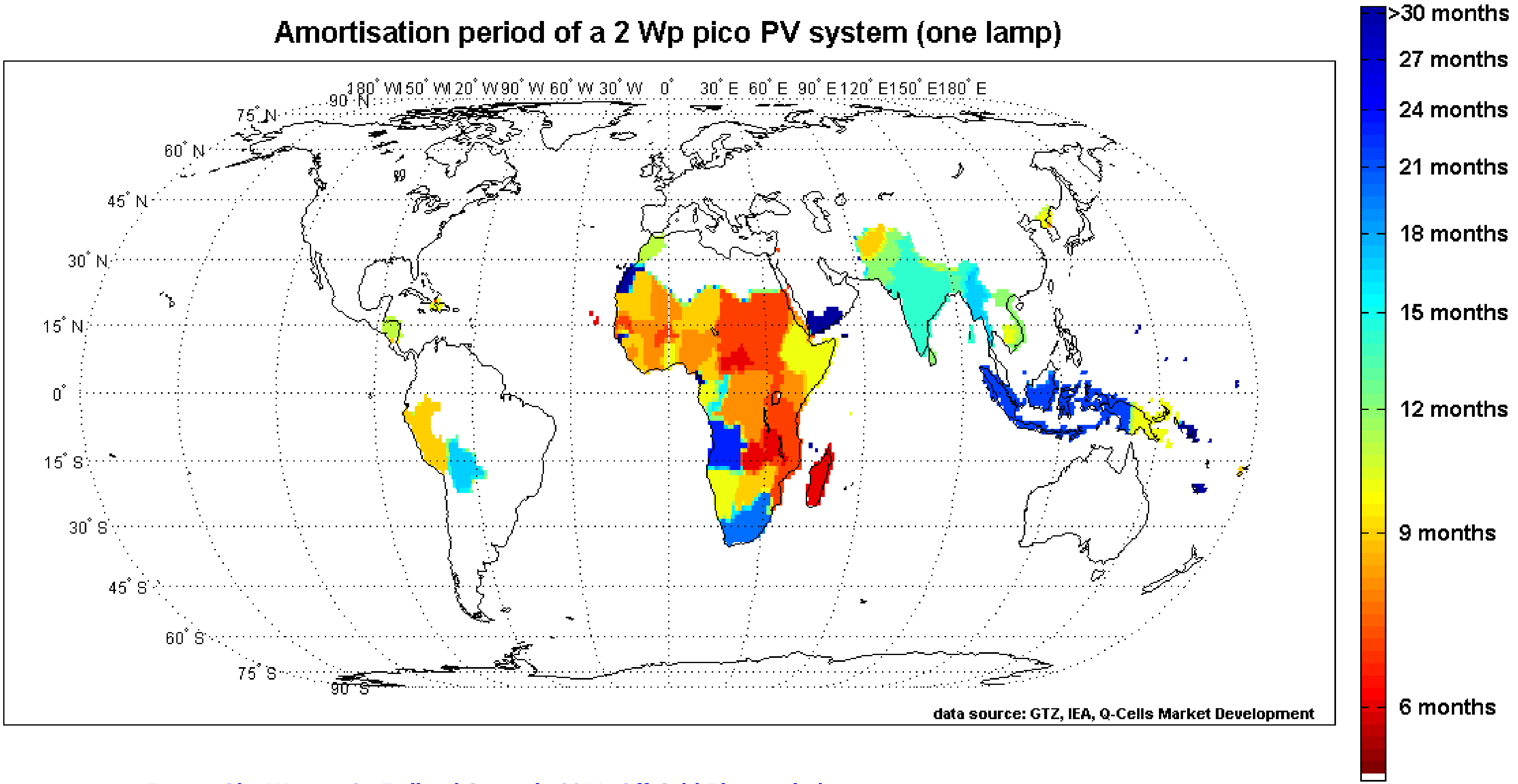
fosera Solar Charging Station

The fosera Solar Charging Station is designed to charge several phones, lanterns or other devices.

It has two USB-Outlets that are able to charge a cell phone within 1 hour, 4 - 8 mobile phones per day.

see: www.fosera.com

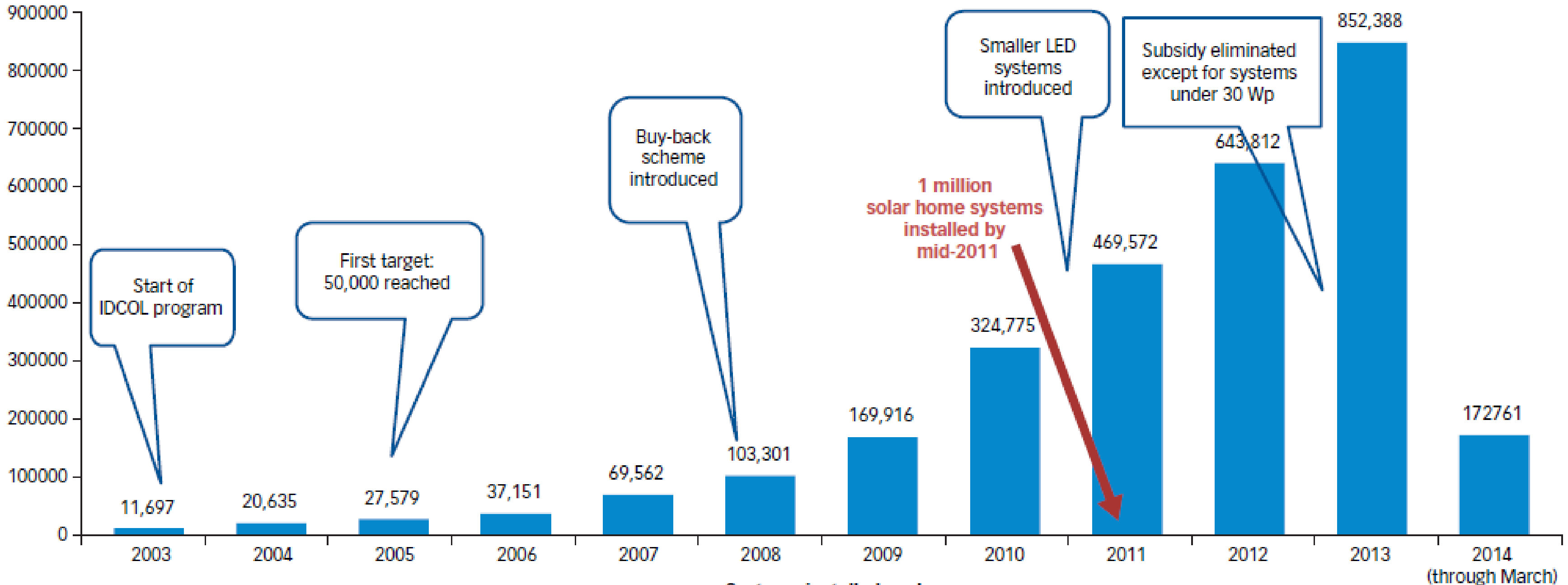
SHS: Perfect Solution for the Poor



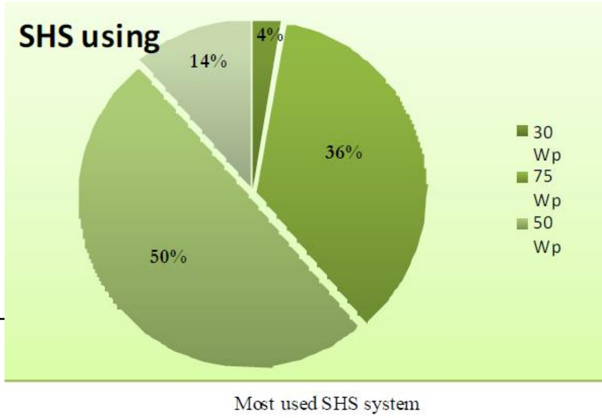
source: Breyer Ch., Werner C., Rolland S., et al., 2011. Off-Grid Photovoltaic Applications in Regions of Low Electrification: High Demand, Fast Financial Amortization and Large Market Potential, 26th EU PVSEC

Bangladesh, the leading SHS market globally

Solar home systems installed each year, 2003–14



Source: IDCOL.



source: World Bank, 2014. Scaling up access to electricity: The case of Bangladesh; Khan S.A. and Azad A.M., 2014. Social impact of SHS in rural Bangladesh: A case study of rural zone, Sustainability Energy and the Environment, 1, 5-22

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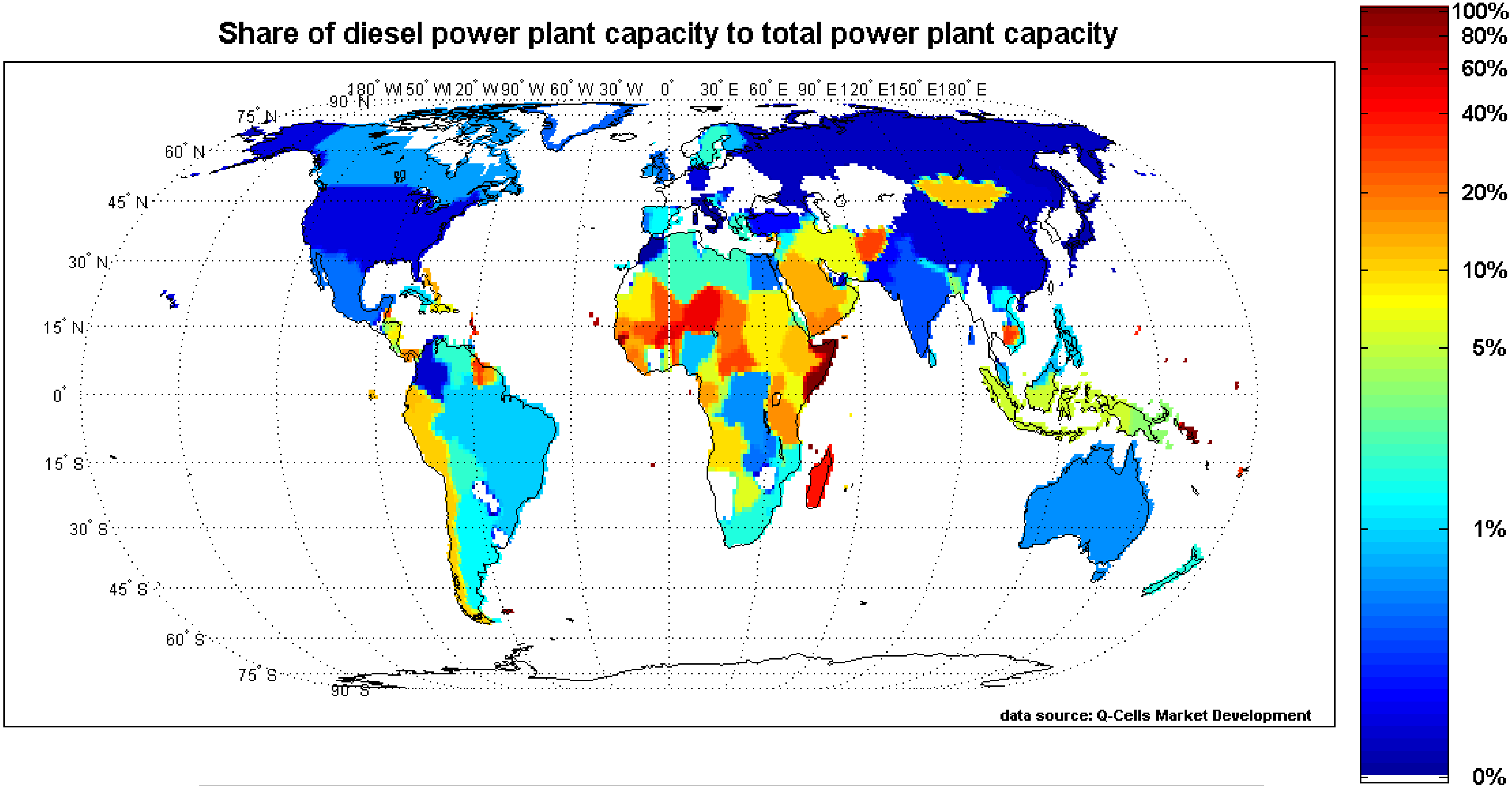
Off-Grid: Diesel-Grids

Share of diesel power plant capacity to total power plant capacity

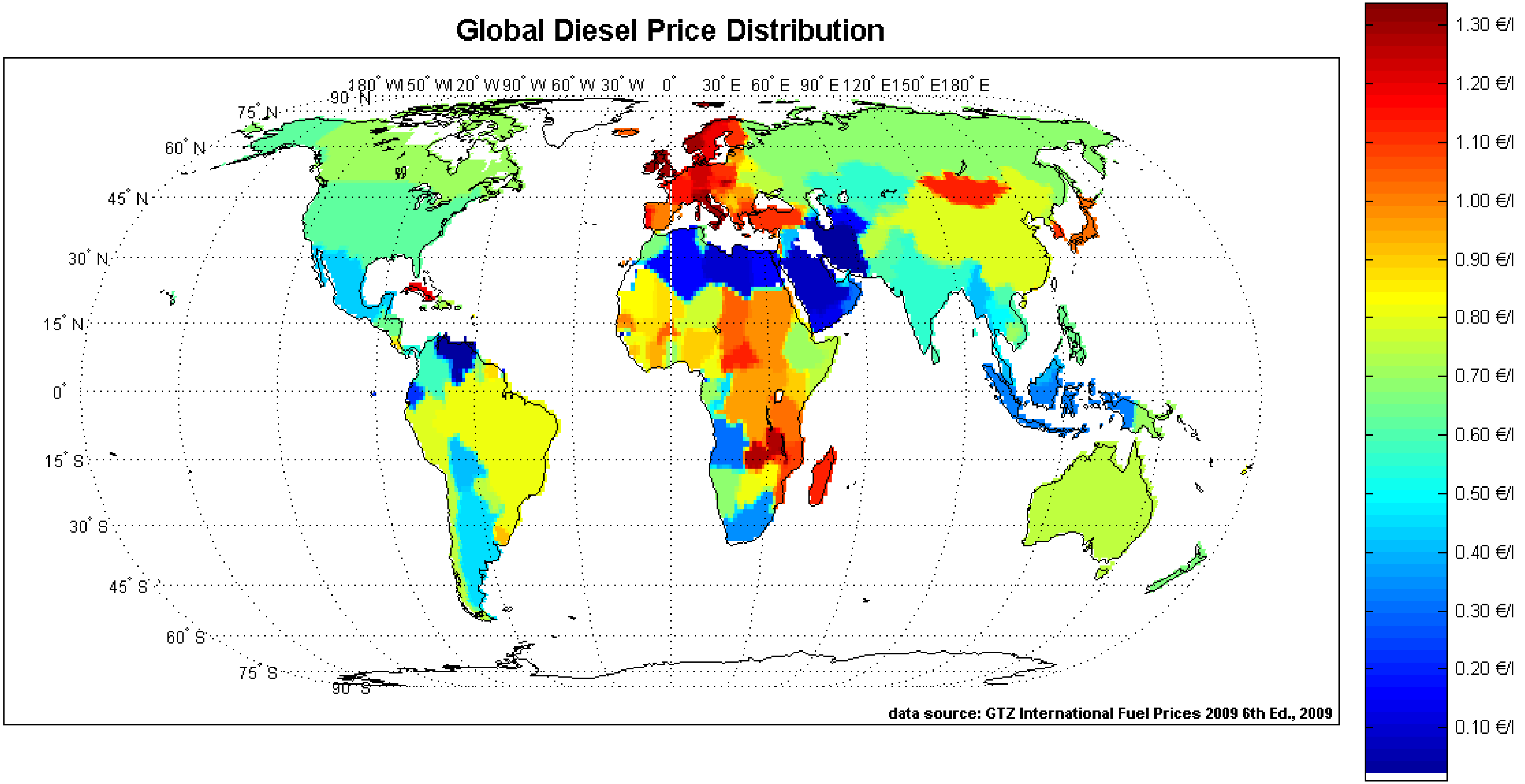


the higher the diesel share, the more local diesel-grids can be expected

source: Breyer Ch., Werner C., et al., 2011. Off-Grid Photovoltaic Applications in Regions of Low Electrification: High Demand, Fast Financial Amortization and Large Market Potential, 26th EU PVSEC, Hamburg, September 5-9

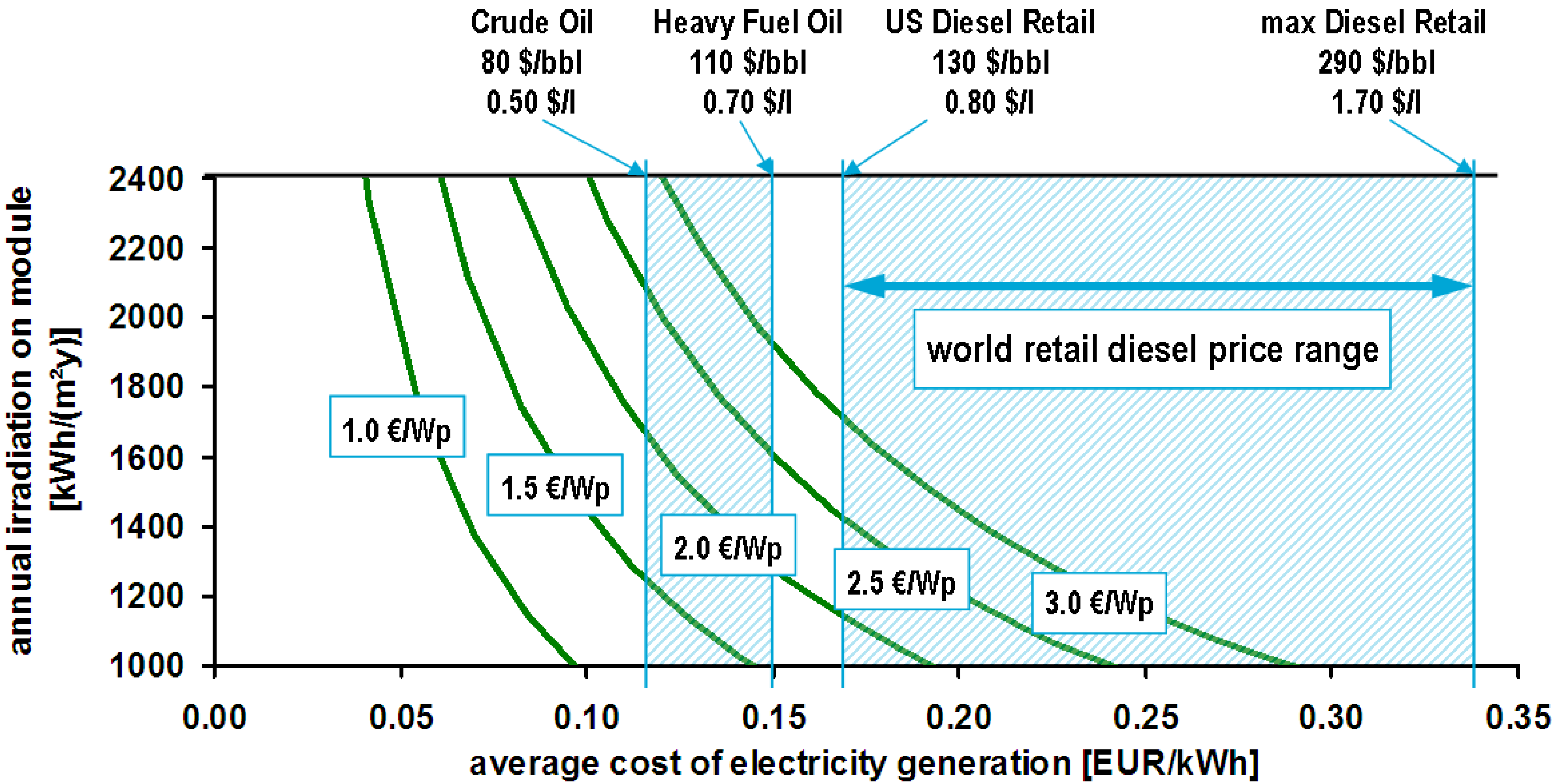
Off-Grid: Global Diesel Prices

Global Diesel Price Distribution



source: Breyer Ch., Werner C., et al., Off-Grid Photovoltaic Applications in Regions of Low Electrification: High Demand, Fast Financial Amortization and Large Market Potential, 26th EU PVSEC

Diesel-Parity: PV capex, Irradiation, Oil Price

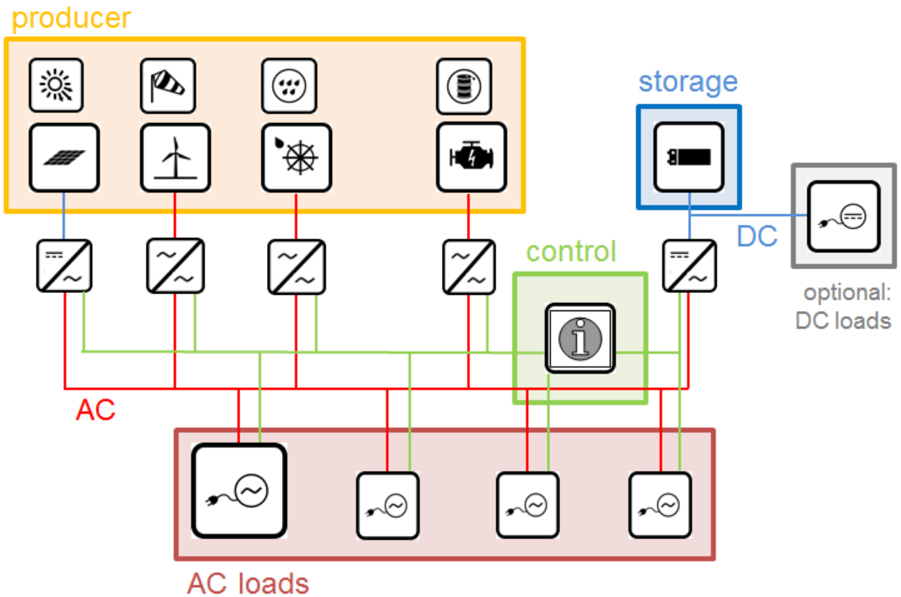


Key insights:

- current PV system prices of < 2,000 €/kWp enable PV LCOE of 10 – 15 €ct/kWh
- cost of diesel generated power is significantly higher, if no subsidies are paid for diesel

source: Breyer Ch., Gerlach A., et al., 2010. Fuel-Parity: New Very Large and Sustainable Market Segments for PV Systems, IEEE EnergyCon, Manama, December 18–22

Renewable Energy Mini-Grids



Mini-grids consist of at least

- one **energy producer,**
- one **energy storage,**
- one **consumer load,**
- one **control unit** and
- a **capacity** in the range of kW - MW.

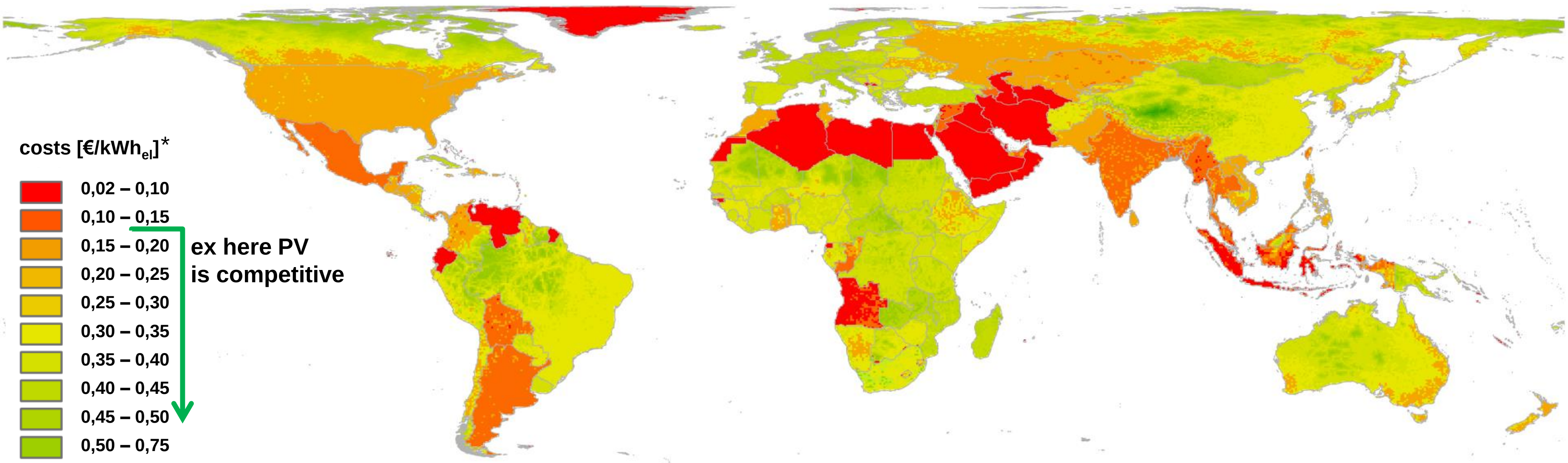
Conditioned by **AC-coupling**, a mini-grid can easily be expanded with further producers and consumer loads, in order to react flexibly on growing needs.

Three-phase loads for commercial usage can be integrated and if required a connection to the national grid is possible.

source: Breyer Ch., Gaudchau E., Gerlach A.-K. et al., 2012. PV-based Mini-Grids for Electrification in Developing Countries, study on behalf of cdw Stiftungsverbund

PV Mini-Grids: Local Diesel Price Worldwide

Electricity generation costs of pure diesel grids



- Costs of local energy production depend highly on the diesel price.
- Subsidization and taxation of diesel have strong effects on costs.
- High diesel prices call for renewable energy sources for electrification.

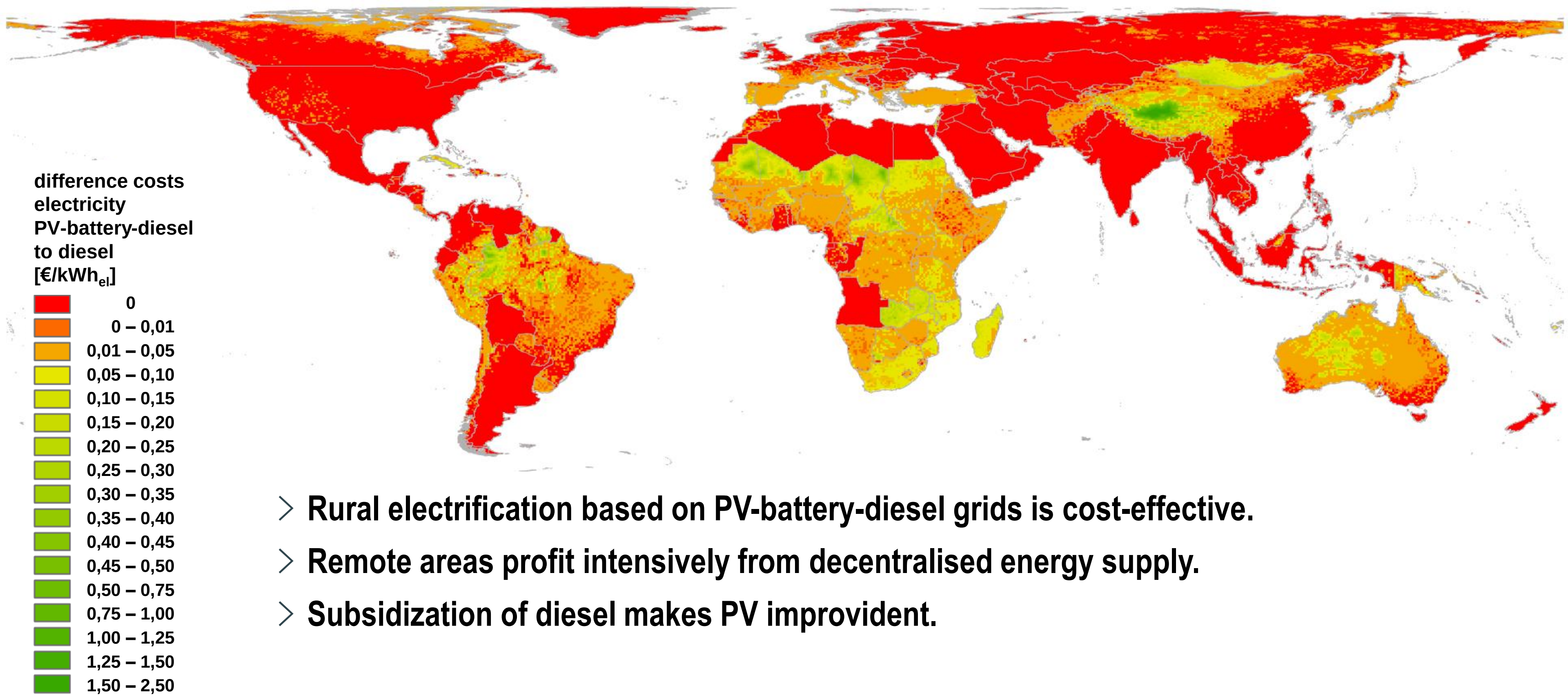
* 1 l diesel corresponds to ca. 3 kWh_{el}

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

source: Breyer Ch., Gaudchau E., Gerlach A.-K. et al., 2012. PV-based Mini-Grids for Electrification in Developing Countries, study on behalf of cdw Stiftungsverbund

PV Mini-Grids: Savings Generated by PV in Mini-Grids

Cost advantage of hybrid PV-battery-diesel systems vs. Diesel



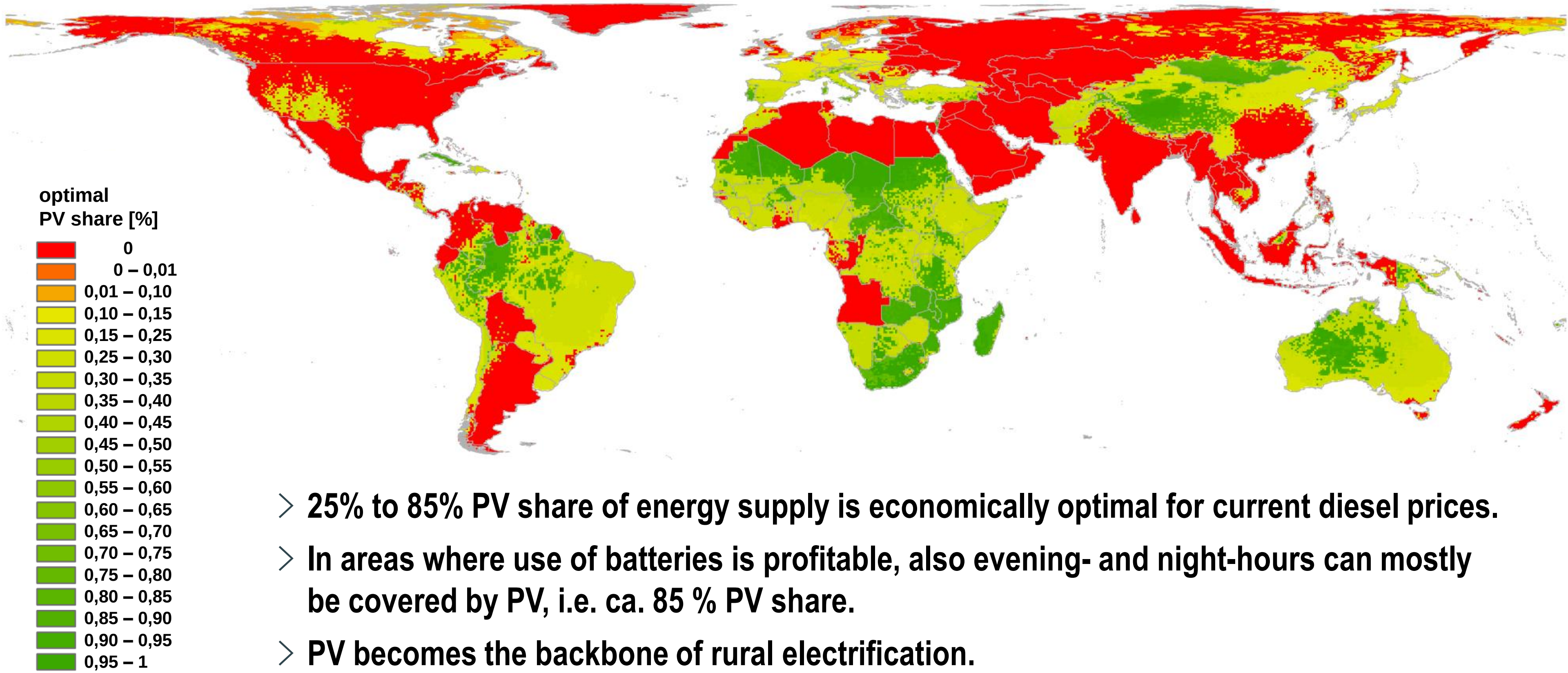
- **Rural electrification based on PV-battery-diesel grids is cost-effective.**
- **Remote areas profit intensively from decentralised energy supply.**
- **Subsidization of diesel makes PV improvident.**

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

source: Breyer Ch., Gaudchau E., Gerlach A.-K. et al., 2012. PV-based Mini-Grids for Electrification in Developing Countries, study on behalf of cdw Stiftungsverbund

PV Mini-Grids: Economically Optimal PV share

PV share in hybrid PV-battery-diesel systems

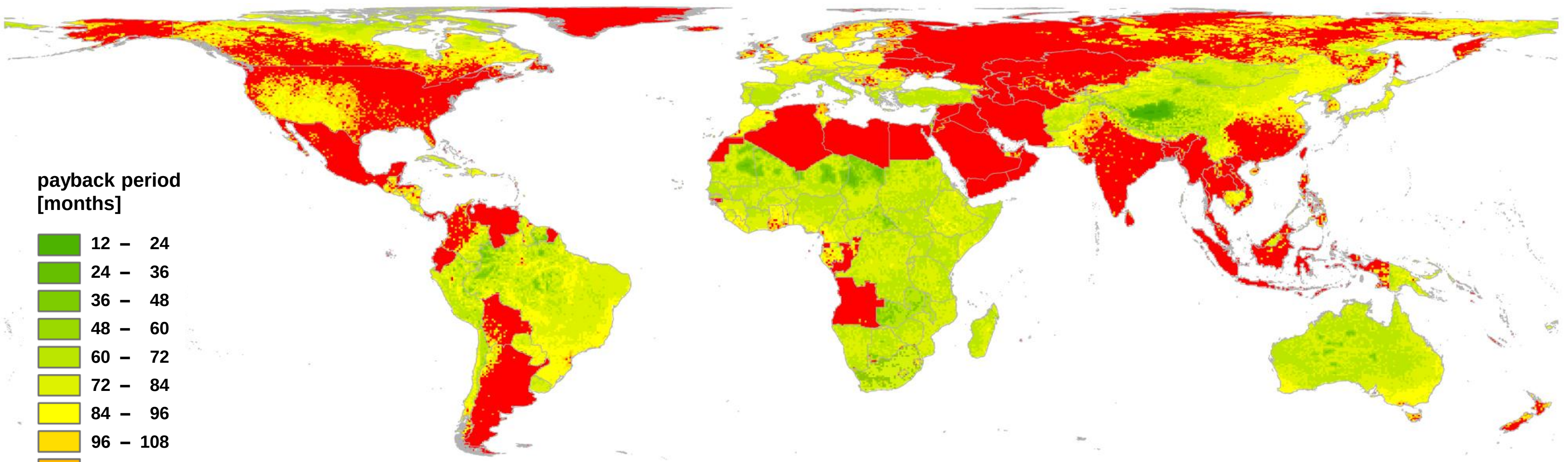


- 25% to 85% PV share of energy supply is economically optimal for current diesel prices.
- In areas where use of batteries is profitable, also evening- and night-hours can mostly be covered by PV, i.e. ca. 85 % PV share.
- PV becomes the backbone of rural electrification.

source: Breyer Ch., Gaudchau E., Gerlach A.-K. et al., 2012. PV-based Mini-Grids for Electrification in Developing Countries, study on behalf of cdw Stiftungsverbund

PV Mini-Grids: Payback Period

Amortisation of hybrid PV-battery-diesel systems vs. diesel



- The payback period of a PV mini-grid depends highly on the local diesel price.
- In many regions in Africa and South America very attractive payback periods of 5 – 7 years can be reached.
- In very remote areas very lucrative payback periods of less than 4 years arise for PV mini-grids.

source: Breyer Ch., Gaudchau E., Gerlach A.-K. et al., 2012. PV-based Mini-Grids for Electrification in Developing Countries, study on behalf of cdw Stiftungsverbund

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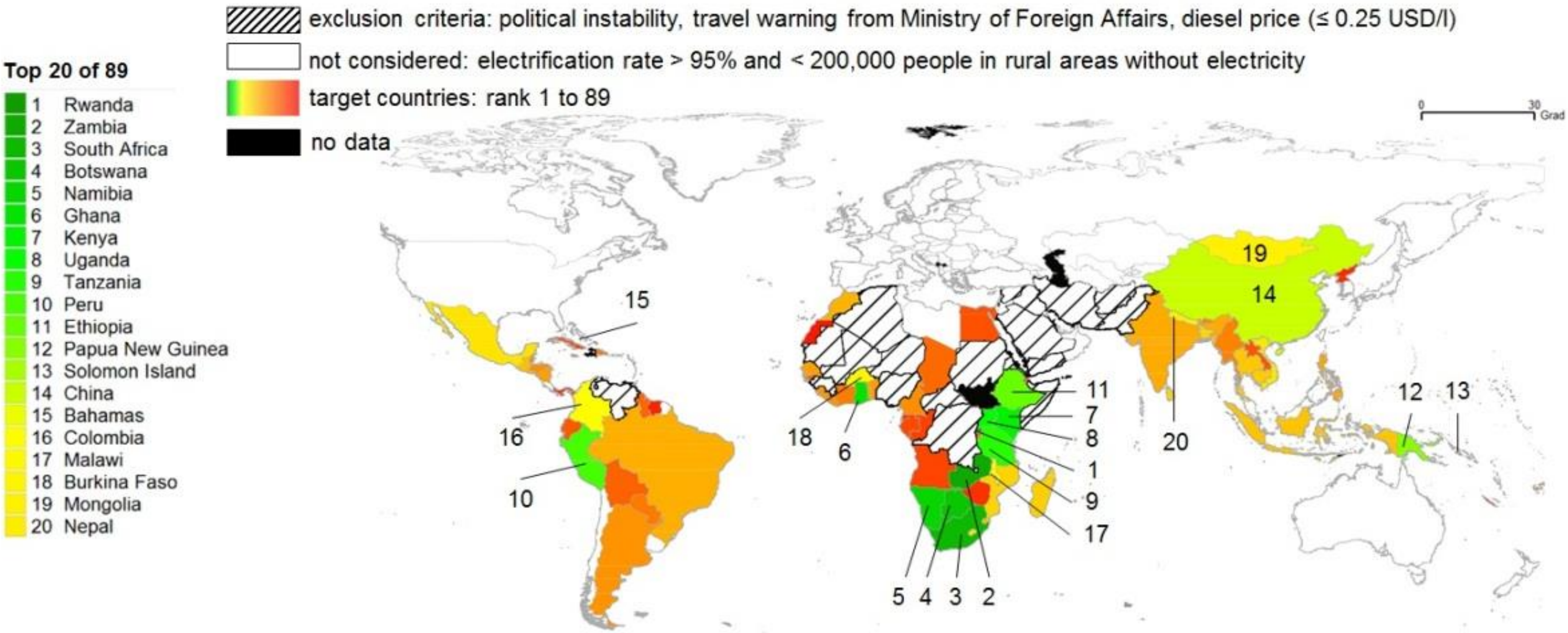
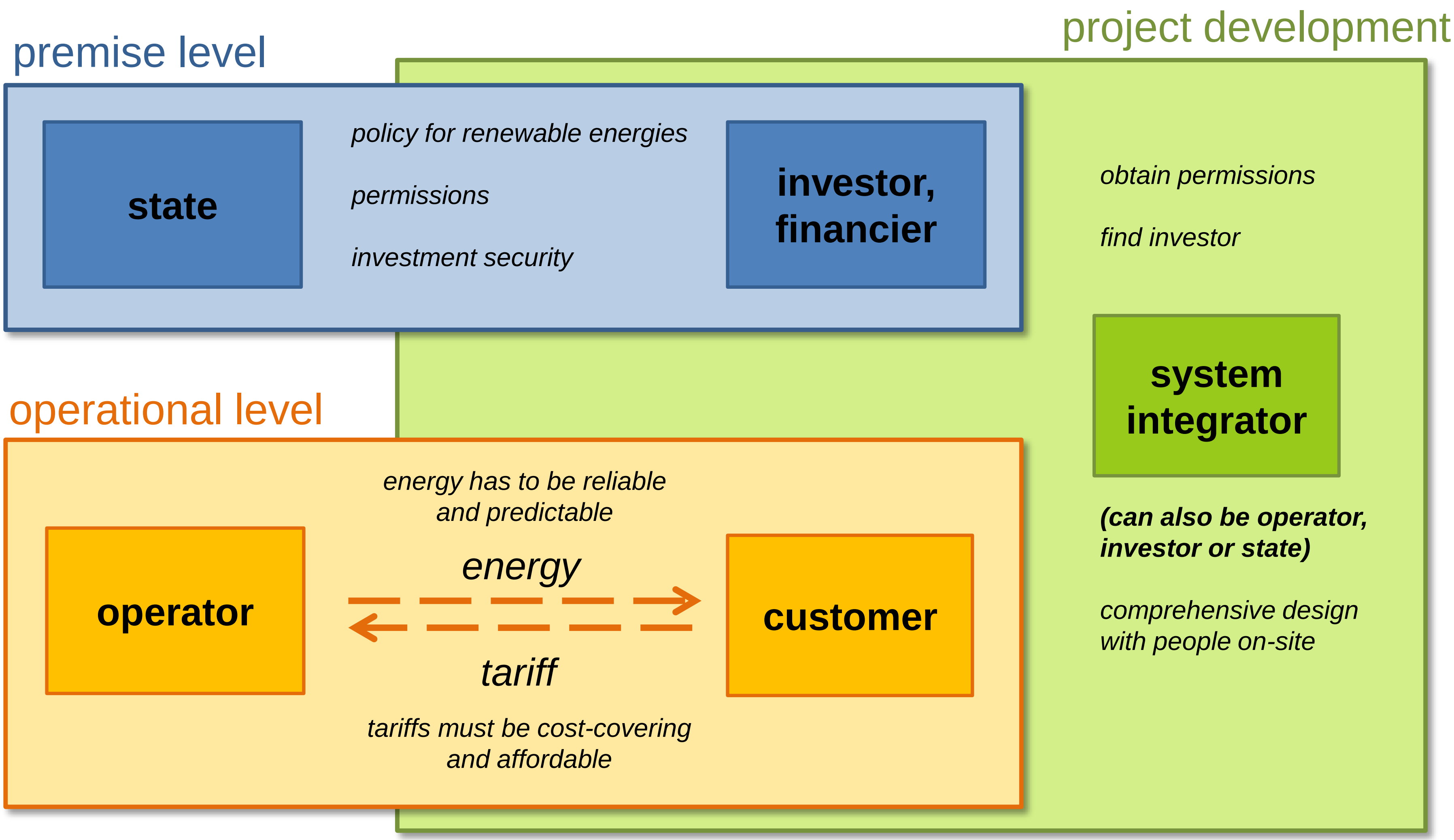
Results of the Country Ranking



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

source: Gerlach A.-K., Gaudchau E., Breyer Ch., et al., 2013. Comprehensive Country Ranking for Renewable Energy Based Mini-Grids Providing Rural Off-Grid Electrification, 28th EU PVSEC, Paris

PV Mini-Grids: Levels and Participants



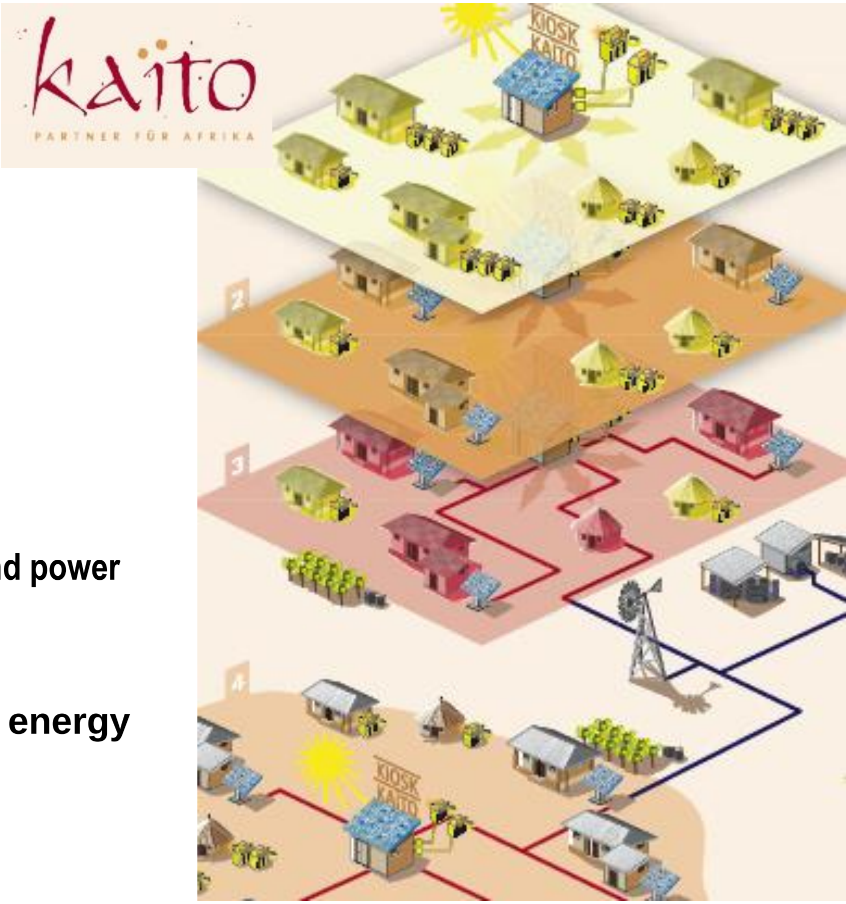
source: Breyer Ch., Gaudchau E., Gerlach A.-K. et al., 2012. PV-based Mini-Grids for Electrification in Developing Countries, study on behalf of cdw Stiftungsverbund

KAÏTO Concept of Phases

- **phase 1: charging station (franchise)**
  - renting of battery-operated lamps and energy-cases
  - charging cellphones, torches, etc.
  - lamps, spare parts, installation material
- **phase 2: additional PV systems**
  - for public institutions and workshops on lease
  - maintenance by Kaïto staff

if demand for energy increase:

- **phase 3: interconnection to an AC grid**
  - additional energy production with plant oil, biogas or wind power minimum purchase needed for connection
  - cross-linking of all installed generators
- **phase 4: interconnection of village grids to regional energy clusters**
  - option for the future



Concept of 4 phases [© KAITO Energie AG, München]

- Single phases build upon each other and will be realized depending on the energy demand and commitment of population

source: Gaudchau E., Gerlach A.-K., Wasgindt V., Breyer Ch., 2013. Business Models for Renewable Energy Based Mini-Grids in Non-Electrified Regions, 28th EU PVSEC, Paris, September 30 – October 4

INENSUS Micro Power Economy

- public private partnership (ppp)
  - private investor owns production units (power station operator)
  - community owns fixed assets (mini-grid operator)
  - micro finance inst. allows capital expenditures in commercial activities
- six months contract duration
  - continous adapting to needs
  - sufficient planning security
  - satisfaction and good service through periodical negotiations
- electricity blocks
  - units of fixed energy amount and specific capacity
  - only valid in determined period
  - additional energy is available at higher prices
- Load Management and Accounting Unit (LAU)
  - load shedding based on determined priorities
  - prepayment meter and house connection
  - electricity block trading

- subsidies for grid possible
- prospective subsidies will not be necessary through proven model and growing trust

INENSUS

pictures: top: technician; below: LAU [INENSUS]

▶▶ Separation of property enables mutual quality check and flexible ending of business relationship at breaking contracts

see: www.inensus.de

source: Gaudchau E., Gerlach A.-K., Wasgindt V., Breyer Ch., 2013. Business Models for Renewable Energy Based Mini-Grids in Non-Electrified Regions, 28th EU PVSEC, Paris, September 30 – October 4

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The role of batteries – case of Tanzania – step 1

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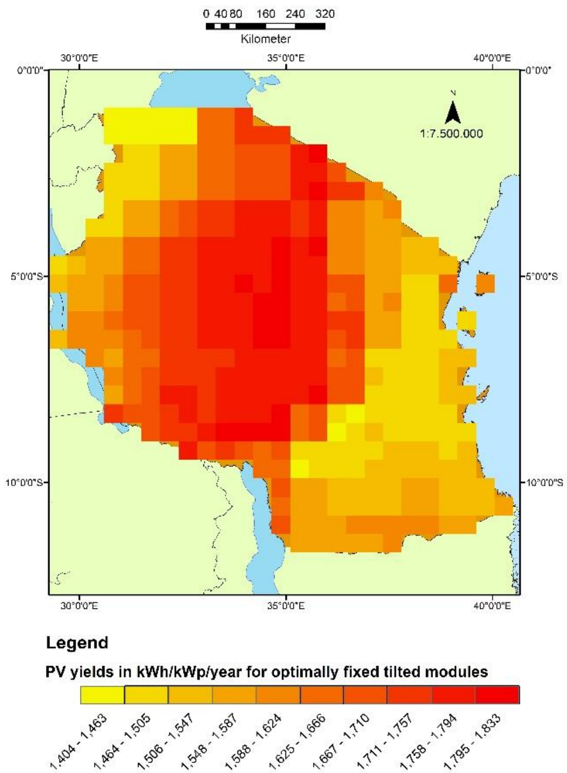
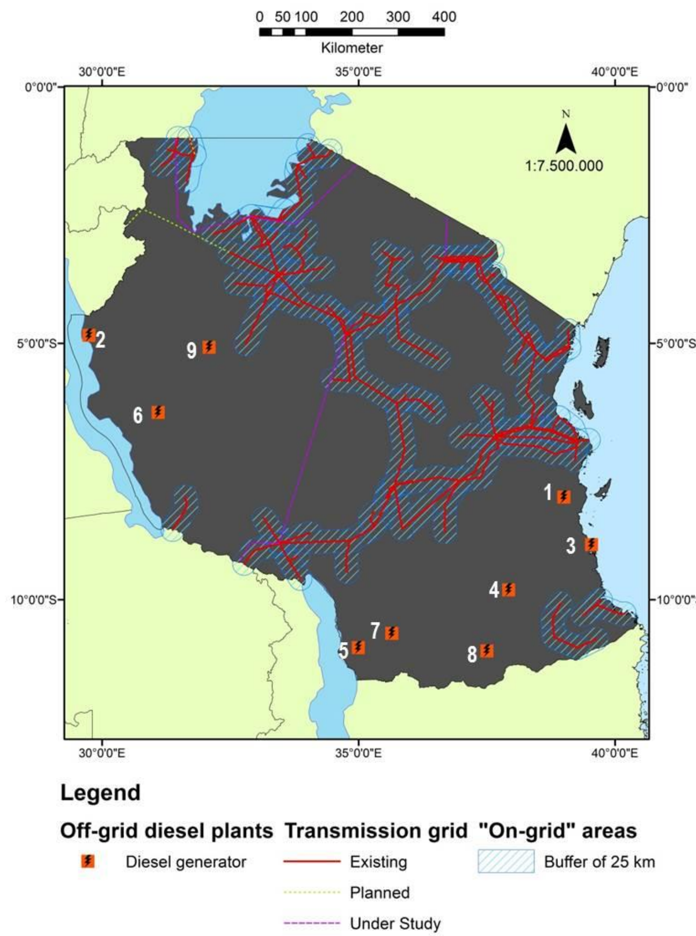


Identification of off-grid diesel-grids
Georeferenced diesel gensets not connected to the national grid



Identified off-grid diesel power plants

Location	Diesel unit	Operator	MW	City	State
1	Ikwiriri IC 1	Tanesco	0.42	Ikwiriri	Pwani
	Ikwiriri IC 2	Tanesco	0.42	Ikwiriri	Pwani
2	Kigoma IC 2	Tanesco	0.50	Kigoma Town	Kigoma
	Kigoma IC 3	Tanesco	0.64	Kigoma Town	Kigoma
	Kigoma IC 4	Tanesco	0.64	Kigoma Town	Kigoma
	Kigoma IC 5	Tanesco	0.64	Kigoma Town	Kigoma
	Kigoma IC 6	Tanesco	0.66	Kigoma Town	Kigoma
3	Kilwa Masoko IC 1	Tanesco	0.35	Kilwa Masoko	Lindi
	Kilwa Masoko IC 2	Tanesco	0.35	Kilwa Masoko	Lindi
4	Liwale IC 3	Tanesco	0.06	Liwale	Lindi

source:
Bertheau P., Breyer Ch. et al., 2014. Energy Storage Potential for Solar Based Hybridization of Off-Grid Diesel Power Plants in Tanzania, Energy Procedia, 46, 287-293

The role of batteries – case of Tanzania

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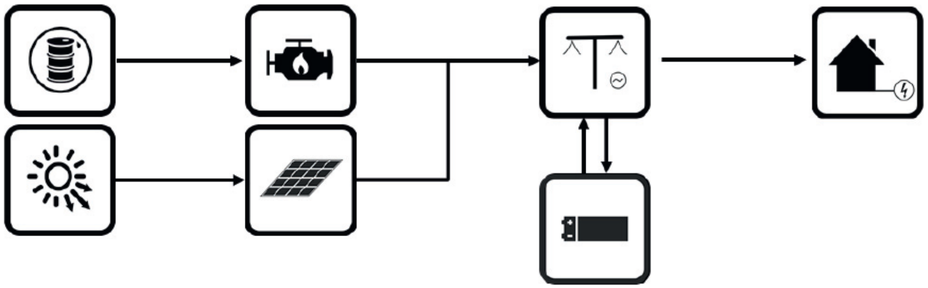
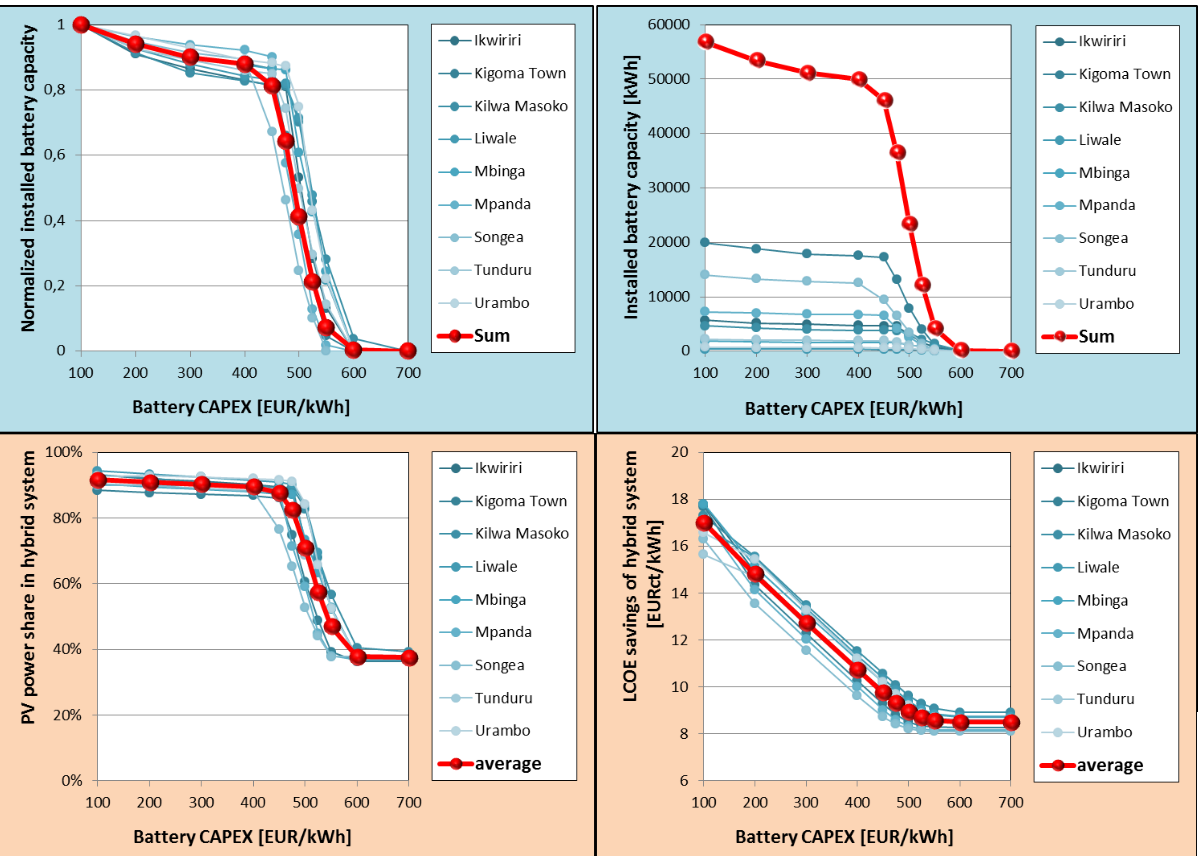


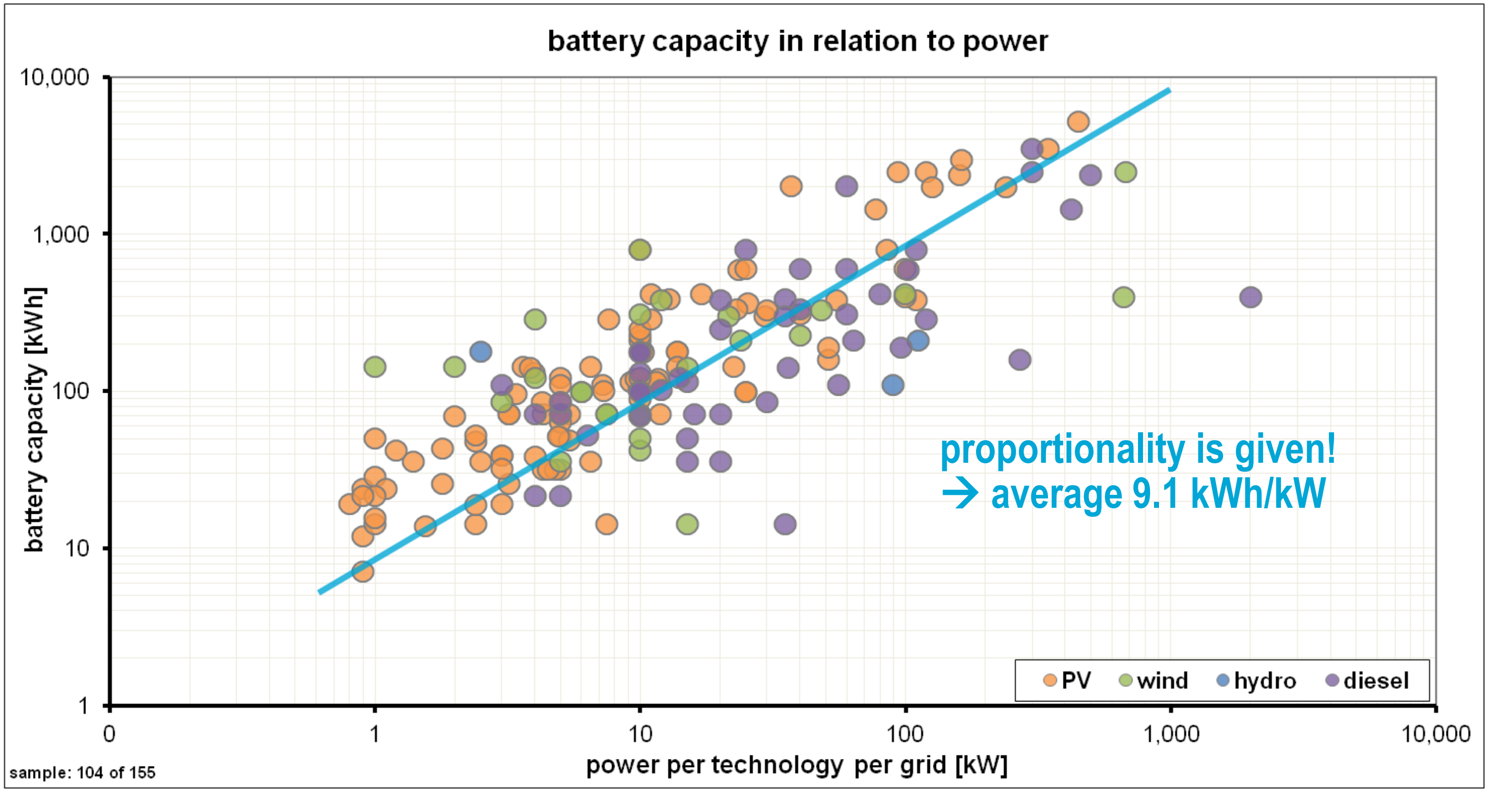


Key insights:

- upgrade of diesel grids with PV saves 8 €ct/kWh
- PV share can be increased from 40% to 90% for battery capex less than 500 €/kWh (similar to a tipping point)
- cost savings increase linearly with a decrease in battery capex up to 15 €ct/kWh for battery capex of 150 €/kWh

source:
[Bertheau P., Breyer Ch., et al., 2014. Energy Storage Potential for Solar Based Hybridization of Off-Grid Diesel Power Plants in Tanzania, Energy Procedia, 46, 287-293]

Mini-Grids: storage sizing



- average ratio of storage per power per technologies:

→PV: 15.7 kWh/kW

→PV + wind: 10.1 kWh/kW

→PV + diesel: 8.4 kWh/kW

→PV + hydro + diesel: 5.0 kWh/kW

→PV + wind + diesel: 4.0 kWh/kW

→PV + wind + hydro + diesel: 1.0 kWh/kW

source: Werner C. and Breyer Ch., 2012. Analysis of Mini-Grid Installations: An Overview on System Configurations, 27th EU PVSEC, Frankfurt, September 24-28

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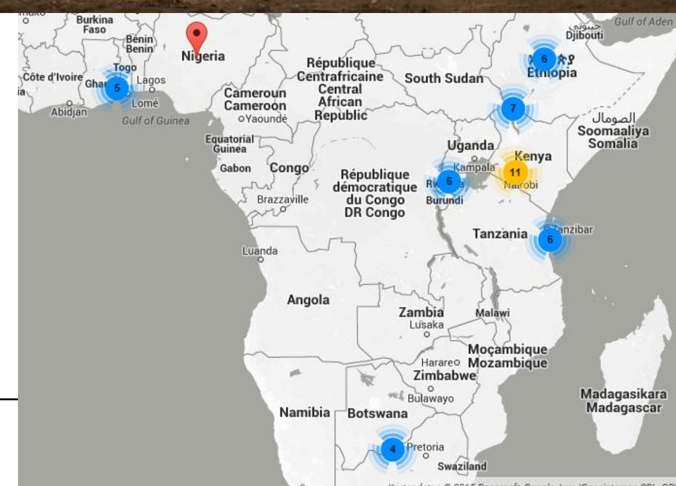
Solarkiosk – an innovative business model

- Solarkiosk offers electricity based products in remote off-grid regions in East Africa (charging of cell phones/ batteries/ lights, internet connection, cooling of products and medication, copy/ print/ scan, water purification, news & entertainment etc.)
- leasing model, i.e. companies own the Solarkiosk, but the lessee can work hard to acquire the property of the Solarkiosk
- the Solarkiosk can evolve into the new social center of a village



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Solarkiosk – an innovative business model

SOLARKIOSK Managing Directors

Rachna Patel
Managing Director
Kenya

Samson Bekele
Managing Director
Ethiopia

Evary Murasa
Managing Director
Rwanda

Patricia Safo
Managing Director
Ghana

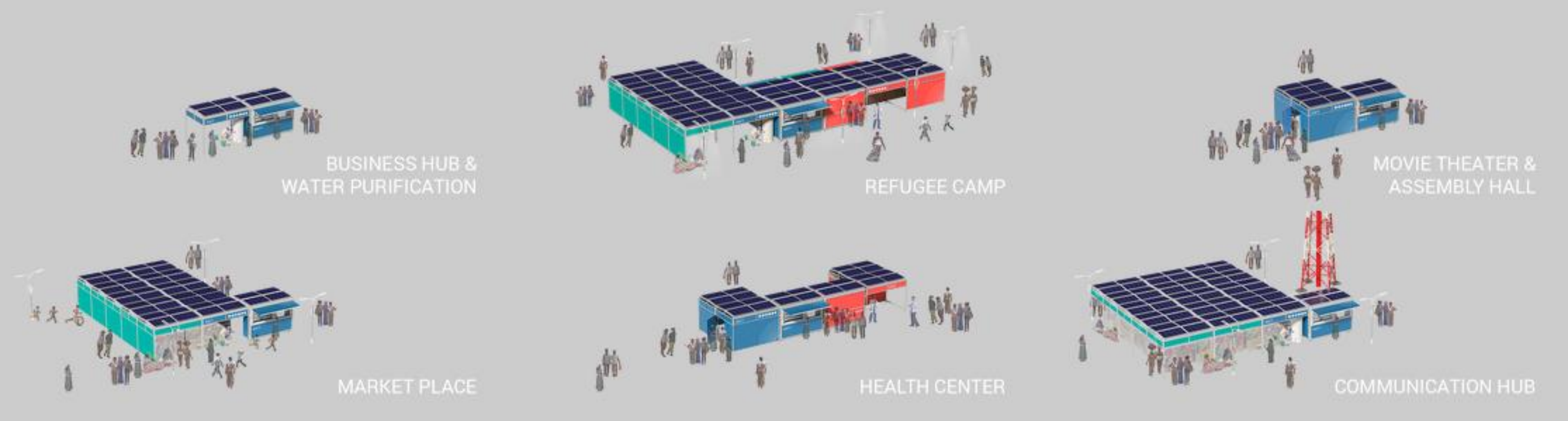
Wolfgang Spengler
Managing Director
Tanzania

Ishaan Patel
Managing Director
Botswana

see: www.solarkiosk.eu

Solarkiosk – an innovative business model

45	337500	10	7500	120750	3770
Number of E-HUBBs	People impacted	Countries reached	Avg. population of Solarkiosk community	KWh of energy produced each year	Solar products sold over E-HUBB lifetime
71	**1080**	**23**	**204041**	**90**	**9**
Installed KWp of photovoltaic capacity	Hours of training given	KGs of CO2 savings by each sold solar product per year	KGs of CO2 reduced per year by E-HUBBs and sold solar products	Women empowered as SOLARKIOSK operators and assistants	KWh of energy created annually by each solar product



see: www.solarkiosk.eu

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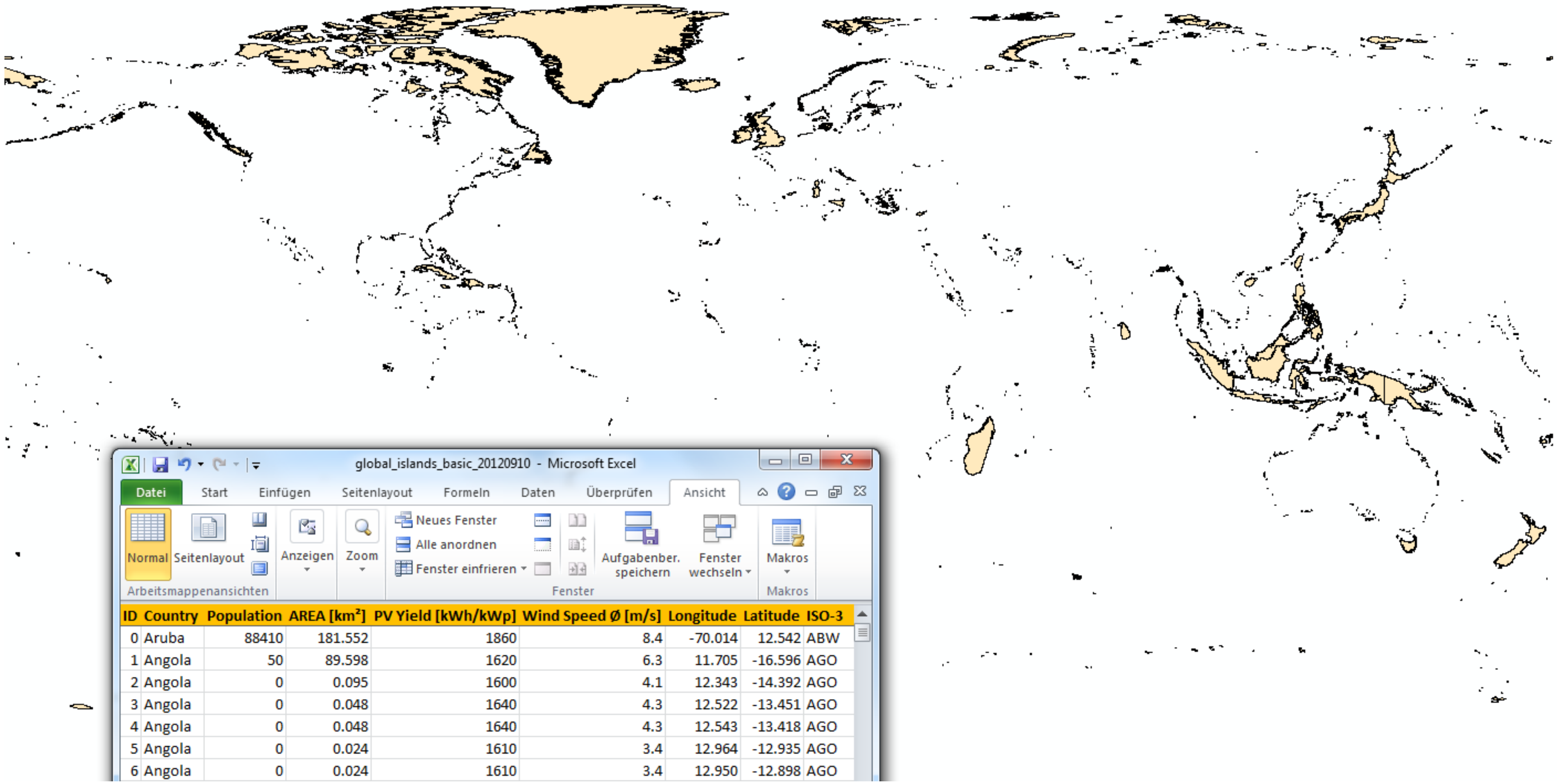
Island Database



ID	Country	Population	AREA [km²]	PV Yield [kWh/kWp]	Wind Speed Ø [m/s]	Longitude	Latitude	ISO-3
0	Aruba	88410	181.552	1860	8.4	-70.014	12.542	ABW
1	Angola	50	89.598	1620	6.3	11.705	-16.596	AGO
2	Angola	0	0.095	1600	4.1	12.343	-14.392	AGO
3	Angola	0	0.048	1640	4.3	12.522	-13.451	AGO
4	Angola	0	0.048	1640	4.3	12.543	-13.418	AGO
5	Angola	0	0.024	1610	3.4	12.964	-12.935	AGO
6	Angola	0	0.024	1610	3.4	12.950	-12.898	AGO

- all islands in the world of about 24,000 m² (~150x150 meter) are included in the database
- Further data: inhabitants, coordinates, solar and wind resources, diesel prices and nationality
- detailed (economic) analyses can be performed including rankings for relevant categories

source: Howe E., Breyer Ch. et al., 2013. Analyzing drivers and barriers for renewable energy integration to small islands power generation – tapping a huge market potential for mini-grids, 2nd MES, Berlin

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Island Database: Rough Structure

Population size class	Islands	Population Total [1,000]	Area [km²] Total [1,000]
Uninhabited	75,786	0	715
1-100	7,310	126	213
100-1.000	2,134	775	482
1.000-10.000	1,237	4,132	1,010
10.000-100.000	457	14,380	2,440
100.000-1.000.000	151	45,383	727
1.000.000-10.000.000	41	136,325	1,754
≥10.000.000	13	540,457	2,731
Inhabited Islands (≥1)	11,343	741,578	9,358
Total	**87,129**	**741,578**	**10,073**

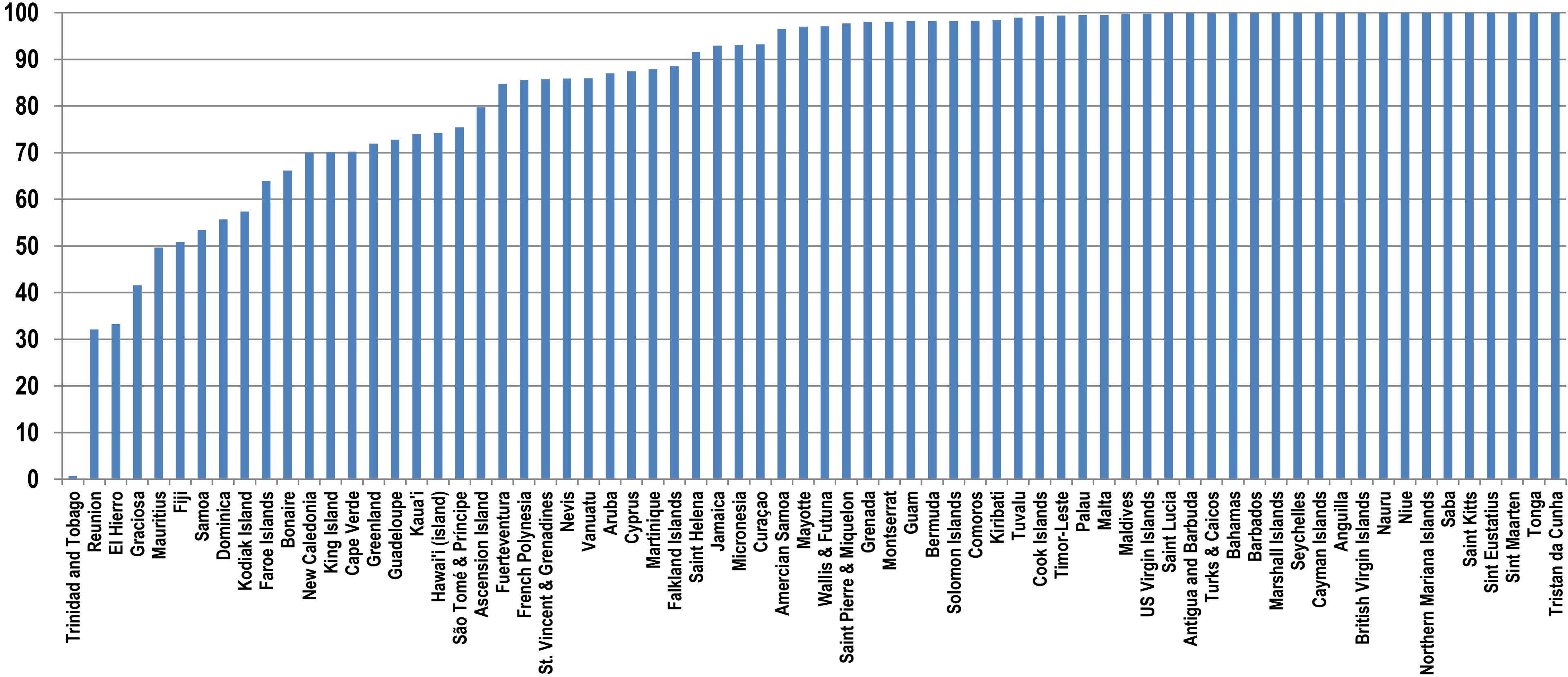
Key insights:

- 13% of global islands (~87,100) of significant size are statistically inhabited (~11,300)
- 10% of global population live on islands
- ~11,300 islands with less than 1 million inhabitants accumulate a theoretical maximum market potential of more than 65 million inhabitants (1% of world population)
- hence, islands represent an important niche market, accompanied by continental off-grids

source: Howe E., Breyer Ch. et al., 2013. Analyzing drivers and barriers for renewable energy integration to small islands power generation – tapping a huge market potential for mini-grids, 2nd MES, Berlin

Island Database: Oil Dependency

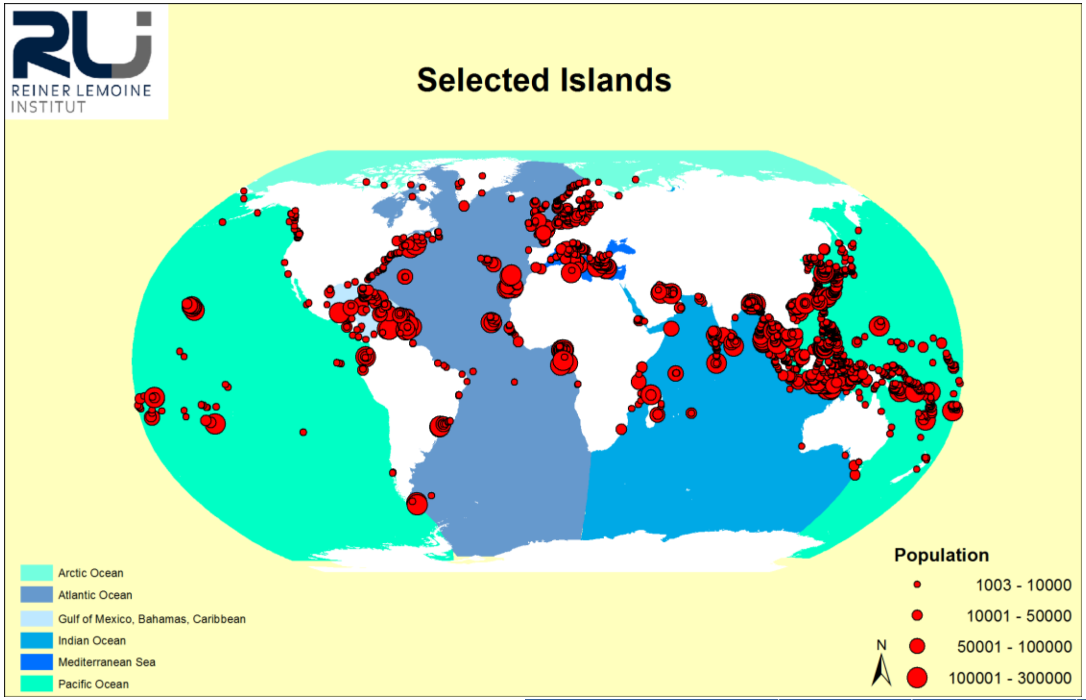
Dependency on oil - percentage of oil based installed power plant capacity (n=70)



- the large majority of islands in the world is strongly dependent on oil based power supply
- oil based power supply is very expensive, typically higher than 30 €ct/kWh

source: Howe E. et al., 2012. Analysis of Socio-Economic Determinants for Implementing Photovoltaics into Island Electricity Systems, 5th IRED, Berlin, December 4-6

PV Potential on Small Islands: 1,000 – 300,000 pop.



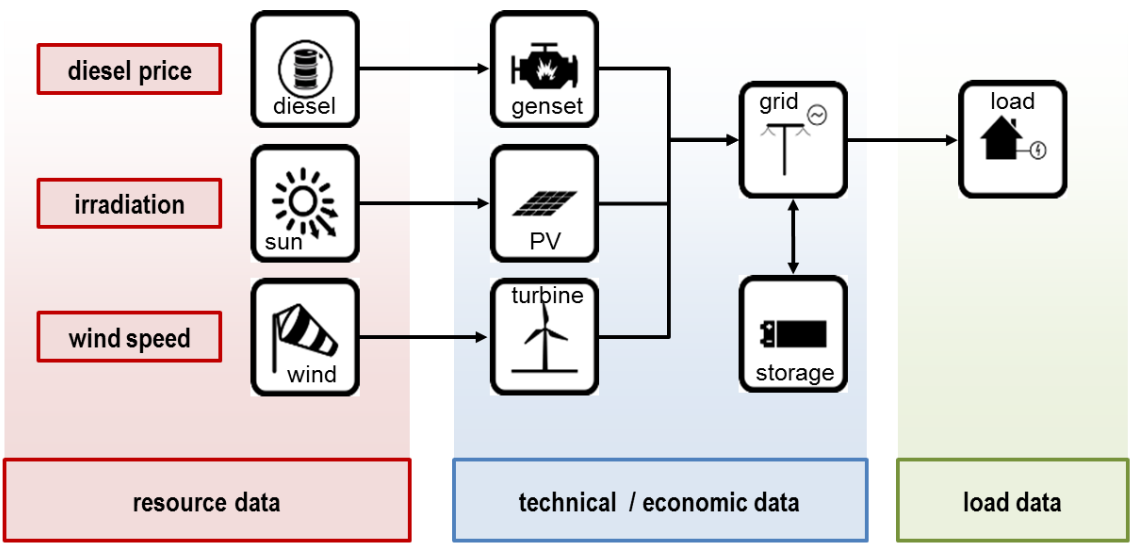
Key characteristics:

- typically power supply on diesel or HFO basis
- typical power generation costs between 25 - 50 €ct/kWh
- every island is different

source: Seguin R., Blechinger P., Cader C., Bertheau P., Breyer Ch., 2013. PV-Potential of Small Island Mini-Grids, 28th EU PVSEC, Paris

Region	Number of Islands	Average Population per Island	Total Population	Average GDP [USD/cap]	Total Estimated Electricity Cons [TWh/year]	Estimated Electricity Consumption per island [GWh/year]
Atlantic and Arctic Oceans	437	17,120	7,482,200	19,850	25.9	59.3
Caribbean, Bahamas, Gulf of Mexico	112	25,640	2,871,600	18,400	10.1	90.1
Indian Ocean	247	21,770	5,378,100	3,200	3.6	14.6
Pacific Ocean	1,250	16,160	20,202,800	10,450	37.6	30.1
Mediterranean Sea	109	17,300	1,885,700	35,650	8.0	73.4
Total	**2,155**	**17,550**	**37,820,400**	**13,128**	**85.2**	**39.6**

PV Potential on Small Islands: 1,000 – 300,000 pop.



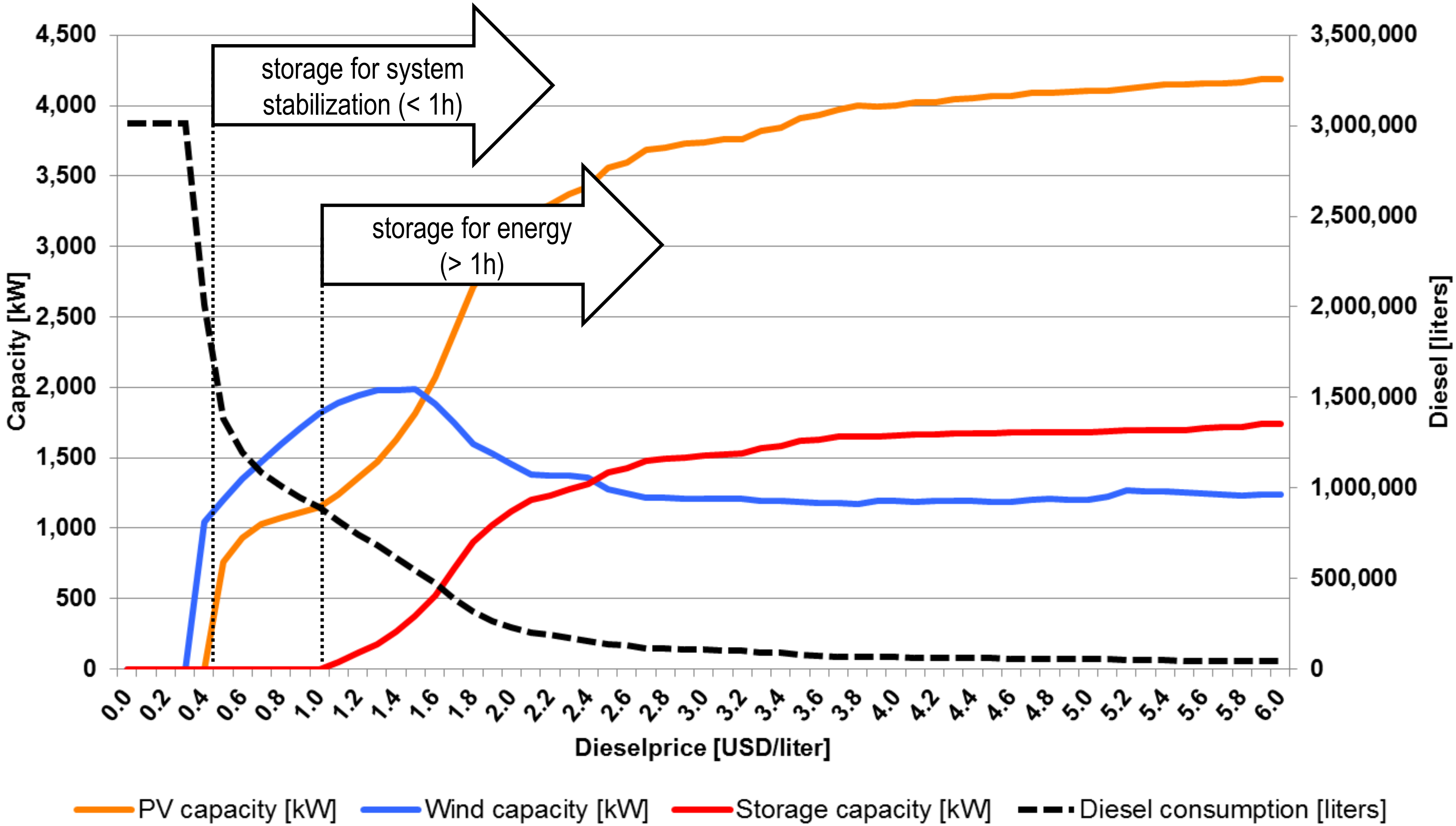
Key assumptions:

- Diesel price (0.63 €/l average world market price in 2012, 5 % annual increase, additional transportation costs depending on remoteness)
- solar irradiation and wind speed by DLR.
- CAPEX (Diesel: 0 €/kW, PV: min. 2,200 €/kWp (high costs due to small individual market size, additional transportation costs depending on remoteness), wind: min. 1,500 / 1,200 €/kW (depending on turbine, additional transportation costs depending on remoteness), WACC (7 %), project duration: 20 years, additional costs for system stability per kW RES installed.

source: Seguin R., Blechinger P., Cader C., Bertheau P., Breyer Ch., 2013. PV-Potential of Small Island Mini-Grids, 28th EU PVSEC, Paris

Scenarios	"Base"	"Grid Stability"	"2015"	"Battery conservative"
Base year*	2013		2015	
Battery CAPEX [EUR/kWh]	320			580
Stability System Size [EUR/kW RES]	300	700	300	
Total Installed Capacities of Cost-Optimized Systems				
PV [GW]	**11.3**	**10.4**	**17.4**	**13.0**
Wind [GW]	20.7	17.8	21.4	22.7
Battery [GWh]	3.6	2.5	20.8	1.2

Results according to different diesel prices



source: Blechinger P., et al., 2012. Energy Storage Systems for Renewable Island Systems – An enormous global Market Potential, 7th IRES, Berlin, November 12-14

Agenda

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- Overview
- Solar Home Systems/ pico SHS
- PV upgrades for diesel grids
- Country ranking business models
- Role of batteries: case of Tanzania
- Solarkiosk: catalyst for electrification
- Islands: on-grid but off-grid
- 100% RE for the case of South-East Asia
- Summary

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Scenarios assumptions

15 regions
- 2 regions in Australia (East and West)
- 4 regions in Indonesia (according to major islands)
- 2 regions in Malaysia (East and West)
- Mekong countries

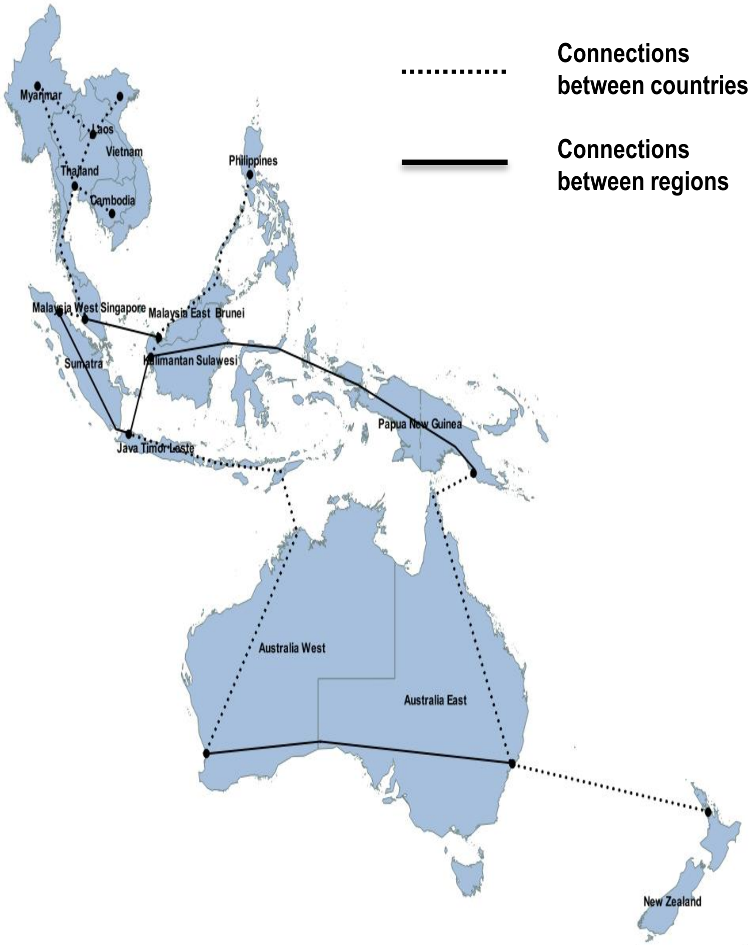
Key data
- ~646 mio population
- ~1629 TWh electricity demand (2030)
- ~256 GW peak load (2030)
- ~13 mio km^2 area
- ~10 bil m^3/a water desalination demand (2030)

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Scenarios assumptions

Grid configurations

- **Regional-wide open trade**
  (no interconnections between regions)
- **Country-wide open trade**
  (no interconnections between countries)
- **Area-wide open trade**
  (country-wide HVDC grids are interconnected)
- **Area-wide open trade with water desalination and industrial gas production**



Assumption	Scenarios: Regional-wide open trade	Country-wide open trade	Area-wide open trade	Area-wide open trade Des-Gas
PV self-consumption	X	X	X	X
Water Desalination				X
Industrial Gas				X

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Key Objective

Definition of an optimally structured energy system based on 100% RE supply

- optimal set of technologies, best adapted to the availability of the regions' resources,
- optimal mix of capacities for all technologies and every sub-region of South-East Asia,
- optimal operation modes for every element of the energy system,
- least cost energy supply for the given constraints.

LUT Energy model, key features

- linear optimization model
- hourly resolution
- multi-node approach
- flexibility and expandability

Input data

- historical weather data for: solar irradiation, wind speed and hydro precipitation
- available sustainable resources for biomass, geothermal energy and A-CAES caverns
- synthesized power load data
- gas and water desalination demand
- efficiency/ yield characteristics of RE plants
- efficiency of energy conversion processes
- capex, opex, lifetime for all energy resources
- min and max capacity limits for all RE resources
- nodes and interconnections configuration

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Methodology
Full system

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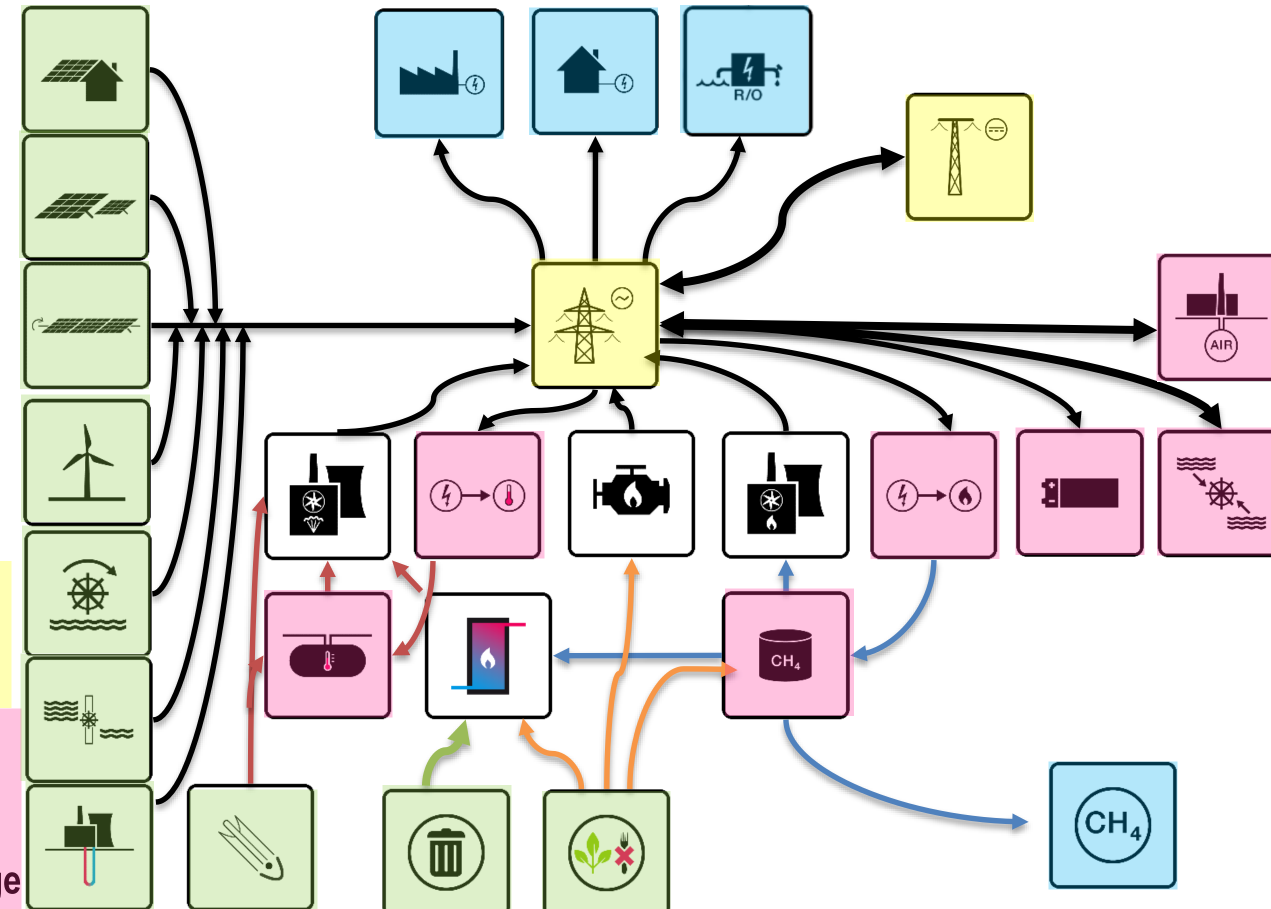
Renewable energy sources
- PV ground-mounted
- PV single-axis tracking
- PV rooftop
- Wind onshore
- Hydro run-of-river
- Hydro dam
- Geothermal energy
- CSP
- Waste-to-energy
- Biogas
- Biomass

Electricity transmission
- node-internal AC transmission
- interconnected by HVDC lines

Storage options
- Batteries
- Pumped hydro storages
- Adiabatic compressed air storage
- Thermal energy storage, Power-to-Heat
- Gas storage based on Power-to-Gas
  - Water electrolysis
  - Methanation
  - CO_2 from air
  - Gas storage



Energy Demand
- Electricity
- Water Desalination
- Industrial Gas

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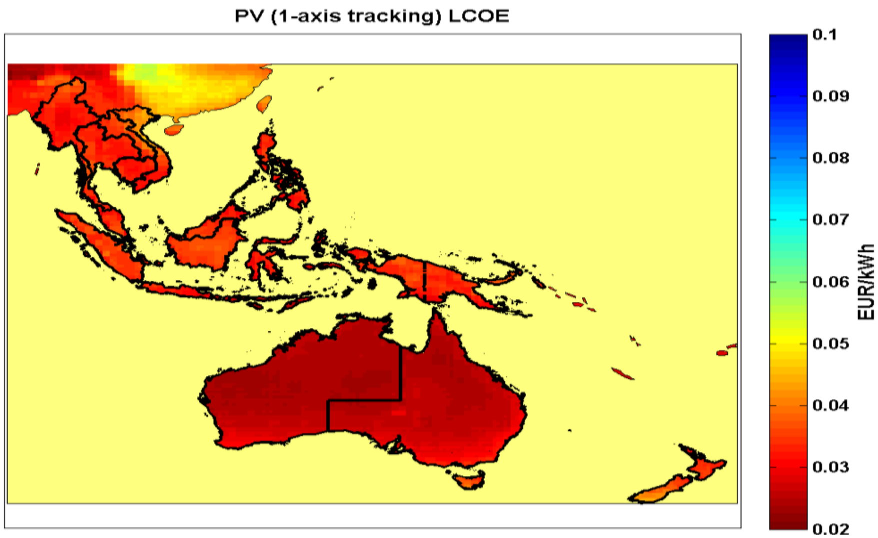
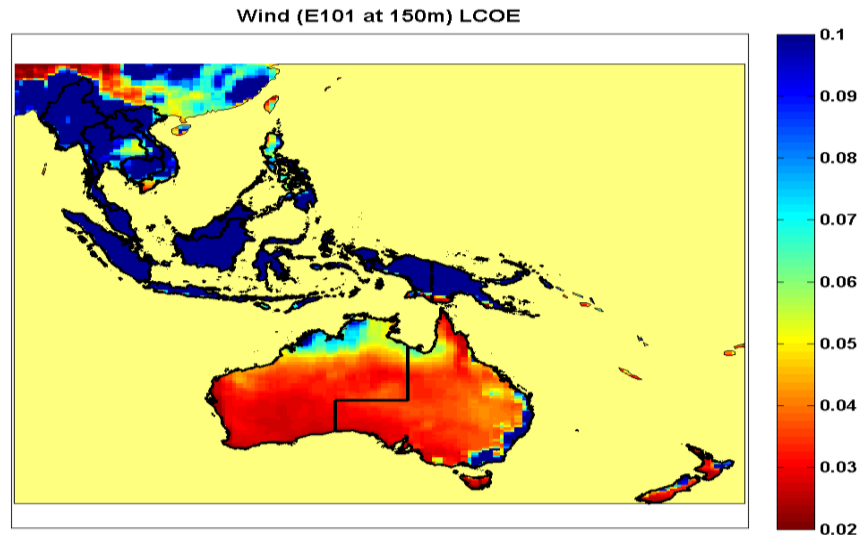
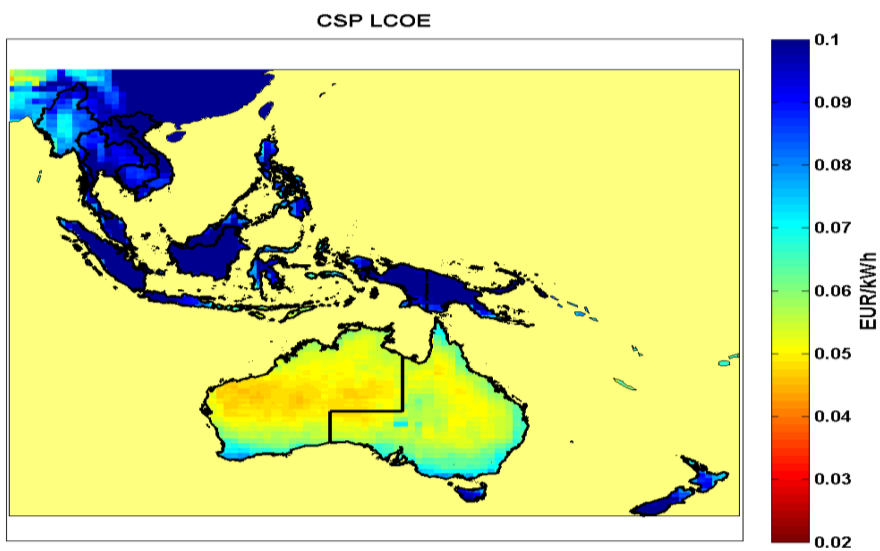
Scenarios assumptions

PV and Wind LCOE (weather year 2005, cost year 2030)







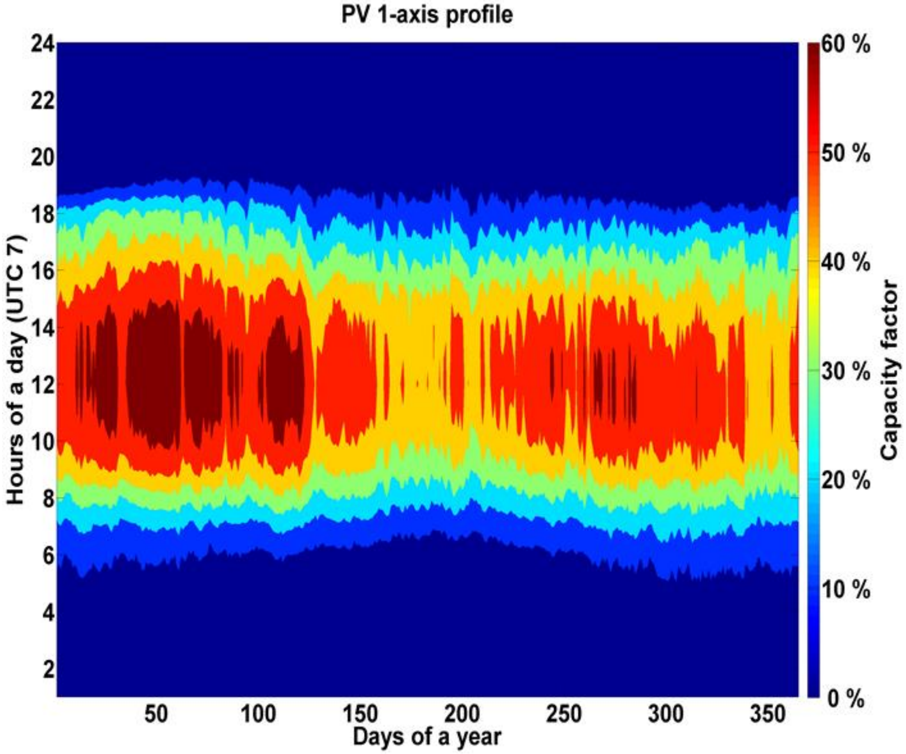
source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Scenarios assumptions

Generation profile (area aggregated)

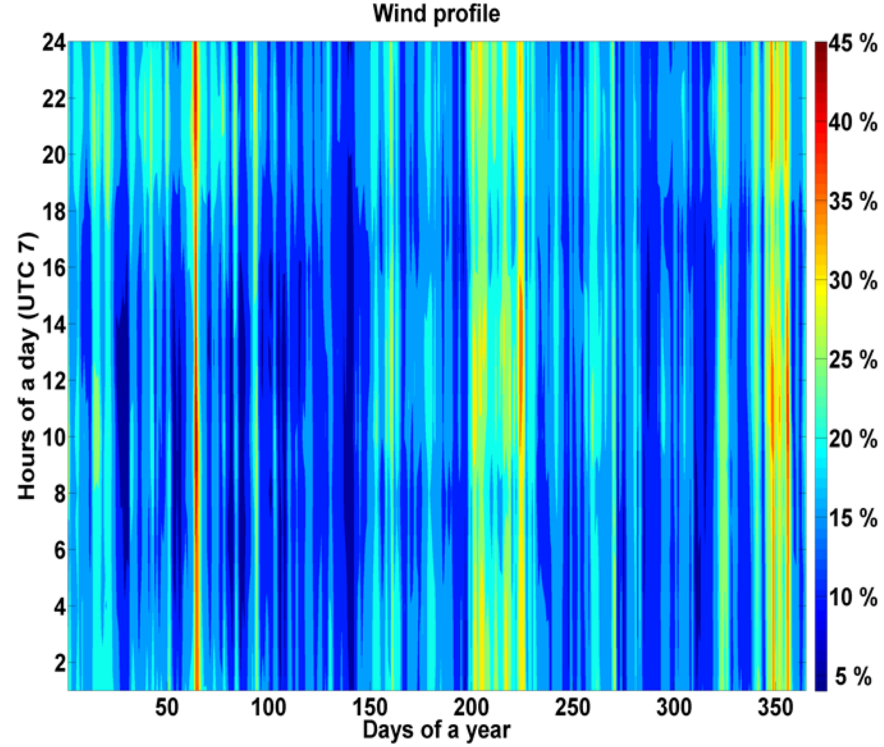
PV generation profile

Aggregated area profile computed using earlier presented weighed average rule.



Wind generation profile

Aggregated area profile computed using earlier presented weighed average rule.



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source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Results

2030 Scenario	Total LCOE [€/kWh]	LCOE primary [€/kWh]	LCOC [€/kWh]	LCOS [€/kWh]	LCOT [€/kWh]	Total ann. cost [bn €]	Total CAPEX [bn €]	RE capacities [GW]	Generated electricity [TWh]
Region-wide	0.067	0.044	0.002	0.021	0.000	109	919	763	1780
Country-wide	0.066	0.044	0.002	0.020	0.000	108	914	755	1773
Area-wide	0.064	0.046	0.001	0.016	0.001	104	883	705	1714
Area-wide Des-Gas*,**	0.051	0.039	0.001	0.010	0.001	153	1339	1151	2794

Total LCOE*** prosumer [€/kWh]	LCOE primary prosumer [€/kWh]	LCOS prosumer [€/kWh]	Total ann. Cost prosumer [bn €]	Total CAPEX prosumer [bn €]	RE capacities prosumer [GW]	Generated electricity prosumer [TWh]
0.067	0.039	0.028	13	132	150	233

* additional demand 97% gas and 3% desalination

** LCOS does not include the cost for the industrial gas (LCOG)

*** fully included in table above

LCOW: 0.57 €/m^3

LCOG: 0.095 €/kWh$_{th,gas}$

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Results

Self-Consumption – South-East Asia super-region area-wide open trade

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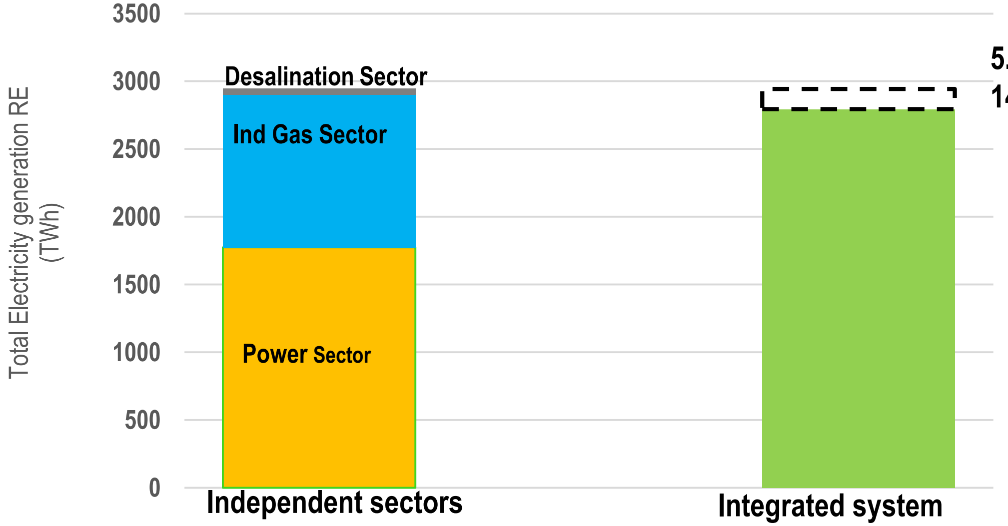
	2030		
	RES	COM	IND
Electricity price [€/kWh]	0.130	0.132	0.125
PV LCOE [€/kWh]	0.028	0.037	0.038
Self-consumption PV LCOE [€/kWh]	0.035	0.044	0.051
Self-consumption PV and Battery LCOE [€/kWh]	0.063	0.073	0.068
Self-consumption LCOE [€/kWh]	0.063	0.073	0.067
Benefit [€/kWh]	0.067	0.059	0.058
Installed capacities			
PV [GW]	65	37	47
Battery storage [GWh]	81	46	44
Generation			
PV [TWh]	101	59	73
Battery storage [TWh]	26	14	14
Excess [TWh]	16	8	10
Utilization			
Self-consumption of generated PV electricity [%]	80.8	83.9	84.2
Self-coverage market segment [%]	12.5	12.0	10.8
Self-coverage operators [%]	62.8	59.9	54.2

Source (electricity prices): Gerlach A., Werner Ch., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam, September 22-26

Results

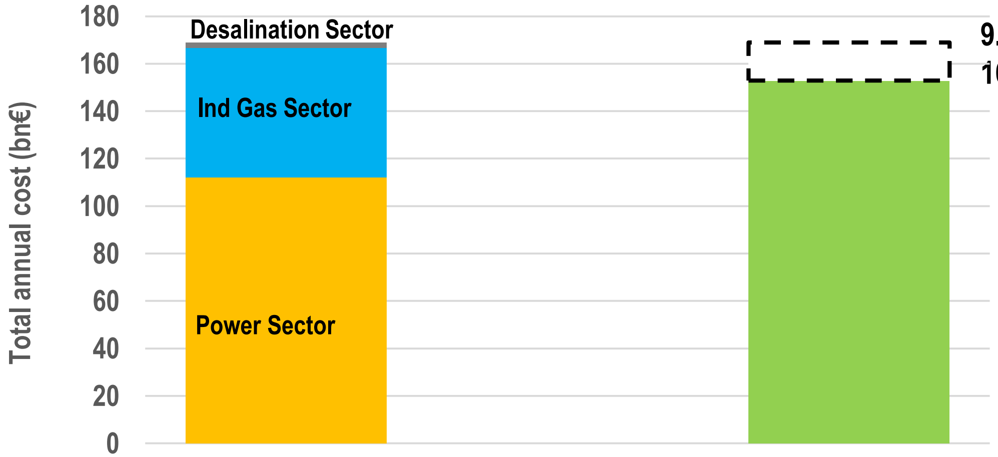
Benefits of electricity and industrial gas sectors integration – Area-wide desalination gas



5.1% relative integration benefit
149 TWh absolute integration benefit

Key insights:

- integration benefits: decrease in total electricity demand, in electricity curtailment losses, in total capex and in total annual levelized cost



9.5% relative integration benefit
16 bn€ absolute integration benefit

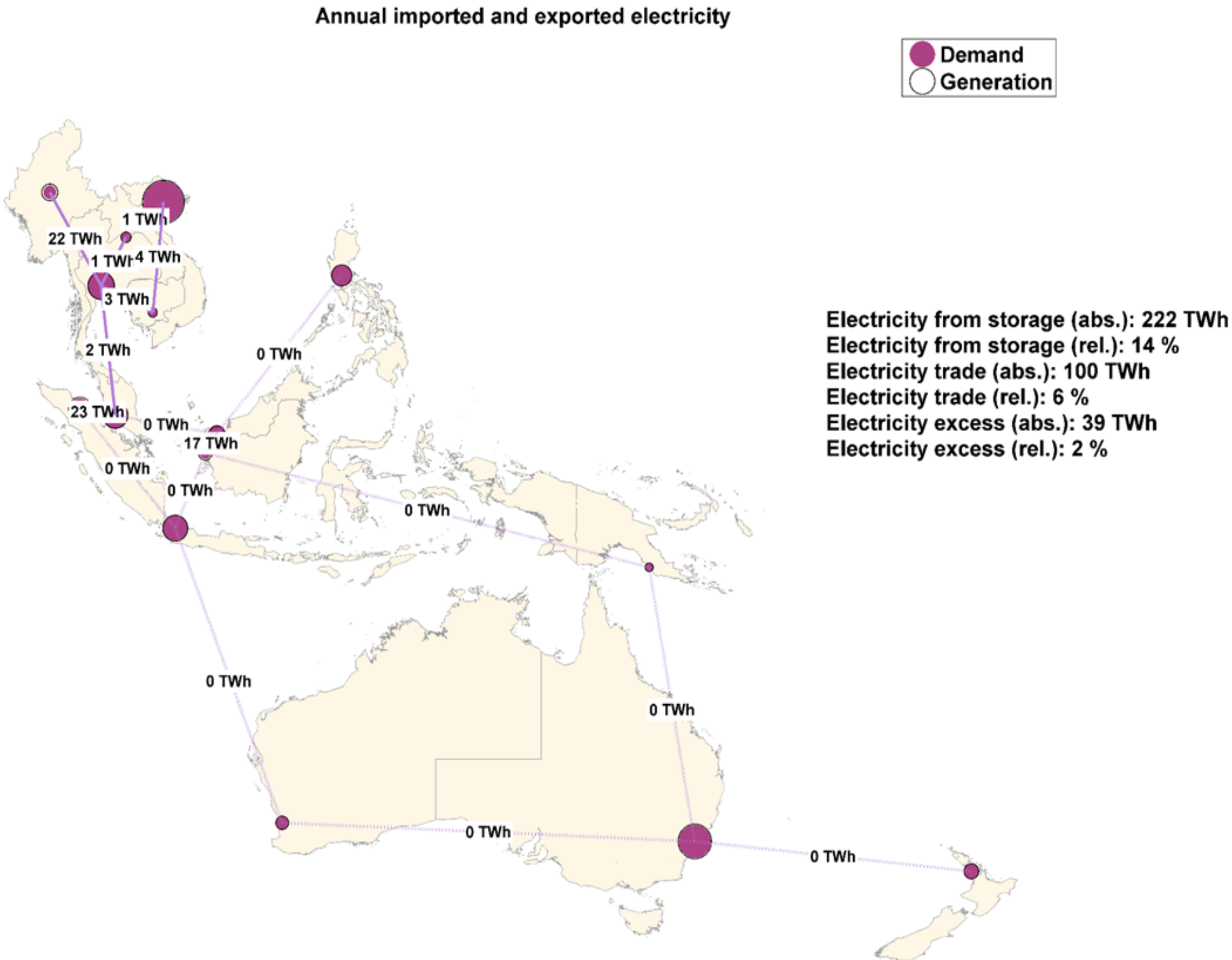
- decrease in total electricity demand by 5.1% (149 TWh absolute), in total electricity curtailment losses by 45% (61 TWh absolute), in total capex by 8.9% (131 bn€ absolute) and in total annual costs by 9.5% (16 bn€ absolute)

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Results

Import / Export (year 2030)

Area-wide open trade



Key insights:

- Net Importers: Malaysia West and Singapore, Thailand, Malaysia East and Brunei
- Net Exporters: Sumatra Myanmar, Indonesia Kalimantan Sulawesi
- benefits of HVDC power lines are limited, since no transmission from Australia in ASEAN rim (depite of lower primary generation costs; HVDC power lines are finally less competitive than local storage)

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Results

Components of LCOE – area-wide open trade and area-wide desalination gas

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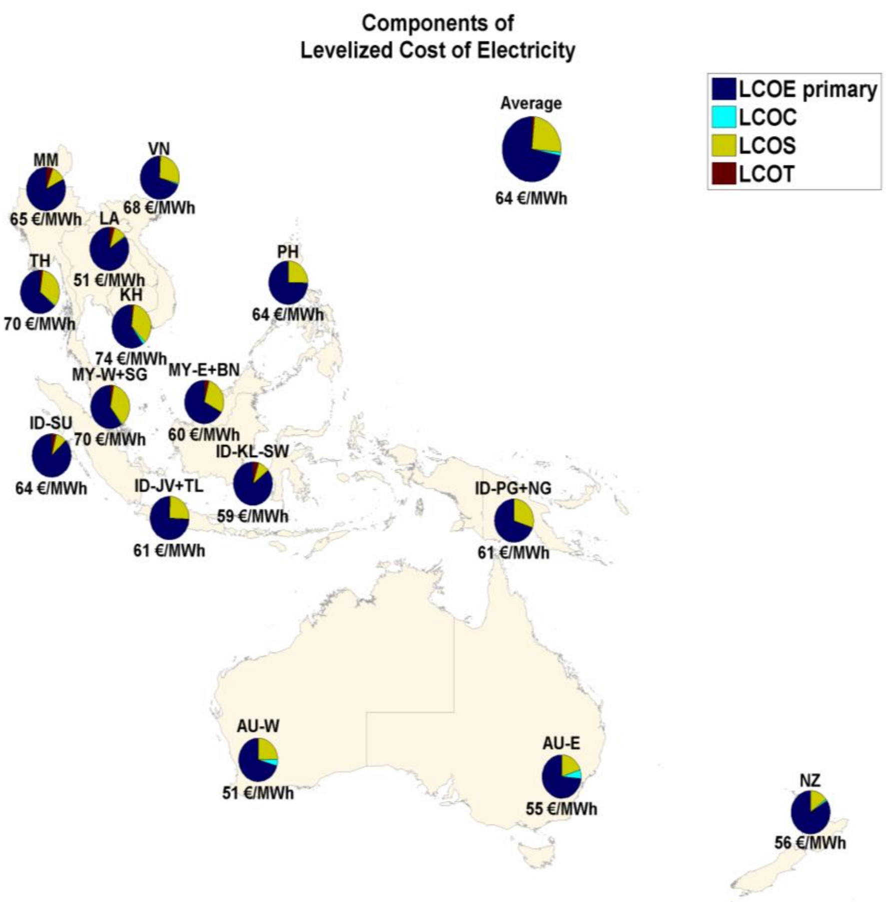
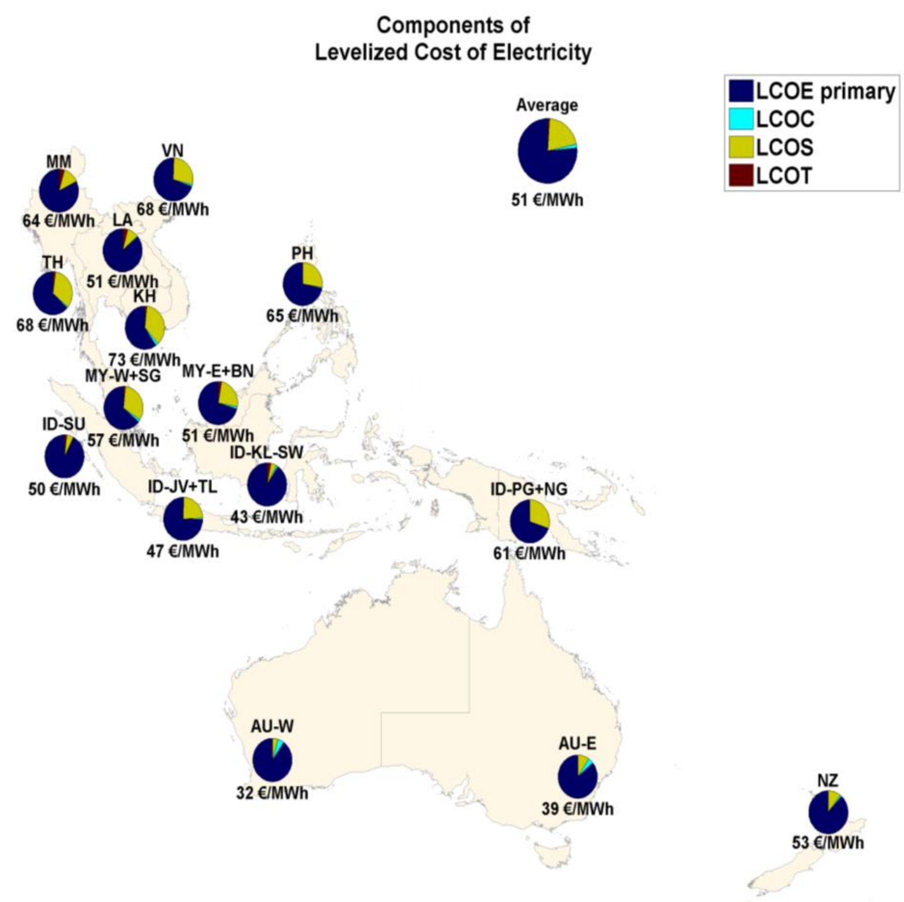
Area-wide open trade



Area-wide open trade desalination gas



source: [Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30]

Results

Installed Capacities

2030 Scenario	Wind [GW]	PV [GW]	Hydro RoR [GW]	Hydro dams [GW]	Biogas [GW]	Biomass [GW]	Waste [GW]	Geothermal [GW]	Battery [GWh]	PHS [GWh]	CAES [GWh]	PtG [GW_{el}]	GT [GW]
Region-wide	115	502	28	38	25	31	3	11	763	9	847	11	27
Country-wide	115	495	28	38	25	30	3	12	759	9	780	10	25
Area-wide	115	448	27	39	21	31	3	17	678	9	205	4	20
Integrated	255	758	27	39	20	30	3	15	752	6	269	118	8

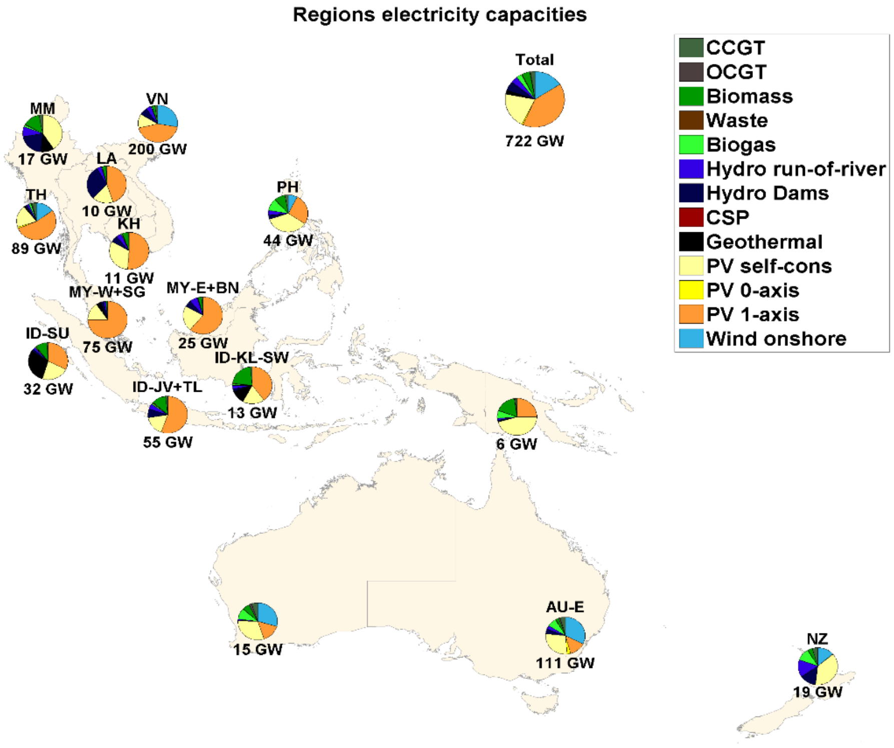
2030 Scenario	PV fixed-tilted [GW]	PV single-axis [GW]	PV prosumers [GW]	PV total [GW]	Battery system [GWh]	Battery prosumers [GWh]	Battery total [GWh]
Region-wide	5	347	150	502	591	172	763
Country-wide	5	341	150	495	588	172	759
Area-wide	5	294	150	448	507	172	678
Integrated	5	604	150	758	580	172	752

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

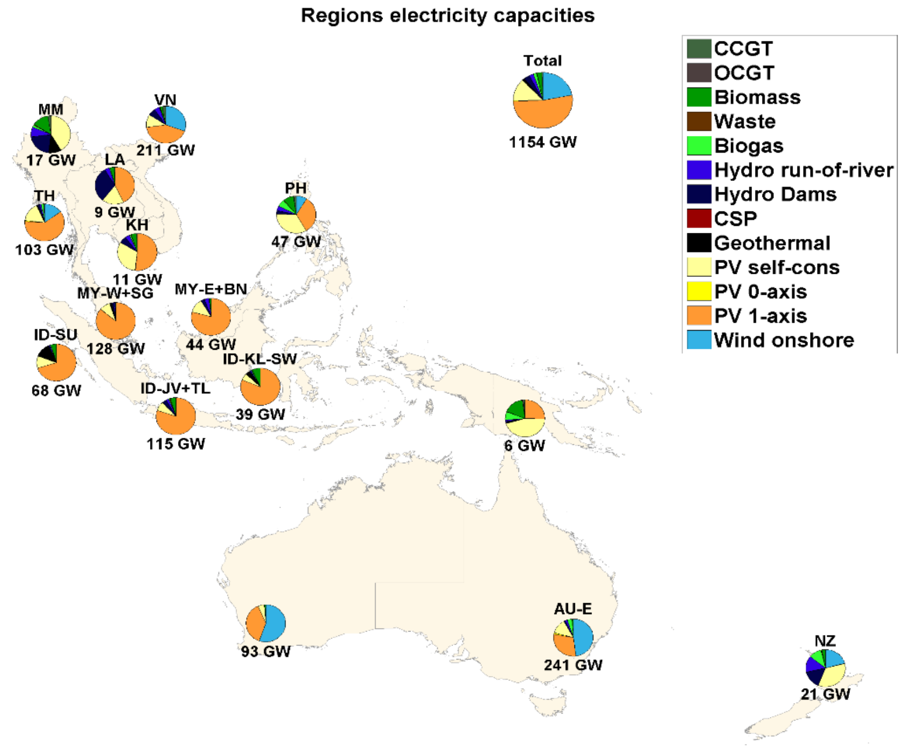
Results

Regions Electricity Capacities – area-wide open trade

Area-wide open trade



Area-wide open trade desalination gas



Key insights:

- Area-wide scenario shows high PV capacities which are dominated by PV single-axis and complemented by prosumer PV installations

Key insights:

- Area-wide desalination gas scenario is dominated by PV
- PV single-axis and wind being the main source of electricity for seawater desalination and industrial gas production, especially for importing regions

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Results

Storages Capacities – area-wide and area-wide open trade desalination gas

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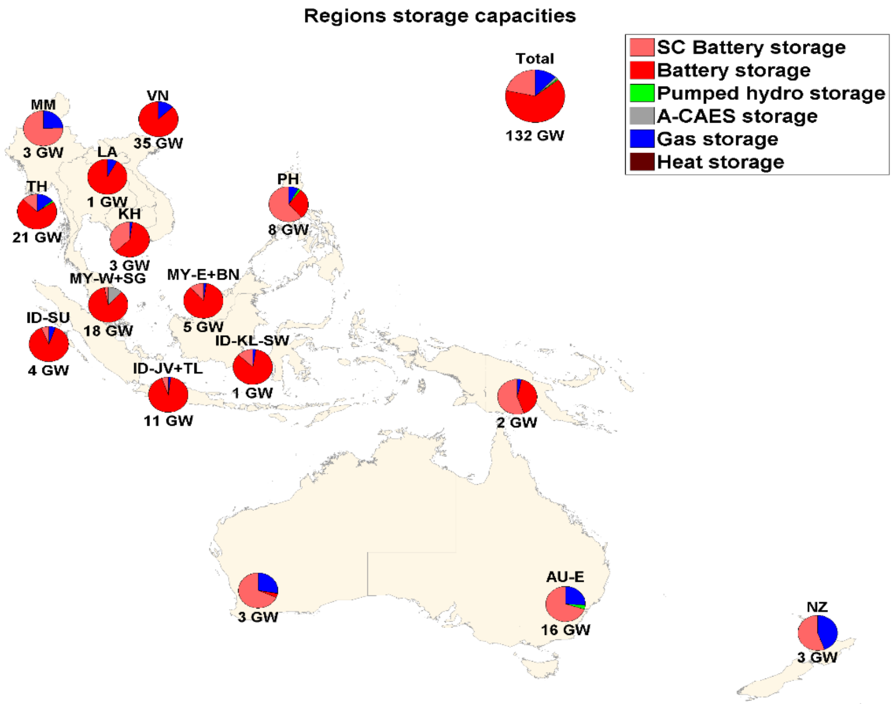
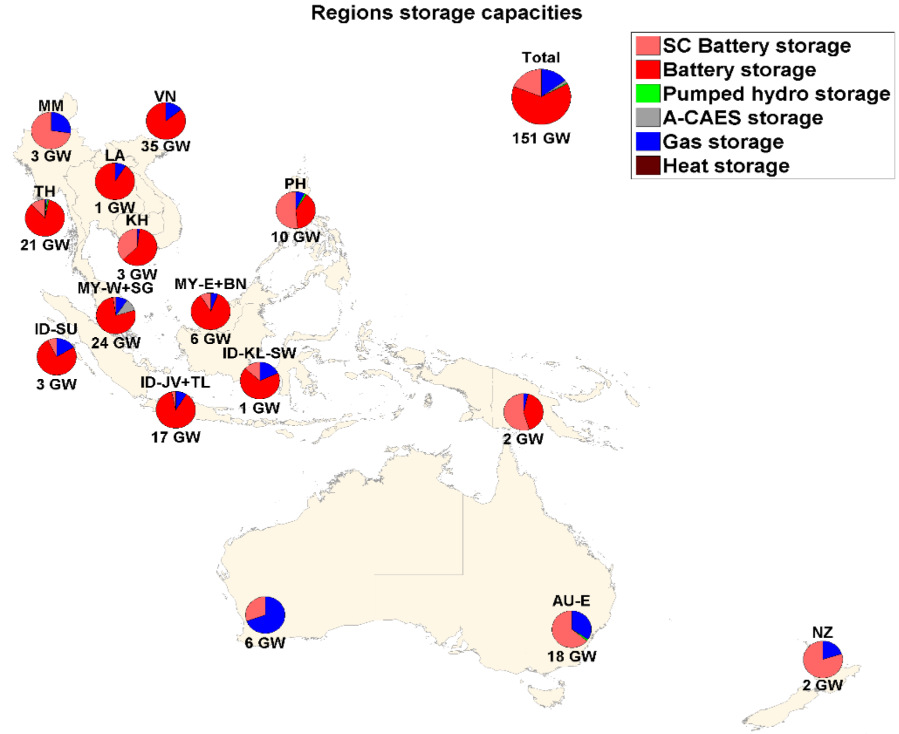
Area-wide open trade



Area-wide open trade desalination gas



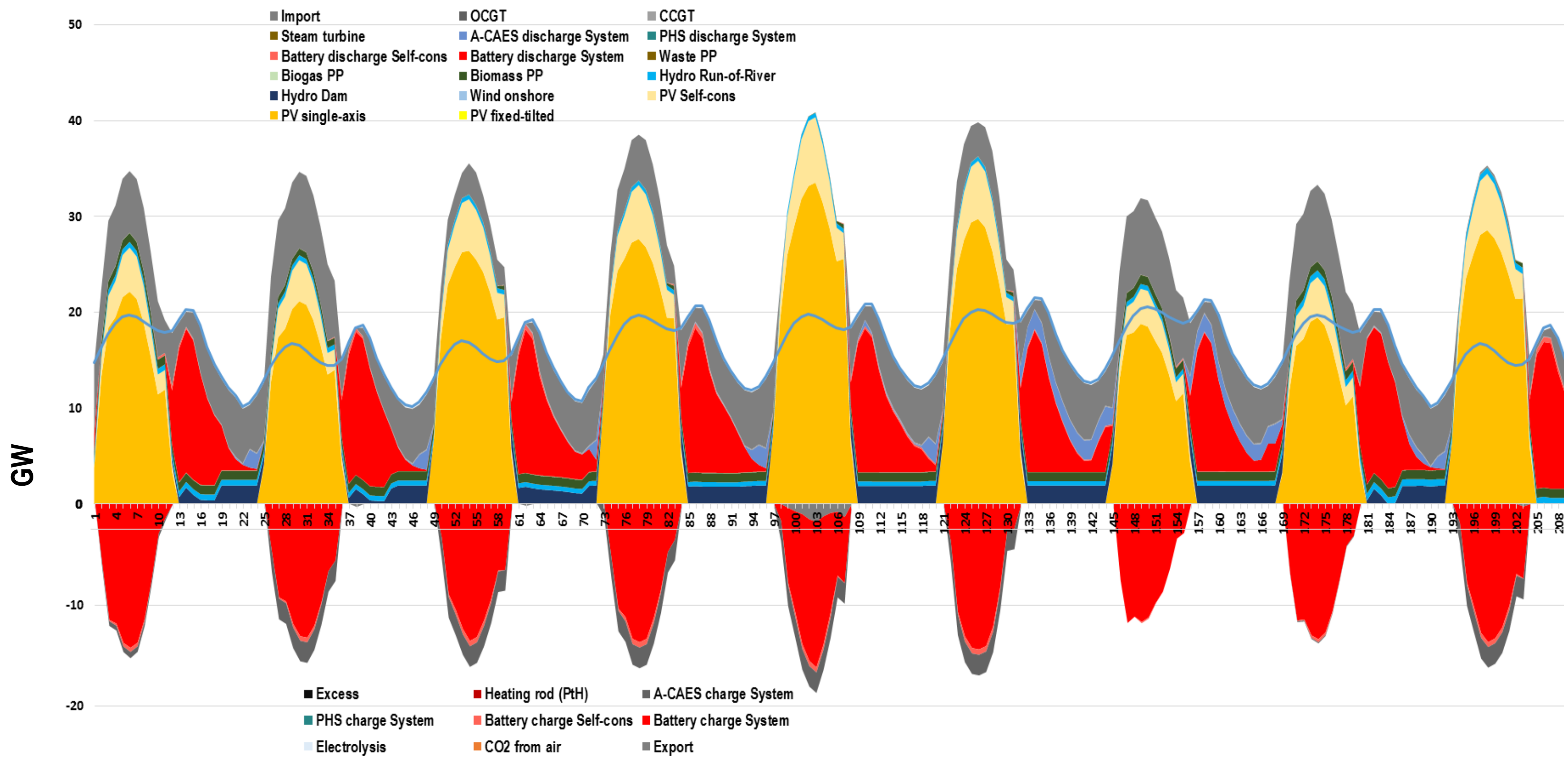
Key insights:

- Excess energy for area-wide open trade desalination gas: higher in absolute numbers, but similar to relative ones.
- Hydro dams are very important as virtual battery, batteries in a key role for prosumers but also on the grid level and gas storages for balancing periods of wind and solar shortages
- A-CAES important for region-wide and country-wide scenarios, however trading within regions is lower in cost than A-CAES

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Results

Net importer region – Malaysia West + Singapore



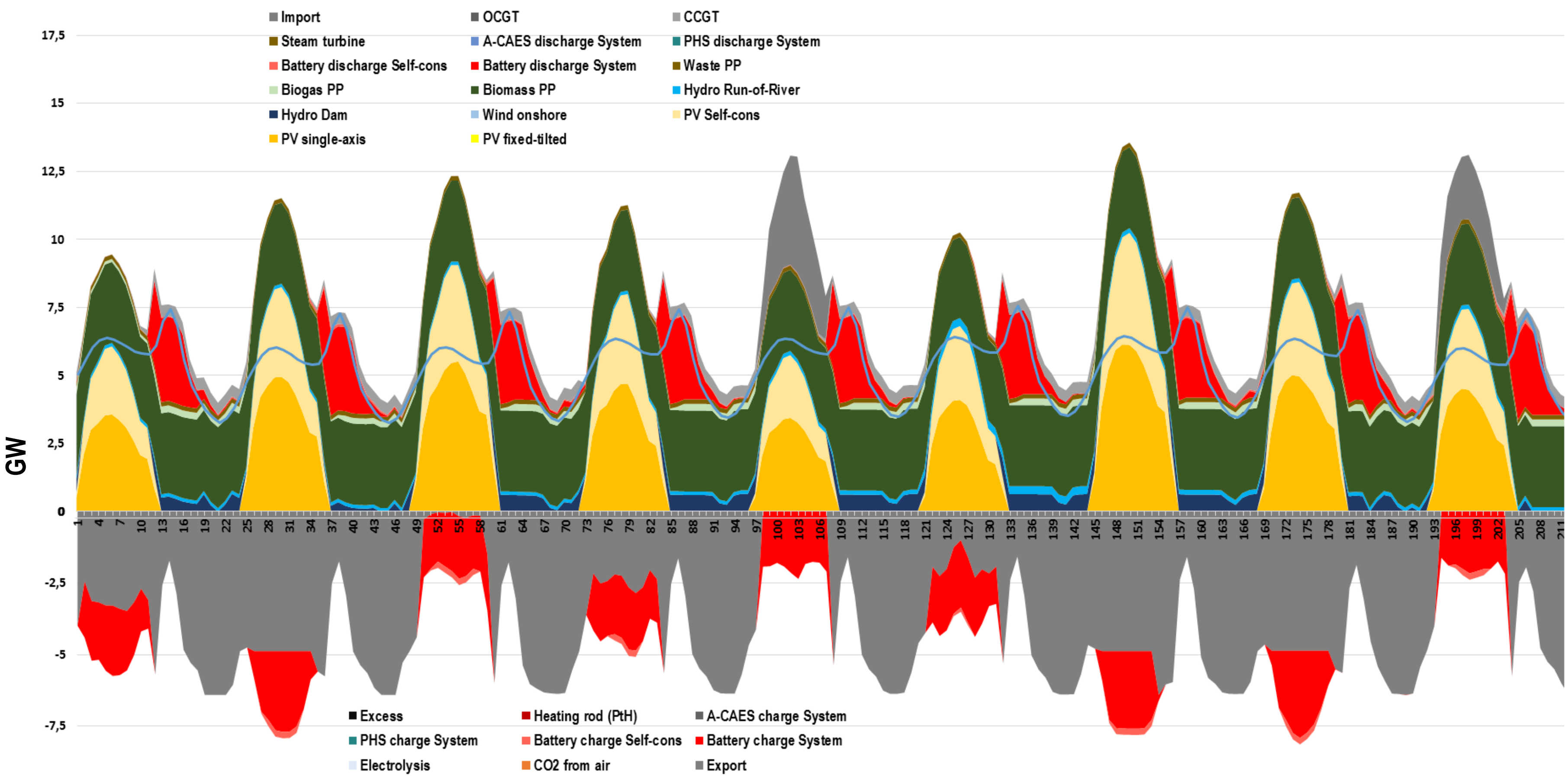
Key insights:

- Malaysia West + Singapore imports 31 TWh of electricity from the grid (neighbouring regions)
- own generation is based on PV (prosumer, single-axis)
- batteries and A-CAES charged during daytime and discharged in afternoon (only batteries) and evening (both)

source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Results

Net exporter region – Sumatra



Key insights:

- Sumatra exports 29 TWh of electricity to the grid (neighbouring regions)
- Energy mix is mainly based on PV (prosumers), hydro dams and biomass
- Batteries shift PV-based electricity in the afternoon and night
- Hydro dams and biomass is used flexibly in hours of no PV

Results

Energy flow of the System of area-wide open trade desalination gas (2030)

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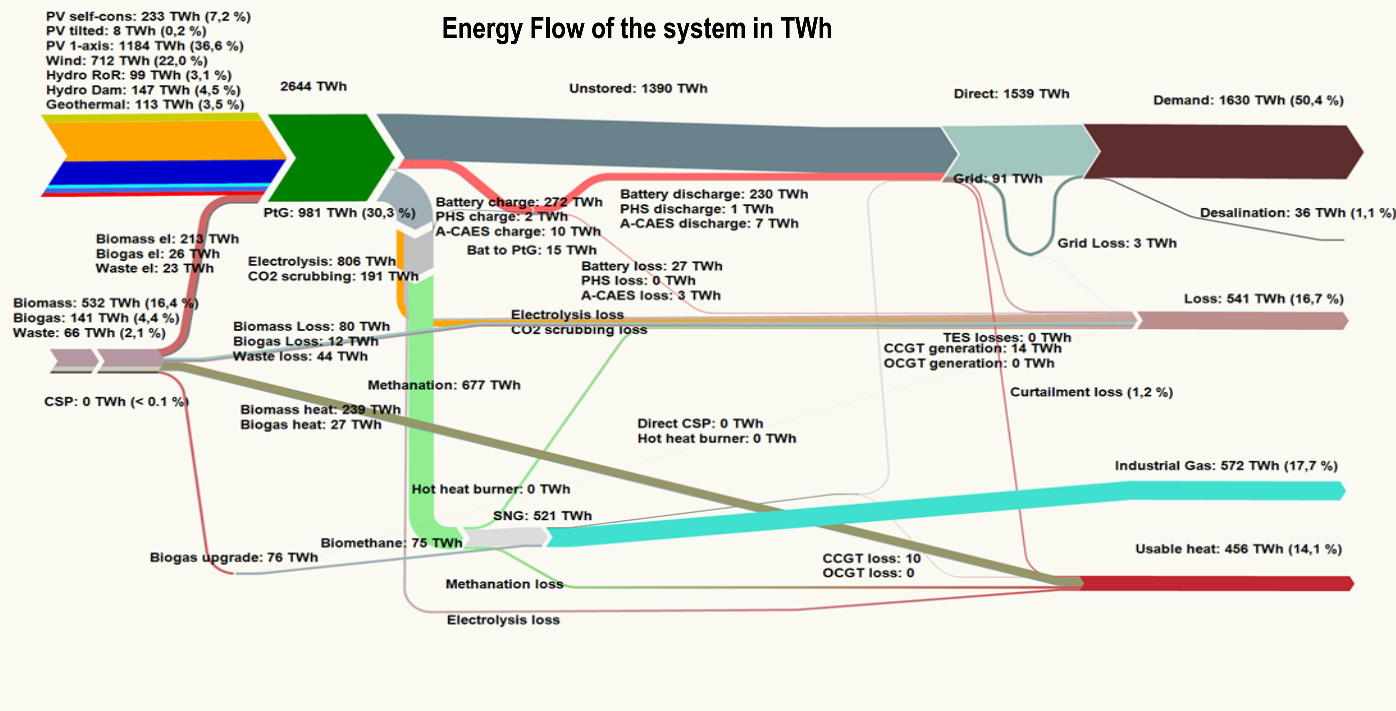

Key insights:

- PV is the major energy source (prosumers contribute significantly)
- Wind energy and biomass are further major energy sources
- Low fraction to be stored or traded within regions via grids

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source: Breyer Ch., Gulagi A., Bogdanov D., 2015. South-East Asia and the Pacific Rim Super Grid for 100% RE power supply, 45th IEA PVPS Task 1 Meeting, Istanbul, October 27-30

Comparison to other regions

Regions	LCOE total region-wide [€/MWh]	LCOE total area-wide [€/MWh]	Integration benefit** [%]	storages* [%]	grids interregional trade* [%]	Curtailment [%]	PV prosumers* [%]	PV system* [%]	Wind* [%]	Biomass* [%]	hydro* [%]
North-East Asia	77	68	6.0%	10%	26%	6%	14.3%	27.5%	48.2%	7.8%	7.2%
South-East Asia	67	64	9.5%	8%	3%	3%	7.2%	36.8%	22.0%	22.9%	7.6%
Eurasia	63	53	23.2%	<1%	13%	3%	3.8%	9.9%	58.1%	13.0%	15.4%
South America	62	55	7.8%	5%	12%	5%	12.1%	28.0%	10.8%	28.0%	21.1%

* Integrated scenario, supply share
** annualised costs

Key insights:

- 100% RE is highly competitive
- least cost for high match of seasonal supply and demand
- PV share typically around 40% (range 14-44%)
- hydro and biomass limited the more sectors are integrated
- flexibility options limit storage to 10% and it will further decrease with heat and mobility sector integration
- most generation locally within sub-regions (grids 2-26%)

sources: see www.researchgate.net/profile/Christian_Breyer

LCOE of alternatives are NO alternative

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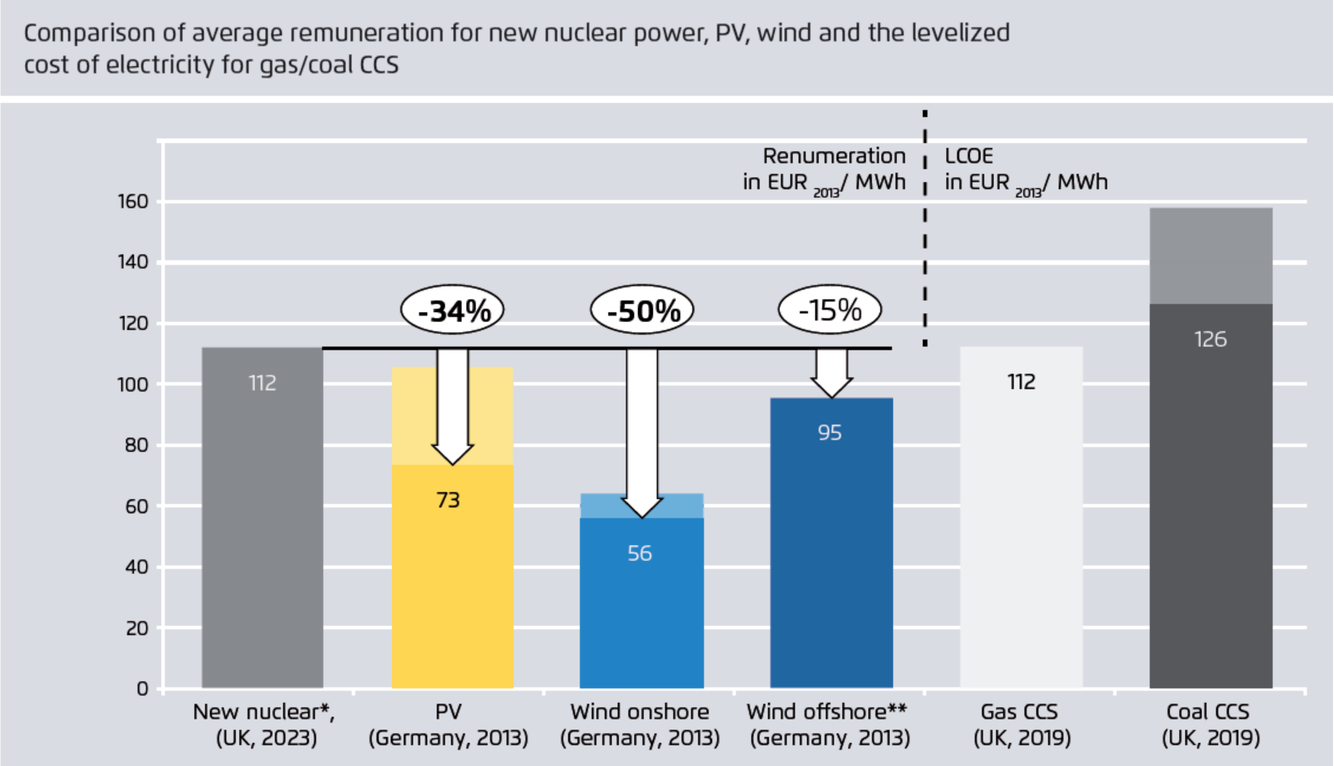

Key insights

- PV-Wind-Gas is the least cost option (with existing hydro)
- nuclear and coal-CCS is too expensive
- nuclear and coal-CCS are high risk technologies
- high value added for PV-Wind due to higher capacities needed

source: Agora Energiewende, 2014. Comparing the Cost of Low-Carbon Technologies: What is the Cheapest option, Berlin

Comparison to latest IEA report on SE Asia

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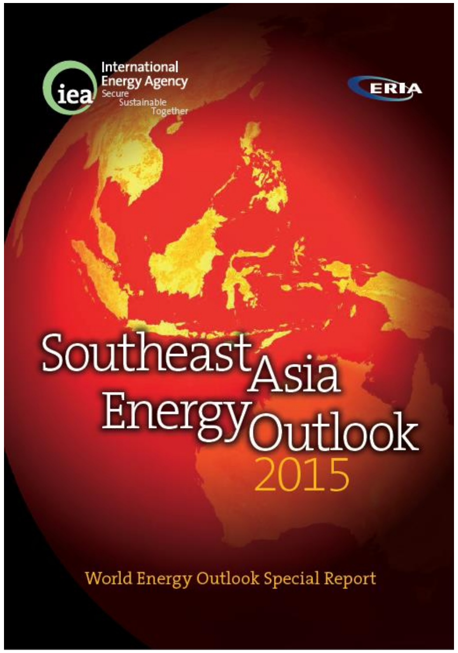
Table 2.2 ▷ Electricity generation by fuel in Southeast Asia (TWh)

	1990	2013	2020	2040	Shares 2013	Shares 2040	CAAGR* 2013-2040
Fossil fuels	120	648	925	1 699	82%	77%	3.6%
Coal	28	255	482	1 097	32%	50%	5.6%
Gas	26	349	406	578	44%	26%	1.9%
Oil	66	45	36	24	6%	1%	-2.2%
Nuclear	-	-	-	32	-	1%	n.a.
Renewables	34	141	180	481	18%	22%	4.7%
Hydro	27	110	119	255	14%	12%	3.2%
Geothermal	7	19	27	58	2%	3%	4.2%
Bioenergy	1	10	22	75	1%	3%	7.7%
Other**	-	2	12	93	0%	4%	16.0%
Total	154	789	1 104	2 212	100%	100%	3.9%

*Compound average annual growth rate. **Includes wind and solar PV.

Table 2.3 ▷ Cost and operational features of key power generation technologies in Southeast Asia, 2030

	Capital cost ($/kW)	Fixed O&M cost ($/kW)	Thermal efficiency	Capacity factor	Construction time (years)
Coal supercritical	1 600	64	41%	75%	5
Gas CCGT	700	25	58%	60%	3
Wind (onshore)	1 700	43	n.a.	27%	1.5
Solar PV (large scale)	1 600	24	n.a.	17.5%	1.5
Large hydro	2 500	55	n.a.	33%	4
Geothermal	3 200	64	10%	75%	4



Key insights:

- IEA does not assume any major change in the energy mix
- IEA uses outdated (much too high) PV capex numbers, since in 2015 the PV capex is around 1000 €/kWp (<< 1600 USD/kWp in 2030)
- IEA numbers include subsidies for coal and gas, due to no CO_2 price and heavy metal emissions (reason for coal decline and PV and wind investments in China)
- Country-wide scenario for 100% RE is 67 €/MWh for 2030 compared to about 73 USD/MWh for IEA mix for 2040 (assuming 80 USD/t for coal and 10 USD/MBtu for gas) with substantial higher risk for stranded investments
- Policy recommendation seems to be careless!

Agenda

- Overview
- Solar Home Systems/ pico SHS
- PV upgrades for diesel grids
- Country ranking business models
- Role of batteries: case of Tanzania
- Solarkiosk: catalyst for electrification
- Islands: on-grid but off-grid
- 100% RE for the case of South-East Asia
- Summary

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Summary

- 1.3 bn people have no access to electricity
- good solar resources lead to solar PV solutions
- SHS and pico SHS show excellent economics
- PV upgrade of unsubsidized diesel grids is financially very beneficial
- countries in East and Southern Africa show good business conditions
- affordable batteries are a key for high RE shares
- Solarkiosk is a catalyst for electrification
- PV upgrade of existing diesel grids on islands is very beneficial
- however, total off-grid market potential might be about 100 GWp
- 100% renewable energy is a real policy option!

Thanks for your attention!

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