TASK 13 WORKSHOP: PV System Performance and PV Module Reliability

Technical Assumptions used in PV Financial Models

(report download: http://www.iea-pvps.org/)

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Main messages

- Financial risks is more than energy generation uncertainty
- Risk mitigation may include a detailed project assessment by an independent Technical Advisor
- Uncertainties can be quantification and included in the financial model
- Risk mitigation can include illustrative graphs of the calculated distribution of possible output metrics like the IRR
Motivation

Solarpark Vandel I, Denmark: 74.2 MWp
Sold to Allianz Global Investors GmbH
Project financing by HSH Nordbank up to 30 m€
Risk mitigation by investor

**Strategize**
- Top level must define mitigation strategy, define quality ambitions - and hire a Technical Advisor (TA)

**Classify**
- TA shall inspect PV project and verify compliance to industry standard design and solutions

**Understand**
- Root causes of observations and non-conformance must be identified and impact on financial performance assessed

**Manage**
- Ensure sufficient QC and follow-up is implemented
PV Financial model

1. Project
   - Task 13
   - Project type: Fixed tilt

2. Site
   - Horizontal global irradiation (GHI): 1,050,0
   - Reference yield (irradiation in the POA) (Y_r): 1,207,5

3. Engineering design
   - DC power for park: 10,000,0

4. Energy yield assessment
   - Irradiation loss due to shading: 2,00%
   - Module loss due to incidence/reflection (IAM): 3,00%
   - Specific energy yield (Y_f): 1,017,2
   - Performance Ratio (Y_f/Y_r): 84,24%

5. Capital expenditures
   - Turn-key installation cost in total: 700,00

6. Power production & power sales
   - Technical unavailability: 1,0%
   - Feed-In-Tarif - price year #1: 53,8

7. Operational expenses
   - A0. Land lease - fee per area: 2,000
   - B1. O&M - fixed yearly fee: 40,000
   - C1. Insurance - fixed yearly fee: 10,000
   - G1. Other cost - fixed yearly fee (e.g. Monitor): 5,00

8. Financing
   - Economical operational lifetime: 30

9. Revenues
   - Power production delivered to the grid [MWh]: 281,188
   - Revenue from power sales [EUR]: 14,102,274
   - Project IRR by CAPEX: 2,94%
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1. Project framework

- Planning conditions conformance: restriction zones, hedgerows, fence type, height of panels..
- Geotechnical survey: ramming depth, drainage..
- Environmental impact assessment: fauna protection..
- Climatic and air conditions: nearshore location, salt-mist & ammonia resistance, special sources of soiling..
- Landscape: landslide, visual impact
2. Site specific solar resource estimate

- Validate resource assessment quality and source
- Long term trend
- Uncertainty analysed

Uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate variability</td>
<td>±4% - ±7%</td>
</tr>
<tr>
<td>Irradiation quantification</td>
<td>±2% - ±5%</td>
</tr>
<tr>
<td>Conversion to POA</td>
<td>±2% - ±5%</td>
</tr>
</tbody>
</table>
3. Engineering, design

- Validation of selected components and conformance to datasheet and specifications

THE Honey™ plus MODULE
TSM-DD05A.08 (II)

60 CELL
MONOCRYSTALLINE MODULE

275–290W
POWER OUTPUT RANGE

17.7%
MAXIMUM EFFICIENCY

0/+5W
POSITIVE POWER TOLERANCE

Excellent low light performance on cloudy days, mornings and evenings
- Excellent low light performance on cloudy days, mornings and evenings
- Improved surface area
- Improved surface area

Maximize limited space with top-end efficiency
- up to 177 W/m² power density
- Low thermal coefficients for greater energy production at high operating temperatures

Good aesthetics for residential applications
- Quiet micro-inverters
- Quiet micro-inverters

Highly reliable due to stringent quality control
- Over 200 in-house tests [VOC, TC, FT, and many more]
- In-house testing gives overall beyond certification requirements
- All modules have to pass electro-luminescence (EL) inspection
- PIC/INEN inspection
- 1000 VAC/1000 VDC IEC certified

Certified to withstand challenging environmental conditions
- 5400 Pa wind load
- Solar Power (Irradiance)
- 39 mm half-profile at 1,07 km/h
- Normalized mechanical load (long-term)
- Normalized mechanical load (long-term)

LINEAR PERFORMANCE WARRANTY
- 15 Year Product Warranty x 25 Year Linear Power Warranty

88 kVA transformerless solar inverters

Technical data M89H

<table>
<thead>
<tr>
<th>Model</th>
<th>M89H</th>
<th>88 kVA</th>
<th>110 kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Power</td>
<td>420 VDC</td>
<td>420 VDC</td>
<td>420 VDC</td>
</tr>
<tr>
<td>Output Power</td>
<td>88 kW</td>
<td>110 kW</td>
<td>110 kW</td>
</tr>
<tr>
<td>Frequency</td>
<td>50/60 Hz</td>
<td>50/60 Hz</td>
<td>50/60 Hz</td>
</tr>
<tr>
<td>Browser</td>
<td>230 V AC 1000 V DC</td>
<td>230 V AC 1000 V DC</td>
<td>230 V AC 1000 V DC</td>
</tr>
<tr>
<td>Surge Protection Class</td>
<td>Type 2, EN 61643-11</td>
<td>Type 2, EN 61643-11</td>
<td>Type 2, EN 61643-11</td>
</tr>
<tr>
<td>Input Power Factor</td>
<td>&gt; 0.9</td>
<td>&gt; 0.9</td>
<td>&gt; 0.9</td>
</tr>
<tr>
<td>Input Voltage Tolerance</td>
<td>± 10%</td>
<td>± 10%</td>
<td>± 10%</td>
</tr>
<tr>
<td>Output Voltage Tolerance</td>
<td>± 2.5%</td>
<td>± 2.5%</td>
<td>± 2.5%</td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt; 95%</td>
<td>&gt; 95%</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>DC Arc Protection</td>
<td>4.5 x Iq (10–14 times)</td>
<td>4.5 x Iq (10–14 times)</td>
<td>4.5 x Iq (10–14 times)</td>
</tr>
<tr>
<td>AC Arc Protection</td>
<td>4.5 x Iq (10–14 times)</td>
<td>4.5 x Iq (10–14 times)</td>
<td>4.5 x Iq (10–14 times)</td>
</tr>
<tr>
<td>Power Rating</td>
<td>88 kVA</td>
<td>110 kVA</td>
<td>110 kVA</td>
</tr>
<tr>
<td>Protection</td>
<td>Transformerless</td>
<td>Transformerless</td>
<td>Transformerless</td>
</tr>
</tbody>
</table>

United Kingdom
Email: sales.uk@delta-energy.com
Tel: 0800 261 4260 (Price Line)

International
Email: sales european@delta-energy.com
Tel: +49 7541 455 547

www.delta-energy.com
4. Energy yield: Modelling

- Validation of model and input assumptions

**Uncertainties**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature model</td>
<td>1° C - 2° C</td>
</tr>
<tr>
<td>PV array model</td>
<td>± 1% - ± 3%</td>
</tr>
<tr>
<td>PV inverter model</td>
<td>± 0.2% - ± 0.5%</td>
</tr>
</tbody>
</table>
5. CAPEX: quality, PR, Guaranties

- What is the impact of lack of quality:
  - microcracks observed in the field?
  - missing zinc coating protecting
  - insufficient cable protection
  - missing duct closure

- How do we address such quality issues in the PV Financial model?

- These issues are not covered by a PR guarantee...
6. Power sales

- What is the business model: FIT, Market premium, PPA?
- Energy marked: Balancing cost, negative prices?
- Grid connection: curtailment, grid support, Power Factor
- Inverter: Power Factor capability, reactive power during night?
- Technical Unavailability
7. Operation & Maintenance

- Schedule for grass cutting and panel cleaning
- PR guarantee by O&M provider or EPC?
- Availability guarantee/ambitions impact O&M cost
- Provisional Acceptance Test: PR assessment over a long period w/o Temperature correction
8. Financing

- Financial input parameters not in scope of this work:
  - Financial lifetime of project, depth/equity ratio, interest, depreciation, tax rate, asset management fee, reserve account etc...

<table>
<thead>
<tr>
<th>8. Financing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical operational lifetime</td>
</tr>
<tr>
<td>Real discount rate for LCOE calculations</td>
</tr>
<tr>
<td>Bank interest - deposit</td>
</tr>
<tr>
<td>Loan #1 - Depth ratio</td>
</tr>
<tr>
<td>Loan #1 - Interest</td>
</tr>
<tr>
<td>Loan #1 - Maturity</td>
</tr>
<tr>
<td>Loan #1 - Grace period</td>
</tr>
<tr>
<td>Loan #1 - change in interest p.a.</td>
</tr>
<tr>
<td>Loan #1 - Type</td>
</tr>
<tr>
<td>Capitalised depreciable project costs - unlevered</td>
</tr>
<tr>
<td>DSRA funding in percent of next year instalments</td>
</tr>
<tr>
<td>Loan arrangement fee (loan no 1 only)</td>
</tr>
<tr>
<td>Tax depreciation (accelerated)</td>
</tr>
<tr>
<td>Tax depreciation (linear)</td>
</tr>
<tr>
<td>Tax rate</td>
</tr>
<tr>
<td>Decommissioning bond - total reserve</td>
</tr>
<tr>
<td>Decommissioning bond - First year to build bond</td>
</tr>
<tr>
<td>Decommissioning bond - no of years to build bond</td>
</tr>
</tbody>
</table>
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**PV financial model: inputs parameters**

**System Parameters**
- Module power
- Solar Resource
- Ground/roof coverage
- Module tilt
- Array azimuth

**Loss Parameters:**
- Shading
- Soiling
- Temperature
- Initial degradation
- Annual degradation

**Project Parameters**
- Licencing costs
- Installation costs
- Unavailability
- O&M fixed costs
- O&M contingencies

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Garbage In = Garbage Out
### Feasibility – based on parameters:

Most parameters used in simulations are accompanied by a variance:

<table>
<thead>
<tr>
<th>1. Project</th>
<th>Best estimate</th>
<th>Risk/uncertainty distribution function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module Power ( [W_p] )</td>
<td>270.0</td>
<td>Uniform distribution: ( \text{Min}=270.0; \text{Max}=278.1 ) (-0/+3%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Site</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal global irradiation ( \text{kWh/m}^2/\text{year} )</td>
<td>1.050.0</td>
<td>Normal distribution: ( \mu=1050; \sigma=5% ) of 1050</td>
</tr>
<tr>
<td>Irradiation increase due to tilt angle ( [%] )</td>
<td>15.00%</td>
<td>Normal distribution: ( \mu=0.15; \sigma=2% ) of 0.15</td>
</tr>
<tr>
<td>Ground Coverage Ratio ( [%] )</td>
<td>40.7%</td>
<td>Triangular distribution: ( \text{Min}=30%; \text{Mode}=41%; \text{Max}=50% )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Energy yield assessment</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiation loss due to shading ( [%] )</td>
<td>2.00%</td>
<td>Normal distribution: ( \mu=0.02; \sigma=1.5% ) of 0.02</td>
</tr>
<tr>
<td>Irradiation loss due to soiling ( [%] )</td>
<td>1.00%</td>
<td>Uniform distribution: ( \text{Min}=0.0%; \text{Max}=3.0% )</td>
</tr>
<tr>
<td>Module loss due to temperature ( [%] )</td>
<td>1.50%</td>
<td>Normal distribution: ( \mu=0.015; \sigma=1.0% ) of 0.015</td>
</tr>
<tr>
<td>Module loss due to LID/deviation from nominal power ( [%] )</td>
<td>2.00%</td>
<td>Triangular distribution: ( \text{Min}=0.0%; \text{Mode}=2.0%; \text{Max}=5.0% )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Capital Expenditures</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn-key installation cost in total ( \text{EUR/kWp} )</td>
<td>700.00</td>
<td>Uniform distribution: ( \text{Min}=600; \text{Max}=750 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5. Power production &amp; power sales</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical unavailability ( [%] )</td>
<td>1.0%</td>
<td>Triangular distribution: ( \text{Min}=0.0%; \text{Mode}=1.0%; \text{Max}=3.0% )</td>
</tr>
<tr>
<td>PV system (module) degradation ( [%/year] )</td>
<td>0.50%</td>
<td>Triangular distribution: ( \text{Min}=0.0%; \text{Mode}=0.5%; \text{Max}=0.8% )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. Operational expenses</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O&amp;M - fixed yearly fee ( \text{EUR/year} )</td>
<td>40.000</td>
<td>Normal distribution: ( \mu=40.000; \sigma=5% ) of 40.000</td>
</tr>
</tbody>
</table>
Feasibility – based on parameters:

Uniform Distribution $-0/+3\%$
Feasibility – based on parameters:

Normal Distribution
Feasibility – based on parameters:

Triangular Distribution
Feasibility – based on parameters:

P50

Triangular Distribution
Feasibility – based on parameters:
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A Feasible Outcome

First Year Energy Production

Revenue from Energy Sales

Project IRR by CAPEX

Leveraged IRR after Tax
A Feasible Outcome

First Year Energy Production

Pareto Plot for Power production delivered to the grid [MWh]

- **P50**: Probability at 50th percentile
- **P90**: Probability at 90th percentile
Visual Aids

Tornado Plot for Power production delivered to the grid [MWh]

- Horizontal global irradiation [kWh/m2/year]
- PV system (module) degradation (%/yr)
- Module loss due to LID/deviation from nominal power [%]
- Module Power [Wp]
- Irradiation loss due to soiling [%]
- Technical unavailability [%]
- Irradiation increase due to tilt angle [%]
- Module loss due to temperature [%]
- Ground Coverage Ratio [%]
- B1. O&M - fixed yearly fee [EUR/year]
- Turn-key installation cost in total [EUR/kWp]
- Irradiation loss due to shading [%]
- Inverter loss during operation (conversion efficiency) [%]
Visual Aids

Spider Plot for Revenue from power sales [EUR]

- Mean

- Horizontal global irradiation [kWh/m2/year]
- Module loss due to LID/deviation from nominal power [%]
- PV system (module) degradation (%/yr)
- Turn-key installation cost in total [EUR/kWp]
The success of utility scale PV relate to the low LCOE (Levelized Cost of Electricity) obtained by:
- Cheap standard PV modules supplied as a commodity
- Fast, efficient project development and cheap BOS & construction
- Yearly stable and fairly predictable energy yield
- Low maintenance & service cost during 20+ years of operation

Investors need a full PV financial modelling with:
- Energy Yield Modelling, CAPEX, O&M & Financial details
- Risk mitigation strategy based on a Technical Due Diligence

In this work we’ve demonstrated, how uncertain Technical Assumptions can be included in the PV financial model by use of Monte Carlo statistics

Graphical tools of KPI with variability may support the risk mitigation strategies
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Thank you