TECHNICAL AND ECONOMIC ANALYSIS OF THE EUROPEAN ELECTRICITY SYSTEM WITH 60% RES

EDF R&D

The full costs of electricity provision

OECD NEA

Paris, 20 January 2016
System effects are strongly country specific and depend on the penetration level of VRE

<table>
<thead>
<tr>
<th>Country</th>
<th>Power area size (peak demand)</th>
<th>Internal grid strength</th>
<th>Interconnection (actual and potential)</th>
<th>Geographical spread of VRE generation</th>
<th>Flexibility of dispatchable generation portfolio</th>
<th>VRE (2012)</th>
<th>Curtailment</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td>Italy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Iberia (ES and PT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21%</td>
<td>&lt;0.3%</td>
</tr>
<tr>
<td>Brazil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>NWE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Japan (East)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>ERCOT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9%</td>
<td>3.8%</td>
</tr>
</tbody>
</table>

Source: IEA
Simulation of the EU Energy Roadmap « HiRES 2030 » scenario

HiRES scenario
EU energy roadmap
Generation Mix 2030

High RES 2030 | GW | Load factor (h/yr)
--- | --- | ---
Solar (PV) | 220 | 1100
Onshore wind | 280 | 1900
Offshore wind | 205 | 3200
Hydro | 120 | 3800

Fuel | Price
--- | ---
Coal | 86 €/t
Gas | 10 €/MMBtu
Oil | 107 €/baril
CO₂ | 35 €/t
What is this study about?

Flexibility to handle variability

Connecting RES and load

Keeping the lights on

Balancing the economics
And the good news are…

The lights will stay on so no emerging market for candles!
Geographical diversity does help, but there is still significant variability at European level.

Variable RES are key to the decarbonisation of electricity production but the system still needs backup capacity for security of supply.

Not only conventional generation, but also variable RES, will contribute to balancing and ancillary services.

Variable RES production should potentially provide new services like fast frequency response (inertia).

Storage and active demand may to a certain extent supplement generation to balance supply and demand.

The pace of deployment of RES should be optimised in order to limit costs of storage or excessive curtailment.
Geographical diversity does help, but there is still significant variability at European level.

Wind onshore generation for different geographical areas.

- **France**
- **Brittany**
- **Farm**

Onshore wind daily average generation: 30 climatic years

- Average load factor: 25%
- Installed power: 280 GW
- Average difference of daily generation: 90 GW

You can reduce the variability of wind and PV at local level but the correlation in wind regimes acts as a limit at continental level.
Integrating a large share of variable RES requires a coordinated development of RES and networks.

RES geographical distribution

Network development scenario

Interconnection reinforcement (GW) similar to TYNDP 2014

Interconnection reinforcement TYNDP 2010 (GW)
Variable RES are key to the decarbonisation of electricity generation but the system still needs backup capacity for security of supply.

Average CO$_2$ with 60% RES = 125 g CO$_2$ /kWh
Average CO$_2$ with additional coal/gas replacement = 73 g CO$_2$ /kWh
(average CO$_2$ today = 350 g CO$_2$/kWh)

Full decarbonisation can only be achieved with a significant share of carbon free base load, such as nuclear.
Not only conventional generation, but also variable RES, will contribute to balancing and ancillary services.

Penetration of RES > 100%

RES need to provide downward flexibility as well as ancillary services.

400 GW ramp between Sunday and Monday

Middle of the day valley

Net demand (demand – variable RES)
Variable RES production should potentially provide new services like fast frequency response.

Due to lower inertia a reference incident leads to:
- a risk of load shedding (f< 49 Hz) 0,8 % of the time
- a violation of ENTSO-E security limit (f< 49,2 Hz) 25% of the time

Curtailment to avoid stability problems during critical periods can only be limited if variable RES have the technical capability to provide fast frequency response (synthetic inertia).
Storage and active demand may to a certain extent supplement generation to balance supply and demand.

Net benefit interval as a function of storage cost and installed capacity.

Storage and flexible demand contribute to the flexibility required for balancing but do not replace the need for backup generation.
The pace of deployment of RES should be optimised in order to limit costs of storage or excessive curtailment.

The system value of variable RES will decrease as their penetration levels increases and this is more pronounced for PV.

With ~0% RES, the first MWs of RES have a value close to the base price.
VARIABLE RES INTEGRATION COST ARE SYSTEM SPECIFIC SINCE THESE DEPEND ON THE TYPE OF SYSTEM AND THE CHARACTERISTICS OF THE SYSTEM

- System effects depend on grids and the generation mix.
- We see RES integration costs as the difference between the total system cost of two alternative pathways to serve a given demand: a pathway with VRE and a pathway without VRE.
- The key cost components required in order to estimate total system cost are:
  - **Grid infrastructure investment**
  - **Production costs**: energy, flexibility, reserves and other ancillary services
  - **System adaptation costs**: Costs associated to technologies and services required to ensure the reliability, operability and security of a system with a large share of VRE
    - Adaptation/replacement of protection systems
    - Investment in new technologies to mitigate the effects of low inertia and short circuit strength and advanced solutions for voltage and frequency regulation
    - Advanced supervision and control solutions to operate a system under a new paradigm

System adaptation costs to ensure reliability, operability and security add to these costs and increase significantly for penetrations above 40%. The cost for reaching ultra high penetrations (> 80%) are still uncertain.
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Variable RES are key to the decarbonisation of electricity production but the system still needs backup capacity for security of supply

Storage and active demand may to a certain extent supplement generation to balance supply and demand

Integrating a large share of variable RES requires a coordinated development of RES and networks

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THANK YOU FOR YOUR ATTENTION!