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e-Highway2050: a research project analysing very long term investment needs for the pan-European transmission system

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SUMMARY

The Energy Union policy has fixed ambitious goals for 2020 and 2030, for the climate protection, where the interconnected European electricity grid with more cross-border interconnections, storage facilities, and smart grids to manage demand should ensure a secure energy supply in a system with higher shares of variable renewable energy. In this respect the gradual construction of the pan-European electricity highways should play a key role.

As a matter of fact, the often decentralized location of Renewable Energy Sources generation with respect to the big consumption centres has increased the interest towards analysing perspective investments in extra-high voltage point-to-point connections that could allow to efficiently convey the resulting bulk power flows. However, the related high investment costs imply a new methodology of analysis oriented to the very long time horizon.

On this background, the research project e-Highway2050 was launched in September 2012, with the aim of delivering a Modular Development Plan of the pan-European transmission system at the time horizon 2050 supporting the planning of a pan-European "Electricity Highway System".

The project workflow is developed around five extreme but realistic scenarios at long term horizon. The pan-European power system is represented by a consistent set of zones, while system simulations are performed in order to highlight weak points of the transmission grid. This brings to identify few grid architectures per scenario, corresponding to technological choices reflecting each a different degree of public acceptance of the deployment of new overhead lines, and taking into account a Cost-Benefit Analysis. For this analysis, an extended set of robust cost-benefit indicators was selected, including economic factors, socio-environmental aspects, all factors being accounted for in quantitative economic terms.

This paper presents the final results of the research project, illustrating the methodological approach that has been followed in order to elaborate the scenarios and to perform the methodology on the grid architectures selected. The quantitative results for the target year 2050 are thoroughly discussed and conclusions are drawn concerning the long-term evolution of the pan-European system.

KEYWORDS: Pan-European Transmission System, Electricity Highway System, Transmission System Operator, grid planning, scenario, Renewable Energy Sources.

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INTRODUCTION

On March 27th 2013[1], the Green Paper published by the European Commission (EC) framed an upgraded policy environment within which Europe ought to design its whole energy system from 2020 up to the middle of the twenty-first century (2050). Such a long-term perspective had already been laid out in 2011 [2], and then continued through the Energy Roadmap 2050 [3], and the Transport White Paper [4]. Moreover, each of these key policy papers had witnessed a parent European Parliament Resolution [5] aimed to converge on a “low carbon” vision for the European economy by 2050. An intermediate 2030 framework was then proposed, refined and finalized by the EC and the Member States (MS) in January 2014, assuming that:

- The EU28 is making significant progress towards meeting its existing climate and energy intermediate targets for 2020;
- The 2050 perspectives still hold plausible, which means reducing greenhouse gas emissions by 80-95% below the 1990 levels by 2050.

Overall, since October 2014, there has been a renewed integrated climate and energy policy framework available in Europe to reach a set of 2030 targets. It involves a clear regulatory framework for investors and proposes a more coordinated approach among Member States: this is the Energy Union strategy. This renewed policy framework aims at strengthening the plausibility of the 2030 targets as agreed by the EU leaders. It puts forward five mutually-reinforcing and closely intertwined dimensions designed to support the three pillars of energy security, sustainability and competitiveness.

The 2030 targets and 2050 long term goals have a direct impact on European energy infrastructures, and more specifically on the pan-European electrical power system. The Ten-Year Network Development Plan (TYNDP) prepared by the European Network of Transmission System Operators for Electricity (ENTSO-E) addresses the development of the pan-European electricity transmission network from now on until 2030.

But what about longer term horizons and the transition paths to support the European Union in reaching the low carbon economy envisioned by 2050?

This is where the approach developed in the e-Highway2050 project comes into the picture in order to complement the 2030 TYNDP visions [6].

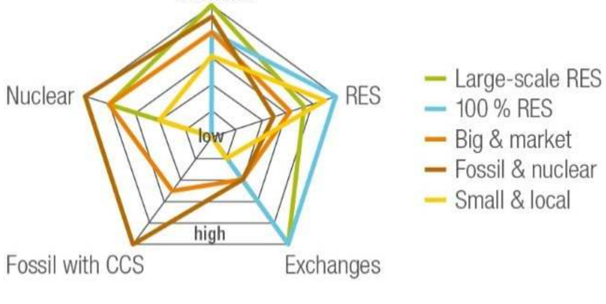
The main results of the e-Highway2050 project are summarized in the present paper [7].

THE SCENARIOS OF THE PROJECT

The scenarios presented hereafter are the outcome of a sorting process implemented to select the extreme scenarios regarding their impact on the transmission grid [8]. They aim to explore a wide scope of plausible and predictable challenges to be faced by the power system. These challenges are driven by changes in generation, demand, energy storage and level of power exchanges. The e-Highway2050 scenarios are neither predictions nor forecasts about the future; the project consortium does not consider any of them to represent the future, nor does it assume any to be more likely than the others.

The five scenarios selected are:

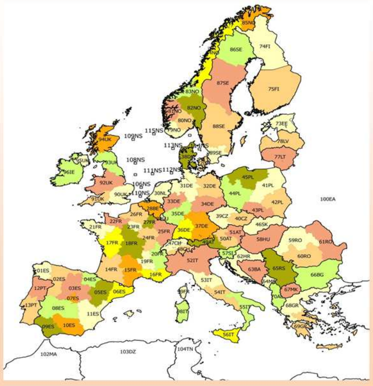
- Fossil & nuclear,
- Big & market,
- Large-scale Renewable Energy Sources (RES),
- Small & local,
- 100% RES



At first, the demand development towards 2050 was depicted based on scenario specific socio-economic prognoses about gross domestic product (GDP) and population. After that, the effect of technological developments (e.g. increase of efficiency in electrification of heating and transport) and demand-side management are used to adopt the yearly demand level as well as hourly profiles for each scenario.

The share of Renewable Energy Sources ranges from 40% to 100%. Wind generation is significantly high in the scenarios Large-scale RES and 100% RES at levels of 40-50% of the generation mix. Solar generation plays a major role in the scenarios 100% RES and Small & local with about 25% of the total generation mix. Nuclear generation ranges from 19 to 25% of the generation mix in three of the five scenarios (Large-scale RES, Big & market and Fossil & nuclear). Indeed, nuclear helps achieving the 2050 EU decarbonisation orientations. The 100% RES scenario is nuclear generation free. Fossil energy sources remain significantly high in the scenarios Big & market and Fossil & nuclear with 18% and 33% of the generation mix, respectively, since for these scenarios, the Carbon Capture Storage (CCS) technology is assumed to be mature. The share of fossil generation in the other scenarios stands below 5%.

Model with 100 clusters



For the study, the European power system is represented via a zonal model with 100 clusters. Demand and installed capacities for each generation technology have been defined per cluster, and for each scenario.

For each scenario, generation capacities are defined in Europe to meet the demand, consistent with each of the scenario backgrounds. The geographical dimensions retained for the study involved one hundred “clusters” covering the whole Europe. Indeed, due to the uncertainties of such a long-term horizon and the complexity of addressing the whole continent, more detailed descriptions – like the substation level – are neither attainable nor needed for the present work.

The main goal of the approach is to ensure an overall consistency, meaning European targets translated into local generation portfolios.

The RES capacities are located preferably in the most profitable clusters. However, a criterion of national energy autonomy is also taken into account for each scenario. For instance, in the scenario Small & local, no country supplies more than 10% of its electricity demand using imports. By contrast, in the scenarios Large-scale RES and 100% RES, some countries import nearly 60% of their electricity needs.

Thermal generation is also defined with a European perspective. Simulations are performed to assess the appropriate number of power plants necessary to ensure adequacy (assuming infinite network capacities). Thus, over capacity for generation unites in Europe is avoided.

It should be noticed that the implementation of such top-down scenarios would require a very high level of coordination within Europe, thus differing significantly from national plans.

For each scenario, Figure 1 (below) depicts the 2050 European installed capacities per technology with a reminder of the situation in 2012.

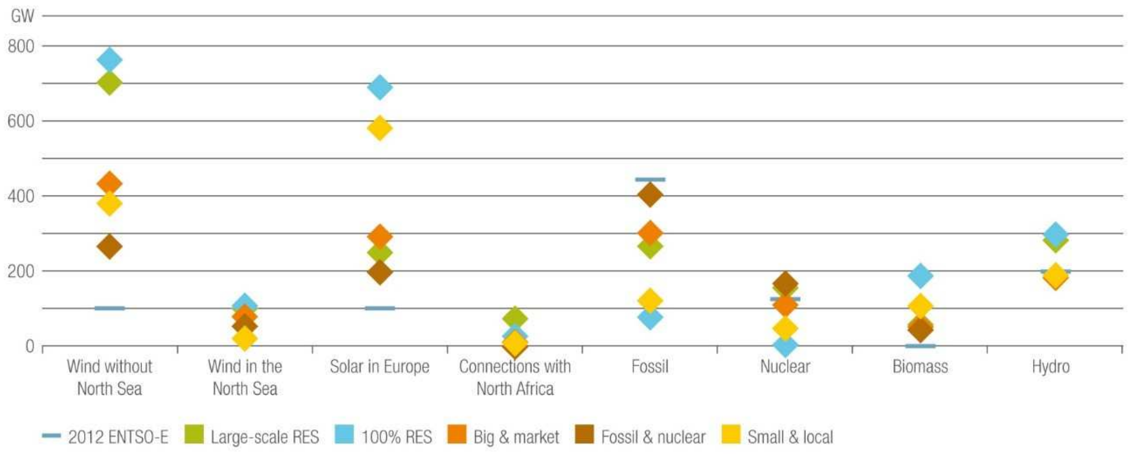


Figure 1: European installed capacities in the five scenarios at 2050 (compared to 2012).

Wind generation capacity ranges from 260 GW to 760 GW, and from 15 GW to 115 GW in the North Sea. For solar generation, capacities range from 190 to 690 GW in Europe. Solar generation in North Africa is very high in the scenario Large-scale RES, covering up to 7% of the European demand for a solar installed capacity of 116 GW. In the 100% RES scenario, it covers 3% of the European demand and less than 1% for the other scenarios. The nuclear capacity increases compared to 2012 in the scenarios Fossil & nuclear and Large-scale RES – up to 169 GW and 157 GW, respectively. It decreases in the other scenarios. Biomass-based electricity generation, being a dispatchable RES source, reaches significant levels in the scenarios with high RES penetration. It reaches almost 200 GW in the scenario 100% RES. It is noteworthy that there are also “fossil” plants in the scenario 100% RES. It actually corresponds to plants that are necessary for adequacy; they are referred to here as “fossil” but other solutions, like more biomass/storage, or DSM measures, could also be imagined.

With the high shares of renewable energy, the development of storage and demand side management is expected in the future. Ambitious assumptions are thus taken into account in the five scenarios [7].

From today to 2050

The TYNDP 2014 [6] has defined four “visions” to address the 2030 horizon. To assess the trajectory of the power system from 2030 to 2050, a corresponding 2030 vision is identified for each of the five 2050 scenarios consistent with the TYNDP2016 visions: it is considered as the most likely antecedent. Five 2040 scenarios are then defined by interpolating between the 2030 datasets of the TYNDP 2016 and the e-Highway2050 scenarios.

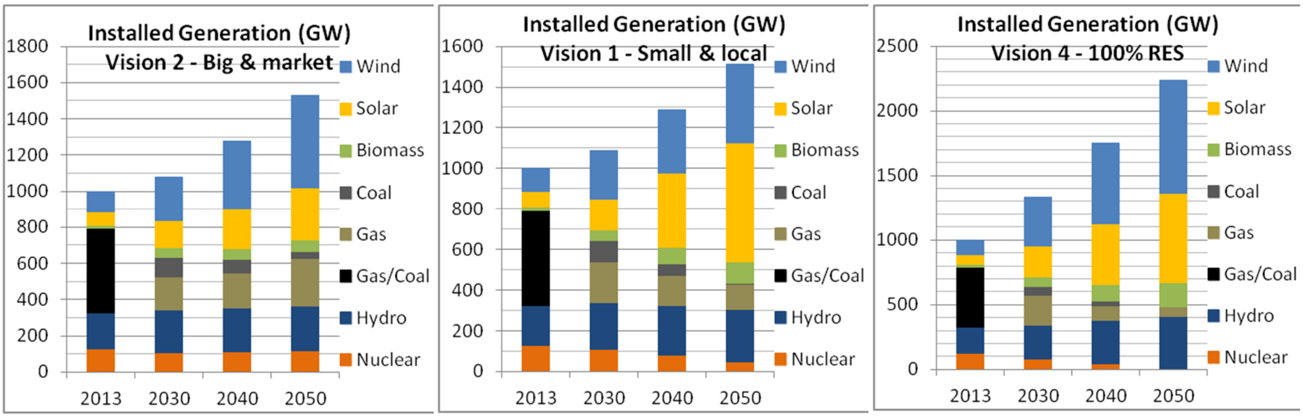


Figure 2: Trajectories of the installed capacities per technology from today to 2050 for three e-Highway2050 scenarios

As shown in the Figure 2 above, all trajectories are characterized by a large increase in the total installed capacity in Europe. This is mainly due to the high share of renewable: more renewable capacity is needed to produce as much energy as thermal generation.

THE POTENTIAL GRID BOTTLENECKS BY 2050

The first step of the analysis is to assess, based upon the generation capacities and the demand foreseen by 2050 in the different scenarios, whether the 2030 transmission grid could be appropriate without any new investments. To do so, an equivalent grid model is implemented allowing to perform “system simulations” in order to pinpoint the impacts of the grid limitations. The possibility to implement non-grid solutions is then briefly discussed.

The scope of the project covers the period 2030-2050, thus the starting grid, which represents the initial conditions in the grid architecture, is set with the following assumptions:

- the transmission network existing today will still be in operation in 2050, i.e. the existing overhead lines and cable links will have the same topology and characteristics in 2050, even if they have been refurbished;
- the transmission network developments for 2030, foreseen by the TYNDP 2014, which include, for example, major North-South HVDC corridors in Germany (see figure 3), will all be completed;

Based on a detailed model of this transmission network (made of more than 8000 nodes), an equivalent grid model of one hundred clusters is computed to best match the flows occurring on the real grid. For each line of this simplified model, an equivalent impedance and a Grid Transfer Capacity (GTC) is estimated. This equivalent model provides the grid initial conditions, i.e. the starting grid, for the simulations. The detailed model and the starting grid are shown in figure 3. As can be seen on the right-side of the graph below, the starting grid considered is already meaningful, especially in continental Europe. It is already a major step toward the electricity highways.

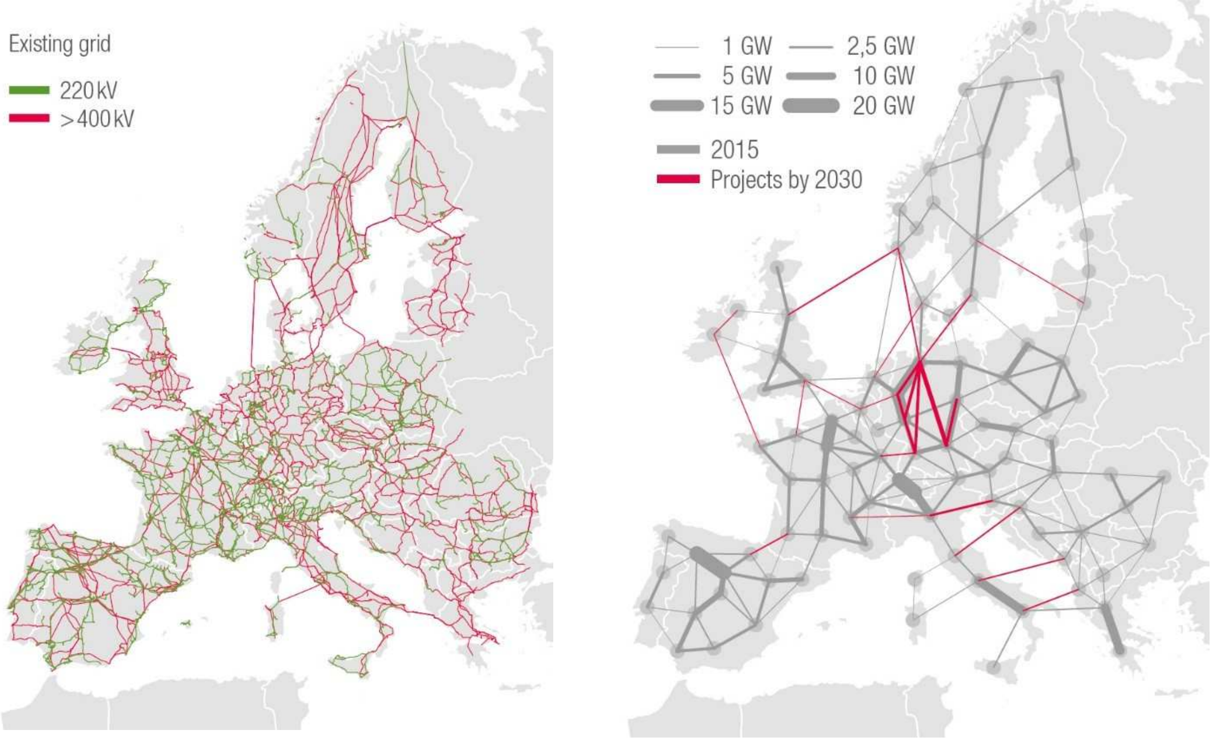


Figure 3: Starting grid of the e-Highway2050 project. Existing grid (left) and starting grid (right, the grey lines represent the existing lines and the purple ones represent the projects to be realized by 2030 as stated in the TYNDP 2014).

System simulations

An innovative approach is applied to provide a robust numerical model of the behaviour of the whole European power system. The starting grid, as well as the description of the demand, storage and generation portfolios are embedded in the numerical “system simulations”. These simulations optimise the dispatch of generation in terms of cost for each hour of the year, taking into account the starting grid topology and characteristics (impedances and GTC). Thus, this optimisation problem identifies the cheapest generation to

cover the demand while keeping flows on the networks within their limits (optimal power flow). The operating costs of the pan-European power system can be estimated for the starting grid and for any modified grid architecture. This is at the core of the cost-benefit analysis.
Given the high share of RES, the simulation of only one climatic year cannot ensure robust results. It is to tackle this issue that probabilistic simulations of 99 possible years are performed using a Monte-Carlo approach. All results presented in this paper are the minimum, maximum or average values over these Monte-Carlo years.

If no further grid development is performed beyond 2030, the simulations show that the power system will face major issues in all the 2050 scenarios.

First, during some periods and in some regions, load cannot be completely supplied. These situations occur in clusters where generation is not sufficient and bottlenecks in the starting grid prevent available generation in other clusters to serve this load. The significance of such events strongly depends on the regions and on the scenarios. On the other hand, a significant amount of renewable generation cannot reach load centres due to grid congestions and has to be curtailed. This does not systematically result in load shedding since local thermal generation can sometimes be used instead. However, these local generations have significant fuel costs and lead to CO_2 emissions.

e-Highway2050 focuses on transmission solutions

The e-Highway2050 project aims at only assessing grid solutions in detail. Transmission grid development is expected to be a very efficient solution since it combines the following assets:

- It can transport renewable energy from areas where it is not needed to load centres. This is typically the case for the North Sea offshore wind parks or for RES generation in Scandinavia;
- It enables areas having very different load and generation patterns to support each other. For instance, southern countries can export PV generation during the day to northern Europe and during the night northern Europe can export wind generation to southern consumption areas;
- It can smooth the RES fluctuations between European countries. For instance, France and Germany may not encounter high winds during the same periods.

THE POWER GRID INFRASTRUCTURE SUITED FOR A LOW CARBON ECONOMY BY 2050

Thanks to the electric system simulations described above, several transmission grid architectures (i.e. the starting grid with modifications) can be compared to assess their techno-economic efficiency. The purpose of the grid development process is to find an optimal solution between two extreme options:

- No further reinforcements are implemented beyond 2030. The grid investments are then minimal: yet, the operating costs of the power system are high since grid congestion can prevent from using the cheapest generation units.
- Infinite capacities are built between all the clusters of the starting grid (the so-called “copper plate” assumption). The grid investment is then virtually infinite, but the operating costs of the power system are minimal since the cheapest generation units can always be used wherever their location.

For each scenario, a methodology is thus applied to define an efficient grid architecture from a European techno-economic perspective. It relies on iterative simulations to assess the impact of different grid architectures.

The granularity of the results is not as accurate as in a study that would tackle shorter time horizons, using a full grid model (like for instance the TYNDP approach of ENTSO-E,).The clustering approach enables focusing on transmission needs between clusters only, thus being unable to detail the needs for intra-cluster reinforcements. The priority is therefore given to the detection of major electric energy transmission issues, meaning long distance and large capacity reinforcements (often higher than 2 GW), forgetting about the possible necessity of smaller reinforcements. Quite often, more than one path/route is possible to reach the same electric system objective. As a result, it may be possible to identify paths which differ from those suggested in the study, but which fulfil similar requirements.

Grid architectures for 2050

The final report of the project [7] provides an overview of the proposed new transmission reinforcements in support of each of the five scenarios.

Even if the scenarios are extremely diverse, some major corridors are common to all of them. They appear robust to face the large uncertainties in 2050 and are thus good candidates for mid-term grid investments. The figure 4 pinpoints the similarities between the scenarios, emphasizing only the corridors that have been reinforced in at least two of the covered scenarios. This figure also displays a reminder of the power ranges for the corridors to be developed.

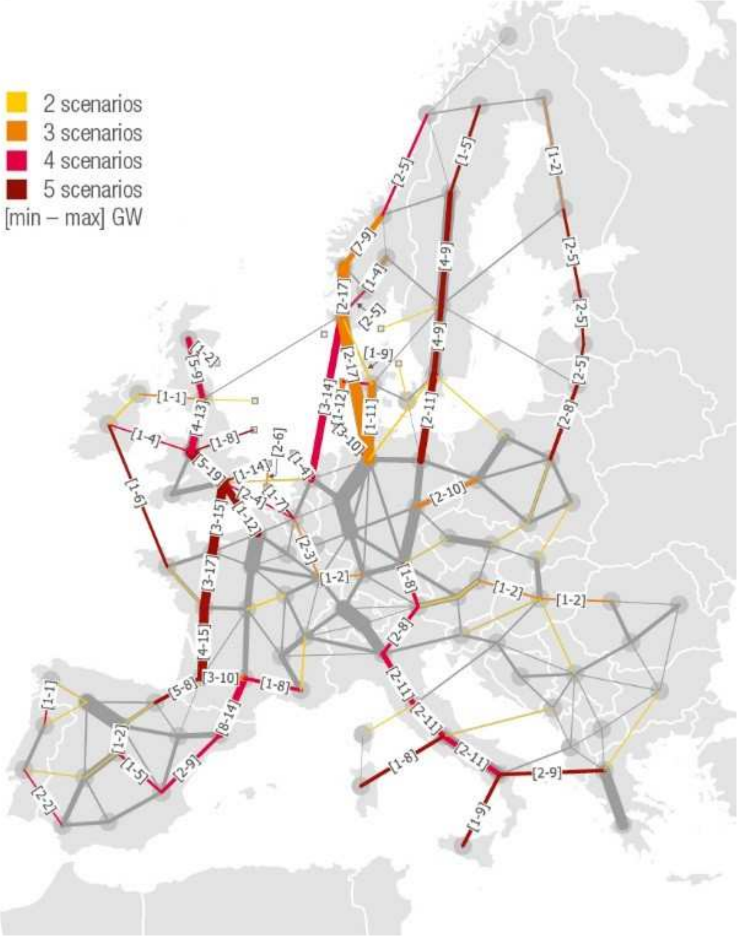


Figure 4: Common reinforcements (widths are according to average reinforcement capacity and the color represents the number of scenarios where the reinforcement is needed).

Cost benefit analysis

A comprehensive Cost-Benefit Analysis (CBA) has been developed, which appraises in monetary terms several aspects that are usually only investigated in a qualitative manner. The CBA is implemented in a toolbox allowing an automatic application of the methodology starting from the scenario simulation files and allowing a complete appraisal of the cost/benefit indicators, the elaboration of a scoring parameter and the creation of a final reporting, both in tabular and graphical form. Figure 5 shows the main aspects of the CBA methodology.

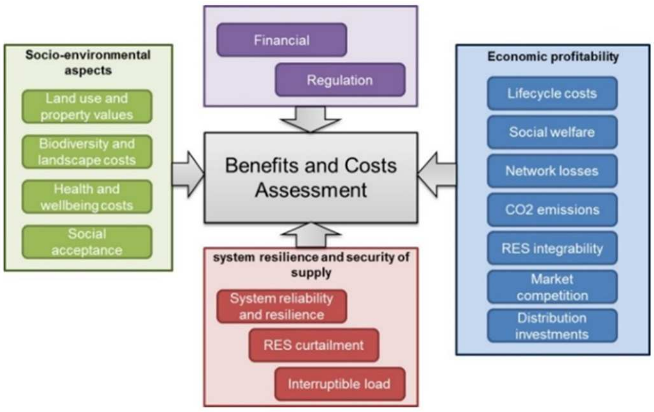


Figure 5: Relevant components included in the CBA methodology

The approach includes several elements that can be grouped in a few categories:

- Economic profitability indicators: lifecycle costs, social welfare, CO2 emissions, inter-zonal network losses, potential to increase RES hosting capacity due to a stronger transmission network, bidding and potential exercise of market power, distribution investments;
- Socio-environmental aspects: costs for rights-of-way compensation, extra time for approval of new infrastructures;
- System security of supply: reliability costs, costs related to system resilience.

Furthermore, the level of risk allocated to investors in transmission infrastructure impacts market perception of the firm which could translate into a specific cost of the capital.

An algebraic sum of benefits and costs is constructed since all CBA components are expressed in monetary terms. A scoring parameter can then be used for selecting one solution among several investment alternatives. Sensitivity analyses are also carried out based upon the uncertainty over the different scenarios and possible modifications in the scoring due to a change in the reciprocal importance given to the costs and benefits factors.

The CBA assessment has been applied to the five reference scenarios in order to compare few grid expansion strategies featuring the utilization of different technologies in order to account for extra constraints due to the public acceptability of the new infrastructures and cover a wide range of possible costs.

Going from 2030 to 2050

To identify the modular development of the 2050 architectures, a “minimal” grid architecture is defined for 2040. It is created by using a subset of the 2050 reinforcements, thus aiming at solving as many problems as possible at horizon 2040, while still being profitable in each scenario. Thus constraints may still persist with this minimal grid and dedicated extra reinforcement may consequently be needed. Nevertheless, this minimal grid constitutes an interesting portfolio of project to be further investigated, as they prove to be robust in the framework of this study for 5 very contrasted scenarios. The main corridors identified in 2050 do already exist in 2040, but with a smaller power size due the shorter time horizon, and also in order to be compatible with the five different scenarios [7].

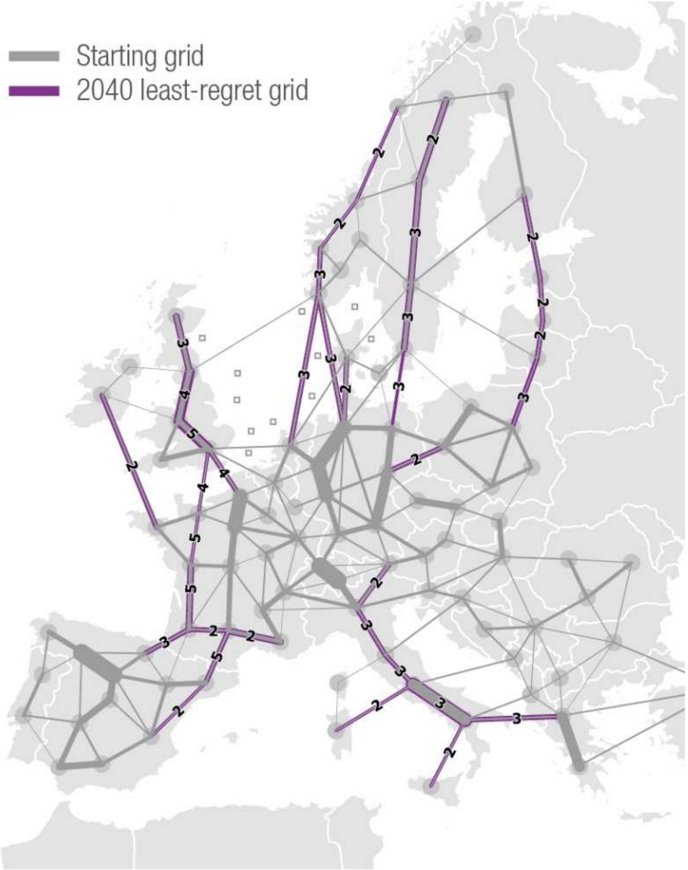


Figure 6: grid architecture for 2040, robust to the 5 scenarios (grey: starting gird, purple: reinforcements)

CONCLUSION

The e-highway2050 project has developed a new methodology which allows the power system stakeholders and policy makers to anticipate the future transmission network development needs in line with the long term decarbonisation goals set at European level. This methodology gives a first, yet reliable, estimate of the main challenges that transmission system operators may face if the suggested new lines reinforcements are not implemented.

This methodology is able to:

- Address long term horizons,
- Cover the whole Europe,
- Cope with the European low carbon objectives, translated at national, and local levels, while building global grid architectures.

An invariant set of new lines and reinforcements has been identified in consistency, and in continuity with the TYNDP. The proposed architectures integrate the present pan-European transmission grid, without needing a new separate ‘layer’ within this existing transmission network.

A significant number of assumptions were necessary to perform the e-Highway2050 study. Even though the solid methodology and the consideration of various scenarios ensure the relevance of the results, further studies could for sure be performed with different assumptions, in particular deeper assessment of alternative solutions to the transmission grid.

For future studies, the e-Highway2050 results and methodologies can provide an excellent starting point.

The operability of the European power system, as described in the e-Highway2050 scenarios, is a critical issue. Preliminary analyses were conducted within project but further research is essential to anticipate the coming challenges.

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