Case Study of a 20 MW PV Power Plant in El Salvador

Large-Scale Photovoltaic Power Plants for Developing Countries

Fred Wendt, April 2012
Case Study of a 20 MW PV Power Plant in El Salvador

**Agenda**

- 3D Visualization
- Project Description
- Methodology
- Technical Assessment
- Financial Implications
- Economic Assessment
- Project Implementation
- Conclusions
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Project Description

Introduction

- “15 de Septiembre” 14.2 MW
- “Guajoyo” 3.6 MW
- Funded by KfW
- Client CEL (Comision Ejecutiva Hidroelectrica del Rio Lempa)
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Project Description

Results Conceptual Plant Design 15 de Septiembre

- Installed power 14.2 MW
- Module tilt of 12°
- 60,480 x Module 235 W
- 840 x Inverter 15 kW
- ~10,500 piles
- Grid connection 46 kV
- Performance Ratio 78.5%
- Specific Yield 1,615 kWh/kW
- Area 240,000 m²:
  - 32 soccer / 45 football fields
  - area of Champ de Mars, Paris
Project Description

Results Conceptual Plant Design Guajoyo

- Installed power 3.6 MW
- Module tilt of 12°
- 15,552 x Module 235 W
- 216 x Inverter 15 kW
- ~3,000 piles
- Grid connection 46 kV
- Performance Ratio 80.8%
- Specific Yield 1,605 kWh/kW
- Area 61,000 m²:
  - 8 soccer / 11 football fields
  - footprint of Cheops pyramid
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Methodology

Key Questions

- Rapidly evolving technologies
- Favorable political and societal conditions
- Secure revenue structures
- Sustainable investments
- Low-emission
- High operational safety

<table>
<thead>
<tr>
<th>Potentials</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Project reliability</td>
<td>• Changing political and economic market conditions</td>
</tr>
<tr>
<td>• Availability of renewable energy sources</td>
<td></td>
</tr>
</tbody>
</table>

How can the potential electricity generation of the sites in El Salvador be maximized, and technical and legal framework risks be minimized?
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Methodology

Techno-Economic Feasibility Study

**Technical Assessment**

- Site Assessment
  - Geotechnical-
  - Environmental-
  - Social-
  - Climatic aspects

- Technology Assessment
  - PV Module Selection
  - Inverter Concepts
  - O&M Requirements

- Permitting process
  - Validation of grid connection
  - Legal Framework Report

**Technical Design**

**Financial Implications**

- Evaluation of CDM Revenues
- Evaluation revenue and operating expenditures
  - Feed-in tariff analysis
  - Demand analysis

- Assessment capital expenditures
  - Investment costs incl. decommissioning

- Financing Plan and Structure
  - Co-operation with international financing Institutions

Yield Verification
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Technical Assessment

**Site Assessment**

**Objective Site Assessment**

- Evaluation of the site suitability based on:

  1. Meteorological data
  2. Terrain usability
  3. Area accessibility
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Technical Assessment

- **Irradiation El Salvador**

**S/W yield verification:**
PV Sol, PV Syst, Insel, ILF inhouse

**Solar Data resources:**
- local rooftop plant:
- local measurement station
- data supplier such as:
  - SoDA, Meteonorm, SolarGIS, NASA, DLR, RETscreen, …
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Technical Assessment

Site Evaluation

Resulting area 15 de Septiembre

Resulting area Guajoyo
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Technical Assessment

Environmental and Social Evaluation

Objective

- Identification of sensitive environmental and social features
- Consideration of impacts
  - Site preparation
  - Construction
  - Operation
  - De-commissioning
- Development of mitigation measures

Result

- Both sites are feasible for development of a PV plant
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Technical Assessment

- **Technology Selection**

**Objective of Technology Assessment**

- **Identification** of potential technological solutions

- **Evaluation** of the following technical components:
  1. PV Modules
  2. Mounting Structure and Foundations
  3. Inverter Concept
## Module Selection

<table>
<thead>
<tr>
<th>Description</th>
<th>Thin Film Technology</th>
<th>Crystalline Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amorphous Silicon a-Si</td>
<td>Cadmium Telluride CdTe</td>
</tr>
<tr>
<td>Module Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Number of Modules / MW</td>
<td>10,020</td>
<td>12,528</td>
</tr>
<tr>
<td>Module Area / MW</td>
<td>14,329 m²</td>
<td>9,020 m²</td>
</tr>
<tr>
<td>Total Area</td>
<td>1.9 ha - 3.1 ha</td>
<td>1.3 ha - 2.2 ha</td>
</tr>
<tr>
<td>Max Power El Salvador / ha</td>
<td>0.5 MW</td>
<td>0.75 MW</td>
</tr>
<tr>
<td>Yield / Year</td>
<td>*****</td>
<td>1,528 kWh/kW</td>
</tr>
<tr>
<td>PR</td>
<td>*****</td>
<td>79.8 %</td>
</tr>
<tr>
<td>Turnkey Price in Euro per kW</td>
<td>2,300 € - 2,600 €</td>
<td>2,300 € - 2,600 €</td>
</tr>
</tbody>
</table>

Result: Poly-crystalline
Technology Selection

2. Objective Mounting Structure

- **Elaboration** of cost and time efficient adequate mounting structure
- **Identification** of geological requirements

Results

- **15 de Septiembre:**
  - Pile driven foundations sometimes pre-drilling required
- **Guajoyo:**
  - Pile driven foundations often pre-drilling required
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Technical Assessment

Technology Selection

3. Objective Inverter Concept

- **Elaboration** of adequate inverter technology based on availability of maintenance and cost-efficiency
- **Identification** of costs and service availability

Results

**String inverter concept**

- No on-site maintenance services required
- Maintenance for central inverter concept are not available in El Salvador
- Less operation costs
Operation & Maintenance

Status Operation & Maintenance

Extremely low O&M
No rotating equipment

Results

→ O&M Concept

- 24 h security service
- Cleaning of modules
- Maintenance main components
- Maintenance low and medium voltage system
- Visual inspection
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Technical Assessment

## Permitting Process

<table>
<thead>
<tr>
<th>Results of Legal Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Permits and Authorizations</td>
</tr>
<tr>
<td>− Environmental Permit Process</td>
</tr>
<tr>
<td>− City Hall Permit</td>
</tr>
<tr>
<td>− Working Establishment regulation</td>
</tr>
<tr>
<td>• Connection to Grid</td>
</tr>
<tr>
<td>• Contract and Pricing</td>
</tr>
<tr>
<td>• Tax Benefits</td>
</tr>
</tbody>
</table>

Dialogue with Authorities
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Financial Implications

- **Financial Analysis:**
  - Irradiation/ Net Generation
  - CAPEX/ Investment
  - OPEX
  - Electricity Tariff
  - CER Certificates
  - Start of operation
  - Operation period/ Project Lifetime
  - Financing/ Funding Structure
  - Expansion Plan

- **Key Financial Metrics:**
  - Financial Rate of Return
  - Levelized Electricity Cost
  - Debt Service Coverage Ratio
  - Net Present Value
  - Avoided Emissions
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Financial Implications

**Financial Analysis:**

- **Irradiation/ Net Generation:** 9,878 MWh/a
- **CAPEX/ Investment:** 17,950 TEUR
- **OPEX:** 205,87 TEUR/a
- **Cost-based vs. Market regulated Tariff**
- **CER Certificates:** 12 EUR/ t
- **Start of operation:** 2012
- **Operation period:** 25 years
- **KfW Funding/ CEL Equity**
- **Potential Ext. Steps**

- **FIRR:** 7.36%
- **LEC:** 0.13 EUR/KWh
- **DSCR:** 1.60
- **NPV:** 13,836.01 TEUR
- **Avoided Emissions:** 158,494 t
## Case Study of a 20 MW PV Power Plant in El Salvador

### Financial Implications

#### Cost Estimation

<table>
<thead>
<tr>
<th>Description</th>
<th>15 de Septiembre Initial</th>
<th>15 de Septiembre Extension</th>
<th>Guajoyo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TEUR</td>
<td>TEUR</td>
<td>TEUR</td>
</tr>
<tr>
<td>Modules</td>
<td>8,612.68</td>
<td>11,485.24</td>
<td>5,169.11</td>
</tr>
<tr>
<td>Inverter</td>
<td>1,375.00</td>
<td>1,825.00</td>
<td>822.50</td>
</tr>
<tr>
<td>Civil material and construction</td>
<td>760.00</td>
<td>207.00</td>
<td>459.75</td>
</tr>
<tr>
<td>Electrical Material</td>
<td>3,894.80</td>
<td>4,832.90</td>
<td>2,394.13</td>
</tr>
<tr>
<td>Grid connection</td>
<td>717.50</td>
<td>-</td>
<td>567.50</td>
</tr>
<tr>
<td>Engineering, tendering, site supervision</td>
<td>840.00</td>
<td>655.00</td>
<td>460.00</td>
</tr>
<tr>
<td>Insurances</td>
<td>81.00</td>
<td>95.03</td>
<td>49.36</td>
</tr>
<tr>
<td>Contingencies</td>
<td>1,628.10</td>
<td>1,910.02</td>
<td>992.24</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,522</strong> (3,556 USD)</td>
<td><strong>2,340</strong> (3,299 USD)</td>
<td><strong>2,701</strong> (3,808 USD)</td>
</tr>
</tbody>
</table>

Specific Investment Costs (EUR/kW)

- **15 de Septiembre Initial**: 2,522 (3,556 USD)
- **15 de Septiembre Extension**: 2,340 (3,299 USD)
- **Guajoyo**: 2,701 (3,808 USD)
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Economic Assessment

Definition

Economic Analysis

- Quantification of costs and opportunity cost of compared to conventional thermal power generation
- Focus is on a macro-economic and national level
- Costs and Benefits adjusted to market structure and government intervention

Financial Analysis

- Focus on interest of shareholders of the project infrastructure
- Application of market prices, exertion of factors i.e. inflation and taxes
- Application of Funding Scenarios

Performance Indicators

- Economic Rate of Return
- Benefit – Cost Ratio
- CO2- Avoiding Costs

Performance Indicators

- Internal Rate of Return (IRR)
- Net Present Value (NPV)
- Levelized Energy Cost (LEC)
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Economic Assessment

Impact Parameters on Economic Ratios

- Irradiation/ Net Generation
- CAPEX/ Investment
- OPEX
- Avoided Energy Input
- Avoided CO2 Emissions
- Diesel Price
- Operation period/ Project Lifetime
- Local Market Distortions

- Economic Rate of Return
- CO2 Avoiding Costs
- Amount of Avoided Emissions
- Cost Benefit Ratio
## Impact Parameters on Economic Ratios

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiation/ Net Generation</td>
<td>9,878 MWh/a</td>
</tr>
<tr>
<td>CAPEX/ Investment</td>
<td>26,083 TUSD</td>
</tr>
<tr>
<td>OPEX</td>
<td>297 TUSD</td>
</tr>
<tr>
<td>Avoided Energy Input</td>
<td>2,069.4 TUSD</td>
</tr>
<tr>
<td>Avoided CO2 Emissions</td>
<td>7,083 t CO2/a</td>
</tr>
<tr>
<td>Diesel Price</td>
<td>718.13 USD/t</td>
</tr>
<tr>
<td>Operation period/ Project Lifetime</td>
<td>25 years</td>
</tr>
<tr>
<td>Grid Emission Factor El Salvador</td>
<td>0.717 t CO2/ MWh</td>
</tr>
</tbody>
</table>

- **ERR:** 6.01%
- **CO2 Avoid. Costs:** 59.99 USD/t
- **Avoided Emissions:** 7,083 t/a
- **Cost Benefit Ratio:** 0.7
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Project Implementation

Objective

- **Elaboration** of project time “initial phase”
- **Identification** of milestones

Results

- **Initial project phase** >19 months
- **Tender phase** > 9 months
- **Construction phase** > 10 months
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Conclusions

- Recommendations

  - **Communication of PV Technology**
    - Presentation Workshop with Local Authorities
    - Project Visualization
  - **Sourcing Strategy**
    - Local Content -> Assessment of Local Capacities
    - Knowledge Transfer -> Training
    - Technology Selection -> Consideration of Local Skills
    - Make projects attractive to int. EPCs
  - **Reliable Tariff System for RE must be established**
    for project lifecycle
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Thank you for your attention!