Electricity system modelling

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From energy to electricity system analysis

- The electricity system is a heavily intertwined subpart of the comprehensive energy system.
- We focus this training on modelling the electricity system,
- More specifically: finding the least-cost sustainable electricity system development.
Electricity system

Complex system involving: extraction and/or import facility, power plants, transmission and distribution lines, storage, transport, industrial uses, residential uses, transportation, and others.
Elements of an electricity system model

The complexity of electricity systems requires a well-organized model structure.
Demand

The demand for electricity has to be met instantly when it arises.

Where does demand come from?
- Industry
- Tertiary
- Residential
- And others

Why not simply aim to satisfy the average annual demand?
- Consumers activities are different during the day/year.
- Accordingly, electricity demand varies over time.
- Average or total annual demand can not capture the daily and yearly variations.
Time slices

- All characteristics of the system vary over different time scales (days, weeks, seasons). Think for instance of:
  - Electricity demand;
  - Rainfall patterns;
  - Irrigation needs and duration of the daylight.
- The year is therefore broken down into representative pieces called **time slices**.

Both demand and supply (especially intermittent renewables!) are therefore studied at the scale of the individual time slices.
Why are time slices important?

Electricity (load curve)

- Electricity Demand (MW)
- Availability (%)

Water resources (Availability)

Sample of California Hourly Demand and Solar and Wind Production

- Electricity Demand
- Solar Production
- Wind Production

- Hour of Day

0 8760

Thursday, January 31, 2013
Planning the electricity system

Type and schedule of new capacity additions for an uncertain future

- Total system capacity requirements
- Demand for new capacities
- Demand projection
- Existing system capacity

MW

Time
Levelised Cost of Electricity (LCOE)

\[
\text{LCOE} = \left( \frac{\text{INV} \times \text{CRF} + \text{FOM}}{\text{PLF}} \right) \times \frac{8760}{\eta} + \text{VOM} + \frac{\text{P}_{\text{FUEL}}}{\eta} + \left( \frac{\text{DECOM} \times (1 + i)^{-\text{PLF} + \text{T}}}{8760} \right)
\]

LCOE, in $/kWh of electricity output

- **INV**: Overnight investment costs per kW of installed capacity, $/kW_e
- **CRF**: Capital recovery factor (annuity)
- **DECOM**: Decommissioning costs per kW of installed capacity, $/kW_e
- **FOM**: Fix operating and maintenance costs per year, $/kW_e
- **VOM**: Variable operating costs, $/kWh
- **P_{FUEL}**: Fuel price per kWh, in $/kWh input
- **PLF**: Plant factor, i.e., full load hours of plant operation per year, fraction of year
- **PLT**: Plant life time, years
- **\( \eta \)**: Plant thermal efficiency, in %
- **i**: Discount rate, in %
Is LCoE the only decision criterion?

Technologies compete to gain a share in the energy supply, based on their techno-economic characteristics (e.g. **Levelized Cost of Electricity**), but also on a number of other constraints – e.g. resource availability, intermittency of production, ramping rates, etc.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Coal</th>
<th>Natural Gas</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>Wind</th>
<th>Solar PV</th>
<th>Biomass</th>
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<td>IT DEPENDS ON THE LOCATION, ON GEOPOLITICAL CONSTRAINTS, ON CLIMATE CONDITIONS</td>
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More favourable  Less favourable
# Basic technology characterization

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<tr>
<th>Expansion / replacement options</th>
<th>CCGT</th>
<th>GT</th>
<th>Coal PP</th>
<th>Coal CCS</th>
<th>Diesel</th>
<th>Hydro</th>
<th>Wind PP</th>
<th>Solar PV</th>
<th>Solar thermal (CSP)</th>
<th>Nuclear</th>
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<td>1 000</td>
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<td>150</td>
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<td>2</td>
<td>100</td>
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<td>Efficiency (%)</td>
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<td>34</td>
<td>39</td>
<td>35</td>
<td>30</td>
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<td>--</td>
<td>--</td>
<td>-</td>
<td>35</td>
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<td>Fuel</td>
<td>Gas/LFO</td>
<td>Gas / LFO</td>
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<td>Coal</td>
<td>Diesel</td>
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<td>500</td>
<td>2 200</td>
<td>4 100</td>
<td>450</td>
<td>2 000</td>
<td>1 600</td>
<td>2 500</td>
<td>4 500</td>
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<td>7</td>
<td>28.15</td>
<td>52</td>
<td>7</td>
<td>12</td>
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<td>Variable O&amp;M cost excl. fuel ($/MWh)</td>
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<td>104.5</td>
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Exercise 2

**Comment in 5 bullet points** the graphs shown in slide 27 of this presentation.

Answer the following guiding questions:

- Which are the main features of each of the technologies plotted?
- Why one needs to look at LCOE to compare technologies and decide which one minimizes costs?
- Besides what is included in the LCoE calculations, what other criteria need to be taken into account select technologies for an electricity system?
LCOE with realistic load factors

![Graph showing LCOE generating costs per MWh for different sources: CCGT, GT, Coal PP, Diesel, Hydro, Wind, Solar PV, CSP, and Nuclear. The costs range from 0.0 to 12.0 $/MWh. Diesel has the highest cost, followed by Solar PV and CSP. CCGT and Coal PP have the lowest costs.]
To correctly reference this work, please use the following: