System Effects in Low-Carbon Electricity Systems

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Recent fast deployment of subsidised Variable Renewable Energy (VRE) had a significant impact on the whole electricity systems in many OECD countries.

- Increasing needs for T&D infrastructure, challenges for balancing.
- Significant impacts on the mode of operation and flexibility requirements of conventional power plants in both the short- and long-run.
- Large effects on the electricity markets (lower prices, higher volatility) and on the economics of existing power plants.

- Traditional metrics such as the LCOE are not sufficient anymore to adequately characterise and compare different generation sources.
- Need to look at the electricity system as a whole and not at each component in isolation.

Increasing attention has been given to the definition, analysis and quantification of system effects and costs (*integration costs*) in the scientific literature and in the policymaking areas.
Quantitative analyses performed by IER Stuttgart based on very detailed modelling of the German electricity system. Twelve scenarios, with 4 shares of VRE generation.

**50% Renewables scenario (35% of VRE)**

- Residual demand load is determined more by the production of VRE than by the demand.
- Residual demand load loses its characteristics seasonal and daily patterns.
  - More difficult to plan a periodic load-following schedule.
  - Loss of predictable peak/off-peak pattern (ex: impact of PV and effect on hydro-reservoir economics).
- Significant number of hours in which Renewables fully meet the demand.
• High gradient of change in residual load (more than 20 GW/h, about 25% of maximal load !)
• Those changes must be assured by a reduced number of dispatchable generators.
• The unpredictability of those changes adds an additional difficulty to the challenge.

More and more flexibility will be required from **all** components of electricity system.
  - Significant load-following will be required from all dispatchable generators including base-load.
  - Large amounts of storage capacity required at high penetration level of VRE.
  - Curtailment of VRE or Demand Side Management are the most cost-effective solution.
In the **short-run**, renewables with zero marginal costs replace technologies with higher marginal costs, including nuclear as well as gas and coal plants. This means:

- Reductions in electricity produced by dispatchable PP (lower load factors, *compression effect*).
- Reduction in the average electricity price on wholesale power markets (*merit order effect*).
- Declining profitability especially for OCGT and CCGT (nuclear less affected).
- No sufficient economical incentives to built new power plants.
• Production from VRE will change generation structure for the residual system.

• Renewables will displace base-load on more than a one-to-one basis, especially at high penetration levels: base-load is replaced by wind and gas/coal (more carbon intensive).

• Cost for residual load will rise as technologies more expensive per MWh are used.

• These effects (and costs) increase substantially with penetration level.
We compare two situations: the residual load duration curve for a 30% penetration of fluctuating wind (blue curve) and 30% penetration of a dispatchable technology (red curve).
• The auto-correlation of VRE production reduces the its effective contribution to the system and thus its **market value** at increasing penetration level.

![Graph showing declining value of VRE contribution](image)

- Wind value factor drops from 1.1 at zero market share to about 0.5 at 30% (*merit-order* effect)
- Solar value factor drops even quicker to 0.5 at only 15% market share
- Existing capital stock interacts with VRE: systems with much base load capacity feature steeper drop
• **In some countries (France, Germany, Belgium) significant flexibility is required from NPPs:**
  
  o Primary and secondary frequency control.
  
  o Daily and weekly load-following.

**Power history of a French PWR reactor**

- For 2/3 of the cycle the load fluctuates between 85% and 100%, while in the last third of the cycle the plant is operated in a base load mode.
- Daily load following, with power reductions up to 35%-40% of nominal power.
- “Stretch” can be observed in the last few days of operation.
Contribution to reduce system effects: flexibility of nuclear power plants (II)

- Flexibility of nuclear power plants has constantly improved over time.
  - Several Gen II plants were already built with sufficient manoeuvring capabilities or have been already upgraded.
  - Strong flexibility is required by utilities and already implemented in the design of new Gen III NPPs.

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Start-up Time</th>
<th>Maximal change in 30 sec</th>
<th>Maximum ramp rate (%/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open cycle gas turbine (OGT)</td>
<td>10-20 min</td>
<td>20-30 %</td>
<td>20 %/min</td>
</tr>
<tr>
<td>Combined cycle gas turbine (CCGT)</td>
<td>30-60 min</td>
<td>10-20 %</td>
<td>5-10 %/min</td>
</tr>
<tr>
<td>Coal plant</td>
<td>1-10 hours</td>
<td>5-10 %</td>
<td>1-5 %/min</td>
</tr>
<tr>
<td>Nuclear power plant</td>
<td>2 hours - 2 days</td>
<td>up to 5%</td>
<td>1-5 %/min</td>
</tr>
</tbody>
</table>

- Economic impact of significant flexibility from NPPs
  - No proven impacts on fuel failures and major components.
  - Studies have shown correlation between load following and increased maintenance needs, but were unable to quantify the related costs.
  - EdF has observed a reduction in availability factor due to extended maintenance (1.2-1.8%).
  - The main economic consequence of load following is the load factor reduction.
The NEA study on system effect was pioneering and has contributed to progress in the area.

Increasing attention is given on the topic in the scientific literature and policy-making areas:
- Work at the IEA on the integration of VRE.
- An in-depth analysis of the large VRE integration at an EU scale from the French utility EdF.
- NEA is undertaking a follow-up of the System Cost study.

Different effects in the short-run and the long-run:
- VRE displace peakers in the short-run and base-load technologies in the long-run.
- Effect on average market price is transitory: market prices will have to go back to long-term average cost recovery. However more volatility is to be expected.
- The impact on CO2 emissions in the long-run.

System costs are country-specific, strongly interrelated and depend on penetration level:
- Integrating the first 10% of intermittent resources do not pose the same economic and technical challenges as increasing penetration level from 20 to 30%.
- What is the technical and economic limit to the integration of VRE?

The value of VRE generation decreases drastically with penetration level:
- This affect both the market value (private) and the system value (social).

System costs are large and need to be appropriately accounted for and internalised.
Thank you for your attention.

The NEA reports are available online:

- "System Cost"  
  [Link](http://www.oecd-nea.org/ndd/pubs/2012/7056-system-effects.pdf)

- "Nuclear new built"  

- "Load Following"  
  [Link](http://www.oecd-nea.org/ndd/reports/2011/load-following-npp.pdf)

- "The EdF study"  
  [Link](http://www.energypost.eu/wp-content/uploads/2015/06/EDF-study-for-download-on-EP.pdf)

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