Technical and economic assessment of hybrid PV mini-grid projects

Optimized Layout and Sizing of Off-Grid Power Plant for SKA1-Low Radio Telescope

Lluís Millet Biosca, Johannes Wüllner, Matthias Vetter, Antony Schinckel

Fraunhofer Institute for Solar Energy Systems ISE

3rd International Hybrid Power Systems Workshop. Session 4B: Economic Issues

8-May 2018, Tenerife

www.ise.fraunhofer.de

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Fraunhofer ISE

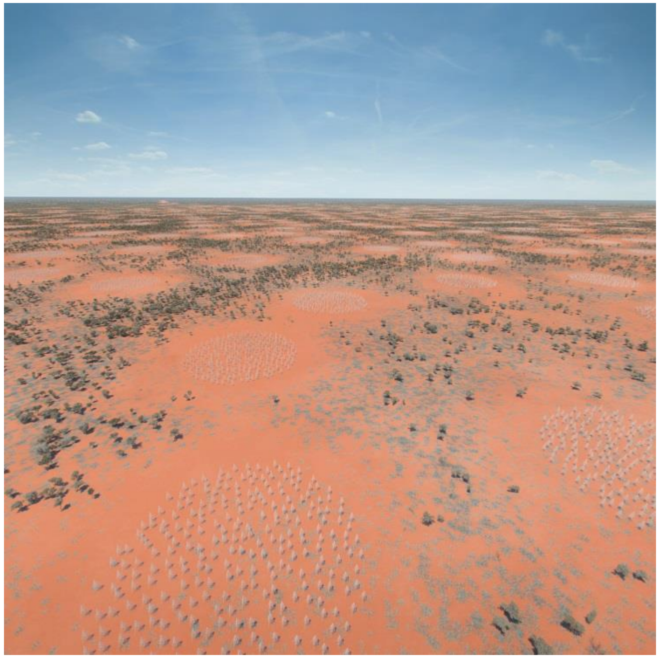
AGENDA

- Introduction
  - The Square Kilometer Array (SKA), objectives and precedents
- Power system design
  - Topology, component base prices, operational constraints
  - Optimal sizing of components
- Economic evaluation
  - Central vs. distributed power
- Final design proposal
- Conclusions

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Introduction
The Square Kilometer Array (SKA)

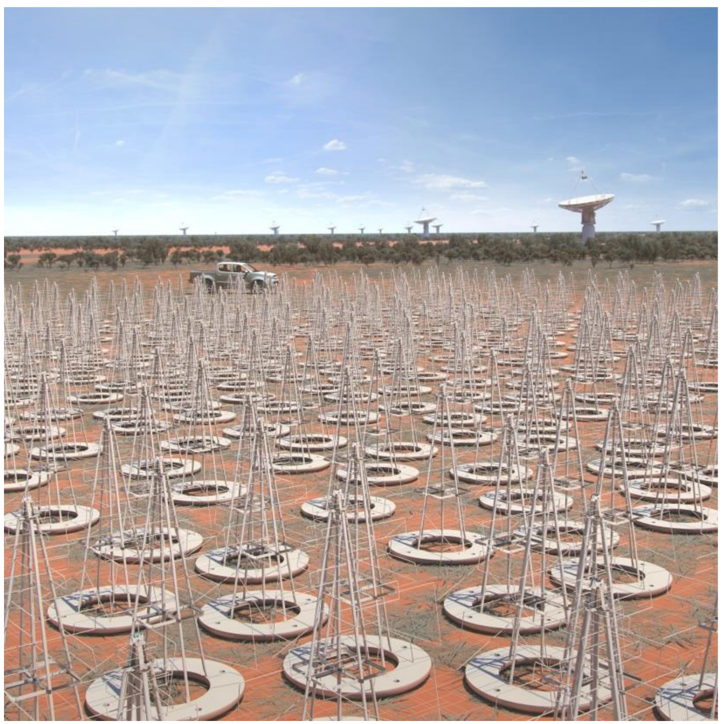
- More than 25 years since SKA project started. 10countries, ~500engineers
- Co-hosting: Karoo Region, South Africa
  Murchison Radio-astronomy Observatory (MRO), outback WA

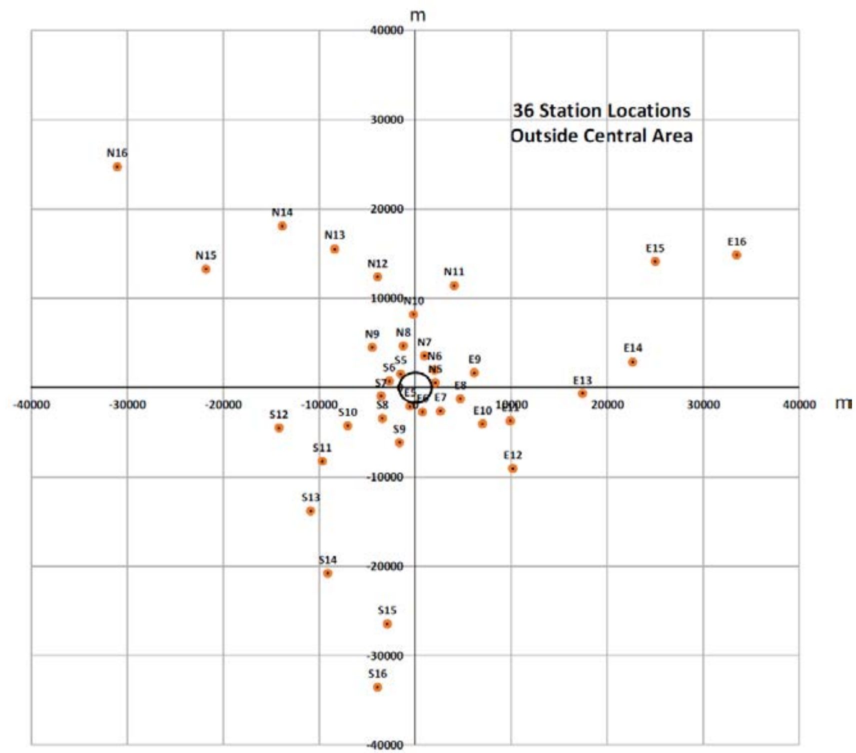


© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Introduction
The SKA1-Low Australia

- 131,000 antennas (50-350MHz) → radio waves from 13 billion years ago
- Data processing: 5x internet traffic in 2015





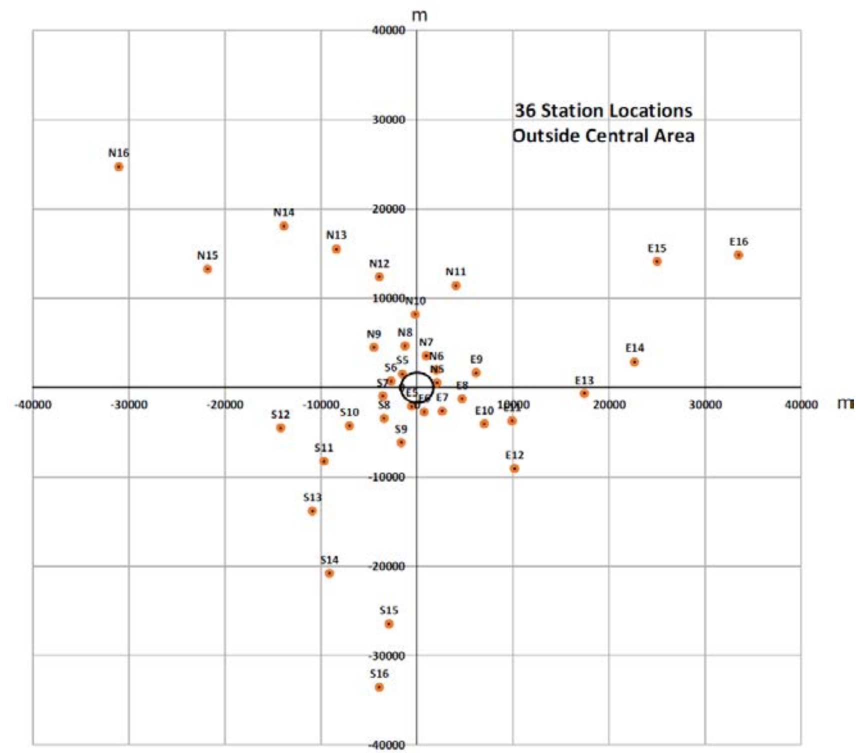
© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Introduction
Objectives

- 131,000 antennas (50-350MHz) → radio waves from 13 billion years ago
- Data processing: 5x internet traffic in 2015

- Total power consumption: 3 MW
- 36 Remote Processing Facilities (32 kW per RPF)

Load	Power Budget
Data Processing Racks	19 kW
Racks' Cooling	7 kW
Antennas Power Load	6 kW
Total (Sum)	**32 kW**

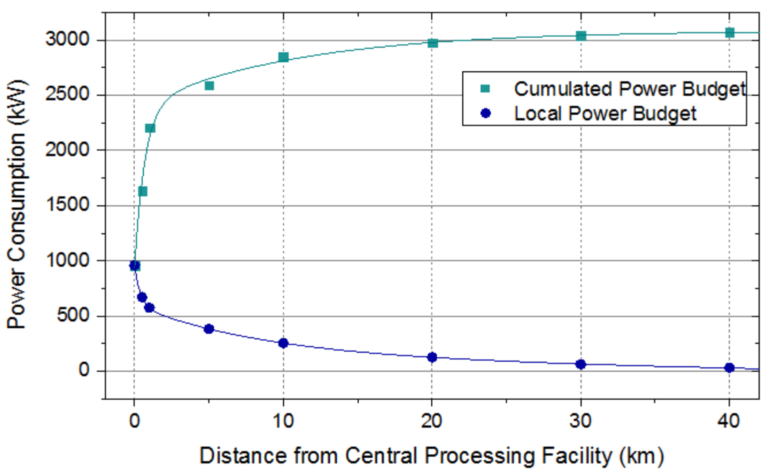


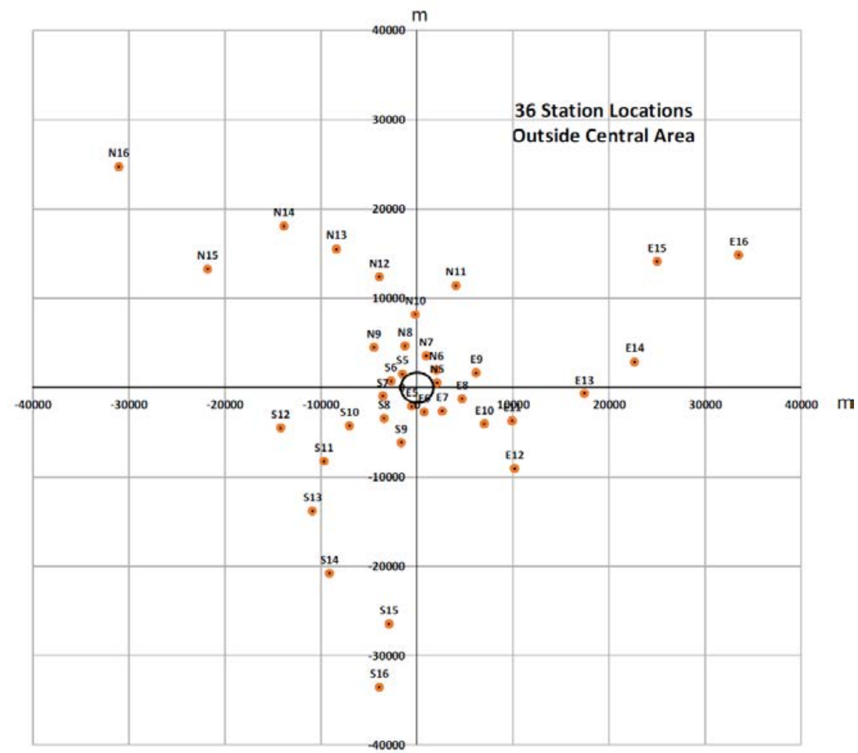
© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Introduction
Objectives

- 131,000 antennas (50-350MHz) → radio waves from 13 billion years ago
- Data processing: 5x internet traffic in 2015

- Total power consumption: 3 MW
- 36 Remote Processing Facilities (32 kW per RPF)





© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

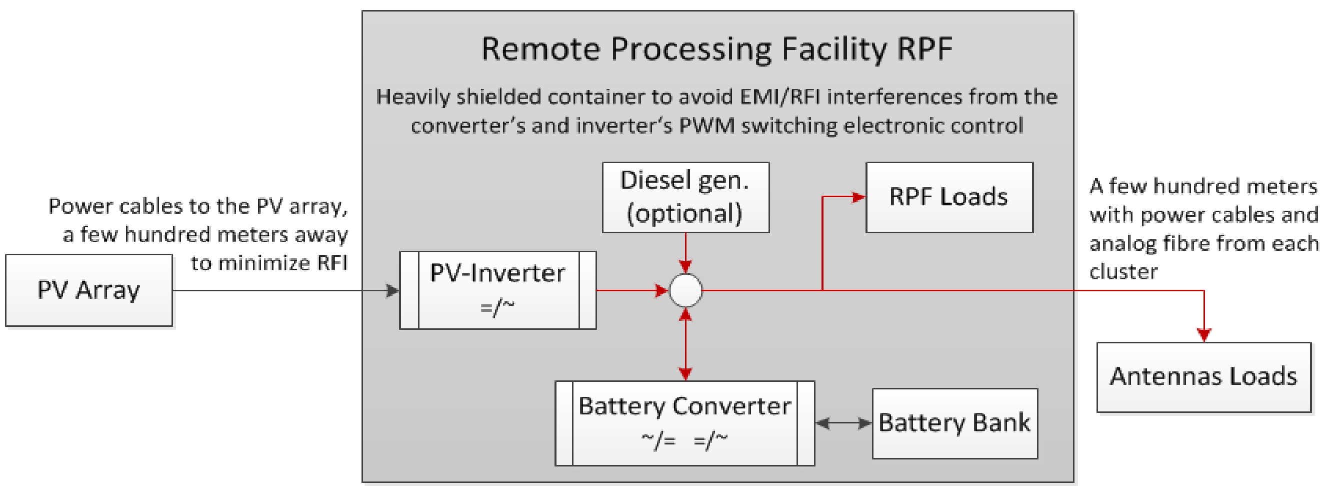
Introduction
Precedents

- Murchison Widefield Array (MWA)
  - 1.6 MWp PV power plant + 2.7 MWh lithium-ion battery storage

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Power system design
Topology

- AC-coupling, preferred over DC-coupling:
  - Simpler PV inverter, better-established products, more cost-effective
- Central inverter
  - Minimizes danger of EMI/RFI propagation, single-stage PV inverter, less wiring losses (although higher MPPT and voltage mismatch losses)



© Fraunhofer ISE
FHG-SK: ISE-INTERNAL
CSIRO SKA Fraunhofer ISE

Power system design
Component base prices and operational constraints

Component	Inputs for price estimation of HRES components		
	Capital costs	*Lifetime*	*O&M costs*
PV Modules	500 €/kWp	25 years	13 €/(kWp.year)
PV Inverter	90 €/kW	15 years	3 €/(kW.year)
PV BOS	90 €/kWp	25 years	5 €/(kWp.year)
Li-Ion Battery	450 €/kWh	10 years ~3,000 cycles	5 €/(kWh.year)
BMS	130 €/kWp + 50 €/kW	10 years ~3,000 cycles	5 €/(kWh.year)
Battery Converter	170 €/kW	15 years	3 €/(kW.year)
Diesel (optional)	500 €/kW	15,000 runtime hours	0.03 €/h + 1.1€/L (fuel)

- Battery operation constraint to 90%DOD
- Minimum diesel operating time 30 minutes

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

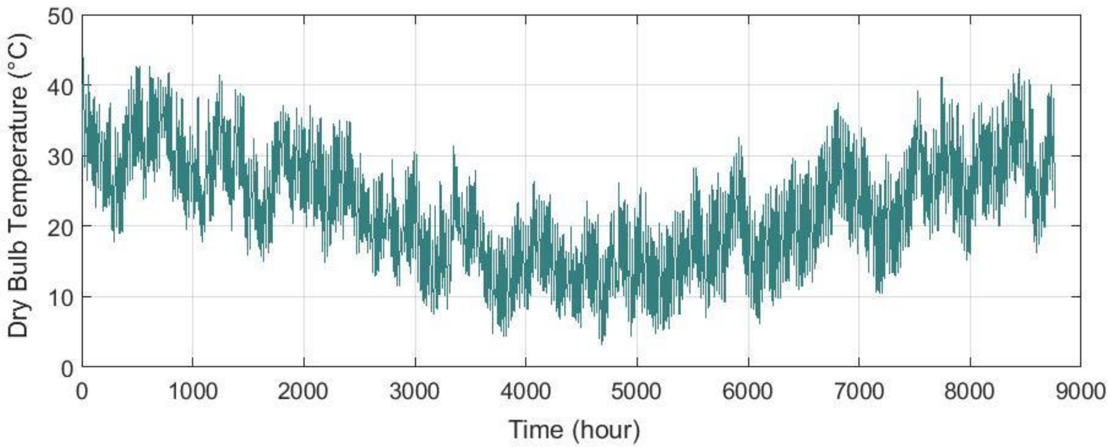
Power system design
Optimal sizing

- Simulation setup:

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Power system design
Optimal sizing

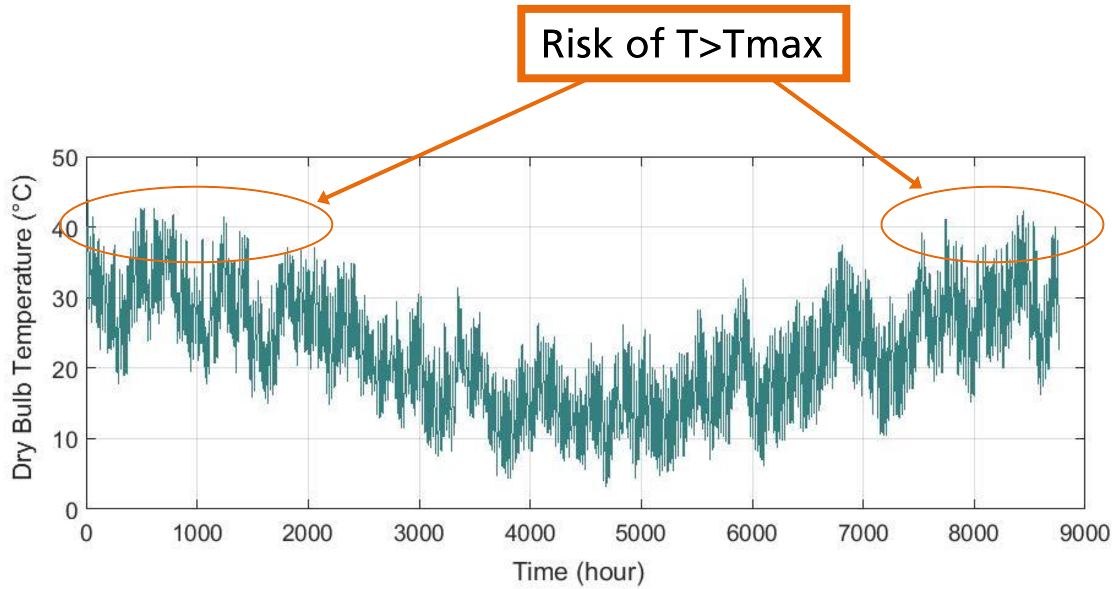
- Simulation setup:
  - Weather data from Meekatharra Airport and Mundiwindi weather stations
  - Effective irradiance of 1700-1750 kWh/(m^2.year)

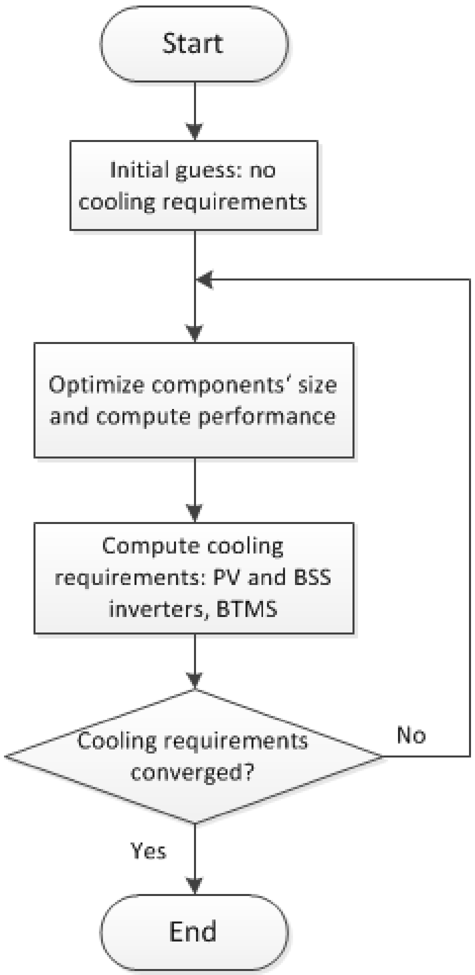


© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Power system design
Optimal sizing

- Simulation setup:

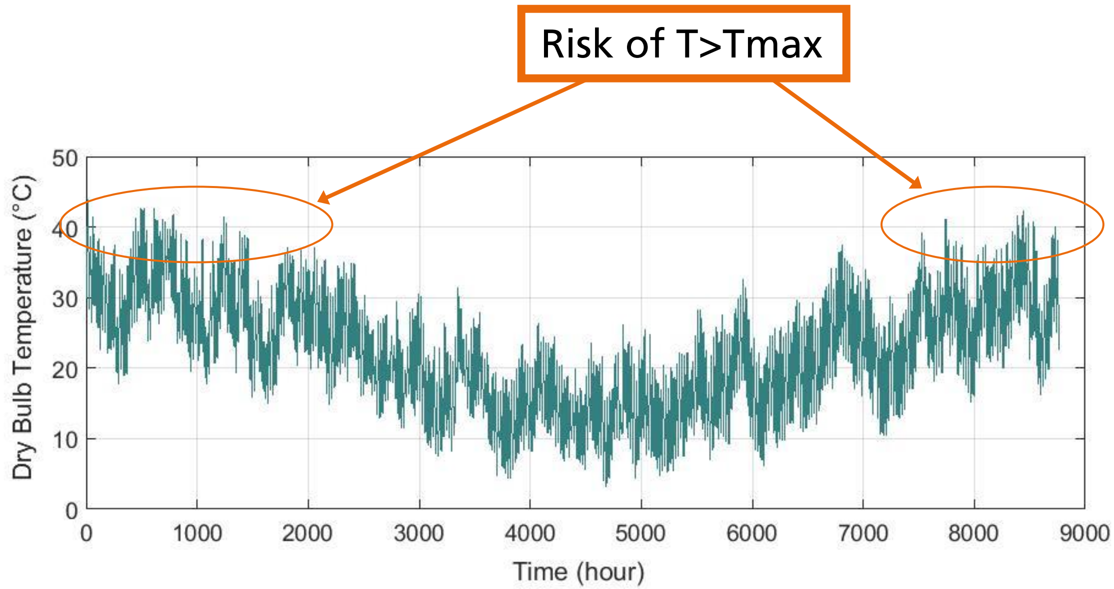


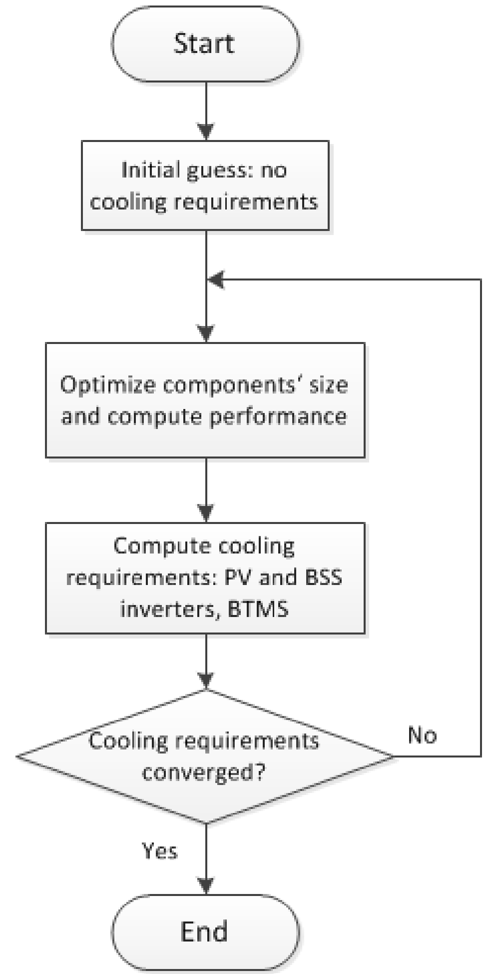


© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Power system design
Optimal sizing

- Simulation setup:

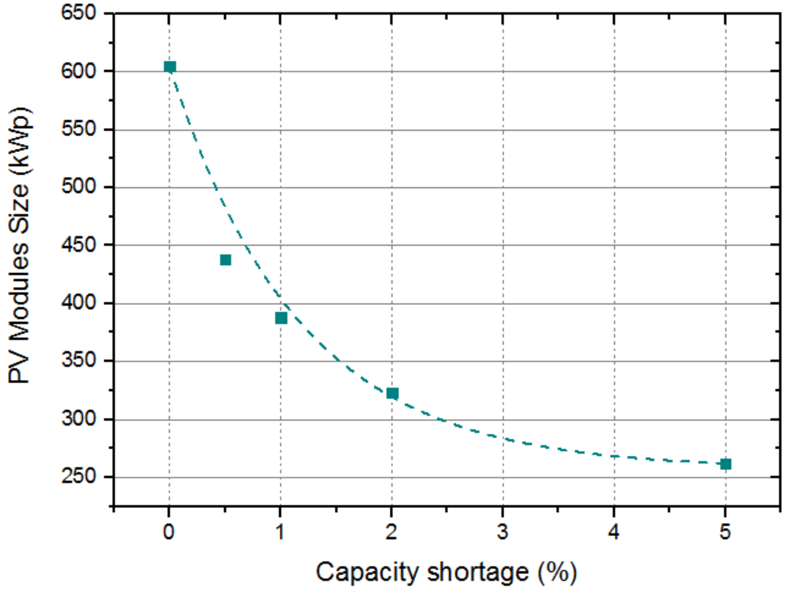


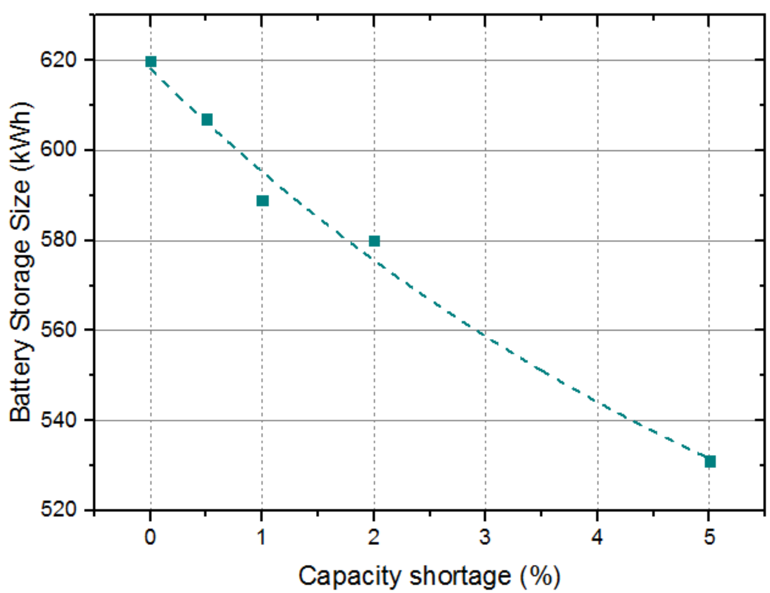


→ Cooling req. add ~3% to global power budget

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL
CSIRO SKA SQUARE KILOMETRE ARRAY Fraunhofer ISE

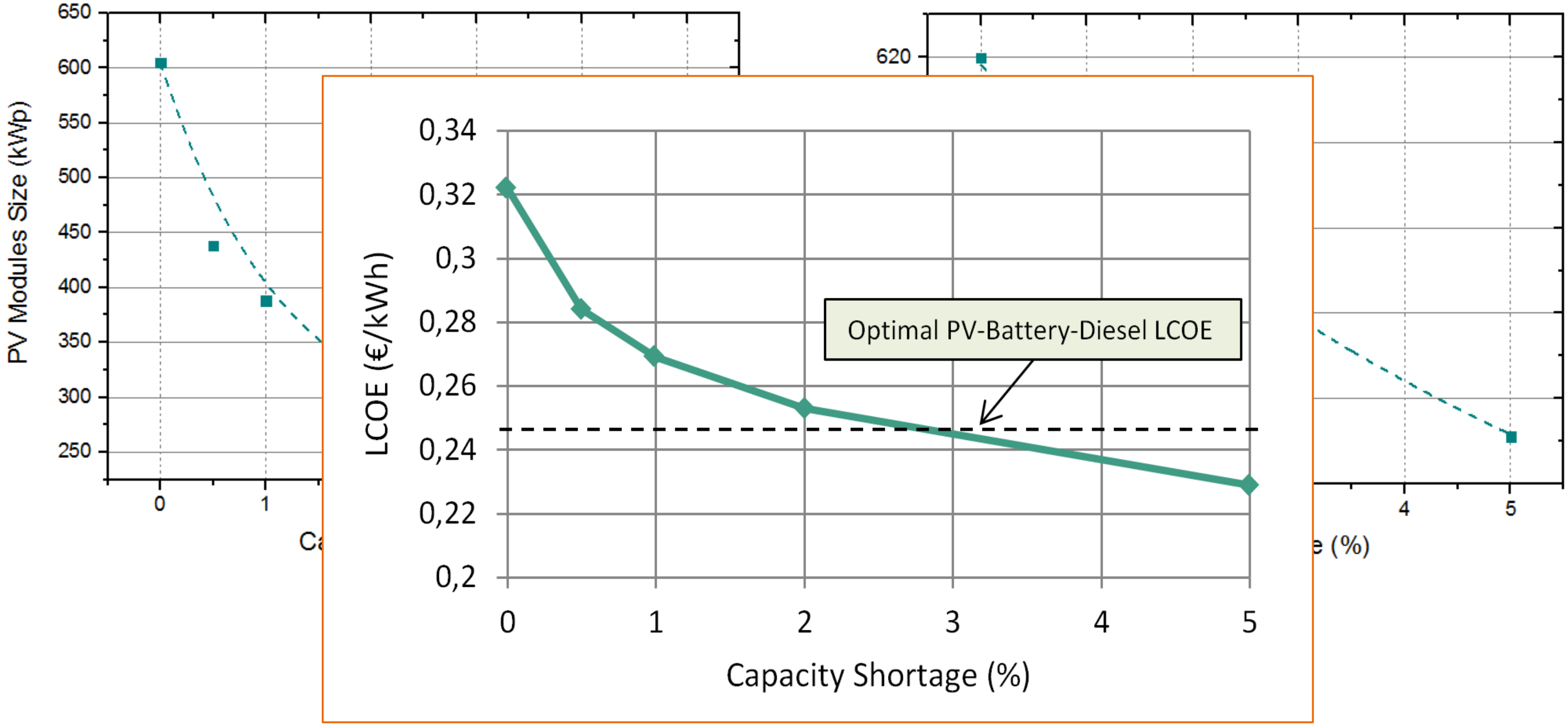
Power system design
Optimal sizing: Results





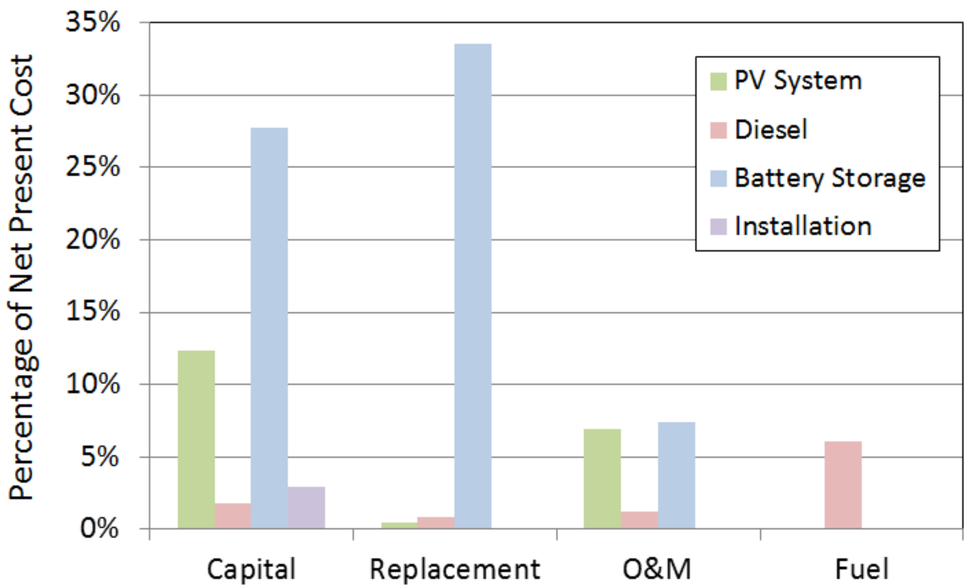
© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

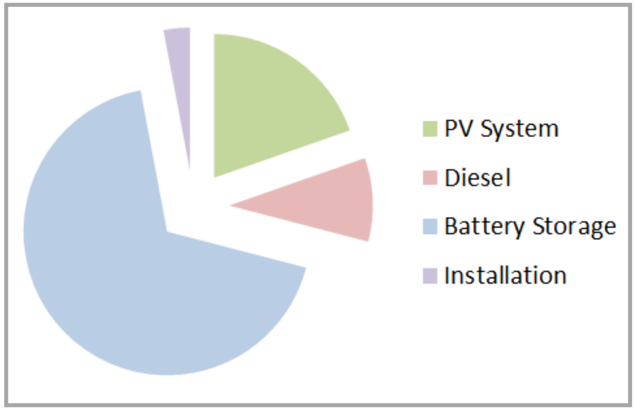
Power system design
Optimal sizing: Results



© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Power system design
Optimal sizing: Results





- Renewable fraction, $f_{ren} = \frac{E_{renewables \rightarrow AC,Load}}{E_{AC,Load}} = 95.6\%$

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Central vs. Distributed power

- Power transmission costs
- Improvements of LCOE estimation
  - Effect of components' size
  - Price-experience curve
  - Locality effects

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Power transmission costs

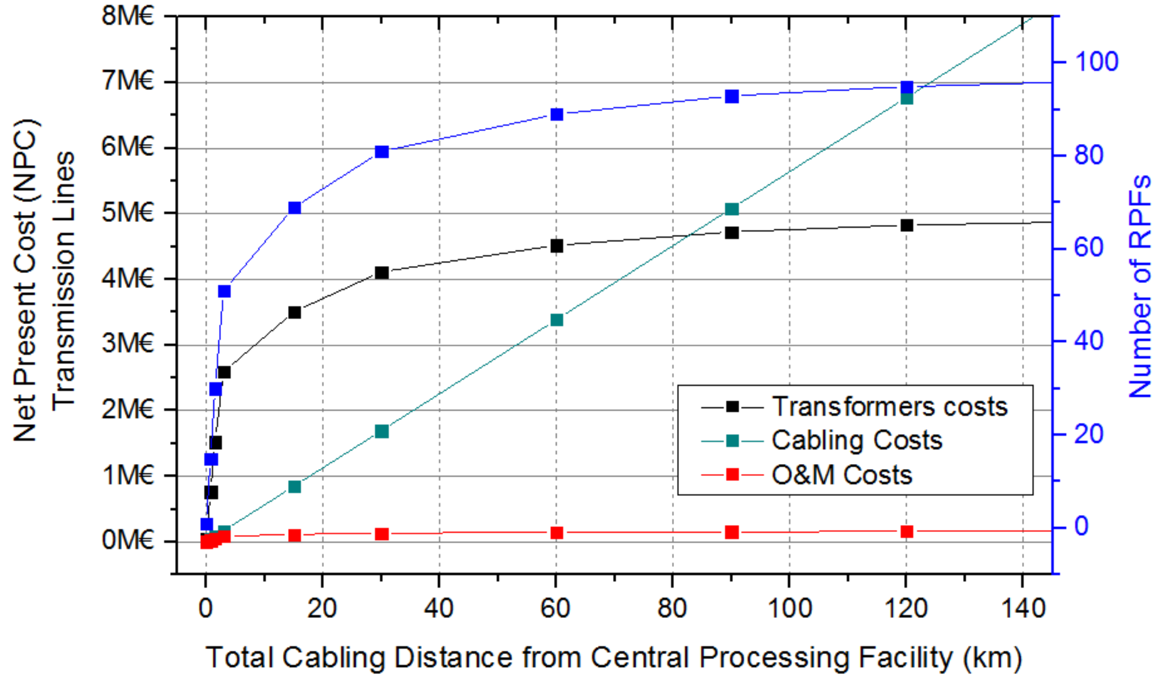
- Step-down transformer, switchboard, HV terminations at each RPF
- Highly shielded 11kV cable

Item / Component	Price
11 kV Shielded Cable	51,000 €/km
Trenching/Installation	19,000 €/km
Step-down Transformer	63,000 €/RPF

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Power transmission costs

- Step-down transformer, switchboard, HV terminations at each RPF
- Highly shielded 11kV cable

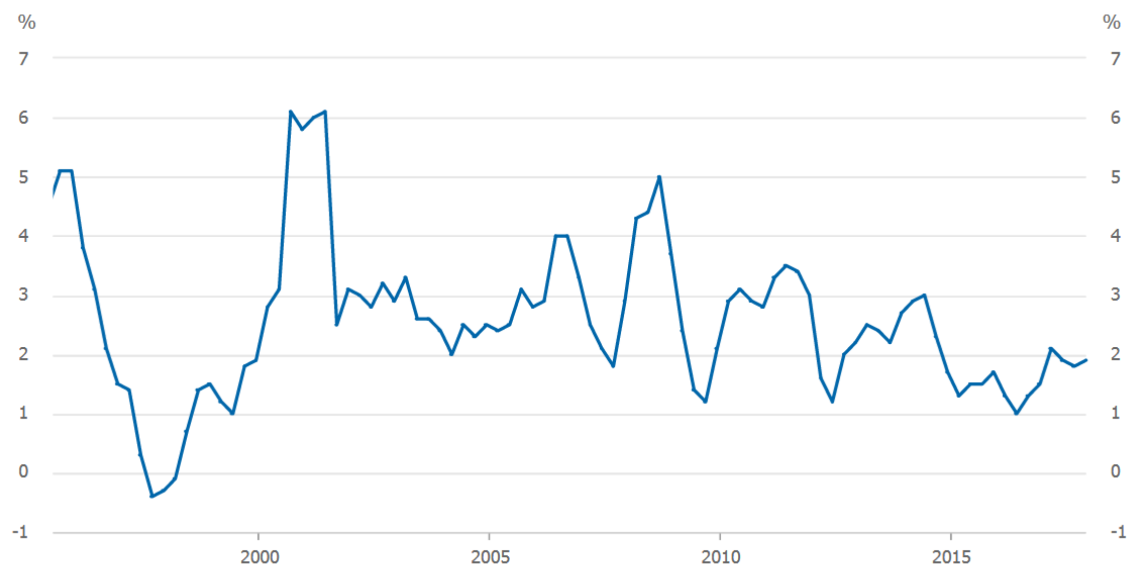


© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

Macro- / Microeconomic environment

- Discount rate
- Inflation rate

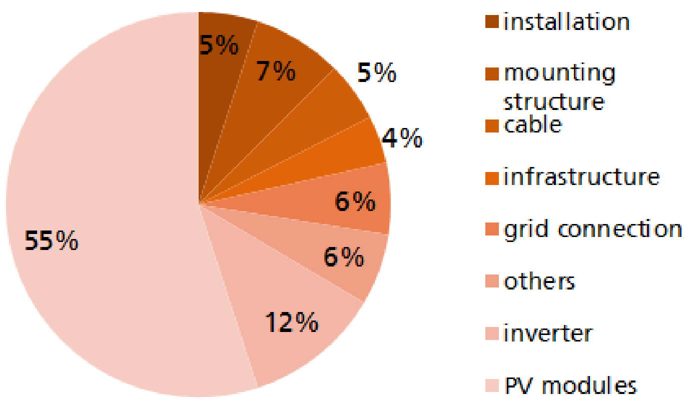


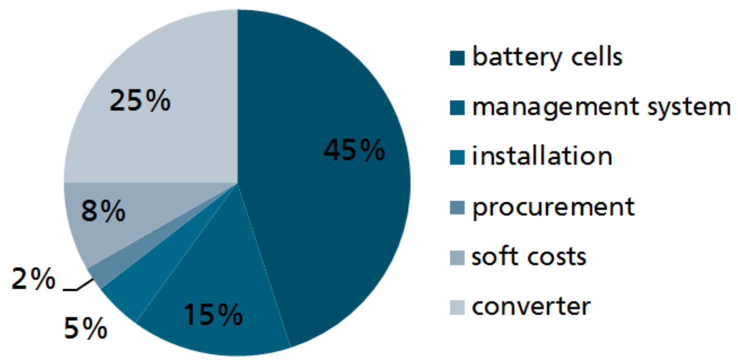
Source: [1] *Measures of Consumer Price Inflation,* Reserve Bank of Australia (RBA), rba.gov.au

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

- Components' size effects

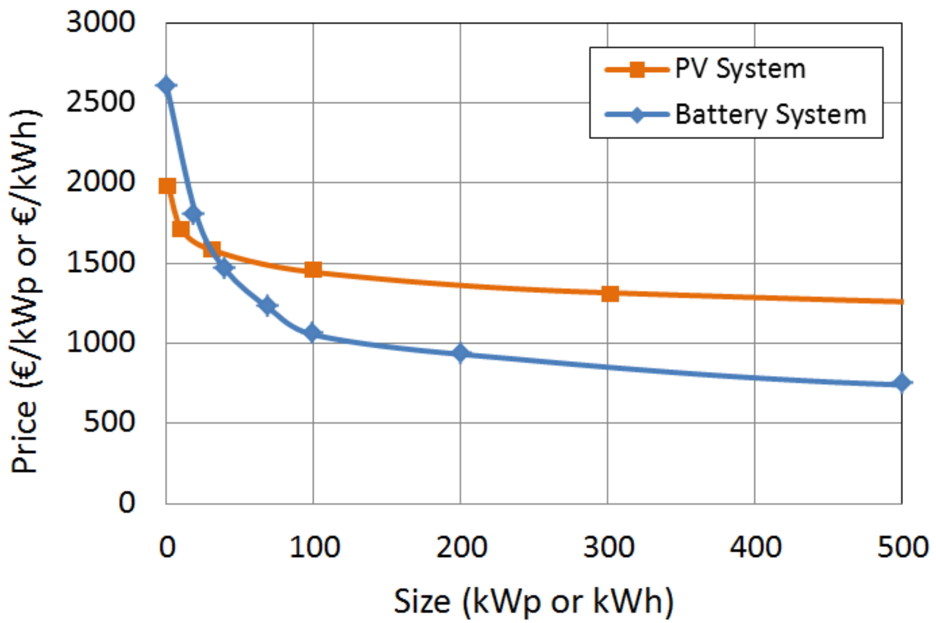




© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

- Components' size effects



Sources: [2] *Lithium-Ion Battery Costs and Market*, Bloomberg New Energy Finance; [3] *Battery Energy Storage Market: Commercial Scale, Lithium-ion Projects in the U.S.*, National Renewable Energy Laboratories; [4] *Electricity Cost from Renewable Energy Technologies in Egypt*, Fraunhofer ISE; [5] *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017*, National Renewable Energy Laboratory

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

- Price-experience curve effects

$$C(x_t) = C(x_0)\left(\frac{x_t}{x_0}\right)^{-b}$$

$$\mathrm{LR} = 1 - 2^{b} = 1 - PR$$

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

- Price-experience curve effects

$$C(x_t) = C(x_0)\left(\frac{x_t}{x_0}\right)^{-b}$$

$$\mathrm{LR} = 1 - 2^b = 1 - PR$$

Learning rate

- PV ~ 18-23%
- Li-ion batteries ~ 10-14%

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

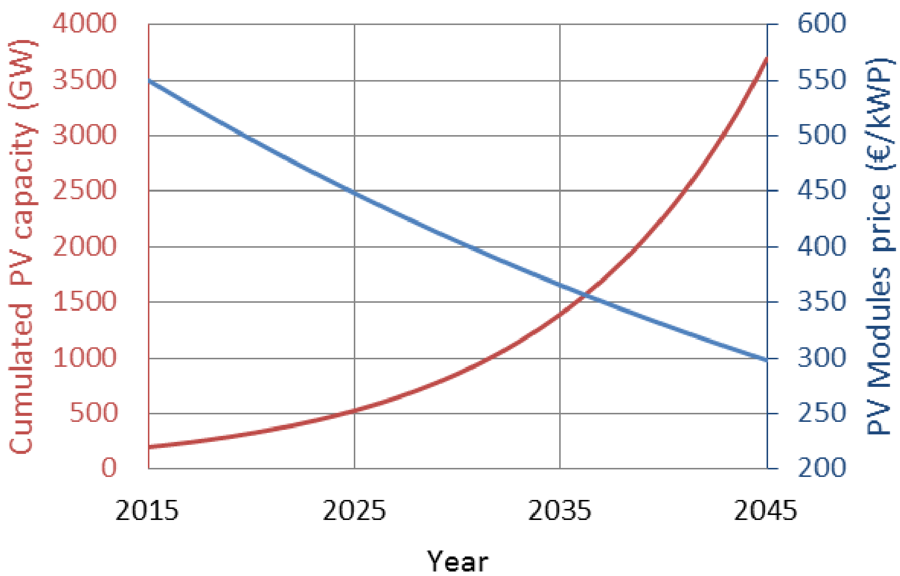
- Price-experience curve effects

$$C(x_t) = C(x_0)\left(\frac{x_t}{x_0}\right)^{-b}$$

$$\mathrm{LR} = 1 - 2^b = 1 - PR$$

Learning rate

- PV ~ 18-23%
- Li-ion batteries ~ 10-14%

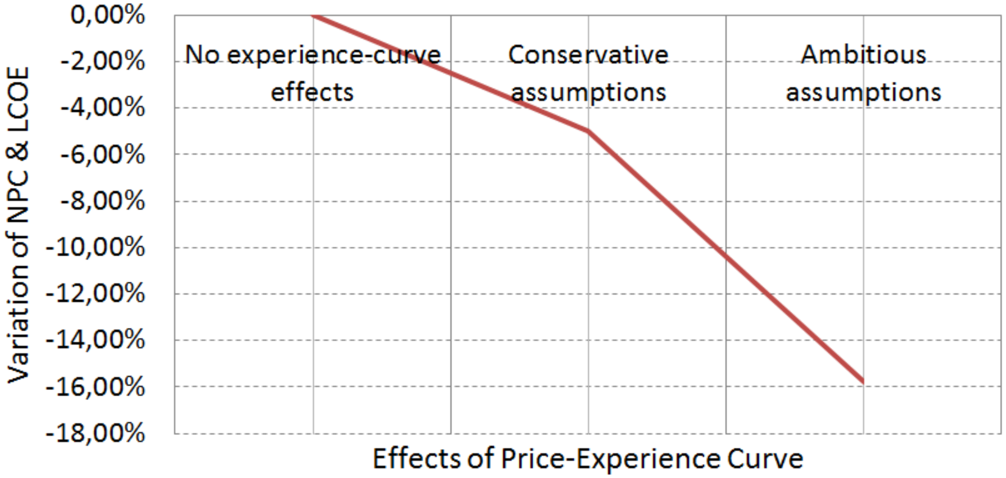


Source: [6] *Agora Energiewende: Current and Future Cost of Photovoltaics*, Fraunhofer ISE

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

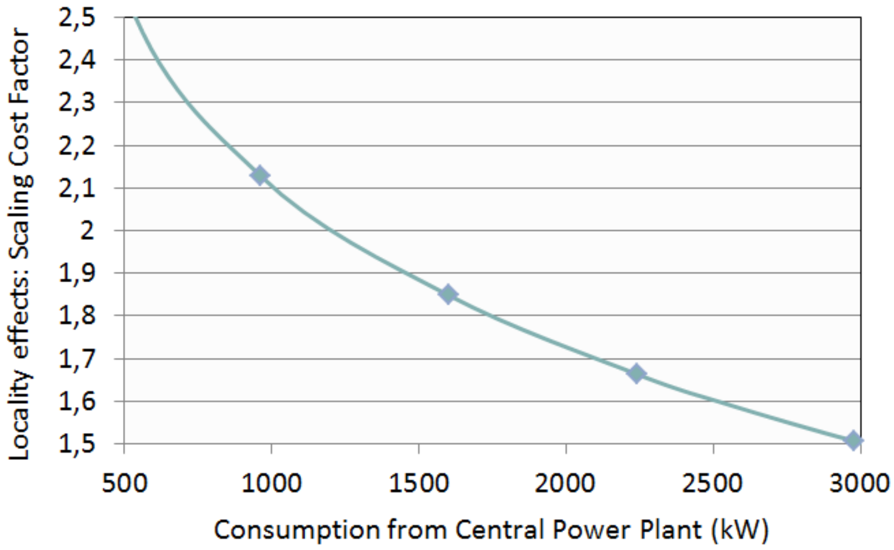
- Price-experience curve effects
  - Apply to all replacement expenses



© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Economic evaluation
Improvements of LCOE estimation

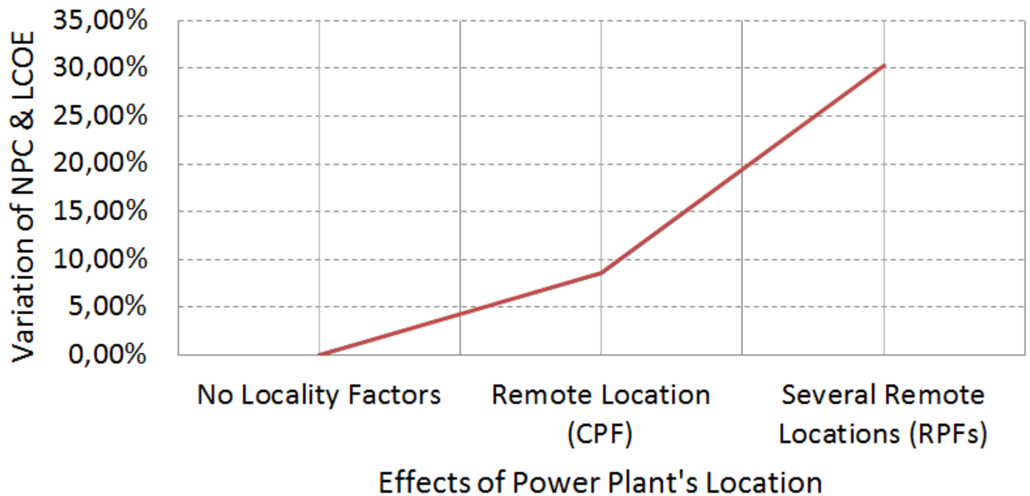
- Locality effects / particularities
  - Fuel costs are not substantially affected (from MWA experience), since yearly fuel demand is high
  - Locality scaling factor applies to installation and O&M costs



© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

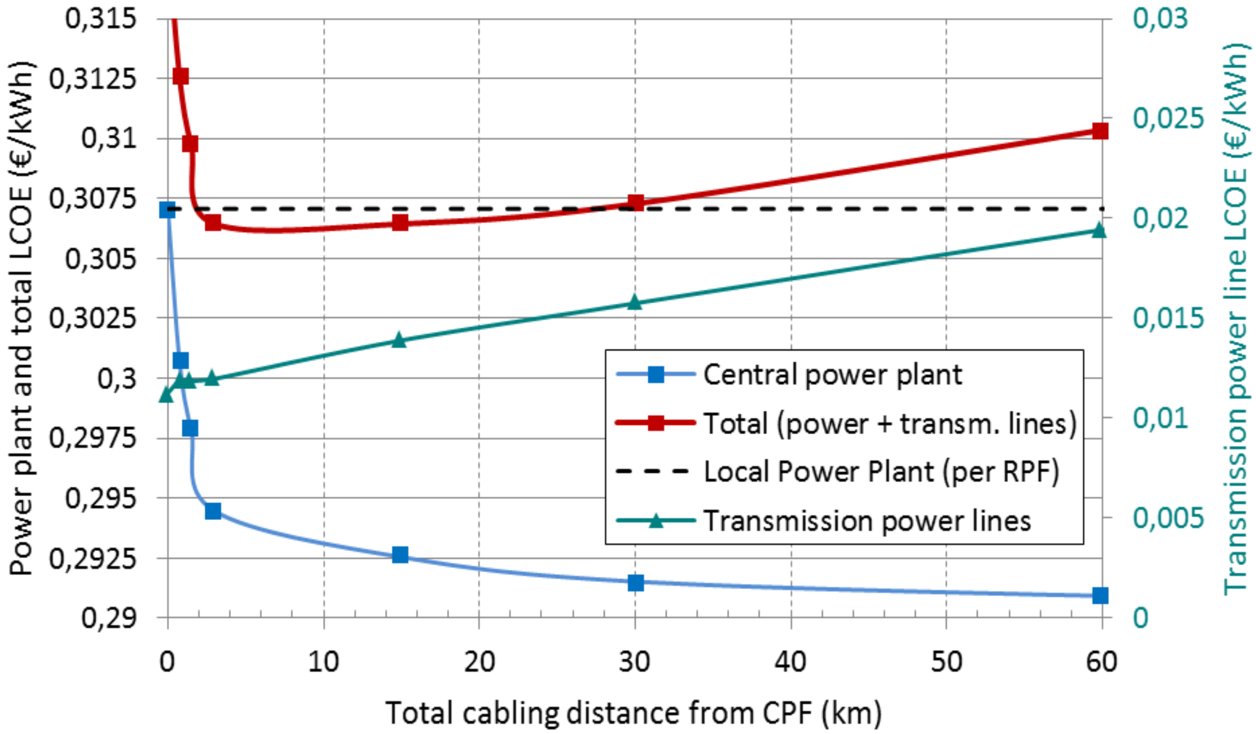
Economic evaluation
Improvements of LCOE estimation

- Locality effects / particularities
  - Fuel costs are not substantially affected (from MWA experience), since yearly fuel demand is high
  - Locality scaling factor applies to installation and O&M costs



© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Final design proposal



© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Final design proposal

- Central power plant powering 80% of total telescope load (2,400 kW)
  - Solar PV: 17 MWp / 9MW
  - Li-Ion BSS: 40 MWh / 5.5MW
  - Diesel Gen. Set: 3.2 MW
- 20% outermost antennas clusters, powered locally
  → 15 RPFs (distance from CPF > 10km)
- LCOE = 0.307 €/kWh

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

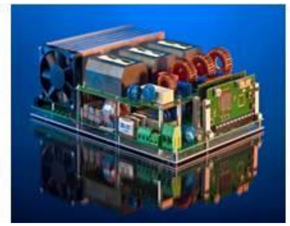
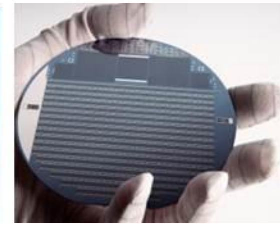
Conclusions

- At the studied site, in outback Western Australia, an **all-renewables** system (PV+Battery) **is economical for capacity shortage > 3%** Higher power reliability (or self-sufficiency) requires diesel integration
- Cooling requirements add up to 25% power under hot conditions However, it translates to only 3% increase in yearly energy consumption
- Up to **30% LCOE increase for this very remote location**, due to increased transport and installation costs
- **Price-experience curve is essential** for an accurate estimation of LCOE and NPC (**up to 15% LCOE decrease** due to high share of battery replacement expenses)
- Even with very high cabling costs, scale effects favor **central power generation** model for **up to 80% of the telescope load**

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Thank you for your attention!




Fraunhofer Institute for Solar Energy Systems ISE

Lluís Millet Biosca

www.ise.fraunhofer.de

lluis.millet.biosca@ise.fraunhofer.de

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL

Fraunhofer ISE