Session III: Novel planning methodologies at pan-European level

Grid Development for Long Term Planning

Thomas Anderski, Amprion – Work Package leader
Objectives of grid architecture development in e-Highway 2050

To define energy scenarios and grid structure that reach EU Climate targets in 2050

- Basis is Ten Years Network Development Plan by ENTSO-e

- Definition of main transmission requirements in Europe

- Results to be understood as complete architecture for scenarios

- Identification of “no-regret” investments
Steps of grid architecture development

Scenario definition

European grid model

Scenarios quantification

Grid development

Five scenarios

100% RES

Large scale RES

Big & market

Fossil & nuclear

Small & local

Based on Grid 2014 + TYNDP ’14

Inst. capacities per Scenario
What is the starting point for analyses?
- What is the status of available transmission system at the beginning?

Deliverable 2.2 - European Grid Model
Target of the infrastructure development is to define required bulk power transmission corridors.

Objectives of work in e-Highway were to:

- consider high variety of possibilities for grid development
- define main transmission requirements in Europe
- identify “no-regret” investments
  → European grid model

- cluster are used as smallest units for system modeling
- cluster modeled as single market node (“copperplate”)
- installed capacities and demand defined on this level

- transmission equivalents represented by:
  Transmission Capacity (TC) and equivalent impedance (Zeq)

TC + Zeq
Cluster model defined and consulted among the TSO Community

- 106 Clusters
- Consultation of TSOs to apply knowledge about particular Systems
  - Improvement of Clusters (Incl. Justification of Changes)
- 95 Clusters
Major grid reinforcement projects are already included the starting grid

Based on the TYNDP, significant grid reinforcements have already been considered in the starting grid:

- Inter and intra country connections
- Further interconnector projects
- DC cable links
What are the energy scenarios?
- How do the energy mix and installed capacities look like?

Deliverable 2.1 - Data sets of scenarios for 2050
Scenario building methodology based on combination of **Futures** & corresponding **Strategies**

**Uncertainties (examples)**
- Technical uncertainties
- Economic/financial uncertainties
- Political/social/environmental uncertainties
- Research, Development & Deployment uncertainties

**Options (examples)**
- Technical options
- Economic/financial options
- Political/social/environmental options
- Research, Development & Deployment options

**Futures**
- 5

**Strategies**
- 6

**Scenarios**
- 30

**Consistent Scenarios**
- 17

**Which are relevant for Grid Development Planning?**

EU Climate Targets are achieved in all Scenarios
Focus on scenarios that pose a big challenge for the existing grid

Three main influences define the need for grid reinforcements:

- **Effects of generation mix**
  - Share of Fossil Fuel
  - Share of Nuclear
  - Renewables (centralized & decentralized)
  - Centralized Storage

- **Effects of demand**
  - GDP Increase
  - New Uses / Demand Shift
  - Efficiency

- **Effects of energy exchanges**
  - EU internal
  - EU external

→ Selection of these five scenarios
Challenge of scenario quantification is to merge top-down and national approaches.

Scenario definition:
- Energy mix
- Demand level
- Energy exchanges

Determination installed capacities on macro-area level

National policies and regulation:
- Nuclear policy
- Renewable action plans

Determination installed capacities on country-level

Determination installed capacities on cluster

Simulation on EU-Level
Different aspects were considered to forecast the yearly demand per scenario

For each scenario, assumptions on:

- GDP and population growth
- New uses of electricity
- Energy efficiency

![European demand (TWh)](chart)

- New uses for heating
- New uses for transport

Reduction due to energy efficiency
**Distribution of generation and exchanges in accordance with the scenario definition**

- **Renewable generation capacities are distributed by:**
  - profitability in the different areas
  - distribution of demand

- Depending on scenario the factors are weighted differently

- But: Installed capacities respect a maximal level of net import/export over the year in each country

<table>
<thead>
<tr>
<th></th>
<th>Large RES</th>
<th>100% RES</th>
<th>Big &amp; Market</th>
<th>Large CCS &amp; nuclear</th>
<th>Small &amp; Local</th>
<th>2014*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal annual energy Balance (% of the national demand)</td>
<td>± 80%</td>
<td>± 80%</td>
<td>± 30%</td>
<td>± 30%</td>
<td>± 10%</td>
<td>± ~10%</td>
</tr>
</tbody>
</table>

*average value in Europe – data by ENSTO-e
Final energy mixes and installed capacities in the 2050 scenarios

Large scale RES
- 5% Hydro
- 20% Wind
- 6% Solar
- 14% Biomass
- 40% Nuclear
- 16% Fossil

100% RES
- 9% Hydro
- 24% Wind
- 16% Solar
- 52% Renewable
- 8% biomass

Big & market
- 33% Hydro
- 19% Wind
- 13% Solar
- 32% Biomass
- 18% Nuclear
- 10% Fossil

Fossil & nuclear
- 17% Hydro
- 12% Wind
- 33% Solar
- 7% Biomass
- 25% Nuclear
- 5% Fossil

Small & local
- 19% Hydro
- 18% Wind
- 10% Solar
- 28% Biomass
- 23% Nuclear
- 23% Fossil

Installed capacities (GW)

- Wind without North Sea
- Wind in the North Sea
- Solar in Europe
- Connections with North Africa
- Fossil
- Nuclear
- Biomass
- Hydro

2012 [ENTSOe]
- Large-scale RES
- 100% RES
- Big & market
- Fossil fuel & nuclear
- Small & local
Which additional transmission grid by 2050?
- Which transmission requirements are needed to solve constraints in the starting grid

Deliverable 2.3 - Grid Development for 2050
Optimum for grid development lays in between copper plate and starting grid situation

**Best case in terms of:**
- Annual investment costs
- Public acceptance
- Maintenance costs

**Best case in terms of:**
- Operation costs
- System adequacy
- Dump-energy
System simulations are done with Antares.

... a stochastic tool (Monte-Carlo scheme: Wind, Solar and load generation ... weather conditions)

... optimize generation of dispatchable units (merit order) to satisfy net demand

... taking into account grid constraints (DC approximation: Kirchhoff laws)

... time step resolution of one hour ... for a period covering one year.

Optimization of whole European system in one shot (minimization of the generation cost)
Decision for grid reinforcements based on manual analyses of key-indicators

- Identification of the in-efficiencies resulting from grid constraints:
  - Energy not served
  - Increase of renewable spillage
  - Increase of expensive generation
  - Decrease of cheap generation

- Reinforcements to solve issues

- Benefit assessment over 99 Monte-Carlo years and compared to investment cost

- NB: Focus is on major reinforcements, some smaller could be profitable as well
Iterative assessment process

- Constraints analysis (Identification of Key-Indicators in European Clusters)
- Proposal of reinforcements (Introduction of additional transmission capacities)
- Annual benefit assessment (Comparison of benefits and annual investment costs)
- Analysis of the remaining constraints (Sufficient security of supply & system costs reached?)
- Final grid proposal for the scenario (Set of transmission capacities to be realized)

>= 4 steps per scenario
Energy scenario in 100% RES:
high imbalances and high need for exchanges

European energy shares

- Medium/high demand: 4500TWh
- High share of non dispatchable generation
- Renewables are dominated by wind
- Peaking units included (DSM & storage)

Installed capacities (GW)

*Imbalances in copper-plate simulation
Overall drivers for grid development, benefits and inclusion of renewables - 100% RES

Changes in System (per year):
- 51 TWh of ENS avoided
- 465 TWh of spillage avoided
- 39 b€ of savings in operating costs

Total investment cost: 245 to 345* b€

NB: only some of the key factors are displayed

*depending on available technologies
Comparison of the final architectures

- Large scale RES
- Fossil & nuclear
- Big & market
- Small & local
- 100% RES

Comparison of the final architectures.
Common reinforcements that appear in two or more scenarios

- Displayed are all lines reinforced throughout two or more scenarios
  - Colors according to number of appearances in scenarios

- Reinforcement of high interest driven by RES implementation and needed exchange capacities
  - North Sea for wind integration
  - Scandinavia to central Europe develop wind and storage potential
  - Connection Great Britain ↔ France ↔ Spain to distribute renewables (PV vs. Wind)

→ Need to transport energy from renewable sources thanks to North-South corridors
Conclusion

Investment in grid infrastructure is a beneficial way to support the EU energy targets for 2050

► Main advantages of the Grid are:
  • Possibility to allocate renewables in most profitable areas
  • Utilization of smoothening effects in RES-production due to geographical distribution

► Need for transmission capacity correlated with share of renewables in energy mix
  • Even the Small & local scenario requires further grid reinforcements

► Interconnection capacities between countries should be among the top priorities
  • Allowing higher exchanges between countries (usually utilized both ways)

► Planned reinforcements for 2030 are sustainable in perspective of EU 2050 climate targets
For more details see deliverables:

« **D2.1 : Data sets of scenarios for 2050** » on [www.e-highway2050.eu](http://www.e-highway2050.eu)

« **D2.2 : European cluster model of the Pan-European transmission grid** » on [www.e-highway2050.eu](http://www.e-highway2050.eu)

« **D2.3 : System simulations analysis and overlay-grid development** » to be published very soon

Back-Up
Thank you for your attention!

Contact: rte-e-highway2050@rte-france.com
Web: www.e-highway2050.eu
Follow us on Twitter: @e_Highway2050
Summary of the main assumptions for grid development

- Only the inter-clusters transmission requirements are assessed
- Focus is on the major ones, some smaller could be profitable as well
- The 2030 grid from TYNDP2014 is the starting point, major projects like HVDC in Germany are thus already assumed
- The detailed routes and connection points are unknown
- Each transmission requirement could be realized through many parallel reinforcements
- For each scenario, a complete set of reinforcements for Europe is suggested, the reinforcements are not assessed independently.
- The time horizon is 2050: the profitability of the reinforcements is not proven before.
Consultation among ENTSO-e TSOs to reveal differences between e-Highway 2050 starting Grid and final TYNDP 2014.

- France to UK:
  Final TYNDP includes further DC-projects with a total capacity of 3.4 GW

- France (internal):
  Reinforcement along western part of additional 1 GW

- France to Spain:
  Final TYNDP plans an additional 1 GW

- France to Germany
Elaboration of Clustering criteria to split Europe into homogeneous clusters

- Definition of criteria for clustering (measurable and non-measurable)
- Allocation of measurable criteria to NUTS-3 regions inside each country
- Mathematical optimization to identify homogeneous clusters inside countries (first step)
Methodology for setup of e-Highway2050 scenarios

- A detailed **bottom-up approach** is necessary to ensure transparency and efficient communication of scenario boundaries to the other WP's in e-Highway2050.
- Scenarios are constructed as a combination of **Uncertainties** (that cannot be controlled by the decision maker) and **Options** that can be chosen by the decision maker.
- A combination of **Uncertainties** create a unique **Future**
- One or more **Options** combined gives a **Strategy**
- A combination of a **Strategy** used within a **Future** is a **Scenario**

**Note:** The e-Highway2050 scenarios are **neither predictions nor forecasts** about the future. We do not conclude that one scenario will be more likely to happen than another, nor that one scenario is more preferred or "better" than another. Rather, each e-Highway2050 scenario is **one alternative image** of how the future of European Electricity Highways (EHS) could unfold.
## Five possible Futures

<table>
<thead>
<tr>
<th>Main Uncertainty</th>
<th>Possible Values</th>
<th>Future 1 Green Globe</th>
<th>Future 2 Green EU</th>
<th>Future 3 EU-Market</th>
<th>Future 4 Big is beautiful</th>
<th>Future 5 Small things matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and Climate Policy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>International Climate Agreement</td>
<td>Global agreement / EU alone</td>
<td>Global agreement</td>
<td>EU alone</td>
<td>EU alone</td>
<td>Global agreement</td>
<td>EU alone</td>
</tr>
<tr>
<td>Dependency on fossil fuels from outside Europe</td>
<td>High/Medium/Low</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Joint transnational initiatives</td>
<td>Difficult/Common</td>
<td>Common</td>
<td>Common</td>
<td>Difficult</td>
<td>Common</td>
<td>Difficult</td>
</tr>
<tr>
<td>Fuel Costs</td>
<td>High/Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>CO2 cost</td>
<td>High/Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Technological development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage technology maturity</td>
<td>Small scale/Large scale/All</td>
<td>All tech mature</td>
<td>All tech mature</td>
<td>All tech mature</td>
<td>Large-scale</td>
<td>Small-scale</td>
</tr>
<tr>
<td>CCS maturity</td>
<td>Yes/No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Electrification in Transport - Heating - Industry</td>
<td>Residential/Large scale/All</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>Large scale (commercial, industry&amp;freight)</td>
<td>Residential (Homes, person vehicles)</td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demographic change</td>
<td>Growth/Migration only</td>
<td>Growth</td>
<td>Growth</td>
<td>Migration only</td>
<td>Growth</td>
<td>Migration only</td>
</tr>
<tr>
<td>GDP growth in EU</td>
<td>High/Medium/Low</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Socio-political perceptions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public perceptions to RES</td>
<td>Positive/Indifferent</td>
<td>Positive</td>
<td>Positive</td>
<td>Indifferent</td>
<td>Indifferent</td>
<td>Positive</td>
</tr>
<tr>
<td>Public perceptions to Nuclear</td>
<td>Positive/Indifferent/Negative</td>
<td>Negative</td>
<td>Indifferent</td>
<td>Indifferent</td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Public perceptions to Shale gas</td>
<td>Positive/Indifferent/Negative</td>
<td>Negative</td>
<td>Negative</td>
<td>Indifferent</td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Shift towards 'greener' behaviours</td>
<td>Major shift/Minor shift</td>
<td>Major</td>
<td>Major</td>
<td>Minor</td>
<td>Minor</td>
<td>Major</td>
</tr>
<tr>
<td>Assumptions - Constant Uncertainties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Six relevant Strategies

<table>
<thead>
<tr>
<th>Main Options</th>
<th>Strategy 1 MARKET LED</th>
<th>Strategy 2 LARGE SCALE RES</th>
<th>Strategy 3 LOCAL SOLUTIONS</th>
<th>Strategy 4 100% RES</th>
<th>Strategy 5 CARBON FREE CCS &amp; NUCLEAR</th>
<th>Strategy 6 NO NUCLEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment of centralized RES</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Deployment of de-centralized RES (including CHP and Biomass)</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Deployment of centralized Storage</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Deployment of de-centralized Storage</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Deployment of nuclear plants</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>No</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Deployment of fossil fuel plants with CCS</td>
<td>Medium</td>
<td>No CCS</td>
<td>No CCS</td>
<td>No CCS</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Deployment of fossil fuel plants without CCS</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Increase of energy efficiency (include DSM and flexibility)</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Increase of funds and better coordination of RDD activities (at EU level)</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Electricity imports from outside Europe</td>
<td>Medium</td>
<td>High RES (Desertec)</td>
<td>Medium</td>
<td>High RES (Desertec)</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Permitting framework (incl EU nature legislation)</td>
<td>Convergent and Strong framework</td>
<td>Convergent and Strong framework</td>
<td>Heterogeneous framework at EU level</td>
<td>Convergent and Strong framework</td>
<td>Heterogeneous framework at EU level</td>
<td>Convergent and Strong framework</td>
</tr>
</tbody>
</table>

### Assumptions - Constant Option

| EU Policy for GHG reduction emissions | Strong | Strong | Strong | Strong | Strong | Strong |

---

32
### The 5 final e-Highway2050 scenarios

<table>
<thead>
<tr>
<th>Criteria (options / uncertainties)</th>
<th>x-1</th>
<th>x-2</th>
<th>x-3</th>
<th>x-4</th>
<th>x-5</th>
<th>x-6</th>
<th>x-7</th>
<th>x-8</th>
<th>x-9</th>
<th>x-10</th>
<th>x-11</th>
<th>x-12</th>
<th>x-13</th>
<th>x-14</th>
<th>x-15</th>
<th>x-16</th>
<th>x-17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of centralized renewable</td>
<td>60%</td>
<td>20%</td>
<td>60%</td>
<td>40%</td>
<td>20%</td>
<td>60%</td>
<td>30%</td>
<td>20%</td>
<td>40%</td>
<td>60%</td>
<td>30%</td>
<td>40%</td>
<td>25%</td>
<td>40%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>M/H</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>M/L</td>
<td>High</td>
<td>L/M</td>
<td>M/H</td>
<td>Low</td>
<td>M/H</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of decentralized renewable</td>
<td>20%</td>
<td>60%</td>
<td>40%</td>
<td>40%</td>
<td>15%</td>
<td>60%</td>
<td>40%</td>
<td>20%</td>
<td>60%</td>
<td>20%</td>
<td>40%</td>
<td>5%</td>
<td>20%</td>
<td>60%</td>
<td>60%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of renewable</td>
<td>80%</td>
<td>80%</td>
<td>100%</td>
<td>80%</td>
<td>75%</td>
<td>80%</td>
<td>50%</td>
<td>80%</td>
<td>60%</td>
<td>100%</td>
<td>35%</td>
<td>60%</td>
<td>85%</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of Fossil fuel plants with CCS</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>15%</td>
<td>0%</td>
<td>30%</td>
<td>30%</td>
<td>0%</td>
<td>0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of Fossil fuel plants without CCS</td>
<td>0%</td>
<td>5%</td>
<td>5%</td>
<td>0%</td>
<td>10%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of Fossil fuel in CCS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of nuclear</td>
<td>20%</td>
<td>20%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>15%</td>
<td>10%</td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of nuclear in CCS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of centralized storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of centralized storage in CCS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enable EU international exchanges</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enable EU international exchanges in CCS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New use emerging (including DSM)</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New use emerging (including DSM in CCS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population changes (demographic changes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDP increase</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Focus on Scenarios that pose a big Challenge for the existing Grid

Three main Influences define the need for grid reinforcements

- **Effects on Generation Mix**
  - Share of Fossil Fuel
  - Share of Nuclear
  - Renewables (centralized & decentralized)
  - Centralized Storage

- **Effects on Demand**
  - GDP Increase
  - New Uses / Demand Shift
  - Efficiency

- **Effects on Energy Exchanges**
  - EU internal
  - EU external
Load Forecasts considers socio-economical and technical developments towards 2050

- EuroHeat. Heat Roadmap Europe 2050
- Energy efficiency
- Technical developments
  - Alternative technologies
- Step 4: Final electricity demand including losses
  - European Commission Directorate-General for Energy
  - European Environment Agency

Step 1: Economic and Financial
- GDP/capita

Step 2: Technology
- New use
- Transport

Step 3: Political, socio-political and environmental
- Smarter demand

Network losses
Assessment of System Adequacy and need of extra capacities

Hourly stochastic simulations at macro area level

Inputs: set of time series (11 wind and PV and 3 load)

- Wind time series
- PV time series
- Load time series

Installed capacities (GW)

- wind
- PV
- CSP
- nuclear
- biomass
- fossil

Adequacy OK?
Energy mix OK?
Imbalances OK?

Redistribution of the generation between macro areas

Range of Imbalances

<table>
<thead>
<tr>
<th></th>
<th>Large RES</th>
<th>100% RES</th>
<th>Big &amp; market</th>
<th>Large fossil fuel</th>
<th>Small &amp; local</th>
</tr>
</thead>
<tbody>
<tr>
<td>+/- Imbalances</td>
<td>+/- 80%</td>
<td>+/- 80%</td>
<td>+/- 30%</td>
<td>+/- 30%</td>
<td>+/- 10%</td>
</tr>
</tbody>
</table>

NO

Final installed capacities/ final Imbalances
Incl. assessment of storage and Demand Side Management needs

3-4 November 2015
European installed capacities

- Wind without North Sea
- Wind in the North Sea
- Solar in Europe
- Connections with North Africa
- Fossil
- Nuclear
- Biomass
- Hydro

2012 [ENSTOE]
Large Scale RES
100% RES
Big and Market
Fossil fuel and Nuclear
Small and Local

Installed capacities (GW)
Assumptions for demand side management and storage

- Controllable load includes: a share of EV, a share of heating and a share of all the other appliances.

- Localization and power/energy ratio of storage follow typical Pumped Storage characteristics

![Graph showing demand side management and storage assumptions](image-url)
Annual benefit assessment

New system simulation (99 MC years x 8760 hours) with the chosen reinforcements are performed to assess their impact

- The cost of the tested set of reinforcements is assessed to compare it with the benefits
- Some reinforcements can be modified if they are inefficient/over-sized (flows<<capacity, very small remaining MCV)
Analysis of the remaining constraints

- Iterations to solve the remaining constraints

- End of the iterations when no more significant issues (small and spread volumes of ENS/ Spillage/ Redispatch)
Scenario *Large Scale RES*
Presentation of the scenario **Large Scale RES**

- Highest demand: 5200 TWh
- High participation of large scale RES, especially wind in North Sea (~105GW) and Solar in North Africa (~150GW)
- Dispatchable generation is dominated by nuclear

**European energy shares**

- 40% Fossil
- 16% Wind
- 14% Nuclear
- 6% Biomass
- 5% Solar
- 20% Hydro

**Installed capacities (GW)**

- **Imbalances**: *imbalances in copper-plate simulation*
Level of constraints in the Starting Grid

Unsupplied energy:
- Germany (44%)
- Poland (19%)
- Spain (17%)

Spilled energy:
- North sea (35%)
- North Africa (23%)
- Norway (13%)
- Sweden (5%)

Gas generation:
- Germany (27%)
- Italy (24%)
- Spain (14%)
- Netherlands (14%)
- Sweden (14%)

Nuclear generation:
- Germany (27%)
- Italy (24%)
- Spain (14%)
- Netherlands (14%)
- Sweden (14%)

Operational costs:
- UK (38%)
  - France (26%)
  - Sweden (23%)

ENS costs:
- Large scale RES
  - Copper plate $10,000/€MWh
  - Sensitivity with 1000 €/MWh

energieway2050 | Final Conference | Brussels | 3-4 November 2015 | 43
Final architecture for scenario *Large scale RES*.

- **Starting grid**
- **Reinforcements**

(Values in GW)

### Copper plate

<table>
<thead>
<tr>
<th></th>
<th>ENS (TWh)</th>
<th>Spillage (TWh)</th>
<th>Operating cost (b€)</th>
<th>CO₂ (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Final grid</strong></td>
<td>0</td>
<td>38</td>
<td>62</td>
<td>81</td>
</tr>
<tr>
<td><strong>Savings</strong></td>
<td>-23</td>
<td>-521</td>
<td>-79</td>
<td>-192</td>
</tr>
<tr>
<td><strong>Financial Benefit</strong></td>
<td>230 b€</td>
<td>***</td>
<td>79 b€</td>
<td>***</td>
</tr>
</tbody>
</table>

**Annual benefits**: 309 b€ *

*Assuming a cost of unsupplied energy equal to 10 k€/MWh. With 1k€/MWh 102b€.*
Grid Development Process – Start

NB: other weeks and parameters are also studied
Grid Development Process – Final Step

NB: other weeks and parameters are also studied

Annual ENS (TWh)
- Europe
- France
- Germany
- UK

Annual Spillage (TWh)
- Europe
- North Sea
- Norway
- France
- UK

Peaking Units redispatch (TWh)
- Europe
- France
- Germany
- Italy

Biomass redispatch (TWh)
- Europe
- Germany
- France
- Spain

ENS > 200MW
- Delta TH > 100MW
- Delta TH < 200MW
- Spillage > 200MW
- New Reinforcements
- Previous Reinforcements
Final architecture for scenario *Large scale RES*

<table>
<thead>
<tr>
<th></th>
<th>Copper plate</th>
<th>Starting grid</th>
<th>Final grid</th>
<th>Savings</th>
<th>Financial Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENS (TWh)</td>
<td>0</td>
<td>51</td>
<td>0</td>
<td>-51</td>
<td>510 b€</td>
</tr>
<tr>
<td>Spillage (TWh)</td>
<td>208</td>
<td>773</td>
<td>308</td>
<td>-465</td>
<td>***</td>
</tr>
<tr>
<td>Operating cost (b€)</td>
<td>6</td>
<td>49</td>
<td>10</td>
<td>-39</td>
<td>39 b€</td>
</tr>
<tr>
<td>CO₂ (Mt)</td>
<td>0</td>
<td>86</td>
<td>6</td>
<td>-80</td>
<td>***</td>
</tr>
</tbody>
</table>

Annual benefits: 549 b€ *

*Assuming a cost of unsupplied energy equal to 10 k€/MWh. With 1k€/MWh 90b€

Connections to North Africa are assumption of the scenario not incl. in starting Grid
Scenario *Big & Market*
Presentation of the scenario *Big & Market*

- Medium demand: 4300 TWh
- Nuclear and fossil energies are significant
- Renewables are dominated by wind especially North Sea (~71 GW)

*European energy shares*

![Diagram showing European energy shares](image-url)

- Hydro: 32%
- Wind: 13%
- Solar: 19%
- Biomass: 10%
- Nuclear: 8%
- Fossil: 13%

![Map showing installed capacities (GW)](image-url)
Final architecture for scenario *Big & market*

Connections to North Africa are assumption of the scenario not incl. in starting Grid

### Table: Savings Financial Benefit

<table>
<thead>
<tr>
<th></th>
<th>Copper plate</th>
<th>Starting grid</th>
<th>Final grid</th>
<th>Savings</th>
<th>Financial Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENS (TWh)</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>-11</td>
<td>110 b€</td>
</tr>
<tr>
<td>Spillage (TWh)</td>
<td>3</td>
<td>205</td>
<td>22</td>
<td>-182</td>
<td>***</td>
</tr>
<tr>
<td>Operating cost (b€)</td>
<td>56</td>
<td>82</td>
<td>60</td>
<td>-22</td>
<td>22 b€</td>
</tr>
<tr>
<td>CO₂ (Mt)</td>
<td>39</td>
<td>101</td>
<td>47</td>
<td>-54</td>
<td>***</td>
</tr>
</tbody>
</table>

**Annual benefits**: 132 b€ *

*Assuming a cost of unsupplied energy equal to 10 k€/MWh. With 1k€/MWh 33b€*
Distribution of wind and solar capacities

Big & market - Wind capacities (GW)
0-1
1-5
5-20
>20

Big & market - PV capacities (GW)
0-2
1-5
15-20
>35
Scenario Fossil & nuclear
Presentation of the scenario *Fossil & nuclear*

- After X-5, second highest annual European demand: 4854 TWh
- Lowest shares of RES among all scenarios
- Nuclear and fossil fuel plants with CCS as main production
- No exchanges with North-Africa

*European energy shares*

![Map showing energy shares and installed capacities (GW)](image-url)
Final architecture for scenario Fossil & nuclear

- Starting grid
- Reinforcements

(Values in GW)

<table>
<thead>
<tr>
<th></th>
<th>Copper plate</th>
<th>Starting grid</th>
<th>Final grid</th>
<th>Savings</th>
<th>Financial Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENS (TWh)</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>-7</td>
<td>70 b€</td>
</tr>
<tr>
<td>Spillage (TWh)</td>
<td>0</td>
<td>42</td>
<td>1</td>
<td>-41</td>
<td>***</td>
</tr>
<tr>
<td>Operating cost (b€)</td>
<td>92</td>
<td>103</td>
<td>92</td>
<td>-11</td>
<td>11 b€</td>
</tr>
<tr>
<td>CO₂ (Mt)</td>
<td>40</td>
<td>78</td>
<td>42</td>
<td>-35</td>
<td>***</td>
</tr>
</tbody>
</table>

Annual benefits: 81 b€ *

*Assuming a cost of unsupplied energy equal to 10 k€/MWh. With 1k€/MWh 18b€
Scenario Small & local
Presentation of the scenario *Small & local*

- Lowest demand: 3278 TWh
- Focus on local solutions: generation close to demand
- 85% of energy is generated from RES (mainly decentralized)

**European energy shares**

- Hydro: 4%
- Wind: 18%
- Solar: 19%
- Biomass: 23%
- Nuclear: 28%
- Fossil: 10%

**Installed capacities (GW)**

*Imbalances in copper-plate simulation*
Final architecture for scenario Small & local

Starting grid
Reinforcements
(Values in GW)

Connections to North Africa are assumption of the scenario not incl. in starting Grid

<table>
<thead>
<tr>
<th></th>
<th>Copper plate</th>
<th>Starting grid</th>
<th>Final grid</th>
<th>Savings</th>
<th>Financial Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENS (TWh)</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>-5</td>
<td>50 b€</td>
</tr>
<tr>
<td>Spillage (TWh)</td>
<td>54</td>
<td>107</td>
<td>60</td>
<td>-47</td>
<td>***</td>
</tr>
<tr>
<td>Operating cost (b€)</td>
<td>33</td>
<td>43</td>
<td>33</td>
<td>-10</td>
<td>10 b€</td>
</tr>
<tr>
<td>CO₂ (Mt)</td>
<td>43</td>
<td>68</td>
<td>44</td>
<td>-23</td>
<td>***</td>
</tr>
</tbody>
</table>

Annual benefits: 60 b€ *

*Assuming a cost of unsupplied energy equal to 10 k€/MWh. With 1k€/MWh 15b€
Results - Big & market

Per year:

- 11 TWh of ENS avoided
- 182 TWh of spillage avoided
- 22 b€ of savings in operating costs

Total investment cost: 138-216** b€

* Depending on the cost of ENS: 1k€/MWh or 10k€/MWh
* *Depending on the acceptance of over-head lines

NB: only some of the key factors are displayed
Results – Small & local

Per year:

- 5 TWh of ENS avoided
- 47 TWh of spillage avoided
- 10 b€ of savings in operating costs

Total investment cost: 110-190** b€

- Depending on the cost of ENS: 1k€/MWh or 10k€/MWh
- *Depending on the acceptance of over-head lines

NB: only some of the key factors are displayed
Common reinforcements
Average Capacity of all reinforcements

- Displayed are all lines reinforced throughout all five scenarios

- Widths according to average reinforcement capacity
  \[ \frac{\text{Cap (X5) + Cap (X7) + \ldots + Cap (X16)}}{5} \]

\[ \rightarrow \] National borders are first object for reinforcements

- Single corridors are very valuable in single scenarios
Benefits of the architectures are significant in all the scenarios:
- At least 10 b€ of savings on the operating cost, and up to 80 b€ per year
- At least 40 TWh of spilled RES avoided, and up to 500 TWh
3 strategies to identify costs of possible realization

- The costs of a possible realization are dependent on implemented technologies
- Available technologies are influenced by the public acceptance of new lines

Three “strategies” to encompass levels of acceptability

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Social assumption</th>
<th>Technical description</th>
<th>Cables</th>
<th>Up-grade of OHL’s</th>
<th>New OHL</th>
<th>New OHL on non existing corridors</th>
</tr>
</thead>
<tbody>
<tr>
<td>New grid acceptance</td>
<td>Public acceptance for new OH Lines.</td>
<td>The most efficient (cost &amp; technical) solution is selected.</td>
<td>x</td>
<td>(x)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Re-use of corridors</td>
<td>Public acceptance for new lines in existing infrastructure corridors.</td>
<td>Re-use of existing infrastructure corridors or construction of underground cable otherwise</td>
<td>x</td>
<td>(x)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Status Quo</td>
<td>No public acceptance for new OH Lines.</td>
<td>Only up-grade of existing lines with same visual impact, or construction of underground cables otherwise</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The cost of the full architecture is calculated for each strategy.
Costs of the architectures

- Investment costs range from 100 to 400 b€, they are compensated by the benefits
- Scenarios Large Scale RES and 100% RES need twice more reinforcements, but those reinforcements are extremely profitable