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1. Background
2. Purpose of ETOAG report and META
3. Representative countries
4. Power generation technology options
5. Power delivery technology options
6. Methodology and approach
7. Example results from ETOAG Report and META
8. Uncertainty analysis
9. Impact of environmental externality cost
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Background

- Study of Equipment Prices in the Power Sector (Dec. 2009)

- expand the list of generation technologies
- expand the list of T&D technologies
- take into account positive and negative externalities of power generations

- **Electricity Technology Options Assessment Guide (ETAOG)**
- **Model for Electricity Technology Assessments (META)**
The main purpose of ETOAG and META is to provide information and a tool that allows users to evaluate electricity technology options.

ETOAG and META provide:
- Guide to the technologies and the capital, fuel and operating costs of each of the technologies.
- Generic estimates of the levelized cost per kWh of generating electricity and of electricity transmission and distribution.
- Curve showing levelized cost per kWh for a range of capacity factors from 10% to 90%.
### Representative countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Broad Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>Developing</td>
</tr>
<tr>
<td>Romania</td>
<td>Middle-income</td>
</tr>
<tr>
<td>USA</td>
<td>Large developed</td>
</tr>
</tbody>
</table>
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Power generation technology options

- Various power generation technologies
  - Different technologies
    Solar, Wind, Hydro, Thermal, Nuclear etc.
  - Different sizes
    Unit size range of 50W to 1,350MW
  - Grid types
    Off-grid, Mini-grid and Grid Connected
# Renewable Energy Generation Technology Options

<table>
<thead>
<tr>
<th>Generating types</th>
<th>Off-grid</th>
<th>Mini-grid</th>
<th>Grid-connected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10W 100W</td>
<td>10kW 100kW 1MW</td>
<td>10MW 100MW 1GW</td>
</tr>
<tr>
<td>Solar PV</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Wind</td>
<td>●</td>
<td>● on-shore</td>
<td>● on-shore</td>
</tr>
<tr>
<td>PV-Wind Hybrids</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Concentrated Solar Power</td>
<td>●</td>
<td>● binary</td>
<td>● with storage</td>
</tr>
<tr>
<td>Geothermal</td>
<td>●</td>
<td></td>
<td>● dual flush</td>
</tr>
<tr>
<td>Biomass MSW</td>
<td>●</td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Biogas Landfill Gas</td>
<td>●</td>
<td>● micro</td>
<td>● large pumped storage</td>
</tr>
<tr>
<td>Hydro</td>
<td>● pico</td>
<td>● micro</td>
<td>● mini</td>
</tr>
<tr>
<td>Energy Storage</td>
<td></td>
<td></td>
<td>● lead acid battery NaS</td>
</tr>
</tbody>
</table>
# Thermal Power Generation and Nuclear Generation Technology Options

<table>
<thead>
<tr>
<th>Generating types</th>
<th>Off-grid</th>
<th>Mini-grid</th>
<th>Grid-connected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10W</td>
<td>100W</td>
<td>1kW</td>
</tr>
<tr>
<td>Reciprocating engine</td>
<td>gasoline generator</td>
<td>diesel generator</td>
<td></td>
</tr>
<tr>
<td>Micro gas turbine</td>
<td>100W</td>
<td>1MW</td>
<td>10MW</td>
</tr>
<tr>
<td>Fuel cell</td>
<td></td>
<td>100kW</td>
<td>100MW</td>
</tr>
<tr>
<td>Gas turbine</td>
<td></td>
<td>1MW</td>
<td>1GW</td>
</tr>
<tr>
<td>Coal fired</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGCC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal CFB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil/Gas Steam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>simple cycle</td>
<td>subcritical</td>
<td>PWR</td>
</tr>
<tr>
<td></td>
<td>combined cycle</td>
<td></td>
<td>PHWR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ABWR</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
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Power delivery technology options

- Transmission technologies include a range of transmission voltages and substation voltages.

<table>
<thead>
<tr>
<th>Country</th>
<th>Transmission voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300 ~ 500kV</td>
</tr>
<tr>
<td>India</td>
<td>400kV</td>
</tr>
<tr>
<td>Romania</td>
<td>400kV</td>
</tr>
<tr>
<td>USA</td>
<td>345, 500kV</td>
</tr>
</tbody>
</table>

- Average distribution costs per kWh for each country are estimated.
Grid applications

- Off-grid
- Mini-grid
- Grid Connected

Customer

Power Station

Distribution system

Generator

New Transmission line

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ETOAG – comprehensive guide & database

- Brief description of technology (e.g., Coal-fired)
  - Design assumptions (capacity, life, storage capacity)
  - Technology development status and prospects
  - Levelized cost per kWh for each technology
Fundamental approach

1. Collected cost and performance data from published documents, websites and Chubu's internal database

2. Calculated capital cost, O&M cost, fuel cost, environmental externality cost, and levelized cost per kWh in 2010 US$ price level

3. Project capital costs normalized to standard cost of generic plants using regression analysis
Normalization of capital cost

Regression Curve for Capital Cost of Combined Cycle Plant in USA
Major economic & design premises

● Environmental control technologies

➢ Report/META take as an assumption that power generation plants comply with the stricter of the local environmental regulations or the World Bank environmental guidelines.

➢ The capital and operating costs and performance parameters include environmental control technologies.

  - FGD (Fuel-gas desulfurization)
  - SCR (Selective catalytic reduction)

➢ The User of META has the option to remove FGD and SCR and may evaluate the results.
Major economic & design premises

- **Environmental externality costs**
  - Report/META incorporates the cost of environmental externalities from emissions of CO$_2$, SO$_2$, NOx and PM$_{10}$.
  - Report/META do not consider all potential externality costs; e.g., habitat and biodiversity loss due to changes to river flows (hydropower), disruption of migrating birdlife due to windfarms.
  - Users of META have the option to add a premium to the capital and operating costs in order to reflect their assessment of impacts.
Major economic & design premises

● Overnight costs

➢ Report/META use overnight costs in order to avoid the impact of project specific financing cost.

➢ The user can use META to calculate and add IDC to the overnight cost along with financing expenses
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Off-grid Generation Cost in India

- Gasoline generator: 300W, CF=30%
- PV-wind hybrid: 300W, CF=25%
- Pico hydro: 300W, CF=30%
- Solar PV: 300W, CF=20%
- Wind onshore: 300W, CF=30%

(US¢/kWh)
Mini-grid Generation Cost in India

- PV-wind hybrid
  - 100kW, CF=30%

- Diesel generator
  - 100kW, CF=80%

- Micro gas turbine
  - 150kW, CF=80%

- Wind onshore
  - 100kW, CF=30%

- Micro hydro
  - 100kW, CF=30%

- Geothermal binary
  - 200kW, CF=70%
Screening curve analysis for USA

- Nuclear AP1000 1200MW
- Coal supercritical 500MW
- Gas combined-cycle 650MW
- Wind onshore 100MW
- Large hydro 300MW

Generation Cost (US$/kWh) vs. CF (%)
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Illustration of uncertainty analysis

Grid connected, USA, 2010

<table>
<thead>
<tr>
<th>Technology</th>
<th>Range</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large hydro 300MW</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal CFB 300MW</td>
<td>4.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal supercritical w/o CCS 500MW</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear AP1000 1200MW</td>
<td>7.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind onshore 100MW</td>
<td>7.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas combined cycle 650MW</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas steam 500MW</td>
<td>5.8</td>
<td></td>
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</tr>
</tbody>
</table>
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External costs

● Types of external costs analysed
  ➢ global (greenhouse gas emissions (GHG))
  ➢ local/regional (SO$_2$, NO$_x$, PM$_{10}$)

● Emissions depend on:
  ➢ generation technology, fuel, FGD/SCR

● Impacts of emissions and the types of cost
  ➢ global warming → economic, health, environment
  ➢ air quality → illness, death, environment

● External costs are added to other costs
# Estimates of external costs of “local” emissions (€/tonne)

<table>
<thead>
<tr>
<th>Study</th>
<th>SO₂</th>
<th>PM10</th>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Croatia, Zagreb</td>
<td>13,483</td>
<td>24,218</td>
<td>19,265</td>
</tr>
<tr>
<td>Representative EU ExternE</td>
<td>10,450</td>
<td>15,400</td>
<td>15,700</td>
</tr>
<tr>
<td>Portugal, ExternE</td>
<td>4,959</td>
<td>5,975</td>
<td>5,565</td>
</tr>
<tr>
<td>EU DG Environment (BeTa Database)</td>
<td>5,200</td>
<td>14,000</td>
<td>4,200</td>
</tr>
<tr>
<td>World Bank, Six Cities Study</td>
<td>96</td>
<td>1,723</td>
<td>255</td>
</tr>
<tr>
<td>ESMAP, China, Shanghai</td>
<td>390</td>
<td>1,903</td>
<td>454</td>
</tr>
</tbody>
</table>
Local external costs - caveats

- Dominated by health costs
- Very wide variation in cost estimates
- Costs depend on a huge range of factors:
  - stack height
  - population concentrations
  - prevailing wind direction
  - ambient air quality
- Do not depend heavily on generic cost estimates
Greenhouse gas emissions

- **Value of CO2 emission reduction:**
  - determined by willingness-to-pay to avoid emissions

- **First UNFCCC “Commitment Period” ends 2012**

- **Beyond 2012**
  - CDM credits recognized post 2012, but no buyers?

- **Default assumptions (US$/tonne of CO$_2$e):**
  - USA – US$30 from 2020
  - Romania – US$20 in 2010, rising to US$30 in 2020
  - India – no carbon cost before 2020
## External cost defaults (US$/tonne)

<table>
<thead>
<tr>
<th></th>
<th>All years</th>
<th>SO₂</th>
<th>PM₁₀</th>
<th>NOₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>120</td>
<td>2,240</td>
<td>330</td>
<td></td>
</tr>
<tr>
<td>Romania</td>
<td>6,450</td>
<td>7,770</td>
<td>7,230</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>8,870</td>
<td>18,280</td>
<td>7,460</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CO₂ equivalent</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Romania</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>USA</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>

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Illustration of use of the tools: Technology costs with externalities
(default external value for SO$_2$ of US$120/tonne for India)
Illustration of use of the tools
Technology costs with externalities
(external value for SO$_2$ of US$5,000/tonne)
Summary of the ETOAG tools

- Purpose: information, database and a model to evaluate diverse electricity technology options
- Three countries (India, Romania and USA) provide default values
- Performance and cost estimates for 54 generation technologies and selection of T&D technologies
- For each technology: description, design assumptions, technology status and prospects
- Major economic & design premises: cost and performance data obtained from various sources – adjusted and normalized by Chubu engineering team
- An output is the levelized cost per kWh for the defaults

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Examples of questions that ETOAG can help answer

- Is the lifetime cost of project A lower than projects B, C, D, ..?
- How do lifetime costs compare when environmental costs are incorporated? How sensitive are the results to environmental cost assumptions?
- Are environmental controls cost-effective? Are environmental damage costs greater than control costs?
- Is a distributed generation option w/o distribution costs cheaper than large-scale generation with distribution?
- What happens to electricity costs if international fuel prices rise in the future?
- etc...