e-Highway2050 – A European Grid Vision

Many ideas on a low-carbon European future have been presented. In most cases, the technical challenges have been ignored or played down.

Now, a large-scale project, supported by the EU Seventh Framework Programme, has collected data, developed methods and performed detailed analyses of a European power grid from 2030 to 2050. A booklet[1] gives an excellent overview of assumptions and results.

A large number of clarifying documents are available at the project's homepage[2].

The project partners are European Transmission System Operators (TSOs), research institutes and other experts.

The basic condition is a 95% reduction of CO_2-emissions by 2050. Five very different scenarios meet that requirement. They all have a considerable increase in non-dispatchable generation with low capacity factors. The result will be that the installed capacity in all scenarios must be higher than justified by the growth of electricity demand. The higher installed capacity and the influence of non-dispatchable generation will require reinforcements of the primary grid in Europe.

The e-Highway2050 booklet outlines the grid requirements for the five scenarios.

The booklet is brief and well written, but the full documentation is comprehensive. Therefore, reservations are made for possible misinterpretations.

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[1] Europe's future secure and sustainable electricity infrastructure, e-Highway2050 project results, November 2015
[2] http://www.e-highway2050.eu/results/

My Views on e-Highway2050

The starting grid 2030

- The starting grid 2030 has been developed within ENTSO-E. The German grid extension plans until 2030 are ambitious. It is questionable if all extensions can be complete by 2030

The five scenarios 2030 to 2050

- The exploration of a wide range of possible futures is wise. It adds credibility and political neutrality to the results.
- The scenarios have different contributions to transport and heating sectors. Economic comparisons might be misleading.
- Energy savings in the five scenarios vary between 20% and 50%. These considerable savings are decisive to the results of the project.

Operating conditions in 2050

- Non-dispatchable sources will deliver between 22% and 70% of the total European electricity production depending on the scenario.
- The variation range of the residual demand will increase. Covering a larger demand variation with smaller controllable resources will be a major challenge.
- Flexible demand and new electricity storages are assumed, but the focus of the project is to analyse grid solutions in detail.

The 2030 Grid Cannot Serve the 2050 Scenarios

- The project finds grid solutions (“Final grids”) in 2050 somewhere between using the starting grid and using a “copper plate”, which is a grid without bottlenecks.
- Countries with high shares of solar power, staying at the starting grid until 2050, will have most unserved demand.

The common corridors

- In spite of the differences, reinforcements of certain corridors are common for the five scenarios.
- This observation was a key to the *least-regret grid 2040* on the front page of this note.

How the Scenarios Meet the Requirements

- The change from starting grids to final grids cause considerable improvements concerning unserved demand, spillage, operating cost and CO_2 emissions.
- Spillage is between 0.1% and 9.5% of RES depending on scenario. The 9.5% spillage seems to be on the high side.

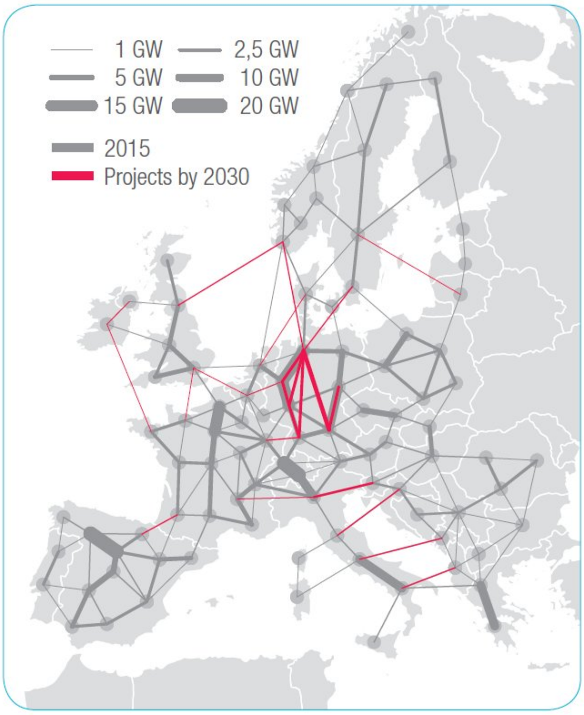
Barriers

- There will be public resistance against large transmission projects, particularly against overhead lines.
- Power system planning, operation and trade should be organized at European level.
- The assumed flexibility measures and energy savings depend on technologies and methods, which are not yet commercially available. Targeted research and development will be needed.
- The creation of supranational bodies will be a sensitive matter.

The Starting Grid 2030

The project has divided Europe into a number of clusters, corresponding to the Nordpool price zones. The links between the clusters make a simplified grid. The clusters have been arranged with a view to making potential future bottlenecks links between clusters.

The source of the starting grid is ENTSO-E's Ten Year Network Development Plan (TYNDP 2014)[3].



The most remarkable changes until 2030 are the comprehensive reinforcements of the internal German grids. The German plans are ambitious and a risk of delays cannot be excluded.

The starting grid includes new North Sea links from Norway to Germany and to Northern England, and the Cobra cable between Denmark and the Netherlands.

Additional links across the English Channel are planned.

Together with reinforcements between Northern Ireland and the Irish Republic, a new link between Ireland and France will form a western backbone in Europe for the transfer of Irish wind power directly to the continent.

A corresponding eastern backbone will connect Finland and the Baltic states with Poland. A new link from Sweden to Lithuania will support the eastern backbone.

Other interesting new links will cross the Adriatic Sea from Italy to Croatia, to Montenegro and to Albania.

[3] https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Pages/default.aspx

The Five Scenarios

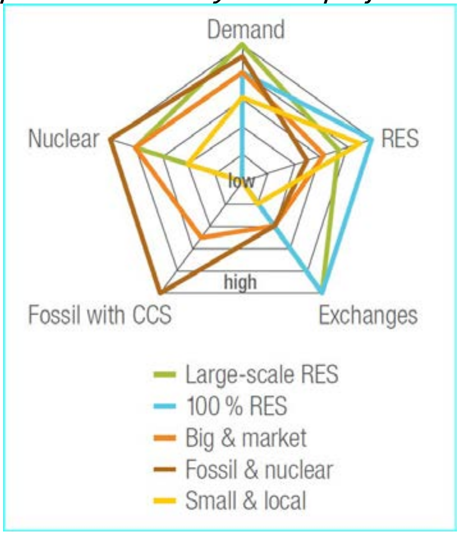
The five scenarios represent five very different policies regarding economy, technologies, energy policy and social behaviour. The actual future combinations will depend on both unpredictable circumstances and on political decisions. *Therefore, it is wise that the project explores a wide range of possibilities. It adds credibility and political neutrality to the project.*

The major differences between the scenarios concern:

- Electricity demand
- Renewable energy sources (RES)
- Electricity exchanges
- Production on fossil fuels and CCS[4]
- Nuclear power

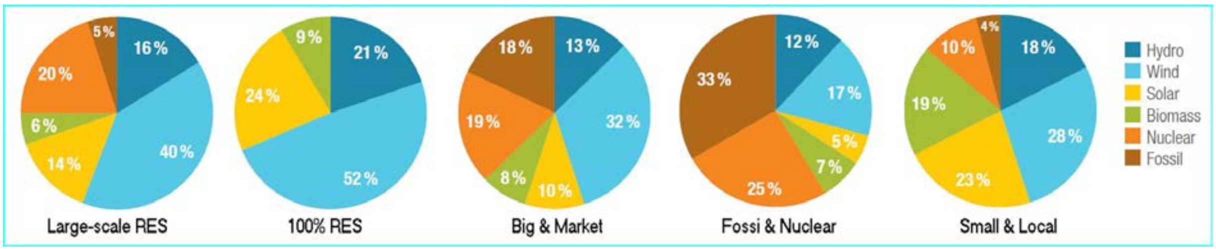
The names of the five scenarios are:

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



The chart indicates the weight of the five main parameters for each of the five scenarios.

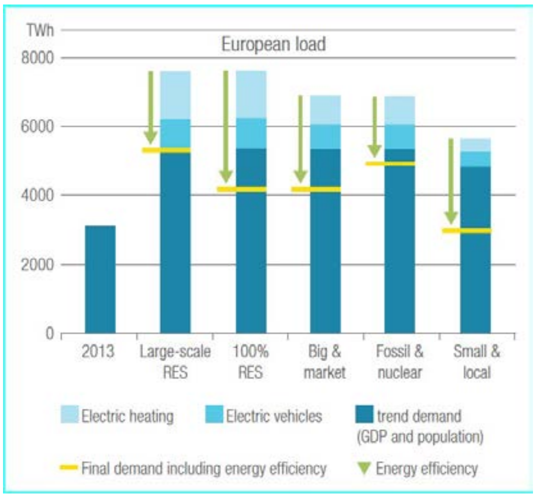
The annual generation mix for the five scenarios at European level:



In Large-scale RES 116 GW solar power in North Africa covers 7% of the demand in Europe.

The electrical demand is different in the five scenarios. The differences reflect:

- Different supplies for space heating
- Different transport works
- Different levels of energy savings



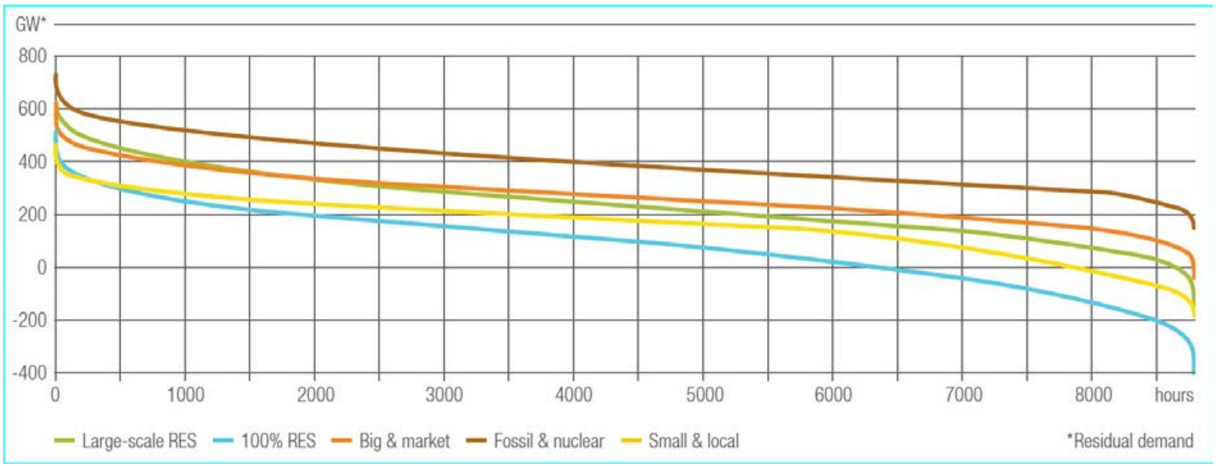
Therefore, the scenarios do not contribute equally to the overall energy system and economic comparisons may be misleading.

Energy savings in the five scenarios vary between 20% and 50%. *These considerable savings are decisive to the results of the project.*

[4] CCS: Carbon Capture and Storage

Operating Conditions in 2050

The **residual demand** is the consumer's demand minus non-dispatchable generation. The residual demand must be balanced by controllable resources such as dispatchable generation and flexible demand. The duration curves for residual demand give a fair impression of the magnitude of the operational problems.



In the most conventional scenario, "Fossil & nuclear", European flexible resources must cover about 500 GW load variation. The dispatchable generation covers 78% of the energy consumption. In "100% RES" the range will be about 900 GW, and the dispatchable generation covers 30% of the energy consumption. Spillage up to 400 GW must be absorbed.

Covering a larger demand variation with smaller controllable resources will be a major challenge.

The project assumes that **demand side management** (DSM) means shifting load within a day.

Energy storages are assumed available in the study. Their properties are based on typical pumped storage plants.

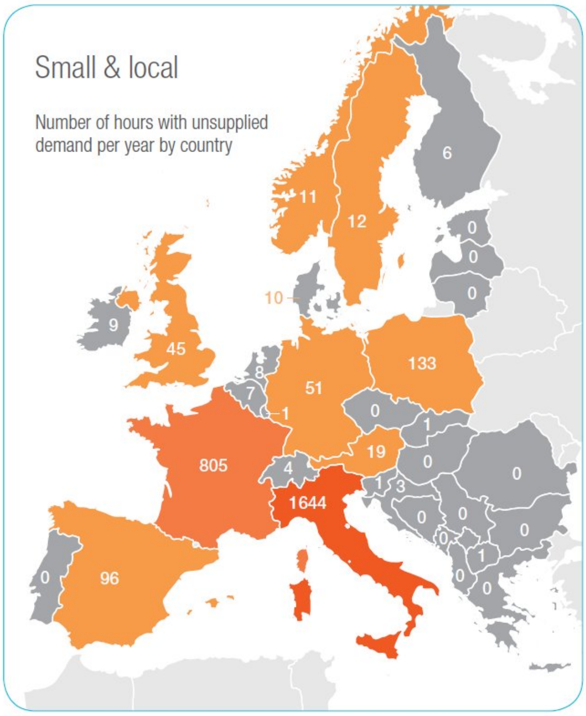
These facilities will add up to 133 GW controllable resources to the European power system.

Max power GW	DSM	Storage
2012	~0	45
Scenario		
Large-scale RES	54	95
100% RES	65	113
Big & Market	12	73
Fossil & Nuclear	14	73
Small & Local	15	73

The booklet explains that it is beyond the purpose of the e-Highway2050 project to analyse all combinations of potential measures. Additional studies might be able to find better solutions. *The focus of e-Highway2050 is to assess grid solutions in detail.*

The 2030 Grid Cannot Serve the 2050 Scenarios,

As an interesting experiment, the project has analysed security of supply for the scenario “Small & local” with the assumed 2030 grid.



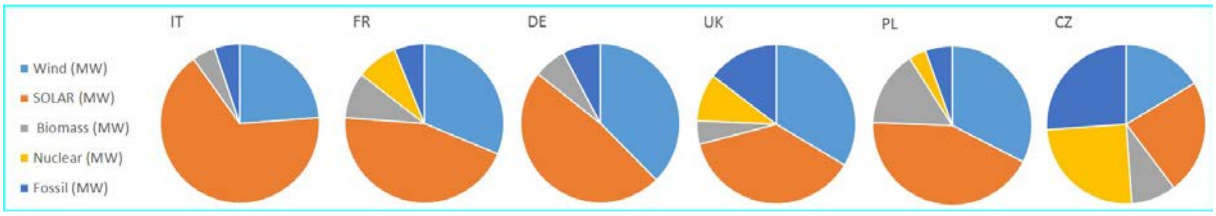
“Small & local” is characterized as “the least critical scenario”. The electrical demand is assumed to be about the same as in 2013.

Nevertheless, the described level of security of supply will be unacceptable in most countries. Italy, France, Poland and Spain have most hours with unserved demand.

The essential difference from now is that non-dispatchable sources produce more than 50% of the electricity in Europe.

The acceptable limit for a country is traditionally considered to be about one hour (LOLP[5] = 10^{-4}).

A few country capacity profiles can illustrate the differences:



The security of supply for a country depends on the availability of controllable resources and on the interconnector capacity. Grid reinforcements can increase the interconnector capacity.

The analysis also included the level of RES curtailment. The top six:

- The North Sea: 22%
- Norway: 19%
- Italy: 11%
- Sweden: 8%
- Ireland: 8%
- Spain: 7%

The need for both stronger grids and controllable resources is obvious.

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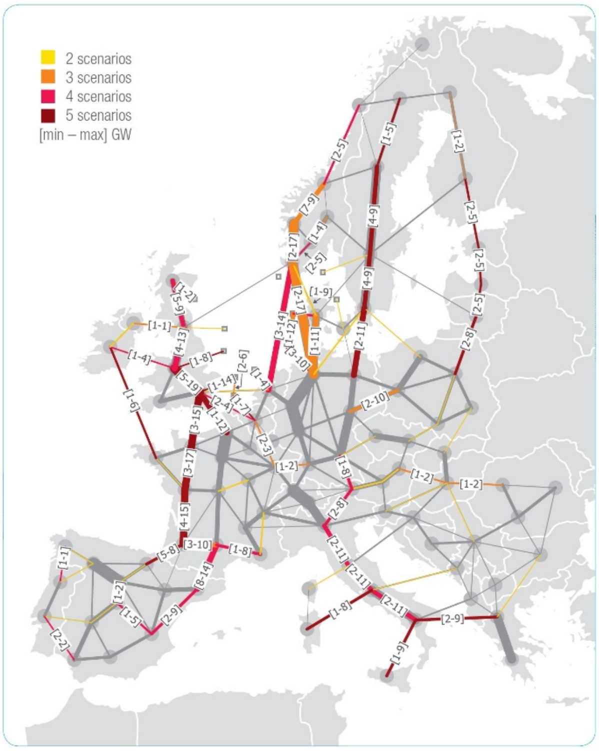
[5] LOLP: Loss of Load Probability

The Common Corridors



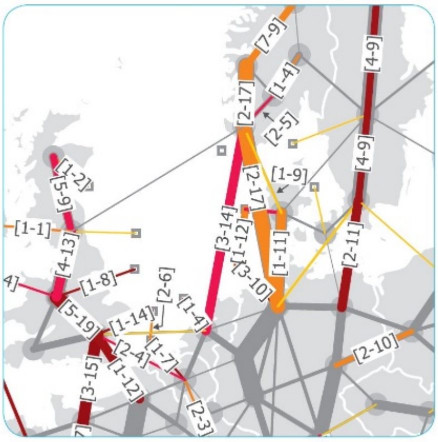
Transmission requirements in 2050 have been calculated for each of the five scenarios. The necessary grid extensions are very different for the five scenarios.

The total estimated investments are very uncertain. They depend particularly on the choice between overhead AC[6] lines and DC[7] underground cables. The estimates cover a range from 120 billion € to 640 billion €.

In spite of the differences, reinforcements of certain corridors are common for the five scenarios.

The dark corridors in the chart are reinforced in most scenarios. One important corridor goes from Scotland to Southern France. Another important corridor goes from Sweden to Germany. A third corridor connects Switzerland with Southern Italy.

The two figures on reinforced links are minimum and maximum extensions of that link among the five scenarios.



The North Sea area is potentially a large wind power location. The capacity ranges from 15 GW to 115 GW. The report says that wind power from the Danish part of the North Sea can go via Denmark to Germany or direct to Germany. Denmark will not need the production. The chart shows both alternatives.

The link from Norway to Germany is shown in orange colour. The extensions up to 17 GW are needed in the three scenarios with high shares of non-dispatchable generation.

Based on these results a map with a least-regret grid 2040 was developed (see the front page of this note). This map is a reasonable starting point of the next phase of the joint European grid planning.

[6] AC: Alternating current

[7] DC: Direct current

How the Scenarios Meet the Requirements

Two extremities have been analysed and used as reference points: the starting grid 2030 and a "copper plate", which is a grid without bottlenecks. Somewhere between these two extremities, grid extensions have been determined so that the benefits exceed the estimated costs.

The effects of the grid reinforcements between 2030 and 2050 are characterized by the following variables:

- Energy not supplied (ENS)
- Spillage (Energy wasted)
- Operating cost
- CO_2 emissions

Spillage as fraction of wind plus solar generation:

Scenario	Wind + solar production	Spillage
	TWh	
Large-scale RES	2801	3.1%
100% RES	3259	9.5%
Big & Market	1820	1.2%
Fossil & Nuclear	1066	0.1%
Small & Local	1653	3.6%

The booklet emphasizes proudly the improvements, which are indisputable results of the grid reinforcements.

Scenarios	Copper plate	Starting grid	Final grid	Benefit (final – starting)
Large-scale RES				
ENS (TWh)	0	23	0	-23
Spillage (TWh)	38	609	88	-521
Operating cost (b€)	62	149	70	-79
CO2 (Mt)	81	292	100	-192
100% RES				
ENS (TWh)	0	51	0	-51
Spillage (TWh)	208	773	308	-465
Operating cost (b€)	6	49	10	-39
CO2 (Mt)	0	86	6	-80
Big & Market				
ENS (TWh)	0	11	0	-11
Spillage (TWh)	3	205	22	-182
Operating cost (b€)	56	82	60	-22
CO2 (Mt)	39	101	47	-54
Fossil & Nuclear				
ENS (TWh)	0	7	0	-7
Spillage (TWh)	0	42	1	-41
Operating cost (b€)	92	103	92	-11
CO2 (Mt)	40	78	42	-35
Small & Local				
ENS (TWh)	0	5	0	-5
Spillage (TWh)	54	107	60	-47
Operating cost (b€)	33	43	33	-10
CO2 (Mt)	43	68	44	-23

However, in total terms the spillage is high in some scenarios and may seem unacceptable. Therefore, there is room for further studies, as anticipated in the booklet.

Besides grid extensions, energy savings, energy storages and flexible demand are necessary measures. Technologies and infrastructure for these measures are not yet commercially available in sufficient scale.

Research and development activities within these areas will be decisive conditions for realization of the visions by 2050.

Barriers

eHighway2050 has presented visions, which will require the installation of heavy transmission equipment.

It has always been difficult to achieve public acceptance of new transmission facilities, particularly for high voltage overhead lines. It is hard to imagine how the assumed transfer capabilities could be established in densely populated European regions as AC overhead lines. On the other hand, it will be very expensive to install the same capacity as HVDC[8] cables. The booklet is fully aware of the dilemma. The optimal solution may be different for an AC solution and a HVDC solution.

The authors of the booklet seem to be worried about the operational security of a grid with parallel operation of HVDC links and traditional AC lines. This should not be seen as a decisive barrier. Operational experience with HVDC technology has been accumulated over several decades, and more advanced control systems are still being developed. In several cases, HVDC links have stabilized distressed AC systems during emergencies.

The responsibility for grid operation in Europe rests with a number of transmission system operators (TSOs). Many European TSOs are state-owned authorities.

Common planning activities are made within ENTSO-E. Among the results are the TYND plans and the adequacy forecasts. In an integrated grid development, costs and benefits will be unevenly distributed among countries. It will not always be possible to reach a reasonable solution by bilateral negotiations, and the question on supranational authorities will be raised.

Large grid systems always have bottlenecks and the demand for transport of energy often exceeds available capacities. In a complex system, the determination of security limits can be difficult, and there will often be an interest in operation close to the limits. Small events can start cascading failures. An assessment of the operating security for the entire European power system may require supranational system control facilities.

There are several electricity markets in Europe. Market couplings have been established, but the need for an optimal allocation of resources may require an international electricity market organized at European level.

The results of eHighway2050 depend on assumptions on demand side management and storage technologies. These methods are not yet available in the necessary scale. It will take a targeted research and development process to bring them to commercial maturity in due time.

The development and implementation of integrated European solutions do not only depend on the solution of technical problems. Some of the crucial barriers are political. The creation of the necessary supranational bodies can be a sensitive matter and may take long time.

[8] HVDC: High voltage direct current