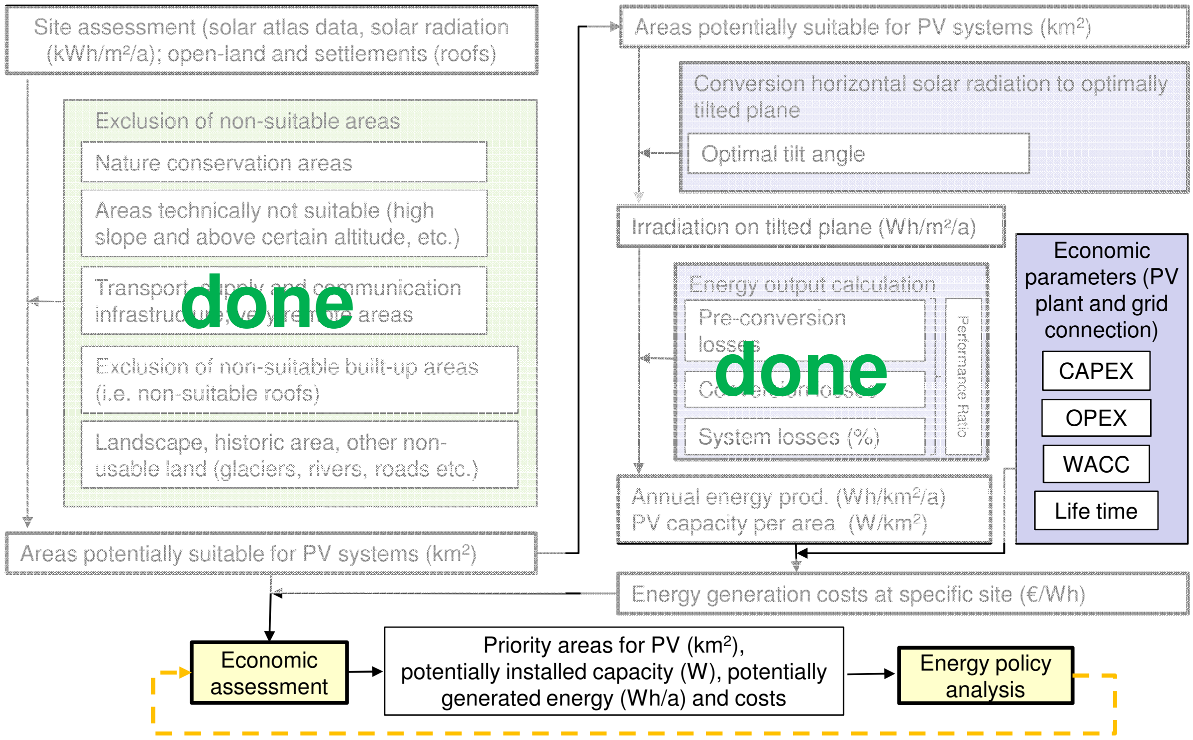
Session 3:
Economic assessment of PV and wind for energy planning

IRENA Global Atlas
Spatial planning techniques
2-day seminar

Central questions we want to answer

1. Once we know how much electricity can be produced in our country with given resources (technical potential), we will be able to **estimate their generation costs**
2. As all available data comes with uncertainties, we should know
   a. how **sensitive** results react on changing input parameters, and,
   b. what **socio-economic effect** highly uncertain input data could have.



CAPEX = Capacity expenditure, OPEX = Operation expenditure, WACC = Weighted average cost of capital (depth, equity)

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2. Worked example: LCOE sensitivity of PV projects
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4. Worked example: Effects of data uncertainty on the LCOE of PV

1. LEVELIZED COST OF ELECTRICITY (LCOE)

Levelized Cost of Electricity (LCOE)

- Calculates the average cost per unit electricity. LCOE takes into account the time value of money (i.e. capital costs).

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Q_{el}}{(1+i)^t}}$$

Where:

- LCOE: Average Cost of Electricity generation in $/unit electricity
- I_0: Investment costs in $
- A_t: Annual total costs in $ in each year t
- Q_{el}: Amount of electricity generated
- i: Discount interest rate in %
- n: useful economic life
- t: year during the useful life (1, 2, …n)

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Levelized Cost of Electricity (LCOE) - example

Price per kWh	10				
Cost of capital	5%				
Year	**0**	**1**	**2**	**3**	**4**
CAPEX (=Investment)	4000	0	0	0	0
OPEX	0	900	1200	800	800
Total expenses	-4000	-900	-1200	-800	-800
kWhs sold	0	280	260	180	160
Revenues	0	2800	2600	1800	1600
Annual cumulated cash flows	-4000	1900	1400	1000	800
Cumulated inflow (static)	-4000	-2100	-700	300	1100
Discount factor	1,00	0,95	0,91	0,86	0,82
Discounted cash flows	-4000	1810	1270	864	658
Net present value	601				
Internal Rate of Return	12,46%	Net present value at IRR:			0
LCOE	9,24				

I_0 + Total disc. annual costs

/

Total disc. annual electricity generation

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LCOE: Pros and cons

Interpretation:

LCOE = Total Life Cycle Cost / Total Lifetime Energy Production

- Analytical tool which allows to compare alternative technologies with different scales of operation, investments or operating periods.

PRO

- Strongly depends on underlying assumptions, especially the interest rate
- Interest rate difficult to define
- The same interest rate is applied to revenues (electricity generation and costs)

CONS

Worked example:

2. LCOE SENSITIVITY OF PV PROJECTS

Worked example – Grid-tied PV in Tanzania

• Project type:	Grid-tied
• Location at latitude:	5° South
• Reference irradiation:	2100 kWh/m²/a
• Reference specific yield (P50):	1580 MWh/MWp
• System size:	10 MWp
• Specific project CAPEX:	2.000.000 USD/MWp
• Project annual OPEX:	1.5% of project CAPEX
• Discount rate (WACC):	8%
• Project duration:	25 years
• Inverter replacements:	2
• Solar panel degradation:	0,7% p.a. (linear)

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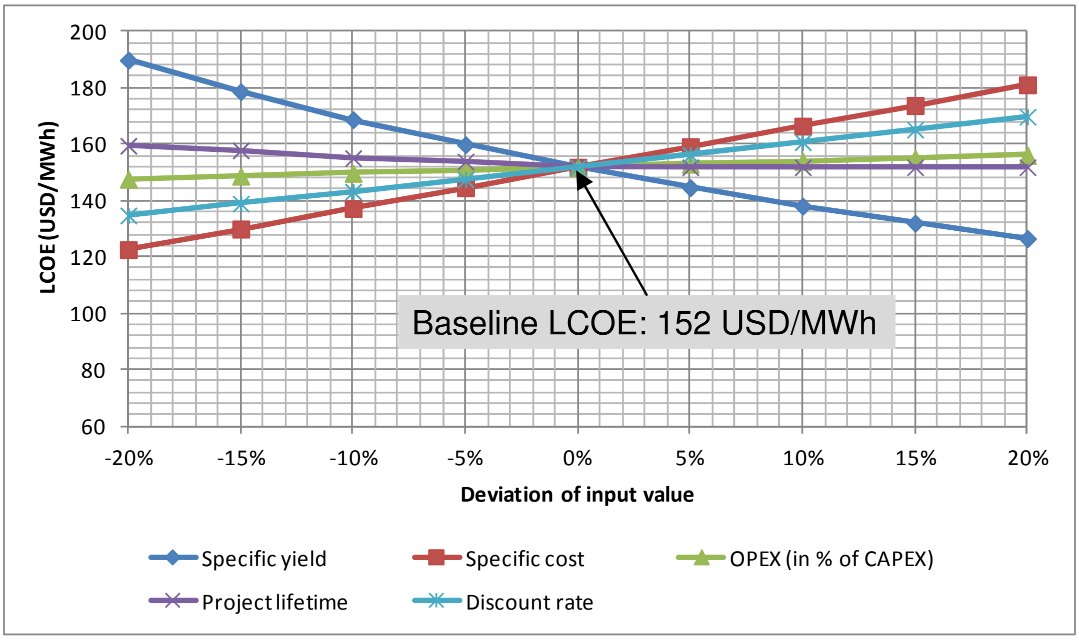
LCOE sensitivity (absolute)



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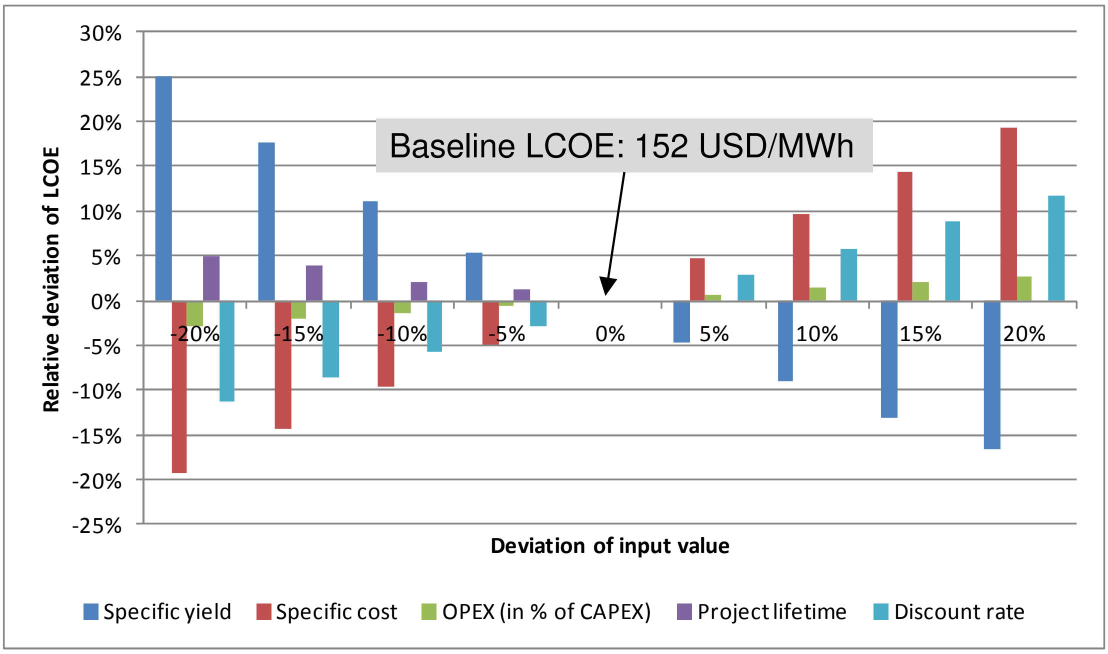
LCOE sensitivity (relative)



Worked example:

3. LCOE SENSITIVITY OF WIND PROJECTS

Worked example – Grid-tied wind project in Tanzania (variation A)

Project type:	Grid-tied wind
Location at latitude:	Near Arusha / TZ
Average wind speed @ 80m:	7.3 m/s
Wind distribution, shape parameter:	3.5
Wind distr., scale parameter:	8.11
Technical availability:	97%
Reference specific yield (P50):	3,202 MWh/MW (techn. Availability considered)
Capacity factor:	36.6%
System size:	8 MWp (4 turbines)
Specific project CAPEX:	4.000.000 USD/MWp
Project annual OPEX:	3.0% of project CAPEX
Discount rate (WACC):	8%
Project duration:	20 years

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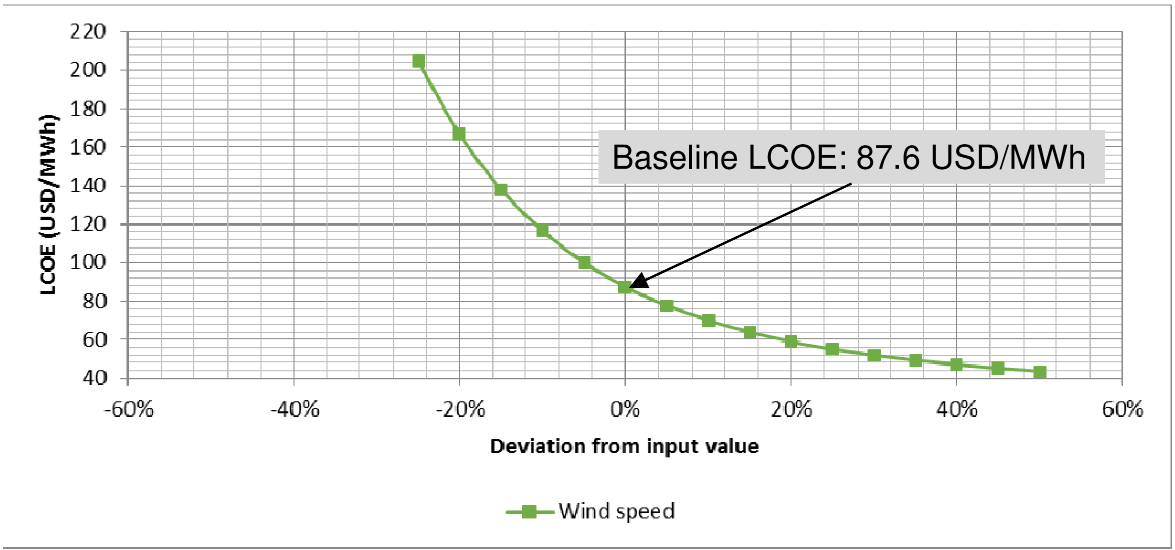
LCOE sensitivity (absolute) – Wind speed only



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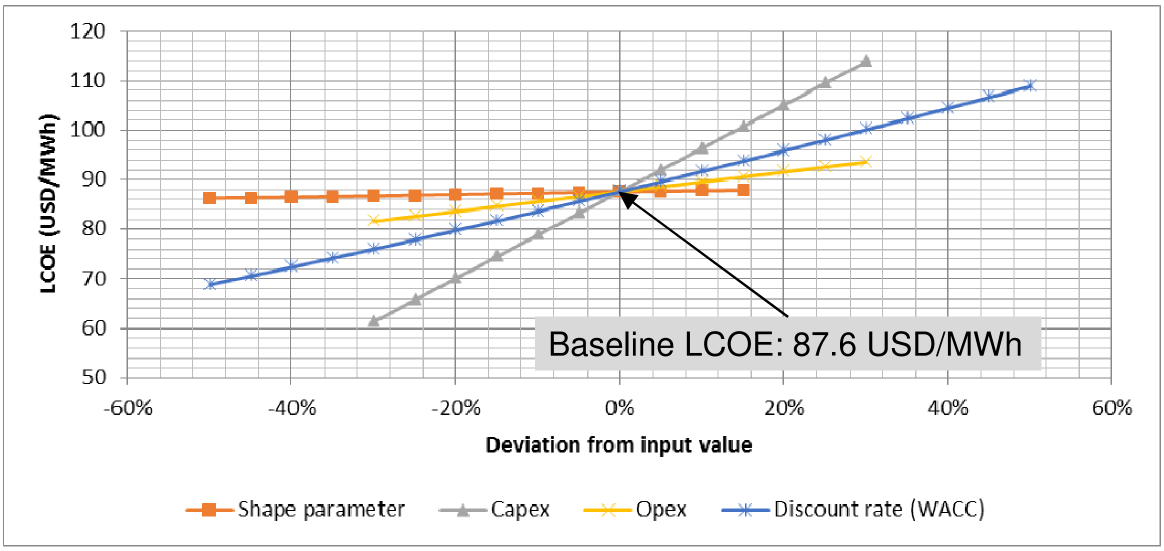
LCOE sensitivity (absolute) – other parameters



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Worked example – variation B: lower wind speed & lower shape parameter

- Project type: Grid-tied wind
- Location at latitude: Near Arusha / TZ
- Average wind speed @ 80m: ~~7.3 m/s~~ **5.5 m/s**
- Wind distribution, shape parameter: ~~3.5 m/s~~ **1.5 m/s**
- Wind distr., scale parameter: **6.11**
- Technical availability: 97%
- Reference specific yield (P50): 3,202 MWh/MW (techn. Availability considered)
- Capacity factor: 36.6%
- System size: 8 MWp (4 turbines)
- Specific project CAPEX: 4.000.000 USD/MWp
- Project annual OPEX: 3.0% of project CAPEX
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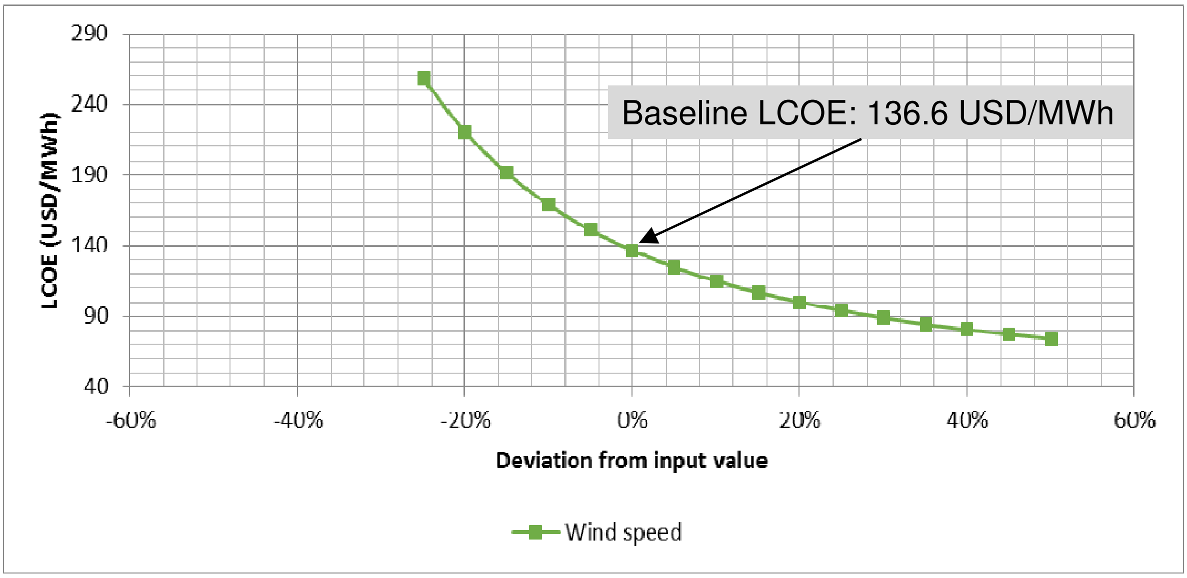
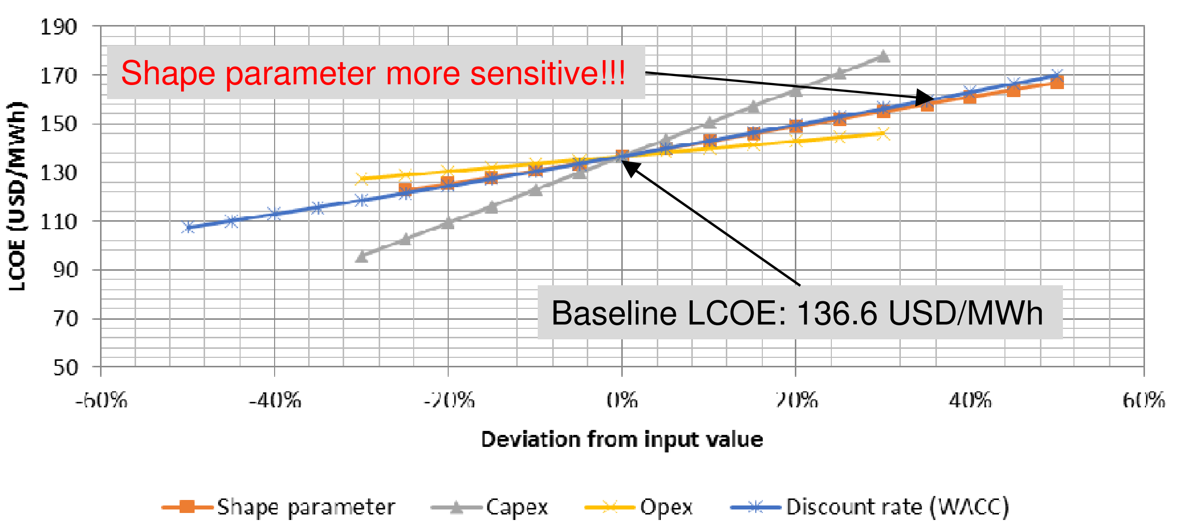
LCOE sensitivity (absolute) – Wind speed only



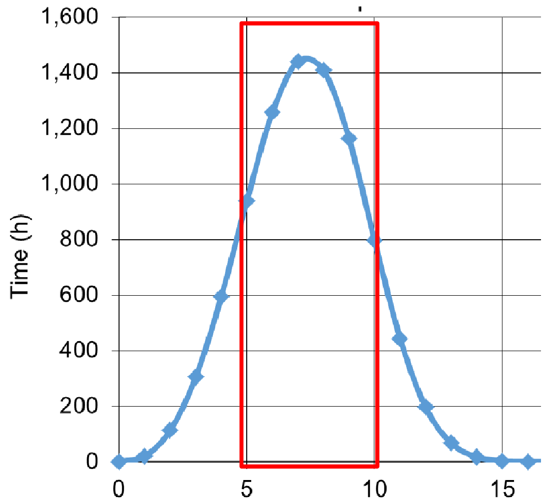
LCOE sensitivity (absolute) – other parameters

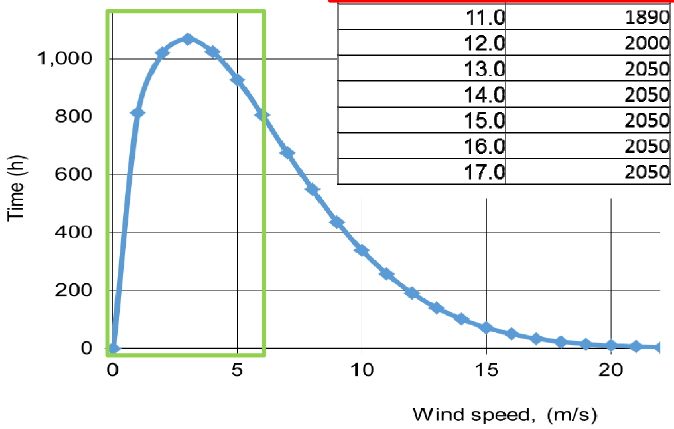


Conclusions on sensitivities and for scenario development

- Variations of the shape parameter of the Weibull distribution of wind can have very different effects depending on the chosen scenario
  - In variation A (high wind, high shape factor), varying of the shape factor only had a **very little effect** on the LCOE.
  - In variation B (lower wind, lower shape factor), varying of the shape factor had a **considerable effect** on the LCOE.
  - **Reason**: the chosen wind turbine for the scenario has a power curve which operates better under stronger winds. The Weibull function produces a wind distribution where relative low wind speeds occur comparably often.
  - It is crucial for wind scenario developments, to chose appropriate turbines for sites with different wind speeds and wind speed distributions.

Comparison of Weibull curves for variations A (left) + B (right)





v_i (m/s)	Output power of E82-2000, (kW)
0.0	
1.0	0
2.0	3
3.0	25
4.0	82
5.0	174
6.0	321
7.0	532
8.0	815
9.0	1180
10.0	1612
11.0	1890
12.0	2000
13.0	2050
14.0	2050
15.0	2050
16.0	2050
17.0	2050

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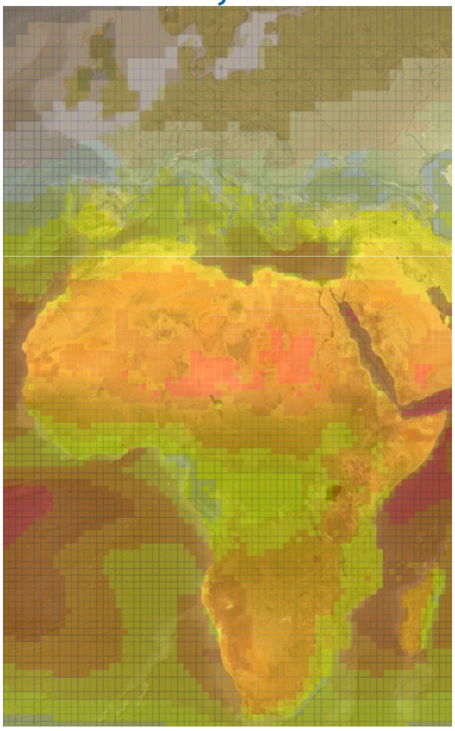
Worked example:

4. EFFECTS OF DATA UNCERTAINTY ON THE LCOE OF PV

Sample solar data source 1: NASA SSE, release 6

- Satellite data
- Global coverage
- Data period: 1983 - 2005
- Resolution
  - 1° Latitude x 1° Longitude
  - ~ 100 x 100 km
- Average uncertainty
  - GHI: 13,7% (on tilted solar panels)

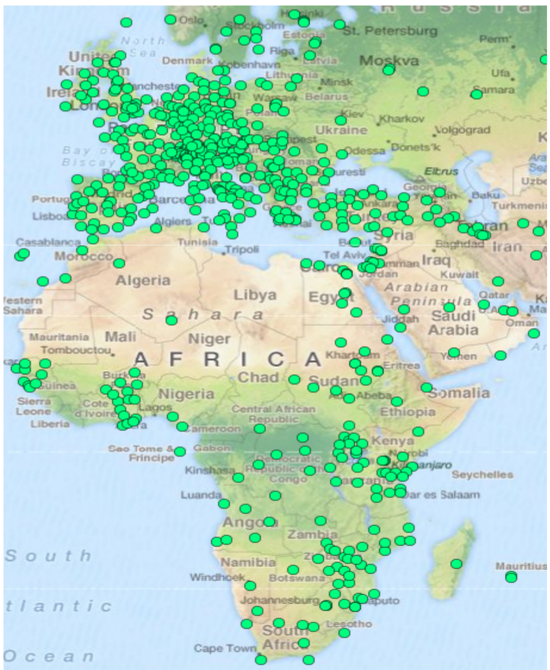


**GHI: Global Horizontal Irradiation*
**DNI: Direct Normal Irradiation*
**DHI: Diffuse Horizontal Irradiation*

Source: NASA SSE release 6 - Methodology
Picture: Global Atlas screenshot

Sample solar data source 2: Meteonorm, release 7

- Ground stations and/or satellite data
- Global coverage (8.325 ground sites)
- Data period satellites: 2004 - 2010
- Resolution
  - When no ground source is available,data is interpolated from nearest ground sources and/or satellite data
- Average uncertainty
  - GHI: 3…12% (on tilted solar panels)
  - DNI: 3.5…20%



Source: Meteonorm, release 7 - Handbook
Picture: Meteonorm 7 screenshot

Sample data source 3: Ground measurement station

- Highest possible accuracy for a specific location (<=3%)
- Long-term average needed (years!)
- Regular maintenance / data plausibilty check

*DNI = GHI - DHI

Source: DLR

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Why data quality is so important

- All data comes with **uncertainties**:
  - **Measurements** are always subject to deviations, and ,
  - **models** used for predictions can never simulate what happens in reality.
- It is obvious that the lower uncertainty is the more accurate predictions will be. This, in turn, will enable us to **make better estimates**.
- In the following, we will demonstrate how good data (i.e. data with low uncertainties) will potentially help **saving funds** for PV Power Purchase Agreements.

Uncertainty assumptions

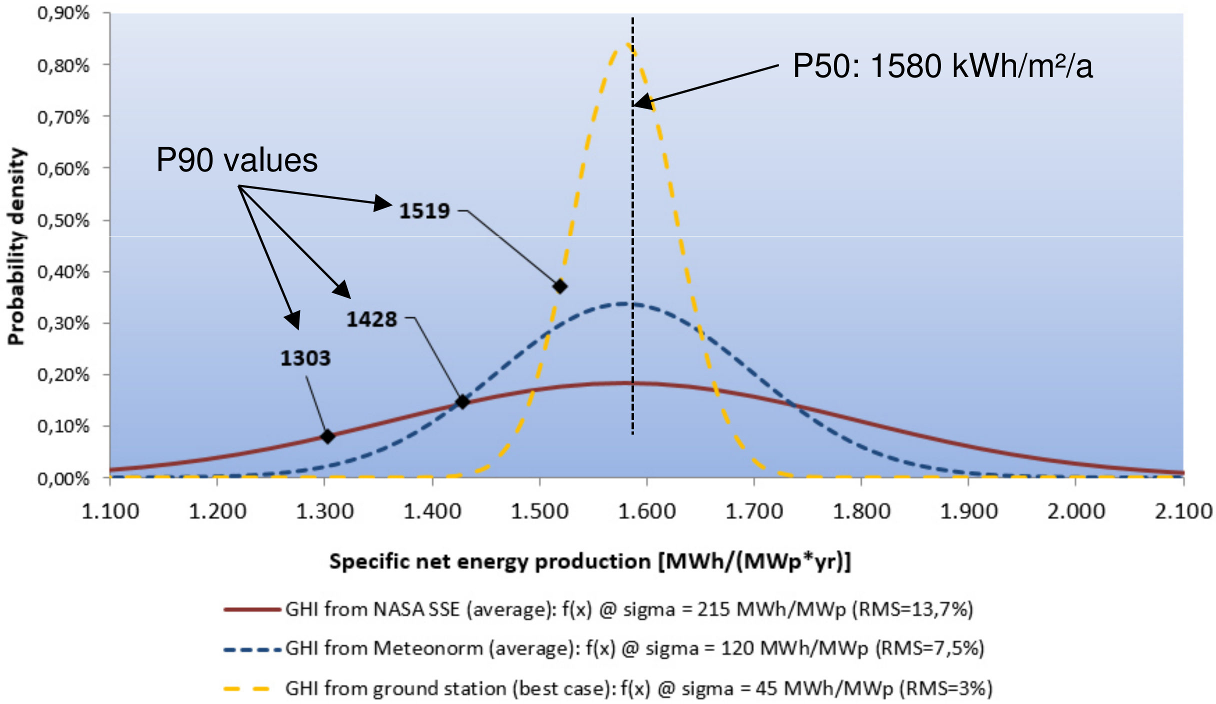
- Low resolution NASA SSE data: +/- 13,7%
- Average Meteonorm 7 data: +/- 7,5%
- Best ground measurement at site: +/- 3,0%

- **Important note**: Besides uncertainty of irradiation data, there is also uncertainty within the simulation model and nameplate capacity. However, the latter are comparably small so that we will, to keep the example simple, only look at resource uncertainty. In real-life, when it comes to detailed project development, one should always ask the project developer to provide information about his uncertainty assumptions.

Worked example – Grid-tied PV in Tanzania

- Project type: Grid-tied
- Location at latitude: 5° South
- Reference irradiation: 2100 kWh/m²/a
- Reference specific yield (P50): 1580 MWh/MWp
- System size: 10 MWp
- Specific project CAPEX: 2.000.000 USD/MWp
- Project annual OPEX: 1.5% of project CAPEX
- Discount rate (WACC): 8%
- Project duration: **30 years**
- Inverter replacements: 2
- Solar panel degradation: 0,7% p.a. (linear)

Exceedance probability



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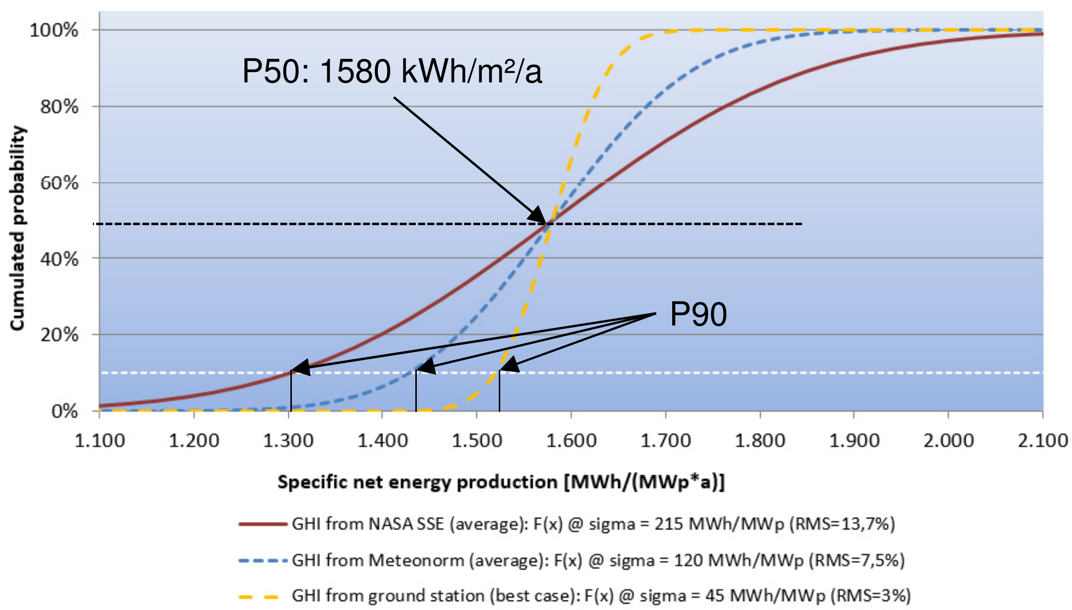
Exceedance probability (alternative view)



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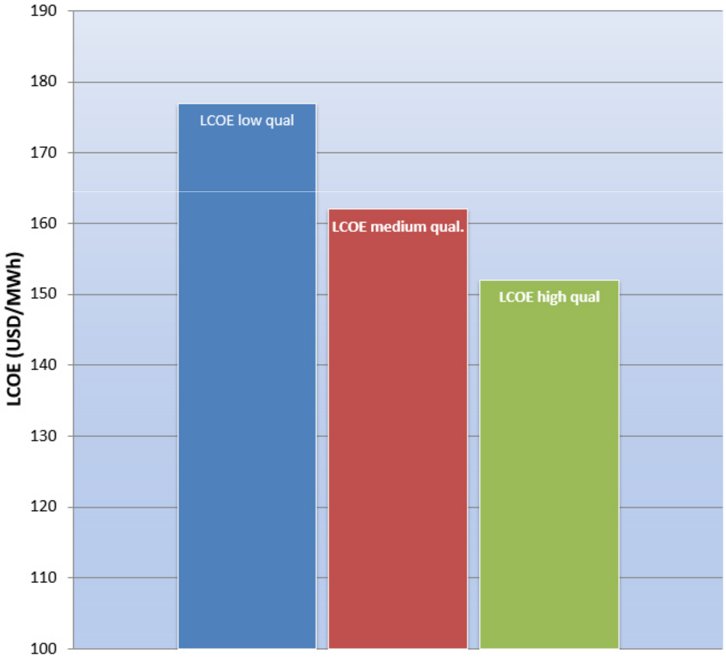
LCOE depends on quality of meteo data



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LCOE is key factor for PPA tariff calculation

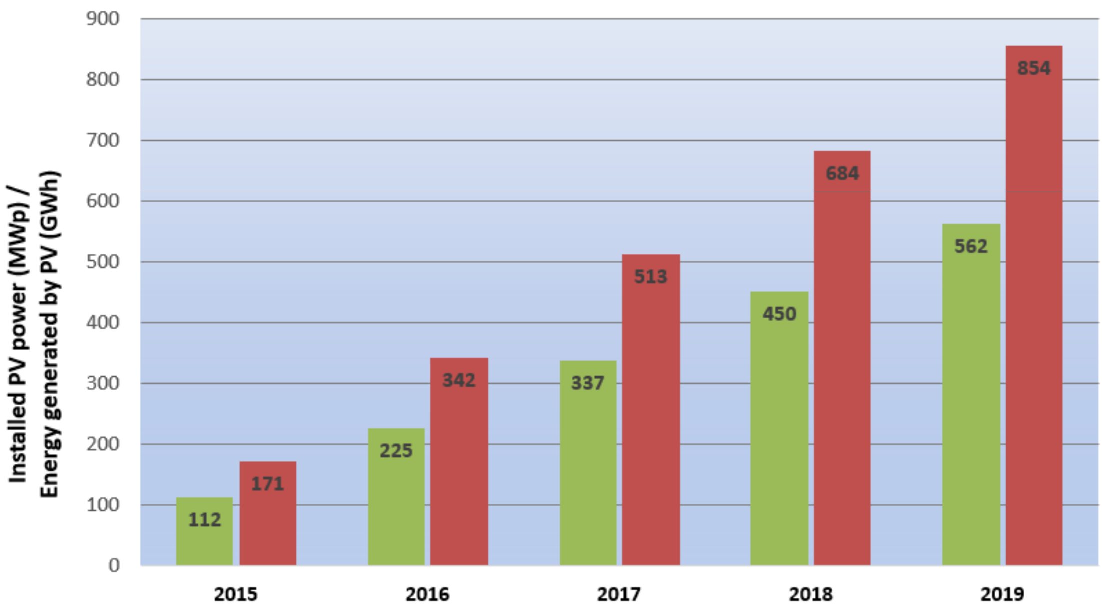
- Assuming a 10% premium on the LCOE as margin for IPP
  - Best case: 152 USD/MWh +10% = 167 USD/MWh
  - Worst case: 177 USD/MWh +10% = 195 USD/MWh
  - Delta: 28 USD/MWh (incl. 10% premium)

Country sets a 20% PV goal by 2020

• Sample:	Tanzania
• Total electricity demand 2012:	4.3 TWh (Source: Google Public Data)
• 20% of total:	0.9 TWh
• PPA tariff difference:	28 USD/MWh
• „Unnecessary“ payments:	9000,000 MWh * 28 = 23.5 Mio USD p.a.
• PV power needed:	562 MWp (with best P90 value)

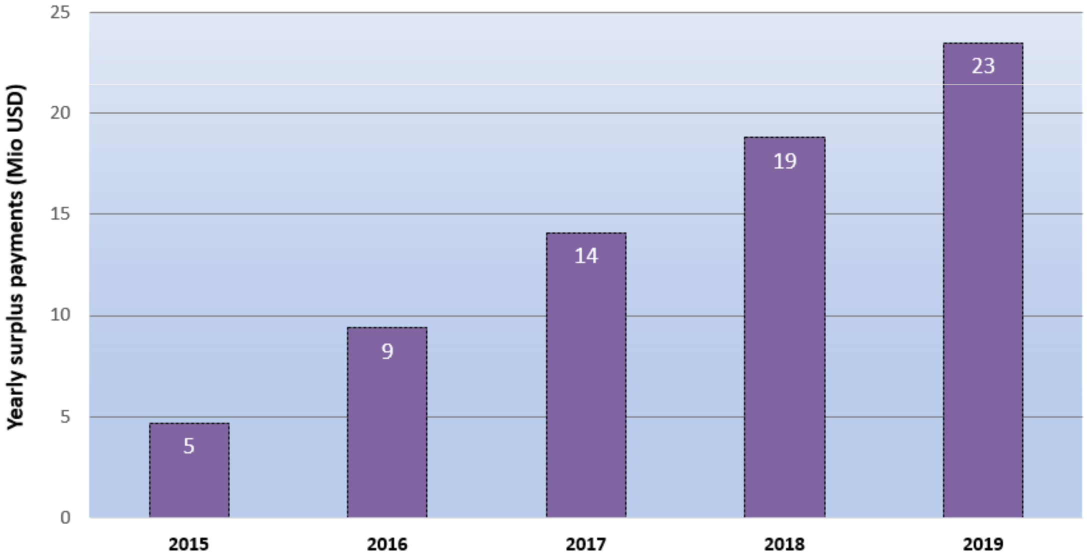
Country sets a 20% PV goal by 2020

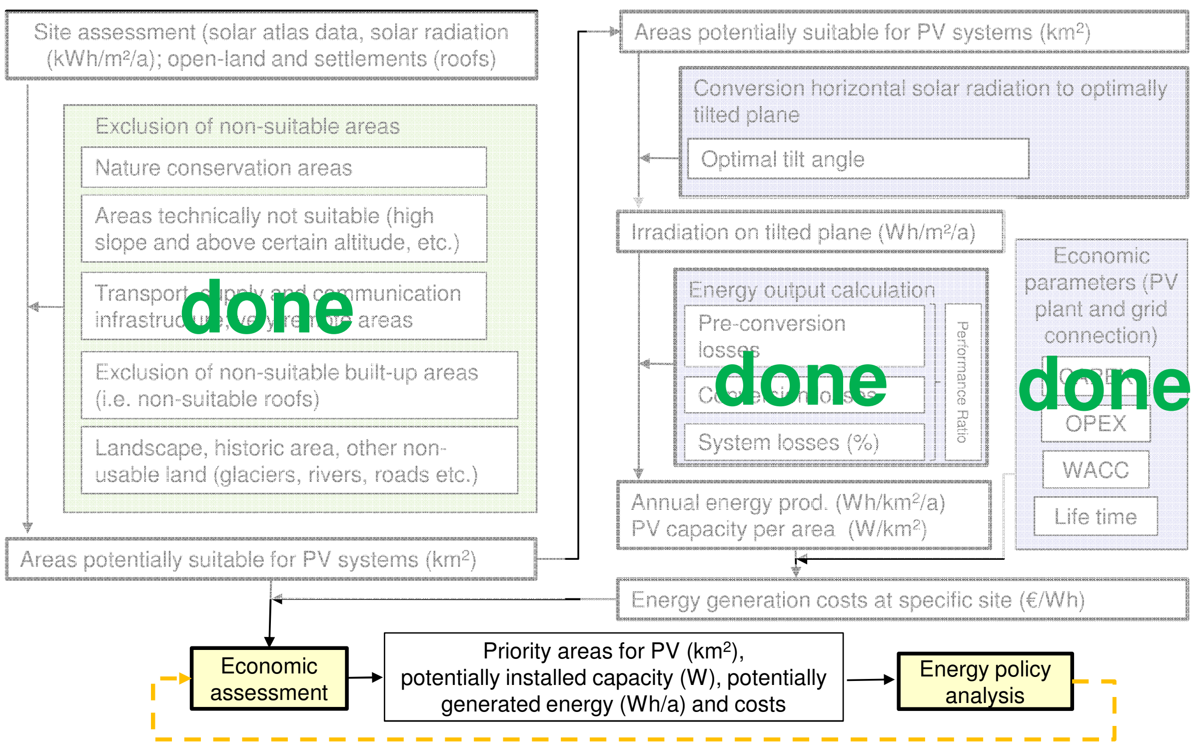
- PV power needed by 2020: 562 MWp (with best P90 value)



„Unnecessary“ payments due to inaccurate data

- VV power needed by 2020: 562 MWp (with best P90 value)
- **Aviodable payments: 70 Mio USD**





CAPEX = Capacity expenditure, OPEX = Operation expenditure, WACC = Weighted average cost of capital (depth, equity) renac renewables academy

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Thank you very much for your attention!

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